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Our Ref: FOI2019/08631

[redacted]

18 December 2019

Dear [redacted]

Thank you for your email requesting the following information:

File reference: AB38/2123

As confirmed previously, we have treated your correspondence as a request for information under the Freedom of Information Act 2000 and we can advise that the Ministry of Defence (MOD) holds information in scope of your request.

We attach the following document:

- File AB38/2123 - Chernobyl Accident (USSR): post-accident review

If you wish to complain about the handling of your request, or the content of this response, you can request an independent internal review by contacting the Information Rights Compliance team, Ground Floor, MOD Main Building, Whitehall, SW1A 2HB (e-mail CIO-FOI-IR@mod.gov.uk). Please note that any request for an internal review should be made within 40 working days of the date of this response.

If you remain dissatisfied following an internal review, you may raise your complaint directly to the Information Commissioner under the provisions of Section 50 of the Act. Please note that the Information Commissioner will not normally investigate your case until the MOD internal review process has been completed. The Information Commissioner can be contacted at: Information Commissioner's Office, Wycliffe House, Water Lane, Wilmslow, Cheshire, SK9 5AF. Further details of the role and powers of the Information Commissioner can be found on the Commissioner's website at https://ico.org.uk/.

Yours sincerely,

Defence Nuclear Organisation Secretariat

UNITED KINGDOM ATOMIC ENERGY AUTHORITY

Prefix Letters

Registered Number

CHERNOBYL MISCELLANEOUS
AUGUST 1986 - ~~DECEMBER~~ SEPTEMBER 1986
Post-accident Review

AB 38/2123

Former File	Other relevant Files	Referred to	Date
(For Registry use only)			

Reviewed: 22/1/01
Class: DECLASSIFIED
J.J.Clifton, UKAEA, Risley JJClifton

5
Closed
1022

Referred to	Date	Referred to	Date

Authority fo

Initials

Branch

Date

CLOSED UNTIL
2018

AT. EN. Form 11(b).

IN CONFIDENCE

LIMITED DISTRIBUTION

10/4

FOR INFORMATION

HSSC(87)P15
For information

UNITED KINGDOM ATOMIC ENERGY AUTHORITY

HEALTH AND SAFETY STUDIES COMMITTEE

Proposed Lecture for Use by the Chairman of the UKAEA

Wilton Park Conference 304 : 6-10 April 1987.
The Global Environment after Chernobyl : Industrialisation and Pollution of a Shrinking Earth.

Attached are copies of the slides and speaking notes that it is proposed the Chairman should use in his opening address in the debate "Is nuclear power safe?: an assessment one year after Chernobyl" at the Wilton Park Conference. The speaking note for each slide, highlighting important points and providing additional information, faces the slide. Walter Patterson and Eric Fersht (Greenpeace) will be contesting the motion.

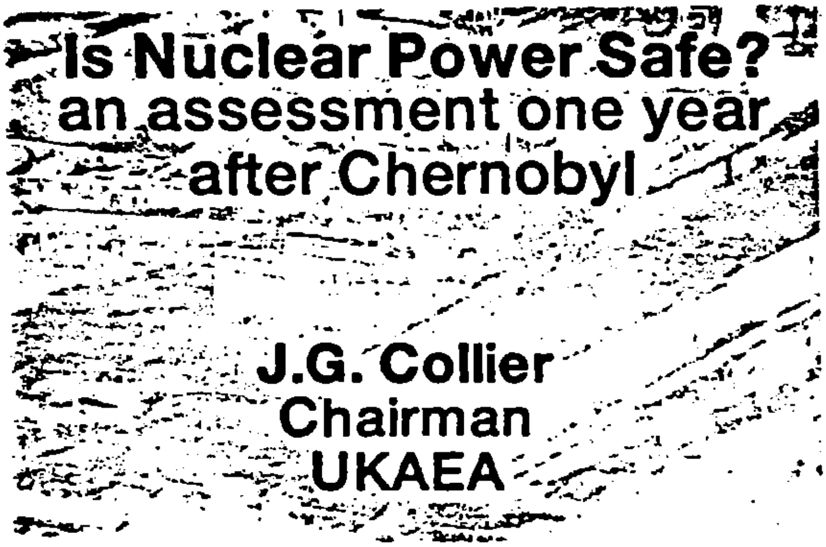
J. H. Gittus, SRD
M. R. Hayns, SRD

April 1987

SRD, Culcheth

Distribution

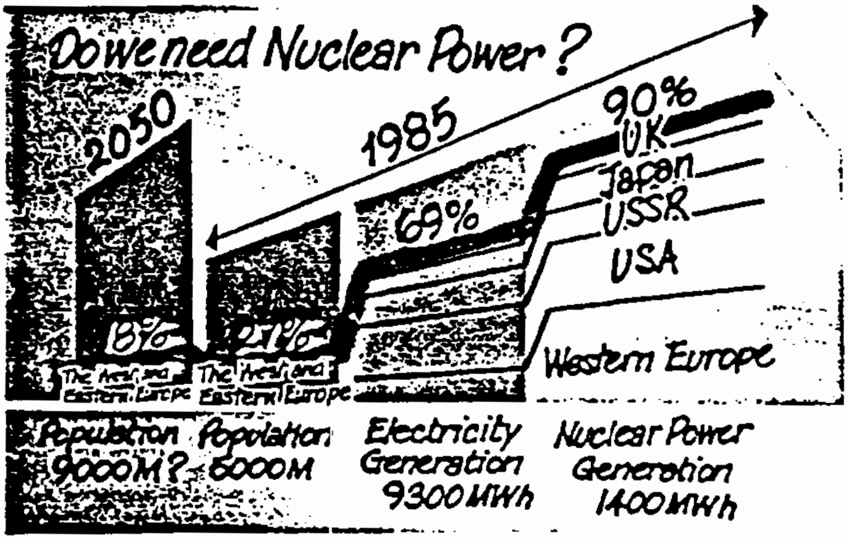
Standard HSSC



Is Nuclear Power Safe?

an assessment one year after Chernobyl

J.G. Collier
Chairman
UKAEA


Do we need Nuclear Power?
2050
1985
90%
UK
Japan
USSR
USA
69%
18%
The West and Eastern Europe
21%
The West and Eastern Europe
Western Europe
Population 9000M?
Population 6000M
Electricity Generation 9300 MWh
Nuclear Power Generation 1400 MWh

ENERGY DEMANDS

- INDUSTRIALISED COUNTRIES HAVE ONLY ABOUT ONE QUARTER OF THE WORLD'S POPULATION AT PRESENT
- THIS FRACTION IS SHRINKING - IT COULD BE LESS THAN ONE FIFTH BY THE YEAR 2050
- BUT THESE COUNTRIES USE OVER TWO-THIRDS OF THE ELECTRICITY GENERATED
- AND COMMAND 90% OF NUCLEAR POWER GENERATION

POWER GENERATION BASED ON IAEA AND EUROPEAN NUCLEAR SOCIETY DATA FOR YEAR TO END OF 1985 (REPORTED IN THE IAEA BULLETIN, AUTUMN 1986 AND NUCLEAR EUROPE, JULY/AUG 86).

POPULATION DATA BASED ON UN DOCUMENT "PERSPECTIVES FOR WORLD POPULATION ESTABLISHED IN 1982", PUBLISHED IN FINAL FORM IN 1985, AND SUMMARISED IN ANNEX 4 OF "FUTURE STRESSES FOR ENERGY RESOURCES" BY J-R FRISCH (1986).

'WESTERN' AND 'EASTERN EUROPEAN' COUNTRIES MEANS 'NORTH' REGION IE NORTH 1 (NORTH AMERICA + WESTERN EUROPE + INDUSTRIALISED COUNTRIES OF THE PACIFIC + SOUTH AFRICA) PLUS NORTH 2 (EASTERN EUROPE).

- **We run out of:**
  Coal in 460 years
  Oil in 40 years
  Gas in 60 years
  at present rates of consumption
- USA
  USSR } "Haves" (77% of World's Fossil Reserves)
  China
- **Rest of World "Have Nots"**
- **They will use Nuclear Power**

OIL AND GAS COULD RUN OUT WITHIN A GENERATION, COAL WILL LAST LONGER (BUT PROBLEMS OF POLLUTION AND "GREENHOUSE EFFECT").

TIMES TO FUEL DEPLETIONS ARE FOR WHOLE WORLD BURNING PROVEN RECOVERABLE RESERVES AT PRESENT RATES OF CONSUMPTION (BASED ON DATA IN ANNEXES 5, 10, 11 AND 12 OF "FUTURE STRESSES FOR ENERGY RESOURCES" BY J-R FRISCH, PUBL 1986 BY GRAHAM AND TROTMAN UNDER THE AUSPICES OF THE WORLD ENERGY CONFERENCE.

COAL MEANS BITUMINOUS, SUB-BITUMINOUS AND LIGTINE ('BROWN COAL') SOLID MINERAL FUELS. ADDITIONAL RECOVERABLE RESERVES OF SOLID MINERAL FUELS COULD BE THREE TIMES GREATER THAN THE PROVEN RECOVERABLE RESERVES. CORRESPONDING FACTORS FOR CONVENTIONAL OIL AND GAS ARE ABOUT ONE-THIRD AND TWO RESPECTIVELY.

Current World Utilization of Nuclear Power

Number of Countries operating Nuclear Plant	26
Total number of Nuclear Power Plants	378
Total Generating Capacity	265,808MWe
Nuclear share of World's Electricity	15%

- MANY COUNTRIES NOW USE NUCLEAR POWER
- THERE ARE SEVERAL HUNDRED NUCLEAR POWER PLANTS OPERATING
- THEY GENERATE A SIGNIFICANT FRACTION OF THE WORLD'S ELECTRICITY

DATA RELATES TO 31 DECEMBER 1986 AND WAS REPORTED IN NUCLEAR NEWS, FEBRUARY 1987. THE NUCLEAR SHARE OF THE WORLD'S ELECTRICITY IS FROM THE IAEA BULLETIN, AUTUMN 1986.

MARINE NUCLEAR PROPULSION UNITS ARE NOT INCLUDED IN THE DATA.

League Table of Dependence on Nuclear Power

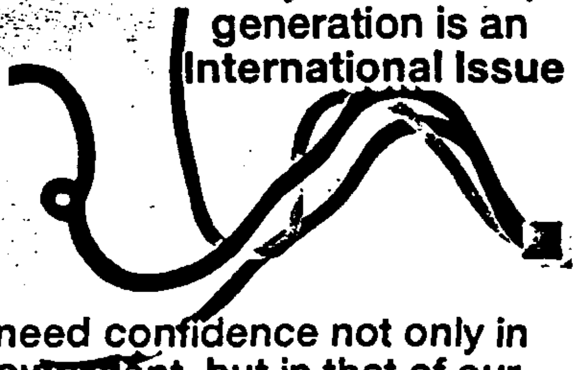
Country	%Nuclear	Country	%Nuclear
France	65	USA	16
Belgium	58	Czechoslovakia	15
Taiwan	52	Canada	13
Sweden	42	GDR	12
Switzerland	39	Argentina	11
Finland	38	USSR	10
Bulgaria	32	Netherlands	7
FRG	31	Yugoslavia	6
Hungary	24	Italy	5
Japan	23	South Africa	4
Spain	22	India	2
Korea	22	Brazil	2
UK	21	Pakistan	1

- SEVERAL COUNTRIES ARE NOW HIGHLY DEPENDENT UPON NUCLEAR POWER

LEAGUE TABLE IS BASED ON IAEA AND ENS DATA FOR THE YEAR TO THE END OF 1985, REPORTED IN THE IAEA BULLETIN, AUTUMN 1986 AND NUCLEAR EUROPE, JULY/AUG 1986.

THE DATA FOR THE USSR IS SUBJECT TO UNCERTAINTY. IAEA ESTIMATES HAVE BEEN USED TO MAINTAIN A CONSISTENT BASE WITH DATA FOR OTHER COUNTRIES, BUT THE IAEA ESTIMATE OF 152 TWh (10.3%) NUCLEAR GENERATION IN 1985 IS SOMEWHAT LESS THAN THE 170TWH (15%) STATED BY THE SOVIETS AT THE CHERNOBYL POST-ACCIDENT REVIEW MEETING IN VIENNA, AUGUST 1986.

Chernobyl re–emphasised that the safety of nuclear power generation is an International Issue



We need confidence not only in our own plant, but in that of our neighbours too

A COUNTRY CANNOT WASH ITS HANDS OF NUCLEAR ISSUES, BECAUSE IT CAN BE AFFECTED BY THE ACTIONS OF ITS NEIGHBOURS - WHETHER AS A RESULT OF A LARGE NUCLEAR ACCIDENT OR TRANS-BOUNDARY POLLUTION SUCH AS ACID RAIN IF COAL BURNING IS INCREASED.

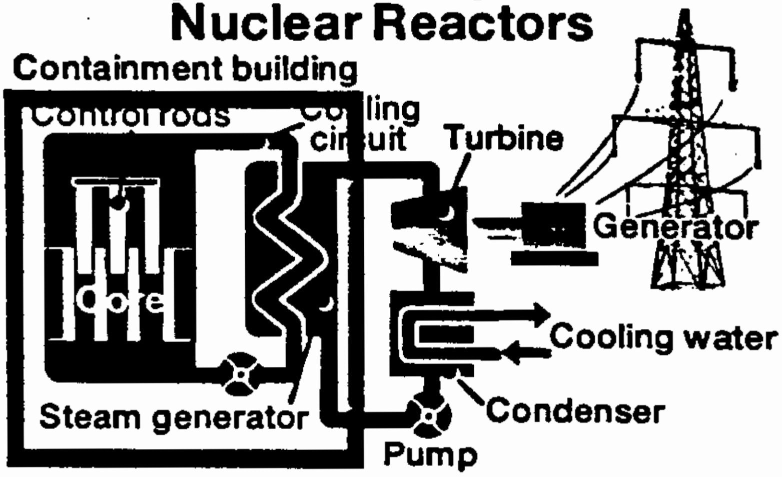

NORWAY
SWEDEN
UNION OF SOVIET SOCIALIST REPUBLICS
UNITED KINGDOM
POLAND
GDR
FRG
CZECHOSLOVAKIA
AUSTRIA
HUNGARY
FRANCE
ITALY
SPAIN
ROMANIA
YUGOSLAVIA

MAP OF EUROPE SHOWING LOCATIONS OF NUCLEAR PLANT.

- NUCLEAR PLANT DISTRIBUTED THROUGHOUT WESTERN EUROPE
- MANY QUITE CLOSE TO BORDERS

COUNTRIES NOT COVERED CONSISTENTLY – ALL EXISTING AND PLANNED NUCLEAR POWER PLANTS ARE SHOWN IN THE FRG, WHEREAS FOR FRANCE, MULTIPLE UNIT SITES APPEAR AS SINGLE DOTS AND ONLY OPERATING SITES ARE SHOWN.

Principles of the Operation of Nuclear Reactors

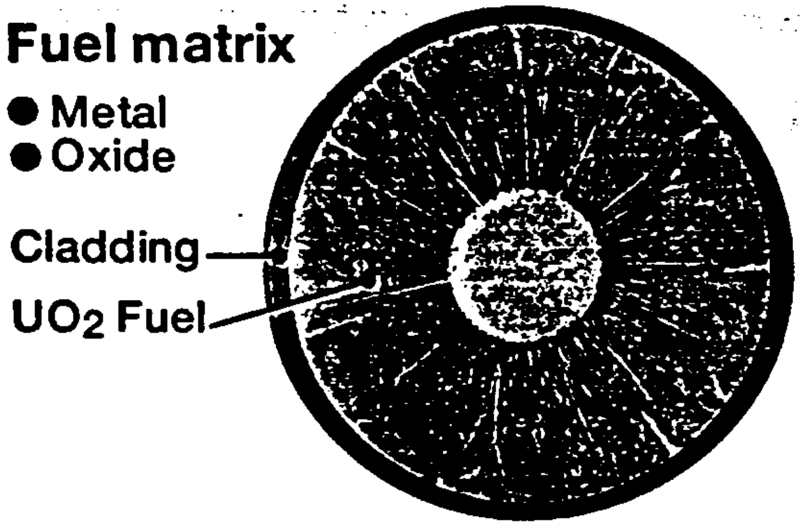


OUTLINE OF NUCLEAR POWER STATION, SHOWS

- **CORE**
- **CONTROL RODS**
- **PRESSURE CIRCUIT (PRIMARY CIRCUIT - INDIRECT CYCLE)**
- **PUMP**
- **STEAM GENERATOR (BOILER)**
- **CONTAINMENT**
- **SECONDARY CIRCUIT (INDIRECT CYCLE)**
- **TURBINE/GENERATOR**
- **CONDENSER**

COOLANT WOULD FLOW CLOCKWISE IN BOTH PRIMARY AND SECONDARY CIRCUITS ON FIGURE.

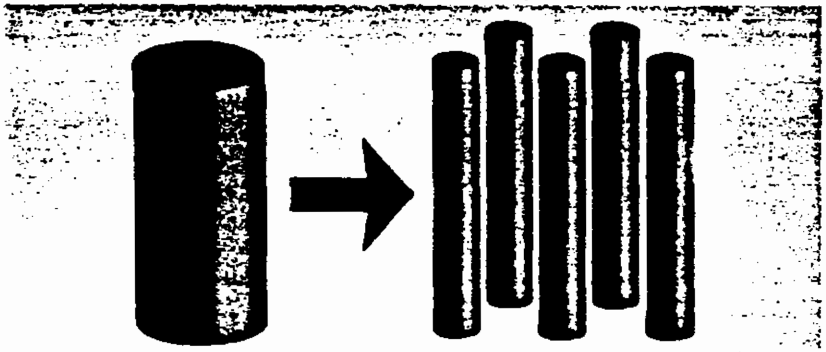
CONTAINMENT ENCLOSES WHOLE OF PRIMARY CIRCUIT.


Fuel matrix
● Metal
● Oxide
Cladding
UO2 Fuel

CROSS-SECTION OF FUEL ROD (FAST REACTOR)

SHOWS UO_2 OXIDE PELLET WITH RADIAL CRACKING AND CENTRAL VOID.

CLAD IN STAINLESS STEEL - NEUTRON ABSORPTION IN STAINLESS STEEL MORE SIGNIFICANT IN THERMAL REACTORS (AGR) AND LEADS TO THINNER CLADDING THICKNESS.



Fuel changed from metal to oxide and fabricated into thinner fuel rods to increase the power generated per tonne (rating)

RAISING RATING INCREASES CENTRAL TEMPERATURE OF FUEL ROD - PURE URANIUM HAS METALLURGICAL PHASE CHANGE AT 660C THAT CHANGES CRYSTALLINE STRUCTURE AND PRODUCES DISTORTION, SO CENTRAL TEMPERATURE OF PURE URANIUM FUEL MUST BE LIMITED.

∴ TO RAISE RATING

- CHANGE TO OXIDE FUEL (NO PHASE CHANGE PROBLEMS AND HIGH MELTING POINT, 2850C).
- FABRICATE FUEL INTO THINNER RODS TO COMPENSATE FOR EFFECT OF REDUCED THERMAL CONDUCTIVITY ON CENTRAL TEMPERATURE.

Material for Fuel Cladding

- Low Cross Section
- Compatible with Fuel and Coolant
- Strong at High Temperature

DESIRABLE PROPERTIES FOR FUEL CLADDING MATERIALS.

FUEL CLADDING HOLDS FUEL PELLETS IN RODS AND PROVIDES BARRIER AGAINST FISSION PRODUCT RELEASE.

MUST ALSO ASSIST HEAT TRANSFER FROM FUEL TO COOLANT (AGR CLADDING HAS ROUGHENED SURFACE).

Heat Removal at Power

Gases

- Poor Heat Transfer/Transport
- Low Rating→Large Reactor
- Low Neutron Absorption
- No Change of Phase

HEAT REMOVAL AT POWER

PROS AND CONS OF GAS COOLING

Heat Removal at Power

Liquids

- Good Heat Transfer/Transport
- Smaller, more Economic Reactors
- High Neutron Absorption (Except Heavy Water)
- Change of Phase

HEAT REMOVAL AT POWER

PROS AND CONS OF LIQUID COOLING

Decay Heat Removal

- 7% and falling with time

PWR – Keep core covered with water and natural circulation occurs (electric kettle)

Gas-Cooled Reactor – Keep gas circulators running (hair dryer)

- Reliable Decay Heat Removal in Both Cases

DECAY HEAT REMOVAL

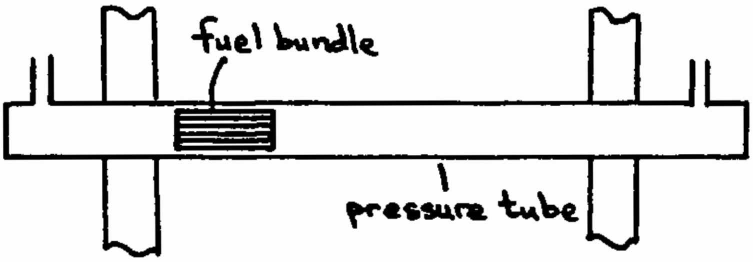
- EVEN WHEN CHAIN REACTION SHUTDOWN, RADIOACTIVE DECAY OF FISSION PRODUCTS FORMED WHILE REACTOR OPERATING PROVIDES SOURCE OF HEAT - DECAY HEAT.

- DECAY HEATING IS A FEW PERCENT OF FULL POWER HEAT PRODUCTION IMMEDIATELY AFTER SHUTDOWN AND FALLS STILL FURTHER WITH TIME.

- PWR - KEEP CORE COVERED AND ALLOW NATURAL CIRCULATION TO STEAM GENERATORS IF WORKING, OR ALLOW WATER IN CORE TO BOIL, REPLENISHING WATER BOILED OFF.

- GAS-COOLED REACTORS -KEEP CIRCULATORS AND BOILERS OPERATING. FOR AGRs, NATURAL CIRCULATION OF GAS SUFFICIENT IF PRESSURE MAINTAINED (BOILERS STILL NEEDED OF COURSE).

PICKERING 'A'

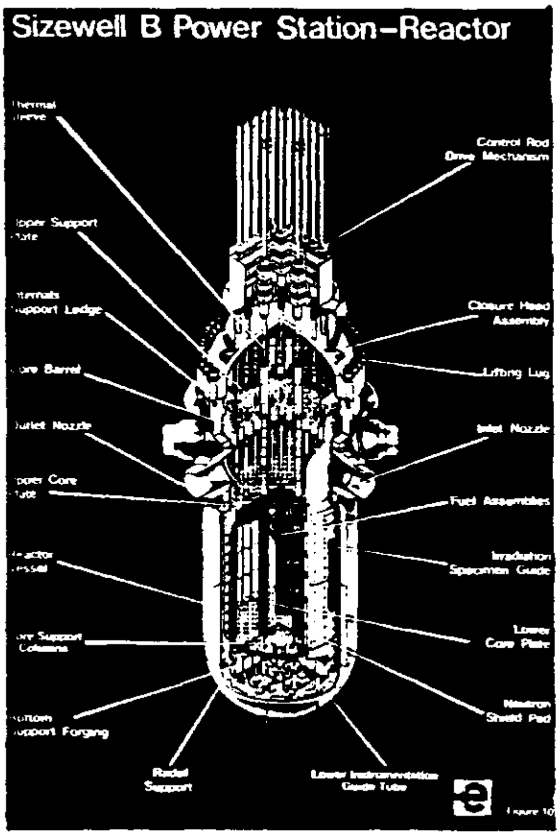


(Properly drawn slide coming soon)

CANDU - PRESSURE TUBE REACTOR

PRESSURE TUBES ARE

- THIN WALLED
- SUBJECT TO HIGH NEUTRON FLUXES
- CLOSE TO THE FUEL
- SHOULD 'LEAK BEFORE BREAK' AND SO FOREWARN OF MAJOR FAILURE



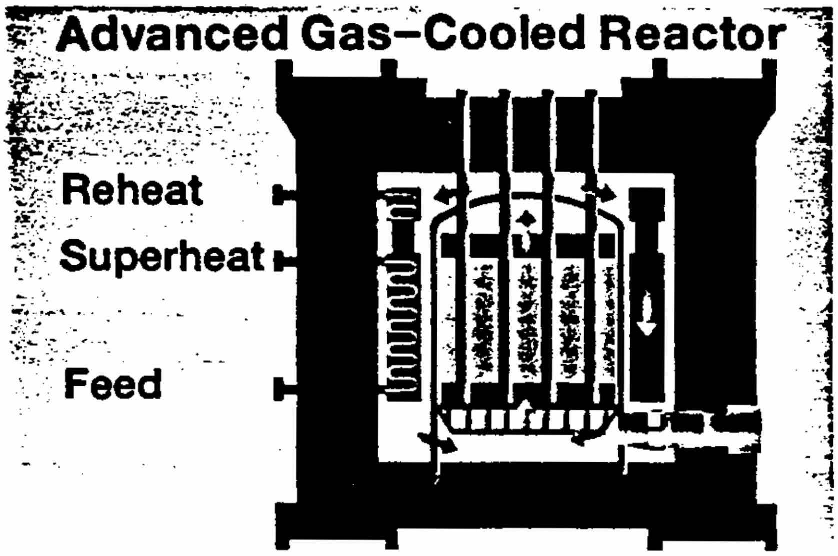
Sizewell B Power Station–Reactor

Figure 10

PRESSURISED WATER REACTOR (PWR)

PRESSURE VESSEL IS

- THICK WALLED (8-10")
- SUBJECT TO LOW IRRADIATION
- REMOTE FROM FUEL
- NEEDS VERY HIGH QUALITY DESIGN, FABRICATION AND INSPECTION


Advanced Gas–Cooled Reactor
Reheat
Superheat
Feed

ADVANCED GAS-COOLED REACTOR (AGR)

PRESSURE VESSEL IS

- CONCRETE (POST-TENSIONED)
- NEEDS TO BE KEPT COOL
- WOULD FAIL PROGRESSIVELY
- BUT INSPECTION IS DIFFICULT

PRESSURE VESSEL ALSO ENCLOSES WHOLE OF PRIMARY CIRCUIT.

Control

- Delayed Neutron Fraction (0.7%)
- Reactivity Changes–
    - –Temperature (Doppler)
    - –Burn–up
    - –Coolant (Negative Void Coefficient)
- Neutron Population Control by Rods

CONTROL MADE POSSIBLE BY 'DELAYED NEUTRONS', PRODUCED UP TO ABOUT 1 MINUTE AFTER NEUTRON CAPTURE. ABOUT 0.7% OF NEUTRONS PRODUCED IN CHAIN REACTION ARE DELAYED. PROVIDED REACTOR IS NOT CRITICAL ON PROMPT NEUTRONS ALONE ('PROMPT CRITICAL'), CHANGES OF REACTIVITY AND POWER ARE 'HELD BACK' BY WAIT FOR DELAYED NEUTRONS AND OCCUR ON CONTROLLABLE TIMESCALES.

REACTIVITY CAN CHANGE DUE TO 'INTERNAL' INFLUENCES

- TEMPERATURE (DOPPLER)
- BURN-UP (DEPLETION OF FISSILE MATERIAL, POISONING)
- COOLANT CHANGES (NEGATIVE VOID COEFFICIENT)

AND DUE TO 'EXTERNAL' INFLUENCES

- CONTROL ROD MOVEMENTS

Protection

- Function to protect reactor from faults
- Diverse and redundant signals
- 'Guard' lines

PROTECTION

RECOGNISE FAULTS CAN OCCUR AND PROVIDE SYSTEMS TO MAINTAIN REACTOR IN SAFE CONDITION.

Safeguards

- To 'trip' the reactor
- To ensure cooling under all conditions:

  Eg.

  Loss of power
  Loss of coolant
- 'Active' and 'passive' devices

SAFEGUARDS

SHUTDOWN REACTOR AND ENSURE ADEQUATE HEAT REMOVAL FROM CORE VIA COMBINATION OF ACTIVE AND PASSIVE DEVICES.

Containment

Needed if Fission Products released during design basis accident

PURPOSE OF CONTAINMENT - WHY SOME REACTORS NEED THEM AND OTHER DO NOT.

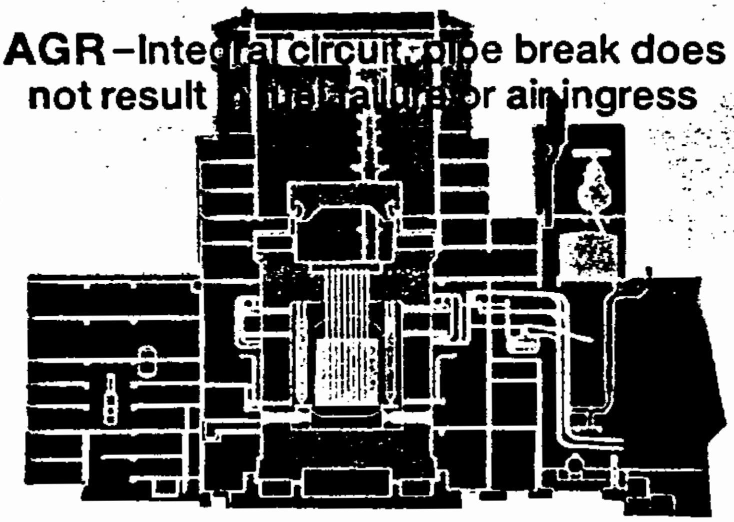
PWR

Large 'LOCA' may result in fuel failures

PWR CONTAINMENT,SHOWING THE LARGE VOLUME THAT COULD CONTAIN ALL THE STEAM AND WATER RELEASED FROM THE PRIMARY CIRCUIT IN AN ACCIDENT WITHOUT THE PRESSURE EXCEEDING THE DESIGN PRESSURE (50 PSIG).

ALL THE PRIMARY CIRCUIT IS ENCLOSED BY THE CONTAINMENT BUILDING (THOUGH SOME CONNECTING PIPEWORK PASSES THOUGH IT).

AGR – Integral circuit: pipe break does not result in fuel failure or air ingress



AGR – PRESSURE VESSEL ENCLOSES WHOLE OF PRIMARY CIRCUIT, COOLANT IS CLEAN SO ADDITIONAL PRESSURE RETAINING BUILDING IS NOT REQUIRED.

Containment of Fission Products

Barriers

1. Fuel matrix
2. Fuel cladding
3. Pressure circuit
4. Containment building

BARRIERS TO FISSION PRODUCT RELEASE

FAILURE OF ONE BARRIER WOULD NOT USUALLY LEAD TO FAILURE OF OTHERS, SO FISSION PRODUCTS WOULD BE CONTAINED.

EXCEPTION IS PRESSURE CIRCUIT FAILURE, WHICH COULD LEAD TO FAILURE OF ALL OTHER BARRIERS, BUT SUCH PROPAGATION OF FAILURE IS MADE HIGHLY UNLIKELY BY ENGINEERED SAFEGUARDS.

Defense in Depth

- Provide a reactor with good inherent safety characteristics
- Assume that things will go wrong and provide automatic, diverse and redundant engineered safeguards
- Prevent releases of radioactivity to the environment

DEFENCE IN DEPTH

DIVERSITY OF SAFETY CONCEPTS EMPLOYED IN DESIGN TO ACHIEVE SAFE OPERATION.

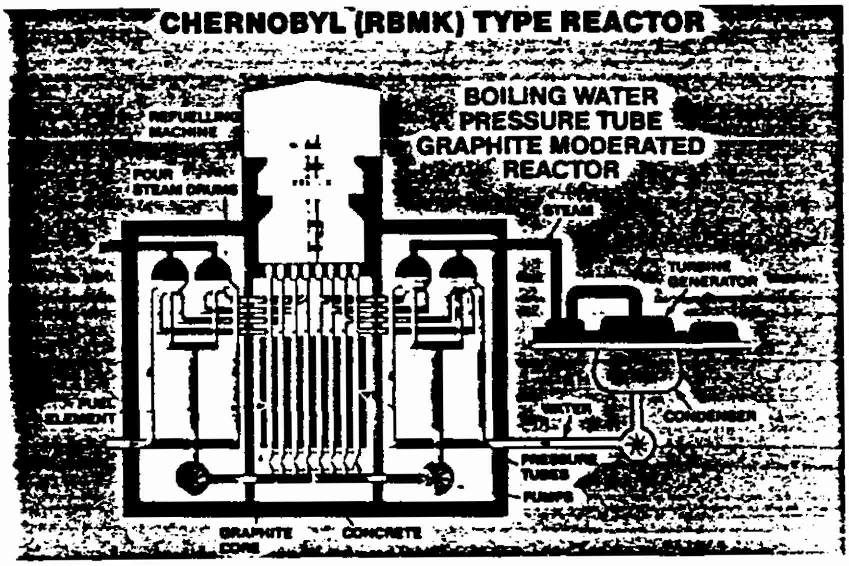
Types of Accident

- Loss of cooling (TMI–2)
- Increase in power (reactivity accident – Chernobyl–4)

TYPES OF ACCIDENT - OTHER EXAMPLES

- NRU FUEL ELEMENT INCIDENT (FUEL BURNED IN FLASK)
- BROWNS FERRY FIRE IN CABLE TRAYS (STARTED WITH CANDLE)
- WINDSCALE PILE (FIRE)
- NRX REACTOR ACCIDENT (SIMILARITIES WITH CHERNOBYL - CHANNEL VOIDING RAISED REACTIVITY, EXPLOSION OCCURRED)
- SL1 ACCIDENT (STEAM EXPLOSION, REACTOR VESSEL ROSE 3M, 3 PEOPLE KILLED)
- EBR-I (MARK II CORE HAD POSITIVE TEMPERATURE COEFFICIENT, SLOW-ACTING RODS ACTIVATED INSTEAD OF SCRAM RODS TO SHUTDOWN REACTOR FOLLOWING FLOW REDUCTION TEST, FUEL MELTED).
- ENRICO FERMI I (ANOTHER FAST REACTOR, FLOW BLOCKAGE CAUSED FUEL MELTING).
- LUCENS REACTOR (SWITZERLAND, EXPERIMENTAL GAS-COOLED, PRESSURE-TUBE, HEAVY WATER MODERATED REACTOR, FUEL CHANNEL BURST, LOSS OF COOLANT).

AND LESS SERIOUS INCIDENTS.


CHERNOBYL (RBMK) TYPE REACTOR
BOILING WATER PRESSURE TUBE GRAPHITE MODERATED REACTOR
REFUELLING MACHINE
FOUR STEAM DRUMS
STEAM
TURBINE GENERATOR
FUEL ELEMENT
WATER
CONDENSER
PRESSURE TUBES
PUMPS
GRAPHITE CORE
CONCRETE

RBMK CROSS-SECTION - HIGHLIGHT

- PRESSURE TUBES
- LIGHT WATER COOLANT
- GRAPHITE MODERATOR
- PARTIAL CONTAINMENT
- COMPLICATED PLUMBING

The Chernobyl Accident

Causes

- Reactor allowed to operate in unstable regime
- Operators seriously degraded shutdown capability
- Additional pumps started for turbogenerator experiment–all water in circuit brought close to boiling
- Operators disabled reactor safeguards–reactor not tripped at start of experiment
- Pumps slowed down, water boiled vigorously and was expelled from core by steam
- Positive void coefficient and positive power coefficient caused reactivity and reactor power to surge

CAUSES OF CHERNOBYL ACCIDENT

- WHAT HAPPENED AND WHY IT LED TO DISASTER

ONLY A ROUGH SKETCH - IT IS EASY TO BE SWAMPED BY DETAIL.

Would the RBMK have received a licence in the UK?

NO – Because it failed to conform to many of the NII's safety assessment principles

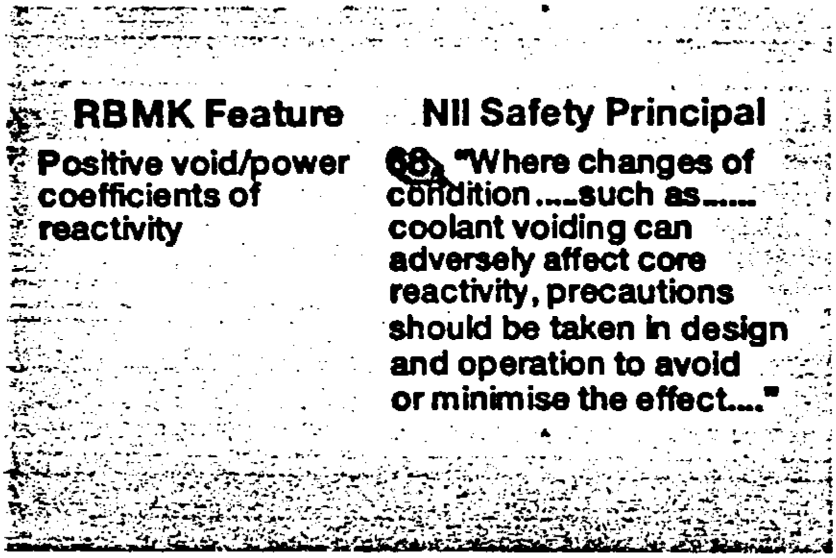
FAILURE OF RBMK TO CONFORM TO NII SAFETY ASSESSMENT PRINCIPLES - EXAMPLES FOLLOW

FIRST EXAMPLE CONCERNS VOID COEFFICIENT, NEXT SLIDE HAS EXAMPLE CONCERNING INTERFERENCE WITH SAFEGUARDS.

NII "SAFETY ASSESSMENT PRINCIPLES FOR NUCLEAR REACTORS" FIRST PUBLISHED 1979 AND ON SALE THROUGH HMSO.

USNRC "REPORT ON THE ACCIDENT AT THE CHERNOBYL NUCLEAR POWER STATION" (NUREG-1250, JANUARY 1987) SHOWS (SECT 3.2.3) THAT RBMK REACTORS DO NOT CONFORM WITH THE SOVIET "GENERAL SAFETY REGULATIONS OF NUCLEAR POWER PLANTS DURING DESIGN, CONSTRUCTION AND OPERATION (OPB-82)" (ATOMNAYA ENERGIYA, 54:(2), 1983).

AS WITH OTHER SOVIET REGULATIONS, THESE ARE TARGETS TO AIM FOR AND NONCONFORMITY WITH THEM WOULD NOT IMPEDE PROGRESS TOWARDS A SET ECONOMIC GOAL. IN THE UK HOWEVER, THE NII CAN COMPLETELY HALT OPERATIONS AT LICENSED NUCLEAR PLANT IF THEY FAIL TO COMPLY WITH SAFETY REGULATIONS.



RBMK Feature	NII Safety Principal
Positive void/power coefficients of reactivity	(68) "Where changes of condition.....such as...... coolant voiding can adversely affect core reactivity, precautions should be taken in design and operation to avoid or minimise the effect...."

EXAMPLE OF NONCONFORMITY WITH NII SAFETY ASSESSMENT PRINCIPLES

- SECOND EXAMPLE FOLLOWS

RBMK Feature	NII Safety Principal
Disabling of safeguards by operators	107) "Adequate protection systems should be provided and, whenever fuel is in the reactor, they should be maintained at a level of readiness adequate to ensure nuclear safety." 131) "The design should be such that the means of access to all protection equipment can be physically controlled to limit access......"

FURTHER EXAMPLE OF NONCONFORMITY WITH NII SAFETY PRINCIPLES.

TWO ADDITIONAL EXAMPLES:

RBMK FEATURE   SHUTDOWN SYSTEM RELIED ON OBSERVANCE OF A RULE (MINIMUM REACTIVITY RESERVE EQUIVALENT TO 15 RODS) TO MAINTAIN ITS EFFECTIVENESS.

NII SAFETY PRINCIPLE   112. "NO SINGLE FAILURE WITHIN THE PROTECTION SYSTEM SHOULD PREVENT ANY PROTECTIVE ACTION ACHIEVING ITS REQUIRED PERFORMANCE." FAILURE TO OBSERVE THE RULE DID PREVENT THE SHUTDOWN SYSTEM ACHIEVING ITS REQUIRED PERFORMANCE.

122. "DIVERSITY OF FAULT DETECTION AND PROTECTION SHOULD BE EMPLOYED WHERE REASONABLY PRACTICABLE BUT WHERE PROTECTION SYSTEM RELIABILITY IS REQUIRED TO BE VERY HIGH OR WHEN THERE IS DOUBT ABOUT THE RELIABILITY OR EFFECTIVENESS OF A NON-DIVERSE SYSTEM, DIVERSITY SHOULD BE INTRODUCED." THE RUSSIANS ARE NOW CONSIDERING INTRODUCING DIVERSITY.

RBMK FEATURE   LIMITED CONTAINMENT OF THE PRESSURE CIRCUIT.

NII SAFETY PRINCIPLE   152. "A CONTAINMENT SHOULD BE PROVIDED AROUND THE REACTOR AND ITS PRIMARY COOLANT CIRCUIT, UNLESS IT CAN BE SHOWN THAT ADEQUATE PROTECTION HAS BEEN ACHIEVED BY OTHER MEANS. THE CONTAINMENT SHOULD ADEQUATELY CONTAIN SUCH RADIOACTIVE MATTER AS MAY BE RELEASED INTO IT AS A RESULT OF ANY FAULT IN THE REACTOR PLANT."

MANY MORE EXAMPLES ALSO AVAILABLE IN CHERNOBYL REPORT (NOR 4200)

Principal Differences Between RBMK and Western Reactors

Magnox

- Fast–acting power coefficient never positive
- No void coefficient (gas coolant)
- No possibility of 'fuel–coolant interactions'
- Graphite provides massive heat sink
- With worst hypothetical reactivity transient, fuel temperature would rise at only 1°C/sec.

RBMK V. MAGNOX

Principal Differences Between RBMK and Western Reactors

AGR

- Fast–acting power coefficient never positive
- No void coefficient
- No possibility of 'fuel–coolant interactions'
- Graphite provides massive heat sink
- Prestressed concrete pressure vessel likely to contain fission products even if fuel melts

RBMK V. AGR

Principal Differences Between RBMK and Western Reactors

PWR

- Fast-acting power coefficient never positive
- Void coefficient either negative or so slightly positive that the power of the reactor cannot run away

RBMK V. PWR

The Russian Graphite Moderated
Channel Tube Reactor

The Chernobyl Accident

- was very serious – a million times worse than TMI – 2
- was caused primarily by design flaw but management and operator errors contributed (human error)

NNC
National Nuclear Corporation Limited

CHERNOBYL ACCIDENT - MAIN POINTS

- MAGNITUDE
- DESIGN FLAWS
- HUMAN ERROR

- - - - - - - - - - - - - -

- NO RBMKs OUTSIDE USSR
- RBMK DESIGN IS UNIQUE

The Chernobyl Accident

The Russian Graphite Moderated
Channel Tube Reactor

- RBMKs were only ever built in the USSR and would not have been built in any western country (NNC report, 1976)
- The Soviets have acknowledged that RBMK reactors are unique and not part of the set of western reactors

NNC
National Nuclear Corporation Limited

The Chernobyl Accident

- revealed no new phenomena
- provides no new lessons on design and operation for the UK and western experts
- has no relevance to PWR design
- does provide information on consequences, crisis management and evacuation

CHERNOBYL ACCIDENT - RELEVANCE TO WEST

- NO NEW PHENOMENA (FUEL DEGRADATION, FCI'S ETC. HAVE ALL BEEN OBSERVED PREVIOUSLY IN EXPERIMENTS)

- NO NEW LESSONS ON DESIGN AND OPERATION - THE WEST LEARNED THE LESSONS YEARS AGO AND WOULD NOT BUILD RBMK REACTORS. UK SAFETY PRINCIPLES ANTICIPATED ALL THE FAILINGS OF RBMK REACTORS THAT THE CHERNOBYL ACCIDENT REVEALED.

- HAS NO RELEVANCE TO PWR'S - POWER COEFFICIENT ALWAYS NEGATIVE, DIVERSE SAFETY SYSTEMS WITH INTERLOCKS, FULL CONTAINMENT THAT CAN WITHSTAND LOSS OF FULL PRIMARY CIRCUIT INVENTORY ETC.

- PROVIDES INFORMATION ON CONSEQUENCES, CRISIS MANAGEMENT AND EVACUATION - WEST HAS NEVER HAD SUCH FIRST-HAND EXPERIENCE.

    - CONSEQUENCES - CHEMICAL FORMS OF FISSION PRODUCTS/DEPOSITION/DECONTAMINATION/HEALTH EFFECTS

    - CRISIS MANAGEMENT - ORGANISATION OF DISPARATE SERVICES IN TIME OF CRISIS

    - EVACUATION - PLANNING, LOGISTICS ETC.

Practical Steps Being Taken Internationally

1. The two conventions
2. The Walker initiative
3. Technical programme under auspices of IAEA
4. Work of other international agencies (OECD, CEC, WHO, etc)

PRACTICAL STEPS

PURPOSE

Future Developments

Development of improved designs

[a] "Inherently safe reactors"

- No reactor can meet inherent safety under all circumstances
- There has to be a compromise between engineered and passive systems
- Some designs look useful for particular applications

  Eg. Process heat (HTR)

  Remote/urban siting (PIUS)

FUTURE DEVELOPMENTS - 'INHERENTLY SAFE REACTORS'

IMPORTANT NOT TO EXAGERATE CLAIMS FOR 'INHERENTLY SAFE REACTORS' - CURRENT REACTORS HAVE SOME INTRINSIC FEATURES THAT PROVIDE INHERENT SAFETY, AND 'INHERENTLY SAFE REACTORS' WILL NONETHELESS REQUIRE SOME ENGINEERED SAFETY FEATURES.

FURTHERMORE, INHERENTLY SAFE REACTORS MAY NOT BE THE ONLY MEANS OF ACHIEVING THE DESIRED GOAL - UTILIZATION OF NUCLEAR POWER WITH NO RADIOLOGICAL RISK TO THE PUBLIC.

Future Developments

[b] Evolution of existing designs

Example: Sizewell 'B' contains safety features not found in older plant

Goal: To isolate the public from even the worst imaginable accident to the reactor

TMI–2 demonstrated partial achievement of that goal even in 1979

FUTURE DEVELOPMENTS - EVOLUTION OF EXISTING DESIGNS

SIZEWELL 'B' IMPROVEMENTS*

- PRA INPUT TO DESIGN PROCESS
- ADDITIONAL HIGH HEAD SAFETY INJECTION PUMPS, WITH INCREASED CAPACITY, DEDICATED TO TASK.
- LARGER ACCUMULATORS
- RING FORGINGS FOR RPV
- IMPROVED AUXILIARY FEEDWATER SYSTEM (EXTRA STEAM DRIVEN PUMP, PUMPS WELL SEGREGATED, STEAM DRIVEN PUMPS DO NOT DEPEND ON SAME SERVICES AS MOTOR DRIVEN PUMPS).
- EMERGENCY CHARGING SYSTEM PROVIDED
- EMERGENCY BORATION SYSTEM PROVIDED
- COMPUTER-BASED INTEGRATED PROTECTION SYSTEM BACKED UP BY SYSTEM OF TYPE USED IN AGRs
- ADDITIONAL DIESEL GENERATORS PROVIDED
- DRY COOLING TOWERS FOR DIVERSITY OF ULTIMATE HEAT SINK.
- ADDITIONAL SHIELDING, REMOTE MAINTENANCE EQUIPMENT TO REDUCE DOSES TO STAFF.
- CONTROL ROOM DESIGNED TO LATEST ERGONOMIC PRINCIPLES AND EMERGENCY CONTROL ROOM IN REMOTE LOCATION PROVIDED.

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* FROM CEGB STATEMENT OF CASE, VOLUME 2, SIZEWELL 'B' PUBLIC INQUIRY.

Industrial Explosions (1907–1944)

	No. Killed
1907–Steelworks, Pittsburgh, USA	59
1915–Petrol storage tank, Pittsburgh	44
1921–Factory, Oppau Germany	565 (town destroyed)
1927–Hydocarbon storage, Pittsburgh	28
1933–Hydocarbon storage, Neuenkirken,Germany	100
1939–Cellulose factory + release of chlorine Brachto, Transylvannia	62
1942–Chemical factory, Limbourg, Belgium	200
1944–LPG tank, Cleveland, USA	136

THE FUTURE DEVELOPMENTS DEMONSTRATE THE NUCLEAR INDUSTRY'S COMMITMENT TO IMPROVING STILL FURTHER UPON ITS ALREADY ENVIABLE SAFETY RECORD.

COMPARED TO OTHER INDUSTRIES, THE NUCLEAR INDUSTRY IS EXCEPTIONALLY SAFE - THOUSANDS OF PEOPLE, BOTH WORKERS AND GENERAL PUBLIC, HAVE BEEN KILLED BY EXPLOSIONS IN OTHER INDUSTRIES DURING THE 20th CENTURY.

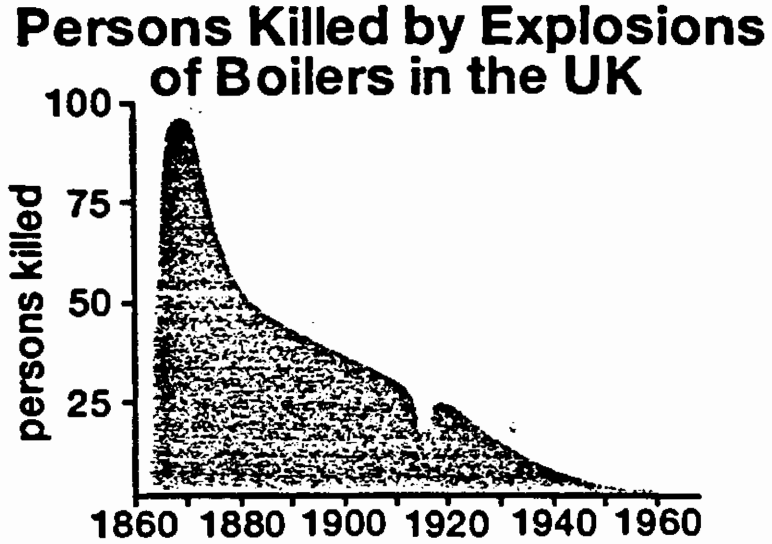
Industrial Explosions (1966–1984)

	No. Killed
1966–Refinery, Feysin, France	17
1974–Chemical factory, Flixborough, UK	28
1976–Dioxin release, Seveso, Italy	NIL (ground contaminated)
1978–Propylene road tanker, Los Alfaques, Spain	216
1979–Railway accident–L.P.G.+Chlorine Mississouga USA	NIL (240,000 evacuated)
1984–Cloud of highly toxic gas Bhopal, India	2600
1984–Explosion at LPG storage site Mexico City	500+

IN 1984, OVER 3000 PEOPLE WERE KILLED BY THE EXPLOSIONS AT BHOPAL AND MEXICO CITY.

IN THE WEST's MOST SERIOUS NUCLEAR ACCIDENT (TMI), NOBODY WAS KILLED OR INJURED.

IN THE WORLD's MOST SERIOUS NUCLEAR ACCIDENT (CHERNOBYL) THERE WERE ONLY 31 EARLY FATALITIES.


Persons Killed by Explosions of Boilers in the UK
persons killed
100
75
50
25
1860
1880
1900
1920
1940
1960

THE NUMBER OF PEOPLE KILLED BY BOILER EXPLOSIONS HAS STEADILY DECREASED OVER THE PAST 100 YEARS.

STATISTICS INCOMPLETE TOWARDS END OF FIRST WORLD WAR.

Fatalities in the Coal, Civil Nuclear and Offshore Oil and Gas Industries

Year	Coal	Civil nuclear industries	Offshore oil and gas
1975–76	59	1	10
1976–77	38	1	17
1977–78	48	1	11
1978–79	72	1	4
1979–80	31	0	10
1980–81	39	1	4
1981–82	34	1	6
1982–83	44	1	12
1983–84	22	2	9
1984–85	12	0	10
Totals	746	10	116

THE CIVIL NUCLEAR INDUSTRY IS MUCH SAFER THAN THE COMPETING ENERGY SUPPLY INDUSTRIES.

Summary

1. The world needs nuclear power – not just the industrialised countries
2. No country is isolated – to be widely used nuclear power must be safe and be seen to be safe
3. The challenge is to continually strive for greater safety – and to convince non–specialists that we are doing it well

SUMMARY

Is Nuclear Power Safe?

Yes – but there must be no weakening of the industry's committment to safety

CONCLUSION

Safety

Facts:

The accident at Chenobyl, Windscale and TMI spanned a factor of 1,000,000 in terms of release of radioactivity

Chernobyl (1986)	20,000,000CiI
Windscale (1957)	20,000CiI
TMI (1979)	20CiI

ADDITIONAL SLIDES

RELATIVE SIZES OF RELEASES FROM CHERNOBYL, WINDSCALE AND TMI.

Safety

Facts:

The risk to the public of nuclear power is not dominated by big accidents

For example Layfield gives following tables

	Annual risk of death
Normal operation	30×10^{-8}
Design basis accidents	4×10^{-8}
Beyond design basis accident	0.2×10^{-8}
total	34×10^{-8}

or 1 in 3 million

ADDITIONAL SLIDES

RISK TO PUBLIC NOT DOMINATED BY BIG ACCIDENTS - EXAMPLE FROM LAYFIELD REPORT (TABLE 47.1.1, P20, SECTION 10).

THIS RUNS COUNTER TO GENERAL PERCEPTION, WHICH IS BASED ON WASH 1400 - BUT THE DEGRADED CORE FREQUENCY CALCULATED IN WASH 1400 FOR SURRY 1 (60×10^{-6}/ROY) IS 50 TIMES GREATER THAN THAT FOR SIZEWELL 'B' (1.2×10^{-6}/ROY, WCAP 9991), IE RISK OF LARGE ACCIDENTS MUCH LESS FOR SIZEWELL 'B'.

TABLE SHOWS MAXIMUM INDIVIDUAL RISK TO MEMBERS OF THE PUBLIC FROM SIZEWELL 'B' (CORRESPONDS ROUGHLY TO RISK AT SITE BOUNDARY). FOR NORMAL OPERATION AND DESIGN BASIS ACCIDENTS, RISK IS THAT OF FATAL CANCERS (NO EARLY DEATHS). FOR BEYOND DESIGN BASIS ACCIDENTS, RISK IS ESSENTIALLY THAT OF EARLY DEATH - RISK OF FATAL CANCER WOULD BE 6 TIMES LOWER.

FOR SOCIAL RISKS, NORMAL OPERATION ALSO DOMINATES (TABLE 47.1.3, LAYFIELD REPORT)

	ANNUAL SOCIAL RISK (DEATHS/YEAR)
NORMAL OPERATION	16×10^{-4}
DESIGN BASIS ACCIDENTS	2×10^{-4}
BEYOND DBA'S	2×10^{-4}
TOTAL	20×10^{-4} (1 EVERY 500 YEARS)

Accident Probabilities

There have recently been claims that meltdown of a nuclear reactor should be expected every 5 to 10 years

These claims are based on:

(1) 2 severe core damage accidents having occurred in 4000 reactor operating years;

(2) PRA's showing the mean core melt frequency of US reactors is about 3×10^{-4} per year

These claims are misleading

ADDITIONAL SLIDES

ACCIDENT PROBABILITIES

1. S. ISLAM AND K. LINDGREN, "HOW MANY REACTOR ACCIDENTS WILL THERE BE?", NATURE VOL. 322, 21 AUGUST, 1986, PP 691-2.

2. STATEMENT BY USNRC COMMISSIONER JAMES K. ASSELSTINE, MAY 22, 1986, TESTIMONY TO HOUSE SUB-COMMITTEE ON ENERGY CONSERVATION AND POWER.

   SUB-REF: LETTER 16 APRIL, 1986, N. PALLADINO TO E. MARKEY, ANSWER 21A.

Accident Probabilities

These claims are misleading because:

- They do not take account of improvements backfitted to Western reactors since the TMI–2 accident
- Claim (1) relies on Western and Chernobyl reactor designs being equivalent in safety terms – Soviet presentations in Vienna, August 1986, demonstrated this to be untrue

ADDITIONAL SLIDES

PROBABILITIES - REASONS WHY THEY ARE MISLEADING.

CRITICISM MIGHT NOT BE VALID FOR ASSELSTINE'S CLAIM, AS HIS MEAN CORE MELT FREQUENCY IS BASED ON PRAs PERFORMED POST-TMI.

Accident Probabilities

The same PRA techniques used in (2) were used in the design of Sizewell 'B' and confirm a core melt probability less than the lowest US values and two orders of magnitude lower than the US average

Core meltdown would in most accidents not lead to an uncontrolled release of radioactivity – TMI–2 caused no immediate deaths and less than one statistical, latent death

ADDITIONAL SLIDES

PROBABILITIES - SIZEWELL 'B' DESIGNED WITH THE BENEFIT OF PRA TECHNIQUES AND HINDSIGHT.

10-11

SAFETY AND RELIABILITY DIRECTORATE
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10 November 1986

Mr R N Simeone
UKAEA
11 Charles II Street
London

Dear Reggie

EXPERT WORKING GROUP ON INTERNATIONAL CO-OPERATION IN NUCLEAR SAFETY AND RADIATION PROTECTION, 3 - 7 NOVEMBER 1986

I am responding to your request for a rapid response briefing on the Expert Working Group meeting in Vienna. Although the meeting was somewhat disappointing in its scope and in the way it was organised and managed, the outcome so far as the UK was concerned was quite satisfactory. In particular, all of the main objectives as outlined in the UK Steering Brief were achieved. The "Walker initiative" was given a boost by the adoption by the group of a UK proposal for work by the Agency along the lines suggested in the Secretary of State's speech to the General Conference. Mr Ryder has already spoken to Mr Morphet on this.

The other more general matters of interest to the UK were also negotiated successfully. There was no 'public' pressure for OSART missions to the UK and the positive assistance by way of making more experts available from the UK was input. Miss Hills of NRPB, who looked after matters relating to radiological protection had no significant concerns at the end of the meeting.

The following are highlights of points of more particular interest to the Authority.

1. <u>OSART Missions</u>

The offer of experienced Authority staff for OSART missions was made. There was some confusion over OSART missions to Research Reactors as the Agency also ran advisory missions to such reactors, but under a different programme to OSARTS. In the main, these are missions to reactors which have been constructed and operated with direct assistance from the Agency. OSARTS themselves are intended to cover power reactors. There may be requests for assistance in either category.

2. Fire Protection

This is an area where the Authority had taken the lead in preparing the UK position. Ours was the only delegation to make a positive input and our lead was followed by the meeting. A high priority was accorded the supplementary programmes proposals in this field. Further, in discussions with the secretariat, I as able to indicate that we could be of assistance to them in developing their programmes. This represents a useful opportunity for the Authority to gain recognition as the "centre of excellence" in this area for both the UK and, through this contact, internationally.

3. Development of Methods for Probabilistic Safety Assessment

This is an area of virtually unanimous agreement that the Agency should expand its activities in providing developing countries with the necessary tools and advice to perform such studies. SRD has been involved in these activities for a number of years. This is probably the most likely area for spin-off contract work from a high profile involvement in the Agency's activities. I have already been approached by the secretariat to assist in setting up this programme.

4. Radiological Protection Matters - Decontamination and Recovery

Harwell had expressed a particular interest in this topic. Most of the areas of work in the supplementary programme which were aimed at post-Chernobyl activities depended upon Soviet support and input. Whilst they never refused to supply any information, or to support proposed Agency activities, they were clearly following a policy line that they would decide what they would give, and in their own good time. My personal feeling is that they are back-peddling from their more open attitudes now that the dust is beginning to settle a little. Thus, many of the proposals in this area received only a low priority marking. This does not mean that they will be excluded from the supplementary programme, but carries a clear message to the Director General.

Overall, the meeting was successful in that a supplementary programme was recommended which contained the most important elements so far as the UK are concerned. This was not achieved without some difficulty as many delegations (Iran, Cuba and China for example) had sent rather more political delegates than technical experts. Much time was taken in "diplomatic fencing" as they tried to include their own needs and political slants.

The work of Group 1, which was specifically to consider the 1987 supplementary programme, was made very much more difficult by the choice of Gonzales of Argentina as Chairman. We were told that both France and Canada had made complaints at Ambassador level on his handling of the meeting. He was very anti-British and we had real difficulty in maintaining our 'equanimity'. Fortunately, it all turned out well but it was not a harmonious meeting. Towards the end of the week Peter Agrell had to leave to go to Tokyo and I took over the lead of the UK delegation.

A visit report containing all 3 working groups and the comments of NII, CEGB and NRPB is in preparation and will be available shortly. In summary, there were no "shocks" and I believe the UK's and the Authority's interests were quite well represented in the final outcome.

Yours sincerely

S Cabery
pp M R Hayns

cc Mr A M Allen
Mr M A W Baker
Mr F Chadwick
Mr A W Hills
Dr T N Marsham
Dr G G E Low
Dr J H Gittus

File No. 8606 2-10

Chr. Dorey

Chairman

c.c. Mr. M.A.W. Baker
Mr. A.W. Hills
Mr. F. Chadwick
Dr. J.H. Gittus ✓
Dr. M. Hayns
Dr. G.I.W. Llewelyn
Dr. A.E. Eggleton

Role of the AEA in IAEA Expert Discussions

During the Special Session of the IAEA Annual Meeting at Vienna on 24th-26th September I had discussions with Mr. Morphet about technical assistance to the Department in future discussions of IAEA experts.

2. The first requirement was for someone to attend a presentation on 2nd and 3rd October of the Safety Programme of the IAEA and to report back to national authorities. Mr. Morphet asked if I would agree to Dr. Hayns taking on this role and after consultation with Dr. Hayns I did so.

3. There is also a plan - not yet confirmed - for an ad hoc meeting in November of an Expert Working Group on International Cooperation on Nuclear Safety. The terms of reference have yet to be agreed but Mr. Morphet discussed with Mr. Ryder, Dr. Hayns, and myself a number of drafts that were being circulated during the week, and I attach the version which was handed to Mr. Rosen of the IAEA on 26th September after consultations with the main Western countries and with the Russians. Mr. Morphet emphasised to me that there could be no guarantee whatever that the final terms of reference would be anything like these proposals or even that the meeting would take place as planned, though he expected it to.

4. He asked me whether for sake of continuity we could release Dr. Hayns as one of the UK experts, and after consultation with Dr. Hayns I agreed to this also. I think that the continuity Dr. Hayns will provide is of considerable importance. It is also most encouraging that the Department are looking to the Authority to provide their technical advice as a counterweight to the views of experts from NII, CEGB, and elsewhere. Dr. Hayns has also made the point that attendance at a meeting like this ad hoc one could well generate additional revenue earning work paid for by the IAEA.

5. Mr. Morphet fully seized the point I put to him that there would have to be some UK coordination for the November meeting to avoid Dr. Hayns being in an invidious position in relation to others sent out by UK organisations. It will also be necessary to have some internal coordination in the Authority, particularly with Harwell, and I should be grateful if Dr. Hayns would make the necessary arrangements to ensure this.

6. Mr. Morphet is well aware of the increasing scale of cost of the AEA's support to the Department in these safety matters and may well raise the idea of a specific item in the Programme Letter to cover such work.

R.N. Simeone
(R.N. SIMEONE)

30th September 1986

1986-09-26

DRAFT TERMS OF REFERENCE FOR AD HOC MEETING IN NOVEMBER OF AN EXPERT WORKING GROUP ON INTERNATIONAL COOPERATION ON NUCLEAR SAFETY:

3 - 7 November 1986

In the light of:

the revised supplementary nuclear safety and radiation protection programme approved in principle by the Board of Governors,

the recommendations in Section VII of the Summary Report of INSAG on Chernobyl, and

further proposals emanating from the Special Session of the General Conference,

the Meeting is to advise on:

- the broad relative priority of current proposals in terms of their importance to international nuclear safety,
- the resources which are likely to be needed, both on Agency and national level, to achieve positive results in the course of 1987 and 1988 and thereafter,
- coordination between the IAEA and other international bodies to ensure a rational use of existing experience,

2. Specific areas to be covered are:

(i) nuclear safety and radiation protection

- the best approach to a review and possible development of NUSS, and the timescale for this,
- updating of work on regulatory regimes,
- the development of commonly shared safety concepts,
- the development of common emergency intervention levels.

(ii) operational safety improvements.

- review and development of the Agency's current programmes,
- operator training,

/ (iii)

(iii) future reactor development

- review of possible activities on advanced designs

The Group should essentially be composed of leading technical experts from relevant disciplines.

This report should be available for discussion at a meeting of the Board on ....

[illegible]

JHG
1-10

Note for the Record

Technical Committee on Advances in Nuclear Power Plant Risk Analysis with Emphasis on External Events, Vienna, 22-26 September, 1986

This meeting was one of several being held by the IAEA Nuclear Safety Division under the general heading of 'Developments in Probabilistic Safety Assessment'. Abel Gonzalez from Argentina was in the chair. There was a very good turnout from a range of countries, including several Eastern Block, Japan and the USA. The general objectives of the meeting were to report on the status of risk analysis methods with particular commentary on methods and data. The emphasis of the meeting was to be on external events and uncertainties. Within the general heading of external events the particular problems associated with seismic response were to be identified. The meeting had as one of its objectives, to produce a document describing this state of the art and it was the intention of the secretariat to publish this document in some suitable form later. The Chairman was at pains to indicate that there was a strong requirement to co-ordinate this kind of activity within the Agency as there were other programmes in related areas which have to be drawn together.

Not surprisingly the Chairman was a great pains to indicate that the use of words and their definition was of importance in topics like this and he took the opportunity again to emphasise that the definition of risk, for example, as adopted by the Agency was that of the ICRP and not of the reactor safety community.

There was a suggestion at the beginning of the meeting that it should concentrate on level 1 PSA but this was not agreed and indeed many of the presentations later addressed issues beyond level 1 seismic PRAs.

The opening paper was given by Bob Budnitz, ex-Division Director from the USNRC who now runs his own firm called Future Resources Associates in San Francisco. He gave a very good summary of recent developments in the methodologies of seismic PSAs, particularly on the creation of engineering insights into plant response and practical applications of the methods being developed. He said that considering the 20 or so fullscale PSAs that have been completed which include proper representation of external events, and here he said that 10 of these had been published, the other 10 he was quoting from, as yet unpublished data, have shown that seismic and internal initiated fires had to be included in any PSA because they usually generated core melt frequencies and/or risk in the same range as those arising from internally initiated events. His talk touched on the 4 main areas associated with a seismic risk assessment, that is:

1. Hazard Analysis
2. Fragility Analysis
3. Systems Analysis
4. Phenomena and Consequence Analysis

He then went into detail on each of these topics but the details of what he said are available in the papers and copies of the overheads that he used which were handed out at the meeting. These are available to anyone who wishes to follow this in detail. Some of the more interesting insights he gave are concerned with the comparison of data obtained from the recent Chile and Mexico City earthquakes which were of course, very much beyond the design basis and which showed that in general the components were able to survive much better than predicted by current design codes. This of course to some extent was dependent upon the definition of failure which was used in this context but nevertheless he indicated that additions to the data base from these events would be very useful. In describing the major insights which could be gleaned from these 20 or so studies, he had 2 points in particular. The first was that to be risk dominant, earthquakes had to be very large indeed. For example, producing ground accelerations of the order of half to .8 g at least. This he said gave some idea of the margins built in to current seismic design codes. Secondly, he indicated something that I think we already knew which was that in any seismic event loss of grid was virtually certain and no matter what else happened to the plant it would have to survive without grid supplies. I do not believe there is anything particularly new about his presentation but it is clear that the lines of development which have been going on in the United States for some time now are gradually coming together.

The development of a PSA guide for regulatory requirements was a paper presented by Mr B Visser of the Ministry of Social Affairs and Employment in the Netherlands. This was essentially along the lines of previous presentations that we have heard from representatives of the Dutch Government concerning their approach to regulation. He did indicate that decisions for the building of further reactors had now been put off at least until the first half of 1988 but nevertheless regulatory requirements had been discussed in Parliament and one result of that was that there were requirements for PSAs to be done by the utilities for regulatory needs. It was noticeable that the representative from Electrowatt who was present at the meeting, Mr M Barents said absolutely nothing during this presentation even though he was on the agenda as a joint presenter and in private admitted that he was glad that he had not been called upon to speak as the use to which the Dutch delegates suggested they would be making of the PSA guide seemed to go beyond the quality of work that had gone in to the contract. This was the contract which we were persuaded to bid for by Mr Versteeg but which we now know had been in the pocket of Electrowatt all along. Judging by my conversations with Barents I suspect that the PSA guide which is being produced will be lightweight. There was much discussion concerning the societal risk aspects of the new Dutch regulations particularly as there was absolutely no mention of uncertainties or indeed how the utility would be instructed to present its data for comparison against the societal risk lines which had been produced. The paper is available for anyone wishing further information.

The following paper by Mr A Gurpinar of the IAEA went through in some detail the input to guidance which was being drawn up by the Agency for countries with no background on the topic of seismic PSA studies. Whilst the talk was comprehensive, these guidance documents seemed to me to lack the insight which could be brought to them by people who had actually been involved in such studies and knew the difficulties and pitfalls for relative newcomers. The presenter clearly had not quite understood the use of the word 'probability' in his talk and whilst it was full of jolly good jargon it was slightly disconcerting that the idea of extrapolating from a historical data base was not at all understood.

The next paper was a Japanese report on a PSA on the Mondu LMFBR. It seems from this paper that the Japanese have put a great deal of effort into performing a complicated level 1 PSA on the Mondu loop design LMFBR. The author claimed that human errors, unscheduled maintenance and outages had all been modelled in this study. Furthermore, fire analysis including, both internally initiated fires and sodium fires, had been included. Perhaps it was the authors problem with the English language but the overall impression was not good. The Japanese had chosen to use the rather strange presentational methodology presented for the first time in NUREG 1050 in which the uncertainties in contributions to core melt frequency were all normalised to the maximum value of core melt frequency. This meant that if a particular aspect or initiating event only made a small contribution then the uncertainties in that were seen as being small in relation to their contribution to the uncertainty to core melt frequency. Whilst this may be true, it means that the contribution of any one particular initiator can only be judged relatively to the contribution from the one which is judged to be dominant. If that is incorrect, or incorrectly modelled in term of its uncertainty distribution then everything else is incorrect too. It was rather intriguing that single sub-assembly failure was not mentioned at all in any of the initiating events whereas structural failure of the core support system was. When questioned about this the Japanese author simply said that they did not believe they would get blocked sub-assemblies. This seems such a different approach from that in Europe that it was quite incredible to me that he had no impression of the importance of what he had said. However, language difficulties made further investigation extremely difficult.

There followed two papers by Turkish authors concerning the application of PSA methods to external event analysis for the Akkyku NPP. These indicated that quite a lot of work has been done in Turkey to establish the capability to consider external hazards for their plant. The plant in question being a Candu type reactor which would be built at that site with assistance from Canada. It was surprising that they had considered such a comprehensive list of external events including of course, seismic but also high winds, floods, gas cloud explosions, aircraft crash and the like. It was slightly intriguing that the worst external hazard apart from seismic which was identified was that from oil slicks presumably which would interfere with the intake system to the condensate tanks. In fact the probability was calculated to be 3 times 10^{-6} of such interference and it was stated that design measures would be taken to ensure that oil could not enter the intakes. I was rather surprised that when the seismic hazards were given that they were so low. Turkey is a very seismically active country indeed and this was supported by a curve which is in their paper which showed that the f-N line for seismic events in Turkey lies well above that for the United States and indeed the return frequency for earthquakes killing more than a thousand people is unnervingly high being above 10^{-2} per year. Nevertheless, the claim was that the site for this reactor meant that .2 g was a reasonable design basis level for the safe shutdown earthquake. Parenthetically this may be compared with .25 g currently being adopted for CEGB plant with a .35 g upper bound being sought by the NII to demonstrate the confidence in the margins available. Nevertheless, these two papers indicated that Turkey was making considerable efforts internally to become knowledgeable in these areas and they had used to some benefit information and support given to them by the IAEA.

The next paper was a rather strange but interesting one from Yugoslavia. This considered the probability for loss of AC power after the malfunction of the auxiliary transformer T3 in the nuclear power station at Krsco. This paper went into some detail on how they had calculated the probability numbers for various configurations of house-load following the loss of a particular transformer which in fact supplied power from a nearby coal fired power station to the plant. The interest here was first of all in the arrangements made for supply of electricity to the plant, that is for the main 380 Kv grid and a 110 Kv special grid line from this coal fired power station as well as 2 on-site diesels. Details of the calculations are given in the paper but the use of fault and event trees was made to examine whether the plant should be allowed to operate with the loss of one source of AC power according to the written procedures. An interesting use of PSA methodology. The final two papers in this first day came from Israel and they considered the conditions in containment during externally initiated severe accidents. I must say that I thought that these papers were contrived, presumably by the secretariat, to allow Israel unusually, to make a contribution to a meeting of this sort. The first paper on the thermohydraulic conditions in reactor containment during externally initiated severe accidents was modest. There was no new information, no new codes, and really was rather boring. The second paper was far from boring because it was quite amazingly naive and I believe, incorrect. In this a model had been produced for Iodine removal by condensation from the containment atmosphere in post-external event conditions. This condensation mechanism is well known to anybody doing source term work and of course the conditions that they had chosen were so far from being representative of any remotely related to severe accidents that the word 'contrived' is really rather modest in describing its addition to this seminar. These papers are available for anyone who is interested.

M R Hayns
SRD

29 September 1986

Distribution

Dr J H Gittus
Mr H J Teague
Dr R S Peckover
Dr F R Allen
Dr G M Ballard
Dr S F Hall
Mr F Abbey
Mr P Barr
Dr D W Phillips
Mr D Levey, LHQ
Dr D Hicks, AERE

2833d

PROVISIONAL AGENDA

TECHNICAL COMMITTEE ON ADVANCES IN NUCLEAR POWER PLANT RISK ANALYSIS (WITH EMPHASIS ON EXTERNAL EVENTS)

22 to 26 September 1986
IAEA Vienna, Meeting Room C07 III

Monday 22 September

09.30 – 09.45	Opening, Remarks by Scientific Secretary and Chairman's Address
09.45 – 10.00	Adoption of Agenda
--	Review of Objectives of the Meeting (Chairman)
10.00 – 10.45	External Initiators in Probabilistic Reactor Accident Analysis Mr. Budnitz (Future Resources Associates, Inc./U.S.A)
10.45 – 11.00	Coffee Break
11.00 – 11.30	The Development of a PSA Guide to Meet Regulatory Requirements Mr. M. Barents (Electrowatt Engineering Services/UK) and – Mr. B. Visser (Ministry of Social Affairs and Employment/ Netherlands)
11.30 – 12.00	Reliability of Structural Components of Nuclear Power Plants under External Events – Mr. Schueller (University of Innsbruck/Austria)
12.00 – 12.30	Modelling and Importance of Seismic Events for PSA Studies – Mr. A. Gurpinar (IAEA)
12.30 – 14.00	Lunch break
14.00 – 14.30	Parameter and Model Uncertainty in PSA Studies for an LMFBR Plant – Mr. Kiyoto Aizawa (Nuclear Fuel Development Corp./Japan)

14.30 - 15.00	An Application of PSA Methodology to Seismic Events for the Akkuyu NPP Site Mr. U. Adalioglu (CEAM/Turkey)
15.00 - 15.30	External Events considered in the Safety Design of Akkuyu NPP Ms. G. Agaoglu (TEK/Turkey)
15.30 - 15.45	Coffee Break
15.45 - 16.45	Probability for Loss of AC Power After the Malfunction of the Auxilary Transformer T3 in NPP Krsko Mr. M. Dusic (REIP/Yugoslavia)
16.15 - 16.45	Thermo-Hydrautic Conditions in Reactor Containment during externally initiated severe accidents Mr. R. Leib (IEC/Israel)
16.45 - 17.15	Iodine Removal by Condensation from Containment Atmosphere in Post External Event conditions Mr. E. Ketter (IAEC/Israel)
18.00	Wine and Cheese Party (VIC Restaurant)

Tuesday 23 September

09.00 - 9.30	The Influence of Risk on Cost-Effectiveness of Nuclear Power Plant - Mr. B. Vojnovic (RBI/Yugoslavia)
9.30 - 10.15	General Discussion
10.00 - 10.45	Discussions on the Scope and Content of Technical Report to be Prepared.
10.45 - 11.00	Coffee Break
11.00 - 12.30	Discussions on the Scope and Content of Technical Report to be Prepared. Assignment of Working Groups
12.30 - 14.00	Lunch
14.00 - 17.30	Discussions Within Working Groups
Meeting rooms reserved for working groups:	C0737, C0739, C0741, C0743, C0751

Wednesday 24 September

09.00 – 09.30	Working Groups Progress Report (plenary)
09.00 – 17.30	Preparation of Technical Document Within Working Groups

Thursday 25 September

09.00 – 09.30	Working Groups Progress Report (Plenary)
09.30 – 17.00	Drafting of Report

Friday 26 September

09.00 – 12.00	Discussion of Draft Report and Revisions
12.00 – 12.30	Final Remarks and Closing

If required, discussions may be extended to an afternoon session. In this case, Final Remarks and Closing will be deferred until 16.00.

RISLEY
UK ATOMIC ENERGY AUTHORITY

Risley Nuclear Power Development Establishment
Northern Division
United Kingdom Atomic Energy Authority
Risley
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Extension: 3502/3813

JHG
30-9

29 September 1986

Mr P Saunders
AERE
Harwell

Dear Peter

POWER NEWS SPECIAL - SEPTEMBER 1986

Have you seen the CEGB Power News special on Chernobyl? It seems to be a near-perfect presentation for our own employees and many of the general public on the accident and its implications.

In many ways, it preempts the document you agreed at Frank Chadwick's meeting on 10 July to write with John Gittus after the IAEA conference. What is your view of it please?

Yours sincerely

David

D H Locke

cc Mr F Chadwick
Mr W McMillan
Dr J H Gittus

Char Mis 30-9

UNITED KINGDOM
ATOMIC ENERGY AUTHORITY

United Kingdom Atomic Energy Authority
11 Charles II Street
London SW1Y 4QP

From the Chairman
Arnold Allen C.B.E.

Telex: 22565 Fax: Tel. Ext 274
Telephone: 01-930 5454.

Dear Colleague,

In my letter of 10th July, I promised that information about the cause of the Chernobyl disaster would be passed on to you when it was received.

During the last week in August, the International Atomic Energy Agency (IAEA) convened a meeting in Vienna of experts from member states to discuss the Chernobyl accident. The Russian authorities presented a comprehensive and detailed report on the accident and its aftermath. As a result of this, and of the extensive discussion and analysis which followed, we now have a fairly clear picture of the cause and nature of the accident.

If a power station becomes disconnected from the national grid, the steam supply to the generator is switched off. The generator, however, continues to "freewheel" for a while. The station managers at Chernobyl were carrying out an experiment to see if enough electricity could continue to be produced from the freewheeling generator as it ran down to power the main reactor cooling pumps and remove heat from the reactor. A combination of circumstances had caused the operators, before the experiment got under way, to switch off the emergency core cooling systems, to withdraw more control rods from the reactor than their instructions allowed, and to bypass emergency shutdown systems. As the power produced from the freewheeling generator ran down, the reactor cooling pumps slowed down, and the core temperature increased. The RBMK design makes the reactor unstable in such conditions, and a dramatic rise in reactor power followed. Because all the safety systems had been switched off, the reactor could not be shut down in time, and calculations made by the Russians indicate that a runaway reaction occurred, bursting some of the pressure tubes containing the fuel and producing a large amount of steam which blew the top of the reactor. Hydrogen and carbon monoxide gases were produced which exploded and burned, carrying fission products and disintegrated fuel into the atmosphere. More fission products were released over the next nine days before the situation was brought under control by dropping some five thousand tons of sand and clay and other materials onto the reactor.

The primary cause of the accident was therefore gross malpractice by the station operators, who, in addition to the errors noted above, also ignored danger signals during the minutes leading up to the accident. In addition, though, the Russians have accepted that the basic instability of the RBMK core design was an important factor: they also take the view that it was a serious shortcoming in the overall design that the emergency cooling and shutdown systems could be over-ridden and switched off by the operators. A number of modifications in the RBMK design are now being implemented by the Russians to overcome the core instabilities and to improve the reactor protection systems.

Thirty-one people have died to date as a result of the accident, all of them employees or firemen on the Chernobyl site, and all but two of them as a result of acute radiation exposure. Between one hundred and seventy and one hundred and eighty people are suffering from various degrees of radiation sickness.

The meeting in Vienna was notable for the full and frank explanations given by the Russian authorities and for their willingness to admit to major design faults in the RBMK system. A number of detailed technical topics have been identified for further study, and appropriate meetings will be organised by the IAEA. The Authority will take part in these studies. However, from the comprehensive Russian account of the causes and consequences of the accident, it is clear that the safety arguments for reactors in the UK and other Western countries are not thrown into doubt.

A great deal of work will need to be done to ensure that the lessons coming out of the disaster are properly understood, and some changes in the balance of the Authority's own R&D activities may well result.

Yours sincerely

Arnold Allen

A. M. Allen

SAFETY AND RELIABILITY DIRECTORATE
UK ATOMIC ENERGY AUTHORITY

Safety and Reliability Directorate
United Kingdom Atomic Energy Authority
Wigshaw Lane
Culcheth
Warrington WA3 4NE

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Extension: 7206

From
Dr John H Gittus
Director

30 September 1986

Dr J E R Holmes
Director
UKAEA
AEE
WINFRITH

Dear John

HUMAN RELIABILITY PROGRAMME ADVISORY GROUP

You asked for the terms of reference of the above Group to help you decide on Winfrith representation. For your information, Harwell have agreed to participate in the activities of the Group. What I suggest is as follows:

Title of Group

Human Reliability Programme Advisory Group

Terms of Reference

To advise on the Authority's programme of work on Human Reliability taking account of the man-machine interaction and the need to strike a balance between human control and automatic control in the operation of nuclear reactors and other nuclear installations.

Background

The accident which occurred in April 1986 at the Chernobyl nuclear power station is attributed by the Russians to a combination of

(a) erroneous actions by the operators

(b) design-deficiencies.

At one stage a computer signalled to the operators that they ought to trip the reactor. The operators failed to obey although had they done so the accident would have been averted. The Russians now admit that an automatic trip should have been fitted, instead of relying on the operators. They are saying that they had not struck the correct balance between human control and automatic control and so the question arises: have we?

To address this question, and related issues, it may be appropriate to expand existing UKAEA work on human reliability and automatic control and protection systems. The Human Reliability Programme Advisory Group is being set up to advise on the form which any such new programme of work should take, its technical content, objectives, locations, staffing and cost.

The new programme will involve research and development of a type applicable to a range of reactors and possibly other nuclear installations. It will not be specifically concerned with the operation of Authority reactors.

Chairman

It is proposed that Dr Geoffrey Ballard, Branch Head, Systems Reliability Technology, SRD, Culcheth, should be Chairman of the Group.

Membership

It is suggested that the Group should comprise eight to ten people drawn from SRD, Harwell and Winfrith and be concerned with

(a) Human Reliability (mainly SRD)

(b) Automatic Control and Protection Systems (mainly Harwell and Winfrith)

(c) The Man-machine Interaction.

Management

The GNSR programme will fund the work of the Group and will set up a new Technical Area within which the recommended programme will be implemented.

Timetable

The Group will, it is hoped, make initial recommendations within one month of its first meeting and it will be dissolved when its final recommendations on the programme to be undertaken, have been accepted.

Yours sincerely

pp JH Gittus/JE

J H GITTUS

cc Mr A M Allen
Mr M A W Baker
Dr T N Marsham
Mr A W Hills
Mr J Bretherton

sc G H Ballard

6800
24/9

HARWELL
UK ATOMIC ENERGY AUTHORITY

Theoretical Physics Division

Harwell Laboratory
United Kingdom Atomic Energy Authority
Oxfordshire OX11 0RA

Telex: 83135
Telephone: Abingdon (0235) 24141

23rd September, 1986

Mr. D. Broadley,
N.N.C.,
Risley,
Warrington.

Dear Don,

Impact of Chernobyl on Fast Reactor Safety

I have just read your interesting preliminary review of the potential impact of the Chernobyl disaster on the LMFBR. There is one topic which is not dealt with and I thought you might like to have the following views, which I have already discussed superficially with Mike Hayns. This concerns the role of fuel fragmentation in the accident and possible parallels with the fast reactor. I do not necessarily think that such a rapid exchange of energy as has been proposed to explain the Chernobyl explosion could occur in a fast reactor, but it will be as well for us to take note of this in answering our critics.

Fuel fragmentation has been observed experimentally in most experiments that have involved heating the fuel close to its melting point on timescales of less than one second. This is true both for in-pile experiments such as the Sandia ACRR series and VIPER, and for out-of-pile experiments such as the direct heating series at Argonne National Laboratory. It is apparent that when fuel containing a significant amount of fission gas is rapidly heated precipitation of the gas on to the grain boundaries results in gross over-pressures which cannot be relived on such timesales by plastic or diffusive processes. It should be possible to predict the circumstances when such fragmentation may occur and we are well on the way towards doing that, having been working on the problem at Harwell since the early 1970's.

Normally such fragmentation would occur safely within the fuel pin and subsequent failures of the pin tend not be explosive. When release of the fuel fragments into the coolant channel occurs it is generally recognised to be a beneficial process which sweeps fuel away from the core and reduces reactivity. This has been the American view consistently since the mid 1970's (see IWGFR-5) but I am less sanguine that this is always the case. In the Chernobyl accident it has not yet been established whether the excursion becomes auto-catalytic i.e. that once the reactor becomes prompt critical more failures accompanied by fragmentation generate more coolant voiding and hence increased the reactivity further, or whether the role of the fragmentation was

Cont'd/.........

solely in generating mechanical work - the Q* effect. The cladding in the Chernobyl fuel was relatively thinner and weaker, as it consisted of Zircaloy, and it is presently assumed that the explosive fragmentation of the fuel produced the failures. We have never seen this in fast reactor fuel, presumably because of the higher strength of stainless steel. It may be desirable to perform some calculations on the loads that could be generated on the cladding by fragmenting fuel in order to check whether such explosive failures could occur in some accident regime.

In my own view the circumstance of most concern is low power operation, or fuel handling during shut down. If an excursion were to occur due to control rod runaway or a fuel loading error (I would need advice as to whether this is a sensible suggestion) it may be possible that explosive failures of the fuel could then increase the reactivity further by voiding the sodium in the central core region after the mixing of sodium and hot fuel. I think we should investigate this possibility and satisfy ourselves that it could never happen and also be able to demonstrate this to our critics. If we cannot do this then we are open to the attack that a Chernobyl type accident could occur with a fast reactor. I would be very keen to hear your views on this topic and also the views of the other recipients of this letter.

Yours sincerely,

J.R. Matthews

c.c. Mr. A.R. Baker)
Mr. C.B. Cowking) Risley
Dr. A.T.D. Butland, Winfrith
Dr. M.R. Hayns, SRD
Mr. K. Brindley, NNC
Dr. R.F. Cameron

8582
29.9

United Kingdom Atomic Energy Authority

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Employee Relations Branch

Dr J H Gittus
Director
Culcheth Safety & Reliability Directorate
Wigshaw Lane
Culcheth
Warrington WA3 4NE

26th September, 1986

Dear John,

Chernobyl

The Chairman is sending a personal letter to all employees on Chernobyl. For your personal information the text of the letter is set out below.

Mrs Gray of Employee Relations Branch (ext.508) is making arrangements with administrative officers at the sites for the distribution of copies of the letter to all employees on Tuesday 30th September, 1986.

Yours sincerely

E T Hollis

cc: Mr J A Peat

UNITED KINGDOM
ATOMIC ENERGY AUTHORITY

United Kingdom Atomic Energy Authority
11 Charles II Street
London SW1Y 4QP

From the Chairman
Arnold Allen C.B.E.

Telex: 22565 Fax: Tel. Ext 274
Telephone: 01-930 5454.

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Yours sincerely

Arnold Allen

A. M. Allen

8578
29.9

United Kingdom Atomic Energy Authority

From Dr D. Hicks
Water Reactors Programme Director

Harwell, DIDCOT
Oxfordshire OX11 0RA
Telephone (0235) 24141 Ext: 2181
Direct Line: Abingdon (0235) 832504

Date: 26 September 1986

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[illegible] include [illegible] paper [illegible]
[illegible]
J.G.

Dear Lord Marshall,

CIMRG - RBMK Design

At the last meeting you may remember that I was unhappy about criticising individual features of the RBMK design as they were described. My reason for doing so is that I believe that the individual features of the design interact with each other, and are the consequence of the ground rules to which the designers were working. This does not show up when features are commented on individually especially if contrasts to UK reactors are also included.

I enclose a short note which represents a personal view of why the designers produced a clever design very vulnerable to operator error. It is based on inferences arising from the Forum visit in 1975 and more particularly from the symposium at Risley in 1977.

Yours sincerely,

David Hicks

D. Hicks

The Lord Marshall of Goring, Kt, CBE, FRS,
Chairman
CEGB
Sudbury House
15 Newgate Street
LONDON EC1A 7AU

c.c. Mr. D.R. Smith, NNC
Dr. J.H. Gittus, SRD

The RBMK - Overall Comments on the Design

A Personal View

by

D. Hicks

1. Introduction

The object of this note is to comment on the rationale behind the design of the RBMK and show how this led to features relevant to the severity of the Chernobyl accident.

The first large RBMK unit at Leningrad was completed in late 1973 and entered commercial service during 1974. It follows that design and development must have been proceeding in parallel with the construction of the smaller VVERs (i.e. PWRs) and preparations for the large 1000 MW(e) class VVERs. There is much published material which indicates that this programme, particularly the introduction of the larger reactors, was straining the available resources. When the British Nuclear Forum Mission visited the USSR in 1975 it was evident that there were three factors dominating the conduct of the RBMK programme.

1) Expected power demand was such that there was a need to establish a parallel line to the VVER enabling large units to be built using different, non-specialised manufactured facilities.

2) All components should be train transportable to give freedom in the choice of sites near to cities where the demand existed.

3) There should be economical use of supplies of enriched fuel.

A further point to bear in mind is that the main features of the RBMK must have been fixed in the late 60's before the tightening of safety standards in the West had begun.

Points 1) and 2) have led to problems of quality especially as 2) necessitates a large amount of work on site. There has been much adverse comment in the Soviet press but it is not clear that this quality aspect bears directly on the Chernobyl disaster.

It will be shown that 2) and 3), particularly 3), led to design decisions which makes the RBMK particularly vulnerable to the operator errors at Chernobyl.

2. Refuelling Mode

The first and most obvious step in achieving fuel cycle economy was to adopt on-load refuelling. This implies that the reactor must have a charge face giving access to individual channels. From the safety point of view the machine and the charge face need to be inside the primary containment (as in CANDU) or the machine (when in use) and the charge face together must provide the containment barrier (as in AGR). In fact the charge face, and more particularly, the structures beneath it seem only to have been designed with a single small pipe failure in mind (see 5 below). In order to enable the machine to achieve the required refuelling rate the decision to fuel on-load introduced an urge to reduce the number of channels to be visited (see 4 below).

3. Choice of Lattice Design

Very broadly the fuel pin diameter is fixed by the need to achieve an economic rating in MW/tonne fuel without reaching temperatures where fission gas release from the UO_2 is excessive. Cooling considerations to obtain an adequate margin against dryout (or heat transfer crisis as the Russians call it) with an economic expenditure of pumping power, lead to a UO_2 to H_2O coolant passage volume ratio in the vicinity of unity. The free parameter governing the overall reactor physics characteristics is then the ratio of graphite volume to UO_2 volume. Broadly as more graphite is used more moderation is provided, resonance escape increases and the reactivity increases. Eventually a point of diminishing return is reached where the increased thermal neutron absorption of additional graphite offsets any further improvement in resonance escape.

The designers of the RBMK in their quest for fuel economy chose to use a relatively large volume of graphite in order to give the lattice a high reproduction constant. Unfortunately, for reasons which they obviously well understood, this decision leads to a positive steam void reactivity coefficient. At the Symposium at Risley in 1977 they expressed confidence that they could design a control system to cope with the problem. They were relying on the fuel Doppler coefficient to offset the positive void coefficient but this is only effective at sufficiently high powers.

4. The Cooling of the Graphite

A further step in the drive for fuel economy was the recovery of the 5% of the heat output generated in the graphite and its utilisation in the steam cycle. This was achieved by extracting the heat through the pressure tube walls so heating the primary coolant. The graphite runs hotter than the coolant and the diffusion path lengths within the graphite must be restricted to avoid excessive temperatures in the graphite.

The graphite cooling restraint fixes the absolute size of the graphite blocks. It has already been shown that the reactor physics determines the volume ratios of the materials. The two considerations together fix the size of the lattice cell; the pitch of 250mm and pressure tube diameter then follow. This pressure tube inside diameter of 80mm is only large enough to accommodate an 18 pin fuel cluster. In order to include a sufficient tonnage of fuel to give the required thermal output the designers had the choice of having a very large number of channels (about 3400) of the height commonly used in BWRs (about 3.5m) or a smaller number of much taller channels. Faced with the problems of visiting channels for on-load refuelling and leading all the pipework to a reasonable number of steam drum nozzles, they chose to double the height and have about 1700 fuelled channels. Even so because the steam drum diameter was limited by the need to transport the drums by train, it was necessary to provide two drums on each side of the reactor for each circuit.

In a tall channel the axial leakage of neutrons is small and the power distribution becomes "floppy", i.e. relatively easily perturbed by local changes of steam voids or movements of control rods. The operators were supposed to trim the axial power distribution and channel flows carefully to preserve a rather tightly specified margin against dryout. The control rods in a tall core also need to travel greater distances to achieve a given reactivity effect and the slow speed of insertion provided following reactor trip is puzzling. It meant that the operators could not effectively correct their intentional error of inhibiting the trip that should have been applied as the turbine run down commenced.

5. The Emergency Cooling System

The first RBMK at Leningrad was well on the way to completion when the LOCA/ECCS controversy broke out in the USA. This probably caused the designers to rethink their earlier view that large pipe failures were incredible, and a high pressure ECCS system was included in later reactors. It was also claimed that the compartments containing primary circuit components could withstand the consequences of a guillotine failure of the largest pipe in the compartment. This meant that the upper compartment, which contained no large headers, did not in their view need to be very strong.

The operators had switched the ECCS off at Chernobyl. However, since the circuit was subtantially disrupted early in the transient it is doubtful whether functioning of the ECCS in the intended manner would have made much difference to the course of events. On the other hand the non-return valves provided as part of the ECCS played some part in the accident. When the massive generation of steam began it is deduced that these valves must have closed both cutting off inlet flow and forcing the steam to escape upwards. They must therefore have made the transient worse than it otherwise would have been and directed the full force of the steam explosion upwards into an area designed to cope with only a single tube failure.

Conclusions

Although the prime causes of the Chernobyl accident were operator errors (notably attempting to work in an unstable regime and disconnecting trips) it is inferred that the designers were working to requirements which led them to a design peculiarly vulnerable to the errors made. In particular an urge to optimise fuel cycle performance overrode safety considerations.

WINFRITH
UK ATOMIC ENERGY AUTHORITY

Ch human factors

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Extension: 3450

From the Director
Dr J E R Holmes

Mr C W Blumfield
Director
Dounreay Nuclear Power Development Establishment
UKAEA Northern Division
Thurso, Caithness KW14 7TZ

29 September 1986

Dear Cliff,

POST CHERNOBYL REVIEW OF PROCEDURES FOR SAFE OPERATION

As you know the proposals for a joint discussion between reactor operators was discussed in general terms at the EDC and was endorsed.

I am much in favour of co-ordination between Management Units on the response to Chernobyl on operator responsibilities. I have now spoken to Bert Negus and he is agreeable and willing to take part in the joint discussions.

I believe your proposed terms of reference are appropriate and should give the group adequate scope to explore the many facets of the issue. I would suggest that a first task for the group would be to explore these terms of reference to see if they think they meet their requirements. At some stage in their considerations, it may be appropriate for the Group to crystallise the criteria which they apply when delegating responsibilities to operators and the extent to which the protection system may be bypassed.

Yours Sincerely
John Holmes

J E R HOLMES

cc Dr T N Marsham
Dr G G E Low
Dr J H Gittus—
Mr R N Simeone
Mr B F Negus

2/15

ORGANISATION FOR ECONOMIC
CO-OPERATION AND DEVELOPMENT

NUCLEAR ENERGY AGENCY

SINDOC(86)156

RESTRICTED

Paris, drafted: 22nd Sept 1986

dist: 23rd Sept 1986

English text only

STEERING COMMITTEE FOR NUCLEAR ENERGY

COMMITTEE ON THE SAFETY OF NUCLEAR INSTALLATIONS

Exchange of Information on Possible Safety Modifications following the accident at the Chernobyl Reactor

At the ad-hoc meetings of the CNSI Enlarged Bureau held in Vienna on 27th and 29th August 1986 it was suggested that Member countries with operating NPP should exchange information on possible safety modifications likely to be implemented in their countries in the short term, consequent on the accident at the Chernobyl reactor, and also a list of areas requiring further study.

Attached is the first response to this initiative - from the United States. This is being circulated for information and with a request to respond at your earliest convenience (preferably by telefax) with your own list of intended changes and areas for further study. The NEA Secretariat will be pleased to re-distribute this information, on receipt, to Member countries with nuclear power programmes.

- Please note that the NEA now has its own Telefax machine:

(33) + (1) + 45 24 96 24

WORKING DRAFT

9/10/86

CHERNOBYL IMPLICATIONS ASSESSMENT

INTRODUCTION

The worst accident in the history of worldwide commercial nuclear power occurred at Unit Number 4 of the Chernobyl Nuclear Power Station in the Ukraine region of the U.S.S.R. The accident has resulted in 31 deaths and 203 individuals hospitalized with radiation-related injuries. Radioactive contamination of the environment in the vicinity of the plant is extensive.

The cause of the accident has been attributed to both human factor aspects and specific design deficiencies which combined to allow the reactor to be placed in a highly unsafe condition. The initiation of a planned, routine test then resulted in a large, rapid reactivity insertion, associated rapid power increase, and ultimate disassembly of the core via steam overpressurization (possibly due to the thermal interaction between highly fragmanted fuel and water).

The human factor aspects have been summarized into three general areas, namely: (1) the test procedures were deficient in that they violated certain Soviet safety regulations, (2) the reactor operators violated certain parts of the test procedure, and (3) the operators apparently lost their sense of vigilance towards safety.

Similarly, the design aspects which appear to have directly contributed to causing the accident are (1) the apparent simplicity with which safety and protection systems could be overridden, (2) the slow insertion rate of the control rods, and (3) the positive void reactivity feedback.

In Appendix A of this report, a more comprehensive description of the accident scenario is provided, in which the significance of the above items is readily apparent. Reviews of the accident and the Chernobyl design done to date by both the NRC staff and others have not identified any aspects of the accident which show a clear-cut nexus to U. S. commercial nuclear power plants requiring immediate regulatory action.

However, in order to confirm this judgment, a more vigorous and systematic investigation must be performed. The purpose of this report is to identify those areas and issues associated with the Chernobyl accident that warrant further investigation to either ensure that current regulatory practices and policies remain sound, or to be considered for revisions to the Commission's rules and regulations.

Once the issues are identified that have potential regulatory implications, they will be prioritized according to their potential safety benefits and costs, and those issues receiving a high priority score will be investigated in further detail. Any new requirements arising from these investigations will, of course, be subject to evaluation in accordance with the Commission's backfitting rule.

I. OPERATIONS

I.1 Administrative Controls

A significant aspect of the Chernobyl accident involved administrative controls that apparently did not exist or were blatently violated by the operators.

The concerns raised with administrative controls are broad in scope and cannot be treated in a global manner, but rather must be dealt with as a number of individual issues. Each of these issues is discussed in further detail below.

I.1.a Approval of Tests and Other Unusual Operations

The testing being performed on Chernobyl at the time of the accident was stated to have been prepared by an individual not familiar with the RBMK-1000 type of plant. Moreover, the Soviet report stated that "the quality of the programme was poor and the section on safety measures was drafted in a purely formal way. . . ."

In the U.S., all changes, tests and experiments planned to be performed in reactors licensed by the NRC are governed by the requirements of 10 CFR 50.59, "Changes, Tests, and Experiments." While we continue to believe that the requirements set forth in 10 CFR 50.59 provide adequate assurance that all changes, tests, or experiments planned to be performed in reactors licensed by the NRC will be conducted in a safe manner, a more systematic review of these requirements in light of the Chernobyl accident will be performed.

I.1.b Controls to Assure Administrative Procedures are Followed

One of the contributing causes of the Chernobyl accident was that the operators deviated from the approved test procedures in order to complete the test. For instance, although the test procedure called for the test to be run at 700 to 1000 MWth, the operators could only achieve 200 MWth, but decided to conduct the test anyway. Other examples were the raising of the control rods beyond their administrative limits such that the reserve shutdown reactivity margin limits were violated, and the starting of the two additional coolant pumps at very low power. Other deviations were reported to have occurred; however, some were probably associated with bypassing safety systems, which will be discussed as a separate issue elsewhere.

Based on the experiences at Chernobyl, it is prudent to examine the adequacy of controls at U.S. plants to ensure that unauthorized deviations from operating or testing procedures cannot occur.

I.1.c Bypassing Safety Systems

Perhaps the most significant contributor to the Chernobyl accident was the bypassing of safety systems by the operator. Three separate systems were disconnected during the test, two of which most likely would have shut the reactor down before the test was initiated. These were (1) blocking the reactor trip on steam separator pressure and level, and (2) disconnecting the reactor trip on turbine trip. While the ECCS system was disconnected early into the test program, it is believed it would not have had any impact on the initial power excursion or steam explosion. It is possible, however, that it may have been able to provide some cooling water to the core region after the initial explosion.

The first concern raised by this item is the ability of operators to override, or bypass, safety and protection systems. The second concern is possibly design specific, and involves the acceptability of operators to bypass protection systems directly from the control room.

Both issues need to be reviewed in light of the Chernobyl experience to ensure that current procedures and designs for U.S. plants are adequate and not susceptible to the apparent deficiencies at Chernobyl.

I.1.d Availability of Engineered Safety Features

The Chernobyl operators bypassed the ECCS early in the test program. While this did not have a direct bearing on the initial course of the accident, it brought to light the issue of bypassing engineered safety features. While Item I.1.2 deals with the issue in general, this item specifically involves the required bypassing of engineered safety features under certain plant conditions. Specifically, as a plant descends or ascends in power, certain engineered safety features must be bypassed or reconnected as system conditions dictate. Safety analyses will be reviewed to ensure that plants are adequately protected during periods when such systems must be bypassed.

II. DESIGN

II.1 Reactivity Accidents

Evaluation of the information provided by the USSR delegation to the Vienna conference (August 25-29, 1986) indicates that the Chernobyl accident was essentially a reactivity insertion accident (RIA). The NRC analyzes a wide variety of RIAs as part of every license review. The Chernobyl design and the circumstances of the accident sequence appear to be unique. However, due to the severity of the Chernobyl accident it appears that even such unlikely events may have the potential to contribute to the risk profile of any plant, hence a re-examination of potential RIAs in licensed power reactors within the U.S. is warranted.

The staff will review the reactivity conditions and potential reactivity insertion accidents associated with the various operational states of the various classes of licensed power nuclear reactors in the United States. The objectives of the study is to identify reactivity insertion mechanisms and/or reactivity accident conditions that, based on risk related assessments, warrant consideration beyond that currently given to such events. An example is the question of whether the ejection of multiple control rods should be analyzed. As with most NRC reviews in this area the review will include evaluation of reactivity balances between excess (available) reactivity and available control reactivity for the spectrum of normal and abnormal operating conditions associated with the various classes of reactors. The review will compare the rates at which excess reactivity can be introduced under the various operational and accident conditions to the rates at which control reactivity can be inserted. Due consideration will be given to generation and application of control signals and drive system designs. The evaluation will incorporate the effects of all reactivity coefficient components. This review will provide an assessment of existing practices within the NRC with regard to the evaluation of reactivity insertion accidents to determine if changes and/or additions to the current procedures are necessary.

II.2 Low Power Accidents

One of the unique aspects of the Chernobyl accident was that it occurred at relatively low power (~7%). This has been a cause for some concern since low power operation is generally considered to be a safer condition than high or full power operation.

In the U.S., most of the safety analyses of design basis accidents are performed with the plant at full power, based on the assumption that this will result in consequences that are limiting. (Some exceptions are noted, such as the steam line break and boron dilution accident.)

A review of design basis accidents under low power or shutdown conditions is warranted to confirm that analyzed cases remain limiting. The applicability and appropriateness of technical specifications as applied to low power and shutdown conditions will specifically be looked at as well. Finally, a review of accident initiators at low power will be made to ensure the design basis events currently considered remain valid.

II.3 Multiple Unit Protection

The radioactive release at Chernobyl Unit 4 spread to the other three operating units at the site. The airborne radioactivity was transported to other units via a common ventilation system, as well as via general atmospheric dispersion paths. This raises the question of how accidents at one unit of a multiple unit site affect the remaining units. General Design Criterion 5, "Sharing of Structures, Systems, and Components," in Appendix A to 10 CFR 50 details the general regulatory requirements for adequately protecting multiple unit sites regarding shared equipment. Beyond this, however, is the issue of severe accidents at multiple unit sites. For example, if a core melt and offsite release is predicted for certain external event initiators (e.g., seismic event), how will a multiple unit site be affected?

To address this, a review of the overall issue will be undertaken.

III. CONTAINMENT

III.1 Beyond DBA Capabilities

The serious consequences of the accident at Chernobyl have focused our attention once again on the importance of containment performance at nuclear power plants. We have long recognized the significance of containment design capabilities. An important segment of our severe accident program is dedicated to evaluation of containment performance given a severe accident. We have maintained a strong analytical and experimental program in this area for many years now. As a result of our current severe accident review activities we have found that some containment designs have greater capability to accommodate the consequences of severe accidents than others. A major product from our program will be to identify possible needs for any additional strengthening of the existing safety margins. Although the Chernobyl containment concept differs significantly from those used in U.S. plants, any relevant information and insights from the Chernobyl accident will be factored into this effort.

III.2 Venting

An approach which is presently under serious study to further reduce the consequences of serious accidents is to vent the containment in a controlled manner thus preventing its gross failure and potential increase in the consequences of the accident. This approach has been pursued by some OECD member countries (France, Sweden), and as a result of Chernobyl - and the "maturing" of severe accident research, it is also being seriously considered by additional OECD member countries such as the Federal Republic of Germany and Switzerland among others. As was discussed in III.1 a major product from the Commission's severe accident implementation program will be to identify possible needs for any additional strengthening of the existing safety margins and venting is one of the areas which is being pursued. Venting is also being pursued in a more accelerated fashion as a way of managing a spectrum of severe accidents in BWR MARK type of containments (handled by DBBWR). The Chernobyl experience, as well as the actions in this area of those countries with major nuclear programs will be looked at very carefully for any relevant information and insights before they are factored into this effort. Before venting, on any other fix is recommended for further consideration it is important that its practicalities and risk provisions are well understood.

V. SEVERE ACCIDENT PHENOMENA

V.I. Source Terms

The magnitude of the source term in the Chernobyl accident was very large, comparable in many respects to the most severe accident source terms in WASH-1400. Since the NRC has recently issued a reassessment of the technical bases for estimating source terms with the intent of modifying source term based regulations, it is important to review the processes that occurred in the Chernobyl accident:

(1) to determine whether the releases that occurred in the accident are confirmatory or contradictory to what would be predicted by the current methods,

(2) to identify any processes that may not have been previously considered.

Because of the significant differences in the plant design, the accident sequence and the chemical conditions existing in the plant during the accident in comparison with U.S. commercial power reactors, the magnitude of the source term at Chernobyl cannot be used as a benchmark of comparison for validating methods of analysis applicable to light water reactors. The differences in the controlling processes are too great.

Nevertheless, it is possible at this time, having examined the various stages of radionuclide release in the accident, to conclude that these releases can be explained with existing knowledge of severe accident phenomena and that there is no reason, based upon these results, to change our perspective of LWR source terms significantly. This does not mean that there still aren't some mysteries in the data that we currently have or that further examination is unwarranted.

Some specific aspects of the Chernobyl accident that warrant further investigation are:

(1) Excursion release mechanisms for both the volatile and non (less) volatile radioactive components.

(2) Plume buoyance mechanisms and effects.

(3) Chemical forms of iodine and cesium, and size distribution of particulate matter in the release.

V.2 Steam Explosions

Current U.S. regulations limit reactivity insertion accidents (RIAs) to peak radial average fuel enthalpies of less than 280 calories per gram. Ample experimental evidence exists demonstrating that such events do not lead to energetic fuel/coolant interactions. Even if more severe excursions are assumed the race between coolant voiding and fuel failure would be strongly affected by the negative coolant void reactivity in LWRs (in contrast to Chernobyl) and would promote the increasing separation (in time) between these two events. This reduces the possibility of an energetic fuel/coolant interaction. It may be worthwhile, however, to re-examine steam explosions within the broader context of reactivity insertion accidents (RIAs), consistent with modern PRA approaches, in order to obtain a more comprehensive picture of the risk due to RIAs. That is, without arbitrary limits on what is presumed as a credible event, but rather by considering the likelihood of all possible events. Within such efforts it may become necessary to quantify the severity of fuel/coolant interactions within a phenomenological context outside the realm of present (or past) assessments. The extent of new efforts in such areas should be dictated by the likelihood of corresponding initiating events. A task force effort should be undertaken to assess whether there is a need for any further work in this area, and what type, if any.

Based on our initial look, none of the current assessments of steam explosions in slow meltdown sequences (i.e., loss of cooling accidents) are affected by the phenomena observed in the Chernobyl accident. Even though no particular action in this area is deemed necessary a further look will be undertaken in order to confirm this initial consideration.

V.3 Combustible Gas

The Chernobyl accident produced large amounts of combustible gases (e.g., Hydrogen, Carbon Monoxide) which most probably played some role in the evolution and consequences of the accident. Of course the large amounts of zirconium in a Chernobyl-type reactor can produce much more hydrogen than LWRs under accident conditions. Also, the reaction of the hot graphite moderator can produce (and probably produced) additional quantities of combustible gases, such as carbon monoxide. Following the TMI-2 accident we recognized the potential threat to containments from the release of hydrogen in core degraded accidents, and as a result hydrogen control systems were backfitted in BWR MARK III and Ice Condenser type of containments (BWR Mark I and IIs are inerted) to reduce this residual threat. Because of their size large dry containments rely on volume dilution, pending a more complete assessment of whether there is a need to backfit control systems in these containments also. Even though the Commission's severe accident program does include the assessment of the production and the evaluation of the potential threat that could be posed by the production of all types of combustible gases as a severe accident sequence evolves to the point of challenging the containments, any relevant Chernobyl related lessons or insights that could add to the Commission's severe accident program will be considered.

VI. Economic Effects

The economic consequences of reactor accidents -- on-site and off-site -- should receive further study regarding whether and to what extent they should be considered in benefit-cost evaluations of potential reactor safety improvements.

Action

8570
24-9

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Dealt with Monday P

Dr. J. Gittus,
Director,
Safety and Reliability Directorate,
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WA3 4NE.

94

23rd September 1986.

Dear Dr Gittus

Chernobyl and UKAEA leaflets for the Public

Further to our conversation last Thursday, I enclose a draft of the text I would like to insert in the leaflets 'Nuclear - Safe Power', 'Effects and Control of Radiation' and 'Radiation and You' to replace the paragraph on TMI. Could I please have your comments.

To the paragraph that you wrote for me on the accident, I have added a paragraph by Peter Saunders on radiation doses in Britain, some comments of Mr. Chadwick , and merged the whole into what I hope is a coherent piece.

Although longer than originally indicated, this text can be accommodated in the two radiation leaflets by shuffling text. For Safe Power, the radiation paragraph can be dropped and the text replace the B & W illustration of AGR foundations. We should then be able to print 100,000 leaflets with minimal cost and without further delay.

Yours sincerely,

DJDancy

D.J. Dancy
Information Services Branch

cc. F. Chadwick
P. Saunders
M. Rowland

encs.

Mr. J.H. Lightfoot
Department of Energy
Atomic Energy Division
Thames House South
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Ms V Collins
M Hake

This is some very interesting information here.

24/9/86

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Our ref

Your ref

Date 22 September 1986

Dear John,

I am sorry not to have replied sooner to your letter of 29 July to Barbara Cooper inviting comments on Dr. Francesco Lama's letter of 14 May about the safety of nuclear power.

Although you have asked only for a line to deal with Dr. Lama's questions about computer control of operations at nuclear power stations, it might be helpful if I comment on some of the other points raised.

Turning first to Dr. Lama's point concerning methods of assessment of the probability of failure in reactors I should explain that the CEGB's probability statements are based on assigning individual probabilities from known data to each failure, covering all conceivable situations. Large data banks of information on reliability of plant are available - covering items such as valve types and electrical components - which have been compiled not just from plant use at nuclear stations, but also from duty in a vast range of other conventional situations and test rigs.

At the next stage in this process, the Safety Systems' requirements to mitigate each fault sequence are identified and, by breaking the systems down to their major components and referring to the reliability data available, the probability of each fault sequence failing to reach a safe shutdown state is evaluated. During this stage a great deal of transient analysis is carried out using large computer codes to show that the available safety systems do lead to a satisfactory shutdown state and also to determine the extent to which safety systems need only partially work to achieve shutdown.

By combining the probability of a particular fault occurring with the probability of the safety systems failing to bring the reactor to a satisfactory safe state following the fault, the risk from the whole sequence can be evaluated. By summing over all sequences in a fault category and then summing over all categories, the probability of an unacceptable reactor accident occurring is evaluated. As you will see this methodology is firmly based on a formulation from 'a large number of events' and not from a basis of 'one reactor breaking down' as Dr. Lama's letter implies.

/Moving on ...

Moving on to the probability of faults, Dr. Lama's figure regarding consequences for faults having a total permissible frequency of 1 chance in 10,000 years is incorrect. The CEGB have a number of design targets relating to accidental releases. These were fully discussed at the Sizewell Inquiry and are summarised in some detail in the Closing Submissions. The main aims of these targets are to ensure firstly that accidents which have unacceptable consequences in practical terms will not occur, and secondly that accidents which in practical terms could conceivably happen have consequences which can be accepted.

Insofar as the first of the aims is concerned the most relevant design target is that the total frequency of all accidents leading to a large uncontrolled release of radiation should be less than 1 in 1,000,000 years and not 1 in 10,000 years as quoted by Dr. Lama. Carrying out the same approximate calculation for 100 operating reactors as reported in Dr. Lama's letter leads to the result that such an accident could occur about once every 10,000 years.

I should add that, in evaluating the frequency of faults leading to a large uncontrolled release, there are considerable conservatisms included in the analysis. For example, if during the transient analysis it is found that fuel design limits are exceeded, the assumption is made that a core melt and a large release would result. For many fault sequences this assumption is pessimistic since although the fuel cladding could now no longer be relied upon to contain the radioactive fission products, the primary coolant circuit and the containment building would still have to be breached before a large uncontrolled release could take place.

Turning now to the second of the aims, the relevant design target is that the frequency of accident sequences which could lead to a dose to any member of the public of between one tenth and one Emergency Reference Level should not exceed 1 per 10,000 years. The Emergency Reference Level is the lower limit for evacuation and is triggered by a 10 rem whole body dose or a 30 rem thyroid or other single organ dose or a 100 rem skin dose. This represents an extremely stringent limit for the amount of radioactivity that may be released. The consequences of a release of this magnitude are much less than those Dr. Lama had in mind when making his comments on the viability of the nuclear option and in particular are far removed from those of the recent accident at Chernobyl. The results of work outlining the consequences of worst fault in this range were reported in the closing submissions at the Sizewell 'B' Public Inquiry. The main consequence was found to be the possibility of one extra case of fatal cancer occurring in the United Kingdom over the next few tens of years following the fault.

Again carrying out Dr. Lama's calculation for 100 reactors leads to the result that a fault in this release range could occur about once in one hundred years and the consequences would be the possibility of one extra cancer fatality. Important though that one death would be, if it occurred, the risk of death from reactor accidents of this frequency and extent is clearly very small compared with the risk from many other industrial and other activities.

/Turning now ...

Turning finally to the question of computer control of operations at nuclear stations, I should explain that the computer control of reactors is an advanced technology which is drawn on in nuclear stations where it is necessary. Dr. Lama's experience at Dungeness 'A' shows not that the control of the plant is deficient, but that the need for such methods is not great on such plant. It is a different matter on more highly rated plant such as AGRs and PWRs. In such cases the response of the plant is more rapid and the fullest advantage is taken of modern computer methods to support the operation of the plant.

I hope this is helpful.

Yours sincerely

Peter H

Mr. P. Haslam

22 September 1986

8564
23-9

MEMORANDUM

Your Ref.
Our Ref.
Tel Ext.

To Mr R N Simeone, LHQ

Subject Post-Chernobyl - IAEA Follow-up Activities

We have now received an early draft of the INSAG specialist report on the Information meeting held in August. It is rather long. I have extracted the Recommendations for IAEA follow-up activities and these are attached. As a starting point I have marked each suggestion with H, M or L to indicate possible Authority interest in and contribution to these areas. These reflect the reviews expressed by Dr Gittus in the annex to AEX(86)61, but because the proposals are at a more detailed level than the "13 points" enunciated in Vienna, we are able to be more precise.

I believe it would be useful to have further advice from Harwell (Alan Eggleton) and LHQ (Barry Carpenter) on the radiological protection and medical aspects.

Sheena Carbery
pp M R Hayns
SRD

cc Dr J H Gittus, SRD ✓

22 September 1986

Page 1 of 9

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1986-09-04: 15:00
Nozawa, Chung, Dai, Lepecki, Verraraghavan, Vuorinen
Beninson, Rabold (B. Edmondson)

SECTION 9 RECOMMENDATIONS

(I). NUCLEAR SAFETY

9.1. Follow-up Activities

Evaluation and analysis of the complex physical and chemical phenomena of the Chernobyl accident sequence and consequences are in the early stages. Further work is necessary for understanding such accidents with a view to preventing them and mitigating their consequences. The IAEA should set up the necessary arrangements with the different laboratories in the USSR which will play the leading role in these exchanges and the mechanisms to disseminate the technical information. INSAG wishes to be kept informed of the progress of these activities.

9.2 Further IAEA and Other International Activities

A. Study of Severe Accidents

A.1 The IAEA should promote and, where appropriate, co-ordinate analyses of severe accidents and facilitate the flow of the necessary information. Such analyses should include studies of the behaviour of structures and materials under the extreme conditions of a major accident. Ⓗ

AEA already involved.

Ⓗ Ⓗ A.2 The IAEA should strengthen its work in promoting, assisting and facilitating the use of probabilistic safety assessment (PSA), by reviewing the techniques developed in Member States for the use of PSA, assisting in the formulation of guidelines for its use and helping Member States to apply such guidelines in order to enhance safety in all nuclear power plant operating modes.

B. Human Factors and the Man-Machine Interface

B.1 Ⓗ The IAEA should devote special effort to promoting exchanges of experience, developing additional guidelines – in particular relating to the prevention of severe accidents – and giving assistance in the field of operator qualification, education and training so as to create a "safety culture" in nuclear power plant operation. The feasibility of voluntary international accreditation of operator training programmes should be considered.

CEGB likely to take the lead. ← Ⓜ

B.2 Ⓗ The IAEA should increase its efforts to promote exchanges of experience concerning the man-machine interface, with particular emphasis on the balance between automation and direct human action and on the need for additional operator aids in the nuclear power plant control room. Exchanges should include, in particular, the experience of nuclear power plant operators, and the IAEA should co-operate with international organizations representing such operators.

again CEGB likely to lead but AEA operators could contribute. Ⓜ

B.3 Ⓜ IAEA should organize a programme of work including an international topical meeting on "Quality Assurance Activities in Nuclear Power Plant Operation" with particular emphasis on control room procedures. The topic includes detailed prescription of procedures, required verification, shift turnover, confirmation of follow-up actions, and notifications to proper authorities.

C. Safety Principles

C.1 Ⓗ The IAEA should establish a working group to discuss and further develop, under the guidance of INSAG, commonly accepted objectives and principles for ensuring nuclear power plant safety. The resulting general criteria should be capable of being adopted for specific design concepts.

But CEGB and NII will certainly be keen to keep an eye on this one.

C.2 Existing international standards (NUSS) should be reviewed in order to ensure the incorporation of the lessons learned from the Chernobyl accident regarding important matters such as:

(Breeder implications) Ⓗ (a) reactivity-initiated accidents; especially for losely coupled cores.

For SRD fires service but for water reactor projects

Ⓗ (b) fire prevention and fire-fighting; and

Ⓗ (c) [primary-coolant parameters sensitive to safety.]

C.3 An operational guide on safety aspects of nuclear power plant operation during non-routine tests should be prepared by the IAEA within the framework of the NUSS programme.

Hard to see how generic guidance for non-routine tests can be produced. Ⓜ

D. Operational Safety

D.1 Member States should be encouraged to demonstrate their commitment to nuclear power plant operational safety by strengthening their co-operation with the IAEA through the invitation of OSART missions and the provision of experts for such missions. The IAEA should enhance its capability to provide OSART services. Ⓛ

D.2 The IAEA's Incident Reporting System (IRS) should be upgraded and expanded so as to broaden the information input base, and the information provided to the IRS should be analysed more extensively with a view to learning lessons which can be made available to Member States. Ⓜ

This is in conflict with other national and international IRS'. c.f. NEA activities and CEC. Ⓔ

D.3 The IAEA should organize a conference on "The Interaction between Reactor Design and the Operator", with particular emphasis on design features which can mitigate the effects of operator error. Ⓜ

E. Fire Protection at Nuclear Power Plants

The IAEA should organize a fire protection symposium covering:

(M)

(a) the development of the scientific and technical bases for fire prevention and fire-fighting techniques, account being taken of severe conditions such as high temperatures and of the nuclear materials present; and

(b) improvements in fire prevention and fire-fighting equipment for nuclear power plants.

It is expected that the symposium results would serve as input in developing possible new standards for fire prevention and fire-fighting (see sub-section C.2).

(II). RADIATION PROTECTION

9.3 Follow-up Activities

(M)

(i) The IAEA should take the lead in evaluating the considerable experience gained through the Chernobyl accident in the assessment, prognosis and treatment of non-stochastic effects in highly exposed persons - particularly the acute radiation syndrome and radiation-induced skin lesions. Also, guidance should be developed for the establishment of basic therapeutic schemes and the formulation of correct prognoses.

AEA input here
but NRPD and
MRC also involved (H)

(ii) The IAEA should, in collaboration with other organizations (for example, UNSCEAR, WHO and NEA/OECD), arrange for an exchange of experience of past epidemiological studies with a view to determining the usefulness of their results for the development of a methodology (including procedures for the establishment of a data base and of registers of individuals) for an epidemiological study of the late effects of radiation exposure in Chernobyl nuclear power plant workers and in selected groups of the population living in the region around the plant.

(iii) Ⓗ The IAEA should, together with other international organizations, co-operate in an assessment - planned by UNSCEAR and covering both Chernobyl nuclear power plant workers and members of the general public - of the individual and collective doses due to the radiological impact of the Chernobyl accident within the Soviet Union and worldwide.

(iv) Ⓜ The IAEA should examine the experience gained in sheltering and evacuating the public after the Chernobyl accident with a view to determining the effectiveness of such protective measures, the problems associated with their introduction and their applicability as a function of time and environmental contamination levels.

9.4 Further IAEA and Other International Activities

A. Intervention Levels

Advice from AEA but a Gov./NRPB matt

A.1 Ⓛ Given the fact that the lack of internationally recommended values for the dose per unit intake (by inhalation or ingestion) of radionuclides as a function of the age of the individual and as a function of the physical-chemical forms of radionuclides found in the environment was a problem encountered in many countries in assessing the consequences of the Chernobyl accident, the IAEA should promote the establishment of agreed values - initially for the most relevant radionuclides.

as above

A.2 Ⓛ On the basis of experience gained from the Chernobyl accident, the IAEA should, in collaboration with organizations such as WHO and FAO, develop additional guidance on intervention dose levels and corresponding derived intervention levels appropriate to reducing the stochastic risk and collective dose equivalent commitment, expecially at distances beyond the immediate area of accident impact.

B. Emergency Measures

B.1 The IAEA should develop technical guidance on criteria and procedures for radiological sampling and monitoring under emergency conditions, where the time and accuracy requirements, the radiation environment and the decision-making needs differ from those associated with routine radiological sampling and monitoring. (H)

B.2 The IAEA should develop technical guidance for the rapid reporting, compiling and collating of large quantities of data after a nuclear accident (including environmental contamination data and meteorological data) to be used as input for radiological assessments. (M)

B.3 The IAEA should develop criteria for re-entry into facilities affected by nuclear accidents and into off-site areas and for recovery operations. (H)

B.4 The IAEA should develop, in the light of the Chernobyl accident, technical guidance (criteria and specifications) for clothing which will protect against very high levels of airborne beta-contamination. (M) (?)

B.5 The IAEA should develop technical guidance on assessments of the large-scale contamination of people (external and internal contamination), equipment, facilities, premises, ground, water and air after a nuclear accident with a view to determining the scale of decontamination operations needed and on radiation protection of the personnel carrying out such assessments. (M)

B.6 The IAEA should develop technical guidance on radiation protection aspects of the decontamination of a nuclear power plant and large areas of surrounding land after a nuclear accident. (M)

B.7 The IAEA should formulate practical guidance for responding to releases of radioactive material into the national environment which originate outside the national boundaries but nevertheless require measures to be taken for protection of the public.

(L)

C. Development and Validation of Models

C.1 The IAEA should develop technical guidance on the use of real-time models able to accept actual meteorological and radiological monitoring system data in predicting the radiological consequences of a nuclear accident for persons and the environment and in determining what protective measures are necessary.

(H)

C.2 In order to improve predictions of the consequences of accidental releases of radioactivity, the IAEA should, in collaboration with WMO, review and intercalibrate models of atmospheric transport of radionuclides over short and long distances and of radionuclide deposition on terrestrial surfaces (soils, vegetation, buildings, etc.) and establish a data base for validation studies on such models. In addition, it should carry out similar activities with regard to models of the transfer of radionuclides through the terrestial environment and in food chains, their transfer through surface waters (fresh water and seawater) and their transfer in urban evironments.

(H)

D. Probabilistic Assessment of Accident Consequences

The IAEA should promote an exchange of information on computer codes available or being developed for the probabilistic assessment of accident consequences[and on the use of the results of such assessments in siting and design decisions.]

(H)

E. Education

L

E.1 It is very important to enable physicians, like specialists in various fields and general practitioners, to give appropriate advice to members of the public concerning health consequences of accidental radiation exposure of various magnitudes and in various conditions. It appears an equally valid requirement that physicians who may be engaged in first medical aid and early treatment of accidentally exposed persons should possess adequate education and training. Therefore the IAEA should initiate, in collaboration with WHO, a study as to which subjects, and to which extent, should be introduced into and post-graduate training of physicians to assure fulfilment of these specified needs and requirements.

(III) GENERAL

Under the IAEA expanded programme in nuclear safety there are actions intended to help nuclear plant operators to maintain the highest possible safety level, with a priority given to prevention of accidents.

These actions are already under way in the Agency programme, but could be significantly expanded with a clear safety benefit for the international community.

In particular, a provision should be made for IAEA providing special assistance on request, particularly in support of countries with limited resources.

SAFETY AND RELIABILITY DIRECTORATE
UK ATOMIC ENERGY AUTHORITY

2

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From
Dr John H Gittus
Director

19 September 1986

Mr D Ramsden
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DT2 8DH

Dear Mr Ramsden

Thank you for your letter 18 September 1986 concerning the Symposium 'Radiological Protection - What Chernobyl has Taught Us' which is to be held on 27 January 1987.

I would be pleased to act as Chairman of the Symposium and also to give the first paper.

Yours sincerely

M. O'Hara

p.p. J H GITTUS

Comments on Commentary paragraphs in Section 2

P2.1 (Reactor Vault)

We do not think the statement "The RBMK graphite dose and temperature levels are more onerous than in AGRs" could be substantiated. From our own simple quick checks the fast neutron doses are not very far apart and this has been confirmed by John Young. On a slightly smaller lattice pitch the dose gradients, which would be important if differential shrinkage across the brick ligaments resulted as in the AGR, are also unlikely to be any more severe. For that reason the reference to dose should be deleted unless there is specific evidence to confirm.

On graphite temperature there is a major difference in that once the re-entrant proportion is set on an AGR then a well defined level of coolant flow is imposed over the brick surfaces determined by the core pressure drop itself reactor power related. Thus implicitly an adequacy of graphite coolant is provided through the full power range. In shart distinction the graphite in the RBMK is immersed in a helium/nitrogen gas mix (dependent on power level) and relies on the rings to transmit heat via the zirconium tube to the coolant.

I therefore suggest the first sentence of the paragraph be deleted and a sentence added to the paragraph on the lines:

"In the AGR, heat removal from the graphite is more direct as a positive flow of the CO_2 coolant is maintained over the graphite surfaces at a rate closely corresponding to the reactor power. It is controlled only by the reactor structures and implicitly will always be available whilst the circulators are running".

P2.2 (Process Channels - Fuel and Absorber Rods)

Boron ball emergency shut-down devices have been installed in each of the steel pressure vessel Magnox reactors. These rapid, though short-term, shut-down devices give an additional protection to the reactor should insufficient control rods enter the core in the event of a depresurisation by fracture of a top or bottom duct. The devices are automatically initiated by rate of change in gas coolant pressure and insert the boron balls into the core. They are intended to provided a supplementary line of protection to the more conventional shut-down systems. At NII's request the feasibility of providing similar devices on the concrete pressure vessel Magnox reactors is being investigated as part of the Long Term Safety Review.

In addition, each Magnox reactor is now fitted with a boron dust injection facility which provides a means of injecting neutron absorbing powder into the core as a long-term hold-down system. This system once initiated ensures that complete and permanent shut-down of the reactor would occur.

In the latest AGR's, as a back up against the extremely remote possibility of a fault in the primary system preventing a substantial number of control rods entering the core when required, secondary shutdown and hold-down systems are also provided. Fast shutdown is achieved by a system that automatically injects nitrogen from beneath the core into 165 interstitial core channels. A boron bead injection system is also provided designed to give long-term hold-down in the extremely unlikely situation where an insufficient number of control rods have been inserted into the core for this purpose and depressurisation of the reactor is required, which would of course release the nitrogen. The System is based upon that at Hartlepool/Heysham I where it also provides diversity although for a restricted range of faults.

For the remaining earlier AGRs a nitrogen secondary shutdown system is also provided and requires manual initiation. Facilities for long-term hold-down are also provided and are based upon either water injection or boron bead injection.

I therefore suggest you delete the last sentence of the commentary and replace it with something along the lines:

"In the UK adequate diversity of shutdown has been provided whenever mechanisms which could inhibit insertion of the normal control rods have been identified. This philosophy has been extended on the latest AGRs to provide diversity of shutdown for all frequent faults whether or not such mechanisms can be identified"

P2.3 (Control & Protection System)

We understand from John Young that there is no intention to increase the number of control rods in the RBMK.

I therefore suggest you delete the last sentence of your second paragraph, and the following paragraph in bold type, and replace with the following (in ordinary type):

"The rate at which reactivity is reduced as a control rod enters the core depends strongly on its insertion and is relatively low when the insertion of the rod is small. As a consequence of this, in the case of the RBMK reactor, where rapid rate of removal of reactivity after a trip is required, it is necessary to ensure that during operation some minimum number of control rods are adequately inserted into the core. Following the Chernobyl accident this minimum number of rods has been enhanced in order to increase the rate at which reactivity is removed as control rods enter the core immediately following a scram.

Additionally the Russians are developing a fast shut-down system based on the injection of solid, liquid or aqueous material. Furthermore remedial measures are intended such that prompt criticality could not ensue from any possible coolant density change."

I also suggest you delete the remaining proposed commentaries in bold type and replace them with a single commentary, at the end of the section, along the following lines:

With the UK gas cooled reactors it has been ensured that the control rod arrays and insertion rates following scram will always shut the reactors down sufficiently rapidly and will subsequently hold the reactors in a shut down condition with ample margin.

I would suggest that diversity of shut down has already been covered under 'Process Channels'.

Pages 2.4, 2.5 (Leakage of fission products from the main cooling water pipes.)

I suggest that any comment is based upon the note on the containment issue which was prepared for the CIMRG. An edited version follows:

"All nuclear fuel is enclosed inside sealed cans, often referred to as the fuel cladding. These cans are the first "barrier" against the escape of radioactivity and are common to all reactor types.

The fuel together with the other components of the reactor core and the primary coolant, whether it be gas or water, are enclosed within a primary pressure circuit, which provides the second "barrier" to the escape of radioactivity. In a light water reactor, like the PWR, the second barrier is provided by the pressure vessel and the main coolant circuit, made of extremely thick, tough steel. In the early Magnox reactors the pressure vessel is also made of steel. Although not so thick, because the gas pressure in a Magnox reactor is only modest compared to a light water reactor, we are nevertheless confident that it, too, will not fail catastrophically. In the later Magnox reactors, and in all the Advanced Gas Cooled reactors, a concrete pressure vessel is used. Sometimes this second barrier is called primary containment.

For reactor system such as the magnox reactor, AGR or PWR, the pressure vessel "contains" the pressure of the system. In practice, this barrier cannot be complete, it cannot be a totally closed cylinder or sphere, otherwise there would be no way to get the coolant, either water or gas, in and out. There must be pipes penetrating this barrier so the heat can be removed, so the control rods can get in and out and so that instruments can be inserted and taken out.

In the Western world, for water reactors like the PWR or the boiling water reactor, where there is a breach in the primary boundary for whatever reason, steam will escape from the primary circuit. That steam will be radioactive because water borne corrosion products are irradiated in the reactor core, and there are sometimes failed fuel elements in the reactor. That steam must be contained so that the radioactivity is not released into the environment. For this reason all water cooled reactors must have a third barrier in the form of a containment building. In the event of such an accident, the steam trapped inside the containment building is automatically sprayed with cold water and thereby condensed back into water.

Gas cooled reactors also behave very differently from water reactors in the event of a loss of coolant accident. In gas cooled reactors the gas will simply stream out and the pressure inside the primary circuit will steadily drop, but nothing much else will happen. Gas cannot change suddenly into something else as water can change into steam. Consequently, the environment of the fuel elements changes relatively slowly and there are numerous devices which ensure that the coolant can be kept circulating past the fuel. In those circumstances, leakage of radioactivity from the fuel, if any, into the coolant will only occur to a limited degree and the coolant will remain relatively clean.

Therefore, in these accidents, in contrast to the water reactors, there is no harm in releasing the CO_2 gas directly to the environment and there is no necessity to provide a containment building."

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From
Dr John H Gittus
Director

19 September 1986

Professor J H Fremlin
46 Vernon Road
Edgaston
Birmingham
B16 9SH

Dear Professor Fremlin

Thank you for your letter of 18 August 1986.

I enclose the the various documents which you ask for in your letter:-

1. The Chernobyl Accident and its Consequences

2. USSR State Committe on the Utilization of Atomic Energy The Accident at the Chernobyl Nuclear Power Plant and its Consequences, Part I and II

Yours sincerely

M. O'Hara

p.p. J H GITTUS

MODELLING STUDIES OF THE SPREAD OF THE CHERNOBYL RELEASE ACROSS EUROPE AND THE LONG TERM CONSEQUENCES

H.M. ApSimon, J.J.N. Wilson, S. Guirguis, P.A. Stott

Under Article 37 of the Euratom treaty member states are required to consider the possible trans-frontier consequences of accidental releases of radionuclides when planning new nuclear power plants. In this connection models have been developed to simulate the transport of hypothetical accidental releases of radionuclides over long distances. The Chernobyl accident has provided an occasion to test these models, and in the process to give a useful insight into the transport and deposition of material across Europe. This paper describes the preliminary analysis of the Chernobyl accident for two key nuclides I^{131} and Cs^{137} using one particular model - the MESOS model(1) developed at Imperial College under contracts with CEA/EURATOM and the C.E.C. The model results(2) quickly provided a general picture of how and when radioactivity reached different parts of Europe and the enhancement of deposition where precipitation occurred. This provided a framework for interpreting the measurements from different countries.

Using model results in conjunction with measurements, approximate estimates have been made of the quantities of radioactivity released. Finally, the calculated results, normalised to the estimated source terms, have been combined with dose factors and the population distribution across Europe to obtain initial estimates of collective dose commitments resulting from the Chernobyl release.

The Meteorological Situation

The meteorological situation over Europe from 26th April to 5th May is shown in Fig.1. Initially the 1024 isobar illustrates well how material was carried from Chernobyl towards Scandinavia in the early phases of the release. Conditions then became very stagnant for a couple of days over the Ukraine and North Eastern Europe, with a front giving some rain over Scandinavia. By Wednesday 30th April a tongue of clean air from the Atlantic was thrusting across France and England towards Denmark. This change had a marked effect on the subsequent dispersal of the cloud, giving rise to a high pressure region that moved Eastwards across the North of Europe. Contaminated air travelled clockwise round this high pressure area, reaching Britain, on the 2nd of May, seven days after the start of the release. Some material then circulated round the low pressure region to the West of Britain while material from Central Europe was funnelled up Northwards over the North Sea and Norway.

Radiosonde data close to the reactor on the weekend of 26th to 27th of April indicates an inversion at 700 mbar and effective vertical mixing up to a height of 3000 metres. Surface inversions at night would have been penetrated by the heat in the release. Plume rise and good vertical mixing would have tended to reduce both air concentrations close to the reactor and dry deposition. The exact location of any concentrated wet deposition, particularly in localised convective storms in this unstable air mass, thus becomes very important.

The MESOS Model and Estimated Trajectories

The MESOS model(1) used in this study makes use of standard meteorological observations routinely reported from the World-wide network of synoptic stations. The first step was the calculation of trajectories, using 1000 mbar pressure fields, originating from Chernobyl (51° 16'N, 30° 17'E) at 3-hourly intervals. Fig.2 shows specimen trajectories originating between 12.00 hours on Friday 25th April and 12.00 on Tuesday 29th April. These are consistent with the meteorological situation described above. Trajectories originating at the beginning of the release pass up over Finland and then swing slightly anticlockwise to pass over Sweden. Trajectories originating between 06.00 hours on Saturday and early Sunday do not pass off the map area to the North but stagnate and then swing back across Central Europe, the later ones eventually reaching the U.K. This implies that it was material released on Saturday 26th that reached the U.K.

The situation at Chernobyl over Sunday morning and Monday indicates very light winds. Trajectories from mid-day on Sunday to 18.00 hours on Monday leave the map area to the East. Independent trajectory calculations (3) indicate that this material continues Eastwards and does not return across Europe. Trajectories originating later on Monday and on Tuesday do however swing round to follow a more Southerly route across Europe before turning Northwards. Thus we can distinguish between the early part of the release which appears to have followed a more Northerly track across Europe to France and the U.K., and the later part travelling a more Southerly path across Romania, Hungary and Yugoslavia but swinging North across Germany to the North Sea when the high pressure region has moved further East.

In the MESOS simulations the passage and dilution of discrete puffs is followed along each trajectory, taking into account spatial and temporal changes in meteorological conditions deduced from synoptic observations. Temperature profiles were adjusted in accordance with the initial radiosonde data to give a diurnal cycle with enhanced vertical mixing. The occurrence of precipitation is deduced from observations of "present weather", indicating the type and character of rain. From these puff histories the dispersal of successive uniform 3 hour releases is derived. Over each 3 hour period the material is assumed to fan out between the tracked puffs initiated at the beginning and end of that period, with some additional spreading to represent lateral dispersion of an instantaneous puff.

Simulation of the Release

At this stage very simple release scenarios have been considered. The accident is reported to have occurred just after 1 a.m. on Saturday 26th April, equivalent to 21.00 hours GMT on Friday 25th April 1986. The USSR reported that the release of radioactivity from the reactor's core had effectively finished by Wednesday 30th April. It has therefore been assumed that I^{131} and Cs^{137} were released over the 99 hour period from 21.00 hours on Friday 25th to 00.00 hours on Wednesday 30th. An initial scenario based on a uniform release over this period indicated too large a relative contribution from the later part of the release when compared with measurements from different countries. The results given in this paper therefore represent a release pattern with a constant release rate from the start of the accident until midnight on Sunday 25th April, with a reduction by a factor of 3 on Monday 26th and a factor 10 on Tuesday 27th. With hindsight a rather less rapid reduction in the tail of the release would have given a better overall agreement with measurements, and future work will try to refine on this.

Because of uncertainties in our knowledge of the reactor system and its mode of operation prior to the accident, when it is reported to have been shut down for maintenance work, it is difficult to estimate reliable core inventories for many nuclides. Consequently, a PWR inventory from the WASH-1400 report (4) of 3.1 x 10^{18} Bq of I^{131} (85 MCi) and 2.1 x 10^{17} Bq of Cs^{137} (5.8 MCi) has been used in this initial analysis. The results presented correspond to 25% of the inventory of these two nuclides being released. This is an upper limit on our estimate, based on early measurements, for these two nuclides of between 15 and 25% and hence levels of contamination may be slightly overestimated. A more detailed discussion of source term evaluation is given in (5).

It is difficult to be precise about the rise of the plume above the source since we do not know how much heat the fire at the reactor generated. It is unlikely that the plume directly penetrated the temperature inversion at 3000 metres, although some fraction of the material may have subsequently escaped aloft in rain systems and followed rather different trajectories. In these calculations an initial spread of the plume on release over a depth from 50 to 1000 metres has been assumed. With rapid deep vertical mixing this is not important at longer distances.

For I^{131} an effective dry deposition velocity of .3 $cm.s^{-1}$ has been assumed, as found appropriate for the Windscale release of 1957(1) at longer distances, but this could be different if the ratio of gaseous to particulate iodine was significantly different. For Cs^{137} a lower deposition velocity of .1 $cm.s^{-1}$ has been used. For both nuclides a wash-out coefficient for wet deposition in precipitation of $5.10^{-5}J^{0.8}$ has been applied where J is the estimated rainfall rate in mmh^{-1}. Sensitivity studies to these parameters will be undertaken in future, but a lower deposition velocity for I^{131} was found to be inconsistent with the measurements.

Spread of the Release

Fig.3 illustrates the spread of the release across Europe in a series of maps showing accumulated deposition of Cs^{137} by different dates. Similar illustrations have been given for I^{131} in (2) and are broadly consistent with measurements. Thus the early part of the release spread up into Scandinavia on Sunday 27th to 28th, passing close to the NE corner of Poland as observed on the Sunday evening. Precipitation and air concentrations were highly variable with some high values over Southern Sweden and Norway. Some wet deposition in convective storms was also implied in the Ukraine and near Gomel. The results fail to predict observed deposition on the S.W. tip of Finland, probably because the surface level trajectories are predicted slightly too far West.

On 29th the release spread down Southwards into Poland and the GDR giving air concentrations over Poland of the order of 100 $Bq.m^{-3}$ of I^{131}. This spreading persisted on the 30th, gradually clearing from Norway and Sweden and by 1st May was thrusting in a wedge across FRG. At this point the cloud was almost splitting into two parts, that blocked to the East by the anticyclone, and that which had flowed South of it. Air concentrations were higher in S.Germany than in the North, which like Denmark had escaped the radioactivity, being protected by the anticyclone which also pushed the cloud away from N.Poland. The calculated arrival of the cloud was a few hours ahead of observations at this point resulting in an overshoot of the radioactivity into N.Spain. There was a band of heavy rain giving high wet deposition over Bavaria, and stretching over Switzerland into S.France. There was also further rain over Sweden.

On Thursday 1st to Friday 2nd May the cloud spread much more extensively reaching up behind the anticyclone towards the U.K. The later part of the release now led to contamination over Southern Europe but there was little precipitation. By Friday 2nd to Saturday 3rd May material had largely cleared away from the source regions and Poland. Air now flowed Northwards behind the anticyclone with a band of more polluted air from Austria to the north coast of FRG, and large parts of Britain were within the cloud. Rain led to some relatively high values of deposition on the Western side and then over Scotland on 3rd to 4th May, although by this time the cloud was more dilute. From this point on the air circled round a depression centred just to the West of Britain and was drawn Northwards from Europe with frontal systems giving precipitation over the North Sea, Denmark and Norway. Until this time Denmark had remained relatively free of the cloud. Trajectories and air concentrations in this latter part of the release are difficult to estimate as material was carried aloft into the frontal systems.

Fig.4 illustrates the agreement between observed concentrations of I^{131} in air at some specific locations for which data was available and calculated average concentrations for the grid cells in which these points lie. In general the time of arrival of material is predicted quite well. However the cloud seems to have had a remarkably sharp edge indicated by a steep rise in concentrations on arrival. There are also instances where recorded air concentrations at sites close together compared with the dimensions of the grid cells, of area 10^4 km^2, differ sharply. Thus, I^{131} air concentrations at Ispra 18 km from Varese are very similar, whereas at Trino 80 km away, they are considerably higher and peak a day later, although both sites are in the same adjacent cell. Similarly, total β measurements from Budapest indicate a maximum on 1st May greater than that on the 6th, the reverse of the I^{131} measurements

This illustrates the difficulty of interpreting measurements from many sources. For I^{131} in particular many measurements refer only to the particulate fraction which is typically 1/3 to 1/4 of the total. A factor of 3 has been applied to allow for I^{131} in the vapour phase where this is the case.

More extensive comparison between model results and measurements will be undertaken as more reliable data becomes available, and to cover other nuclides. In general the present calculations give a good general picture of dispersal of the cloud and the resulting distribution of contamination. However calculated levels over S.Italy, Greece and other S.European countries tend to be slightly too low indicating rather more activity in the tail of the release; whereas in parts of the U.K., and over Denmark towards 6th to 7th May, calculated air concentrations are a little too high. This overestimation may be partly due to convergence and conveyor belt transport of the cloud aloft in frontal systems.

Long Term Dose Commitment from Cs Isotopes

The long term exposure of the European population from Chernobyl will be largely due to Cs^{137} and Cs^{134}. The maps of accumulated total deposition of Cs^{137} allow approximate estimation of the collective dose commitment resulting to the European population outside the USSR– bearing in mind uncertainties, a tendency towards pessimism in dose factors used in risk analysis and any reduction which may have resulted from the introduction of control measures. Two modes of exposure are dominant for Cs^{137}, the whole body irradiation from deposited Cs^{137} and ingestion. These two modes are almost equally important.

For external irradiation the shielding effect of buildings will reduce the dose. Also deposition retained on smooth urban surfaces is likely to be considerably less than on soils and vegetation. Charles et al (6) give the effective dose commitment for an individual constantly outdoors following deposition of 1 Bq m^{-2} of Cs^{137} on the soil as $1.2.10^{-7}$ Sv and recommend an overall shielding factor of .5. Applying this dose factor to the calculated pattern of Cs^{137} deposited over Europe weighted by the population distribution of 550 million people outside the USSR leads to a total of $9.0.10^{4}$ man Sv as the effective dose commitment to this population from external irradiation by Cs^{137}.

Doses resulting from ingestion of Cs^{137} depend on the dietary habits of the population but diets vary considerably throughout Europe. Also not all food is locally grown. However estimates of doses resulting from ingestion of Cs^{137} generally indicate values similar to that for external irradiation implying that the total dose commitment from Cs^{137} is approximately $1.8.10^{5}$ man Sv.

The distribution of deposited Cs^{134} will be similar to that for Cs^{137} but only about 60% as much activity is estimated to have been released. Cs^{134} also has a shorter half life of 2 years and dose factors are slightly lower; for external irradiation $6.8.10^{-8}$ Sv as opposed to $1.2.10^{-7}$ Sv per Bq m^{-2} deposited. Cs^{134} therefore adds about 30 to 40% to the dose commitment, implying a total collective dose commitment from Cs isotopes to the European population outside the USSR of approximately $2.4.10^{5}$ man Sv. Averaged over the population of 550 million people this amounts to an average dose commitment per individual over 50 years of 0.4 m Sv. 75% of the estimated 5.5×10^{16} Bq of Cs^{137} released was deposited within the total map area shown in Fig.3. In severe hot spot areas outside the USSR with up to 50 times the average estimated deposition of 2 to 3 kBq. m^{-2} of Cs^{137} and Cs^{134}, the average individual dose commitment estimated on this basis is 20 mSv. By comparison the maximum permitted dose limit over a lifetime for a member of the public is 70 mSv.

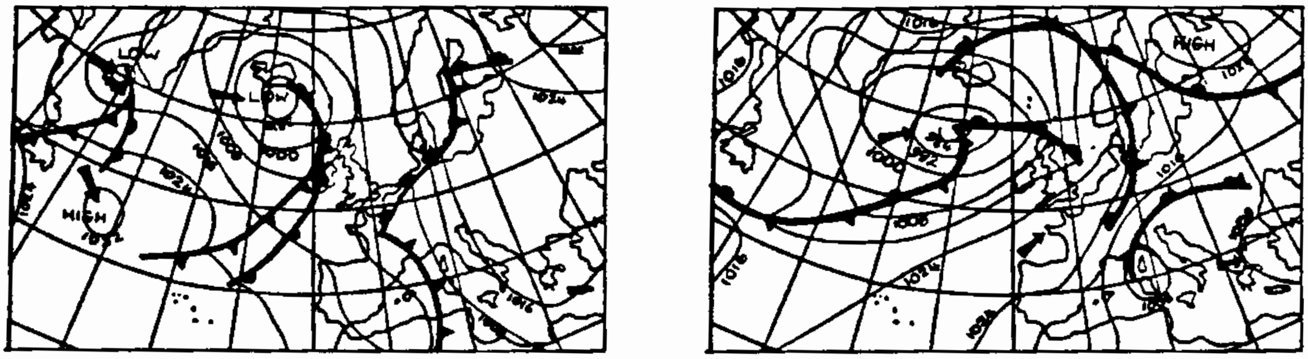
Summary and Conclusion

The long range transport model MESOS has been successfully applied to obtain a general picture of the dispersal of the Chernobyl release across Europe. By comparing predicted levels with preliminary measurements it has been estimated that between 15 and 25% of the core contents of I^{131} and Cs^{137} were released. Collective dose calculations indicate that the effective dose commitment to the European population outside the USSR from the dominant longer lived Cs isotopes is approximately $2.4.10^{5}$ man Sv, and that in hot spots the individual dose commitment, estimated on the same basis, is 20 mSv, compared with an average value of 0.4 mSv.

References

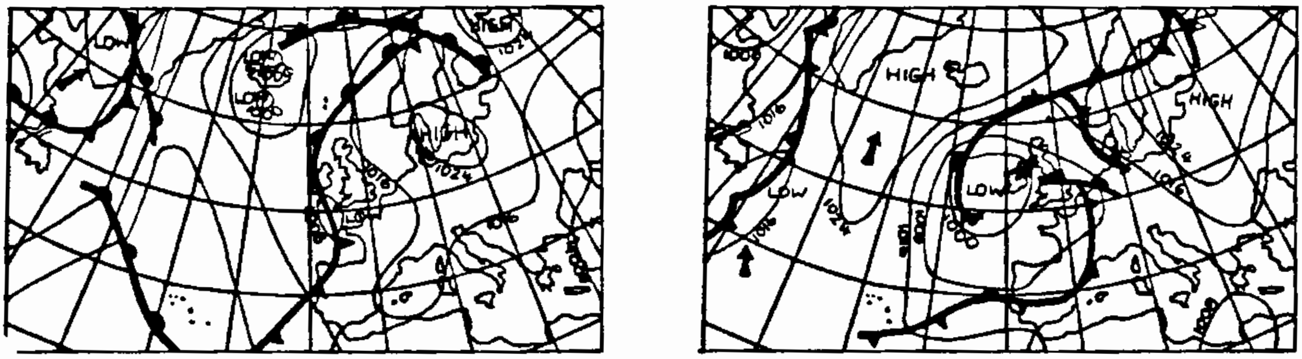
1. H.M. ApSimon et al. Long-range atmospheric dispersion of radioisotopes Part I - The MESOS model, Part II, Application of the MESOS model. Atmospheric Environment, 19, 99-125 (1985).
2. H.M. ApSimon and J.J.N. Wilson. Preliminary analysis of dispersion of the Chernobyl release. Imperial College, London. Paper given at the Nuclear Installations Inspectorate, 20th May 1986.

3. J. Pruchnicki. Inst. of Meteorology and Water Management, Warsaw, Poland. Private communication dated 21st May 1986.
4. U.S. Nuclear Regulatory Commission. Reactor safety study (WASH 1400, NUREG 75/014), Washington 1975.
5. H.M. ApSimon, H.F. MacDonald, J.J.N. Wilson. An initial assessment of the Chernobyl Reactor Accident Release Source. Submitted to Soc.Rad.Prot.Journal.
6. D. Charles et al. DOSE-MARC. The dosimetric module in the methodology for assessing the radiological consequences of accidental releases. NRPB-M74, HMSO.



i) Saturday 26.4.86

ii) Wednesday 30.4.86



iii) Friday 2.5.86

iv) Monday 5.5.86

Figure 1. Midday Weather Charts 26.4.86 - 5.5.86.

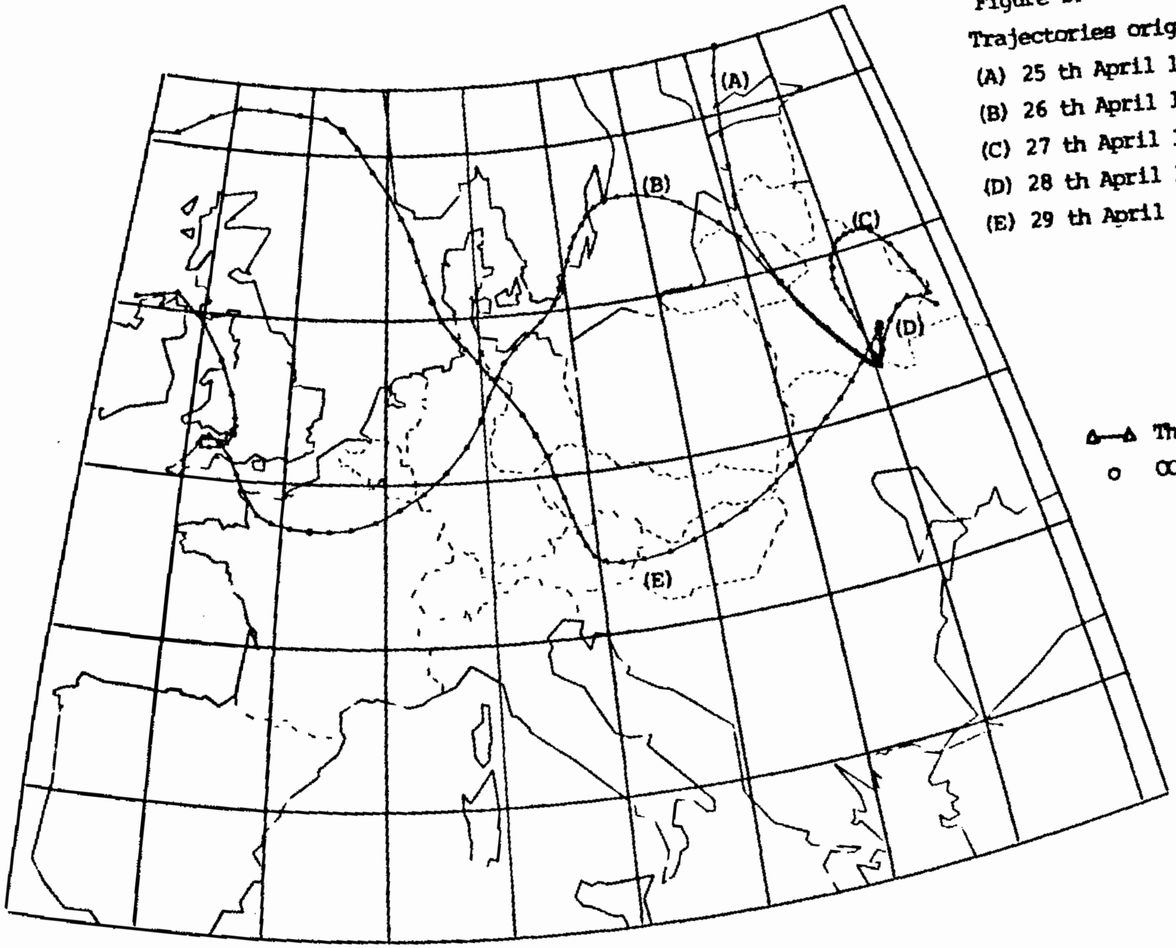


Figure 2.

Trajectories originating on:

(A) 25 th April 1986 12:00 GMT

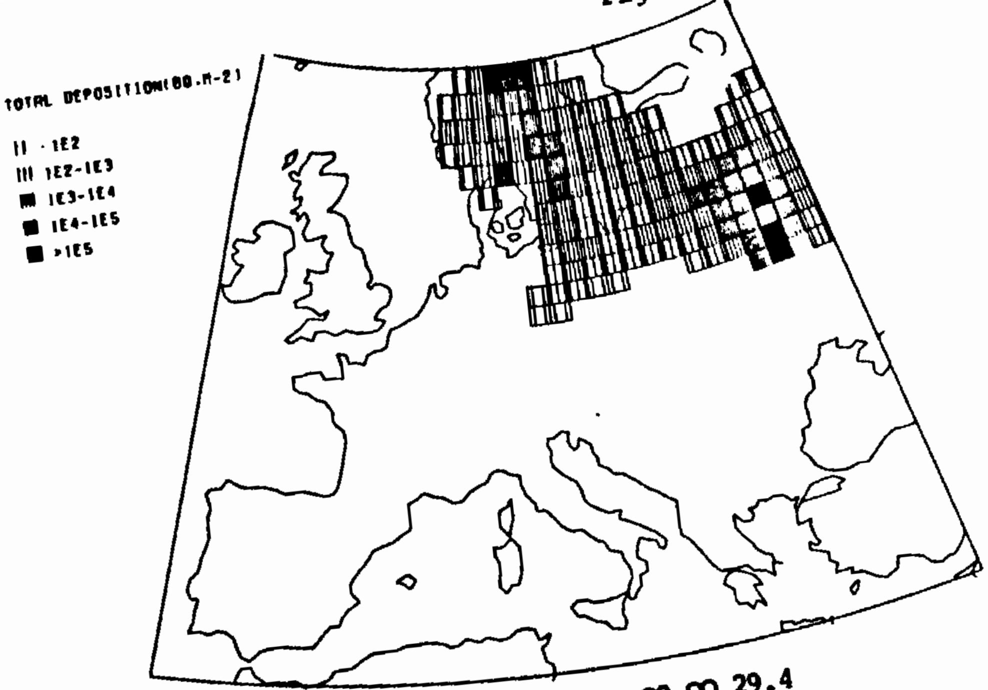
(B) 26 th April 1986 12:00 GMT

(C) 27 th April 1986 12:00 GMT

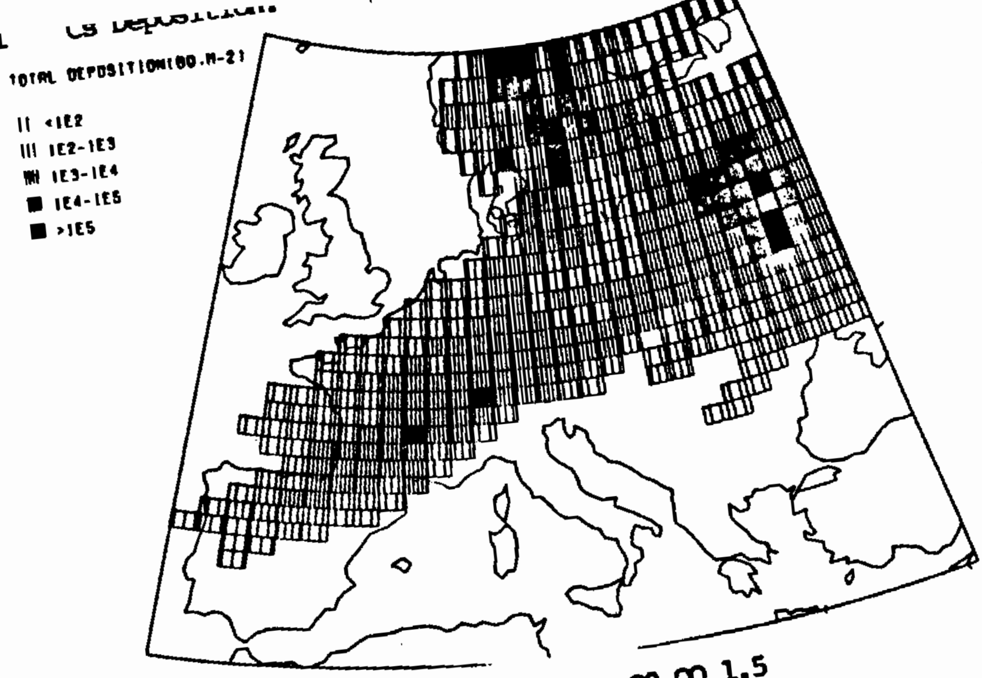
(D) 28 th April 1986 12:00 GMT

(E) 29 th April 1986 12:00 GMT

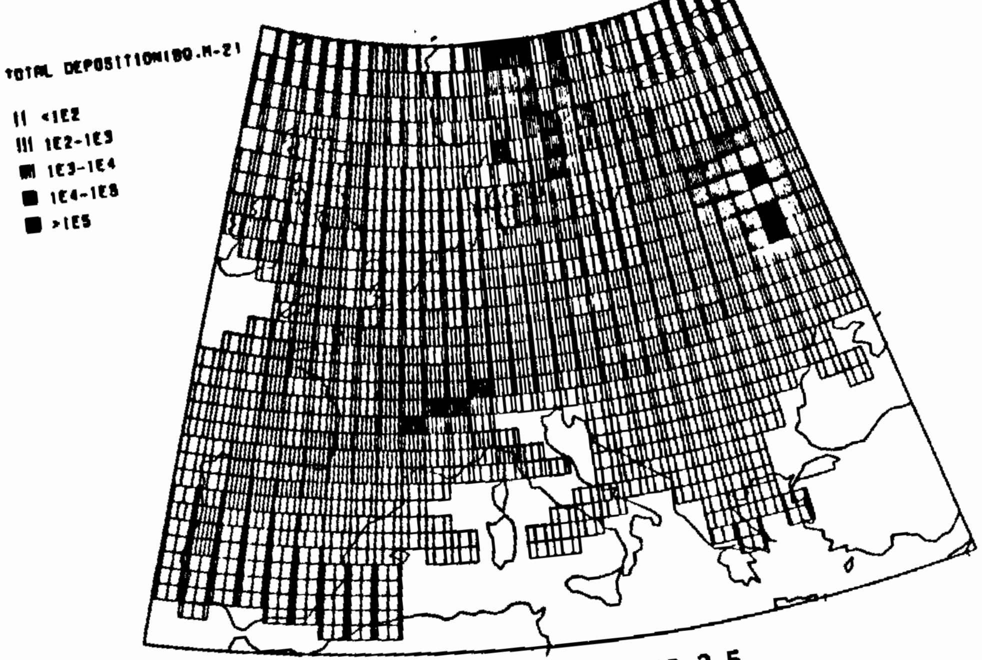
Figure 3. Cumulative Total Cs Deposition



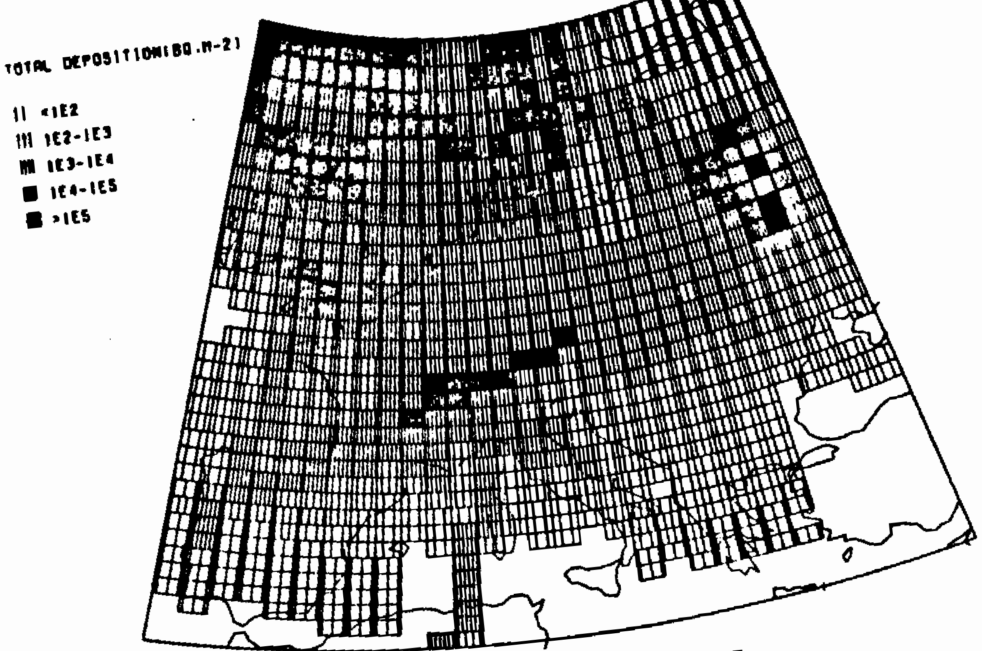
i) 21.00 25.4 - 09.00 29.4



ii) 21.00 25.4 - 09.00 1.5



iii) 21.00 25.4 - 09.00 3.5



iv) 21.00 25.4 - 09.00 8.5

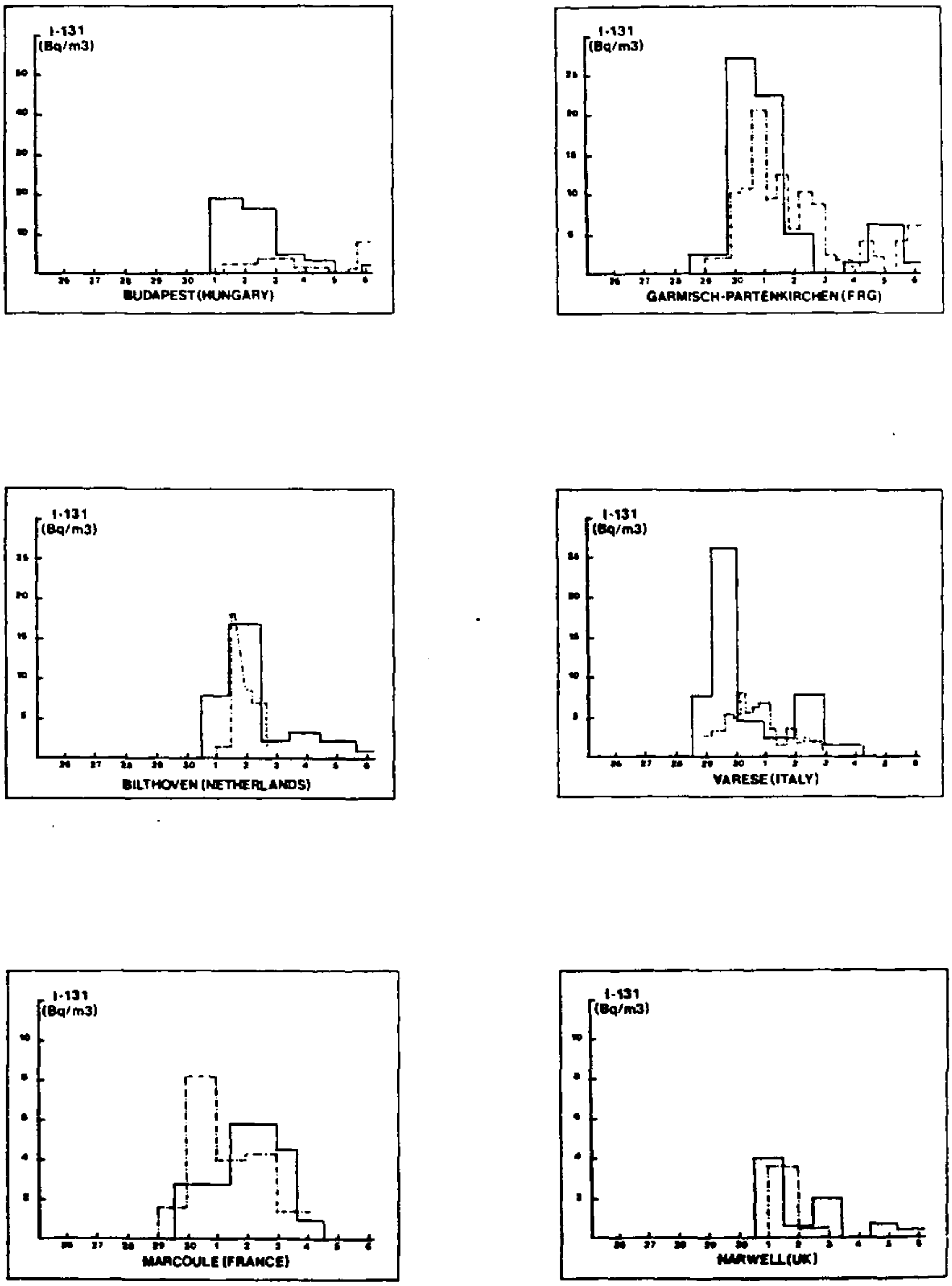


Figure 4.

Measured I^{131} concentrations (dashed line) and concentrations calculated with the MESOS model assuming a total release of 21 M Ci=7·8·10^{17} Bq (full line)

Copy [illegible] [illegible] JHG
19-9

United Kingdom Atomic Energy Authority

11 Charles II Street
London SW1Y 4QP

From: Authority Personnel Officer

Telephone: 01-930 5454

FACSIMILE

18th September 1986

Dr. J.H. Gittus,
Director,
UKAEA,
Safety & Reliability Directorate,
Wigshaw Lane,
Culcheth,
Warrington. WA3 4NE

✓ cc EDC file

Dear John

Chernobyl

Mr. Blumfield told the EDC that he had been asked by the NDBM to take the lead in co-ordinating a discussion between Senior Reactor management at Harwell, Winfrith and Dounreay on the lessons to be learnt from Chernobyl, with a view to producing an agreed report on necessary actions to be submitted to the EDC and AEX. There seemed to be some scope in his proposals for overlap with work that you already have in hand, and I asked what SRD's involvement would be. He gave me the impression that he thought it would be best to leave SRD out of the subject at this stage, but other Directors backed my view that SRD should be involved. It was therefore agreed that he would ask you to provide somebody to act as secretary to the group. He should approach you on this before long. I think it probably does not need Senior SRD representation at this stage; but will ask for that if you think it necessary.

Yours sincerely

Mark Baker

M.A.W. BAKER

AN INITIAL ASSESSMENT OF THE CHERNOBYL-4 REACTOR ACCIDENT RELEASE SOURCE

H. M. ApSimon*, H. F. Macdonald, J. J. N. Wilson***
*** Department Mechnical Engineering, Imperial College, London**
**** CEGB, Berkeley Nuclear Laboratories, Berkeley, Glos.**

SUMMARY

The long-range atmospheric dispersion model MESOS has been used to provide a preliminary evaluation of the distribution over Western Europe of radioactivity released during the accident which occurred at the Chernobyl-4 reactor in the USSR in April 1986. The results of this analysis have been compared with observations during the first week or so following the accident of airborne contamination levels at a range of locations across Europe in order to obtain an estimate of the accident release source. The work presented here was performed during the 6-8 weeks following the accident and the results obtained will be subject to refinement as more detailed data become available. However, at this early stage they indicate a release source for the Chernobyl accident, expressed as a fraction of the estimated reactor core inventory, of ~ 15-20% of the iodine, tellurium and caesium isotopes, ~ 1% of the ruthenium and lesser amounts of the other fission products and actinides, together with an implied major fraction of the krypton and xenon noble gases.

Introduction

This paper describes the application of the results of a preliminary analysis of the dispersion over Western Europe of radionuclides released during the Chernobyl-4 reactor accident(1) in order to evaluate the accident release source. The dispersion of radioactivity across Europe was estimated using the Lagrangian puff trajectory model MESOS(2) which was developed for the study of routine and hypothetical accidental airborne releases from nuclear installations within the European Community out to distances up to 1-2000 km from the source. It utilises meteorological data extracted from standard observations recorded and reported routinely from meteorological stations across Europe. The model is thus well suited for the investigation of the atmospheric dispersion of, as well as dry and wet deposition processes associated with, material released in the Chernobyl accident and transported over the regions of Europe to the west of the source.

The Chernobyl accident occurred during the last week of April 1986, commencing at 0123 hours local time on 26/4 or 2123 hours GMT on 25/4, and the assessment of the release source described here was carried out during the following 6-8 weeks (N.B. dates/months cited here and throughout this paper refer to 1986 and times to GMT). The results of MESOS calculations of airborne concentrations due to unit releases of ^{131}I and ^{137}Cs have been used to obtain a preliminary estimate of the accidental release source for a range of radionuclides observed as contaminants in air samples collected at several locations across Western Europe during the first week of the accident. No attempt is made here to analyse in detail enhanced environmental dose rates or contamination levels in environmental materials and foodstuffs associated with the Chernobyl accident. These data are considered to be subject to greater variability than the air sample data due to the complex physical and chemical processes governing activity deposition and transfer through terrestrial and aquatic pathways. Investigation of these aspects of the Chernobyl accident is judged to be more appropriate once a more complete and better validated data base has been established, including in particular details of spatial and temporal variations in rainfall rates across Europe during relevant periods.

Although the observed air sample data are subject to some uncertainty due to plume depletion processes in transit, and the reactor operating history prior to and temporal pattern of release during the accident are not known in detail at present, it is of interest to investigate the degree to which data acquired over many hundreds of kilometres from Chernobyl can be utilised to generate a self-consistent accident release source term. The results presented here are believed to give a broad indication of the accident release source, but will be subject to refinement as more data become available. However, even at this preliminary stage they provide a demonstration of the capability of long-range atmospheric dispersion models in the evaluation of transfrontier consequences of a nuclear accident, as well as giving an indication of the severity of the Chernobyl accident in comparison with accidents postulated for reactor systems operating or proposed for construction in the UK and elsewhere. In addition, they provide a basis for the estimation of the radiological impact of the accident within the USSR and in particular in the regions close to the Chernobyl site.

The MESOS model and estimated trajectories

The MESOS model(1), results from which form the basis for the release source estimates described here, was designed to utilise standard meteorological observations at synoptic stations. The initial stage in modelling of an accidental release within MESOS is the evaluation of the trajectories of a series of discrete puffs of activity originating from the source and collectively representing the total quantity of activity discharged. The accidental release is divided into a series of quasi-continuous releases of 3 hours duration, each of which is simulated by first tracing the histories and development of puffs released at the beginning and end of each 3 hour period. The assumption that the release over the 3 hours corresponds to a continuous series of puffs following intermediate trajectories then leads to contamination of the whole area along and between the calculated trajectories; additional spreading, to represent the lateral dispersion of the instantaneous puffs, is also included. Detailed examples of this procedure are given in an earlier application of the MESOS model to a reconstruction of the accidental release which occurred from the Windscale No. 1 pile in the UK in October 1957(2).

The MESOS simulation of the Chernobyl accident was based upon a series of trajectories originating between 1200 hours on 25/4 and 1200 hours on 29/4. As an example, the trajectory originating from Chernobyl (at 51°16′N, 30°17′E) at 1200 hours on 26/4 is reproduced in Figure 1; this trajectory initially moves away from the source towards Scandinavia, but then stagnates over the Baltic before swinging back westwards across Central Europe and eventually reaching the UK on 2/5. A more detailed account of the estimated trajectories during the Chernobyl accident, including discussion of the prevailing meteorological conditions, is given in Reference 1 and only a brief outline is included here in order to aid understanding of the application of the MESOS results in the accident release source evaluations.

During the early stages of the accident the trajectories predicted by MESOS are directed north over Sweden, apparently slightly too far to the west since the observed deposition over the SW tip of Finland is not predicted by the model. Later trajectories originating between 0600 hours on 26/4 and early on the following day show a decreasing tendency to travel towards Scandinavia, tending more to stagnate over the Baltic Sea and NE Poland under the influence of an anticyclonic ridge which developed early on 29/4 and persisted for several days. This effect is evident in Figure 1, and material stagnating in this region effectively acted as a secondary source for a series of trajectories directed westward across Europe. Similar trajectories originating late on 28/4 and on 29/4 follow a more direct southerly route across Europe before turning northwards and crossing the North Sea into the North Atlantic region. In addition, very light winds existed in the Chernobyl area early on 27/4 and on 28/4, whereas trajectories originating after 1200 hours on 27/4 and during the following day leave the map area covered by the present MESOS model to the east, thus any postulated release during this period would make no contribution to activity levels calculated to the west of Chernobyl (see below).

In the MESOS calculations the passage of the 3-hourly puffs along the trajectories discussed above takes into account changing meteorological conditions en route. In addition, vertical temperature profiles were fitted to radiosonde data to give a diurnal cycle with deep mixing and the release source was given

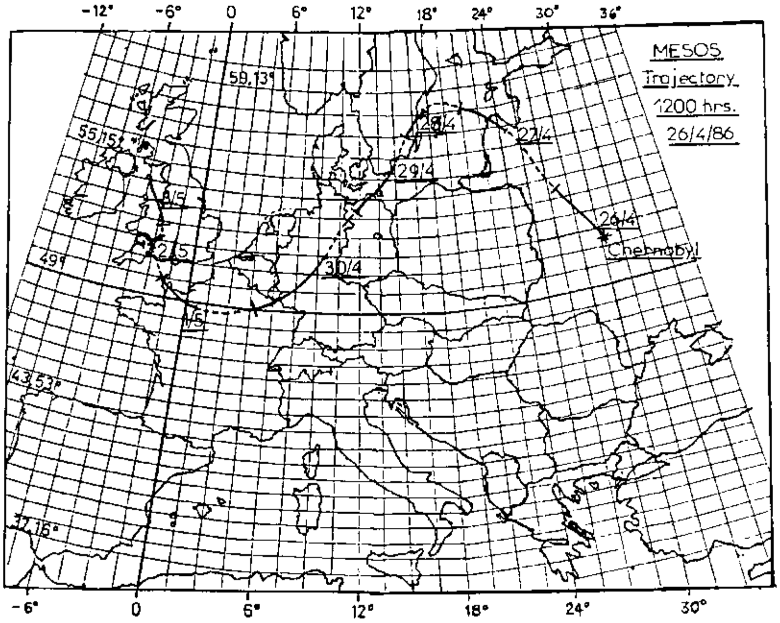


Figure 1: The MESOS Trajectory Originating from Chernobyl at 1200 hours GMT on 26th April 1986[1].

an initial spread over heights from 50-1000 m to reflect the considerable plume rise suggested in early reports of the accident. Finally, the occurrence of precipitation was deduced from observations of "present weather" indicating the type and intensity of any rain.

Postulated release pattern and MESOS results

In order to use the MESOS model to evaluate airborne concentrations of released material and associated levels of ground contamination due to dry and wet deposition processes it is necessary to postulate the rate of release of activity throughout the accident. In the absence of specific information on this point for the Chernobyl accident a simple release scenario was postulated for the preliminary MESOS analysis(1). This involved an initial short term release of noble gases over a period of a few hours and terminating at 2400 hours on 25/4, together with an extended release of ^{131}I and ^{137}Cs over the 99 hour period from 2100 hours on 25/4 to 2400 hours on 29/4. An initial scenario based upon a uniform release of activity over the 99 hour period indicated too large a relative contribution from the later part of the release and this was modified to concentrate the majority of the release into the first two days of the accident. Thus the results presented here are based upon a temporal release pattern normalised to a unit release of ^{131}I or ^{137}Cs per 3 hour period from 2100 hours on 25/4 to 2400 hours on 27/4, with a reduction by a factor of 3 on 28/4 and by a factor of 10 on 29/4.

In addition, in order to model the depletion of the plume due to deposition processes, both dry and wet deposition were included in the MESOS analysis(1). For ^{131}I a dry deposition velocity of 3×10^{-3}m s^{-1}, was assumed, together with a wash-out coefficient of $5 \times 10^{-5} \times J^{0.8}$ s^{-1}, where J is the estimated rainfall rate in mm h^{-1}. For ^{137}Cs a lower dry deposition velocity of 10^{-3}m s^{-1} was used, with the same wash-out rate as for iodine. Details of the results of the MESOS calculations for ^{133}Xe in air and ^{131}I in air, together with ^{131}I wet deposition levels, have been given elsewhere(1); the results for ^{131}I in air for the nine day period from 0900 hours on 26/4 to 0900 hours on 4/5 are reproduced in Figures 2(a) to 2(i) inclusive. The values corresponding to the various symbols in the MESOS grid squares are given in the key and represent the average airborne concentrations of ^{131}I at each location over sequential 24 hour periods, as indicated. Each grid square on the map is of approximately 10^4 km^2 area and the airborne concentrations given in Figure 2 assume a total release of 21 MCi (780 PBq) of ^{131}I.

The dispersion of the ^{131}I component of the Chernobyl release over Western Europe depicted in Figure 2, and comparable MESOS results for ^{133}Xe and ^{137}Cs, are broadly consistent with observations reported during the first few weeks following the accident (see for example References 1 and 3; also the discussion below). Thus, the early part of the release spreads northwards into Scandinavia on 27-28/4, passing close to the NE corner of Poland where it was observed on the evening of 28/4. Airborne concentrations are high just to the south of Stockholm, where relatively high levels were observed, while in addition precipitation over Scandinavia produced high levels of deposition over southern Sweden and Norway during this period$^{(1, 3)}$.

On 29/4 the airborne contamination begins to spread southwards into Poland and the GDR, continuing during the following days as levels over Norway and Sweden begin to fall. On 30/4 and 1/5 the release continues to spread westward across the FGR and France, while at the source the release is now assumed to have ceased. In line with observations during this period airborne levels are higher in Southern Germany than in the north, while Denmark and the northern coast of Germany have essentially escaped the cloud. Also at this time the MESOS calculation indicates high wet deposition of material over France, the southern part of the FRG, Switzerland and Austria, as well as further deposition over Eastern Sweden$^{(1, 3)}$. During 1/5 and 2/5 the cloud spreads even more extentively over Western Europe, extending to the UK, Spain and northern Italy, while the later part of the release is affecting Romania, Hungary and Czechoslovakia. By the final stages of the period covered by the MESOS analysis the released material is distributed across almost the whole of Europe; although the results shown in Figure 2 indicate that the plume has cleared from the source region at this stage; as noted earlier, the present MESOS estimates take no account of material carried along trajectories which leave the map area to the east. With the release pattern assumed here this could affect up to ~20% of the released activity, some or all of which could subsequently have returned westwards across the source region. However, independent trajectory calculations imply that this did not happen$^{(4)}$, while data are available to extend the area studied further to the east and north and it is intended to do this in the future$^{(1)}$.

Data sources and release source estimates

In principle, concentration estimates of the type presented in Figure 2 may be compared with observed ^{131}I in air levels at various locations across Western Europe in order to evaluate the Chernobyl accident release source for this and, allowing for radioactive decay effects, other radionuclides. In practice the situation is not quite as straightforward as this due to uncertainties both in the MESOS calculatio and in the observations. For example, the 24 hour average air concentrations estimated using MESOS cannot include the localised variations in both space and time induced by precipitation and major topographical features encountered by the plume. Also, much of the observed data available in the first few weeks following the accident were incompletely specified in terms of factors such as sampling period and/or sampling techniques employed. As noted earlier, it was judged that these uncertainties were minimised in the case of airborne activity concentration data, as compared for instance with deposited activity or contamination levels in environmental materials and foodstuffs. Thus air concentration data were used as the basis of the present preliminary estimates of the Chernobyl accident release source.

Observed airborne concentrations for a range of radionuclides at various locatio across Western Europe were selected for comparison with MESOS predictions and are summarised in Table 1. The basis of their selection is discussed below, prior to presentation of the release source estimates derived from them. In addition, limited data sets for ^{131}I and ^{137}Cs concentrations observed in the FRG and regions to the south were also included in this study at a later stage and are considered below. The locations of the various data sources used here are shown in Figure 3, which also indicates the grid squares from which MESOS data were derived for comparison with the observed values.

The earliest observations of the Chernobyl release which were reported came from Scandinavia and the Studsvik data shown in Table 1 represent 24 hour average concentrations recorded on 28/4(5). Based on the observed ^{131}I/^{137}Cs ratios elsewhere in Europe and on inventory considerations outlined below, the iodine data appear to represent only the particulate fraction of the release. Early observations from NE Poland were reported by the IAEA(6) as daily maximum and minimum total airborne activity levels over the period from 28/4 to 3/5, together with maximum and minimum values throughout this period for selected isotopes. Peak to mean ratios were typically ~2 and the activities shown in Table 1 are 50% of the reported maximum values which have been taken to persist over the 48 hours of 29-30/4, as indicated by the temporal pattern of the total activity data. These latter observations are compared with the predicted ^{131}I and ^{137}Cs in air levels obtained from the MESOS analysis in Figure 4; all three histograms have been normalised to unit integrated airborne activity (Bq s m^{-3}) over the period from 28/4 to 3/5 inclusive to facilitate comparison of the time variation in activity levels. Noting that the observed and calculated activity levels plotted in Figure 4 are 24 hour averages, the MESOS model can be seen to predict the arrival of the plume and subsequent decline in activity levels over NE Poland reasonably well.

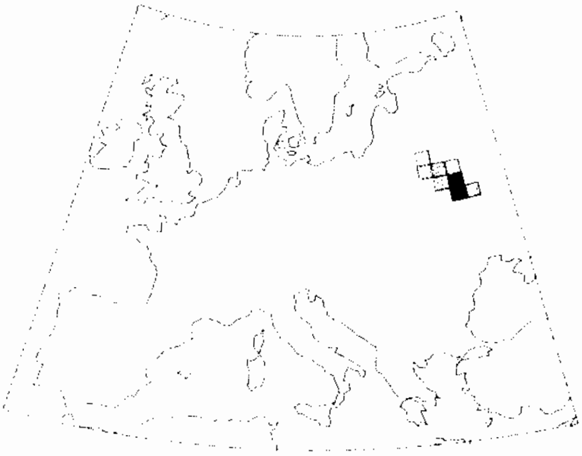
The Mol data included in Table 1 are 6 hour mean values recorded between 0900 and 1500 hours on 2/5(7); here the quoted ^{131}I activity is the particulate fraction, with a reported particulate to gaseous iodine ratio of 1:2. Two sets of UK data are included in Table 1, both being integrated airborne concentrations recorded at Chilton(8) and Berkeley(9, 10) respectively. In the latter case the quoted iodine activity is again the particulate fraction with an observed particulate to gaseous ratio of 1:4(9). The similarity between the ^{131}I/^{137}Cs ratios for the two UK locations shown in Table 1 suggests that a similar particulate to gaseous iodine ratio is appropriate in both cases.

In addition, limited data sets comprising integrated airborne concentrations of ^{131}I and ^{137}Cs observed at several other locations in the FRG, Switzerland, Italy and Yugoslavia are summarised in Table 2. The Aachen/Julich and Munich data were recorded over the period from 30/4 to 7/5(11), while those from the Leibstadt nuclear power plant were observed between 1/5 and 3/5(12). The ^{131}I data from the Trino and Caorso nuclear power plants were measured between 30/4 and 5/5, as were those from Zagreb and Belgrade(12). In the latter case only maximum values were reported and the levels shown in Table 2 were

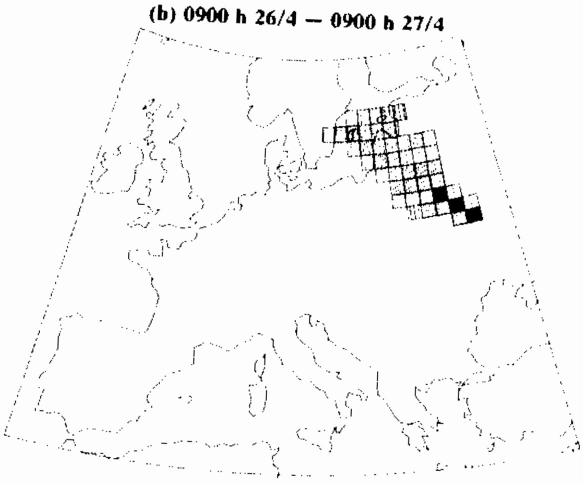
Table 1
Observed Airborne Concentrations of Radionuclides Released from Chernobyl at Various Locations Across Europe

Radionuclide	*Observed Airborne Concentration*				
	Studsvik(5) /Bq m^{-3}	*NE Poland(6) /Bq m^{-3}*	*Mol(7) /Bq m^{-3}*	*Chilton(8) /Bq s m^{-3}*	*Berkeley(9, 10) /Bq s m^{-3}*
^{60}Co	0.01	—	—	—	$2.0.10^{2}$
^{89}Sr	—	—	0.31	—	—
^{90}Sr	—	—	0.04	—	$9.0.10^{2}$
^{95}Zr/^{95}Nb	0.17	—	—	—	$6.0.10^{2}$
^{99}Mo/^{99m}Tc	0.7	—	—	—	$8.35.10^{3}$
^{103}Ru	0.4	14.5	—	$1.2.10^{5}$	$2.85.10^{4}$
^{106}Ru	0.23	—	—	$4.5.10^{4}$	$2.11.10^{4}$
^{131}I	6.0	93	7.8	$1.6.10^{5}$	$4.36.10^{4}$
^{132}Te/^{132}I	2.0	106	—	$1.9.10^{5}$	$1.05.10^{5}$
^{133}I	1.15	—	—	—	$5.8.10^{2}$
^{134}Cs	0.97	5	—	$3.2.10^{4}$	$1.03.10^{4}$
^{136}Cs	—	—	—	—	$3.92.10^{3}$
^{137}Cs	1.9	9.5	3.6	$7.6.10^{4}$	$1.91.10^{4}$
^{140}Ba/^{140}La	3.5	—	—	$2.4.10^{4}$	$9.65.10^{3}$
^{141}Ce	0.13	—	—	—	—
^{144}Ce	0.2	—	—	—	—
^{239}Np	0.7	—	—	—	—
$^{239/240}$Pu	—	—	$2.5.10^{-5}$	—	2.88
^{238}Pu/^{241}Am	—	—	$<2.7.10^{-5}$	—	4.32
^{242}Cm	—	—	8.10^{-5}	—	0.14

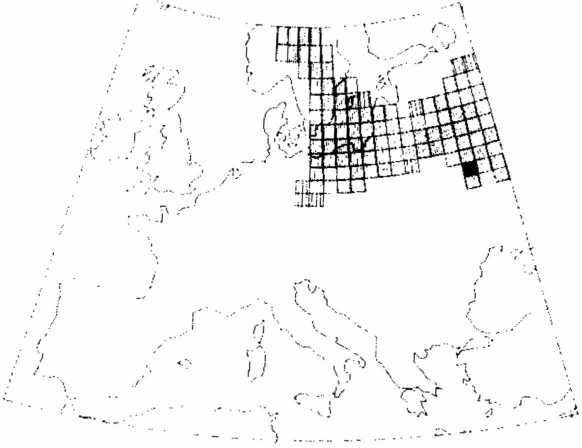
(a) 2100 h 25/4 — 0900 h 26/4



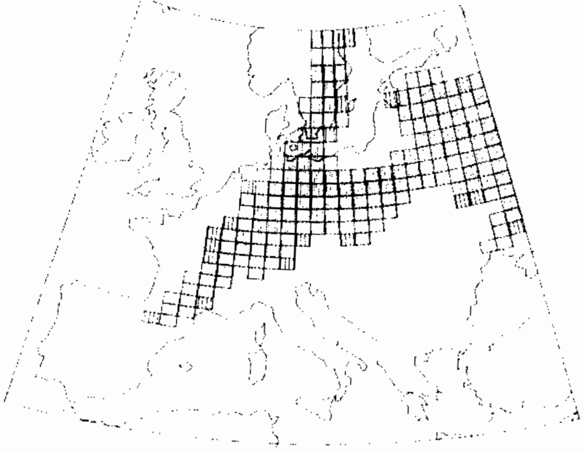
(b) 0900 h 26/4 — 0900 h 27/4



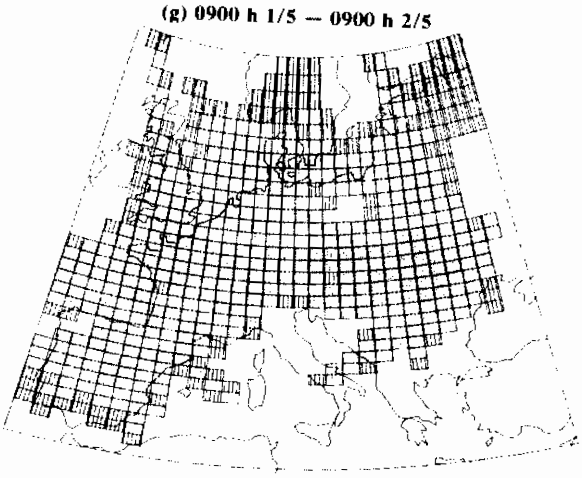
(d) 0900 h 28/4 — 0900 h 29/4



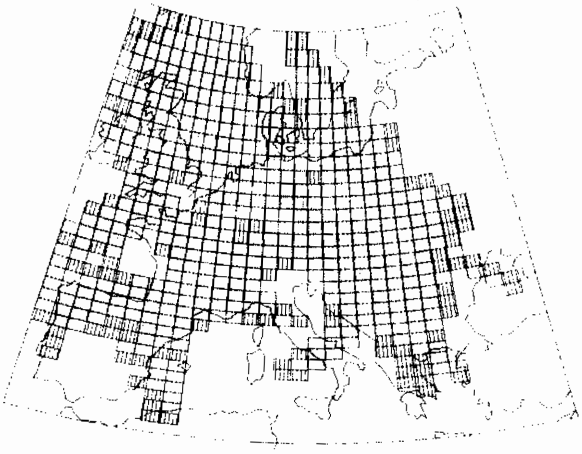
(e) 0900 h 29/4 — 0900 h 30/4



(g) 0900 h 1/5 — 0900 h 2/5



(h) 0900 h 2/5 — 0900 h 3/5



(c) 0900 h 27/4 — 0900 h 28/4

MEAN AIR CONCN(BQ.M-3)

||| <1E0

||| 1E0-3.16E0

||||| 3.16E0-1E1

||| 1E1-3.16E1

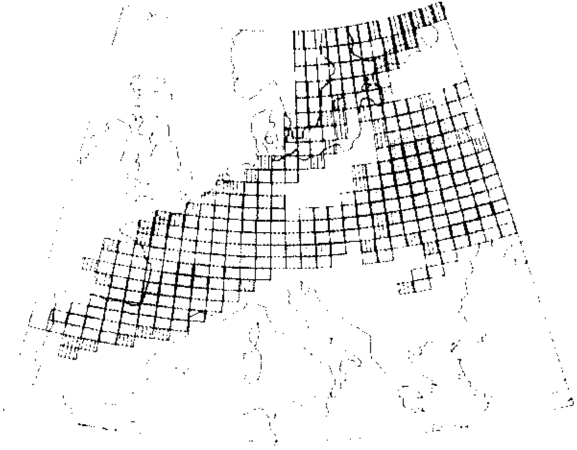
||||| 3.16E1-1E2

||| 1E2-3.16E2

||||| 3.16E2-1E3

■ >1E3

(f) 0900 h 30/4 — 0900 h 1/5



(i) 0900 h 3/5 — 0900 h 4/5

Figure 2: Estimated 24 hour Average ^{131}I in Air Concentrations over Western Europe for the Period from 26th April to 4th May 1986(1).

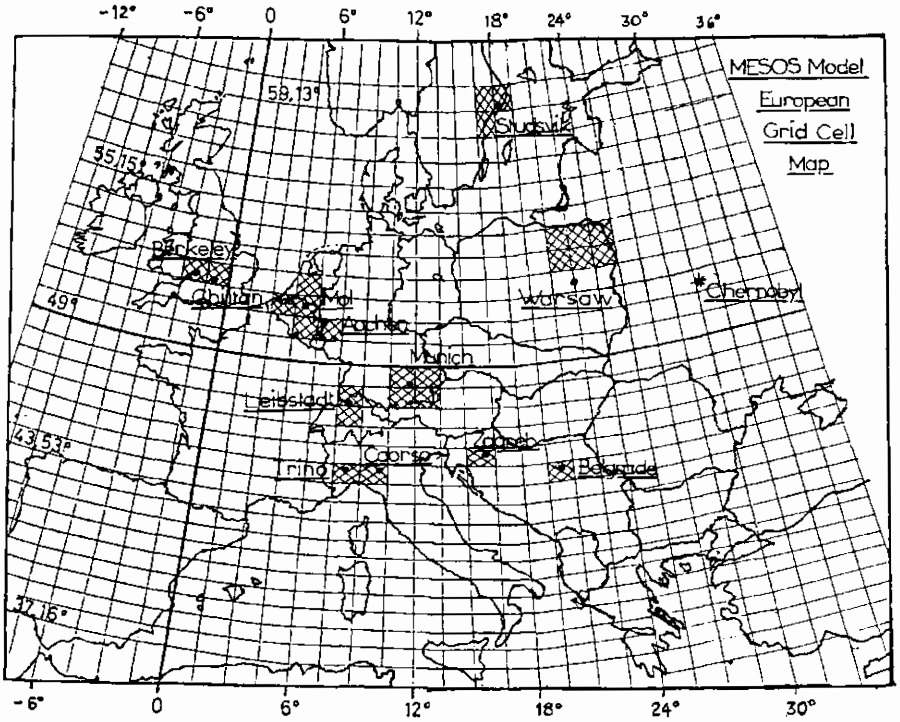


Figure 3: The MESOS European Grid Cell Map Showing Data Sources and Associated Cells used in the Release Source Evaluations.

estimated assuming a peak to mean ratio of ~2, similar to that applied earlier in the case of the data for NE Poland.

The Chernobyl accident release source estimates derived by comparing the observed activity concentrations of Table 1 with the MESOS model predictions are summarised in Table 3. Also shown in Table 3 is the estimated core inventory at the time of the accident evaluated using the RICE code⁽¹³⁾, assuming irradiation of 180 tonnes of 2% enriched UO_2 fuel for 420 days at a rating of 16 MW t^{-1}. This represents a burn-up of 6720 MWd t^{-1} which, in the absence of detailed information on the irradiation history of the Chernobyl-4 reactor, was determined on the basis of the observed $^{134}Cs/^{137}Cs$ activity ratios (see Table 1). This estimated core inventory was used to derive the elemental release fractions shown in the final column of Table 3. These release fractions are the geometric means of the data for the various locations across Europe included in this study and, where indicated, have been corrected to allow for the reported or deduced particulate to gaseous iodine ratios. The elemental release fractions deduced here are compared in Figure 5 with the equivalent parameters for the UK1 degraded core accident postulated for the proposed Sizewell 'B' PWR reactor(14). The dashed lines of unit slope shown in Figure 5 provide a basis for comparison of the Chernobyl acciden with the PWR/UK1 accident; obviously the scenarios for the two accidents are not strictly comparable, apart from differences in the design features and safety philosophies of the two reactor systems. For example, while the PWR/UK1 release category embraces a group of sequences in which a containment by-pass exists from the reactor core to the environment with the release occurring over a period of a few hours(14), that at Chernobyl appears to have extended over several days. However, in the sense that the UK1 scenario represents a severe accident involving the whole reactor core the comparison shown in Figure 5 can be said to represent the Chernobyl-4 reactor accident as one involving ~5-50% of the whole core, with a geometric mean value of ~15%. This perhaps

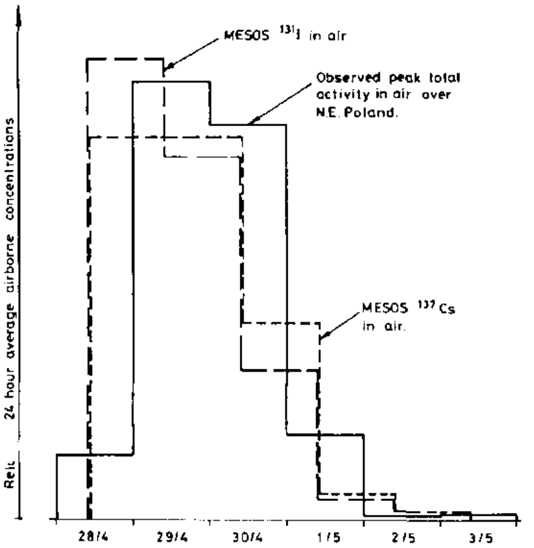


Figure 4: Comparison of the Temporal Pattern of Total Airborne Contamination over NE Poland[6] with that of ^{131}I and ^{137}Cs in Air Levels Predicted by the MESOS Model[1, 3].

gives a perspective of the severity of the accident in relation to extreme low probability fault sequences postulated for the PWR system proposed for introduction into the UK and operating elsewhere.

Additional release source estimates for ^{131}I and ^{137}Cs, based on the observations summarised in Table 2, are given in Table 4. The results for Aachen/Julich, Munich and Leibstadt are reasonably consistent with those of Table 3 for these two radionuclides. In terms of the estimated release fractions for iodine and caesium, inclusion of these additional results has a marginal impact, increasing them by about 4%, to 19 and 22% respectively. However, the results for ^{131}I based on the observations over Northern Italy and Zagreb appear too high, representing fractional releases of the estimated Chernobyl core inventory for this radionuclide of $\geqslant$100%. Given the reasonable consistency of the ^{131}I release source estimates derived from observations elsewhere in Europe, these anomalous results for Northern Italy and Yugoslavia indicate that the MESOS calculations are underpredicting the ^{131}I in air concentrations over this region. Three independent effects, or a combination of them, could explain this result, namely;

(a) underestimation of the activity release rate during the later stages of the accident when the predicted trajectories tended to take a more southerly route across Europe (see earlier discussion),

(b) inaccuracies in the estimation of these trajectories causing them to pass too far to the north in the region of Northern Italy, and

(c) neglect of material which initially followed trajectories to the east of Chernobyl and subsequently turned back over southern Europe.

These and other possible effects will be the subject of further investigation as a more detailed radiological and meteorological data base for this region is established.

Summary and conclusions

In this paper the results from a preliminary analysis of the dispersion over Western Europe of radioactivity released during the Chernobyl-4 reactor accident have been utilised to provide an initial estimate of the accident release source. In particular, the results of long-range atmospheric dispersion calculations performed using the MESOS code have been outlined and compared with airborne concentrations of radionuclides observed at a range of locations across Europe during the week or so following the accident. The work reported here was undertaken during the first 6-8 weeks following the accident and utilised monitoring data readily available during that

Table 2
Observed Airborne Concentrations of ^{131}I and ^{137}Cs Released from Chernobyl at Locations in Central and Southern Europe

Radio-nuclide	*Observed Airborne Concentration/Bq s m^{-3}*						
	Aachen/Julich[11]	*Munich*[11]	*Leibstadt*[12]	*Trino*[12]	*Caorso*[12]	*Zagreb*[12]	*Belgrade*[12]
^{131}I	2.4.10^{6}	1.1.10^{7}	1.0.10^{6}	3.2.10^{6}	6.3.10^{6}	6.0.10^{6}	2.9.10^{6}
^{137}Cs	2.5.10^{5}	1.7.10^{6}	4.5.10^{5}	—	—	—	—

Table 3
Chernobyl-4 Reactor Accident Release Source Estimates and Comparison with the Estimated Reactor Core Inventory

Radio-nuclide	*Estimated Core Inventory/ 10^{16} Bq*	*Release Source Estimates/10^{16} Bq Based upon Observations at:*					*Fraction of Core Inventory Released (%)*
		Studsvik	*NE Poland*	*Mol*	*Chilton*	*Berkeley*	
^{60}Co	—	0.017	—	—	—	0.012	—
^{89}Sr	330	—	—	1.1	—	—	0.54
^{90}Sr	12.2	—	—	0.13	—	0.052	
^{95}Zr/^{95}Nb	509	0.30	—	—	—	0.039	0.02
^{99}Mo/^{99m}Tc	490	2.2	—	—	—	2.5	0.48
^{103}Ru	384	0.57	6.0	—	8.1	1.9	1.0
^{106}Ru	66.4	0.39	—	—	2.7	1.3	
^{131}I	267	65*	50	195**	85*	23*	15
^{132}Te/^{132}I	395	29*	94	—	46	25	
^{133}I	589	70*	—	—	—	32*	
^{134}Cs	7.88	1.7	1.9	—	1.9	0.62	18
^{136}Cs	10.3	—	—	—	—	0.33	
^{137}Cs	14.4	3.2	3.6	12	4.6	1.2	
^{140}Ba/^{140}La	521	6.8	—	—	2.1	0.84	0.44
^{141}Ce	493	0.23	—	—	—	—	0.08
^{144}Ce	284	0.34	—	—	—	—	
^{239}Np	5080	2.5	—	—	—	—	0.05
$^{239/240}$Pu	0.153	—	—	$8.1.10^{-5}$	—	$1.7.10^{-4}$	0.06
^{238}Pu/^{241}Am	$2.52.10^{-2}$	—	—	$<8.7.10^{-5}$	—	$2.6.10^{-4}$	
^{242}Cm	0.910	—	—	$2.6.10^{-4}$	—	$8.7.10^{-6}$	

* Values based on a particulate to gaseous iodine ratio of 1:4, as observed at Berkeley(9).
** Value based on reported particulate to gaseous iodine of 1:2 at Mol(8).

Table 4
Chernobyl-4 Reactor Accident Release Source Estimates for ^{131}I and ^{137}Cs Based on Observation in Central and Southern Europe

Radio-nuclide	*Release Source Estimates/10^{16} Bq Based upon Observations at:*						
	Aachen/Julich	*Munich*	*Leibstadt*	*Trino*	*Caorso*	*Zagreb*	*Belgrade*
^{131}I	47	180	180*	310	600	300	17
^{137}Cs	2.3	14	4.8	—	—	—	—

* Value based upon a particulate to gaseous iodine ratio of 1:4, as observed at Berkeley(9).

period. At the time of writing, data related to the radiological impact of the Chernobyl accident are continuing to be assembled and it will be some time before a complete and validated data base is established. At that stage it will be possible to refine the MESOS calculations and the release source estimates derived from them, but in the interim the results presented here provide an insight into the severity of the Chernobyl-4 reactor accident and may be used as a source term for environmental impact studies aimed at understanding the radiological implications of the accident and the remedial actions being undertaken within the USSR.

Given the uncertainties within the MESOS model and in the data utilised in this study, the accident release source estimates presented in Tables 3 and 4 show a remarkable degree of consistency. The majority of the values calculated lie within a factor of 2 of the mean values for individual radionuclides, particularly where several sets of observations are available. Where anomalous results occur, as in the case of the ^{131}I levels in air over northern Italy, these can be understood at least qualitatively in terms of limitations in the present MESOS calculations and available data. For example, the concentrations assigned to individual MESOS grid cells in the present analysis are uncertain

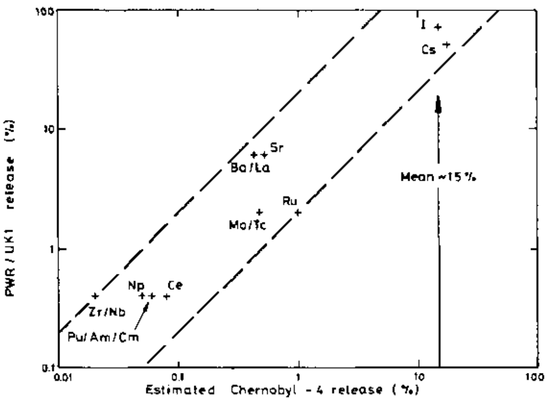


Figure 5: Comparison of PWR/UK1(13) and Estimated Chernobyl-4 Release Fractions.

to within a factor of almost 2 (see key to Figure 2). Overall the uncertainty associated with the release source estimates of Table 3 is considered unlikely to be greater than a factor of about 2-3, with a greater degree of confidence being placed in the relative releases of the various fission product and actinide elements included therein. Indeed, the relative releases show good agreement with broad classifications of fission product releases from damaged UO_2 fuel derived earlier, largely on the basis of theoretical considerations (see for example Table 1 of Reference 15).

Finally, it has been suggested that in a sense the Chernobyl-4 reactor accident can be described as one involving 5-50% of the whole core, with a mean of ~15%. While this approach may be helpful in comparing the Chernobyl accident with other severe accidents postulated in design and safety studies for other reactor systems, it is one which should be used with extreme caution. A more meaningful, and arguably the only, way to discuss the release is in terms of the fractional releases of individual fission product and actinide elements. On the basis of the initial assessment presented here this would lead to a current best estimate of the Chernobyl-4 reactor release source of ~15-20% of the iodine, tellurium and caesium inventory, ~1% of the ruthenium and lesser amounts of the other fission products and actinides, together with an implied major fraction of the krypton and xenon noble gases.

Acknowledgements

One of the authors (H. F. Macdonald) acknowledges permission to publish this paper granted by the Central Electricity Generating Board. The authors also wish to thank numerous colleagues, both in the UK and elsewhere, who have influenced the course of the work presented here both by the provision of unpublished information and in informal discussion on various aspects of the Chernobyl accident.

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x

JHG
19.9

IMPERIAL COLLEGE OF SCIENCE AND TECHNOLOGY

Nuclear Power Section
Department of Mechanical Engineering, City and Guilds College
Exhibition Road, London SW7 2BX
Telephone: 01-589 5111 Telex: 261503 Telegrams: IMPCOL London SW7

18 September 1986

W Nixon
to see & return
to JHG please

Dr F. Gittus
Safety and Reliability Directorate
Wigshaw Lane
Culcheth
Warrington
WA34NE

Dear Dr Gittus,

I appreciate the interest within SRD in the work my group has been doing on the Chernobyl accident. Dr Nixon is coming to see me on Thursday with a view to obtaining our estimated trajectories, and I will then show him our new results for a revised release pattern based on the USSR presentations in Vienna. In the meantime I enclose two recent papers based on our preliminary results to illustrate the applications to source term assessment and collective dose calculations. Please let me know if there are any further details you would like to know.

Yours sincerely,

Helen ApSimon.

Helen ApSimon

Enc. 2

JHG 7.10

B

International Atomic Energy Agency
BOARD OF GOVERNORS

GOV/2268
16 September 1986

RESTRICTED Distr.
Original: ENGLISH

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Item 1(c) of the provisional agenda
(GOV/2264)

POST-ACCIDENT REVIEW MEETING

Note by the Director General

1. Pursuant to a decision taken by the Board of Governors on 2 May 1986,[1] a post-accident review meeting on the Chernobyl accident was held in Vienna from 25 to 29 August 1986.

2. After the review meeting, the International Nuclear Safety Advisory Group (INSAG), with the assistance of invited experts, prepared the attached report to the Director General, who herewith submits it to the Board for its consideration.

3. Section VII of the report contains recommendations which were taken into account by the Secretariat in preparing the proposals for expanded nuclear safety and radiation protection contained in document GOV/2269.

RECOMMENDED ACTION BY THE BOARD

4. It is recommended that the Board take note of the attached report and request the Director General to submit it to the General Conference for consideration at its special session.

---

[1] See GOV/OR.649, paras 117-119.

J Dunster is to be shown a draft of my paper for factual comment. The final version ~~is to~~ ~~month~~ is to be prepared within a month. We ~~are to~~ will add a final chapter on emergency arrangements, the Soviet response to the accident, evacuation, fire protection, decontamination + medical details.

LM placed an action on all CIMRG members to write to me with their proposed modifications/additions. The most important thing is to expand the comments. We shall have to stimulate GDCD, BNL, PMT and NNC to provide us with their comments. The typical thrust of a comment will be: "It would not be like that in the UK because our philosophy is as follows... ~~For~~ An example of that philosophy is given by the following features of the AGR."

CIMRG 44 "The Chernobyl Accident –
Why it could not happen in the UK"

We discussed vocabulary: "a slow nuclear explosion." The majority were against the use of this phrase. We all agreed that we need to make the point "it wasn't like a bomb." It was agreed that we would call the event "a power surge leading to a steam explosion." J Allicker reminded us that the BORAX experiment in the '50s was done with just this purpose in mind: to demonstrate that a reactor might explode but not like a nuclear weapon.

Technical Aspects of hypothetical Reactivity Accidents
CIMRG.43 JGC.

— Fast Reactivity excursion CIMRG 48
D. Smith

LM's answer to the question "Why could not the Chernobyl Accident happen here?"

1. Intrinsic shortcomings of the Russian reactor.
2. Relied on obedience of operators to their instructions.
3. Failed to inculcate safety culture: poor training.
4. In AGR + Magnox we cannot, generally, have prompt critical excursions. More generally "Doppler" plus the protection system will prevent prompt criticality.

ie, in PWR, prompt criticality ~~can~~ could be produced by main steam line failure leading to blow down of two steam generators: the primary coolant temperature falls and ~~it~~ it only needs to fall 7 °C. However the ~~rods~~ protection system will detect this ~~bets~~ and the shut-down rods will be inserted quickly, preventing prompt criticality.

5. LM has asked for a brief on CANDU safety so as to indicate ~~how~~, that ~~we~~ there are ways of designing a reactor which is safe despite a positive void coefficient

7

I agreed to produce a UK paper on the 13 topics agreed in Vienna for international collaboration. It is to identify which UK organisation is interested in which topic. I am to agree it ~~bef~~ with the UK organisations represented at the CIMRG.

Halsbury scale. LM insists on a two parameter scale (individual dose and cost). We need for a criterion which differentiates what the ~~Bo~~ Minister for Industry publishes and what it requires Ministers to publish. Halsbury himself favoured a) dose to workers and b) dose to public — ie two parameters.

Date of Next Meeting 21 Oct. (We shall have fixed monthly meetings for 12 months, Jan)

14-10

16 Sept 86 I don't circulate — too late; Chairman bf CIMRG 1

Notes. JHG. → RNS MAWB AHull SAC ± Hall Lloyd Nam Dunbar Powell

SC SC

Lord Marshall reported that

Most of the discussion at the "Chairmen's meeting" with Mr Goodlad had centred on emergency plans. On Regulatory matters public acceptance had been touched on. Mr Morphet advised that a further similar meeting should be held, perhaps later this year (December). ~~W~~LM said we would write to Mr Goodlad a letter, updating the position in preparation for the meeting. BNFL agreed to host a "dinner meeting".

Edmondson said that at the start of the experiment the plant was at 200 MWth. Operation below 700 MWth for extended periods is forbidden because they have a positive power coefficient at these levels.

They had 3 options for the test and intended to try them one after the other. That is why the reactor was not shut down when the test started. The reactor was poisoned by water, not by Xenon. The purpose of the experiment was to demonstrate that the alternator could power the ECCS pumps: ~~it was~~ they used the main coolant pumps as a "dummy load" instead of the ECCS pumps.

Morphet reported that the Italians are going to have a "National Energy Debate" at the end of the year. Colombo favours the domino theory and Corbolini the sacrifice theory, vis a vis Latina. If it becomes an international debate then LM wishes to go.

Explaining the Chernobyl Accident to the Public

We shall have three reports:

i) The IAEA report (by ENSAG)

ii). A formal UK report and commentary. I agreed to prepare this (based upon CIMRG 42) <

iii) A popularized version of ii): JGC has this in draft.

It will be reviewed by the Watt Committee .. and, if JGC can arrange it, by the Fellowship of Engineering

<u>Explaining to CEGB staff</u>: An all day CEGB seminar will be held in the Barbican on 24th Sept. 10.30 am. All station managers (fossil and nuclear) will be invited. An hour will also be given to acid rain. (or Andy Clark
There will be four talks:

i) What happened at Chernobyl (JGC's account)
ii) Implications of C for CEGB operations (Ed B)
iii) Radiological effects and emergency planning (Phil Partman)
iv) Summing up (LM). Key things to convey to the public.

UKAEA etc are invited to send two or three observers each to the meeting. LM suggested that UKAEA, NNC etc should arrange similar seminars etc in their own organisations. The UKAEA have a video (which I made) and articles will appear in the next issue of ATOM.

On 24th ~~September~~ Mr Peter Walker will make a major speech in Vienna. He may mention what CEGB are doing.

Ryder (NII) and ACSNI (Horlock) will wish to make public statements ultimately, based ~~perhaps~~ on a review of the report. NII did a report on TMI which reinforced the UK licensing situation.

Morphet said:

1) OSART of UK nuclear power stations: Ministers are not thinking of an invitation of that kind. Mr Walker will, in Vienna, say something about what IAEA should do to promote convergence of regulatory matters.

3.

2). The NEA need to be kept ~~under~~ "on the party-line", supporting the IAEA work.

3) The vocabulary of 'prompt criticality' needs to be agreed.

CIMRG 46: IAEA INSAG review: will be reviewed later.

CIMRG 45: Chernobyl Accident Sequence. — to be adopted in my report (ii) in its final form as defined at the next CIMRG meeting.

CIMRG 42. The Chernobyl Accident and Its Consequences ~~(My Report)~~

Chapter 2. Dereck Smith + EDGD will be particularly required to comment on this

LM will write a foreword. We are to imagine that "reviewers are the Fellowship of Engineering and the Watt Committee

We must take account of CIMRG 44.

Two types of comment will be interpolated: RBMK reactor and its characteristics; whether features reproduced in AGRs — mainly the first of these, with the latter as illustration.

Other documents commissioned by LM were ~~see~~ 'AGR in the light of Chernobyl', 'Magnox ditto' & 'Sizewell B ditto'. Not an urgent or detailed requirement. Dereck Smith & I agreed that UKAEA/NNC should propose a similar document for the Fast Reactor.

Cher - Misc JHG 23-9

56

EMERITUS PROFESSOR J.H. FREMLIN
46 Vernon Road
Edgbaston
Birmingham
B16 9SH

Telephone: 021-454 0314

17th September 1986

Dr John H. Gittus,
Director,
Safety and Reliability Directorate,
U.K.A.E.A.,
Culcheth,
Cheshire.

Dear Dr Gittus,

Thank you very much <u>indeed</u> for your Report, which gave a detailed and comprehensive account of the Chernobyl accident as well as the vitally important collective doses received by the Soviet population.

This has come in nice time for the section on Chernobyl that I want to add to the paperback edition of my book (Power Production - What are the Risks?). This is to be published by OUP next spring or summer, but they have given me the beginning of October as the date by which the need the addition.

In referring to your report, should I say "Private Communication", or is it to be published by the IAEA?

Yours sincerely,

John Fremlin

John Fremlin.

Extract from Minutes of EDC(86)M3 **Meeting held on** 17.9.86

Item 4

Mr. B.C. Carpenter
Mr. D.M. Levey
Mr. W. McMillan

4. DEVELOPMENTS FOLLOWING THE ACCIDENT AT CHERNOBYL

EDC(86)P16

23. In discussion of EDC(86)P16, the following points were made.

4.1 Briefing on Plant for Local Media/Public Enquiries

24. (i) DR. LOW and DR. HOLMES confirmed that briefing was available, on the reactors at Harwell and Winfrith, to deal with local enquiries.

(ii) MR. BLUMFIELD said that a summary could be produced, for briefing purposes, of a recent paper to the Northern Division Board of Management (NDBM) on the PFR but pressure of other work had prevented the preparation of briefing on other plant at Dounreay.

(iii) DR. EYRE said that, while Springfields and Windscale fell within BNFL's emergency and associated arrangements, an NDBM paper on safety procedures for the various plant at FETD could also be summarised for use as briefing. It was slightly surprising that, following the Chernobyl accident, the media had not shown a closer interest in the Windscale piles.

(iv) For licensing purposes, the NII were asking Dounreay for details of chemical hazards on the site, which would then become publicly available.

(v) DR. LOMER said that, when tritium was introduced into JET, local discussion would need to be arranged and media briefing prepared.

(vi) The reply to various questions raised by the Atomic Energy Division of the Department of Energy on points arising from the Chernobyl accident, eg. the positive void co-efficient and prompt criticality, would need to be prepared in the context of discussions in the nuclear industry as a whole. It would still be up to the Authority to reply, in view of the nature of Atomic Energy Division's responsibilities.

4.2 Advertising of Authority Leaflets and Other Publications

25. There would be value in pursuing the possibility of advertising Authority publications but the objectives should be properly thought out and the publications would need to be selected to ensure that they were up-to-date and suitable in content and tone.

4.3 Open Days

26. (i) DR. LOW said that a series of open days (for employees' families and invited guests) was planned at Harwell, starting in the Autumn.

(ii) The experience of Sellafield might suggest that there was a need for open days for the general public but Winfrith's local advertisements for visits by ticket had met with little response. Ways were being sought of making visits to Winfrith more easily available without the expense of a full Open Dey. On the other hand, Dounreay's invitation to the public to visit PFR, advertised in local hotels through the [illegible] Tourist Board, had been very successful.

(iii) The Authority would be involved in BNFL's arrangements for a series of [illegible] to mark the [illegible] anniversary of the uranium fuel element.

4.4 Local Liaison Committees

27. (i) MR. BLUMFIELD said that it had been agreed that the press should attend the next Dounreay Local Liaison Committee meeting. The agenda was being checked for any confidential items.

(ii) DR. EYRE said that certain of BNFL's Local Liaison Committees which covered FETD sites were already open to the media but local councillors had objected to this arrangement for the Springfields Committee.

4.5 Observers at Emergency Exercises

28. (i) Some Local Liaison Committee members already observed emergency exercises in their capacity as council officials but it might be unwise to set a precedent by inviting elected councillors to do likewise.

(ii) It would also be unwise to invite the press to observe emergency exercises since these used scenarios of extreme conditions, giving a misleading impression which could be carried over into press reports.

4.6 Funding of Public Relations Initiatives

29. Although not a matter for the Council, there was some concern at how any increase in public information activities might be funded. The Department of Energy were looking at the Public Information Programme Letter but any increase in funding would be at the expense of other Programme Letters.

4.7 Managerial Issues Arising from the Post-Accident Review

30. (i) There was a need to circulate information on the accident to Authority employees in two different contexts. First was the need to keep all employees informed on a general basis. To this end, a further letter from the Chairman and a video on Chernobyl were in preparation. The second strand was to provide adequate detail to operators and first line supervisors for them to understand the full background.

(ii) Dr. Eggleton had given a very popular lecture at Harwell, particularly on the environmental aspects of the accident.

(iii) MR. BLUMFIELD said that he had been invited by the NDBM to consult Harwell and Winfrith about the possibility of a joint statement on the balance of human and engineered safety controls at their reactors. It was agreed that it would be useful for SRD to be involved at a junior level in this exercise, perhaps by providing a secretary.

[illegible] would be pursuing this as part of the GNSR programme.

(v) The Authority should also participate in Lord Marshall's Various initiatives as necessary. This would include monitoring any developments on the safety review of magnox reactors and contributing to the Working Party on emergency arrangements for accidents larger than design base reference accidents.

(vi) The Authority would also want to be involved in any long-term epidemiological study following the accident, although NRPB or MRC would probably take the lead in this.

(vii) The need to review reactor operator training arrangements would probably be considered within Mr. Blumfield's exercise on human and engineered controls in existing plant.

Other Matters

31. (i) In view of the range of sensitive major plant in the Authority, it would be useful to produce a list of all potentially hazardous plant so that the relevant safety provisions could be properly considered.

(ii) The efficiency of the Russian response to the accident suggested widespread understanding of nuclear matters and availability of monitoring instruments. The possible need to look at similar provisions in the UK could usefully be raised in the review of civil contingency arrangements.

(iii) MR. FLETT said that Northern Division had been assured by the managers of the university research reactor on the Risley site that safety procedures had been reviewed in the light of Chernobyl. They would nonetheless welcome details of any changes in safety arrangements in the Authority, particularly for the Materials Testing Reactors, which they might need to consider. This information could be provided to universities through the Radiological Protection Officer at Risley.

32. The COUNCIL

1. noted the points made in discussion;

2. invited Mr. Blumfield and Dr. Eyre to prepare summaries of the recent papers on PFR and FETD plant respectively, for use as briefing for media and other queries;

3. agreed that Mr. Chadwick should be invited, in consultation with the Information Services Committee, to consider further the possibility of advertising Authority publications, bearing in mind the need for these to be carefully selected, and to propose a shortlist of suitable publications;

4. invited Mr. Blumfield to seek an SRD nominee to act as secretary to the discussions he was arranging with Harwell and Winfrith on human and engineered safety controls in existing plant; and

5. agreed that Directors should prepare a list of potentially hazardous plant at their establishments which would need to be included in post-Chernobyl safety reviews.

Ch

8530
15-9

FACSIMILE

To: Dr R D Pearce, Programmes Branch, LHQ

Rpt: Mr M A W Baker, LHQ
Dr J H Gittus, Director, SRD
Mr I A Hodgkinson, LHQ
Dr G I W Llewelyn, LHQ

From: Mr H I Shalgosky, B 551, Harwell

15 September 1986

FURTHER CHAIRMAN'S LETTER ON CHERNOBYL

We suggest the following changes to the draft dated 9 September.

1 Para 3, line 15. After "runaway reaction", insert the words "known as a prompt critical excursion".

2 Add to para 6

However, from the comprehensive Russian account of the causes and consequences of the accident, it is clear that no new phenomenon was involved and the safety arguments for reactors in the UK and other Western Countries are not thrown into doubt.

3 Replace para 7 by

A great deal of work remains to be done to take full advantage of the lessons coming out of the disaster. Further studies will enable safety assessments to be made with greater certainty and thus improve the cost-effectiveness of safety provisions. Some changes in the balance of the Authority's R & D activities may well result.

15 September 1986

8514
11-9

MEMORANDUM

Your Ref.
Our Ref.
Tel Ext.

To Dr R D Pearce, Programmes, LHQ

Subject Chairman's Dear Colleague Letter on Chernobyl

In response to Wynn Llewelyn's notes on the draft of 9 September.

Item 1: I suggest leaving the text as it is. Operating instructions were in place - they were, however, acknowledged as inadequate. Documents sent to Moscow were not considered in time, but there was no suggestion that they were for approval of the tests.

Item 2: I suggest keeping the amendment but delete initial. Operator error occurred in the accident sequence as well as deliberate over-riding of safety functions - but these were not initiating events.

Sheena Corbany
pp M R Hayns
Head, Nuclear Safety
 Technology Branch
SRD

cc Mr Baker, LHQ
   Mr Hodgkinson, LHQ
   Dr Gittus, SRD
   Dr Nixon, SRD

11 September 1986

8.10

ORGANISATION FOR ECONOMIC
CO-OPERATION AND DEVELOPMENT

NUCLEAR ENERGY AGENCY

RESTRICTED
Paris, drafted: 11th Sept. 1986
dist: 12th Sept. 1986

Addendum 2 to:
NE(86)16

FOR INFORMATION

Scale 4

Or. Eng.

STEERING COMMITTEE FOR NUCLEAR ENERGY

ACTIONS TAKEN BY NEA IN THE FIELD OF NUCLEAR SAFETY FOLLOWING THE CHERNOBYL ACCIDENT; PRELIMINARY ASSESSMENT OF THE LIKELY IMPACT ON THE CSNI PROGRAMME

1. In Addendum 1 of document NE(86)16, the Steering Committee was informed of a number of preliminary suggestions for future action by CSNI which emanated from two informal enlarged Bureau meetings, held in Vienna during the week of 25th-29th August 1986. One of the suggestions made during these meetings was inadvertently omitted from this document and is given below:

2. The importance of human factors in nuclear safety has again been underlined by the Chernobyl accident. It was therefore proposed that CSNI should step up its activities in this field. In view of the likelihood that a broad programme in this field will be entrusted to the IAEA, it was considered important for CSNI to focus on the specific topic of simulator development and training for accident situations. In this respect the coupling of a simulator with a thermal-hydraulic facility should be investigated as an international project.

ORGANISATION DE COOPERATION
ET DE DEVELOPPEMENT ECONOMIQUES

AGENCE POUR
L'ENERGIE NUCLEAIRE

DIFFUSION RESTREINTE

Paris, réd: 11 septembre 1986
dist: 12 septembre 1986

Addendum 2 au:
NE(86)16

Barème 4

Or. angl.

COMITE DE DIRECTION DE L'ENERGIE NUCLEAIRE

ACTIONS ENTREPRISES PAR L'AEN DANS LE DOMAINE DE LA SURETE NUCLEAIRE A LA SUITE DE L'ACCIDENT DE TCHERNOBYL ; EVALUATION PRELIMINAIRE DE L'INCIDENCE PROBABLE SUR LE PROGRAMME DU CSIN

1. Dans l'Addendum 1 au document NE(86)16, le Comité de Direction a été informé des suggestions préliminaires relatives aux travaux futurs du CSIN, formulées à l'issue de deux réunions informelles du Bureau élargi du Comité tenues à Vienne dans la semaine du 25 au 29 août 1986. L'une de ces suggestions a été omise par inadvertance de ce document et est soumise ci-après :

2. L'importance des facteurs humains dans la sûreté nucléaire a de nouveau été soulignée par l'accident de Tchernobyl et il est proposé que le CSIN renforce son programme d'activités dans ce domaine. Etant donné que l'AIEA se verra vraisemblablement confier un large programme dans ce domaine, on estime qu'il est important que le CSIN se concentre sur la question spécifique de la mise au point de simulateurs et de la formation de personnel pour faire face aux situations accidentelles. Il conviendrait, à cet égard, d'étudier le couplage d'un simulateur à une installation thermohydraulique dans le cadre d'un projet international.

IN CONFIDENCE

Dr J H Gittus
c/o Lord Marshall
Chairman
Central Electricity Generating Board
Sudbury House
15 Newgate Street
London EC1A 7AX

CHERNOBYL POST-ACCIDENT REVIEW - THE HARWELL REACTORS

This note is in response to your memo of the 5th September, 1986 and is very much an interim reply which will be amplified in the next week or so.

The Harwell reactors are operated within the terms of an annually-renewable Authority-To-Operate issued by the Director, AERE, Harwell after consultation with the Director of Safety and Reliability Directorate. The ATO is based on the reactor Safety Document and Standing Orders approved by the Reactor Safety Committee at Harwell which includes SRD members. The following are in direct reply to the questions in your memo.

1. The void coefficient and overall temperature coefficient of reactivity in DIDO, PLUTO or GLEEP are all negative. Indeed, because of the fairly strong negative void coefficient in DIDO and PLUTO, the flooding of an initially empty thimble with heavy water can add up to 0.35% reactivity to the reactor. An analysis of the consequences of this when the reactor is critical is included in the Safety Document.

2. Prompt criticality requires the addition of at least 0.7% reactivity to a critical core.

    a) GLEEP cannot become prompt critical because under its most reactive conditions its excess reactivity cannot be greater than 0.49%.

    b) DIDO and PLUTO have an excess reactivity well above the prompt criticality figure. However this reactivity is absorbed by a large number of thimbles, rigs, control absorbers and poisons so that the reactivity available for initiating prompt critical events is relatively small and these events have very low probability.

    These include:

    i) continuous withdrawal of control absorbers during start-up

    ii) rapid removal of a stainless steel thimble or cobalt rig from a near-critical reactor

    iii) control arm connecting rod breaks and arm swings out of the core

    iv) main D_2O circulators are started up and inject cold water into the core.

    v) fuel element dropped into the core of a near-critical reactor

Events i) to iv) are dealt with in the reactor Safety Documents, and event v) would involve the breach of the mandatory Standing Orders. All of these are of low probability and would involve the breaking of a chain of trips and safeguards. In all cases the transients would be rapidly terminated by the reactor protection system. Also event iv) is prevented by interlock action.

Standing Orders also demand sufficient negative reactivity margin throughout reactor shutdowns (-4% in DIDO and -4.3% PLUTO) so that two separate failures or errors such as the loss of a coarse control arm combined with one other failure or error will not make the reactor critical. In the unlikely event of this arising, the safety absorbers are raised and available throughout a shutdown period to terminate any unintentional criticality.

Operator Malpractice

This topic covers a wide spectrum from deliberate sabotage through to carelessness. Protection against deliberate malpractice include:-

(a) All operators are security cleared and are subject to an annual review by the reactor management which they must pass before they continue to operate the reactor.

(b) All control and safety circuits are located in cabinets locked when the reactor is at power, with close control of the keys by the Shift Supervisor.

(c) Because of the fail-safe nature of the reactor protection systems and their complexity, only a very few specialist staff could intentionally inhibit the safety system without tripping the reactor or being detected. Consequently the probability of someone inhibiting reactor trips and then initiating a fault condition to damage the reactor is extremely small. The correct operation of all trips and interlocks is tested during each monthly shutdown.

(d) The probability of reactor staff carrying out non-standard operations and tests without the knowledge and approval of the Reactor Manager is extremely low. The Standing Orders define the operating state and degree of protection required at all times. They also state that in addition to the Shift Supervisors, an Assistant Reactor Manager of professional engineer (SPTO) status, must be present during all major changes to the reactor state. These include the loading and unloading of fuel and control or safety absorbers.

I hope that these brief notes will give you the assurance you require. We shall follow them up with a fuller statement.

D B Halliday

D B Halliday
Research Reactors Division
Building 521

12th September 1986

c.c. Dr GGE Low
Dr P Iredale
Dr VS Crocker
Mr J Baxter
Dr ATG Ferguson
Dr B Tofield

P

Immediate Facsimile

To: Mr D I Morphet, Department of Energy, Atomic Energy Division,
Thames House South, Millbank, London

From: Dr M R Hayns, NST, SRD, Culcheth, Warrington, Cheshire

11 September 1986

I have drafted the enclosed note along the lines of our telephone conversation.

Four pages to follow

DID THE CHERNOBYL ACCIDENT INVOLVE A NUCLEAR EXPLOSION?

1. In their description of the events at the Chernobyl nuclear power plant, the Russians, and the other experts gathered in Vienna used technical language which has been interpreted as indicating that the reactor was destroyed by a nuclear explosion. [David Fishlock's article in the F.T., for example]. This note attempts to explain without recourse to technical jargon the meaning of the phrases "positive void coefficient" and "prompt critical excursion" which are at the heart of any interpretation of the accident sequence in this way.

2. How does a Nuclear Reactor Work?

Isotopes of certain very heavy atoms are unstable. Every so often out of a large group, the nucleus of a single atom will split in two, with a simultaneous emission of one or more elementary building blocks of the nucleus, neutrons. The fragments are called 'daughters' and the whole process is called nuclear fission. Each event releases a relatively small amount of energy which ends up as heat or other emissions such as rays. If enough events occur the energy released can add up to very substantial amounts.

The process can be greatly enhanced if the neutrons emitted by a fissioning nucleus collide with other fissionable nuclei. The collision can cause the second nucleus to split. Since, on average more than one neutron is produced each time, a self sustaining chain reaction is theoretically possible. This chain reaction is the basis for both nuclear power stations and atomic bombs (but not, in this simplistic view, hydrogen bombs). The principal difference is that in a nuclear reactor the rate of fission is steady, or changes slowly, whereas in a nuclear bomb, great efforts are made to ensure that the chain reaction increases very rapidly, and is sustained long enough for a large explosion to occur.

3. How is the Chain Reaction Controlled in a Reactor?

In order to have a self sustaining chain reaction from the neutrons coming directly from the primary fission events, a high density of 'available' fissionable nuclei is needed. However, there is another source of neutrons, there are those coming from the further decay of the daughter nuclei, which are themselves unstable against further radioactive decays. We therefore have two kinds of neutrons:

1. Prompt neutrons - coming from the original fission events.

2. Delayed neutrons - coming from the further decay of radioactive daughter nuclei (up to a minute or two after their formation).

In a nuclear reactor, it is the delayed neutrons which sustain the chain reaction. In a reactor, there are many prompt neutrons, but the density of fissionable nuclei is not high enough to allow them to sustain the chain reaction. The delayed neutrons - when added to the prompt ones do allow the chain reaction to be self sustaining but because they appear up to a minute or two after the prompt neutrons, the rate of fission can only rise relatively slowly because of the time lag before the delayed neutrons "catch up". It is this which makes the reactor so easy to control under normal circumstances. In fact "without delayed neutrons there would be no nuclear power" (E Fermi). By placing material which absorbs neutrons into the core, the chain reaction can be slowed down, or stopped altogether. All nuclear power plants are equipped with movable absorbing material usually in the form of 'rods' which are inserted into the core from above or below which can be moved to adjust the number of neutrons being taken out. These "control rods" therefore permit the power level of the reactor to be adjusted. Other rods are provided which can damp down the chain reaction entirely - these are called shutdown rods. The potential of the fissionable material in a reactor is measured in terms of a quantity called reactivity. Since the control rods when inserted shut down the chain reaction they make a negative contribution to reactivity. As well as the materials deliberately introduced into the core to control reactivity, there are reactivity contributions from the other components. Thus, the steel structures absorb, to some extent, neutrons and thus contribute negative reactivity as does any moderating material ["moderator" is described later]. Further, since all designs of reactor must have a coolant medium, whether gaseous or liquid this too will contribute to the overall reactivity balance in the core.

What is a "Moderator" and How Does it Affect the Neutrons?

In most designs of reactor used to generate electricity, another feature of the reaction between neutrons and fissionable nuclei is used. This is that the likelihood of fission is increased if the neutrons are slowed down before they hit the fuel nucleus. This is done by using a moderator. This material slows neutrons down by collisions between them and the nuclei of the atoms of the moderator. Eventually the neutrons will have about the same energy as those of the moderating material - they will be at the same temperature. In the jargon, they have been "thermalized", hence the generic phrase "thermal reactor" used to describe this kind of system. In some reactors this moderating feature is provided by fixed blocks of material permanently in the core - this is usually graphite. This is the system adopted in UK Magnox and AGR's. In Pressurised Water Reactors the moderator is the water used also as the coolant. In the Russian RBMK design there is both fixed, graphite moderator and watercoolant acting as moderator in the core.

In a pressurised water reactor, any accident which lead to a loss of the coolant would also mean the moderator would be lost; this would slow down the chain reaction. Thus, in that type of reactor any loss of water opposes the chain reaction and hence has a negative contribution to reactivity. However, the Russian RBMK design, having both fixed (graphite) and "movable" (water) moderator behaves differently. It is "over moderated". This means that there is more moderator than is necessary to sustain the chain reaction but the water, also absorbs neutrons. If it is removed, the chain reaction speeds up. This is the so called "positive void coefficient". In a reactor like this, boiling the water in the core ("voiding it" in the jargon) reduces the amount of water present (steam has a much lower density of H_2O than water). This process acts to increase the power of the core at the same time as reducing the capability to cool it.

The situation on the night of the 26th April last at the Chernobyl plant was such as to put the reactor in the worst possible state with respect to this effect since the operators were running with the pressure tubes full of water which was very nearly boiling. The "test" ensured that the pressure tubes all boiled almost simultaneously; speeding up the chain reaction and hence increasing the power of the reactor.

Where does the 'Prompt Critical Excursion' Come In?

As explained above, it is possible to maintain a chain reaction using only the neutrons created immediately when the initial fission occurs. This requires a very efficient arrangement of the fuel. A chain reaction which is just self sustaining using these neutrons is called 'Prompt Critical'. Such a situation is very unstable. A 'prompt critical excursion' is when the chain reaction is increasing in rate due to immediate fission neutrons. Large amounts of energy can be produced very quickly. However, because the fuel has to be in a particularly efficient arrangement for this to occur, disturbing this arrangement can stop the reaction very quickly.

How is a 'Prompt Critical Excursion' Related to an Atomic Bomb?

In a bomb, the chain reaction is made as efficient as possible by enriching the material with fissionable nuclei. The thermal reactor has about 2% enrichment - a bomb has as much as you can get but certainly greater than 90%. This means that more of the neutrons are likely to find fissionable nuclei and hence greatly speed up the chain reaction. Also, in an event which dumps large amounts of energy into a solid material quickly, there is a tendency for the arrangement of the fuel to be disturbed, shattered or "be blown apart". In fact, this feature would limit the efficiency of a bomb considerably, since only a small fraction of the available energy is sufficient to blow the material apart, and hence shut down the reaction. Special measures are taken to keep the material compacted as long as possible to increase the yield.

In the reactor, not only is the reaction much less vigorous because of the very low enrichment, it also shuts itself down very quickly because of dispersion of the fuel. In the Chernobyl accident, in fact, it looks as if the particles of fuel were blown apart quite quickly, much of it impregnating the graphite moderator. Clearly, a lot of energy was involved but it fell far short of the release expected in even a small, inefficient atomic bomb.

When is an Explosion not an Explosion?

If you take a small amount of gunpowder; pile it up and set fire to it, it does not "explode" but rather burns rapidly - "woosh" being a descriptive word!

If the same amount is now placed under a tin can and lit, the 'woosh' is more rapid, and the can flies up into the air.

Take the same amount and pack it solidly in a cardboard tube and ignite and it goes 'bang'.

An explosion has a complicated technical description in terms of shock waves and the speed of sound in the material. However, the essential feature is that there must be confinement as well as a rapid reaction (chemical in case of gunpowder).

One of the "secrets" of the atomic bomb was how to 'confine' the material long enough to get sufficient of it involved in the chain reaction to give a good sized bang. We now know that this was done by means of specially shaped charges of conventional explosives.

In the reactor, no confinement remotely capable of holding the fissioning material together long enough exists. The mass of the core, the graphite or even the concrete and steel 'box' cannot do this. In addition, of course, there is relatively little fissionable material available compared to a bomb, again reducing the effect. Confinement was possible in this case, but only with respect to the steam generated and not the nuclear chain reaction.

Was Chernobyl a Nuclear Explosion?

Having described the features of prompt criticality and the efficiency with which energy can be converted and the need for confinement, it seems to me that the 'classification' of the Chernobyl accident as a 'nuclear explosion' is wrong. The explosion which destroyed the reactor was due to excessive steam pressure generated by the hot fuel particles becoming mixed with the water/steam in core at the time.

M R Hayns

Safety and Reliability Directorate,
Culcheth
10 September, 1986

+ Stubbs

IMMEDIATE FACSIMILE

TO: MR P T McINERNEY, MANAGING DIRECTOR, NIRIX
(FAX NO 0235-835153 Ext 236)

CC MR A M ALLEN, UKAEA, LHQ ✓
MR W McMILLAN, UKAEA, LHQ ✓

FROM: DR J H GITTUS, SRD, CULCHETH)
(FAX NO 0925-76-3936)

10 SEPTEMBER 1986

THE WESTERN MORNING NEWS, 10 SEPTEMBER 1986

You will know by now that I am being quoted in the above paper as having stated that nuclear waste could be buried in Cornwall and that this is a scheme which is under definite consideration.

Needless to say, this is a gross distortion amounting practically to a fabrication of a conversation which I had with a reporter during a Press Conference concerned with the launch of a new HSE/SRD database yesterday in London.

I wish to issue a correction or denial immediately and would value your urgent assistance with the drafting of this please.

I have in mind the following:

"In a conversation with a reporter I answered general questions about the principles involved in the storage of radioactive waste. I never once suggested a specific geographical location in the British Isles where such storage would be undertaken. My remarks were of a perfectly general kind, ~~and invol~~ved a description of the principles, ~~for example,~~ the identification of suitable rock structures ~~within which~~ waste might safely be stored. The current ~~NIREX programme~~ of exploratory drilling is intended to identify such structures.

It is certainly not correct to say that I either suggested Cornwall or agreed to suggestions put to me by the reporter concerning Cornwall".

sc ✓ Dr J H Gittus, c/o Dr T N Marsham
✓ Mr H J Teague, SRD

Dr FJ Stubbs, S 329.
FAX - 83259/
0235.

IMMEDIATE FACSIMILE

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FACSIMILE

TO: DR R D PEARCE, PROGRAMMES BRANCH, LHQ

CC MR M A W BAKER, LHQ
MR I A HODGKINSON, LHQ
DR G I W LLEWELYN, LHQ

FROM: DR J H GITTUS, SRD, CULCHETH

9 SEPTEMBER 1986

FURTHER CHAIRMAN'S LETTER ON CHERNOBYL

Herewith draft Letter on Chernobyl incorporating several changes.

I do think it would be appropriate if you consulted EMScD at Harwell.

cc Dr M R Hayns, SRD
Mr W Nixon, SRD

CHAIRMAN'S DEAR COLLEAGUE LETTER ON CHERNOBYL

In my letter of 10 July, I promised that information about the cause of the Chernobyl disaster would be passed on to you when it was received.

2. During the last week in August, the International Atomic Energy Agency (IAEA) convened a meeting in Vienna of experts from member states to discuss the Chernobyl accident. The Russian authorities presented a comprehensive and detailed report on the accident and its aftermath. As a result of this, and of the extensive discussion and analysis which followed, we now have a fairly clear picture of the cause and nature of the accident.

3. If a power station becomes disconnected from the National Grid, the steam supply to the generator is switched off. The generator, however, continues to "freewheel" for a while. The station managers at Chernobyl were carrying out an experiment to see if enough electricity could continue to be produced from the freewheeling generator as it ran down to power the main reactor cooling pumps and remove heat from the reactor. A combination of circumstances had caused the operators, before the experiment got under way, to switch off the emergency core cooling systems, to withdraw more control rods from the reactor than their instructions allowed, and to switch off emergency shutdown systems. As the power produced from the freewheeling generator ran down, the reactor cooling pumps slowed down and the core temperature increased. The RBMK design makes the reactor unstable under such an unusual combination of conditions, and a dramatic rise in the core temperature followed. Because all the safety systems had been switched off

the reactor could not be shut down in time, and a runaway reaction occurred, bursting the pressure tubes containing the fuel and producing a large amount of steam which blew the top off the reactor. Hydrogen and carbon monoxide gases were produced which also exploded and burned, carrying fission products and disintegrated fuel into the atmosphere. More fission products were released over the next 9 days before the situation was brought under control by dropping some 5000 tons of sand and clay and other materials onto the reactor.

4. The primary cause of the accident was therefore gross malpractice by the station operators. In addition, though, the Russians have accepted that the basic instability of the RBMK core design was an important factor; it was also a serious shortcoming in the overall design that the emergency cooling and shutdown systems could be over-ridden and switched off by the operators. A number of modifications in the RBMK design are now being implemented by the Russians to overcome the core instabilities and to improve the reactor protection systems, making them less dependent upon operator judgements.

5. 31 people have died to date as a result of the accident, all of them employees or Firemen on the Chernobyl site, and all but two of them as a result of acute radiation exposure. Between 170 and 180 people are suffering from various degrees of radiation sickness.

6. The meeting in Vienna was notable for the full and frank explanations given by the Russian authorities and for their willingness to admit to major design faults in the RBMK system. A number of detailed technical topics have been identified for further study, and appropriate meetings will be organised by the IAEA. The Authority will take part in these studies.

7. A great deal of work will need to be done to ensure that the lessons coming out of the disaster are properly understood, and some changes in the balance of the Authority's own R&D activities may well result.

Action

FACSIMILE

To: Mr H I Shalgosky, EMScD, B.551, Harwell

Rpt: Mr M A W Baker, LHQ
Dr J H Gittus, Director, SRD
Mr I A Hodgkinson, LHQ
Dr G I W Llewelyn, LHQ

From: Dr R D Pearce, Programmes Branch, LHQ

9th September 1986

FURTHER CHAIRMAN'S LETTER ON CHERNOBYL

Mark Baker has asked that a further Chairman's letter on Chernobyl be prepared following the Vienna IAEA meeting. The attached has been drafted with the benefit of comments from SRD, and Mr Baker has approved it in principle. Do you have any points you wish to register before a final version is issued?

2 PAGES TO FOLLOW

DRAFT 9th September 1986

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IN CONFIDENCE

DECLASSIFIED

8544
17-9

Dr J H Gittus
c/o Lord Marshall
Chairman
Central Electricity Generating Board
Sudbury House
15 Newgate Street
London EC1A 7AX

cc MRH
PRA

CHERNOBYL POST-ACCIDENT REVIEW - THE HARWELL REACTORS

This note is in response to your memo of the 5th September, 1986 and is very much an interim reply which will be amplified in the next week or so.

The Harwell reactors are operated within the terms of an annually-renewable Authority-To-Operate issued by the Director, AERE, Harwell after consultation with the Director of Safety and Reliability Directorate. The ATO is based on the reactor Safety Document and Standing Orders approved by the Reactor Safety Committee at Harwell which includes SRD members. The following are in direct reply to the questions in your memo.

1. The void coefficient and overall temperature coefficient of reactivity in DIDO, PLUTO or GLEEP are all negative. Indeed, because of the fairly strong negative void coefficient in DIDO and PLUTO, the flooding of an initially empty thimble with heavy water can add up to 0.35% reactivity to the reactor. An analysis of the consequences of this when the reactor is critical is included in the Safety Document.

2. Prompt criticality requires the addition of at least 0.7% reactivity to a critical core.

   a) GLEEP cannot become prompt critical because under its most reactive conditions its excess reactivity cannot be greater than 0.49%.

   b) DIDO and PLUTO have an excess reactivity well above the prompt criticality figure. However this reactivity is absorbed by a large number of thimbles, rigs, control absorbers and poisons so that the reactivity available for initiating prompt critical events is relatively small and these events have very low probability.

   These include:

   i) continuous withdrawal of control absorbers during start-up

   ii) rapid removal of a stainless steel thimble or cobalt rig from a near-critical reactor

   iii) control arm connecting rod breaks and arm swings out of the core

   iv) main D_2O circulators are started up and inject cold water into the core.

   v) fuel element dropped into the core of a near-critical reactor

Events i) to iv) are dealt with in the reactor Safety Documents, and event v) would involve the breach of the mandatory Standing Orders. All of these are of low probability and would involve the breaking of a chain of trips and safeguards. In all cases the transients would be rapidly terminated by the reactor protection system. Also event iv) is prevented by interlock action.

Standing Orders also demand sufficient negative reactivity margin throughout reactor shutdowns (-4% in DIDO and -4.3% PLUTO) so that two separate failures or errors such as the loss of a coarse control arm combined with one other failure or error will not make the reactor critical. In the unlikely event of this arising, the safety absorbers are raised and available throughout a shutdown period to terminate any unintentional criticality.

Operator Malpractice

This topic covers a wide spectrum from deliberate sabotage through to carelessness. Protection against deliberate malpractice include:-

(a) All operators are security cleared and are subject to an annual review by the reactor management which they must pass before they continue to operate the reactor.

(b) All control and safety circuits are located in cabinets locked when the reactor is at power, with close control of the keys by the Shift Supervisor.

(c) Because of the fail-safe nature of the reactor protection systems and their complexity, only a very few specialist staff could intentionally inhibit the safety system without tripping the reactor or being detected. Consequently the probability of someone inhibiting reactor trips and then initiating a fault condition to damage the reactor is extremely small. The correct operation of all trips and interlocks is tested during each monthly shutdown.

(d) The probability of reactor staff carrying out non-standard operations and testa without the knowledge and approval of the Reactor Manager is extremely low. The Standing Orders define the operating state and degree of protection required at all times. They alao state that in addition to the Shift Supervisors, an Assistant Reactor Manager of professional engineer (SPTO) status, must be present during all major changes to the reactor state. These include the loading and unloading of fuel and control or safety absorbers.

I hope that these brief notes will give you the assurance you require. We shall follow them up with a fuller statement.

DB Halliday

D B Halliday
Research Reactors Division
Building 521

12th September 1986

c.c. Dr GGE Low
Dr P Iredale
Dr VS Crocker
Mr J Baxter
Dr ATG Ferguson
Dr B Tofield

0752 26 66 26 C Davidson

Western morning news.

James Mildren. Environmental correspondent.

from J Evans

Dr Gittus

The Western Morning News'

10 Sept 1986

Cornwall may be nuclear waste dump

I did not mention slate

by BOB BRYANT

I did not

FOR the first time, a senior Atomic Energy Authority scientist admitted yesterday that Cornwall could become a graveyard for highly radioactive nuclear waste.

laboratory

The experiments I referred to were ~~at Harwell~~ large scale waste packaging

Experiments by Harwell scientists in West Cornwall, which The Western Morning News revealed in July were directed into the country's vast slate deposits, have convinced them that safe disposal in slate would be possible.

Dr. John Gittus, Director of the U.K. Atomic Energy Authority's Safety and Reliability Directorate, told me that waste, so radioactive that it must be kept for 1,000 years before it loses its danger, could be entombed under Cornwall or even under the sea-bed off the Cornish coast.

I did not mention 1000 y

I did not mention Cornwall

The disclosure, reported after official assurances that Cornwall's granite rocks were quite unsuitable for disposal of the waste and that experiments in Cornwall were only a scientific study, is bound to create an outcry from conservationists.

"Burying waste in deep geological formations of slate offers an attractive solution to the problem of the disposal of nuclear waste," said Dr. Gittus.

I did not single out slate

"Harwell has been working on the disposal of waste for some time and we believe they have cracked many of the problems.

"The advantage of using hills of slate that have been there for more than 100-million years is that they are geologically sound and safe from movement.

"One could drill on land and at sea into vast slate deposits and bury waste encased in concrete."

Using slate instead of creating massive man-built concrete bunkers to bury all categories of radioactive waste, could eventually appeal to companies such as NIREX, the Government agency responsible for the disposal of all nuclear waste both from British plants and from as far afield as Japan.

I did not refer to Japan

For a start, slate is non-porous and on land, where it currently lies, it is assumed to be safe from shifts in earth movement after being stable for millions of years.

Also it is a dump ready-made by Nature making it far cheaper and obviously more attractive for consideration for the future disposal of nuclear materials.

I put possibility of using Cornwall's slate directly to Dr. Gittus. He never once suggested that other areas of massive slate deposits, such as Wales might be used for nuclear repositories.

he did not notice i.e. does not say what I am supposed to have replied.

Asked whether the large slate deposits in Cornwall might offer a cheap solution to the interment of toxic waste, he said: "It is an attractive solution."

A lie

Whether Cornwall becomes the next on the list to be used as the dumping ground for nuclear waste is obviously still on ice. But if the county is deemed suitable to be the scrapyard for radioactive waste, no one is saying when and where it could happen.

Such revelations might be too controversial even for the Government. But despite the silence from Whitehall, the people of Cornwall must now fear the war against nuclear waste is about to reach their doorsteps.

A NIREX spokesman denied knowledge of Dr. Gittus's findings but confirmed that nowhere in Britain could yet be ruled out of the hunt for a waste dump.

NIREX will publish a consultation document later this year on the options available for disposing of intermediate level nuclear waste. Scientists are studying geological formations for suitability and might consider any suggested by Dr. Gittus.

I have suggested none.

SAFETY AND RELIABILITY DIRECTORATE
UK ATOMIC ENERGY AUTHORITY

Safety and Reliability Directorate
United Kingdom Atomic Energy Authority
Wigshaw Lane
Culcheth
Warrington WA3 4NE

Telex: 629301 Fax: (0925) 76 3936
Telecom Gold: SRD 002
Telephone: Warrington (0925) 31244
Extension: 7206

From
Dr John H Gittus
Director

10 September 1986

The Editor
The Western Morning News
Leicester Harmsworth House
65 New George St
PLYMOUTH P11 1RE

Dear Sir

"CORNWALL MAY BE NUCLEAR WASTE DUMP" BY BOB BRYANT,
THE WESTERN MORNING NEWS, 10 SEPTEMBER 1986

In your article under the above heading remarks which I made in a general conversation with a reporter have been incorrectly described.

I answered general questions about the principles involved in the storage of radioactive waste. I never once suggested a specific geographical location in the British Isles where such storage would be undertaken. My remarks were of a perfectly general kind and related to the research being carried out to investigate water movement through rock of the type present in the Reskajeage Quarry. In such rock water moves through pores and fractures. This rock type occurs widely throughout the United Kingdom and the work will be relevant to many potential disposal sites.

Yours faithfully

John Gittus

J H GITTUS

023

IMMEDIATE FACSIMILE

TO: MR P T McINERNEY, MANAGING DIRECTOR, NIREX
(FAX NO 0235-835153 ~~Ext 236~~)

CC MR A M ALLEN, UKAEA, LHQ
MR W McMILLAN, UKAEA, LHQ

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Needless to say, this is a gross distortion amounting practically to a fabrication of a conversation which I had with a reporter during a Press Conference concerned with the launch of a new HSE/SRD database yesterday in London.

I wish to issue a correction or denial immediately and would value your urgent assistance with the drafting of this phrase.

I have in mind the following:

"In a conversation with a reporter I answered general questions about the principles involved in the storage of radioactive waste. I never once suggested a specific geographical location in the British Isles where such storage would be undertaken. My remarks were of a perfectly general kind, and involved a description of the principles, for example, the identification of suitable rock structures within which waste might safely be stored. The current NIREX programme of exploratory drilling is intended to identify such structures.

It is certainly not correct to say that I either suggested Cornwall or agreed to suggestions put to me by the reporter concerning Cornwall."

cc Dr J H Gittus, c/o Dr T N Marsham
Mr H J Teague, SRD

SAFETY AND RELIABILITY DIRECTORATE
UK ATOMIC ENERGY AUTHORITY

Safety and Reliability Directorate
United Kingdom Atomic Energy Authority
Wigshaw Lane
Culcheth
Warrington WA3 4NE

Telex: 629301 Fax: (0925) 76 3936
Telecom Gold: SRD 002
Telephone: Warrington (0925) 31244
Extension: 7206

From
Dr John H Gittus
Director

10 September 1986

The Editor
The Western Morning News
Leicester Harmsworth House
65 New George St
PLYMOUTH Pl1 1RE

Dear Sir

"CORNWALL MAY BE NUCLEAR WASTE DUMP" BY BOB BRYANT,
THE WESTERN MORNING NEWS, 10 SEPTEMBER 1986

In your article under the above heading remarks which I made in a general conversation with a reporter have been incorrectly described.

I answered general questions about the principles involved in the storage of radioactive waste. I never once suggested a specific geographical location in the British Isles where such storage would be undertaken. My remarks were of a perfectly general kind and related to the research being carried out to investigate water movement through rock of the type present in the Reskajeage Quarry. In such rock water moves through pores and fractures. This rock type occurs widely throughout the United Kingdom and the work will be relevant to many potential disposal sites.

Yours faithfully

John Gittus

J H GITTUS

'The Western Morning News'

10 Sept 1986

Cornwall may be nuclear waste dump

by BOB BRYANT

FOR the first time, a senior Atomic Energy Authority scientist admitted yesterday that Cornwall could become a graveyard for highly radioactive nuclear waste.

Experiments by Harwell scientists in West Cornwall, which The Western Morning News revealed in July were directed into the country's vast slate deposits, have convinced them that safe disposal in slate would be possible.

Dr. John Gittus, Director of the U.K. Atomic Energy Authority's Safety and Reliability Directorate, told me that waste, so radioactive that it must be kept for 1,000 years before it loses its danger, could be entombed under Cornwall or even under the sea-bed off the Cornish coast.

The disclosure, reported after official assurances that Cornwall's granite rocks were quite unsuitable for disposal of the waste and that experiments in Cornwall were only a scientific study, is bound to create an outcry from conservationists.

"Burying waste in deep geological formations of slate offers an attractive solution to the problem of the disposal of nuclear waste," said Dr. Gittus.

"Harwell has been working on the disposal of waste for some time and we believe they have cracked many of the problems.

"The advantage of using hills of slate that have been there for more than 100-million years is that they are geologically sound and safe from movement.

"One could drill on land and at sea into vast slate deposits and bury waste encased in concrete."

Using slate instead of creating massive man-built concrete bunkers to bury all categories of radioactive waste, could eventually appeal to companies such as NIREX, the Government agency responsible for the disposal of all nuclear waste both from British plants and from as far afield as Japan.

For a start, slate is non-porous and on land, where it currently lies, it is ascribed to be safe from shifts in earth movement after being stable for millions of years.

Also it is a dump ready-made by Nature making it far cheaper and obviously more attractive for consideration for the future disposal of nuclear materials.

I put possibility of using Cornwall's slate directly to Dr. Gittus. He never once suggested that other areas of massive slate deposits, such as Wales might be used for nuclear repositories.

Asked whether the large slate deposits in Cornwall might offer a cheap solution to the interment of toxic waste, he said: "It is an attractive solution."

Whether Cornwall becomes the next on the list to be used as the dumping ground for nuclear waste is obviously still on ice. But if the county is deemed suitable to be the scrapyard for radioactive waste, no one is saying when and where it could happen.

Such revelations might be too controversial even for the Government. But despite the silence from Whitehall, the people of Cornwall must now fear the war against nuclear waste is about to reach their doorsteps.

A NIREX spokesman denied knowledge of Dr. Gittus's findings but confirmed that nowhere in Britain could yet be ruled out of the hunt for a waste dump.

NIREX will publish a consultation document later this year on the options available for disposing of intermediate level nuclear waste. Scientists are studying geological formations for suitability and might consider any suggested by Dr. Gittus.

Action HRH dealt with.

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10-9

FROM 01 930 5454

'86,09,09 15:55

File No. 1986

cc Mr Hayns

18

Dr. Pearce

c.c. Dr. Gittus - SRD (By Facsimile)
Mr. Baker - LHQ
Mr. Hodgkinson - LHQ
Dr. Hayns - SRD (By Facsimile)
Mr. Nixon - SRD (By Facsimile)

Chairman's Dear Colleague Letter on Chernobyl

I would like to suggest the following additions to Dr. Gittus' draft letter dated 9th September, subject to his comment.

1. Amend the third sentence of para.3 to read - "The station managers at Chernobyl were carrying out an experiment, for which the operating instructions had not been given the requisite approval, to see if enough electricity .....".

2. Amend the first sentence of para.4 to read - "The primary cause of the accident was therefore gross malpractice by the station operators, who, in addition to their initial errors, also ignored danger signals during the sequence of subsequent events."

G.I.W. Llewelyn

G.I.W. Llewelyn

Programmes Branch, LHQ
9th September 1986

FACSIMILE

TO: DR R D PEARCE, PROGRAMMES BRANCH, LHQ

CC MR M A W BAKER, LHQ
MR I A HODGKINSON, LHQ
DR G I W LLEWELYN, LHQ

FROM: DR J H GITTUS, SRD, CULCHETH

9 SEPTEMBER 1986

FURTHER CHAIRMAN'S LETTER ON CHERNOBYL

Herewith draft Letter on Chernobyl incorporating several changes.

I do think it would be appropriate if you consulted EMScD at Harwell.

sc Dr M R Hayns
Mr W Nixon

CHAIRMAN'S DEAR COLLEAGUE LETTER ON CHERNOBYL

In my letter of 10 July, I promised that information about the cause of the Chernobyl disaster would be passed on to you when it was received.

2. During the last week in August, the International Atomic Energy Agency (IAEA) convened a meeting in Vienna of experts from member states to discuss the Chernobyl accident. The Russian authorities presented a comprehensive and detailed report on the accident and its aftermath. As a result of this, and of the extensive discussion and analysis which followed, we now have a fairly clear picture of the cause and nature of the accident.

3. If a power station becomes disconnected from the National Grid, the steam supply to the generator is switched off. The generator, however, continues to "freewheel" for a while. The station managers at Chernobyl were carrying out an experiment to see if enough electricity could continue to be produced from the freewheeling generator as it ran down to power the main reactor cooling pumps and remove heat from the reactor. A combination of circumstances had caused the operators, before the experiment got under way, to switch off the emergency core cooling systems, to withdraw more control rods from the reactor than their instructions allowed, and to switch off emergency shutdown systems. As the power produced from the freewheeling generator ran down, the reactor cooling pumps slowed down and the core temperature increased. The RBMK design makes the reactor unstable under such an unusual combination of conditions, and a dramatic rise in the core temperature followed. Because all the safety systems had been switched off

the reactor could not be shut down in time, and a runaway reaction occurred, bursting the pressure tubes containing the fuel and producing a large amount of steam which blew the top off the reactor. Hydrogen and carbon monoxide gases were produced which also exploded and burned, carrying fission products and disintegrated fuel into the atmosphere. More fission products were released over the next 9 days before the situation was brought under control by dropping some 5000 tons of sand and clay and other materials onto the reactor.

4. The primary cause of the accident was therefore gross malpractice by the station operators. In addition, though, the Russians have accepted that the basic instability of the RBMK core design was an important factor; it was also a serious shortcoming in the overall design that the emergency cooling and shutdown systems could be over-ridden and switched off by the operators. A number of modifications in the RBMK design are now being implemented by the Russians to overcome the core instabilities and to improve the reactor protection systems, making them less dependent upon operator judgements..

5. 31 people have died to date as a result of the accident, all of them employees or Firemen on the Chernobyl site, and all but two of them as a result of acute radiation exposure. Between 170 and 180 people are suffering from various degrees of radiation sickness.

6. The meeting in Vienna was notable for the full and frank explanations given by the Russian authorities and for their willingness to admit to major design faults in the RBMK system. A number of detailed technical topics have been identified for further study, and appropriate meetings will be organised by the IAEA. The Authority will take part in these studies.

7. A great deal of work will need to be done to ensure that the lessons coming out of the disaster are properly understood, and some changes in the balance of the Authority's own R&D activities may well result.

DEX MESSAGE FROM

CENTRAL ELECTRICITY GENERATING BOARD

BERKELEY NUCLEAR LABORATORIES
BERKELEY, GLOUCESTERSHIRE, GL13 9PB

DEX NUMBER 0453 812529
Query number 0453 810451 EXTENSION 2245

TO: DR J. GITTUS
SRD CULCHETH

FROM: E. W. CARPENTER

Number of pages: 5 (including this one)

Date: 11-9-86

bf
Clarkey /cc MR Haynes

DEX to:

Mr A W Clarke, NOSG

9th September 1986

cc: Mr B V George, PMT, Booths Hall
Mr D R Smith, NNC, Booths Hall
Mr J Gray, SSEB, Cathcart
Mr J G Collier, GDCD
Dr J K Wright, Sudbury House
Mr M Davies, Sudbury House
Mr P N Vey, Press Office, Sudbury House

From: E W Carpenter

Following yesterday's meeting here is another draft of a statement. I am copying it to a large number of other people who will be involved, directly or indirectly next Tuesday. By copy of this, I am asking them to let both you and I have copies of any comments they wish to make.

Please note that there are more words per paragraph than strictly necessary, but it will be easier to reduce if we have agreement on the intention.

The Chairman is anxious to preserve slow nuclear explosion as a 'unique' descriptor which distances Chernobyl from other reactors.

He would have preferred to identify slow nuclear explosion with prompt critical and then say prompt critical was impossible in UK reactors. This does not seem possible.

However, I hope that by next week we will have a clear (NNC, GDCD, PMT) picture of how far the claim of 'no prompt critical' can be made, and whether changes could make it true in an absolute sense as opposed to an engineered low probability.

Dr J Gittus –
Whoops! – Sorry I missed you off!

b4

Griffith [illegible]

1 In normal operation, the coolant of a nuclear reactor removes heat from the fuel at the same rate as it is created within the fuel by the fission process. Fault situations result from a mismatch between the competing processes of heat production and heat removal. There are two broad categories:

- The cooling reduces (eg pipes break, motors fail etc).
- Power increases due to reactivity additions.

2 After some months of speculation, the Russians have, in an extremely frank presentation, provided convincing evidence that the Chernobyl accident was in the second category - a rapid power increase due to reactivity additions.

3 As a physical explanation this did not entirely surprise us, although we were somewhat taken aback by the size of the reactivity excursions and astounded by the series of gross operator errors which were necessary to manoeuvre the plant into the state where such an accident could happen.

4 The question which naturally arises is whether a similar accident could happen again, particularly in the UK. From our full descriptions of the safety of the PWR, it will be obvious that we do not, and will not, claim that accidents are impossible. We claim only that we understand the systems and by deploying both physical principles coupled with sound design and engineering practices we reduce the risks to quite acceptable proportions.

5 So why did Chernobyl happen, and why are we so confident?

6 Several commentators have described the Chernobyl accident as a slow nuclear explosion. I cannot really quarrel with that description, provided you allow me to carefully explain what it means.

A slow nuclear explosion requires two factors. The first is that the energy in the fuel increases so rapidly that the heat removing processes are irrelevant - the fuel doesn't know that the coolant is there. This means that the heating has to take place in a few tenths of a second.

The other condition is that the fuel receives enough energy and gets hot enough such that it then disintegrates with a large increase in surface area. Now heat can be transferred rapidly to the coolant and give rise to mechanical forces which disrupt the reactor.

7 Such events can only occur if the reactor is taken from a normal critical state, when slight power changes typically take place on timescales of a minute or so, to the state known as "prompt critical" where things happen much faster - and power changes by a factor of ten can take place in a few tenths of a second. To get from "just critical" to "prompt critical" requires the addition of an amount of activity which Reactor Physicists quaintly call a 'dollar'. In reactor design, we make sure that reactivity additions of a dollar or so cannot be made quickly.

8 Now the slow nuclear explosion must not be considered as in any way a nuclear bomb - I would regard those as fast nuclear explosions because the energy is released in a few 100 millionths of a second, the material is instantly vaporised and intense shock waves are developed. Bomb designers work very hard to get tens of dollars added in a milli-second. We have always maintained that a nuclear reactor cannot behave like a bomb, and that is still just as true after Chernobyl as before.

9 But even if the slow nuclear explosion does not devastate the surroundings by blast, the fact that it produces enough mechanical energy (equivalent, we think, to about half a ton of TNT in the Chernoby case) to destroy the core, lifting the reactor roof and releasing the accumulated fission products, it is a horrendous event.

10 We are confident that it could not happen here for a number of reasons. In a way it was a relief to know that the Russians had not inadvertently discovered some new hitherto unidentified hidden route to an accident.

All reactor designers must allow for reactivity increases. Since control rods are used in normal operation to take up reactivity, it follows that we must carefully consider the possibility of their inadvertent removal. It is not difficult to engineer a system which limits the rate at which they are withdrawn. Nor is it difficult to arrange physical means of detecting when things begin to go wrong, and arrange for trip circuits which rapidly inject other absorbers into the core. It is quite possible to engineer such protection so that it does not rely on operator intervention, at the same time making it proof against operator mal-operation.

11 It so happens that Mother Nature also lends a hand through what the Physicists call the Doppler coefficient. This simply means that as the fuel gets hot, this in itself takes away reactivity.

For many situations, for example, a fault which allowed for the inadvertent removal of one of the banks of control rods, even without a reactor trip, the fuel would simply increase in temperature until its internal loss of reactivity balanced the increase in reactivity from the removal of the rods. (This was graphically demonstrated in a series of tests on the prototype AGR at Windscale). Although it is not always easy to ensure that you don't get fuel failures due to temperature excursions in a reactivity driven fault, it is really rather surprising that anyone could get a slow nuclear explosion.

How did it happen?

12 The Russian reactor has another characteristic - a positive void coefficient. What this means is that if you take away the cooling water, the reactivity increases. Converting water to steam counts as removing the coolant, because the density change is so great.

Positive void coefficients again are not, in themselves, a fundamental problem. In normal operation, it is perfectly possible for the Doppler coefficient to have a bigger effect than the void coefficient, so that a power increase tends to reduce the reactivity and not add to it.

13 Obviously you should seek to operate the reactor in a regime where this is always true. The Russians had such an operating rule. They broke it. Designers should always assume that this is going to happen, and provide an independent fast acting safety system which would shut the reactor down at the first signs of trouble. The Russians did not have such a system. What they relied on was being able to drive the control rods into the core at a sufficient rate (one dollar per second actually), that they could overcome any reactivity excursion. The Chernobyl operators, in manoeuvring their plant, got into a situation where the control rods were completely ineffective in this safety role.

What is more, in getting to this position, they made the positive void coefficient even worse. The net consequence of all this was that the reactor was sitting waiting for a reactivity accident. It was not the classical fault of adding reactivity, by moving control rods but a sudden voiding of the core. This was triggered by reducing the flow of water to the core so that the steam content increased - and increased and increased because of the positive void coefficient - giving a reactivity increase which nature's Doppler couldn't cope with.

14 The solutions are obvious. They will reduce the size of the void coefficient (by putting in more fixed absorbers). They will increase the number of control rods, and provide <u>physical</u> means to stop them being withdrawn from the core. They will provide <u>independent</u> fast acting safety systems. In short, they will, as far as they are able when with refitting an existing system, apply the standards that we have always applied.

Of course, our gas cooled reactors do not have a positive void coefficient, and although the PWR can have a positive void coefficient, it is in a very special situation which is not relevant to operation, when it always has a negative power coefficient.

9th September 1986

→ RNS.

Immediate Facsimile

To: Mr D I Morphet, Department of Energy, Atomic Energy Division,
Thames House South, Millbank, London

From: Dr M R Hayns, NST, SRD, Culcheth, Warrington, Cheshire

11 September 1986

I have drafted the enclosed note along the lines of our telephone conversation.

Four pages to follow

DID THE CHERNOBYL ACCIDENT INVOLVE A NUCLEAR EXPLOSION?

1. In their description of the events at the Chernobyl nuclear power plant, the Russians, and the other experts gathered in Vienna used technical language which has been interpreted as indicating that the reactor was destroyed by a nuclear explosion. [David Fishlock's article in the F.T., for example]. This note attempts to explain without recourse to technical jargon the meaning of the phrases "positive void coefficient" and "prompt critical excursion" which are at the heart of any interpretation of the accident sequence in this way.

2. How does a Nuclear Reactor Work?

Isotopes of certain very heavy atoms are unstable. Every so often out of a large group, the nucleus of a single atom will split in two, with a simultaneous emission of one or more elementary building blocks of the nucleus, neutrons. The fragments are called 'daughters' and the whole process is called nuclear fission. Each event releases a relatively small amount of energy which ends up as heat or other emissions such as rays. If enough events occur the energy released can add up to very substantial amounts.

The process can be greatly enhanced if the neutrons emitted by a fissioning nucleus collide with other fissionable nuclei. The collision can cause the second nucleus to split. Since, on average more than one neutron is produced each time, a self sustaining chain reaction is theoretically possible. This chain reaction is the basis for both nuclear power stations and atomic bombs (but not, in this simplistic view, hydrogen bombs). The principal difference is that in a nuclear reactor the rate of fission is steady, or changes slowly, whereas in a nuclear bomb, great efforts are made to ensure that the chain reaction increases very rapidly, and is sustained long enough for a large explosion to occur.

3. How is the Chain Reaction Controlled in a Reactor?

In order to have a self sustaining chain reaction from the neutrons coming directly from the primary fission events, a high density of 'available' fissionable nuclei is needed. However, there is another source of neutrons, there are those coming from the further decay of the daughter nuclei, which are themselves unstable against further radioactive decays. We therefore have two kinds of neutrons:

1. Prompt neutrons - coming from the original fission events.

2. Delayed neutrons - coming from the further decay of radioactive daughter nuclei (up to a minute or two after their formation).

In a nuclear reactor, it is the delayed neutrons which sustain the chain reaction. In a reactor, there are many prompt neutrons, but the density of fissionable nuclei is not high

enough to allow them to sustain the chain reaction. The delayed neutrons - when added to the prompt ones do allow the chain reaction to be self sustaining but because they appear up to a minute or two after the prompt neutrons, the rate of fission can only rise relatively slowly because of the time lag before the delayed neutrons "catch up". It is this which makes the reactor so easy to control under normal circumstances. In fact "without delayed neutrons there would be no nuclear power" (E Fermi).
By placing material which absorbs neutrons into the core, the chain reaction can be slowed down, or stopped altogether. All nuclear power plants are equipped with movable absorbing material usually in the form of 'rods' which are inserted into the core from above or below which can be moved to adjust the number of neutrons being taken out. These "control rods" therefore permit the power level of the reactor to be adjusted. Other rods are provided which can damp down the chain reaction entirely - these are called shutdown rods. The potential of the fissionable material in a reactor is measured in terms of a quantity called reactivity. Since the control rods when inserted shut down the chain reaction they make a negative contribution to reactivity. As well as the materials deliberately introduced into the core to control reactivity, there are reactivity contributions from the other components. Thus, the steel structures absorb, to some extent, neutrons and thus contribute negative reactivity as does any moderating material ["moderator" is described later]. Further, since all designs of reactor must have a coolant medium, whether gaseous or liquid this too will contribute to the overall reactivity balance in the core.

What is a "Moderator" and How Does it Affect the Neutrons?

In most designs of reactor used to generate electricity, another feature of the reaction between neutrons and fissionable nuclei is used. This is that the likelihood of fission is increased if the neutrons are slowed down before they hit the fuel nucleus. This is done by using a moderator. This material slows neutrons down by collisions between them and the nuclei of the atoms of the moderator. Eventually the neutrons will have about the same energy as those of the moderating material - they will be at the same temperature. In the jargon, they have been "thermalized", hence the generic phrase "thermal reactor" used to describe this kind of system. In some reactors this moderating feature is provided by fixed blocks of material permanently in the core - this is usually graphite. This is the system adopted in UK Magnox and AGR's. In Pressurised Water Reactors the moderator is the water used also as the coolant. In the Russian RBMK design there is both fixed, graphite moderator and watercoolant acting as moderator in the core.

In a pressurised water reactor, any accident which lead to a loss of the coolant would also mean the moderator would be lost; this would slow down the chain reaction. Thus, in that type of reactor any loss of water opposes the chain reaction and hence has a negative contribution to reactivity. However, the Russian RBMK design, having both fixed (graphite) and "movable" (water) moderator behaves differently. It is "over moderated". This means that there is more moderator than is necessary to sustain the chain reaction but the water, also absorbs neutrons. If it is removed, the chain reaction speeds up. This is the so called "positive void coefficient". In a reactor like this, boiling the water in the core ("voiding it" in the jargon) reduces the amount of water present (steam has a much lower density of H_2O than water). This process acts to increase the power of the core at the same time as reducing the capability to cool it.

The situation on the night of the 26th April last at the Chernobyl plant was such as to put the reactor in the worst possible state with respect to this effect since the operators were running with the pressure tubes full of water which was very nearly boiling. The "test" ensured that the pressure tubes all boiled almost simultaneously; speeding up the chain reaction and hence increasing the power of the reactor.

Where does the 'Prompt Critical Excursion' Come In?

As explained above, it is possible to maintain a chain reaction using only the neutrons created immediately when the initial fission occurs. This requires a very efficient arrangement of the fuel. A chain reaction which is just self sustaining using these neutrons is called 'Prompt Critical'. Such a situation is very unstable. A 'prompt critical excursion' is when the chain reaction is increasing in rate due to immediate fission neutrons. Large amounts of energy can be produced very quickly. However, because the fuel has to be in a particularly efficient arrangement for this to occur, disturbing this arrangement can stop the reaction very quickly.

How is a 'Prompt Critical Excursion' Related to an Atomic Bomb?

In a bomb, the chain reaction is made as efficient as possible by enriching the material with fissionable nuclei. The thermal reactor has about 2% enrichment - a bomb has as much as you can get but certainly greater than 90%. This means that more of the neutrons are likely to find fissionable nuclei and hence greatly speed up the chain reaction. Also, in an event which dumps large amounts of energy into a solid material quickly, there is a tendency for the arrangement of the fuel to be disturbed, shattered or "be blown apart". In fact, this feature would limit the efficiency of a bomb considerably, since only a small fraction of the available energy is sufficient to blow the material apart, and hence shut down the reaction. Special measures are taken to keep the material compacted as long as possible to increase the yield.

In the reactor, not only is the reaction much less vigorous because of the very low enrichment, it also shuts itself down very quickly because of dispersion of the fuel. In the Chernobyl accident, in fact, it looks as if the particles of fuel were blown apart quite quickly, much of it impregnating the graphite moderator. Clearly, a lot of energy was involved but it fell far short of the release expected in even a small, inefficient atomic bomb.

When is an Explosion not an Explosion?

If you take a small amount of gunpowder; pile it up and set fire to it, it does not "explode" but rather burns rapidly - "woosh" being a descriptive word!

If the same amount is now placed under a tin can and lit, the 'woosh' is more rapid, and the can flies up into the air.

Take the same amount and pack it solidly in a cardboard tube and ignite and it goes 'bang'.

An explosion has a complicated technical description in terms of shock waves and the speed of sound in the material. However, the essential feature is that there must be confinement as well as a rapid reaction (chemical in case of gunpowder).

One of the "secrets" of the atomic bomb was how to 'confine' the material long enough to get sufficient of it involved in the chain reaction to give a good sized bang. We now know that this was done by means of specially shaped charges of conventional explosives.

In the reactor, no confinement remotely capable of holding the fissioning material together long enough exists. The mass of the core, the graphite or even the concrete and steel 'box' cannot do this. In addition, of course, there is relatively little fissionable material available compared to a bomb, again reducing the effect. Confinement was possible in this case, but only with respect to the steam generated and not the nuclear chain reaction.

Was Chernobyl a Nuclear Explosion?

Having described the features of prompt criticality and the efficiency with which energy can be converted and the need for confinement, it seems to me that the 'classification' of the Chernobyl accident as a 'nuclear explosion' is wrong. The explosion which destroyed the reactor was due to excessive steam pressure generated by the hot fuel particles becoming mixed with the water/steam in core at the time.

M R Hayns

Safety and Reliability Directorate,
Culcheth
10 September, 1986

F Ch. JHG
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FOR INFORMATION

ORGANISATION FOR ECONOMIC
CO-OPERATION AND DEVELOPMENT

NUCLEAR ENERGY AGENCY

RESTRICTED

Paris, drafted: 3rd Sept. 1986
dist: 9th Sept. 1986

Addendum 1 to:
NE(86)16
Scale 4

DECLASSIFIED

Or. Eng.

STEERING COMMITTEE FOR NUCLEAR ENERGY

ACTIONS TAKEN BY NEA IN THE FIELD OF NUCLEAR SAFETY FOLLOWING THE CHERNOBYL ACCIDENT; PRELIMINARY ASSESSMENT OF THE LIKELY IMPACT ON THE CSNI PROGRAMME

1. As reported in document NE(86)16, a number of preliminary suggestions for future actions by CSNI, resulting from the Chernobyl accident, were identified during the two special meetings which the Committee held respectively on 9th May and 27th June 1986. More recently the IAEA organised a special Post-Accident Review Meeting from 25th to 29th August 1986, which was attended by many members of CSNI, as well as the NEA Secretariat. During that week, two informal enlarged Bureau meetings were held, at which further ideas were discussed concerning additional follow-up activities on the basis of the information provided during the IAEA meeting.

2. The most urgent interest of the OECD nuclear community was to understand all aspects of the accident and its consequences, and to determine the possible short and long term impact on nuclear power plants in the OECD area. There was general agreement that the response to this accident, as well as possible measures taken by OECD countries, should be as coherent as possible. In line with these objectives, a number of recommendations emerged for additional activities.

3. As a first step, it was recommended that relevant RBMK design data and information on the accident, its evolution and

38 412

consequences, should be pooled, to enable Member countries to model the accident and to compare their computations. The Bureau hoped that the first calculations could be completed before the CSNI meeting in November. On the basis of these first results, it was considered desirable to enlarge this comparison by inviting the IAEA to participate.

4. With a view to maintaining a necessary degree of coherence among OECD countries, CSNI delegates emphasized the need to keep mutually informed of measures which Member countries might decide to implement as a result of the Chernobyl accident.

5. It was further recommended that CSNI should take stock of the safety level achieved for nuclear power plants in OECD countries with regard to such items as reactivity control, containment capability, operator performance, emergency cooling- and emergency power supply, and protection against external events, etc. This information should be summarised in an overview report delineating the present status of nuclear safety in OECD countries. In addition, this type of information could be built into an up to date data base to enable national authorities to quickly evaluate a reactor accident with trans-frontier consequences.

6. Furthermore, it was proposed to review emergency plans and procedures in Member countries, in the light of the experience gained so far, in conjunction with the Committee on Radiation Protection and Public Health (CRPPH).

7. The Committee should also study advanced reactor systems, in particular the light water type. Initial emphasis should be put on examining those safety features which are considered to be most desirable by the OECD community at large.

8. The Steering Committee is invited to note the above suggestions made by the CSNI enlarged Bureau and to consider them in conjunction with those presented in document NE(86)16.

cc M R Haynes

DEX to:

Mr A W Clarke, NOSG

9th September 1986

cc: Mr B V George, PMT, Booths Hall
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- The cooling reduces (eg pipes break, motors fail etc).
- Power increases due to reactivity additions.

2 After some months of speculation, the Russians have, in an extremely frank presentation, provided convincing evidence that the Chernobyl accident was in the second category - a rapid power increase due to reactivity additions.

3 As a physical explanation this did not entirely surprise us, although we were somewhat taken aback by the size of the reactivity excursions and astounded by the series of gross operator errors which were necessary to manoeuvre the plant into the state where such an accidant could happen.

4 The question which naturally arises is whether a similar accident could happen again, particularly in the UK. From our full descriptions of the safety of the PWR, it will be obvious that we do not, and will not, claim that accidents are impossible. We claim only that we understand the systems and by deploying both physical principles coupled with sound design and engineering practices we reduce the risks to quite acceptable proportions.

5 So why did Chernobyl happen, and why are we so confident?

6 Several commentators have described the Chernobyl accident as a slow nuclear explosion. I cannot really quarrel with that description, provided you allow me to carefully explain what it means.

A slow nuclear explosion requires two factors. The first is that the energy in the fuel increases so rapidly that the heat removing processes are irrelevant - the fuel doesn't know that the coolant is there. This means that the heating has to take place in a few tenths of a second.

The other condition is that the fuel receives enough energy and gets hot enough such that it then disintegrates with a large increase in surface area. Now heat can be transferred rapidly to the coolant and give rise to mechanical forces which disrupt the reactor.

7 Such events can only occur if the reactor is taken from a normal critical state, when slight power changes typically take place on timescales of a minute or so, to the state known as "prompt critical" where things happen much faster - and power changes by a factor of ten can take place in a few tenths of a second. To get from "just critical" to "prompt critical" requires the addition of an amount of activity which Reactor Physicists quaintly call a 'dollar'. In reactor design, we make sure that reactivity additions of a dollar or so cannot be made quickly.

8 Now the slow nuclear explosion must not be considered as in any way a nuclear bomb - I would regard those as fast nuclear explosions because the energy is released in a few 100 millionths of a second, the material is instantly vaporised and intense shock waves are developed. Bomb designers work very hard to get tens of dollars added in a milli-second. We have always maintained that a nuclear reactor cannot behave like a bomb, and that is still just as true after Chernobyl as before.

9 But even if the slow nuclear explosion does not devastate the surroundings by blast, the fact that it produces enough mechanical energy (equivalent, we think, to about half a ton of TNT in the Chernoby case) to destroy the core, lifting the reactor roof and releasing the accumulated fission products, it is a horrendous event.

10 We are confident that it could not happen here for a number of reasons. In a way it was a relief to know that the Russians had not inadvertently discovered some new hitherto unidentified hidden route to an accident.

All reactor designers must allow for reactivity increases. Since control rods are used in normal operation to take up reactivity, it follows that we must carefully consider the possibility of their inadvertent removal. It is not difficult to engineer a system which limits the rate at which they are withdrawn. Nor is it difficult to arrange physical means of detecting when things begin to go wrong, and arrange for trip circuits which rapidly inject other absorbers into the core. It is quite possible to engineer such protection so that it does not rely on operator intervention, at the same time making it proof against operator mal-operation.

11 It so happens that Mother Nature also lends a hand through what the Physicists call the Doppler coefficient. This simply means that as the fuel gets hot, this in itself takes away reactivity.

For many situations, for example, a fault which allowed for the inadvertent removal of one of the banks of control rods, even without a reactor trip, the fuel would simply increase in temperature until its internal loss of reactivity balanced the increase in reactivity from the removal of the rods. (This was graphically demonstrated in a series of tests on the prototype AGR at Windscale). Although it is not always easy to ensure that you don't get fuel failures due to temperature excursions in a reactivity driven fault, it is really rather surprising that anyone could get a slow nuclear explosion.

How did it happen?

12 The Russian reactor has another characteristic - a positive void coefficient. What this means is that if you take away the cooling water, the reactivity increases. Converting water to steam counts as removing the coolant, because the density change is so great.

Positive void coefficients again are not, in themselves, a fundamental problem. In normal operation, it is perfectly possible for the Doppler coefficient to have a bigger effect than the void coefficient, so that a power increase tends to reduce the reactivity and not add to it.

13 Obviously you should seek to operate the reactor in a regime where this is always true. The Russians had such an operating rule. They broke it. Designers should always assume that this is going to happen, and provide an independent fast acting safety system which would shut the reactor down at the first signs of trouble. The Russians did not have such a system. What they relied on was being able to drive the control rods into the core at a sufficient rate (one dollar per second actually), that they could overcome any reactivity excursion. The Chernobyl operators, in manoeuvring their plant, got into a situation where the control rods were completely ineffective in this safety role.

What is more, in getting to this position, they made the positive void coefficient even worse. The net consequence of all this was that the reactor was sitting waiting for a reactivity accident. It was not the classical fault of adding reactivity, by moving control rods but a sudden voiding of the core. This was triggered by reducing the flow of water to the core so that the steam content increased - and increased and increased because of the positive void coefficient - giving a reactivity increase which nature's Doppler couldn't cope with.

14 The solutions are obvious. They will reduce the size of the void coefficient (by putting in more fixed absorbers). They will increase the number of control rods, and provide physical means to stop them being withdrawn from the core. They will provide independent fast acting safety systems. In short, they will, as far as they are able when with refitting an existing system, apply the standards that we have always applied.

Of course, our gas cooled reactors do not have a positive void coefficient, and although the PWR can have a positive void coefficient, it is in a very special situation which is not relevant to operation, when it always has a negative power coefficient.

9th September 1986

9.9

Dounreay Nuclear Power Development Establishment
United Kingdom Atomic Energy Authority
(Northern Division)
Thurso, Caithness KW14 7TZ

Dounreay

Telex: 75297
Telephone: Thurso (0847) 62121

Extension:

Covering CONFIDENTIAL

DECLASSIFIED

cc MR Haynes
GR Allen

8 September 1986

Mr R N Simeone
Comptroller of Finance & Administration
UKAEA
11 Charles II Street
LONDON SW1Y 4QP

Dear Reggie,

POST-CHERNOBYL REVIEW - PROMPT CRITICAL EXCURSIONS

With your note of 3 September, you attached a letter from Mr Morphet about the post-Chernobyl review meeting in which he asks questions about Authority reactors relative to void coefficient and prompt criticality.

We have produced a note which covers these points for PFR and this will be discussed at the Northern Division Board of Management next week and should be a helpful input to Dr Gittus's proposal on how to reply to Mr Morphet.

NDBM(86)P15

Yours sincerely

C W BLUMFIELD

cc Dr T N Marsham)
Dr J H Gittus ✓) without enclosure

ck ✓

85/5
11-7

United Kingdom Atomic Energy Authority

CULHAM LABORATORY
ABINGDON
OXFORDSHIRE OX14 3DB

Fusion Programme Directorate

From: Authority Programme Director for Fusion
Dr R.S. Pease, F.R.S.

Telephone: Direct lines Abingdon (0235) 463432
23101
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Telex: 83189

✓

Dr J H Gittus
Director
Safety and Reliability Directorate
Wigshaw Lane
Culcheth
Warrington WA3 4NE

9 September 1986

Dear John,

I much appreciated the reports you sent from Vienna of the proceedings of the IAEA Post Accident Review Meeting. It was very helpful to be able to deal with questions at international conferences on the basis of your clear statements.

Yours sincerely

R S Pease

cc Mr D M Levey

8508
10-9

DOUNREAY
UK ATOMIC ENERGY AUTHORITY

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8 September 1986

cc M R Hayns 6741/10.9
FR Allen

Dr J H Gittus
Director, SRD

Dear Dr Gittus

CHERNOBYL POST ACCIDENT REVIEW MEETING

Thank you for your letter of 5 September 1986. I shall be away from DNE until 22 September 1986. I have recently prepared a number of briefs for Mr Blumfield who has already asked the questions now being posed by Mr Morphet. The answers to these questions are contained in NDBM(86)P135.

Yours sincerely

Alison Sinclair

pp C V GREGORY
Assistant Director, PFR

cc Mr C W Blumfield

Dounreay

Dounreay Nuclear Powe
United Kingdom Atomic
(Northern Division)
Thurso, Caithness KW1

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[redacted] pd
ded with our
input to the
for RNS/Morphet.
JHG -

Vec

Covering CONFIDENTIAL

8 September 1986

Mr R N Simeone
Comptroller of Finance & Administration
UKAEA
11 Charles II Street
LONDON SW1Y 4QP

Dear Rizzie,

POST-CHERNOBYL REVIEW - PROMPT CRITICAL EXCURSIONS

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NDBM(86)P135

Yours sincerely

C W BLUMFIELD

cc Dr T N Marsham)
Dr J H Gittus ✓) without enclosure

8508
10-9

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8 September 1986

✓ cc MR Hayns
FR Allen

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Director, SRD

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Yours sincerely

Alison Sinclair

pp C V GREGORY
Assistant Director, PFR

cc Mr C W Blumfield

FROM 01 930 5454 Action '86.09.05 09:25

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FACSIMILE

3

To: Dr J H Gittus, Director, SRD

Rpt: Mr W Nixon, SRD
Mr M A W Baker, LHQ
Mr I A Hodgkinson, LHQ
Dr G I W Llewelyn, LHQ

√ cc Mr Hayns

From: Dr R D Pearce, Programmes Branch, LHQ

5th September 1986

Further Chairman's letter on Chernobyl

Mark Baker has asked that a further Chairman's letter on Chernobyl be prepared following the Vienna IAEA meeting. I have prepared the attached draft which Mr Baker has approved, subject to any comments you may have. He has also suggested that in view of recent correspondence you might think it appropriate if I also consulted EMScD at Harwell. I should be grateful for advice.

Yes.

2 PAGES TO FOLLOW

See my changes p1.

J. Gittus
9 Sept.

DRAFT 5th September 1986

CHAIRMAN'S DEAR COLLEAGUE LETTER ON CHERNOBYL

In my letter of 10th July, I promised that information about the cause of the Chernobyl disaster would be passed on to you when it was received.

2. During the last week in August, the International Atomic Energy Agency (IAEA) convened a meeting in Vienna of experts from member states to discuss the Chernobyl accident. The Russian authorities presented a comprehensive and detailed report on the accident and its aftermath. As a result of this, and of the extensive discussion and analysis which followed, we now have a fairly clear picture of the cause and nature of the accident.

3. ~~When~~ If a power station ~~is shut down~~ becomes disconnected from the National Grid, the steam supply to the generator is switched off. The generator, however, continues to "freewheel" for a while. The station managers at Chernobyl were carrying out an experiment to see if enough electricity could continue to be produced from the freewheeling generator as it ran down to power the main reactor cooling pumps and remove heat from the reactor. A combination of circumstances had caused the operators, before the experiment got under way, to switch off the emergency core cooling systems, to withdraw more control rods from the reactor than their instructions allowed, and to switch off ~~the~~ emergency shutdown systems. As the power produced from the freewheeling generator ran down, the reactor cooling pumps slowed down, and the core temperature increased. The RBMK design makes the reactor unstable ~~in~~ under such an unusual combination of conditions, and a dramatic rise in the core temperature followed. Because all the safety systems had been switched off, the reactor could not be shut down in time, and a runaway reaction occurred, bursting the pressure tubes containing the fuel and producing a large amount of steam which blew the top off the reactor. Hydrogen and carbon monoxide gases were produced which also exploded and burned, carrying fission products ~~from~~ and disintegrated fuel into the atmosphere.

4. The primary cause of the accident was therefore gross malpractice by the station operators. In addition, though, the Russians have accepted that the basic instability of the RBMK core design was an important factor; it was also a serious shortcoming in the overall design that the emergency cooling and shutdown systems could be over-ridden and switched off by the operators. A number of modifications in the RBMK design are now being implemented by the Russians to overcome the core instabilities and to improve the reactor protection systems, making them less dependent upon operator judgements.

5. 31 people have died to date as a result of the accident, all of them employees or firemen on the Chernobyl site, and all but two of them as a result of acute radiation exposure. Between 170 and 180 ~~further employees~~ people are suffering from various degrees of radiation sickness.

6. The meeting in Vienna was notable for the full and frank explanations given by the Russian authorities and for their willingness to admit to major design faults in the RBMK system. A number of detailed technical topics have been identified for further study, and appropriate meetings will be organised by the IAEA. The Authority will take part in these studies.

7. A great deal of work will need to be done to ensure that the lessons coming out of the disaster are properly understood, and some changes in the balance of the Authority's own R&D activities may well result.

To: See Distribution

CHERNOBYL POST-ACCIDENT REVIEW MEETING - 24-29 AUGUST 1986

Mr Morphet of the Department of Energy has approached the Authority with two questions concerning Authority reactor operation which arose out of the Russian presentations on the Chernobyl accident last week in Vienna. These questions are:

(i) is there any risk of a positive void coefficient in any Authority reactor?

(ii) is there any risk of either a prompt critical (or super prompt critical) excursion in any Authority reactor?

The background to these questions is of course that the positive void coefficient inherent in the RBMK design has been singled out as a prime contribution to the accident, and that the explosion in the reactor was due to one (or maybe two) prompt critical excursions.

In order to prepare a full reply to these questions could I ask you to let me have a brief statement on the position in respect of your plant. Since the other principal feature of the accident at Chernobyl was the series of departures by the operators from their operating rules, I think it would help if you could indicate the grounds upon which you would base a "it can't happen here because ..." statement. I hope therefore, that your answer will be in two parts; first on the physical situation of the reactor and second on how we guard against operator malpractice (not just error).

The language used for the response to the Department will have to be carefully chosen and not contain technical jargon. However, I would appreciate your response to me, in the first instance, to contain the proper technical description. If you wish to make suggestions as to how this might be written more simply I would be very glad to receive them.

The timescale for response is relatively relaxed, but I would very much appreciate your first stab by the end of next week, Friday, 12 September 1986.

Thanking you in advance.

pp JH Gittus MR Hayns

J H GITTUS

5 September 1986

File No. 8479
4.9

ACTION

cc MR Hayns
RS Peckover
FR Allen
} for urgent comment to Dr Gittus pl.
J.

Chairman

c.c. Dr. T.N. Marsham
Dr. G.G.E. Low
Mr. C.W. Blumfield
Dr. J.E.R. Holmes
Dr. W.M. Lomer
Mr. R.L.R. Nicholson
Mr. M.A.W. Baker
Mr. F. Chadwick
Dr. J.H. Gittus ✓ Good. JHG.

Post-Chernobyl Review - Prompt Critical Excursions

You will wish to see the attached letter from Mr. Morphet, a copy of which has already been sent to Dr. Gittus. I think it would be helpful to have Dr. Gittus's proposals on how I should reply to the two questions at the end of Mr. Morphet's letter, but I have copied the letter widely and would be grateful if Dr. Gittus would circulate his proposals to the copy addressees of this minute.

R.N. Simeone
(R.N. SIMEONE)

3rd September 1986

UNDER SECRETARY/ATOMIC ENERGY DIVISION

DEPARTMENT OF ENERGY
Thames House South, Millbank, LONDON, SW1P 4QJ
Telephone: Direct Line 01-211
Switchboard 01-211 3000

2 September 1986

R N Simeone Esq CBE
UKAEA
11 Charles II Street
London SW1

Dear Reggie,

Post Chernobyl Review Meeting 24-29 August

You will have seen Dr Gittus' reports on this meeting. I am most grateful to him for taking on this task, which was widely appreciated by our delegation.

The review provides a number of lessons, I believe; the need for constant vigilance and attention to detail in all safety matters; the need for continuing international action to help bring standards everywhere to the highest; and the need to plan effectively for the worst in our emergency work.

I am writing to you now on one specific point. It is generally accepted that a prompt critical excursion triggered a steam explosion which lifted the pile-cap. We can expect questions about the nature of such excursions; the risks of this occurring in the UK; and if so, what their consequences might be. It was pointed out by Tanguy at Vienna that a prompt critical event such as Chernobyl has a multiplication time-constant of milliseconds, and that this is not the same as the almost instantaneous 'super prompt critical event' of a bomb, where the time-constant is nano-seconds. Nevertheless the layman may perhaps be forgiven for regarding the event at Chernobyl as being a type of nuclear explosion, even if not of the force or magnitude of a bomb. It is important that we get the language right. To talk of a 'prompt critical event' may sound to some like a technical obfuscation. From what I understand, the event was indeed a 'form of explosion', and would be grateful for your views on whether there is any great difficulty about using the phrase, in layman's language, to describe what happened.

I should also be grateful for advice on the following:

(i) is there any risk of positive void coefficient in any Authority reactor?

(ii) is there any risk of either a prompt critical (or super prompt critical) excursion in any Authority reactor?

Yours sincerely

David

D I MORPHET

cc Dr Gittus

CEGB IN CONFIDENCE

26th August 1986

- 1 SEP 1986

FRA 1777

CHERNOBYL ACCIDENT

IAEA CONFERENCE DAILY NEWS-SHEET NO 1

Content

1. Introduction
2. Digest from Russian Report on Accident Chronology.
3. Conference Proceedings 25th August 1986.
4. Media Comment.

This sheet is issued by: The Director
Nuclear Operations Support Group
CEGB
Sudbury House
15 Newgate Street
London EC1 7AU

(Edited by the Nuclear Operations Services Engineer)

1. Introduction

The daily news-sheet will be issued during the period of and immediately after the IAEA Conference in Vienna, on the Chernobyl accident, from the 25-29 August 1986.

An English translation of the Russian Report is being distributed separately.

This first news-sheet includes a digest of the accident chronology. A daily report on the conference proceedings and media comment will be included in this and subsequent newssheets.

A distribution list is appended.

2. Digest from Russian Report on Accident Chronology

In the experiment the Russians planned to disconnect the turbine from the reactor, with its generator then continuing to supply power to the auxiliary systems by just using kinetic energy of the running down turbine. The intent was that the reactor would continue to operate, partly cooled by some of the pumps which were powered from the grid supply, whilst they measured the ability of the turbine to power other pumps as it ran down.

The Report states that they had carried out such a test previously but they had found that the voltage - which is important in electrical equipment - fell off too rapidly as the turbine slowed down. What they were attempting to do in this case was to put in some sort of improved voltage regulator to keep the voltage up. They state that the procedure for this second test was not properly authorised; the safety aspects had not been throughly thought through; there were departures from the procedures that they had; and there were also significant violations of the main operating rules on the station.

There are some design aspects of the reactor which are relevant to the accident. The most imporrtant design feature of the RBMK is that it has what is called a positive void coefficient. This can be explained in simple terms by recognising that in a reactor of the Chernobyl type a mixture of water and steam is created in the channels as the fuel heats the incoming water. If the power from the fuel increase or the flow of water decreased (or both) the amount of steam in the channel increases. Since vapour is less dense than liquid there will then be less water in the channel. That is a characteristic of any system which lets water boil in the reactor. What is singular to the Chernobyl type of reactor is that it can have a 'positive void coefficient of reactivity' - reactor physicists' jargon which simply means that as a result of losing water the reactor power will increase. In short an increase in power, or reduction of flow, leads to increased boiling and further increases in power and you have the potential for a runaway situation. That is an undersirable feature because it means you have to have quite complex rapidly responding control systems to cope with that situation and compensate for this 'positive feedback'.

/...

This reactor also has very little capability for coping with the build up of the fission product Xenon. What happens with any reactor if you reduce power is that the amount of Xenon builds up. This is a neutron poison and you need to have sufficient control rods dipping into the core so that you can pull them out to overcome this poison before you can increease the reactor power again. The Russian reactor is not very good in that respect and it is also difficult to control at low power.

Two further points are that the design has an emergency core cooling system which is designed to come in if the normal coolant flow fails and this was quire deliberately turned off because the experimenters thought that in the particular conditions it might come on when they did not want it to. This was an unauthorised step.

The reactor protection for this reactor - that is the means by which the rector will shut down automatically - includes various systems and equipment. If two turbines are lost the reactor will automatically trip and shutdown. If the level of water in the steam drums or if the pressure in the steam drums goes outside the limits the reactor will trip. If the feed flow reduces by more than a factor of two the reactor will trip. If the pressure circuit fails the reactor will trip. Now that is quite important as you will see from the sequence. But all those safety trips were deliberately turned off by the Russian operators.

There are, of course, operating rules, administrative controls governing the operation of the reactor, which insist that this protection is available and in particular they specify that this protection is available and in particular they specify the limits for the control rod position. Again that is important, but in the brief not the observance.

On the sequence of events it is important to stress that it is quite difficult to tell from the Russian report what is actual fact and what is information they have deduced from models.

The sequence as presented starts at 1.00 a.m. on 25 April, almost a day before the accident. They started to reduce power from full power conditions. By the middle of that day, about one o'clock in the afternoon, they reached half power condition. They disconnected turbo-generators linked to the reactor - and also, as required by the test, invalidated the reactor emergency protection.

Also at this time, and bearing in mind that later on they wanted to arrange for some of the circulating pumps to be fed directly from the turbine under test, and some to be powered directly from the grid supplies, they reconnected some of the circulating pumps which had been powered from turbo-generator 7, probably to the grid supplied - it is not entirely clear.

/...

Also at this point they disconnected the emergency core cooling system. The intent was that they would now start the turbine run-down test.

It appears that the grid controller requested that they should delay the test for some time, presumably because of a requirement for power. So having taken out the emergency core cooling system; they operated for some time at quite high power in a condition, which although not relevant to the accident, is another example of operator error.

We come now to 11.10 in the evening when the operator sought to reduce poweer to the range 700-1000 megawatts (thermal) which were the test conditions they wanted to achieve. Again there was an operator error in that the operator decided to disconnect the automatic local control system and rely on a combination of manual and general automatic control, the latter employing only 4 rods as compared with the 12 rods for automatic local control.

The problem is that there had been an opportunity for the fission product Xenon to build up. Also with much more coolant flow and low power, there is very little steam in the channels. Both effects decrease reactivity so the opeator has difficulty in removing enough rods to counteract these effects. The reactor power fell as low as 30 MW and he had considerable difficulty in restoring power.

Eventually, by 1.00 a.m. (26 April), the operator managed to stabilise the reactor at about 200 megawatts (thermal). He was unable to increase the power any further because of shortage of reactivity - 200 megawatts was well below the test conditions being looked for. Nevertheless, they decided to proceed with the test despite the fact they had not set up the intended test conditions. Again the report makes no comment as to why they decided to proceed with each stage, merely that they did so.

There are six circulating pumps which are normally used to pump the water around the core and there are two additional pumps which are kept on standby, eight in all. At the end of the test conditions they wished to end up with four pumps cooling the reactor powered by the grid and four pumps connected to the turbine which was running down.

At this stage - between 1.00 a.m. and 1.07 a.m. - they started two more circulating pumps. The effect of this was that the flow rate enhanced by the additional two pumps was much too high and was outside and operating rule limits. The importance of this is that the increased flow further reduced the amount of steam voids in the circuits.

/...

The other effect of the steam voids collapsing, with a positive void coefficient, is that the core reactivity will continue to fall, and therefore to keep the reactor going you have further withdraw the control rods, and it appears that the operator had to manually withdraw them further than the automatic system was prepared to go in order to keep the reactor critical.

During this procedure, because the steam voidage was changing, they were also having trouble maintaining both the water level and pressure in the steam drum within the allowable limits. So, the report says, they took out the reactor protection, which would have tripped the reactor if they had gone outside the limits, in order to keep the experiment going.

To raise the drum water level they increased the feed flow to the drums. This feed water is colder than the recirculating water so the temperature of the water entering the channels was reduced. This will also tend to make reactivity fall and make reactor control more difficult. But with the water level in the drum now rising, at 1.22 a.m., the operator very sharply reduced feed flow. This causes the reactor coolant temperatures to rise so it is nearer to boiling.

We are now at 1.22 a.m. and 30 seconds and the operator is warned by the station computer that his control rods were significantly outside the limits allowed for operation. The rules state he must have a minimum of 30 rods within a particular part of the active core in order to cope with possible transient conditions. It is stated that they only had eight rods within that region.

The rods also were not in a uniform distribution which meant they had a very peculiar power distribution across the reactor and also axially up the height of the reactor. That was also significant in that it meant that the void coefficient was higher, considerably higher, than the designed had assumed it would be.

The opeator noticed that the rods were outside the limits but decided to ignore that and to proceed with the experiment.

At 1.23 a.m. and four seconds he commenced the experiment by closing the stop valve on turbo-generator 8, having previously removed the remaining protection on that turbine to stop that tripping reactor.

The effect, and this must be modelling rather than actual observation, was that pressure in the system began to rise as more steam was produced. The flow began to fall as the turbine ran down and therefore the pumps ran down. The net effect of this, with water temperature increasing but water flow decreasing, was that the steam voidage increased at a rapid rate because the system was near to its boiling point. With the high positive void coefficient the power began to rise in the reactor - producing yet more steam - and clearly a runaway situation was upon them.

At this point - and we are now at 1.23 and 40 seconds - 36 seconds after starting the experiment - the shift manager ordered a manual shutdown of the reactor. The button was pressed which drives the control rods into the reactor rather than letting them freefall. The rods did not fully motor in and banging noises were heard. The operator then disengaged the rod clutches, taking the electrical supplies off the rods, so they could fall in under their own weight, which they did partially. By that time the explosion had already occurred and the core was disrupted.

At 1.24 a.m., burning fragments were observed to be falling on to the turbine roof.

We are now on to the Russian hypothesis or model as to what actually happened. What the Russians deduced is that the massive increase in voidage caused the fuel to overheat in a number of pressure tubes - they do not say how many. The local pressure increased very quickly as a result of that, causing a number of pressure tubes to fail. Some hot fuel was ejected from the channels.

The pressure build up was sufficient to cause substantial failure of the reactor structure and the building. That is probably purely from the pressure build up from the steam. They state that the charge machine which stood on top of the reactor pile cap leapt up and down, causing further failures of the cooling pipework.

Following that there were then reactions between the zirconium, which was the metal used to clad the fuel, and the steam causing hydrogen to be produced. The hydrogen ignited when it came into contact with the air as it came through the breach, causing a number of fires which set light to the turbine hall roof.

The hydrogen release led to small explosions - they talk of about 30 separate fires on the turbine hall roof.

The principle disruptive effect was the rapid production of steam as a result of the rapid increase in power.

As far as release of radioactivity from the accident: the greatest amount was released on the first day 26 April: but they do give information about continuing releases which went on at quite a substantial level - up to half the initial rate - until 6 May, at which point they had managed to take steps to effectively stop the activity release into the atmosphere.

/...

3. IAEA Post Chernobyl Accident - Conference Proceedings 25th August 1986

10.00 to 11.00 hours: Opening of the meeting

The audience was divided between two rooms, one being provided with closed circuit television. The meeting commenced at 10.00 a.m. many TV crews being present for the first speech.

Blix, Director General of the IAEA, opening the meeting, said the results would be transmitted to the IAEA Board before its September meeting. He drew parallels with the Agency's response to the accident at Three Mile Island. Already, following the Chernobyl accident, at the Agency there had been formulated schemes for international accident notification and emergency response. These were to be formally adopted in September. We would not be asked to endorse any resolutions. A factual report to the IAEA Board of Governors on the outcome of the meeting would be prepared by the Secretariat and INSAG (the International Nuclear Safety Advisory Group) in the week following the meeting.

Rometsch, Chairman of the meeting, spoke next. The meeting had three objectives as he saw it:-

(i) To understand the lessons of Chernobyl.

(ii) To apply them, where relevant, in our own countries.

(iii) To assist future international collaboration on nuclear safety.

Legasov, head of the USSR delegation, then addressed the meeting. Construction of nuclear power plant was receiving priority in the USSR since without it they would be "unable to master" the next stage in the development of their society. The Chernobyl incident was a disaster. On a world scale it was leading to a re-evaluation of the part to be played in future by nuclear power. In the USSR since the accident there had been an intensive development of accident prevention measures and a parallel analysis of the nature and effects of the accident itself. The work continues. The USSR would be entirely open to suggestions about decontamination and other methods of limiting the impact of the Chernobyl accident. They would like to open up discussions on all possible ways of improving the reliability of nuclear installations, of reducing risk and of mitigating the damage done should another accident occur. He listed the many eminent USSR engineers and medical specialists who were present at the meeting, indicating their direct involvement with the practical response to the accident. His own work, apart from Chernobyl related responsibilities, was on the development of the High Temperature Reactor at the Kurchatov Institute.

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11.00 to 13.00 hours: Overview of the Accident

Legasov now presented a video of the sequence of events in the Chernobyl accident. The reactor power had been teetering on the brink of dangerous thermal hydraulic and neutronic instabilities because the operators had turned off vital safety systems and had too few absorber rods in the core. When the diverted steam from the turbine this was the last straw. The reactor power rocketed up. Steam pressure burst the reactor and the overheated fuel then gave off many millions of curies of radioactivity. Within a day or so the 100,000 or so people living up to 30 km away were evacuated.

He went on to describe the RBMK reactor. This has a graphite moderator pierced by holes or channels, lined with zirconium-niobium tubes and containing the uranium dioxide fuel. Water in the channels is boiled by the fuel. This produces the steam needed to drive the turbo-alternators and it also keeps the fuel from overheating, by continuously removing the heat generated by nuclear fission. The rate of heat generation is controlled by inserting or withdrawing neutron-absorbing rods. There are pumps to pump water into the bottom of the channels and it boils as it rises up the channels. A mixture of hot water and steam emerges from the top and passes through pipes to steam-separators. Here the steam collects above the water and is led by pipes to the turbines whilst the water is drawn off and pumped back through the channels to be boiled again. The steam from the turbines is condensed and it, too, is pumped back through the channels, completing the cycle.

Legasov summarised the conditions of coolant flow, level, temperature of steam content which could, if allowed to persist, lead to an accident and which therefore normally automatically trigger a "trip" or cessation of heat-generation due to fission. If there are fewer than 15 neutron control rods inserted in the reactor then the rules require it to be tripped by the operators. They judged that the probability of the operators failing to trip it in such a case was lower than the probability of failure of a purely automatic trip system. In the event it was precisely this error that the operators made. They had fewer than 15 rods but did not trip the reactor, leaving it critical and poised on a knife-edge.

Legasov went on to describe the safety systems which take the heat away should an accident commence; the emergency core cooling systems. Then he described the containment philosophy; the steam separators, the pumps and the pipes leading to and from the channels are separately contained, each in its own concrete cell or box. Tubes from each cell are immersed in a "bubbling pool" and the pressure in the cell is released by bubbling, should a pump, a separator, or a pipe burst.

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15.00 to 18.00 hours: Overview of the Accident (continued)

In the afternoon Legasov continued, now concentrating in greater detail upon the reasons for the accident and its progress. Although he followed quite closely the written report which participants had been given he added several important points. In particular he said that the operators felt that they were under extreme pressure to complete the planned experiment that night since they knew that it would be a full year before they would have another chance. It was "a tremendous psychologival mistake" on the part of the designers of the RBMK reactor that they did not foresee that additional protective systems would be needed in the core in order to trip the reactor and keep it cool even if (as occurred in the Chernobyl accident):

(a) the operators deliberately switched off the standard protection systems and in addition;

(b) (completely disobeyed the safety rules concerned with the minimum number of control rods which must be inserted.

This, he said, was the case against the RBMK designers: "Now, with hindsight, we can see that it could have been prevented, in a very easy way using technical means" (by which he meant engineered safety features, not written rules). He illustrated what had happened by means of an analogy. It was, he said, as if the pilot of a passenger plane suddenly started testing the plane in in flight; opening and closing the doors and switching off safety systems. He suggested that the USSR had started later than others to reassess the need to design and protect against this kind of human fallibility.

As for the detailed progress of the accident; this is complicated and sets out in full in his detailed report. In essence, and simplified what Legasov says happened was as follows:-

The operators tried to power the coolant pumps using electricity from a "free-wheeling" turbo-alternator. As the alternator slowed down, so of course did the pumps which it was driving and so the amount of steam being produced increased. It was this that triggered the accident. The operators tried to insert the control rods but the rods were mostly so far out of the core (only 6 were inserted instead of the minimum of 30 required by the rules) that long before the rods could have shut the reactor down it had run away, the power rocketing up. The steam, now produced in vast quantities, burst the pressure tubes. Next the uranium dioxide pellets disintegrated with a further explosive generation of steam which blew the top cover (pile-cap) off the reactor and exposed the hot fuel to the air. Hydrogen and carbon monoxide were produced by the oxidation (in steam and air) of graphite and zirconium. These gases burned or exploded in the air.

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Volatile and gaseous radionuclidges were freely evolved into the air by the overheated fuel.

None of this would have happened had the operators, (by switching off vital safety systems and ignoring the rule about the minimum number of inserted control rods) not allowed the reactor just prior to the experiment to be poised on the threshold of just such a reactivity-excursion.

Development and Consequences of the Acciden

The attention of the IAEA meeting now turned to the immediate consequences of the accident. Legasov continued the presentation, following the written report once more.

The initial release of radioactivity missed the adjacent town of Pripyat. Evacuation was delayed, but Legasov defended this saying that they were initially safer where they were. Indeed those in stone houses were forbibben to leave since the masonry sheltered them from radiation. However, the graphite fire, the increase in graphite temperature and the continued release of activity soon made evacuation of Pripyat vital. It was accomplished in 2 1/2 hours.

The amount of radioactivity released was greatest on the first and ninth days following the accident. The second peak occurred when decay heat and fire had raised the core to its maximum temperature of 2000°C. The graphite fire resulted in the production of a radioactive aerosol which went up into the atmosphere. It was to stifle the graphite fire and stop the escape of the aerosol that 5000 tons of sand, boron carbide and lead were dropped onto the exposed face of the reactor from helicopters. The boron carbide was to prevent fission from restarting locally. The lead was to absorb heat, absorb radionuclides and shield the helicopters from gamma radiation. The sand and clay were to act as aerosol filters. By 6 May the release of activity had ceased, or virtually so, the rise in temperature having been reversed by natural convetion of air and by creating a forced flow of cold nitrogen through the core.

No more than 3 1/2 percent of the activity (excluding the noble gases) was released from the core; less than fifty megacuries.

Temperature measurements in and around the reactor core could not be made except with simple devices such as thermionic valve amplifiers or materials of known melting point. The radiation fields rendered semiconductor instruments unreliable. With the exception of the reactor vault itself, radiation fields have now fallen from thousands of Roentgens per hour (the maximum recorded) to no more than one or two R per hour.

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Release from the reactor is now down to tenths or curies per day, as an aerosol. Temperatures are now below 300°C in the core. A priority task was to shut down Units 1, 2 and 3 following the accident. Units 1 and 2 have been decontaminated and by the year end will be back in operation and the operators rehoused. As for Unit 3, a review is in progress and may permit it to be brought back into use.

The social losses comprise 203 seriously injured, 31 dead, collective doses of 9 million manrem in 1986 and 29 million over the next 50 years. Decontamination of the surrounding land should enable limited economic use to recommence eventually.

The speaker now turned his attention to safety requirements before and after the Chernobyl accident. Beforehand it was permissable for some control rods to be completely withdrawn; now none may be less than 1.2 meters into the core. The minimum number of fully-inserted rods must now be eighty, it was thirty. In the future the fuel enrichment will be raised from 2.0° to 2.4° which coupled with the greater amount of control rods permanently in the core will offset the positive void coefficient which was one of the principle design shortcomings. Finally, the reactor protection systems will be more hightly automated so as to place less reliance on the operators.

Some RBMK reactors are still operating and others will be brought back into operation following these changes. More training is to be given to their operators.

The presentation ended to loud and prolonged applause at 5.0 p.m. It had been a marathon performance, both open and frank.

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4. Media Comment

Friday August 22nd

Times:- The needless catastrophe at Chernobyl.

Guardian:- (i) Soviet alarm at N Plants near town
(ii) The chain of circumstances at Chernobyl

Financial Times:- Plan for Soviet Reactor changes

Daily Telegraph:- Russian blames human blunder
Chernobyl catalogue of errors

Daily Mirror:- Atom death dust pours out

Morning Star:- 6 errors set off Chernobyl

Daily Mail:- Six fatal errors. Russia accuses guilty men from Chernobyl

Standard:- The six unbelievable errors at Chernobyl

Saturday August 23rd

Financial Times:- Countdown to Chernobyl
The Scram that failed

Monday 25th August

Financial Times:- Chernobyl reactor had major design flaws

Guardian:- Russians speed up reactor plans

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NEWS-SHEET

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CEGB IN CONFIDENCE

28th August 1986

CHERNOBYL ACCIDENT

IAEA CONFERENCE DAILY NEWS-SHEET NO 2

Mr Morphet reports that he and Lord Marshall met Dr Blix and the leader of the Soviet experts, Academician Legasof, at separate meetings on Tuesday 26th August. Legasof welcomed Marshall's ideas for follow-up conferences and/or work programmes within the IAEA on:-

i. inter-action between reactor design and the operator, and

ii. decontamination technology.

He also welcomed the principle of collaboration between the Soviet authorities, IAEA and WHO on epidemiological studies and suggested that IAEA should be "encouraged to explore the possibility" of such collaboration. This rather tentative formulation apparently reflected his view of the complexity of pulling together the various USSR agencies and the enormous workload involved.

The UK delegation awaits the Soviet response to these ideas in the Working Groups in Vienna, but Legasof seemed very keen on (i) and (ii) above and favoured a relatively early conference on (ii).

Report by Dr John H Gittus (UKAEA)

Tuesday 26th August. Working Groups

The meeting now divided into four Working Groups, Working Groups 1 and 2 convened in Session 2A; Groups 3 and 4 in Session 2B.

Session 2A, 10.00 to 18.00 hours: Detailed Presentations on Plant Design, Safety Analysis, Accident Description.

Cause of the accident, sequences of events, radioactive releases, short term stabilization and longer term arrangements.

The presentations began with a historical review of the development of nuclear power in the USSR. This was straightforward, starting with the usual claims for the worlds first atomic power station which produced 5MW of industrial power at Obninsk, near Moscow in 19554. Of more interest was an outline of the expansion envisaged for nuclear electricity generation during the next 5 year plan. It was intended to utilize nuclear heating, not only for the generation of electricity but also thermal energy by making use of the 'waste' steam. Combined electricity/thermal power plant and purely thermal output (for urban space heating) were planned. The development and implementation of fast breeder reactors was envisaged during this period with a suggestion that an 800 MW plant being considered.

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The presentations followed closely the text of the first two Annexes to the Russian report. Annexe 1 describes operating experience with the RBMK rectors: Annexe 2 the design of these reactors. Particular attention was paid to the void coefficient (which has a value of 2 X 10^{-4}% steam). It is positive and so an increase in the volume of steam voids (bubbles) in a channel leads to an increase in the amount of heat being given off by the uranium fuel in that channel. As a result even more steam will be generated, and the resultant voidage will further increase the rate of heat generation. Ultimately, if this circular process is not halted by the automatic reactor control and protection systems, the rate of steam production will be so great that it will damage the reactor. This was what happened in the Chernobyl accident. The void coefficient was at its maximum because there were only six control rods in the reactor and the automatic system had been turned off.

A "local automatic regulating system" is used to control the power output of the reactor as a whole. A decision is taken about the amount of power required. It can lie anywhere in the range from 10% to 100% of the maximum possible output. Then the automatic system maintains the power within one percent of the selected level. The system embodies twelve independent local regulators.

Emergency Protection of the Reactor

In an emergency the fission-reaction must be stopped, by tripping the reactor so as to minimise the heat output. This is achieved by the automatic insertion of all the control rods. Such emergencies arose at a number of junctures in the Chernobyl accident but the operators had switched off the trip arrangements and so the generation of heat by fission was not halted.

The emergency protection systems were explained in some detail, including the various levels of protection afforded. The nature of these systems is such that certain signals do not produce full shutdown, but rather permit continued operation at lower power levels. The way the coolant circuit functions was illustrated and all of the operating parameters givn. Natural circulation has been shown to provide satisfactory cooling when the main pumps are turned off at power levels up to 30%. Tests have been made to establish this on operating plant, on special experimental rigs and also by calculation. There was a description of the three train emergency core cooling systems and the provision of multiple safety relief valves to guard against over pressure in the coolant circuit.

Quantitative Description of the Actual Sequence of Events

In attempting to provide an explanation of why the operators made such a series of errors, two points were emphasised. First of all, the accident occurred at a very bad time psychologically. It was the end of the working week and in the early morning. Although not mentioned it is also worth noting that it was the eve of the May holiday. In addition it was suggested that the psychological state of the operators could have been affected by the fact that this Unit had been "top of the league" for availability.

By taking the data which had been recorded by the plants own data processing andd using it to validate a computer model of the reactor system, a very detailed and accurate simulation of the course of events leading to the catastrophe was produced.

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Some emphasis was placed upon the fact that it was not actually necessary to have the reactor operating at power in order to perform these tests. The Russians argue that it was done at power so that if the first attempt had proved unsuccessful, then the would still be enough steam in the operating reactor to restart the turbine, enabling the experiment to be repeated. Preparations for the test, in terms of reactor safety, were minimal. If the reactor presented problems during the experiment, the advise to the operators was only concerned with operating procedures.

When the test was started, a series of events caused the operators to block off essential safety systems. They then were gradually boxed in as a result. Eventually when the realised that an uncontrolled increase in power was imminent it was too late for the reactor to be shut down, even though a full emergency shutdown procedure had by then been initiated.

For the third time we were treated to a rehearsal of the accident sequence and some details which do not appear in the report were given.

The description given was as follows:-

1. The control and safety rods had been withdrawn from the core to compensate for xenon poisoning.

2. All 8 main circulating pumps were in operation. They were circulating hot water which was everywhere near to boiling although little steam was being generated.

3. When the main circulating pumps began to run down (due to run-down of the turbo-generator) flow was reduced, the water boiled and there was a consequent uncontrollable increase in power.

4. Steam pressure destroyed the core and the upper structure of the reactor.

Calculations indicate that the power increased by a factor of 100 in less than 1 second, a "mad-crazy" release of energy which disrupted the fuel into small particles at 3000°C. These converted the remaining water droplets to steam which blew off the reactor cap and destroyed the building. Three to four seconds later according to witnesses outside the building a second explosion occurred. It was probably due to the detonation of hydrogen or carbon monoxide. Hot burning debris caused subsidiary fires which were put out although many of the fire fighters later died.

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Session 2B. 10.00 to 18.00 hours: Detailed Presentations of Emergency Measures and Radiological Consequences.

Evacuation, environmental protection actions, decontamination, environmental, effects, health effects.

The Working Group session was opened by Prof. L.A. Ilyin (Academy of Medical Sciences, Director of the Institute of Diophysics) who outlined the affiliations and specialisms of the speakers to follow and set their contributions in context. Ilyin gave the following time-table of events with respect to medical response:-

26 April 1986

01.25 Accident occurred

01.30 Site Medical Centre informed (3 medical staff on duty).

01.45 2 specialized teams of medical staff set out from Pripyat. Later additional teams sent out.

115 beds made available in regional hospitals.

02.10 First 29 victims admitted to hospitals.

03.00 Distribution started of potassium iodate tablets to all workers on power plant site and to patients. (He compared this with Three Mile Island where tablets were not distributed for 6 hours).

06.40 Special teams of physicists, dermatologists, radiologists and clinicians alerted in Moscow who

11.00 Flew to Kiev in a specially chartered plane.

20.00 Iodate tablets distributed in Pripyat by medical staff and local door to door activists.

Prof.Ilyin said that inretrospect the scale of response to the accident and its organisation was astonishing. Hundreds of institutes in the Soviet Union supplied specialists and millions of dosimetric measurements were taken.

Up to the 10 May several hundred thousand people were medically examined - including blood tests. Some 200 to 300 people were diagnosed with acute radiation sickness. These cases were confined to workers and there were none in the general population.

Thirty-eight million people live in the Dnieper valley and there was much concern over the eluation by rainfall of radioactivity, deposited on the Chernobyl site. They weere lucky in that between 26 April and the end of May very little rainfall fell in the area. Prof.Ilyin attributed this to the intensive weather modification activity of the State Hydro-meteorological Committee who dispersed chemical substances to dissipate the clouds.

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He said that for many years starting from the 1960's the Soviet Union, on the basis of much research work and international experience, developed a conceptual basis for the protection of the population and the inhabited environment in the event of an accident or emergency radioactive release.

In 1969 the Soviet population criteria protection for use in a nuclear accident were published by the IAEA. Soviets are not in favour of developing preliminary standards for water, food, etc., within very narrow limits. They feel that these must be based on certain principles but details should depend on actual circumstances. Ilyin thought their criteria corresponded more or less with those used in other countries though with some specific differences.

From their previous consideration of maximum design accidents and maximum imaginable accidents the situation resulting from the Chernobyl accident was "not totally unexpected". However the accident has emphasised the importance of skin dose in determining the prognosis of accident victims. 20% of the victims had lost 80-90% of their skin area from beta and other radiation. However, as well as steam burns there was no neutron irradiation involved. Prof.Ilyin concluded by referring to the warmth of the enormous emotional response in the rest of the population engendered by the unfortunate victims.

Environmental Monitoring

Prof.Petrov gave a detailed account of the results of environmental monitoring in areas both close to and further away from the plant, from the time of the accident to the end of May. The detailed information is in one of the Annexes to the report and will be available in the UK at the end of the Conference.

Two aeroplances plus helicopters and vehicles were quickly deployed for monitoring activities over 20,000 sq.kilometers. An enormous number of samples were taken of soil, waterways and air.

After the accident radiation levels of the accident plume reached dose rates of 1000 millirem per hour on 27 April and 500 mr per hour on 28 April at a distance of 5-10 Km from the reactor site at a height of 200 metres. Aircraft measured a plume height of 1200 metres in north westerly directions at 30 km from the site of the reactor, though at that height the dose rate was only 1 millirem per hour.

Later calculations put the total activity release in European Russia at 50 megacuries - 3 1/2% of the total energy from the radionuclide inventory in the reactor.

Medical Aspects

Prof.Kuskova gave a presentation on medical aspects. At the time of the accident there were 176 operational staff on site plus 268 workers on the construction sties and auxiliary work areas. 300 people were checked for radiation sickness in the first few days. 203 were found to be suffering from it.

An enormous amount of data now existed from what needed to be done after the accident. Full analysis of it would not be completed for a further 6 to 12 months.

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Severe cases had begun showing radiation sickness symptoms, e.g. vomiting, diarrhoea, skin problems - within an hour of the accident. Within the first 12 hours 129 people had been sent to special hospitals.

Four degrees of radiation sickness were defined of which degree number 4 is the most severe. In category 4 there were 22 victims. They had received between 600 and 1600 rads as a result of which all but one are dead. Of the 23 victims in category 3 (400-600 rads) 7 are dead. In categories 1 and 2 (100-400 rads) there weere 158 victims and 1 has died.

Information was likely to emerge on effective dose thresholds. Again a detailed annex on the medical information has been given to delegates.

Press Comments

26th August 1986

The Guardian:-	Chernobyl's concrete 'tomb' may be complete next month.
Daily Telegraph:-	Russia dodging the questions on Chernobyl.
The Times:-	Chernobyl plant may never reopen.
Financial Times:-	Chernobyl speeds safety accords.
Morning Star:-	Chernobyl talks continue.
Daily Express:-	Chernobyl will kill 70 Britons
City Limits:-	FoE turns on the heat (refer to anti-nuclear campaign to commence on 1st Sept).

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CEGB IN CONFIDENCE

28th August 1986

CHERNOBYL ACCIDENT

IAEA CONFERENCE DAILY NEWS-SHEET NO 3

Report by Dr John H Gittus (UKAEA)

Wednesday 27th August. Working Groups - Session 2A (continued)

Release from the Reactor and Consequences for the Immediate Vicinity.

The release of radioactivity into the environment occurred in 4 phases.

1. The initial explosion propelled particles of fuel, complete with fission products into the atmosphere. A great deal of this fell locally, around Unit 4 and on the site.

2. The rate of release decreased due to the material dropped from helicopters on top of the reactor. The composition of this indicates that it is rather similar to the fuel itself.

3. The material on top of reactor insulates the core and the debris increases in temperature. Release increases and is predominantly of the more volatile fission products - iodine, caesium and tellurium although there is still a significant fraction from fuel particles.

4. A sharp reduction in release rate. This is attributed to improved cooling of the core and to the formation of more refractory chemical components which means that the fission products are locked chemically by the materials dropped into the reactor.

A combination of calculation and measurement was used to evaluate the actual releases of radioactive materials from the core. These calculations seem to be based upon detailed, but relatively local measurements. The results indicated that the release on the first day was about 12 million curies. The major release occurred over a period of about 10 days and up to 50 million curies of activity were released in all. A similar quantity of radioactivity associated with Noble gases was also released, but the radiobiological consequences would have been much less and it is usual not to include those quantities in further calculations. It is important to note that these releases were calculated on 6 May taking into account radioactive decay.

Over all, it is claimed that about 3 1/2 percent of the total radioactivity inventory was released to the environment, with differently large amounts of iodine, caesium and tellurium, the more volatile species. Some 15-20% of the total inventory of the reactor were released.

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Close to the reactor, the radiation levels were very high indeed in the early days of the accident. These levels seriously hindered recovery work and made continued operation of the other reactors difficult. Nevertheless, Unit 3 the one immediately adjacent to the damaged reactor continue to operate until 5 am - about 3 1/2 hours after the accident. Units 1 and 2 were shut down only some 12 hours later. the principal problems appear to have been that ventilation systems drew radioactivity into the buildings.

Many measurement around the reactor have been, and continue to be made. A 50 m square grid is used and readings are taken from both the ground and in the air. In the main, decontamination efforts seem to have been successful and the principal radiation source on the site is the damaged reactor itself.

The condition of the remains of the core are being monitored by special instrument "buoys", lowered onto the debris by helicopters on 240 m of steel rope. Ten will be installed, in total, so far 7 in place. These will provide data on temperature, heat flow and air flow required to determine how the planned concrete 'tomb' should be built.

Final decisions concerning the entombment have still to be made. Some of the requirements for this structure are:-

1. To protect the adjacent site, and particularly the other nuclear Units.

2. To remove residual heat from above the fuel and the collapsed part of the reactor.

3. To ensure proper monitoring of the important physical parameters.

4. To enable contingency plans to be made just in case something goes wrong after the entombment.

Whilst is was stated that an open ventilation system had been chosen for the design, the Russians were keen to invite any advice from other countries on how best to handle this phase of the operation.

Finally, the measures planned for other RBMK reactors were outlined again; they consist of four elements.

1. To reset the upper limit of level of control rods so they are permanently inserted 1.2m into the core. This essentially makes the core "smaller".

2. Reactivity margins will be increased by having a minimum of 80 effective rods as their requirement instead of the current 30.

3. In the longer term, fuel with a higher fraction (enrichment) of U 235 will be used. This will improve the situation on the positive void coefficient. Fuel of 2.4% enrichment has already been tested.

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4. 10 channels in the reactor will be adapted for rapid acting safety rods. These will act over a period of 1-2 seconds (compared with 20 seconds previously). The material for use in these rods has not yet been chosen.

Session 2B (continued)

Bone marrow syndrome occurred in patients who have received doses from 2 Grays (200 rads). They were treated as far as possible in sterilised ward conditions even though standard wards had to be developed for this purpose.

There was considerable press reporting of the bone marrow transplant operations. These were not successful for the patients concerned who had, however, received doses in the region of 4 Grays (400 rads) and most were suffering both from severe radiation sickness and severe radiation burns.

Prof.Kuskova warmly recommended work by Sir Edward Pochin on risk from radiation, which had proved in Soviet experience to be accurate.

Dosimetry

The meeting then heard from Prof.Pavlovski on dosimetry matters. Immediately after the accident people in the largest town in the area, Pripyat, were advised only to shelter because dose rates in the town were still comparatively low. Iodine was distributed to children's establishments because children (high consumers of milk) were seen to be more particularly at risk from thyroid dose. When the dose rate reached 1 roentgen per hour a day after the accident, evacuation had been ordered. It had now been calculated following the very considerable monitoring of people that for 97% of the people evacuated from Pripyat the iodine content of the thyroid indicated a thyroid dose of 30 rad (said by the speaker to be close to UK experience in the Windscale 1957 accident). Mortality from thyroid cancer may have been increased by 1%.

Measurements suggested that the majority of the population in the 30 km zone did not exceed a dose of 25 rem although a few people may have received 30 to 40 rem. The collective dose estimated for the evacuated population was 1.6 million manrems.

The accident had perhaps increased the national death rate in the region by 1.6%.

Decontamination

Dr Krakov then spoke about decontamination. Obviously contamination at the reactor site, around all 4 units was considerable. The principles worked to in decontaminating the area where:-

move from the dirtier to the cleaner areas.

work in the following sequence:

remove debris and rubbish;
decontaminate rooves and the rest of buildings;
remove 5 to 10 centimetres of soil for solid waste disposal.

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The soil removed from the plant area would be replaced by concrete. This would enable further work to be done. Walls would be sprayed with plastic and polymer adhesives which would form a protective film.

There was obviously a large decontamination problem in the 30 km control zone. There would be a considerable redistribution of nuclide deposition over the first year because the current distribution was loose and liable to move. The deposition of activity took 4 years to stabilise in the pine needles in pine forests. Sampling would lead to the construction of a map of the distribution of the activity. The aim was to restore the land to agricultural use but not with food going directly into the food chain. Substances would be introduced to the soil (lime, mineral fertilizers, solvents) to prevent nuclide movements.

Academician V I Trefiloc (Vice-Chairman Ukrainian Academy of Sciences - and Head of Physical Technical and Mathematical Science Section. He also covers some areas in USSR Academy of Sciences) provided an additional non-scheduled account of the post-accident activities of Government organisation of the Ukrainian Soviet Socialist Republic. A Government Commission and a daily operational group were set up, both headed by the Deputy Chairman of the Ukrainian Council of Ministers.

Priority tasks were:-

1. Protection of the population.

2. Localisation of the effects of the accident.

3. Guaranteeing the continue economic activity of the republic.

Factories, plants and a large number of industrial activities carried on around Pripyat were forced to stop and their production had to be replaced by other installations. There were many complex problems related to the evacuation of the population which had to be solved.

A large monitoring organisation involving many institutions was set up with a prime need of standardisation of measurements and the institution of additional monitoring.

A mathematical model was set up involving many different specialists which enabled the storage of a massive amount of data, including detailed hydrological, biological and geographical information. This provided a real time display and was of great value.

/...

There were considerable problems in localizing radioactive contamination especially in relation to the very large number of vehicle movements. Fully automated vehicle monitoring equipment was set up. Much attention was given rendering activity immobile. The clear weather over the nuclear site "guaranteed by the State Hydro-meteorological Commission for a whole month" was a good thing but conversely it increase the resuspension of activity. This was countered by spraying inexpensive, non-toxic substances over thousands of square metres every day, firstly roads, then soil and crops where wind erosion was substantial.

Increased precautions were taken in forested areas to prevent fires which would have redistributed activity on the leaves and forest litter.

In the first few days after the accident measures were taken to provide alternative water supplies. In Kiev 400 wells were bored to replace the supply normally taken from the Dnieper. Water purification techniques were introduced including the use of absorbers which reduced activity 100 fold.

Other major civil engineering works were undertaken and these were particularly substantial in the near neighbourhood of the nuclear site. In the near future the capability of natural purification processes will be assessed. So far they had little data on ground water contamination. He concluded by stressing that the situation both inside and outside the 30 km exclusion zone was now 'calm'.

In May and June urban decontamination of Kiev was effectd and it is now the "cleanest city in the world".

Press Comment

27th August 1986

The Times:-	Nuclear Power resiting for safety.
	Chernobyl rescue made leak worse.
Financial Times:-	Nuclear Blast may have led to Chernobyl disaster.
Daily Telegraph:-	Conscripts rebelled over Chernobyl clean up order.
The Guardian:-	Chernobyl workers strike.
Daily Mirror:-	Chernobyl clean up troops mutiny.

This sheet is issued by: The Director
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(Edited by the Nuclear Operations Services Engineer)

- 2 SEP 1986

29th August 1986

CHERNOBYL ACCIDENT

IAEA CONFERENCE DAILY NEWS-SHEET NO 4

Report by Dr John H Gittus (UKAEA)

Thursday 28th August

The meetings of the four Working Groups continued through Wednesday, 27th and Thursday 28th August. Delegates had posed nearly one thousand questions in writing during the earlier part of the week and these had been consolidated by a dozen experts to produce a smaller number of questions, which the Soviet delegates were now asked to answer. There was, initially, a rather hesitant approach to this, with the Russians at first asking for details of relevant accidents in other countries.

Session 3A, Working Group 1
Chairman - B Edmondson

Discussion of Phenomena and Factors associated with the Short-Term Accident Sequence.

This subject was intended to include the initiating event, sequence of events, reactivity excursion, containment response, instrumentation, operator response, stabilization measures etc.

Dr Edmondson, opening the session, outlined the goals, which were:-

1. To clarify information provided by the USSR delegation.
2. To exchange other relevant information.
3. To identify the broad requirements of nuclear plant safety internationally.

Over 350 questions had been condensed into questions corresponding to broad technical areas; these were:-

1. The accident and its causes.
2. Specify issued related to the sequence of events - particularly core performance.
3. Design of plant to mitigate operator actions.
4. Proceedings to be used to control special experiments or tests.
5. How to guarantee appropriate standards of staff training, management practices etc.
6. The important lessons which can be learned from this event.

/...

The consensus view of the experts was that the general features of the accident, as explained by the Russian delegation, were accepted. Everyone agreed that there were many matters of detail which still needed a considered explanation - but none of these bore materially on the general conclusions that the accident was caused by a combination of design fault and operator error which lead to a prompt critical nuclear excursion whose consequences led to destruction of the reactor.

A difficult situation now arose, where no country appeared willing to offer their own experience of similar accidents. The Russians requested this information, but in vain. Eventually a discussion commenced on one of the questions that had been posed: "What was it that brought the nuclear chain reaction to a halt?" The workshop could not, however, agree an answer, some thinking that it was at least in part due to the fact that some of the fuel had disintegrated and dispersed. The question was identified as one upon which further collaboration was desirable.

The next area discussed was that of operator training, management procedures and organisational matters. Dr Brown of Ontario Hydro was the IAEA-designated expert on this and he outlined the practices in Canada. This stimulated similar contributions from Sweden, Italy and France, all in the spirit of supplying information in response to that which the Russians had supplied.

Attention next turned to "Design and Safety". Dr Frescurn of Italy was the IAEA expert on this. Banks of Canada said that they had learned lessons in this area as a result of a relatively minor accident which occurred in the Canadian reactor NRX in 1954. They saw the need, afterwards, for a shutdown system which could be relied on to respond to all possible situations. The system must be quite separate from the reactor control system. That is: the reactor protection system must be separate from the reactor control system.

Derek Smith (UK,NNC) then described the UK design philosophy which is to employ interlocks which prevent the operators from switching off important safety systems. If they do, the reactor trips.

D Taylor (EPRI) continued the discussion by summarising the changes in thinking concerning the design of Control Rooms in the aftermath of the accident at Three Mile Island (USA). Much was being done with computers, graphic display and information processing. It was suggested that here was a topic to be added to the list of topics for future discussion.

<u>Session 3B, Working Group 4</u>
<u>Chairman - D Beninson</u>

Discussion of the Radiological Consequences of the Accident

This subject was intended to include plume-formation, aerosol dispersion, environmental effects, dose-assessment and health effects.

/...

The Working Party proceeded by considering composite questions compiled by the IAEA expert panel from the questions submitted by delegates. Participants included Dr Gale (USA) who visited Moscow during the crisis. There was detailed technical discussion on the biological and medical aspects. They will be covered and as far as possible summed up in the report of the Chairman of the Working Group to the final Plenary Session. Particular topics were as follows.

1. Methods of assessing doses to the skin.
2. Any complications where there are both radiation burns and thermal burns on the skin.
3. The merits and demerits of using chromosome analysis in addition to physical dose measurements.
4. Whether more is now known about average lethal dose and whether such information is in practice valuable in making clinical judgements.
5. Whether psychological effects had complicated treatment (they did not).
6. Contributions which can and cannot be made by using bone marrow transplant treatment.
7. The side-effects of taking stable iodine in order to block the thyroid (there were few).
8. A long discussion on the prospects for an epidemiological study in the USSR to follow up the Chernobyl data.

Prof. Ilyin, leading for the Soviet delegation, said that work had begun on considering the setting up of such a study but that he was pessimistic about the many difficulties that could arise in carrying our epidemiological studies. Several delegates, notably from the UK, urged the importance of carrying out the most effective study which could be managed whatever the problems and said that the 'UK would supply such methodology information as was available'.

Epidemiology

Academician Ilyin stated that if the IAEA would take upon itself the initiative of organising in some 6 months a 4-5 day workshop on epidemiological matters relevant to the Chernobyl accident, this would be of special support and help for the specialists in the Soviet Union.

He said that the Soviet Union could send experts in the cancer register, geneticists, and statisticians to this workshop.

It was agreed to ask the IAEA to support the workshop proposal.

/...

Session 4A, Working Group 2
Chairman - P Tangny

Discussion of Phenomena Associated with the Long Term Accident Sequence, Plant Recovery Measures and Radioactive Releases from the Plant.

Graphite fire, core damage, use of robotics, long term reliability of safety systems, recovery actions, radioactive release characteristics.

Non-Soviet delegates expressed interest in learning more about preliminary stages of fuel degradation, hydrogen production, possible water interactions, the fragmentation effects of fuel in the core, why one side of the reactor building (the north side) had been more damaged than the other and the number of fuel channels ruptured.

The Russians said that they found delegates' comments helpful in indicating some of the many areas in which further research was necessary. The south side of the building backed onto the machine room and was structurally stronger. That was why the explosion particularly affected the weaker north side.

It was confirmed that the estimated energy in the uranium oxide fuel at the time of the accident was 300 calories per gram - a figure of this order tended to be confirmed by research carried out in the USA (presumably an experiment in PBF) and in Japan. The fact that the top protective plate blew off, amongst other indications, confirmed that all 2000 fuel channels were destroyed - the zirconium was subjected to temperatures of 700 to 750°C and was then easily ruptured. When the upper plate lifted, all the coolant-exit pipes would have been destroyed.

Visual examination confirmed that only a small amount of graphite (10%) had been ejected from the reactor building. Fragmented fuel was not found in the graphite analysed, as most of the graphite came from the reflector regions.

The Russians had not yet formed any views on the extent of possible hydrogen formation through interaction of fragmented fuel with water and would welcome any contributions in this field.

A French delegate indicated the results of some of the French calculations on the accident. It was agreed that reactivity excursion was the likely explanation of the first explosion, the energy involved calculated to be 200 megajoules. The second explosion was either due to an excursion, a steam explosion or a hydrogen explosion.

The Russians said that they did not yet have satisfactory information on the location of the fuel. They hoped to know more later but it seemed that much of it was in the lower water pipeline areas.

They went on to discuss the interactions between concrete and uranium oxide. At 2300°K molten uranium oxide could flow through cracks and pores in the deteriorating concrete.

/...

Detailed calculations were being carried out to try to draw conclusions on the amount of air which had entered the core and any water reaching the core (evidently there was very little of the latter).

There was a presentation on fire fighting activities. Rules existed for all nuclear plant covering the need to protect essential systems, cables and equipment. All plants had their own fire fighting unit. Different measures were designated for different types of area - water for cable rooms, gas for control rooms, foam where oil was present, etc. The head of the unit at the Chernobyl station was experienced - 8 years general experience and 7 years on specialist simulators. All stations had a fire fighting plan.

Three fire fighting units were quickly deployed to the accident - from the plant and Pripyat and Chernobyl towns. The fire had been put out by 5 am mainly using water. Particular measures were taken to protect essential systems and prevent the spread to Unit 3.

The Russians proposed IAEA initiatives in a number of areas where improved knowledge was required - guidance on nuclear fire fighting methods, development of protective clothing, automatic fire fighting robots, graphite fires and consideration of problems in newer reactor systems.

Dr Tom Kress (Oak Ridge National Laboratories) posed questions concerning the nature and quantity of radioactivity released. He related the four stages of the release. The accident gave rise to releases to atmosphere due to two different mechanisms, the boiling off of the more volatile fission products and the mechanical dispersion of fuel particles. The mechanisms governing the latter process have not been widely studied.

The Soviet delegation said that they had a great deal of data which they intended to make available to everyone. They confirmed that the uranium fuel had undergone oxidation during the accident, and may have reacted with the graphite to form carbides.

Details of the amount of fuel materials spread around the site were given:-

i.e. 1. On the site itself - 0.3-0.5% of the fuel
2. Up to 20 km 1.5-2.0% of the fuel
3. to 30 km 1.0-1.5% of the fuel.

The size of the particles varied considerably, being from < 1μm (millionth of a metre) to 10's of μm's.

On matters, relating to Stabilization of the Core Debris, the expert was Dr D Powers of Sandia National Laboratories. The core debris did not interact with the concrete base mat of the reactor. Nevertheless, it was suggested that for other reactor systems it would be useful to exchange ideas and research data on the development of refractory (i.e. high temperature) concretes.

/...

Since the accident management procedures adopted appeared so successful more details were sought on the materials dropped on the reactor, where they went and the sequence in which they were dropped. The following further details were given. About 5000 tons in all were dropped between the 27 April and 10 May, the bulk of it between 28 April and 2 May. First 40 tons of boron carbide were used to ensure that the chain reaction was definitely shut down. Then 800 tons of dolomite (limestone) were used because the CO_2 generated when it decomposed in the heat would starve the graphite fire of oxygen. There followed 2400 tons of lead. The main purpose of this was to remove heat from the core bottom of the debris and carry heat away. The covering material was clay and sand to act as a filter to stop fission products reaching the atmosphere.

Questions on the special building being constructed to entomb the remains of the reactor concentrated upon the criteria which would be used for its construction.

The final part of the session was devoted to finishing the work of Working Group 1. In particular Mr Frescura again addressed the issues of design for safety. Prof. Kuglin gave an overview of procedures in the USSR. These included all the main features of western practice. That is: an examination of a wide range of possible events associated with failures of individual components, from which a list is agreed with the licensing bodies. This is the same for all reactor types. Using this agreed list a volume of "technological justification for safety" is submitted and agreed. From this is derived working documentation.

On the use of probabilistic safety analysis methods, it was said that these methods had been developed, along with the necessary data bases. A full probabilistic analysis had been done for the new RBMK 1500 design. Quantitative safety criteria were included in these. An example was given that the reliability of the reactor protection system was required to be about 10^{-7} per year.

In the summing up, the Russian delegation again chose to highlight the importance of human error and reconfirmed particularly the benefits to be had by further exchanges in the man-machine interface area.

Press Comment

29th August 1986

The Guardian:-	They think it couldn't happen here. Baltic reactor 'less safe than Chernobyl'.
The Times:-	Russians better prepared than Britain for nuclear emergency.
Financial Times:-	Soviet scientist wins plaudits for candour over Chernobyl.
Daily Express:-	Chernobyl could claim 75,000 cancer victims.

This sheet is issued by: The Director
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(Edited by the Nuclear Operations Services Engineer)

CEGB IN CONFIDENCE

1st September 1986

CHERNOBYL ACCIDENT

ADDITION TO IAEA CONFERENCE DAILY NEWS-SHEET NO 6

PRESS COMMENT

30th August 1986 (Saturday)

Financial Times:- IAEA calls for nuclear safety boost

Chernobyl: the lessons for east and west

The Post Mortem's 13 proposals

The Times:- Experts urge research into nuclear fuel dangers

The Guardian:- Progress after Chernobyl

Daily Telegraph:- 'No problems' with second A-plant

31st August 1986 (Sunday)

The Observer:- The monster in our midst.

Sunday Times:- Experts to vet British reactor,

News of the World:- Exposed! Russian roulette in the power game

UNDER SECRETARY/ATOMIC ENERGY DIVISION

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5.19

2 September 1986

R N Simeone Esq CBE
UKAEA
11 Charles II Street
London SW1

Dear Reggie,

Post Chernobyl Review Meeting 24-29 August

You will have seen Dr Gittus' reports on this meeting. I am most grateful to him for taking on this task, which was widely appreciated by our delegation.

The review provides a number of lessons, I believe; the need for constant vigilance and attention to detail in all safety matters; the need for continuing international action to help bring standards everywhere to the highest; and the need to plan effectively for the worst in our emergency work.

I am writing to you now on one specific point. It is generally accepted that a prompt critical excursion triggered a steam explosion which lifted the pile-cap. We can expect questions about the nature of such excursions; the risks of this occurring in the UK; and if so, what their consequences might be. It was pointed out by Tanguy at Vienna that a prompt critical event such as Chernobyl has a multiplication time-constant of milliseconds, and that this is not the same as the almost instantaneous 'super prompt critical event' of a bomb, where the time-constant is nano-seconds. Nevertheless the layman may perhaps be forgiven for regarding the event at Chernobyl as being a type of nuclear explosion, even if not of the force or magnitude of a bomb. It is important that we get the language right. To talk of a 'prompt critical event' may sound to some like a technical obfuscation. From what I understand, the event was indeed a 'form of explosion', and would be grateful for your views on whether there is any great difficulty about using the phrase, in layman's language, to describe what happened.

I should also be grateful for advice on the following:

(i) is there any risk of positive void coefficient in any Authority reactor?

(ii) is there any risk of either a prompt critical (or super prompt critical) excursion in any Authority reactor?

Yours sincerely

David

D I MORPHET

cc Dr Gittus

File No. 8479
4.9

6760
15/9

ACTION

cc [redacted]
RS Peckover
FR Allen
} for urgent comment to Dr Gittus
M. J.

Chairman

c.c. Dr. T.N. Marsham
Dr. G.G.E. Low
Mr. C.W. Blumfield
Dr. J.E.R. Holmes
Dr. W.M. Lomer
Mr. R.L.R. Nicholson
Mr. M.A.W. Baker
Mr. F. Chadwick
Dr. J.H. Gittus ✓ Good JHG.

Post-Chernobyl Review - Prompt Critical Excursions

You will wish to see the attached letter from Mr. Morphet, a copy of which has already been sent to Dr. Gittus. I think it would be helpful to have Dr. Gittus's proposals on how I should reply to the two questions at the end of Mr. Morphet's letter, but I have copied the letter widely and would be grateful if Dr. Gittus would circulate his proposals to the copy addressees of this minute.

R.N. Simeone
(R.N. SIMEONE)

3rd September 1986

Dr. J.H. Gittus
2-9

SECRETARY'S DEPARTMENT
Chairman's Technical Support Unit

To: 1. All Participants.
2. Mr. A.W. Clarke, S8.01

From: L.M. Davies, S14.04 1 September, 1986.

IAEA - Chernobyl Meeting
August 25-29, 1986

Some corrections have been made to the last paragraph of the attached note which was prepared for "broad guidance" last Friday (29th) in Vienna.

LMD/TMH
Encl.1

Revised 1 Sept., 1986.

1. The Russians have been very frank and open about the Chernobyl accident.

2. The accident happened because of a series of operator errors.

3. But the Russians have openly acknowledged that the blame cannot be put on the operators alone. They have admitted design faults which if corrected would have prevented the accident.

4. To amplify this point, Legasov, the leader of the USSR delegation explained that when the RBMK reactors were first planned (more than twenty years ago) the Russians realised that the concept had several 'shortcomings'. In particular it had

a) a positive void coefficient,

b) an instability in the power density distribution in the core (which requires a complex control system)

c) a high energy store in the graphite and metal structure

d) a complex piping system.

But the concept had the merit of being 'buildable' by Russian industry at that time.

5. The decision was taken to build the RBMK reactors and use engineering to overcome these 'shortcomings'.

6. In implementing this decision Legasov stated "The designers made a tremendous psychological mistake. They relied upon written instructions to the operators - not technical means - to maintain sufficient reactivity margin. This, the Russians now realised, placed too much responsibility on the operators.

7. In acknowledgement of this the Russians have already closed down some of their RBMK reactors to make technical changes which prevent control rods being completely withdrawn.

8. They also announced plans to consider rapid acting and independent reactor shut down mechanisms.

9. They also plan to enrich their fuel and add permanent absorbers in the long term .

10. These three technical changes to the design are sufficient, we believe, to avoid recurrence of accidents of the Chernobyl type.

11. The Chernobyl accident was of the type called a "prompt critical excursion". The incident was primarily caused by a combination of

1. the positive void coefficient
2. the weak and slow control system of the Russian design,
3. operator error.

The features (b) and (c) above also contributed to some extent.

12. The prompt critical excursion caused an explosion of the fuel and triggered an enormous steam explosion (perhaps with some further critical excursion of the remaining fuel).

13. The Russians appear willing to join in further discussions on the Man-Machine interface and on, "Design to avoid operator error". This is very important because it seems likely that at the present time the Russians do not have the same "safety climate" as ourselves and, given the shock of Chernobyl, seem willing to change their style.

14. Are these changes enough for us to have confidence in the safety of the Russian reactors? We cannot tell because the conference has concentrated heavily on the specific causes of the Chernobyl accident.

15. But, even with the changes the Russians are now making, we would not consider building them in the UK. Obviously, however, through international collaboration, we want to encourage the Russians to make their reactors as safe as possible.

JHG

16. We shall publish a full account of the details of the accident sequence in a short time. That detail will reinforce our claim that an accident of the Chernobyl type could not happen in the UK.

17. The meeting as a whole endorsed a set of recommendations to the IAEA. Apart from the Man-Machine interaction mentioned above, they all concern post accident matters. This confirms our judgement that so far as reactor design or operator performance are concerned we have little to learn from this incident. Nevertheless we shall review all our design and operational procedures to make quite sure that any safety lesson that can be learnt, will be thoroughly absorbed. In contrast the incident has given us a great deal of valuable information about medical, emergency and radiological matters.

8522
12-9

MEMORANDUM

Your Ref.
Our Ref.
Tel Ext. 7219

To Dr M R Hayns

Subject UNDERLYING RESEARCH PAPER TO SRDBM

Mike

The discussion at the SRDBM concerning the paper on Underlying Research funding for SRD projects raised a few points to note and some possible minor modifications to our paper.

1. There is now an Underlying Research Review Committee (URRC) with an oversight role for the UR programme.

2. The proposed SRD projects fall largely into the Theoretical area and a first approach might be made to Lidiard who is Head of that area (suggested by Vic Crocker).

3. Vic Crocker thought that the environmental consequence modelling projects might overlap RPR projects in some cases and this should be looked at.

4. Under Section 5 para 2 it was noted that UK industry needs to have positive evidence of UR projects contributing to its requirements if such industry is to be encouraged to pay the 10% levy.

5. Under Section 5 para 3 it was noted that the problems of GNSR being driven by immediate applications is made worse now that the CEGB are part funding GNSR. There is thus even less prospect of GNSR being able to fund the depth and breadth of fundamental research.

6. Under Section 6 Vic Crocker made the point that with increasing pressure on UR funds there is an even greater need to ensure that all projects are of high quality (our criterion (i)).

Geoff

G M Ballard

11 September 1986

cc
J H Gittus

FAX: IMMEDIATE

DISTRIBUTION

Mr D I Morphet, Dept of Energy
Dr A G Duncan, Dept of Environment
Lord Marshall, CEGB, Sudbury House
Mr A W Clarke, CEGB, Sudbury House
Mr P Vey, CEGB, Sudbury House
Mr L M Davies, CEGB, Sudbury House
Dr J K Wright, CEGB, Courtenay House
Mr J R Appleby, CEGB, Sizewell 'B' Project, Knutsford
Dr E W Carpenter, CEGB, Berkeley Nuclear Labaratories
Mr H MacDonald, CEGB, Berkeley Nuclear Laboratories
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Mr B C Carpenter, UKAEA, LHQ
Dr A E Eggleton, UKAEA, AERE

Dr B Edmondson, INSAG, CEGB Sudbury House
Dr J D Young, INSAG, CEGB, Berkeley Nuclear Laboratories
Mrs M Hill, INSAG, NRPB

FROM: DR M R HAYNS, SRD, UKAEA, CULCHETH, WARRINGTON

SUBJECT: CHERNOBYL ACCIDENT

AS AN ADJUNCT TO JOHN GITTUS' NOTES OF THE VIENNA MEETING I HAVE PRODUCED THE FOLLOWING WHICH GIVES A SLIGHTLY MORE DETAILED DESCRIPTION OF THE ACCIDENT AND ITS IMMEDIATE CONSEQUENCES.

DR M R HAYNS
HEAD OF NST

1 SEPTEMBER 1986

PLEASE FIND ATTACHED 10 PAGES

MRH1

A SUMMARY DESCRIPTION OF THE EVENTS LEADING TO THE ACCIDENT AT CHERNOBYL UNIT 4, AND THE IMMEDIATE ACTION TAKEN IN RESPONSE TO IT

M R Hayns
Nuclear Safety Technology Branch
SRD

INTRODUCTION

Unit 4 of the Chernobyl nuclear power station was scheduled to be shut down for its annual maintenance on the 25 April. During the process of shutting down the reactor it was planned to perform tests in which electricity was to be extracted from the turbo-alternator during its rundown after the steam supply had been shut off. This electricity was to have been used to power the main circulation pumps. What follows is a chronological account of what happened,. It concentrates only on the important actions and events.

Chronology of the Accident Sequence

25 April 1986

01.00	Commencement in power reduction for maintenance shut down.
13.05	50% power level (1600 MW(th)) achieved. Turbo-alternator number 7 is disconnected from the grid and all house load transferred to the still operating number 8 unit.
14.00	In accordance with the experimental programme, the reactors emergency core cooling is disconnected. Controlled power reduction to 1000MW, for the start of the test was delayed by a request from

the controller in Kiev to keep supplying electricity to the grid. The ECCS was not switched back in violation of the operating rules.

23.10 The power reduction programme is resumed. The aim was to perform the test with the reactor at between 700 and 1000MW. On going to lower power, that set of reactor control rods used to control the power of the reactor at high powers (confusingly called the Local Automatic Rods LAR's) was switched out and a set of rods called the Automatic Rods switched in. However, the latter had not been pre-set for the power-level required (synchronized) and the operator was unable to stop the power of the reactor falling to 30MW(th).

26 April

01.00 Operator succeeds in stabilizing reactor at 200MW(th). Because of poisoning, he has had difficulty in achieving this level and has done so only by removing control rods from the core. His available reactivity at this time was well below the limits laid down in the regulations.

01.03 and 01.07 One additional main circulation pump is switched into each coolant circuit. This made a total of 8 working. This was done to ensure that 4 pumps will remain working after the test (four being involved in the test).

Switching in these pumps increased the flow rate into the core. Since the reactor was already at low power, the hydro dynamic resistance was very low and the flow rate of water through the core was very high. Some pumps were operating beyond their permitted operating regimes. The increased flow caused a reduction in steam formation and a consequent fall in pressure in the steam drums. By this time essentially solid water is being circulated through the reactor. \ loosely led by dilution in steam-drums.

01.19 Operators then tried to increase the pressure and water level by using the feedwater pumps - the reactor should have shut down on low water level in the steam drum but the operators had disengaged that signal. Because the water is replacing steam, the reactivity continues to drop. The water in the circuit is being heated and is nearly at its boiling point.

Cooled it down & reduced pressure.

01.19.58 Turbo generator bypass valve closes. Steam now not being dumped in the condenser.

to increase pressure (temperature) rises

01.22 Operator reduces feedwater flow. No cooler water now going into the reactor.

(temperature) rises

01.22.30 A print out of the available reactivity margins is produced - the parameters are such that immediate shut down is required but the operators continue [there is no automatic shut down on this signal].

temperature rises

01.23.04 Test begins, the regulating values to turbo generator number 8 are closed. Reactor power is still about 200 MW(th). The shut down signal for loss of two turbo generators has been blocked by the operators to permit a re-run of the test if the first is not successful.

steam going nowhere, pressure rises, countering the production of 'void' somewhat.
2×2 4 pumps running off grid
2×2 4 - off turbine → run down & causes boiling

The power of the reactor begins to rise slowly.

01.23.40 Shift foreman orders full emergency shut down. All control and shut down rods are power driven into the core. Not all rods reach low stops, foreman 'unlatches' rods to fall under their own weight. Shocks are felt.

01.24 At about this time observers outside the reactor report two explosions about 3-4 seconds apart. Burning lumps of material and sparks are thrown into the air - some land on the turbine hall and start fires.

What Had Happened

The simplest agreed explanation is that the combination of lower power and high flow lead to the reactor being in its worst state for availability of shut down reactivity. The fact that the channels were full of water at the start meant that the maximum contribution from the positive void coefficial of this design was available. Further, by operating in this mode, the entire coolant circuit was very near to its boiling point at the start of the test. Once the test was begun, the main circulation pumps began to run down, reducing the flow of water through the core. Since the water was almost boiling on entry to the core, flow reduction soon caused boiling in the channels; introducing steam increased the power and this caused more boiling. The power rose very rapidly, leading to a prompt critical excursion. Over a period of about 1 second, the power rose to about 100 times nominal full power. Detailed calculations indicate a second excursion going to some 440 times overpower after this. Energy is deposited into the fuel at a high rate and, because of the large size and thermal inertial of the reactor, it cannot escape. Entrained fission gases shatter the fuel. This is mixed with the steam/water mixture in the channels, heats the steam rapidly and the steam pressure blows off the pile cap, tearing out all the coolant pipes from above the reactor. There is some debate as to whether the second explosion reported is due to a second prompt critical excursion, or to flammable gases produced by the oxidation of zirconium (hydrogen) or interaction of water with hot graphite (carbon monoxide).

The force of the explosion destroys the reactor hall and scatters about 6-8 tones of irradiated fuel into the environment. Some 1-2 tones of this land on the site itself, the remainder is spread on the wind in the form of aerosol particles around the reactor - most of it within 30 km.

After the explosion, the core is exposed to air and the graphite burns. Over a period of about 9 days, significant amounts of activity continues to be released into the atmosphere. This is eventually stopped by blanketing the core with various materials, up to 5000 tones in all.

Response to the Accident and Protective Actions

Because of the large amount of radioactivity distributed around the site, immediate remedial action was very difficult. However, because the fires started by the hot material ejected from the reactor posed a serious threat to Unit 3 (which was not shut down for another 3.1/2 hours after the explosions) and to other potentially dangerous materials on site, the first remedial action was to control these fires with little regard to radiation protection. This lead to the deaths due to over exposure amongst the fire fighters.

Chronology of the Emergency Response

26 April 1986

	Elapsed Time	
01.24	0	Explosions in the reactor, activity spread around the site.
01.30	6 min	Site medical centre alterted, 3 staff on duty.
		Around this time the Moscow emergency centre is notified using the code words nuclear, radioactivity and fire.
01.45	22 min	2 fire and emergency teams dispatched

		from Pripyat Regional hospitals alerted.
02.10	46 min	29 casualties admitted to medical centre.
03.00	1hr 36 min	Stable iodine tablets issued on site.
about 06.00	5hr	Local fires extinguished. Graphite fire continuing. Some confusion over messages sent to Moscow emergency centre. Later reports indicate 'reactor under control' when in fact the reactor had ceased to exist at 01.24 hrs.
11.00	10hr	Moscow emergency team fly to Kiev.
20.00	19hr	Government commission arrive and take charge. Stable iodine issued house to house in Pripyat. Sheltering order advised.
21.00	20hr	Decisions taken on evacuation of Pripyat. Initial plume had missed the town and levels were low. However, the original evacuation plan could have taken people from areas of low danger to high. Plans re-evaluated.
27 April		
11.00	34hr	Pripyat evacuation started. 45,000 people evacuated in 2.1/2 hours.

30 April		
	4 days	Releases reduced to about 2 MCi*/day.
1 May		
	6 days	General milk restrictions imposed at a level of 0.1 Ci/l. This is said by Russians to correspond to 30 rems for children. UK figures might indicate 10 rems.
4-5 May		
	8-9days	Activity release increases. Mainly due to thermal insulation effect of material dumped on top of the core. Fuel temperatures reach > 2000°C. Volatile fission products driven off, but still a sizeable contribution from entrained particles. 90,000 people evacuated from the 30 km zone.
6 May		
	10 days	Release rate falls to below 0.1 MCi/day due to both improved core cooling and chemical reactions forming more refractory compounds. Issuing of stable iodine discontinued.

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*Release calculated relative to 6 May. Actual release on that day would be higher.

8 May

13 days First restriction on foodstuffs commenced. Based possibly on 5 rem to the consumer.

9 May

14 days Release rate down to 0.01 MCi/day.

12 May

17 days Further (but insignificant) restriction on foodstuffs.

30 May

35 days Revised and extended restriction on foodstuffs. Certainly based on 5 rem whole body dose.

Medical Aspects

The medical response to the Chernobyl accident was rapid, highly organised and clearly professionally competent. In the first 36 hours some 350 individuals had been seen in the local medical centre and 129 patients of 203 ultimately diagnosed as showing acute signs of "radiation sickness" had been evacuated to a single specialist hospital in Moscow. These patients were intensively studied, including in vivo dosimetry using blood lymphocyte counts and chromosome aberrations in cultured lymphocytes. The clinical classification of severity of the acute syndrome proved a good predictor of the ultimate severity of the patients' illness. Only 5 patients had significant thermal burns, but the majority had skins burns from beta irradiation up to 100% of their body surface. 21 out of 22 patients who received doses greater than 6 Gy died within 28 days, while 7 out of 23 died after doses of 4-6 Gy, and only 1 out of 98 died after doses below 4 Gy. Treatment was conventional, involving isolation, aseptic (sterile) technique, support with intravenous fluids, blood and blood products, antibiotics, conservative skin care up to skin grafting where necessary. Allergenic bone marrow grafting was carried out in 13 patients and a further 6 patients received transplants of human embryo liver cells. In two of these patients subsequent graft-versus-host reactions may have contributed to the death of the patients and in no case was the transplant a decisive factor in survival. Most deaths were due to overwhelming skin damage due to the initial beta irradiation, in the presence of marrow and other damage from penetrating radiation, not to marrow failure alone.

No member of the public suffered from the acute radiation syndrome. The population evacuated from the 30 km zone around the Chernobyl reactor was intensively investigated as well. This included thyroid counting, blood studies, and, for many, total body gamma counting. Although a register of all the evacuated persons has been compiled, no firm decisions have yet been made as to the extent of health monitoring of this population which will be undertaken for epidemiological purposes.

Other Remedial Actions

During this period, considerable efforts to decontaminate the site, and the local regions were undertaken. On site, soil was stripped to a depth of 5-10 cm and buried or the ground was covered in concrete. Washing down with water and the use of polymerizing solutions to "fix" fission products was undertaken. A great deal will have been learned from these activities but will take some time to digest.

Long-Term recovery plans are in hand to allow the site to be operated again. Unit 4 itself will be entombed in a special building. It is planned to have Units 1 and 2 back in operation in a few months. Unit 3 is more problematical, but, in the longer term it is hoped to operate it again once extensive checks have been carried out.

SAFETY AND RELIABILITY DIRECTORATE
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3 Sept. 11 Sept. 12 at
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From
Dr John H Gittus
Director

31 August 1986

50
36 Authority

Mr A M Allen
Chairman
UKAEA
11 Charles II Street
LONDON
SW1Y 4QP

Dear Arnold

CHERNOBYL ACCIDENT: SOME QUESTIONS ANSWERED

I have listed five questions in an ealier memo. The Russians gave information in Vienna which has enabled us to pencil in the following answers.

Q1. What happened?

A1. As a result of operator malpractice and design-deficiencies the reactor went prompt critical. The ensuing release of energy shattered the fuel, burst the pressure tubes, lifted the pile-cap and shot about five tons of irradiated fuel into the air. Some, about 2 tons, fell near the reactor. The fuel temperature in the core rose to over 2000°C during the week after the accident. All of the fission gas and about 15% of the caesium and iodine were released and blown to distant countries by the wind. It did not rain round about Chernobyl for five weeks. Elsewhere rain washed caesium from the plume to the ground in several places, including the north-west of England and Wales, causing local 'hot spots'.

Q2. What were the consequences?

A2. Thirty-one early deaths. As for the late cancer deaths: these may be far less numerous than had been deduced from the early information - thousands instead of tens of thousands over the next fifty years. The Russians expect to return much of the contaminated area to "partial economic use" quite shortly - next year perhaps.

Q3. Could it happen again?

A3. Yes, the Russians do not appear to have an entirely satisfactory grasp of the physics of the RBMK reactor, thus they had not convinced western reactor physics specialists to whom I spoke that the remedies which they (the Russians) propose will be adequate. Moreover, RBMK reactors are still operating to which not all of the remedies have been applied.

Q4. How effective were the Russian emergency arrangements?

A4. Very. Even making allowance for the gloss which they have, most probably, applied to their account of the fire-fighting, evacuation, medical attention and clean-up, there emerges an impressive picture. The military were involved and it seems that the peasantry were forcibly evacuated when necessary. They had, they said, plans to deal with such an emergency.

Q5. What are the Russian "Institutional arrangements"?

A5. Similar to ours, but appear not properly enforced. They did produce a safety case for the experiment at Chernobyl but had not received any response from the "Inspectorate" to whom the case had been sent. This did not prevent them from performing the experiment. The safety-case did not say that they would switch-off the main automatic protection devices but switch them off they did. It did not say they would operate with an "illegal" and highly dangerous reactivity margin. But they did this too.

I am not prepared to believe that none of these infringements have ever happened before: it is habitual I am sure. I am unconvinced that they have yet changed their attitude, either. For example, they continue to operate RBMK reactors.

Yours sincerely

John Gittus

J H GITTUS

cc Mr R N Simeone

JHG

INTERNATIONAL ATOMIC ENERGY AGENCY
POST ACCIDENT REVIEW MEETING ON THE CHERNOBYL ACCIDENT
25-29 AUGUST 1986

REPORT BY

DR JOHN H GITTUS
Director, Safety and Reliability Directorate
United Kingdom Atomic Energy Authority, Culcheth

31 August 1986

SUMMARY

This meeting of 400 or so experts from Member States had been convened in order to permit the Russians to present their account of the Chernobyl nuclear accident. Opportunity was afforded for Member States to put technical questions so as to improve their understanding of the Russian account.

From my notes of the meeting, the notes of UKAEA colleagues and the documents tabled by the Russians, I have prepared this factual report.

THE ACCIDENT ITSELF

There has emerged a satisfactory working knowledge and understanding of the accident. In brief, the Russians wished to measure the ability of a turbo-alternator to power certain of the cooling pumps whilst free-wheeling to a standstill. It would be advantageous briefly to extend the operation of the cooling pumps in this manner if, following accidental disconnection of the station from the grid, steam had to be diverted from the turbine and the reactor shut down.

As the alternator slowed down, so did the pumps and a point was reached where they were no longer pumping enough water through the reactor to keep it cool. At this point the automatic safety system should have tripped the reactor but it did not, because the operator had turned off the safety system although forbidden to do so. Accordingly the reactor began to generate additional steam and this formed extra bubbles and voids in the cooling water. The amount of heat being generated rose as a result of the voids, because the reactor has a positive void coefficient. A run-away situation had developed, the additional heat generating still more steam.

The operators tried to extricate themselves by releasing the control rods so as to trip the reactor, but they were too late and part of the reactor went prompt-critical. The temperature then rose steeply, fuel disintegrated, steam pressure burst pressure tubes and lifted the pile-cap. Several tons of fuel escaped. Ten to twenty percent of the radioactive iodine and caesium escaped and were carried some hundreds of miles by the wind, causing contamination.

The Russians stated that their reactor design has deficiencies and that these, coupled with operator errors and a deliberate flouting of safety instructions, led to the accident.

PREVENTIVE ACTION BY THE RUSSIANS

To prevent such an accident happening again in another of their RBMK reactors, the Russians have decided to increase the amount and speed of insertion of control rods. The fuel enrichment will be raised to maintain the discharge burnup. They will, in addition, supply the operator with better facilities with which to control the reactor, and give him better training. Half of the reactors have been shut down pending these improvements.

THE OUTCOME OF THE ACCIDENT

Given the nature and severity of the accident, the description of the outcome and consequences given by the Russians seems reasonable. Thirty-one people have died as a result, so far. Some thousands of people in the USSR have received quite high doses of radiation which will, in a proportion of cases, shorten their lives and thousands of square kilometers of Soviet territory have been rendered radioactive.

The Russians are decontaminating their land and buildings and rehoused a proportion of the 135,000 Russians who were evacuated. They are drilling new wells and filtering water supplies in the neighbourhood of the stricken reactor. It will be a year or so before life begins to return to normal in this part of Russia and even then it will probably not be possible to live and work close to the power station, although special precautions will probably be taken to make it safe to resume the operation of the other three reactors on the site.

FUTURE INTERACTIONS WITH THE RUSSIANS

The Russians have shown themselves willing to continue the discussions and interactions at future meetings and "Workshops". They recognise that the West has something to offer and we, on our side, wish to help ensure that this never happens again. Of the various items agreed for the future, three were touched upon by Lord Marshall in discussions with the Head of the Soviet delegation: a workshop on the man-machine interface, a meeting on decontamination and collaboration on medical matters, Workshops and discussions will also occur, concerned with other issues including movement of radioactivity in the environment, the effects upon man, and emergency measures such as fire fighting.

CONCLUSIONS

Thirteen areas of international collaboration were agreed at the Plenary Session, as follows:

1. Severe accident scenarios and phenomenology

2. The man-machine interface: ergonomics - information display etc

3. The balance between automation and operator action

4. Exchange in experience in operator training procedures and management, IAEA to consider international accreditation of operators

5. International standards to be reviewed to ensure lessons learned from Chernobyl are incorporated.

6. Fire protection standards to be upgraded for nuclear power plant operation

7. Setting international Emergency Reference Levels

8. Decontamination

9. Dispersion in the environment - air, food-chain, water

10. Assessment of individual and collective doses

11. Optimization of epidemiological methods

12. Efficiency of treatment procedures for radiation sickness/burns

13. Efficiency of treatment procedures for late health effects.

The meeting has achieved several important objectives, in confirming the nature of the Russian reactor accident and its consequences. It has created a framework within which further discussions and joint work should be possible. These were the main objectives of the UK team and a significant role for UK experts is foreseen in the planned future interactions between Russia and Western countries.

IAEA POST ACCIDENT REVIEW MEETING
ON THE CHERNOBYL ACCIDENT, 25-29 AUGUST 1986

REPORT BY DR JOHN H GITTUS (UKAEA)

Monday, 25 August, Plenary Sessions
10.00 to 11.00 hours: Opening of the Meeting

The audience was divided between two rooms, one being provided with closed circuit television. The meeting commenced at 10.00 am, many TV crews being present for the first speech.

Blix, Director General of the IAEA, opening the meeting, said the results would be transmitted to the IAEA Board before its September meeting. He drew parallels with the Agency's response to the accident at Three Mile Island. Already, following the Chernobyl accident, at the Agency there had been formulated schemes for international accident notification and emergency response. These were to be formally adopted in September. We would not be asked to endorse any resolutions. A factual report to the IAEA Board of Governors on the outcome of the meeting would be prepared by the Secretariat and INSAG (the International Nuclear Safety Advisory Group) in the week following the meeting.

Rometsch, Chairman of the meeting, spoke next. The meeting had three objectives as he saw it:

(1) To understand the lessons of Chernobyl

(2) To apply them, where relevant, in our own countries

(3) To assist future international collaboration on nuclear safety.

Legasov, head of the USSR delegation, then addressed the meeting. Construction of nuclear power plant was receiving priority in the USSR since without it they would be "unable to master" the next stage in the development of their society. The Chernobyl incident was a disaster. On a world scale it was leading to a re-evaluation of the part to be played in future by nuclear power. In the USSR since the accident there had been an intensive development of accident- prevention measures and a parallel analysis of the nature and effects of the accident itself. The work continues. The USSR would be entirely open to suggestions about decontamination and other methods of limiting the impact of the Chernobyl accident. They would like to open up discussions on all possible ways of improving the reliability of nuclear installations, of reducing risk and of mitigating the damage done should another accident occur. He listed the many eminent USSR engineers and medical specialists who were present at the meeting, indicating their direct involvement with the practical response to the accident. His own work, apart from Chernobyl related responsibilities, was on the development of the High Temperature Reactor at the Kurchatov Institute.

11.00 to 13.00 hours: Overview of the Accident

Legasov now presented a video of the sequence of events in the Chernobyl accident. The reactor power had been teetering on the brink of dangerous thermal hydraulic and neutronic instabilities because the operators had turned off vital safety systems and had too few absorber rods in the core. When they diverted steam from the turbine this was the last straw. The reactor power rocketed up, steam pressure burst the reactor and the overheated fuel then gave off many millions of curies of radioactivity. Within a day or so the 100,000 or so people living up to 30 km away were evacuated.

He went on to describe the RBMK reactor. This has a graphite moderator pierced by holes or channels, lined with zirconium-niobium tubes and containing the uranium dioxide fuel. Water in the channels is boiled by the fuel. This produces the steam needed to drive the turbo-alternators and it also keeps the fuel from overheating, by continuously removing the heat generated by nuclear fission. The rate of heat-generation is controlled by inserting or withdrawing neutron-absorbing rods. There are pumps to pump water into the bottom of the channels and it boils as it rises up the channels. A mixture of hot water and steam emerges from the top and passes through pipes to steam-separators. Here the steam collects above the water and is led by pipes to the turbines whilst the water is drawn off and pumped back through the channels to be boiled again. The steam from the turbines is condensed and it, too, is pumped back through the channels, completing the cycle.

Legasov summarised the conditions of coolant flow, level, temperature or steam-content which could, if allowed to persist, lead to an accident and which therefore normally automatically trigger a "trip" or cessation of heat-generation due to fission. If there are fewer than 15 neutron control rods inserted in the reactor then the rules require it to be tripped by the operators. They judged that the probability of the operators failing to trip it in such a case was lower than the probability of failure of a purely automatic trip system. In the event it was precisely this error that the operators made. They had fewer than 15 rods but did not trip the reactor, leaving it critical and poised on a knife-edge.

Legasov went on to describe the safety systems which take the heat away should an accident commence: the emergency core cooling systems. Then he described the containment philosophy: the steam separators, the pumps and the pipes leading to and from the channels are separately contained each in its own concrete cell or box. Tubes from each cell are immersed in a "bubbling pool" and the pressure in the cell is relieved by bubbling should a pump, a separator or a pipe burst.

In the afternoon Legasov continued, now concentrating in greater detail upon the reasons for the accident and its progress. Although he followed quite closely the written report which participants had been given he added several important points. In particular he said that the operators felt that they were under extreme pressure to complete the planned experiment that night since they knew that it would be a full year before they would have another chance. It was "a tremendous psychological mistake" on the part of the designers of the RBMK reactor that they did not foresee that additional protective systems would be needed in the core in order to trip the reactor and keep it cool even if (as occurred in the Chernobyl accident):

(a) the operators deliberately switched off the standard protection systems and in addition

(b) completely disobeyed the safety rules concerned with the minimum number of control rods which must be inserted.

This, he said, was the case against the RBMK designers: "Now, with hindsight we can see that it could have been prevented in a very easy way using technical means" (by which he meant engineered safety features, not written rules). He illustrated what had happened by means of an analogy. It was, he said, as if the pilot of a passenger plane suddenly started testing the 'plane in the flight: opening and closing the doors and switching off safety systems. He suggested that the Soviets had realised, somewhat later than other countries, the need to protect against this kind of human fallibility.

As for the detailed progress of the accident: this is involved. In essence what Legasov says happened was as follows:

The operators tried to power the coolant pumps using electricity from a "free-wheeling" turbo-alternator. As the alternator slowed down, so of course did the pumps which it was driving and so the amount of steam being produced increased. It was this that triggered the accident. The operators tried to insert the control rods but the rods were mostly so far out of the core (only 6 were inserted instead of the minimum of 30 required by the rules) that long before the rods could have shut the reactor down it had run away, the power rocketing up. The steam, now produced in vast quantities, burst the pressure tubes. Next the uranium dioxide pellets disintegrated with a further explosive generation of steam which blew the top cover (pile-cap) off the reactor and exposed the hot fuel to the air. Hydrogen and carbon monoxide were produced by the oxidation (in steam and air) of graphite and zirconium. These gases burned or exploded in the air. Volatile and gaseous radionuclides were freely evolved into the air by the overheated fuel.

None of this would have happened had the operators, (by switching off vital safety systems and ignoring the rule about the minimum number of inserted control rods) not allowed the reactor just prior to the experiment to be poised on the threshold of just such a reactivity-excursion.

Development and Consequences of the Accident

The attention of the IAEA meeting now turned to the immediate consequences of the accident. Legasov continued the presentation, following the written report once more.

The initial release of radioactivity missed the adjacent town of Pripyat. Evacuation was delayed, but Legasov defended this saying that they were initially safer where they were. Indeed those in stone houses were forbidden to leave since the masonry sheltered them from radiation. However, the graphite fire, the increase in graphite temperature and the continued release of activity soon made evacuation of Pripyat vital. It was accomplished in 2½ hours.

The amount of radioactivity released was greatest on the first and ninth days following the accident. The second peak occurred when decay heat and fire had raised the core to its maximum temperature of 2000°C. The graphite fire resulted in the production of a radioactive aerosol which went up into the atmosphere. It was to stifle the graphite fire and stop the escape of the aerosol that 5000 tons of sand, boron carbide and lead were dropped onto the exposed face of the reactor from helicopters. The boron carbide was to prevent fission from restarting locally. The lead was to absorb heat, absorb radionuclides and shield the helicopters from gamma radiation. The sand and clay were to act as aerosol filters. By 6 May the release of activity had ceased, or virtually so, the rise in temperature having been reversed by natural convection of air and by creating a forced flow of cold nitrogen through the core.

Three and a half percent of the radioactive core material were released.

Temperature measurements in and around the reactor core could not be made except with simple devices such as thermionic valve amplifiers or materials of known melting point. The radiation fields rendered semiconductor instruments unreliable. With the exception of the reactor vault itself, radiation fields have now fallen from thousands of Roentgens per hour (the maximum recorded) to no more than one or two R per hour.

Release from the reactor is now down to tenths of curies per day, as an aerosol. Temperatures are now below 300°C in the core. A priority task was to shut down Units 1, 2 and 3 following the accident. Units 1 and 2 have been contaminated and by the year end will be back in operation, the operators rehoused. As for Unit 3: a review is in progress and may permit it to be brought back into use.

The social losses comprise 203 seriously injured, 31 dead, collective doses of 9 million manrem in 1986 and 29 million over the next 50 years. Decontamination of the surrounding land should enable limited economic use to recommence eventually.

The speaker now turned his attention to safety requirements before and after the Chernobyl accident. Beforehand, it was permissible for some control rods to be completely withdrawn: now none may be less than 1.2 meters into the core. The minimum equivalent number of fully-inserted rods must now be eighty: it was thirty. In the future the fuel enrichment will be raised form 2.0% to 2.4% which coupled with the greater amount of control rods permanently in the core will offset the positive void coefficient which was one of the principal design shortcomings. Finally, the reactor protection systems will be more highly automated so as to place less reliance on the operators.

Some RBMK reactors are still operating and others will be brought back into operation following these changes. More training is to be given to their operators.

Tuesday 26 August, Working Groups

The meeting now divided into four Working Groups, Working Groups 1 and 2 convened in Session 2A: Groups 3 and 4 in Session 2B.

Session 2A, 10.00 to 18.00 hours: Detailed Presentations on Plant Design, Safety Analysis, Accident Description

Cause of the accident, sequence of events, radioactive releases, short term stabilization and longer term arrangements.

The presentations began with a historical review of the development of nuclear power in the USSR. This was straightforward, starting with the usual claims for the world's first atomic power station which produced 5MW of industrial power at Obninsk, near Moscow in 1954. Of more interest was an outline of the expansion envisaged for nuclear electricity generation during the next 5 year plan. It was intended to utilize nuclear heating, not only for the generation of electricity but also thermal energy by making use of the 'waste' steam. Combined electricity/thermal power plant and purely thermal output (for urban space heating) were planned. The development and implementation of fast breeder reactors was envisaged during this period with a suggestion that an 800 MW plant was being considered.

The presentations followed closely the text of the first two Annexes to the Russian report. Annexe 1 describes operating experience with the RMBK reactors. Annexe 2 the design of these reactors. Particular attention was paid to the void coefficient (which has a value of 2 x 10^{-4}% steam). It is positive and so an increase in the volume of steam voids (bubbles) in a channel leads to an increase in the amount of heat being given off by the uranium fuel in that channel. As a result even more steam will be generated, and the resultant voidage will further increase the rate of heat generation. Ultimately, if this circular process is not halted by the automatic reactor control and protection systems, the rate of steam production will be so great that it will damage the reactor. This was what happened in the Chernobyl accident. The void coefficient had maximum effect because there were only six control rods in the reactor and the automatic system had been turned off.

A "local automatic regulating system" is used to control the power output of the reactor as a whole. A decision is taken about the amount of power required. It can lie anywhere in the range from 10% to 100% of the maximum possible output. Then the automatic system maintains the power within one percent of the selected level. The system embodies twelve independent local regulators.

Emergency Protection of the Reactor

In an emergency the fission-reaction must be stopped, by tripping the reactor so as to minimise the heat output. This is achieved by the automatic insertion of all the control rods. Such emergencies arose at a number of junctures in the Chernobyl accident but the operators had switched off the trip arrangements and so the generation of heat by fission was not halted.

The emergency protection systems were explained in some detail, including the various levels of protection afforded. The nature of these systems is such that certain signals do not produce full shutdown, but rather permit continued operation at lower power levels. The way the coolant circuit functions was illustrated and all of the operating parameters given. Natural circulation has been shown to provide satisfactory cooling when the main pumps are turned off at power levels up to 30%. Tests have been made to establish this on operating plant, on special experimental rigs and also by calculation. There was a description of the three train emergency core cooling systems and the provision of multiple safety relief valves to guard against overpressure in the coolant circuit.

Quantitative Description of the Actual Sequence of Events

In attempting to provide an explanation of why the operators made such a series of errors, two points were emphasised. First of all, the accident occurred at a very bad time psychologically. It was the end of the working week and in the early morning. Although not mentioned it is also worth noting that it was the eve of the May holiday. In addition it was suggested that the psychological state of the operators could have been affected by the fact that this unit had been "top of the league" for availability.

By taking the data which had been recorded by the plants own data processing and using it to validate a computer model of the reactor system, a very detailed and accurate simulation of the course of events leading to the catastrophe was produced.

Some emphasis was placed upon the fact that it was not actually necessary to have the reactor operating at power in order to perform these tests. The Russians argue that it was done at power so that if the first attempt had proved unsuccessful, then there would still be enough steam in the operating reactor to restart the turbine, enabling the experiment to be repeated. Preparations for the test, in terms of reactor safety, were minimal. If the reactor presented problems during the experiment, the advice to the operators was only concerned with operating procedures.

When the test was started, a series of events caused the operators to block off essential safety systems. They then were gradually boxed in as a result. Eventually when they realised that an uncontrolled increase in power was imminent it was too late for the reactor to be shut down, even though a full emergency shutdown procedure had by then been initiated.

For the third time we were treated to a rehearsal of the accident sequence and some details which do not appear in the report were given.

The description given was as follows:

1. The control and safety rods had been withdrawn from the core to compensate for xenon poisoning.

2. All 8 main circulating pumps were in operation. They were circulating hot water which was everywhere near to boiling although little steam was being generated.

3. When the main circulation pumps began to run down (due to run-down of the turbo-alternator) flow was reduced, the water boiled and there was a consequent uncontrollable increase in power.

4. Steam pressure destroyed the core and the upper structure of the reactor.

Calculations indicate that the power increased by a factor of 100 in less than 1 second, a release of energy which disrupted the fuel into small particles at 3000°C. These converted the remaining water droplets to steam which blew off the reactor cap and destroyed the building. Three to four seconds later according to witnesses outside the building a second explosion occurred. It was probably due to the detonation of hydrogen or carbon monoxide. Hot burning debris caused subsidiary fires which were put out although many of the fire fighters later died.

Session 2B, 10.00 to 18.00 hours: Detailed Presentations of Emergency Measures and Radiological Consequences

Evacuation, environmental protective actions, decontamination, environmental effects, health effects.

The Working Group session was opened by Prof. L A Ilyin (Academy of Medical Sciences, Director of the Institute of Biophysics) who outlined the affiliations and specialisms of the speakers to follow and set their contributions in context. Ilyin gave the following time-table of events with respect to medical response:-

26 April 1986

01.25	Accident occurred
01.30	Site Medical Centre informed (3 medical staff on duty)
01.45	2 specialised teams of medical staff set out from Pripyat. Later additional teams sent out
	115 beds made available in regional hospitals
02.10	First 29 victims admitted to hospitals
03.00	Distribution started of potassium iodate tablets to all workers on power plant site and to patients. (He compared this with Three Mile Island where tablets were not distributed for 6 hours)
06.40	Special teams of physicists, dermatologists, radiologists and clinicians alerted in Moscow who
11.00	Flew to Kiev in a specially chartered plane
20.00	Iodate tablets distributed in Pripyat by medical staff and local door to door volunteers.

Professor Ilyin said that in retrospect the scale of response to the accident and its organisation was astonishing. Hundreds of institutes in the Soviet Union supplied specialists and millions of dosimetric measurements were taken. Up to the 10 May several hundred thousand people were medically examined -including blood tests. Some 200 to 300 people were diagnosed with acute radiation sickness. These cases were confined to workers and there were none in the general population.

Thirty-eight million people live the Dnieper valley and there was much concern over the elution by rainfall of radioactivity deposited on the Chernobyl site. They were lucky in that between 26 April and the end of May very little rainfall fell in the area. Professor Ilyin attributed this to the intensive weather modification activity of the State Hydro-meteorological Committee who dispersed chemical substances to dissipate the clouds.

He said that for many years starting from the 1960s the Soviet Union, on the basis of much research work and international experience, developed a conceptual basis for the protection of the population and the inhabited environment in the event of an accident or emergency radioactive release.

In 1969 the Soviet population protection criteria for use in a nuclear accident were published by the IAEA. Soviets are not in favour of developing preliminary standards for water, food etc within very narrow limits. They feel that these must be based on certain principles but details should depend on actual circumstances. Ilyin thought their criteria corresponded more or less with those used in other countries though with some specific differences.

From their previous consideration of maximum design accidents and maximum imaginable accidents the situation resulting from the Chernobyl accident was "not totally unexpected". However, the accident has emphasised the importance of skin dose in determining the prognosis of accident victims. Twenty percent of the victims had lost 80-90% of their skin area from beta and other radiation. However, there was no neutron irradiation involved. Professor Ilyin concluded by referring to the warmth of the enormous emotional response in the rest of the population engendered by the unfortunate victims.

Enviromental Monitoring

Professor Petrov gave a detailed account of the results of environmental monitoring in areas both close to and further away from the plant, from the time of the accident to the end of May. The detailed information is in one of the Annexes to the report and will be available in the UK at the end of the Conference.

Two aeroplanes plus helicopters and vehicles were quickly deployed for monitoring activities over 20,000 sq kilometers. An enormous number of samples was taken of soil, waterways and air.

After the accident radiation levels of the accident plume reached dose rates of 1000 millirem per hour on 27 April and 500 mr per hour on 28 April at a distance of 5-10 km from the reactor site at a height of 200 metres. Aircraft measured a plume height of 1200 metres in north westerly directions at 30 km from the site of the reactor, though at that height the dose rate was only 1 millirem per hour.

Later calculations put the total activity release in European Russia at 50 megacuries.

Medical Aspects

Professor Kuskova gave a presentation on medical aspects. At the time of the accident there were 176 operational staff on site plus 268 workers on the construction sites and auxiliary work areas. 300 people were checked for radiation sickness in the first few days. 203 were found to be suffering from it.

An enormous amount of data now existed from what needed to be done after the accident. Full analysis of it would not be completed for a further 6 to 12 months.

Severe cases had begun showing radiation sickness symptoms, eg vomiting, diarrhoea, skin problems - within an hour of the accident. Within the first 12 hours 129 people had been sent to special hospitals.

Four degrees of radiation sickness were defined of which degree number 4 is the most severe. In category 4 there were 22 victims. They had received between 600 and 1600 rads as a result of which all but one are dead. Of the 23 victims in category 3 (400-600 rads) 7 are dead. In categories 1 and 2 (100-400 rads) there were 158 victims and 1 has died.

Release from the Reactor and the Consequences for the Immediate Vicinity

The release of radioactivity into the environment occurred in 4 phases.

1. The initial explosion propelled particles of fuel, complete with fission products into the atmosphere. A great deal of this fell locally, around Unit 4 and on the site.

2. The rate of release decreased due to the material dropped from helicopters on top of the reactor. The composition of this release indicates that it is rather similar to the fuel itself.

3. The material on top of reactor insulates the core and the debris increases in temperature. Release increases and is predominantly of the more volatile fission products - iodine, caesium and tellurium although there is still a significant fraction from fuel particles.

4. A sharp reduction in release rate. This is attributed to improved cooling of the core and to the formation of more refractory chemical components which means that the fission products were locked chemically by the materials dropped into the reactor.

A combination of calculation and measurement was used to evaluate the actual releases of radioactive materials from the core. These calculations seem to be based upon detailed, but relatively local measurements. The results indicated that the release on the first day was about 12 million curies. The major release occurred over a period of about 10 days and up to 50 million curies of activity were released in all. A similar quantity of radioactivity associated with noble gases was also released, but the radiobiological consequences would have been much less and it is usual not to include those quantities in further calculations. It is important to note that these releases were calculated on 6 May taking into account radioactive decay.

Over all, it is claimed that about 3½ percent of the total radioactivity inventory was released to the environment, with differentially large amounts of iodine, caesium and tellurium, the more volatile species. Some 15-20% of the total inventory of the reactor were released.

Close to the reactor, the radiation levels were very high indeed in the early days of the accident. These levels seriously impeded recovery work and made continued operation of the other reactors difficult. Nevertheless, Unit 3, the one immediately adjacent to the damaged reactor continued to operate until 5 am - about 3½ hours after the accident. Units

1 and 2 were shut down only some 12 hours later. The principal problems appear to have been that ventilation systems drew radioactivity into the buildings.

Many measurements around the reactor have been, and continue to be made. A 50 m square grid is used and readings are taken from both the ground and in the air. In the main, decontamination efforts seem to have been successful and the principal radiation source on the site is the damaged reactor itself.

The condition of the remains of the core are being monitored by special instrument "buoys", lowered onto the debris by helicopters on 240 m of steel rope. Ten will be installed in total, so far 7 are in place. These will provide data on temperature, heat flow and air flow required to determine how the planned concrete "tomb" should be built.

Final decisions concerning the entombment have still to be made. Some of the requirements for this structure are:

1. To protect the adjacent site, and particularly the other nuclear units.

2. To remove residual heat from the fuel and the collapsed part of the reactor.

3. To ensure proper monitoring of the important physical parameters.

4. To enable contingency plans to be made just in case something goes wrong after the entombment.

Whilst it was stated that an open ventilation system had been chosen for the design, the Russians were keen to invite any advice from other countries on how best to handle this phase of the operation.

Finally, the measures planned for other RBMK reactors were outlined again; they consist of four elements.

1. To reset the upper limit of level of control rods so they are permanently inserted 1.2 m into the core. This essentially makes the core "smaller".

2. Reactivity margins will be increased by having a minimum of 80 effective rods as their requirement instead of the current 30.

3. In the longer term, fuel with a higher fraction (enrichment) of U 235 will be used. This will improve the situation on the positive void coefficient. Fuel of 2.4% enrichment has already been tested.

4. Ten channels in the reactor will be adapted for rapid acting safety rods. These will act over a period of 1-2 seconds (compared with 20 seconds previously). The material for use in these rods has not yet been chosen.

Bone marrow syndrome occurred in patients who had received doses about 2 Grays (200 rads). They were treated as far as possible in sterilised ward conditions even though standard wards had to be developed for this purpose.

There was considerable press reporting of the bone marrow transplant operations. These were not successful for the patients concerned who had, however, received doses in the region of 4 Grays (400 rads) and most were suffering both from severe radiation sickness and severe radiation burns.

Professor Kuskova warmly commended work by Sir Edward Pochin on risks from radiation, which had proved in Soviet experience to be accurate.

Dosimetry

The meeting then heard from Professor Pavlovski on dosimetry matters. Immediately after the accident people in the largest town in the area, Pripyat, were advised only to shelter because dose rates in the town were still comparatively low. Iodine was distributed to children's establishments because children (high consumers of milk) were seen to be more particularly at risk from thyroid dose. When the dose rate reached 1 roentgen per hour a day after the accident, evacuation had been ordered. It had now been calculated following the very considerable monitoring of people that for 97% of the people evacuated from Pripyat the iodine content of the thyroid indicated a thyroid dose of 30 rad (said by the speaker to be close to UK experience in the Windscale 1957 accident). Mortality from thyroid cancer may have been increased by 1%.

Measurements suggested that the majority of the population in the 30 km zone did not exceed a dose of 25 rem, although a few people may have received 30 to 40 rem. The collective dose estimated for the evacuated population was 1.6 million manrems.

The accident had perhaps increased the death rate in the region by 1.6%.

Decontamination

Dr Krakov then spoke about decontamination. Obviously contamination at the reactor site, around all 4 units was considerable. The principles worked to in decontaminating the area were:

move from the dirtier to the cleaner areas;

work in the following sequence;

remove debris and rubbish;

decontaminate rooves and the rest of buildings;

remove 5 to 10 centimetres of soil for solid waste disposal.

The soil removed from the plant area would be replaced by concrete. This would enable further work to be done. Walls would be sprayed with plastic and polymer adhesives which would form a protective film.

There was obviously a large decontamination problem in the 30 km control zone. There would be a considerable redistribution of nuclide deposition over the first year because the current distribution was loose and liable to move. The deposition of activity took 4 years to stabilise in the pine needles in pine forests. Sampling would lead to the construction of a map of the distribution of the activity. The aim was to restore the land to agricultural use but not with food going directly into the food chain. Substances would be introduced to the soil (lime, mineral fertilizers, solvents, to prevent nuclide movement.

Academician V I Trefilov (Vice-Chairman Ukrainian Academy of Sciences - and Head of Physical Technical and Mathematical Science Section. He also covers some areas in USSR Academy of Sciences) provided an additional non-scheduled account of the post-accident activities of the Government organisation of the Ukrainian Soviet Socialist Republic. A Government Commission and a daily operational group were set up, both headed by the Deputy Chairman of the Ukrainian Council of Ministers.

Priority tasks were:

1. Health of the population;
2. Localisation of the effects of the accident;
3. Guaranteeing the continued economic activity of the republic.

Factories, plants and a large number of industrial activities carried on around Pripyat were forced to stop and their production had to be replaced by other installations. There were many complex problems related to the evacuation of the population which had to be solved.

A large monitoring organisation involving many institutions was set up with a prime need of standardisation of measurements and the institution of additional monitoring.

A mathematical model was set up involving many different specialists which enabled the storage of a massive amount of data, including detailed hydrological, biological and geographical information. This provided a real time display and was of great value.

There were considerable problems in localizing radioactive contamination especially in relation to the very large number of vehicle movements. Fully automated vehicle monitoring equipment was set up. Much attention was given rendering activity immobile. The clear weather over the nuclear site "guaranteed by the State Hydro-meteorological Commission for a whole month" was a good thing but conversely it increased the resuspension of activity. This was countered by spraying inexpensive, non-toxic substances over thousands of square metres every day, firstly roads, then soil and crops where wind erosion was substantial.

Increased precautions were taken in forested areas to prevent fires which would have redistributed activity on the leaves and forest litter.

In the first few days after the accident measures were taken to provide alternative water supplies. In Kiev 400 wells were bored to replace the supply normally taken from the Dnieper. Water purification techniciques were introduced including the use of absorbents which reduced activity 100 fold.

Other major civil engineering works were undertaken and these were particularly substantial in the near neighbourhood of the nuclear site. In the near future the capability of natural purification processes will be assessed. So far they had little data on ground water contamination. He concluded by stressing that the situation both inside and outside the 30 km exclusion zone was now 'calm'.

In May and June urban decontamination of Kiev was effected and it is now the "cleanest city in the world".

28 August

The meetings of the four Working Groups continued through Wednesday, 27th, and Thursday 28 August. Delegates had posed nearly one thousand questions in writing during the earlier part of the week and these had been consolidated by a dozen experts to produce a smaller number of questions which the Soviet delegates were now asked to answer. There was, initially, a rather hesitant approach to this, with the Russians at first asking for details of relevant accidents in other countries.

Session 3A, Working Group 1
Chairman - B Edmondson

Discussion of Phenomena and Factors associated with the Short-Term Accident Sequence

This subject was intended to include the initiating event, sequence of events, reactivity excursion, containment response, instrumentation, operator response, stabilization measures etc.

Dr Edmondson, opening the session, outlined the goals which were:

1. To clarify information provided by the USSR delegation.

2. To exchange other relevant information.

3. To identify the broad requirements of nuclear plant safety internationally.

Looking at other technical areas, these were:

1. The accident and its causes.

2. Specific issues related to the sequence of events - particularly core performance.

3. Design of plant to mitigate operator actions.

4. Procedures to be used to control special experiments or tests.

5. How to guarantee appropriate standards of staff training, management practices etc.

6. The important lessons which can be learned from this event.

The consensus view of the experts was that the general features of the accident, as explained by the Russian delegation, were accepted. Everyone agreed that there were many matters of detail which still needed a considered explanation - but none of these bore materially on the general conclusions that the accident was caused by a combination of design fault and operator error which lead to a prompt critical nuclear excursion whose consequences led to destruction of the reactor.

A difficult situation now arose, where no country appeared willing to offer their own experience of similiar accidents. The Russians requested this information, but in vain. Eventually a discussion commenced on one of the questions that had been posed: "What was it that brought the nuclear chain reaction to a halt"? The workshop could not, however, agree an answer, some thinking that it was at least in part due to the fact that some of the fuel had disintegrated and dispersed. The question was identified as one upon which further collaboration was desirable.

The next area discussed was that of operator training, management procedures and organisational matters. Dr Brown of Ontario Hydro was the IAEA-designated expert on this and he outlined the practices in Canada. This stimulated similar contributions from Sweden, Italy and France, all in the spirit of supplying information in response to that which the Russians had supplied.

Attention next turned to "Design for Safety". Dr Frescura of Italy was the IAEA expert on this. Banks of Canada said that they had learned lessons in this area as a result of a relatively minor accident which occurred in the Canadian reactor NRX in 1954. They saw the need, afterwards, for a shutdown system which could be relied on to respond to all possible situations. The system must be quite separate from the reactor control system. That is: the reactor protection system must be separate from the reactor control system.

Derek Smith (UK, NNC) then described the UK design philosphy which is to employ interlocks which prevent the operators from switching off important safety systems. If they do, the reactor trips.

D Taylor (EPRI) continued the discussion by summarising the changes in thinking concerning the design of Control Rooms in the aftermath of the accident at Three Mile Island (USA). Much was being done with computers, graphic displays and information processing. It was suggested that here was a topic to be added to the list of topics for future discussion.

Session 3B, Working Group 4
Chairman - D Beninson

Discussion of the Radiological Consequences of the Accident

This subject was intended to include plume-formation, aerosol dispersion, environmental effects, dose-assessment and health effects.

The Working Party proceeded by considering composite questions compiled by the IAEA expert panel from the questions submitted by delegates. Participants included Dr Gale (USA) who visited Moscow during the crisis. There was detailed technical discussion on the biological and medical aspects. They will be covered and as far as possible summed up in the report of the Chairman of the Working Group to the final Plenary Session. Particular topics were as follows:

1. Methods of assessing doses to the skin.

2. Any complications where there are both radiation burns and thermal burns on the skin.

3. The merits and demerits of using chromosome analysis in addition to physical dose measurements.

4. Where more is now known about average lethal dose and whether such information is in practice valuable in making clinical judgements.

5. Whether psychological effects had complicated treatment (they did not).

6. Contributions which can and cannot be made by using bone marrow transplant treatment.

7. The side-effects of taking stable iodine in order to block the thyroid (there were few).

8. A long discussion on the prospects for an epidemiological study in the USSR to follow up the Chernobyl data.

Professor Ilyin, leading for the Soviet delegation, said that work had begun on considering the setting up of such a study but that he was pessimistic about the many difficulties that could arise in carrying out epidemiological studies. Several delegates, notably from the UK, urged the importance of carrying out the most effective study which could be managed whatever the problems and said that the 'UK would supply such methodology information as was available'.

Epidemiology

Academician Ilyin stated that if the IAEA would take upon itself the initiative of organising in some 6 months a 4-5 day workshop on epidemiological matters relevant to the Chernobyl accident, this would be of special support and help for the specialists in the Soviet Union.

He said that the Soviet Union could send experts in the cancer register, geneticists, and statisticians to this workshop.

It was agreed to ask the IAEA to support the workshop proposal.

Session 4A, Working Group 2
Chairman - P Tanguy

Discussion of Phenomena Associated with the Long Term Accident Sequence, Plant Recovery Measures and Radioactive Releases from the Plant.

Graphite fire, core damage, use of robotics, long term reliability of safety systems, recovery actions, radioactive release characteristics.

Non-Soviet delegates expressed interest in learning more about preliminary stages of fuel degradation, hydrogen production, possible water interactions, the fragmentation effects of fuel in the core, the extent of the ejection of graphite from the core, why one side of the reactor building (the north side) had been much more damaged than the other and the number of fuel channels ruptured.

The Russians said that they found delegates' comments helpful in indicating some of the many areas in which further research was necessary. The south side of the building backed on to the machine room and was structurally stronger. That was why the explosion particularly affected the weaker north side.

It was confirmed that the estimated energy stored in the oxide fuel at the time of the accident was 300 calories per gram - a figure of this order tended to be confirmed by research carried out in the USA (presumably an experiment in PBF) and in Japan. The fact that the top protective plate blew off, amongst other indications, confirmed that all 2000 fuel channels were destroyed - the zirconium was subjected to temperatures of 700 to 750°C and was then easily ruptured. When the upper plate lifted, all the coolant-exit pipes would have been destroyed.

Visual examination confirmed that only a small amount of graphite (10%) had been ejected from the reactor building. Fragmented fuel was not found in the graphite analysed, as most of the graphite came from the reflector regions.

The Russians had not yet formed any views on the extent of possible hydrogen formation through interaction of fragmented fuel with water and would welcome any contributions in this field.

A French delegate indicated the results of some of the French calculations on the accident. It was agreed that a reactivity excursion was the likely explanation of the first explosion, the energy involved calculated to be 200 megajoules. The second explosion was either due to an excursion, a steam explosion or a hydrogen explosion.

The Russians said that they did not yet have satisfactory information on the location of the fuel. They hoped to know more later but it seemed that much of it was in the lower water pipeline areas.

They went on to discuss the interactions between concrete and uranium oxide.

There was a presentation on fire fighting activities. Rules existed for all nuclear plant covering the need to protect essential systems, cables and equipment. All plants had their own fire fighting unit. Different measures were designated for different types of area - water for cable rooms, gas for control rooms, foam where oil was present, etc. The Head of the unit at the Chernoybl station was experienced - 8 years general experience and 7 years on specialist simulators. All stations had a fire fighting plan.

Three fire fighting units were quickly deployed to the accident - from the plant and Pripyat and Chernoybl towns. The fire had been put out by 5 am, mainly using water. Particular measures were taken to protect essential systems and prevent the spread to Unit 3.

The Russians proposed IAEA initiatives in a number of areas where improved knowledge was required - guidance on nuclear fire fighting methods, development of protective clothing, automatic fire fighting robots, graphite fires and consideration of problems in newer reactor systems.

Dr Tom Kress (Oak Ridge National Laboratories) posed questions concerning the nature and quantity of radioactivity released. He related the four stages of the release. The accident gave rise to releases to atmosphere due to two different mechanisms, the boiling off of the more volatile fission products and the mechanical dispersion of fuel particles. The mechanisms governing the latter process have not been widely studied.

The Soviet delegation said that they had a great deal of data which they intended to make available to everyone. They confirmed that the uranium fuel had undergone oxidation during the accident, and may have reacted with the graphite to form carbides.

Details of the amount of fuel materials spread around the site were given:

ie 1. on the site itself ~ 0.3 - 0.5% of the fuel

2. up to 20 km 1.5 - 2.0% of the fuel

3. up to 30 km 1.0 - 1.5% of the fuel.

The size of the particles varied considerably, being from <1 micron (millionth of a metre) to 10's of microns.

On matters, relating to Stabilization of the Core Debris, the expert was Dr D Powers of Sandia National Laboratories. The core debris did not interact with the concrete base mat of the reactor. Nevertheless, it was suggested that for other reactor systems it would be useful to exchange ideas and research data on the development of refractory (ie high temperature) concretes.

Since the accident management procedures adopted appeared so successful more details were sought on the materials dropped on the reactor, where they went and the sequence in which they were dropped. The following further details were given. About 5000 tons in all were dropped between the 27 April and 10 May, the bulk of it between 28 April and 2 May. First 40 tons of boron carbide were used to ensure that the chain reaction was definitely shut down. Then 800 tons of dolomite (limestone) were used because the CO^{2} generated when it decomposed in the heat would starve the graphite fire of oxygen. There followed 2400 tons of lead. The main purpose of this was to remove heat from the core region - the idea being that it would melt, run down to the bottom of the debris and carry away. The covering material was clay and sand to act as a filter to stop fission products reaching the atmosphere.

Questions on the special building being constructed to entomb the remains of the reactor concentrated upon the criteria which would be used for its construction.

The final part of the session was devoted to finishing the work of Working Group 1. In particular Mr Frescura again addressed the issues of design for safety. Professor Kuglin gave an overview of procedures in the USSR. These included all the main features of western practice. That is: an examination of a wide range of possible events associated with failures of individual components, from which a list is agreed with the licensing bodies. This is the same for all reactor types. Using this agreed list a volume of "technological justification for safety" is submitted and agreed. From this is derived working documentation.

On the use of probabilistic safety analysis methods, it was said that these methods had been developed, along with the necessary data bases. A probabilistic analysis had been done for the new RBMK 1500 design. Quantitative safety criteria were included in these. An example was given that the reliability of the reactor protection system was required to be about 10^{-7} per year.

In the summing up, the Russian delegation again chose to highlight the importance of human error and reconfirmed particularly the benefits to be had by further exchanges in the man-machine interface area.

Session 3B, Working Group 3
Chairman - H Rabold

Decision basis for evacuation, sheltering, use of prophylactics; criteria for medical treatment; control of foodstuff and water; prevention of groundwater contamination; decontamination of people, material, soil etc; radiological conditions for plant re-entry.

The Chairman noted that there had been a proposal from the UK that the IAEA should organise a conference on decontamination matters. Dr Eggleton informed the Conference of relevant Harwell work on decontamination of urban surfaces.

The Russians stressed that loose caesium contamination had been a predominant problem. The spray of decontaminant solutions was widely used and vacuum cleaners were used to clear up loose particles. In some cases pastes were put on walls, establishing a quick-drying film which was peeled off with the active particles sticking to it. Solid wastes are being stored in the waste repository for Unit 5, which had already been built.

In regard to emergency measures Mr Dunster outlined the UK system of indicating the thresholds at which action would be considered. The Russians indicated a similar philosophy, the important whole body dose being 25 rem, below which evacuation would not be necessary and 75 rem by which it certainly should be taking place. Similarly, the Russians have reference levels at which they advise sheltering, iodine distribution etc.

Professor Ilyin pointed out that one factor delaying the need to evacuate Pripyat's population was that the accident occurred at night when the people were indoors. The decision to evacuate was taken at 14.00 hours on 27 April. Iodine had already been given out at 08.00 hours.

It was clear that the military people had been much involved in the evacuation. One particular problem which occurred was having to throw away contaminated clothing and give people clean clothes.

The importance was emphasised of rapidly setting up an emergency headquarters which had power to produce the main resources required quickly. Near the plant there were about a thousand people in protective clothing with all sorts of equipment, including concrete mixers (they found a lot of concrete was necessary to cover up surfaces).

The availability of medical resources had been vital. They had mobilised many doctors, some of whom travelled with the evacuees.

Finally, it was agreed that international initiatives were necessary to look at reference levels in safeguarding livestock. The IAEA would be asked to organise discussions on this subject.

Session 3B, Working Group 4
Chairman - D Beninson

Discussion of the Radiological Consequences of the Accident.

Formation of plume, dispersion of aerosols and gases, environmental effects, dose assessment (internal and external) for operational personnel and the public, acute health effects, late health effects.

The discussion covered:

1. Estimating the magnitude, chronology and composition of the radioactive releases.

2. Modelling the subsequent behaviour of the activity firstly in the physical environment and then in the biological environment.

3. Comparing the theoretical estimates with actual measurement.

4. Deriving and using the action levels of activity required for protecting the population.

5. Estimates of individual and collective doses.

The Russians have no local micro-meteorological data for the reactor site itself at the time of the accident. All their meteorological data came from the Met station in Kiev some 100 km distant. Neither was any data given on particle sizes of activity or deposition velocities.

The Soviet atmospheric modelling capability does not seem to be as developed as the West. The figure of 3½% given by the Russians may refer to the fraction of the actual fuel itself released. It underestimates the release of the volatiles, especially iodine and caesium where the release may have been up to a factor 5 greater.

Much attention was paid to the behaviour and modelling of CS 137 behaviour in the Chernobyl area. This is considerably different from that in many other places and reflects the very small amounts of clay and humus in the Ukrainian soil. They have much data and models derived from the behaviour of weapons fall-out. Caesium has proved much more mobile that we would have expected and this results in the ratio of internal to external dose being 10 to 15 times greater than it would have been in the UK, for example.

They have now performed about 1000 whole-body examinations of exposed people and find agreement between observed and calculated Cs levels in only about 3% of cases. The remaining 97% average about ten times lower than expected. This may reflect a different phyical and chemical form of the caesium. In calculating the collective dose given in their report they have used the model value in order not to be accused of under-estimating the number of future cancer cases. In the event the observed collective dose may turn out to be some 10 times lower. Further observations over the next few years are needed to confirm this.

A number of suggestions for future workshops organised by the IAEA emerged.

29 August, Plenary Session
Chairman - R Rometsch

10.00 - 12.30 hours
Summary of the Results of the Working Groups Discussions

The Chairmen of the four working groups presented their conclusions and an indication of the outstanding, detailed issues which needed to be addressed in future.

Both the immediate and the longer term features of the accident sequence were now understood in broad outline. There was scope for further detailed discussions on phenomena such as the disintegration of fuel, gas/vapour explosions, graphite combustion, the long term reliability of safety systems, man-machine interaction and fire control.

The emergency measures taken by the Russians had been extensive and had helped to limit the collective dose. There was a need for international discussions about the dose levels at which food stuffs should be banned.

The radiological consequences of the accident had been described and debated in detail. The dispersion of activity in the environment had a number of features which were not altogether expected (mobility of caesium, ejection of fuel, for example). Further discussions were needed on these matters and also on health effects and epidemiology.

The meeting closed at 12.30 hours, delegates expressing broad satisfaction with what had been achieved.

IMMEDIATE FACSIMILE

TO: MR A M ALLEN, FAX No. 01 930 5454 Ext 274

CC MR R N SIMEONE, ditto

26 August 1986

Mr A M Allen
Chairman
UKAEA
11 Charles II Street
LONDON SW1Y 4QP

Dear Arnold

A LETTER FROM THE FRONT

The Vienna meeting today enters its second phase, detailed discussions by specialist working groups, and I have dodged out to dictate this letter to you which is intended to supplement my "factual report to Government", the first instalment of which is being transmitted by David Morphet this morning (personal copy attached).

Lord Marshall and I spent Saturday and Sunday here in Vienna debating the accident with CEGB and UKAEA colleagues and isolating areas of ignorance upon which we propose to question the Russians. On Sunday afternoon we picked up the official Agency translation of the Russian report but this did not answer our main question. Why precisely were the Russians performing the experiment which triggered the Chernobyl accident? As you can imagine, we have guessed the answer (very detailed) and we shall see whether we are right.

Legasov addressed the meeting all day long on Monday and single-handedly presented the whole of the Russian report. A masterly performance which received a big round of applause when he sat down shortly after 6 pm. He made a number of asides which were very frank and revealing and, indeed, the documentation is remarkably detailed itself. The picture presented is entirely believable; indeed we have independent verification of the truthfulness of the tale being told. As I indicated in my note last week, the accident is due to a combination of two things: shortcomings of the reactor design and wilful, mistaken, actions by the operators: hardly "operator error". Legasov said if they did not complete the experiment that night it would be a year before they had another chance, hence their flagrant disregard for safety. There might have been a medal at the end of the day if it had come off. As it is we find Legasov saying "Before they died the operators gave a confused account of why they acted as they had". One of a number of human and very sad features of his presentation.

The Russians have stated that they want to engage in a vigorous international debate and programme about how to improve reactor reliability, reduce risk and mitigate consequences. They want to enlarge this to include other types of nuclear installation and indeed non-nuclear installations as well. Sir John Hill, with whom I discussed this, said that he would not be concerned to make reprocessing plants earthquake proof since they did not have the potential for harm that nuclear reactors had. The Russians are trying to diffuse their problem into a broader forward-looking activity, I would say, and Morphet agrees. Morphet tells me that the French and the Germans view the Russian initiative on intrinsically safe reactors as being about the same game. Personally I feel that this latter idea is one of the few things that might be suitable for international exploration since, like JET, for example, it is a comfortable distance away from commercial application. A personal view.

The TV camera crews and the world's press were present in force. Both Legasov and Lord Marshall gave impressive press conferences (on Monday); the press are expressing great interest in reactor containment, but I must say that I think it is misplaced. No operating power reactors have containments that have been designed to deal with the activity release in an accident like the one that happened at Chernobyl. The main thing is to ensure that such accidents do not occur, therefore.

At breakfast this morning I began to discuss with Morphet the form that the Secretary of State's speech to the September IAEA Board Meeting might take. Everything depends on the SOS's own views but one can see the alternative lines that might be taken and I will keep you informed about any advice which I give about this as the week goes on.

Yours sincerely

John Gittus.

J H GITTUS
(Vienna)

29 August 1986

Mr A M Allen
Chairman
UKAEA
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Dear Arnold

VIENNA MEETING ON CHERNOBYL

With this you will receive the balance of my factual Report upon the Vienna meeting. I have prepared a summary which is based on a "Report for Ministers" which Morphet asked me to draft.

The Russians have given us a fair amount of detail, none of it particularly surprising although we had not surmised the scale and rapidity which they claim for their emergency response. I am not personally convinced by all of that (it is not verifiable). The picture of the accident, its cause and consequences which we pieced together in the Authority has been shown to be quite accurate. Our one lacuna, the initiating event, proved unimportant since the reactor was in such an unstable state that almost anything could have triggered it off. In the event, it was the disturbance caused when the operators diverted steam from the turbine that did the trick.

3 Septr
Plu to make.

As for the implications of all this for the UKAEA; earlier in the year I suggested what our response should be in a paper which was accepted by the AEX and forms the basis for our present activities. The additional information implies some additional requirements, I think, in the following areas:

1. Our Own Reactors

At the moment we are reviewing the safety cases and the site emergency plans. We shall now need to examine with extra care two things:

(a) Are the reeactor safety provisions such that the operators, if they flouted their instructions as the Russians admit happened at Chernobyl, could bring about such an accident? Or are our reactors quite literally "fool-proof"?

(b) For accidents of this magnitude, what public bodies would we warn and how?

2. Our Own R&D Programmes

Here we have said that we will help the industry for thermal reactors and take the lead for the Fast Reactor. We are re-examining relevant parts of the safety provisions. Following the Vienna meeting, emphasis falls on:

(a) Reactivity coefficients in general and the void coefficient in particular.

(b) Prompt criticality occurred at Chernobyl.
There are special implications here for the Fast Reactor allied to its void coefficient and this I will elaborate to you when we meet.

(c) Control of Graphite Fires. The graphite did burn at Chernobyl, we now know, and radioactive particles embedded in it by the explosion rose on the hot gases to be spread far and wide.

(d) Emergency shut down ("trip") arrangements.
These are being beefed-up by the Russians. They were easily subverted by the operators, were not sufficiently reliable and operated too slowly.

(e) Man-machine interface. Human factors.
The Chernobyl operators made wilful and unintentional errors.

(f) Reliability of reactor control and protection systems.

The Chernobyl systems were unable to cope with the situation created by a combination of a "touchy" reactor and misguided operators.

(g) Computer models of the dispersion of radionuclides in the environment following a big reactor accident and their effects on land, crops, people etc. The Russians used such models to guide evacuation etc during the accident. They were wildly incorrect in several areas such as whole body dose and caesium mobility.

(h) Dosimetry.

3. International Collaboration

Many additional Workshops and meetings were planned in Vienna. They include discussions in some of the areas listed above (but not all). The UKAEA will wish to do its bit.

4. Work for the UK Nuclear Parties

Our involvement with CEGB's response to the situation created by Chernobyl is well established. It will broaden in some of the areas listed under (2) (a) to (g) above of course. In addition they will have other requirements and we shall want to help, where we are able.

The Department of Energy and the Environment will have immediate requirements, for the briefing of Ministers and additional work for the special Cabinet Committee. In the longer term (this Autumn actually) we shall want to seek their support for revisions to our programmes and for what will, no doubt,turn out to be a redistribution (rather than any augmentation) of the trading fund monies.

The NII have recently and for the first time asked SRD to do contract work for them. I think they may ask SRD and Harwell for paid help on Chernobyl-related matters, too.

I will visit you as soon as possible to add flesh to these matters and can now update my two AEX papers (one was on the accident itself, the other on the Authority's response) for the September meeting, if you agree.

Yours sincerely

John Gittus.

J H GITTUS
(Vienna)

PS. My factual report on the Vienna meeting, based on the daily instalments, will be on Mr Simeone's desk on Monday, 1 September.

United Kingdom Atomic Energy Authority

Secretary of the Authority and
Authority Finance and Programmes Officer

R.L.R. Nicholson

11 Charles II Street
London SW1Y 4QP

Telephone: 01-930 5454

Action

9

BU58
27-8

Dr. J. H. Gittus,
Director,
SRD,
Culcheth

Superseded

22nd August 1986

Dear John

I attach a letter which has come into the Chairman's Office though it has been addressed to a Branch at Harwell. Normally I am not certain that we would want to talk to a local borough council about matters arising from the rather peculiar sub-committee that seems to have invited us to talk a somewhat peremptory fashion). However if my geography is correct I think the Killingholme site on which NIREX are proposing to drill is not too far from Brigg and may well be within the area of this borough council. It would therefore seem sensible for someone to talk to them, and it might be best if you could arrange for someone in SRD to take on this duty.

Yours sincerely,

(R. L. R. Nicholson)

c.c. Dr. Marsham
Dr. Flowers
Mr. Chadwick
Dr. Llewelyn

8443
20.8

Risley Nuclear Power Development Establishment
United Kingdom Atomic Energy Authority
Risley, Warrington, Cheshire WA3 6AT.

Risley
UKAEA Northern Division

Telex: 629 301
Telephone: Warrington (0925) 31244

Extension: 2367

20 August 1986

Dr D Hicks
Programme Director
Water Reactors
AERE
Harwell

Dear David,

CHERNOBYL

1. Here are copies of some more of my slides on Chernobyl, some prints of some of them and also some aerial photographs of the Chernobyl site. The photographs are for internal use only otherwise the Authority would have to pay royalties to the agency which supplied them.

2. Fig 1 shows the four units quite clearly and confirms what I thought earlier that units 3 & 4 are of a more recent design and layout (Smolensk) than units 1 & 2 (Leningrad).

3. Fig 2 shows units 3 & 4 in the centre of the picture. Comparison of the residue of unit 4 with what is visible of unit 3 shows that the walls and roof of the fuelling machine hall of unit 4 have disappeared and probably also the steam-drum cells and steam drums. The slide taken from a picture on a TV screen confirms that all these upper structures have disappeared from unit 4. I think the top of the fuelling machine is to the right in the gap in the fuelling machine hall.

4. Attached is a copy of the report in yesterday's Guardian. I wonder still how inadequate cooling of the fuel occurred, how multiple rupture of pressure tubes occurred, and how the graphite caught fire. The Soviet designers had performed three series of experiments on Leningrad-1 & 3 and Kursk-2 to satisfy themselves that reliable cooling of the reactor could be maintained in emergency conditions associated with the transition from forced circulation to natural circulation. These investigations led them to introduce the following measures (amongst others) Ref 1.

(a) Reduction of reactor power is accompanied by a reduction in coolant flowrate.

(b) The modes of operation of the automatic steam-discharge devices and the number of main steam safety valves were optimised.

(c) Supplementary emergency protection of the reactor was added for a number of engineering parameters (flow-rate reduction, increase in pressure in the reactor casing, and loss of water from the monitoring and protection system (MPS) channels).

(d) Automatic regulation of the level and pressure in the steam drums was improved.

According to Ref 2 the coolant circulation pumps are switched off when the emergency safety system is triggered and decay heat is removed by natural circulation of the coolant.

5. With regard to multiple rupture of pressure tubes I wonder if perhaps it was the channel seal plugs which failed and released a blast of steam into the fuelling-machine hall rather than tube failure. The hoop stress in the pressure tubes is normally quite low (10,500 psi, 72.4 MPa) - only about 40% of that in CANDU tubes in Zr-2½Nb - and in addition the tubes are restrained along their length by the graphite rings around them.

6. The initiation of the graphite fire is also something of a mystery. Graphite is notoriously difficult to light - much more difficult than coke or coal. It requires heating to a high temperature, a high heat input and plenty of oxygen. Under the conditions at the time of the accident (24 hours after power reduction to 6% full power) the graphite temperature would have been little more than the reactor coolant temperature (perhaps 300°C or so) and its ignition at so low a temperature would be difficult. At this temperature however hydrogen reacts with graphite to form methane and possibly this took place and helped start the fire. Maybe a clear explanation will come out at the Vienna meetings next week.

Yours sincerely

Bob.

R J HASLAM
CTS

References

1. DOLLEZHAL N A et al. 'Some characteristics of an experience with the operation of nuclear power plants with RBMK-1000 reactors' (Translated from Atomnaya Energiya Vol 54, No 4) April 1983.

2. CHERKASHOV YU M. 'Safety design of the RBMK-1000 reactor'. IAEA-SM-268/84. Risley Translation 5311 by D Hough.

Copies:

Dr T N Marsham
Dr J H Gittus, SRD ✓
Mr R N H McMillan, SRD
Mr J Fell, AEE
Mr A A Farmer, CTS

Chernobyl workers 'were in a hurry'

From Michael White in Washington

Technicians hurrying to complete what they thought was a routine safety test at the Chernobyl nuclear power plant precipitated the disaster last April, the official Soviet account will assert next week.

In effect the report confirms the "human error" theory whereby senior staff allowed "purely formalistic" safety procedures to be used — and have since been fired for misjudgments which cost 30 lives.

But the expected post-mortem at the meeting of the International Atomic Energy Authority in Vienna will be told that, contrary to the evidence of radioactive fallout around the world, there was no meltdown of fuel at the stricken No. 4 reactor.

This claim may arise only from technical or translation problems, or it could be a euphemism like the phrase "partial meltdown" used to describe the previous worst civil nuclear accident at Three Mile Island, Pennsylvania, in 1979.

However many experts here are impressed by Soviet candour — even though they are alarmed by some of the admissions it has produced. Critics fear that the international nuclear industry will close ranks and allow its Soviet colleagues to avoid close questioning at the IAEA symposium in Vienna next Monday.

Without going into details about the extent of contamination of the surrounding area, 70 miles north of Kiev, the 382-page Russian report will concede that about 50 megacuries of fission products (excluding rare gases) were released into the atmosphere. But it does flesh out previously hazy versions of the crisis.

Details of the authorised Soviet version, which hinges upon what is called a "turbine inertia" test not directly involving the reactor itself, have been circulated among IAEA After initially becoming public in Japan, where scientists have estimated that 30 to 40 times the radioactive ash produced by the Hiroshima or Nagasaki atomic bombs was released at Chernobyl, the report's contents are now trickling out of the US Department of Energy.

They portray the accident as starting at 1am on Friday, April 25, when the reactor's operators began reducing the unit's power for a test to establish the amount of residual energy produced by the still-spinning turbine-generator system after its source of power — the reactor — had been shut off.

Unlike most Western systems, Soviet safety equipment generally lacks independent power sources in the event of an emergency shutdown. They were "trying to do it on the cheap," one US nuclear scientist said.

The technicians duly shut down the reactor to around 6 per cent of full power, and turned off virtually all the plant's safety systems, including its computer, its emergency cooling pumps, the power regulating system and the automatic shutdown system. Having done this they disconnected the steam turbines from the residual power coming from the reactor. By now some 24 hours had elapsed.

What went wrong, and why, continues to puzzle Western analysts. It is agreed that the Soviet graphite-moderated reactor is vulnerable to unstable surges in power if it loses its cooling water. The Soviet account suggests that the technicians, "whose basic motive was . . . the striving to complete the test faster," did not realise the risks they ran.

The override of the computer controls and rerouting of the unit's electrical system generated a surge of power to 17 per cent in a few seconds as a result of lost cooling water and "hot spots" inside the core. There is also a suggestion that two extra recycling

Chernobyl staff 'in a hurry'

Continued from page one

pumps which were deployed overheated the coolant.

The Soviet account says the technicians realised that something was wrong soon after the test began at 1.20am on Saturday, April 26. At 1.23 and 40 seconds they tried to shut down the reactor by inserting its control rods to stop the chain reaction. "Banging noises" were heard and no more than a quarter of the rods went into place.

Twenty seconds later the first explosions occurred — initially a steam explosion which blew the thin steel lid off the reactor's top. A heavy crane used to move fuel rods then crashed into the reactor, rupturi[illegible] rods and exposing much[illegible] he graphite core to the atmosphere.

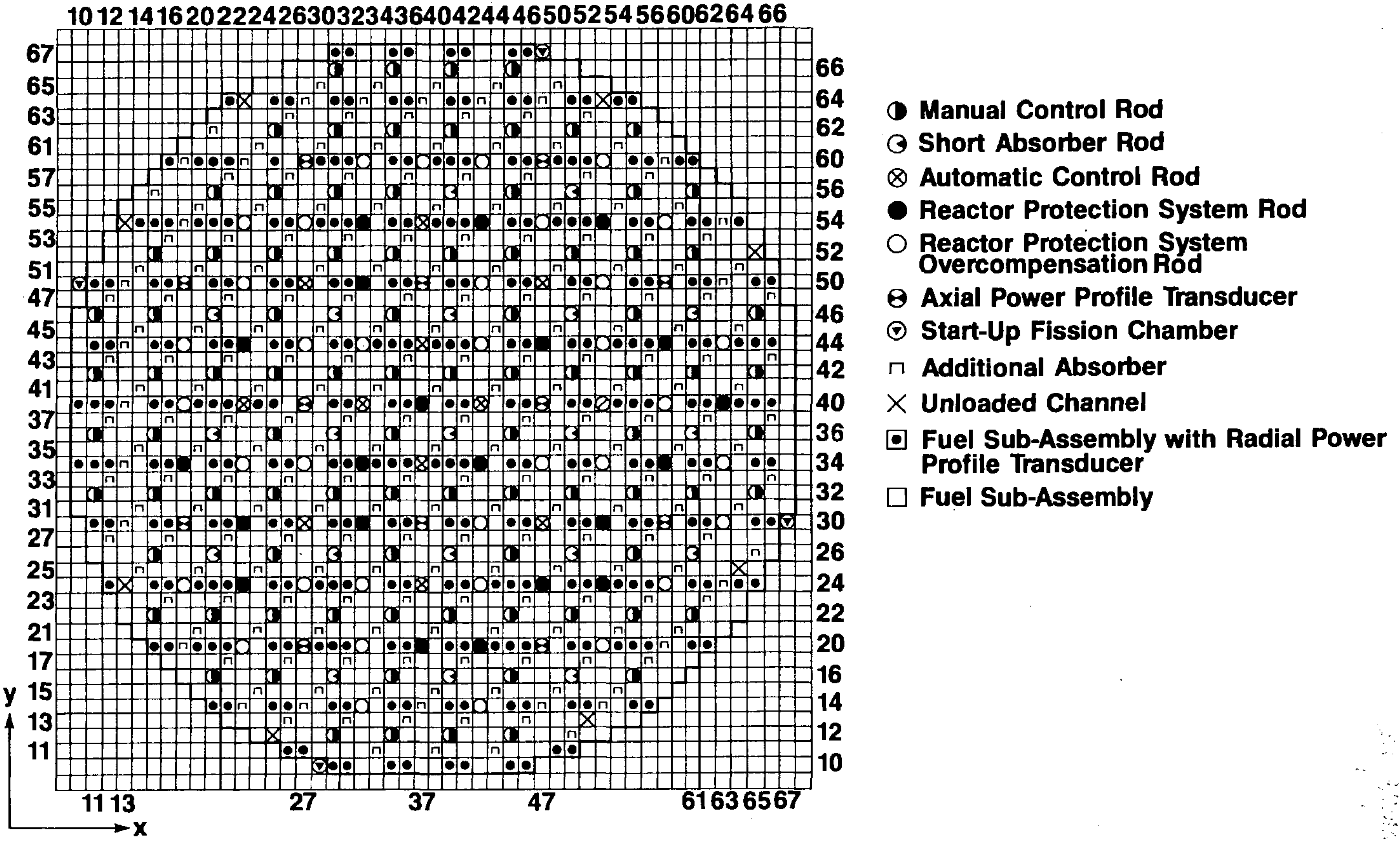
A series of explosions followed and a fireball sent the plume of smoke high into the air.

US reaction to the Soviet account has been mixed. Last night the atomic industry forum's spokesman described it as "very frank and very complete". Other scientists and engineers have expressed alarm at the risk-taking involved in a system already difficult to manage — "in a sense of horror" and "a poorly-considered invitation to disaster", said one.

But environmentalists and other critics of the nuclear energy industry see a convergence of interest between national industries, however much they stress the superiority of their own designs. One former member of the US watchdog body, the Nuclear Regulatory Commission, hinted strongly last night that the US team to Vienna has been chosen to ensure tight control and exclude potential trouble-makers.

It is rumoured that the IAEA is planning to let the Russians make their presentation on Monday without answering questions, though the leak of their report in advance has probably made that option harder to sustain.

PLAN OF RBMK REACTOR CORE



CHERNOBYL AFTERMATH - NEW UKAEA R&D

by J H Gittus

1. Fission Product Retentive Fuel

Develop coated-particle fuel which will retain fission products up to its melting point. For use in AGRs and LWRs.

2. Filtered, Vented Containment

Develop the design concept, which is of a light containment which does not need to be strong because pressure is vented and will nevertheless contain fission-products because of the filter.

Theoretical and experimental work is involved including adaptation of thermal hydraulic containment computer models (MARCH etc) and experiments on filter-beds. Existing buildings could be turned into FVCs by rendering them leak-tight and adding a filtered-vent.

3. Secondary reactor protection systems

Develop the AERE-AEEW microprocessor-based protection systems so that they can be backfitted as back-up secondary protection systems to existing reactors here and overseas. Particularly relevant if, at Chernobyl, the control-rods failed to halt the 'chain' reaction.

4. Super-Umpire

Develop the UMPIRE code to cater for overseas nuclear accidents which, like Chernobyl, affect the UK. The object is to forwarn the Authority of the need for countermeasures nationwide. The code could also be used in table-top exercises.

5. Intrinsic Safety Features

Analyse the safety of intrinsically-safe reactors and of conventional reactors in which the balance between intrinsic and engineered safety features is altered to seek the safest combination.

20 August 1986

18/8/6

GLANFORD BOROUGH COUNCIL
SOUTH HUMBERSIDE
Council Offices, Station Road, Brigg, DN20 8EG · Telephone: (0652) 52441
Telex: 52194

Clerk and Chief Executive Officer: DAVID D.H. CAMERON (Solicitor)

Our Ref: SJB/SG/AP.D/20 Ext: 227 Date: 14th August, 1986

Your Ref:

This matter is being dealt with by:
Mr. S. J. Brumpton.

cc Dr. Marsham
mr. Simeone
18b/8 ✓ mr. Nicholson
mr. Chadwick
mr. Grazebrook
Dr. Llewellyn
ackd 15/8

Mr. A. Allen,
U.K.A.E.A.,
Nuclear Environment Branch,
B 329 Harwell Laboratory,
Didcot,
Oxfordshire.

Dear Sir,

Re: The Chernobyl Disaster

At the last Meeting of the Council's Policy and Resources Committee Members discussed recommendations made by the Preparedness for War and Peace Time Disasters Sub-Committee. As a result I have been requested to invite a representative from U.K.A.E.A. to address the Members of the Policy and Resources Committee on the subject of the Chernobyl Disaster.

The next two meetings of the Committee are due to be held on 2nd October and 13th November; will you please inform me which date will be the most suitable date for your representative to attend.

Yours faithfully,

D.D.H. Cameron.

Clerk & Chief Executive Officer.

United Kingdom Atomic Energy Authority

11 Charles II Street
London SW1Y 4QP

Telephone: 01-930 5454

Mr. B. Westwood,
Barry Westwood Productions,
231 West Street,
Fareham,
Hampshire, PO16 0HZ.

28th August 1986.

Dear Barry,

Thank you for your letter of 26th August.

We seem to be in agreement about the aims and objectives:

1(a) Yes, the programme is intended for viewing exclusively by AEA staff. But videos are easily borrowed and copied; we cannot therefore exclude the possibility of it being seen elsewhere.

(b) With regard to the questions, as interviewer you are, of course, the surrogate for all our AEA viewers.

Not all AEA staff are technical; they cover a range of skills, backgrounds and lifestyles. For instance, London headquarters staff probably live in 'nuclear free' zones and their neighbours take them to task about the future of nuclear power. Whereas around a nuclear research site the spending power from AEA wages and salaries may somewhat reduce criticism. But all AEA staff meet people who have doubts about nuclear power - especially since the Chernobyl accident.

Some possible questions together with a selection of media comment are enclosed.

The answers by John Gittus, then, will be carefully analysed by AEA staff. They will use them, in modified form, to discuss with friends and relatives outside the AEA.

2. Assuming Dr. Gittus finds that the 4 September is suitable then the date and arrangements are fine.

3. Introduction by you. I think that an introduction by you would help. It would ensure that the ground rules for the programme were known by each viewer. I suggest something on the lines of: Chernobyl; this programme is for you, the staff of the AEA; media comment and how do we discuss the issues with our relatives and friends; the Vienna meeting; authoritive answers from the head of the the Safety and Reliability organisation i.e. lead-in to Dr. John Gittus.

4. Maximum running time. In one sense the programme must be as long as is needed to do the job properly. The topic is as serious as any the AEA has had to deal with and I think that AEA staff will expect succinct questions and answers. But they will expect the subject to be covered fully.

5. Mark Brightman is arranging for:

- Parking space
- Electrical power
- Discussion room
- Refreshments

contd./

- Easel, flip chart, sketch pads, fibre pens.

6. Sketches. When John Gittus suggested sketches I encouraged him for two reasons. It is unusual for AEA staff (especially senior staff) to volunteer to communicate visually in such a personal way and I hoped it may encourage others. The second reason was that it is 'in-house' communication and would be the sort of tutorial style that technologists use with each other.

   Admittedly, since then I have been concerned that the sketches may be difficult to animate as we may have "jump cuts" into the stylised illustrations done by our professional artists on their Quantel Paintbox. However, the fact that Dr. Gittus is keen to explain some points visually bodes well for the end product.

7. If we have the job finished by Monday 8th September that will be fine.

8. Cost. Your suggested figure of £2,000 is fine.

9. We will take on board the graphics and animation as a separate item.

10. I will be at Harwell on the 4 September and will say hello to you and John Gittus and ensure you have all you need. I will leave a phone extension in case you need anything. Apart from that I will keep well out of the way and try to ensure that everyone else does the same, until the interview is completed.

Best Wishes,

Yours sincerely,

Harry

G. Gibbons

ccs. Dr. J. Gittus
Mr. F. Chadwick
Mr. W. McMillan
Mr. M. Brightman

1. I live in a "nuclear free-zone" and get a lot of criticism from my neighbours - they tell me that finally the industry's been found out, its not safe, never will be safe; asnd that its "all over" for us.
What can we reply?

2. Another incident like Chernobyl will kill the industry dead. Whats to stop it happening here, or anywhere?

3. What have we learnt from Chernobyl about our safety procedures. And if there are no lessons to be learnt why not? Surely there must be something?

4. Is it really true that we rejected the design? There was a lot of talk at the time that SGHWR looked very similar to the Chernobyl design.

5. What about this talk that there is no containment on the British Magnox reactors?

6. The Russians have blamed junior staff but we all know what all organisations are like - the people at the bottom get the blame - what really happened?

URGENT FAX

To:
Mr A M Allen LHQ
Mr R N Simeone
Mr R L R Nicholson
Mr M A W Baker
Mr A W Hills
Mr F Chadwick
Mr W MacMillan
Mr R N James
Mr B C Carpenter

Mr J Bretherton Dept of Energy

Dr T N Marsham Risley
Dr B L Eyre Risley
Mr A D Evans Risley
Mr J R Askew Risely
Dr G G E Low Harwell
Dr D Hicks Harwell
Dr J E R Holmes Winfrith
Mr C W Blumfield Dounreay

Mr H J Teague SRD
Dr M R Hayns
Dr R S Peckover
Dr F R Allen
Dr G M Ballard

From: Dr J H Gittus, SRD

THE RUSSIAN CHERNOBYL REPORT

An English summary became available yesterday, in advance of next week's meeting in Vienna.

It shows that the operators were to blame. They had, without permission, "switched-off" the automatic reactor trip system and the emergency core-cooling water system together with other safety provisions. This information supplies the "missing link": hitherto we had been unable to fathom why the safety systems had failed to prevent the accident.

The operators wanted to find out whether the reactor coolant pumps and other systems could be adequately powered by the main turbo-alternator when the latter was free-wheeling to a standstill. The coolant pumps, in the event, were not able to keep the reactor cool under the circumstances. It did not trip, since the operators had inhibited this safety provision and the emergency cooling did not operate since the operators inhibited this, too.

Accordingly it overheated, the resultant high steam pressure burst the pressure-tubes and the flimsy containment; radionuclides, evaporating from the by now uncooled fuel, escaped. Both the zircaloy and the graphite were partially oxidized by air and steam and the hydrogen and carbon monoxide so produced burned in the air.

The amount of activity released went through its second peak when a week after the accident the fuel temperature reached its highest value. The fuel did not melt but nevertheless released all the noble gases and three percent of the other radionuclides which it contained (over ten million curies).

Apart from laying the blame on the operators, the main technical short-coming highlighted by the Russians is the positive void coefficient. They say that they intend to minimise this by raising the fuel enrichment and increasing the worth of the absorbers permanently located in the core.

20 August 1986

URGENT FACSIMILE

F

Ch

8452
22-8

TO: Mr D Levey, Overseas Relations, LHQ

IAEA Document Strengthening the Agency's
Nuclear Safety Activities

I am sorry that I have been unable to spend as much time as I would have liked on this document but I am sure you will appreciate that preparations for Vienna and the visit of the Hong Kong delegation has interferred somewhat with my plans. I have sought comments from Geoff Ballard on paras 1 & 20, Tom Nixon on matters relating to quality assurance and Peter Barr on tansport and other technology development areas A3 and H3. In order to save time I am simply including their unfiltered comments as annexes to this note. My comments are related to areas I2, I3 and I4.

Paragraph 17 area, I.2: Now that it is clear what the Russian explanation of the accident cause at Chernobyl is, I am not sure that accident management in the sense of the word used here is going to be all that important. If this were re-interpreted as post-accident recovery and management then I believe there are certainly grounds for supporing IAEA activities in this area. The actual management of a severe accident in the sense that was addressed by the Senior Expert Group of the NEA is rather different and that is how to train operators and provide equipment to actually in some senses, "control" the course of a degraded core accident. The Chernobyl experience indicates very clearly that nothing at all could be done to prevent a severe core degradation given that the management of the plant had been so bad prior to the actual moment of the core destruction. This area of recovery and/or accident management is one which is being highlighted particularly by the French and by the Americans and we should therefore expect there to be strong international support for it. Whether the IAEA is the ideal body to do this is another matter. So far as the OECD countries are concerned I would have thought that the NEA provides a rather better forum for the sort of technical level discussions that countries with developed reactor programmes would benefit from. In terms of teaching and technology transfer then of course the IAEA would be a good vehicle but we would not then expect significant technical returns ourselves for the effort that we would have to put in. The second item in that paragraph concerns drawing lessons regarding source term estimates and here again this is something in principle we would support, however, we do have to recognise that the chemistry of this reactor and the actual physics of the accident scenario are very different indeed from anything that is directly relevant to water reactors or even our own gas cooled reactors. Therefore, we should not expect too much from such

PAGE 1 OF 8

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studies. Again, the only benefit I see from doing this under an IAEA banner rather than an NEA one is that there may possibly be access to further Russian information in this area since the Russian's will be using the IAEA, it seems, as their vehicle for communicating with the West on this topic. As in these other areas the NEA would at first sight provide a better forum for technical debate amongst the developed reactor operating countries.

Area of activity I.3, para 18: Out of all the items here which are suggested for re-examination, so far as I can see at the moment, having now read the summary of the Russian presentation, the only item really of interest in the longer term will be the issue of containment and whether the containment philosophies adopted in the West then would have prevented serious release to atmosphere in a severe accident. Because the RBMK design is so different from those operating in the West both in terms of the nature of the accident initiated, ie. very rapid steam generation, failing a relatively weak structure, it is not clear to me that lessons will be learned concerning safety design of reactors in the West from detailed understandings of how the RBMK responded to this event in detail. I believe that the questions relating to containment and associated matters such as post-accident filtering systems, equipment survivability in a containment during severe accident conditions and the like will be important and I know for a fact that the NEA already have a group considering requirements for containment performance work in an international context (I actually chair that group). I believe we should be very wary of any recommendations emanating from the IAEA on possible upgrading of NUSS standards for existing plant. The IAEA will have such weight in the political arena for the next few years that any pontification from them will have to be considered and it would be unfortunate if this was not consistent with UK requirements.

I.4: Any requests for assistance in reviewing the safety of operating plants I would have thought should be supported at this time. I would expect that from the UK point of view we would be contributing to the reviewing teams rather than being reviewed ourselves but I would have thought that this was something that we should support in principle.

I am sorry if these comments are rather disjointed, if there is time after the Vienna meeting perhaps I could do better.

From: M R Hayns
SRD

21 August 1986

cc Dr J H Gittus ✓

6597
20/8

MEMORANDUM

To Dr M R Hayns

Your Ref.
Our Ref.
Tel Ext. 7219

Subject EXPANSION OF IAEA ACTIVITIES

Mike

You asked for comments about the Data Bank areas of the IAEA proposals for extension of their activities. In broad terms my comments about the IAEA data banks are exactly the same as those about the Ispra databank; that is, the important issue is how the data is used and what analysis can be done. Databanks in themselves contribute little and people generally are not very happy about contributing to a centralised databank. Thus my detailed comments on the IAEA document are:

Paragraph 1

My understanding is that PRIS collects design information about reactors in operation and also availability/generation performance. It does not collect reliability or incident information. As such it may be a useful repository of general design information but that hardly seems a major function that needs additional resources being spent. The analysis of PRIS information appears to be sporadic papers on the availability of various reactors.

Paragraph 20

Without the active co-operation of all utilities and countries a centralised incident databank seems unlikely to be successful (The IAEA notes the need to encourage more active participation!) A more useful function would be to provide a framework for the analysis by each country/utility of its own operating incidents so that the information that can be learnt from incidents can be promulgated widely. Thus the IAEA might liaise with each country to produce an anonymous list of facts and lessons learnt.

Geoff

G M Ballard

20 August 1986

6597
20/8

MEMORANDUM

To Dr M R Hayns

Your Ref.
Our Ref.
Tel Ext. 7219

Subject EXPANSION OF IAEA ACTIVITIES

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Geoff

G M Ballard

20 August 1986

Dr M R Hayns

MEMORANDUM

(For internal use within the Establishment only)

Reference No.

Telephone Ext.

Subject { IAEA – Expanded Nuclear Activities

Comments on GOV/2238/add 1 annex 2.

Area of activity A3 – Advanced Systems & Technology Development

The list of topics involving safety issues omits reference to seismic influences or missile impact ("aircraft crash, plant generated missiles, heavy dropped loads) on containment or reactor structures.

Should anti-sabotage measures also be considered?

Area of activity H3 – Safe Transport of Radioactive Materials

The design of transport containers for both radioactive and special nuclear materials (Pu, U fuel) should not neglect the performance of such containers in fires and transport accidents. Sabotage should also be taken into account.

Peter Haw
19/8/86

3018

Reference No. QA/002

Telephone Ext. 1359

MEMORANDUM

(For Internal use within Establishments only)

Subject: QA & IAEA – GOV/2238/Add1 | 19 Aug 83

To Dr M R Hayns,

1 As you can see from the enclosed list of IAEA QA publications there has already been a great deal of work done on the subject.

2 The safety guides QA 1 to 11 (No QA9) are quite comprehensive covering activities from design to commissioning & operation of NuPP.

3 The SGs are supported by a number of 'User's Manuals', of which only two have been published to date.

4 These manuals are usually referred to rather disdainfully by the 'mature' nuclear nations, but these are sought after by the newcomers in the nuclear business.

5 With reference to the proposal for ~~expansion~~ of the IAEA QA activities, we should support a reappraisal of the present position & press for completion of the detailed manuals.

6 QA training & independent appraisal of member states QA, should also be supported, especially in relation to the operation & maintenance of existing plant.

Tom Nixon

x 1359

Received Feb 86
from IAEA

LIST OF DOCUMENTS ON Q.A. PUBLISHED BY THE I.A.E.A. OR IN PREPARATION

I. NUCLEAR SAFETY STANDARDS

Code of Practice

50-C-QA	Quality assurance for safety in nuclear power plants	Published 1978

Safety Guides

50-SG-QA1	Establishing the quality assurance programme for a nuclear power plan project	Published 1984
50-SG-QA2	Quality assurance records system for nuclear power plants	Published 1979
50-SG-QA3	Quality assurance in the procurement of items and services for nuclear power plants	Published 1979
50-SG-QA4	Quality assurance during site construction of nuclear power plants	Published 1981
50-SG-QA5	Quality assurance during operation of nuclear power plants	Published 1981
50-SG-QA6	Quality assurance in the design of nuclear power plants	Published 1981
50-SG-QA7	Quality assurance organization for nuclear power plants	Published 1983

50-SG-QA8	Quality assurance in the manufacture of items for nuclear power plants	Published 1981
50-SG-QA10	Quality assurance auditing for nuclear power plants	Published 1980
50-SG-QA11	Quality assurance in the procurement, design and manufacture of nuclear fuel assemblies	Published 1983
50-SG-QA5 (Rev. 1)	Quality assurance during commissiong and operation of nuclear power plants	Prepared for Publication

Users' Manuals

Tech.Rep. Ser. 237	Manual on Quality Assurance Programme Auditing	Published 1984
Tech.Doc. 303	Manual on the Selection of Appropriate QA Programme for Items and Services of a Nuclear Power Plant.	Published 1984
-	Manual on Training, Qualification and Certification of QA Personnel	In Publication
-	Manual on QA for the Survey, Evaluation and Confirmation of Nuclear Power Plant Sites	In Preparation
-	Manual on QA for the Computer Software.	In Preparation

-	Manual QA/QC for Installation of Electrical Equipment, Instrumentation and Control.	In Preparation
-	Manual on Handing Nonconformances, Determining of their Root Cause and Initiating Corrective Actions.	Planned
-	Manual on Interrelation of QA Activities with Regulatory Review and Inspections.	Planned
-	Manual of Use of QA Programme for Plant Operation as a Tool for Management Control.	Planned
	Methodology of Measuring Effeciveness of a QA Programme.	Planned

Proceedings

STI/PUB/593 Quality Assurance for Nuclear Power Plants, Proceedings of a Symposium, Paris, 11 - 15 May 1981.

Risley Nuclear Power Development Establishment
United Kingdom Atomic Energy Authority
Risley, Warrington, Cheshire WA3 6AT.

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bf.

19 August 1986

Dr J H Gittus
Director
SRD
Culcheth

Dear John,

CHERNOBYL

1. Here are copies of some more of my slides on Chernobyl, some prints of some of them and also some aerial photographs of the Chernobyl site. The photographs are for internal use only otherwise the Authority would have to pay royalties to the agency which supplied them.

2. Fig 1 shows the four units quite clearly and confirms what I thought earlier that units 3 & 4 are of a more recent design and layout (Smolensk) then units 1 & 2 (Leningrad).

3. Fig 2 shows units 3 & 4 in the centre of the picture. Comparison of the residue of unit 4 with what is visible of unit 3 shows that the walls and roof of the fuelling machine hall of unit 4 have disappeared and probably also the steam-drum cells and steam drums. The slide taken from a picture on a TV screen confirms that all these upper structures have disappeared from unit 4.

Please remember me to Bill Morison (Ontario Hydro) and Gordon Brooks (AECL) when you see them in Vienna and pass on my best wishes to them.

Yours sincerely

Bob.

R J HASLAM

PS Copy of the report in today's Guardian attached.

Chernobyl workers 'were in a hurry'

From Michael White in Washington

Technicians hurrying to complete what they thought was a routine safety test at the Chernobyl nuclear power plant precipitated the disaster last April, the official Soviet account will assert next week.

In effect the report confirms the "human error" theory whereby senior staff allowed "purely formalistic" safety procedures to be used — and have since been fired for misjudgments which cost 30 lives.

But the expected post-mortem at the meeting of the International Atomic Energy Authority in Vienna will be told that, contrary to the evidence of radioactive fallout around the world, there was no meltdown of fuel at the stricken No. 4 reactor.

This claim may arise only from technical or translation problems, or it could be a euphemism like the phrase "partial meltdown" used to describe the previous worst civil nuclear accident at Three Mile Island, Pennsylvania, in 1979.

However many experts here are impressed by Soviet candour — even though they are alarmed by some of the admissions it has produced. Critics fear that the international nuclear industry will close ranks and allow its Soviet colleagues to avoid close questioning at the IAEA symposium in Vienna next Monday.

Without going into details about the extent of contamination of the surrounding area, 70 miles north of Kiev, the 382-page Russian report will concede that about 50 megacuries of fission products (excluding rare gases) were released into the atmosphere. But it does flesh out previously hazy versions of the crisis.

Details of the authorised Soviet version, which hinges upon what is called a "turbine inertia" test not directly involving the reactor itself, have been circulated among IAEA members since last Thursday. After initially becoming public in Japan, where scientists have estimated that 30 to 40 times the radioactive ash produced by the Hiroshima or Nagasaki atomic bombs was released at Chernobyl, the report's contents are now trickling out of the US Department of Energy.

They portray the accident as starting at 1am on Friday, April 25, when the reactor's operators began reducing the unit's power for a test to establish the amount of residual energy produced by the still-spinning turbine-generator system after its source of power — the reactor — had been shut off.

Unlike most Western systems, Soviet safety equipment generally lacks independent power sources in the event of an emergency shutdown. They were "trying to do it on the cheap," one US nuclear scientist said.

The technicians duly shut down the reactor to around 6 per cent of full power, and turned off virtually all the plant's safety systems, including its computer, its emergency cooling pumps, the power regulating system and the automatic shutdown system. Having done this, they disconnected the steam turbines from the residual power coming from the reactor. By now some 24 hours had elapsed.

What went wrong, and why, continues to puzzle Western analysts. It is agreed that the Soviet graphite-moderated reactor is vulnerable to unstable surges in power if it loses its cooling water. The Soviet account suggests that the technicians, "whose basic motive was . . . the striving to complete the test faster," did not realise the risks they ran.

The override of the computer controls and rerouting of the unit's electrical system generated a surge of power to 17 per cent in a few seconds as a result of lost cooling water and "hot spots" inside the core. There is also a suggestion that two extra recycling

Turn to back page, col. 1

Chernobyl staff 'in a hurry'

Continued from page one

pumps which were deployed overheated coolant.

The Soviet account says the technicians realised that something was wrong soon after the test began at 1.20am on Saturday, April 26. At 1.23 and 40 seconds they tried to shut down the reactor by inserting its control rods to stop the chain reaction. "Banging noises" were heard and no more than a quarter of the rods went into place.

Twenty seconds later the first explosions occurred — initially a steam explosion which blew the thin steel lid off the reactor's top. A heavy crane used to move fuel rods then crashed into the reactor, rupturing rods and exposing much of the graphite core to the atmosphere.

A series of explosions followed and a fireball sent the plume of smoke high into the air.

US reaction to the Soviet account has been mixed. Last night the atomic industry forum's spokesman described it as "very frank and very complete". Other scientists and engineers have expressed alarm at the risk-taking involved in a system already difficult to manage — "in a sense of horror" and "a poorly-considered invitation to disaster", said one.

But environmentalists and other critics of the nuclear energy industry see a convergence of interest between national industries, however much they stress the superiority of their own designs. One former member of the US watchdog body, the Nuclear Regulatory Commission, hinted strongly last night that the US team to Vienna has been chosen to ensure tight control and exclude potential trouble-makers.

It is rumoured that the IAEA is planning to let the Russians make their presentation on Monday without answering questions, though the leak of their report in advance has probably made that option harder to sustain.

Guardian
19·8·86

USSR PREDECESSORS OF THE RBMK REACTORS

Status at 31.12.85	Reactor	Cycle	Reactor coolant	Unit output MWe net	No. of units	Commercial operation
All in service	APS-1 (Obninsk)	Indirect	Pressurised water	5	1	1954
	Troitsk	Indirect	Pressurised water	90	6	1958-1963
	Beloyarsk-1	Direct	Boiling water & sup'd steam	102	1	1964
	Beloyarsk-2	Direct	Boiling water & sup'd steam	175	1	1968
	Bilibino	Direct	Boiling water (1)	11	4	1974-1976

Note: (1) These reactors supply electric power to the Bilibino mining area in the Arctic and space heat to the village of Bilibino.

LARGE RBMK UNITS IN SERVICE AND UNDER CONSTRUCTION IN USSR

Status at 31.12.85	Station	Unit output MWe (net)	No of units	Commercial operation
In service	Leningrad	950	4	1974 - 1981
	Kursk	950	3	1976 - 1983
	Chernobylsk	950	4	1978 - 1984
	Smolensk	950	2	1983 - 1985
	Ignalinsk	1450	1	1984
Under construction	Kursk	950	1	1986
	Ignalinsk	1450	1	1986
	Chernobylsk	950	2	1987 - 1989
	Smolensk	950	2	1988 - 1989
	Kostroma	1450	2	1988 - 1989

PWR UNITS IN SERVICE IN USSR

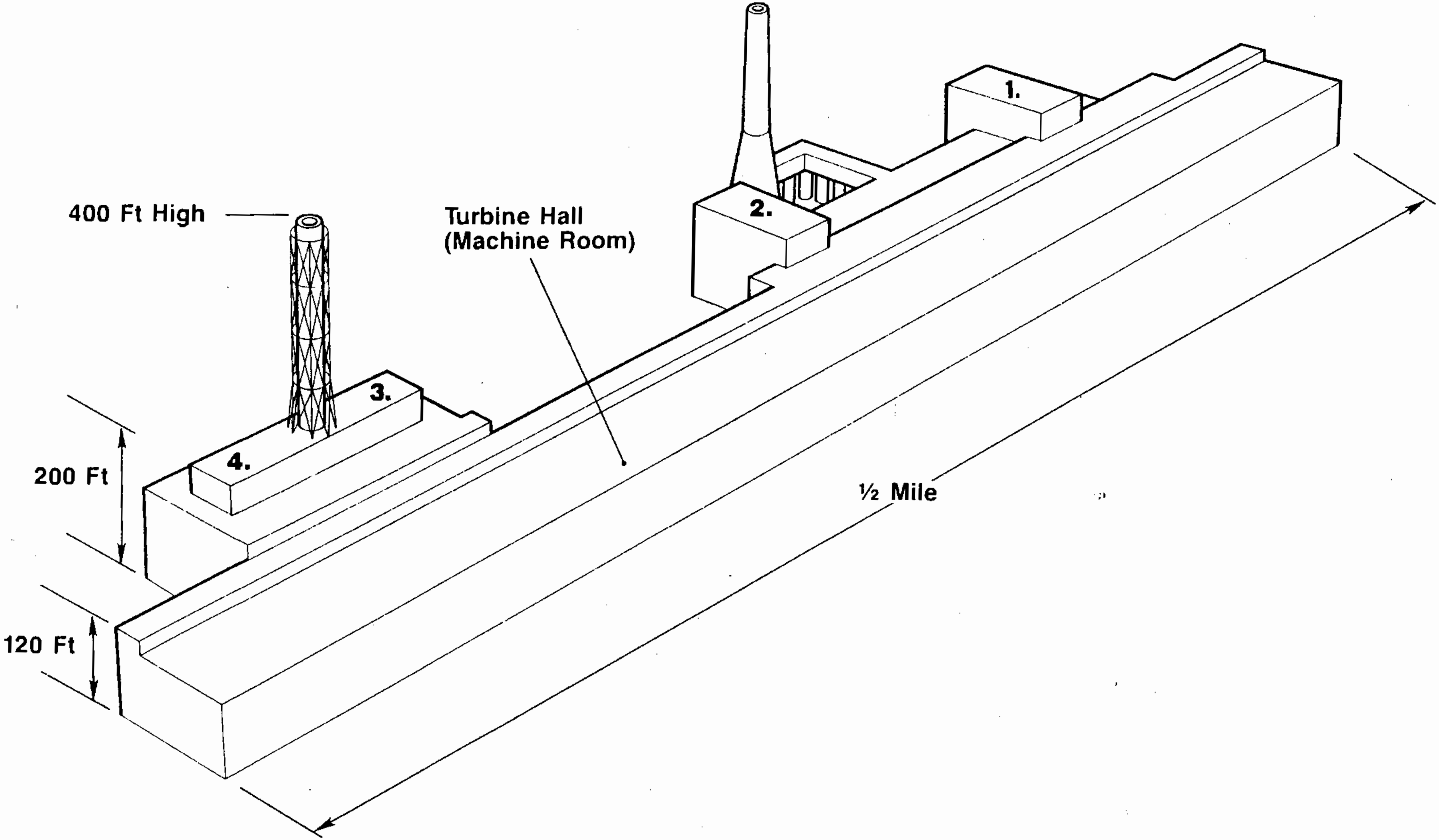
Status at 31.12.85	Station	Unit output MWe (net)	No of units	Commercial operation
In service	Novo Voronezh	265	1	1964
		338	1	1970
		410	2	1972 - 73
		953	1	1981
	Kola	440	4	1973/75, 1982/84
	Armenia	370	2	1976 - 1980
	Rovno	420	2	1981 - 1982
	Nikolaiev	953	2	1984 - 1985
	Kalinin	953	2	1984 - 1985
	Bala Kovo	953	1	1985
	Zaporozhe	953	1	1985

PWR UNITS UNDER CONSTRUCTION IN USSR

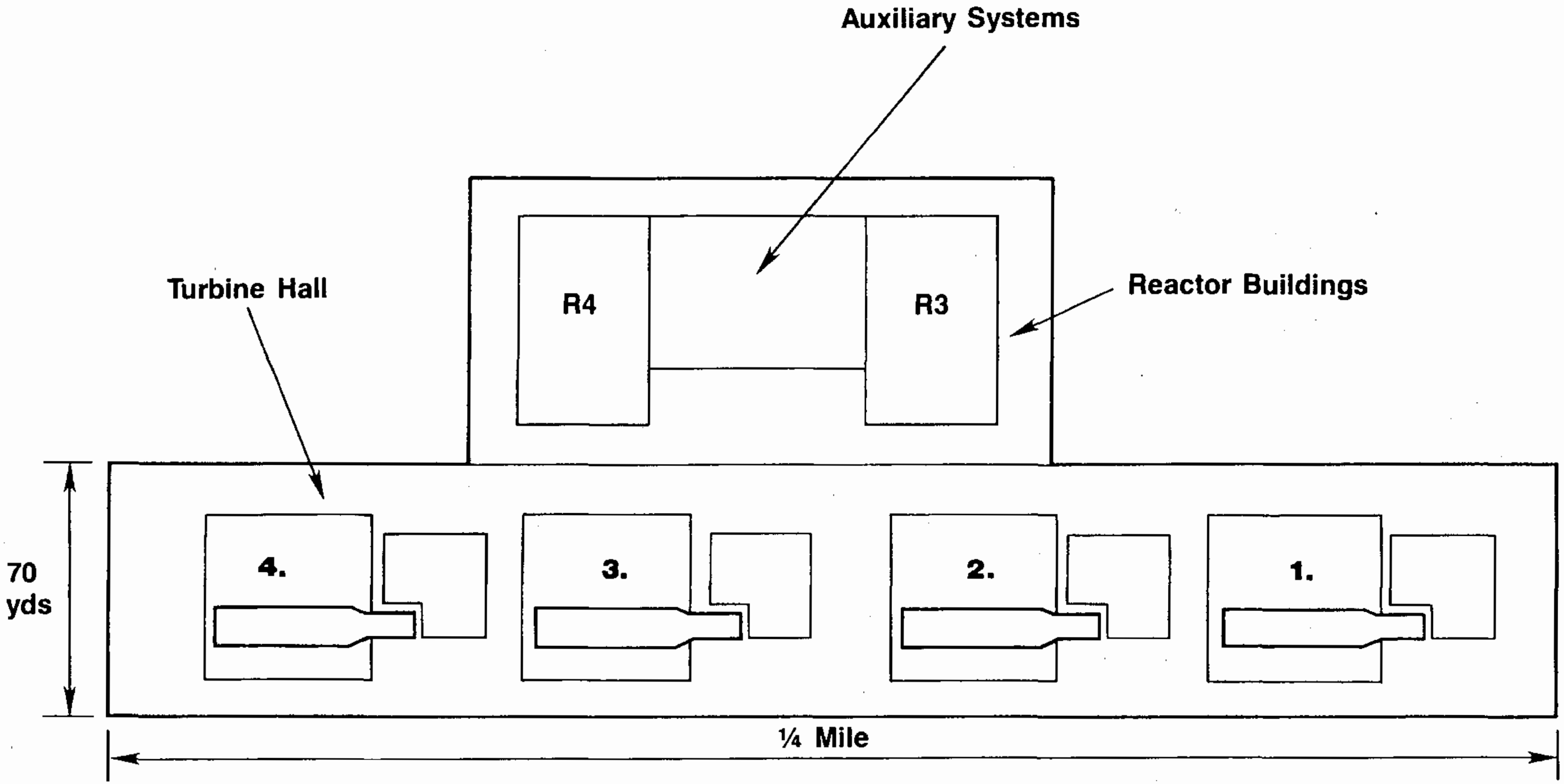
Status at 31.12.85	Station	Unit output MWe (net)	No of units	Commercial operation
Under construction	Zaporozhe	953	5	1986 - 1991
	Khmelnitski	953	4	1986 - 1990
	Nikolaiev	953	2	1987 - 1989
	Aktash	953	2	1987
	Tatar	953	1	1987
	Volgodonsk	953	4	1987 - 1990
	Rovno	953	2	1988 - 1990
	Bashkir	953	2	1988 - 1989
	Odessa	953	2	1988 - 1990
	Balakovo	953	2	1989 - 1990
	Nizhinekamsk	953	1	1989


FINLAND
NORWAY
SWEDEN
Leningrad
(RBMK-1000)
4 units
UNION OF SOVIET
SOCIALIST REPUBLICS
Kostroma
(RBMK-1500)
4 units
Ignalina
(RBMK-1500)
4 units
DENMARK
UNITED
KINGDOM
Smolensk
(RBMK-1000)
6 units
NETHERLANDS
POLAND
Chernobyl
(RBMK-1000)
6 units
Kursk
(RBMK-1000)
(4 units)
BELGIUM
GDR
FRG
CZECHOSLOVAKIA
SWITZERLAND
AUSTRIA
HUNGARY
FRANCE
ITALY
ROMANIA
SPAIN
YUGOSLAVIA

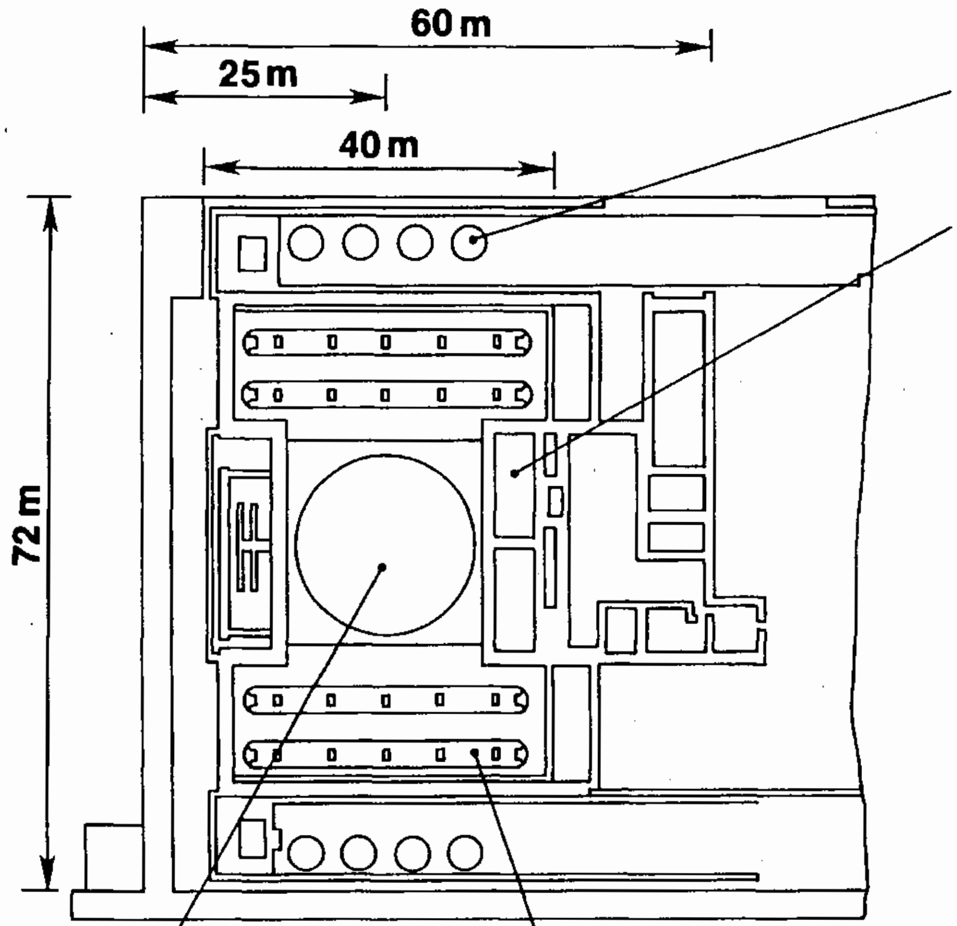
CHERNOBYL UNITS 1 - 4

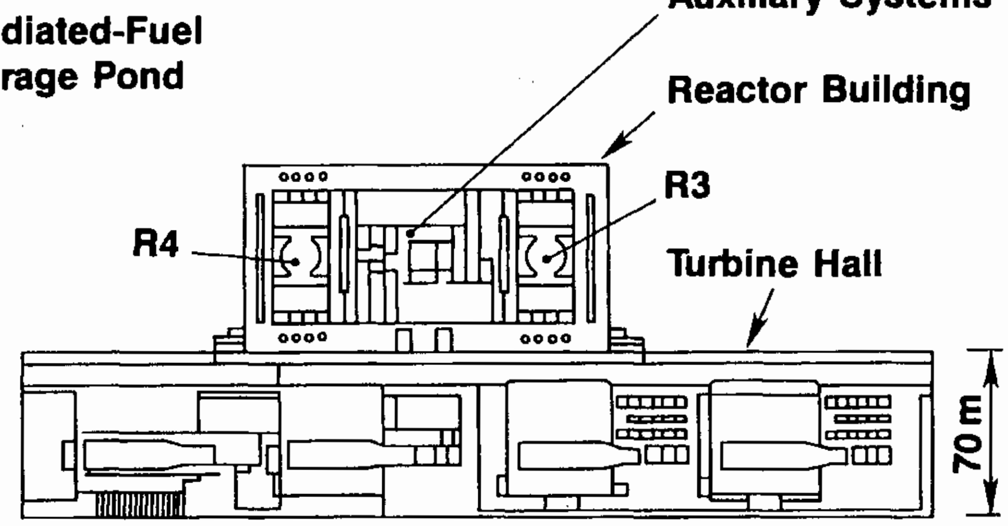


PLAN OF CHERNOBYL 3 AND 4

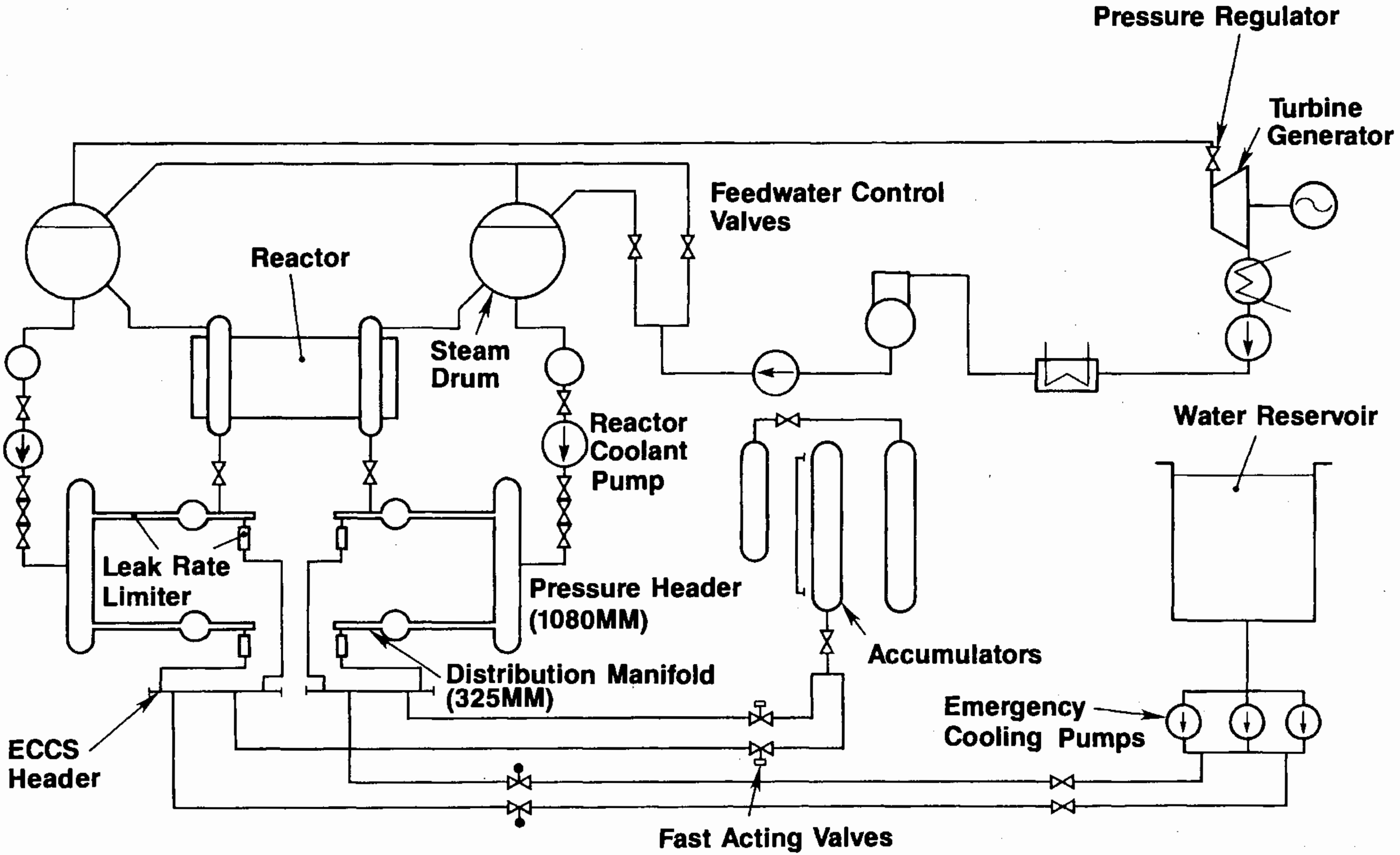


PLAN OF CHERNOBYL 4

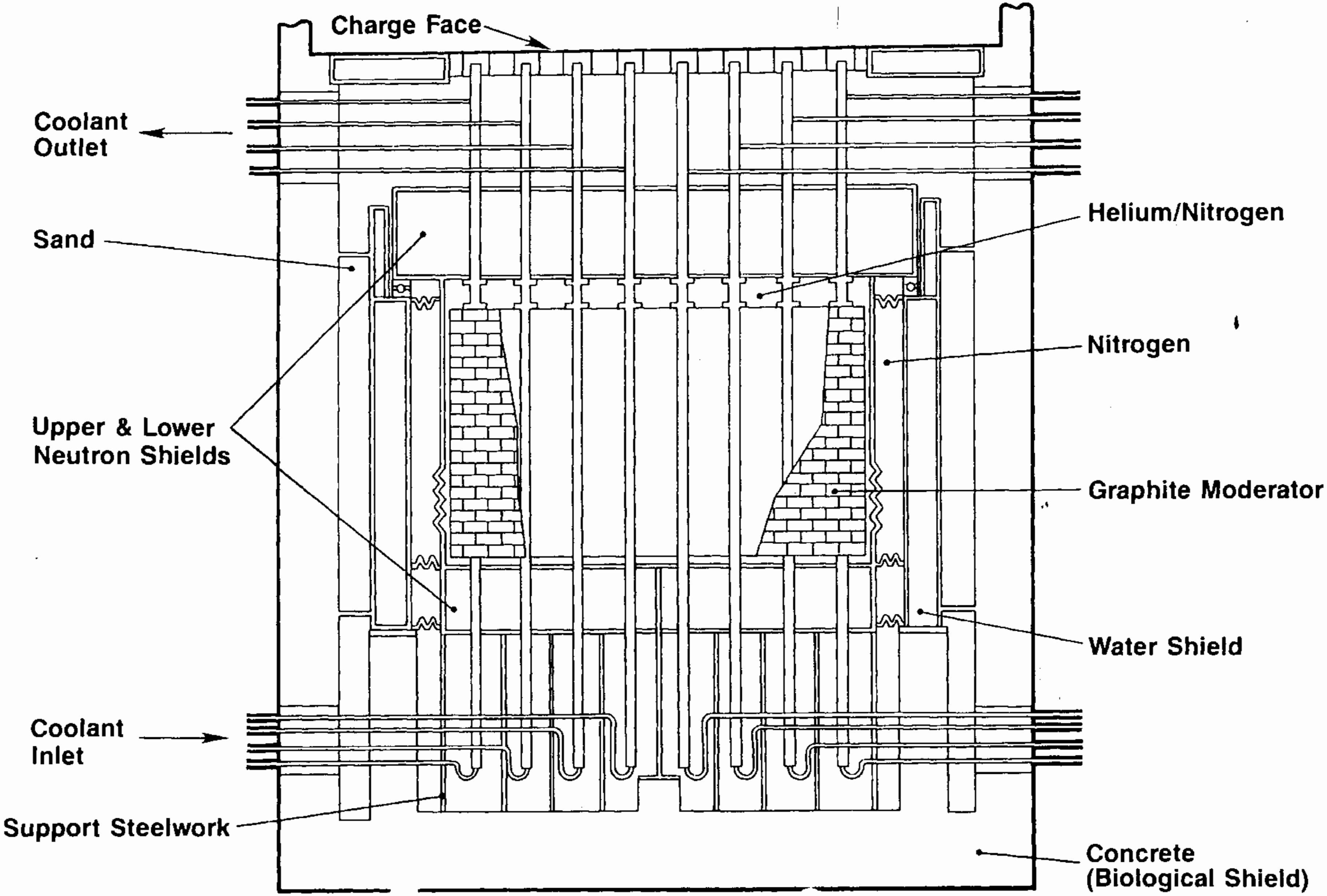




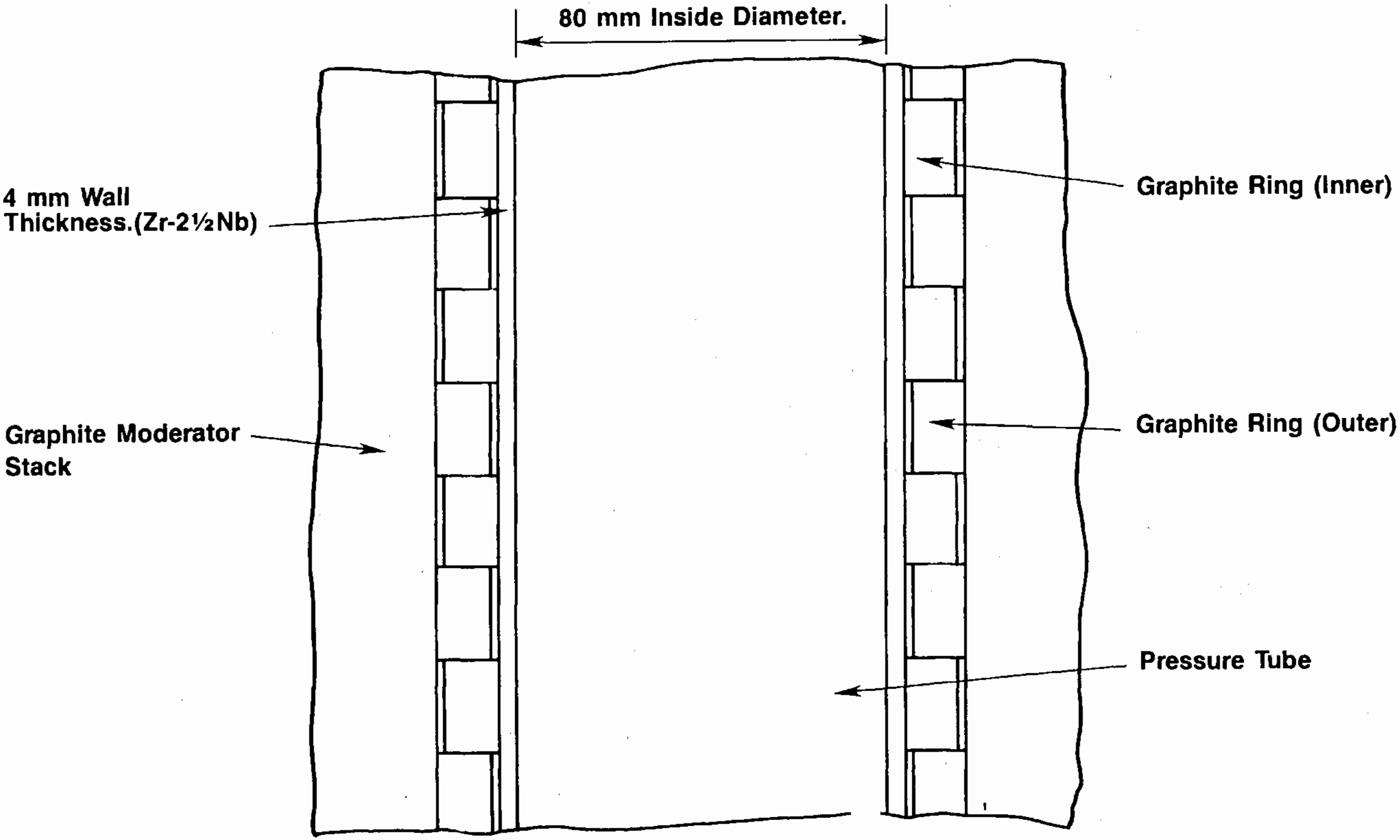
RBMK COOLING SYSTEMS



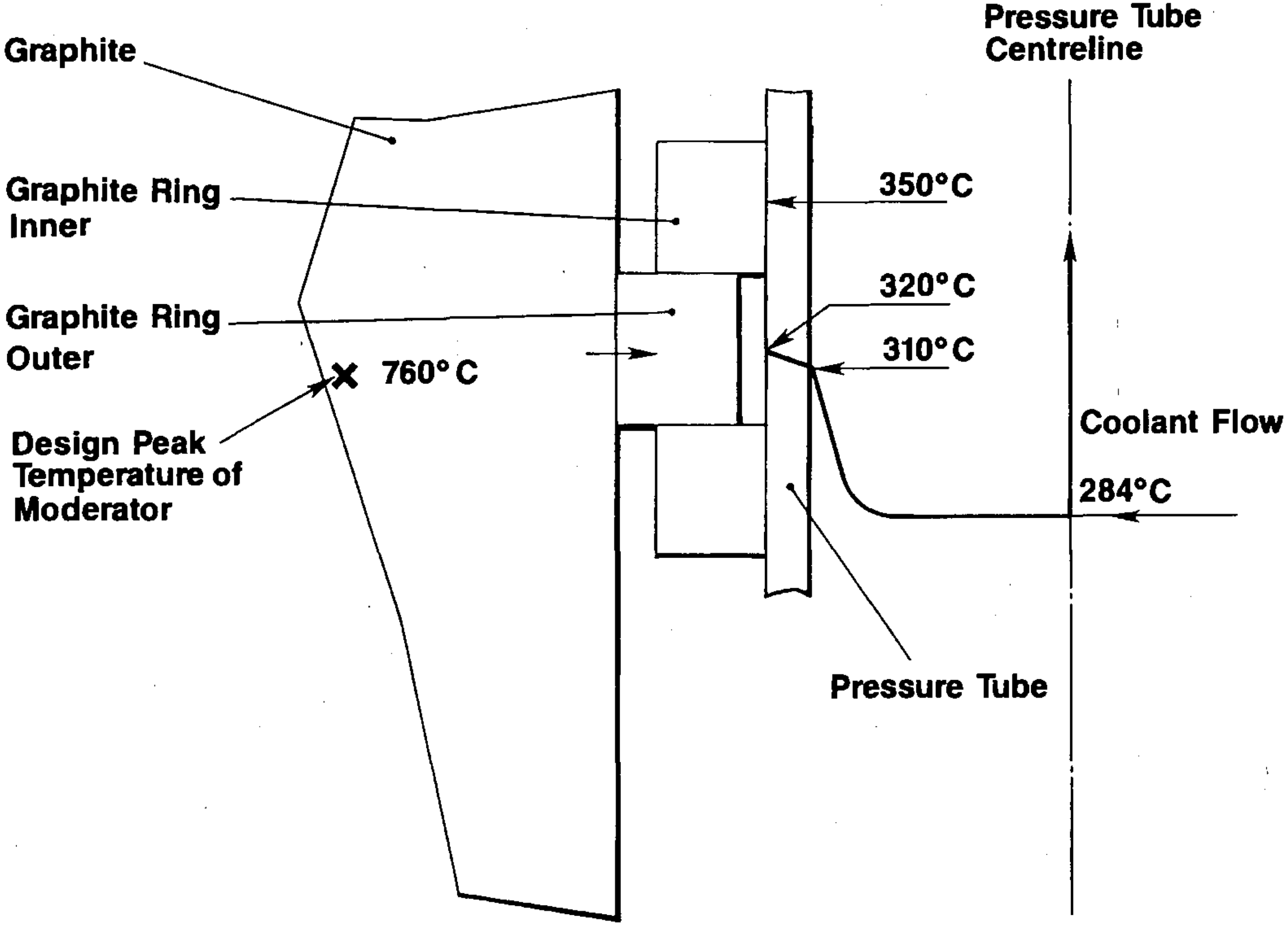
SECTION THROUGH RBMK REACTOR



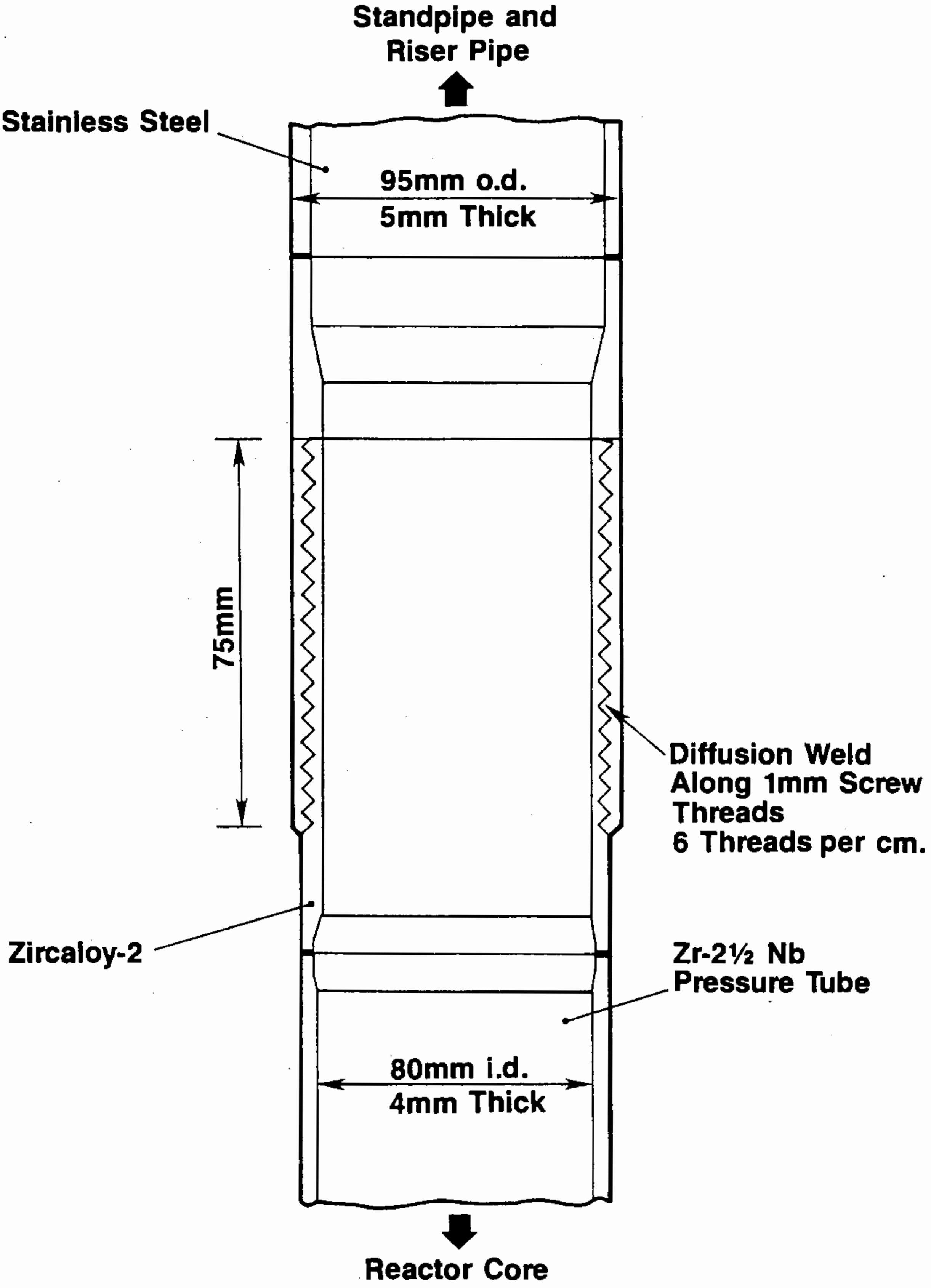
ARRANGEMENT OF PRESSURE TUBES IN REACTOR CORE



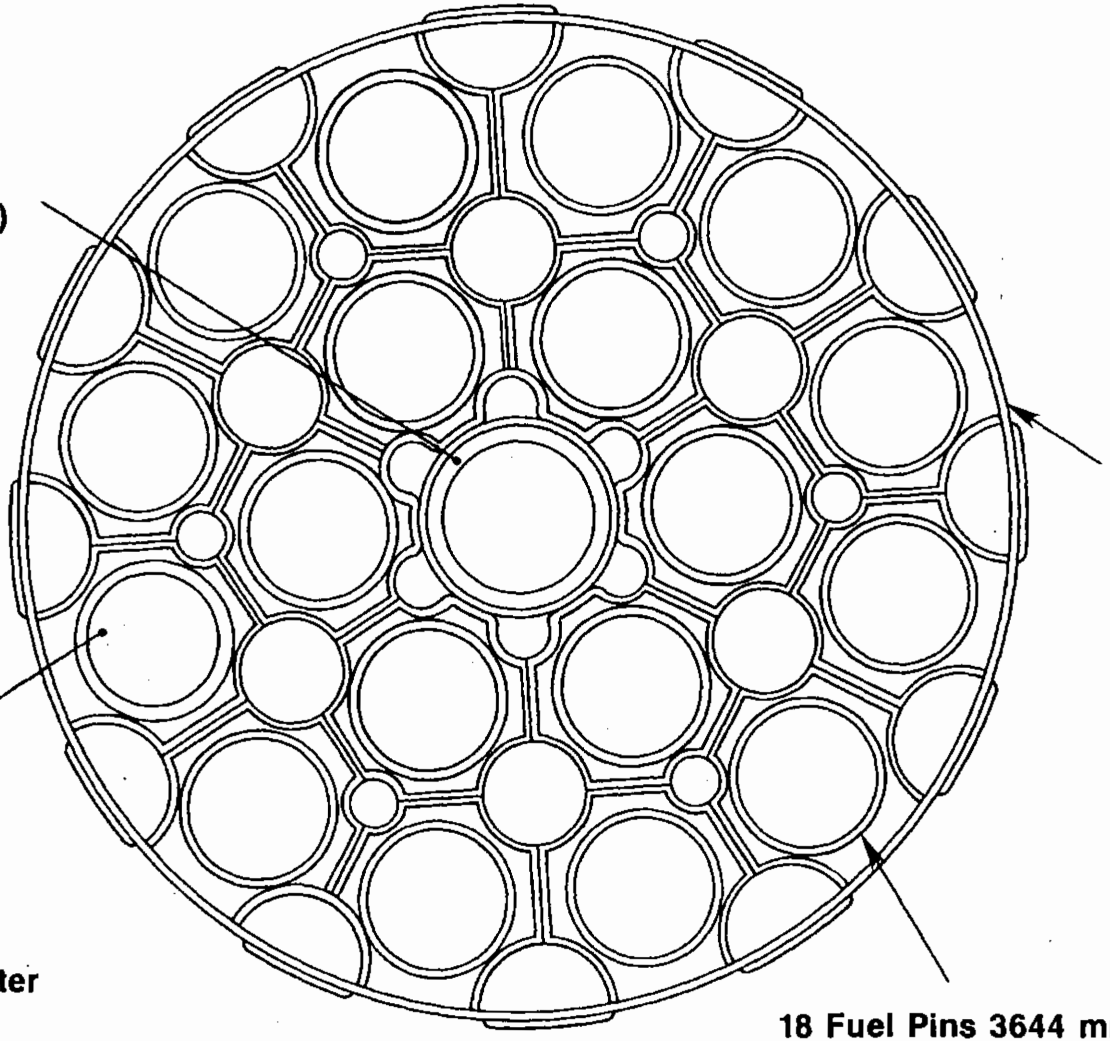
DETAIL OF PRESSURE TUBES IN REACTOR CORE



ZIRCONIUM - STEEL JOINT



SECTION OF SPACER GRID & FUEL PINS



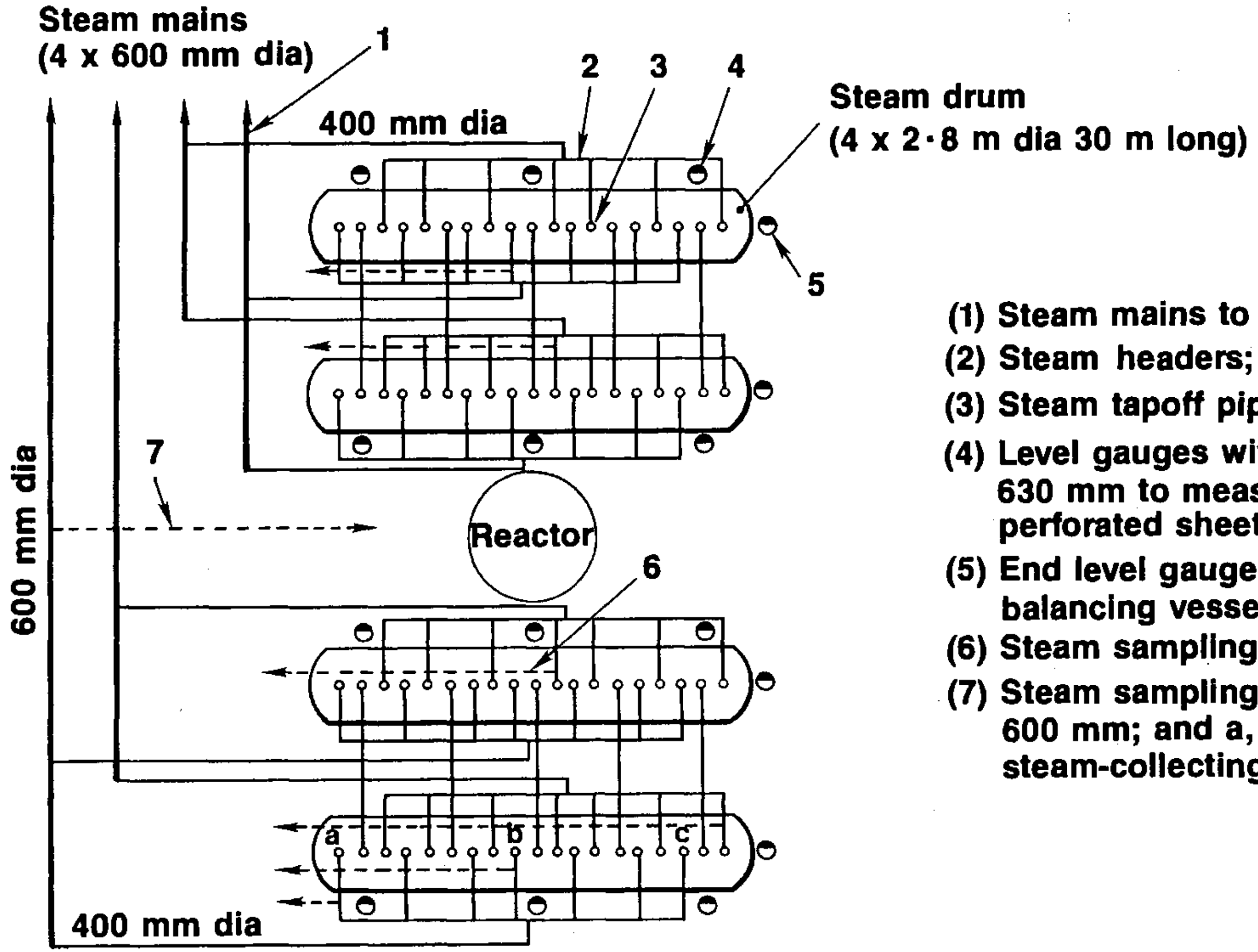
Central Supporting Tube
(With Neutron Detectors)

Spacer Grid

Uo$_2$ Fuel Pellets
(11·5 mm Dia)
Zr-1½ Nb Cladding
13·6 mm Outside Diameter

18 Fuel Pins 3644 mm Long

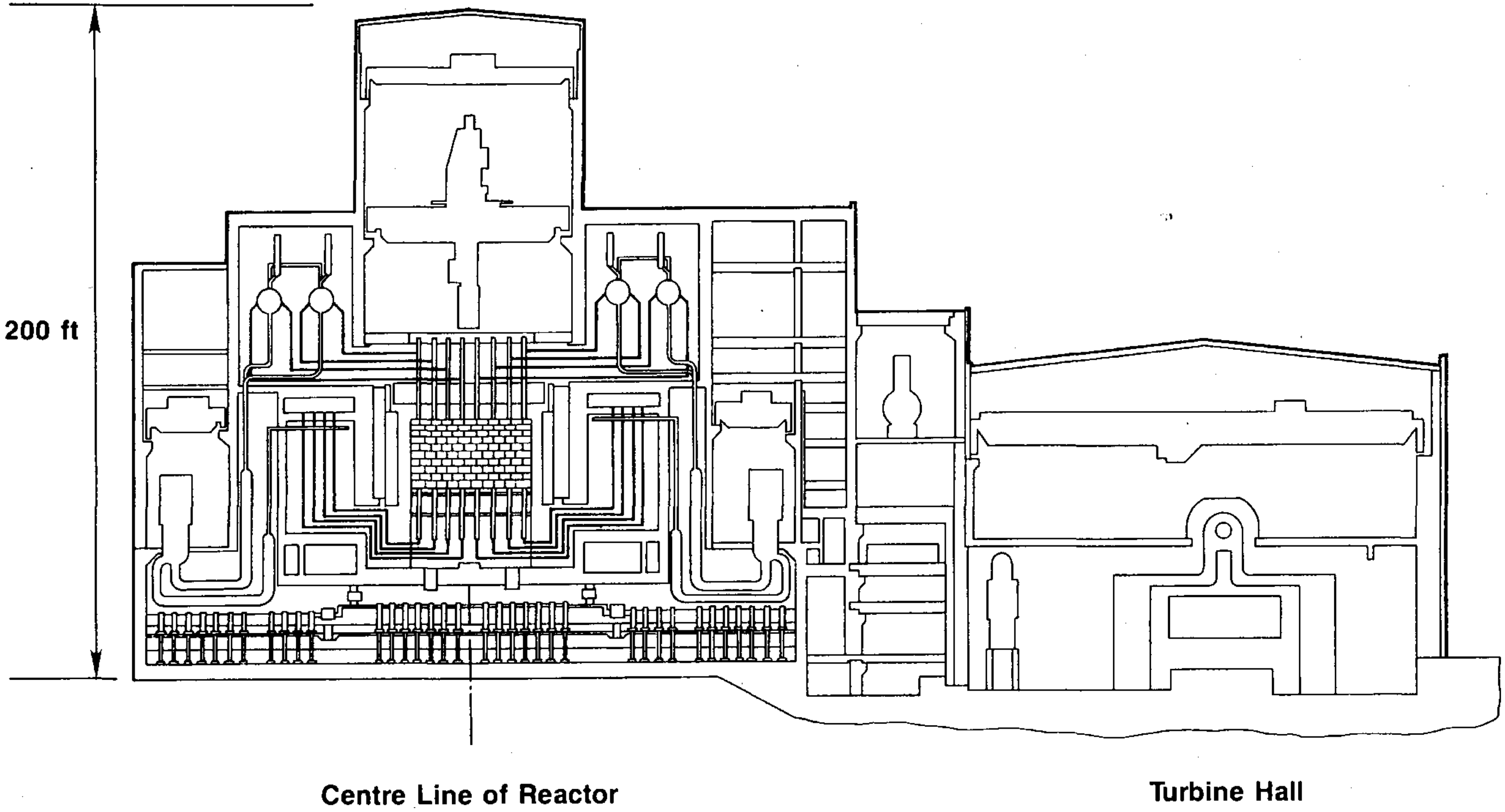
ARRANGEMENT OF STEAM DRUMS & STEAM PIPING, CHERNOBYL 4

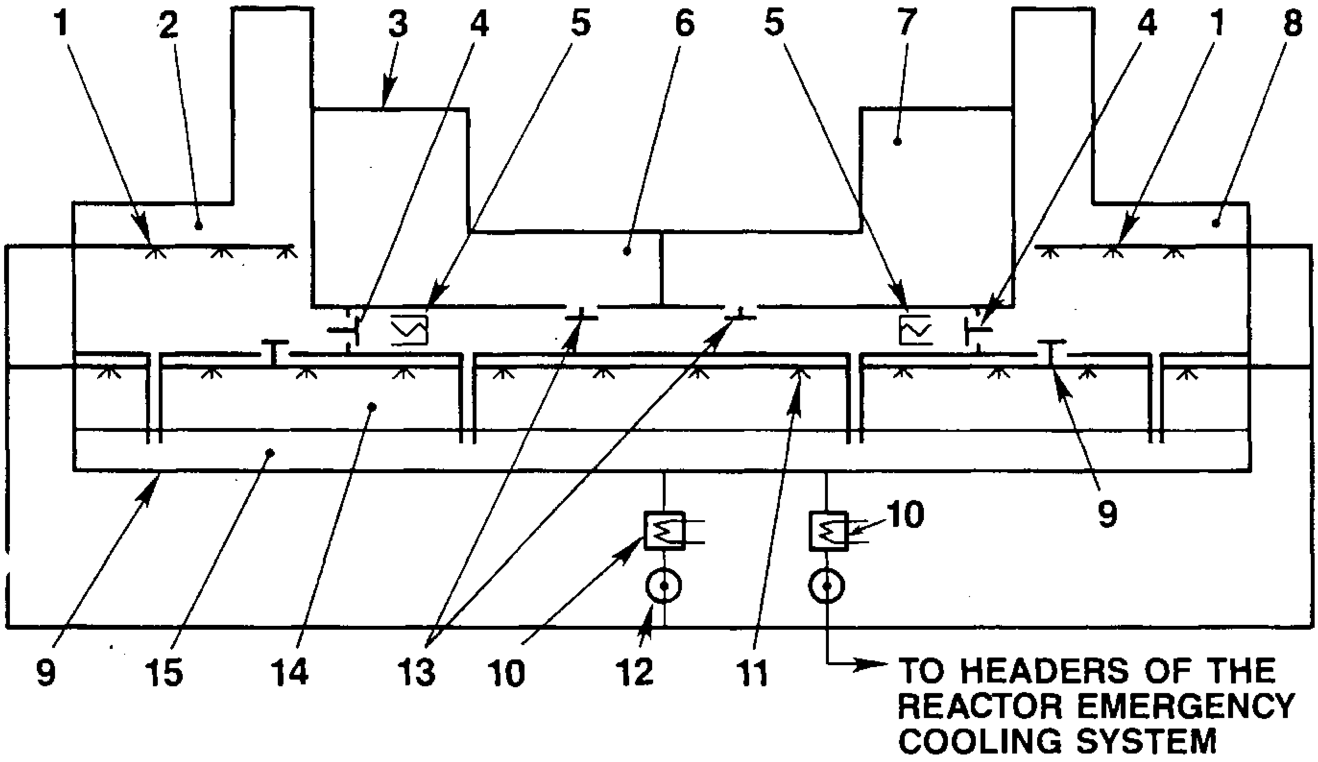


(1) Steam mains to the machine hall;
(2) Steam headers;
(3) Steam tapoff pipes from steam drum;
(4) Level gauges with balancing-vessel baseline of 630 mm to measure water level above immersed perforated sheet;
(5) End level gauges with 1600 mm baseline of balancing vessels;
(6) Steam sampling lines in steam-collecting tubes;
(7) Steam sampling from steam pipe of diameter 600 mm; and a, c, and b end and central steam-collecting tubes respectively.

THE STEAM DRUMS ARE SET PARALLEL TO THE MACHINE BAY (TURBINE HALL)

CHERNOBYL - 4





Schematic diagram of the system for retaining and localizing radioactive products in the event of an accident involving an RBMK-1000 type reactor

1, 11 - Sprinklers
2, 8 - Left and right hand halves of the hermetically sealed chambers
3, 7 - Left and right hand halves of the rooms housing the lower water lines
4 - Valve panels in the partitions separating the chambers and the corridors
5 - Surface type condensers
6 - Steam distribution corridor
9 - Relief valves
10 - Heat-exchanger
12 - Pump
13 - Check valves
14 - Air space above sparge pond
15 - Depth to which sparge pond is filled with water
16 - To emergency reactor cooling system collectors.

From Dr J. H. Gittus
Director

SRD

Safety and
Reliability
Directorate

UKAEA, Wigshaw Lane, Culcheth
Warrington, WA3 4NE, England
Telephone (0925) 31244 Ext. 7206
Telex 629301 ATOMRY G

19 August 1986

Miss V A Windsor
Overseas Relations
UKAEA
11 Charles II Street
LONDON

Dear Miss Windsor

SELIGMAN'S QUESTION 6

You sent me a letter together with a list of questions posed by Mr Seligman asking me to answer question 6. I attach my draft answer.

Yours sincerely

M. O'Hara

P.P. J H GITTUS

sc. M R Hayns.

Committee on Energy, Research and Technology

Note from Madron Seligman, M.E.P.

Answer to Question 6

6. Several measures for improved safety have been suggested, eg (a) Fail safe; (b) Automation to eliminate Human Error; (c) Containment. Do you consider that these would be effective? Can any nuclear reactor be regarded as safe without an effective containment? Does containment guarantee safety for the environment? Can containment be backfitted to all types of reactor? What effect would these different measures have on the cost of nuclear electricity?

Answer

(a) Fail Safe

The intrinsically safe reactor is a "fail safe" reactor. I attach a copy of a brief on this which I have prepared for the Department. The central problem with nuclear reactors is that if they overheat then they will give off radioactive fumes. This is what happened at Chernobyl. In the intrinsically safe reactor should there be any tendency for overheating to occur, the nuclear chain reaction (the main source of heat) stops spontaneously. There remains the problem of removing the residual or decay heat and in the intrinsically safe reactor this heat is removed by natural processes such as convection or radiation.

Existing reactors do embody some intrinsic safety features. These are supported by "Engineered Safety Features", such as pumps to supply coolant. Our analysis convinces us that a reactor which did not embody any engineered safety features and which instead relied on intrinsic safety features would not be the safest. This is because natural processes such as convection are not always to be relied upon. Again, natural safety features can actually result in danger rather than safety under some envisigible circumstances and such natural features cannot be "switched off". The safest reactor would be one that embodied a juditious mix of intrinsic and engineered safety features. The liquid metal cooled fast breeder reactor probably comes closest to the optimum mixture amongst present designs of reactor.

(b) Automation to Eliminate Human Error

Most if not all, foreseeable human actions can be performed more reliably by automatic machinery. Particularly under stress and when called upon to use their intelligence before acting, human beings are less reliable than machines. The CEGB require a level of automation on their nuclear power stations such that should something go wrong there is no need for human intervention in the succeeding period of half-hour: automatic equipment will do all that is required to keep the station safe during that period. Of course, the operators are not "locked out" - if they can think of something sensible to do which would help control the situation during the first half an hour then they are not prevented from intervening. This seems to be a very sensible arrangement because it takes account of the fact that there could be situations which are not properly catered for by the automatic machinery. Situations which were not fully envisaged when the station was designed. These are just the circumstances which we require the operators to deal with; overriding the automatic equipment if necessary and the CEGB philosophy embraces this idea. I would recommend that this sensible approach be re-inforced rather than be substituted by a fully automatic approach in which the operators are effectively debarred from doing anything at all in an accident situation.

(c) Containment

There is quite a lot to be said for the provision of a filtered-vented containment which could consist of a light structure having a hole or vent in it. A filter capable of removing radioactive materials would be placed in the vent so that if there were an accident there could be no build-up of pressure inside the containment but the radioactive material would be filtered out from the escaping steam and other gases. Some French PWRs embody this concept, I believe - certainly the French have given it very serious consideration and one could build on the research and development which they have effected. Containment is very much the last resort in my view since it is not acceptable to have reactors which can destroy themselves even if no damage is done to the public: a nuclear power station costs over one billion pounds.

(d) Fission Product retentive Fuel

Seligman does not mention this but in my view it is an attractive idea. If the fuel at Chernobyl had retained the radioactive fission products then they would not have been released and so no damage would have been done to people or the environment. Coated particle fuel of the type developed by the Authority and others for the high temperature reactor is a fission product retentive fuel. Up to the melting point such fuel can be made so that it will not release fission products in any dangerous quantity. A substantial effort would be involved in redeveloping coated particle fuel so that it could be used in existing PWRs, AGRs etc and in the event such an approach may not be warranted but it certainly deserves consideration.

(e) Secondary Protection Systems

The protection system ensures that the nuclear chain reaction is "switched off" if an accident commences. As explained above, the generation of heat is then virtually terminated. The protection system senses the initiation of any one of many different types of accident and then switches off the nuclear chain reaction. The Sizewell B Pressurised Water Reactor design has a secondary protection system which involves the use of microprocessors. In principle, it would be possible to backfit secondary protection systems of this type to existing reactors and although the safety analysis which has been done for UK reactors does not indicate that this is in any way essential, it might be considered if there were to be a general demand for even higher levels of reactor safety.

"Do you consider that these will be effective"?

I consider that the items listed above would be effective as a way of further improving the safety of reactors. Indeed, the Atomic Energy Authority is working in all of these areas: there is similar work under way overseas. It is not possible to make a nuclear reactor 100% safe and so the question is: are they already safe enough? I would say, certainly with regard to UK installations that the answer to that question is "yes". However, I do recognise that the increased sensitivity created by the Chernobyl accident in particular, may make it desirable further to increase the safety of nuclear reactors and in that case one could bring forward some of the measures listed above and apply them.

"Does containment guarantee safety for the environment"?

Perfect containment would indeed guarantee safety for the environment but we shall not achieve perfection. The strong post-tensioned concrete containment designed for the Sizewell B PWR is very good of its kind but our calculations indicate that in 6% of cases where the core of the reactor melts the containment will not be effective in preventing the fission products released from the molten core reaching people and the surrounding environment. Containments on some existing reactors are probably less effective than this. It may be that a filtered vented containment would be better but even such a containment would not guarantee safety in all cases.

"Can containment be backfitted to all types of reactor"?

The answer must be "yes" - at a price. A simple vented containment could probably be produced by using the existing building which would have to be rendered leak-tight and then furnished with a vent blocked by a filter.

"What effect would these different measures have on the cost of nuclear electricity"?

It all depends on whether the measures are adopted before the reactor is built or backfitted afterwards. Experience with the Sizewell reactor, where a number of additional safety measures were incorporated in the design, indicates that this can be done quite cheaply. I believe that the increase in capital cost attributable in the Sizewell case, to measures which have had a very significant impact on safety was less than 10%. To backfit such features on existing reactors would in many cases be much more costly. Nevertheless, if the pressure of public opinion were so high that it were deemed necessary to seek the additional safety which such backfitting could no-doubt supply then every effort would be made to render backfitting an economic proposition. I would hazard a guess that however clever we were, it would be between two and five times more expensive to backfit than it would be to provide additional safety features at the design stage.

An exception to this would be fission product retentive fuel. The fuel is replaced every year or two and its cost is only a small proportion of a total cost of electricity: the largest proportion comprises capital charges. I envisage that a new fuel capable of retaining fission products up to the melting point might cost 50% more than the existing fuel but this would not add 50% to the cost of electricity. Some of the other provisions might very well involve capital expenditure that would add 50% to the cost of electricity output if they were backfitted.

J H GITTUS

19 August 1986

I

(Information)

COUNCIL

Council resolution of 22 July 1975 on the technological problems of nuclear safety

THE COUNCIL OF THE EUROPEAN COMMUNITIES,

Having regard to the Treaty establishing the European Atomic Energy Community;

Having regard to the Opinion of the European Parliament (¹);

Having regard to the Opinion of the Economic and Social Committee;

Whereas the Commission has forwarded to the Council a communication and a general report on technological problems of nuclear safety;

Whereas it is necessary to keep the public adequately informed on this subject;

Whereas nuclear power has a considerable part to play in supplying energy to the Community;

Whereas the technological problems relating to nuclear safety, particularly in view of their environmental and health implications, call for appropriate action at Community level which takes into account the prerogatives and responsibilities assumed by national authorities;

Whereas, by aligning safety requirements, the national authorities responsible for nuclear safety and constructors and energy producers will be able to benefit from a harmonized approach to the problem at Community level;

Whereas nuclear safety problems extend beyond the frontiers not only of Member States but of the Community as a whole, and it is incumbent on the Commission to act as a catalyst for initiatives to be taken on a broader international plane,

HEREBY ADOPTS THIS RESOLUTION:

THE COUNCIL

1. requests the Member States as well as the licensing authorities, and the safety and inspection authorities on the one hand, and the operators and constructors on the other, and finally the agencies responsible for applied research programmes to continue to collaborate effectively at Community level;

2. agrees to the course of action in stages indicated below by the Commission in respect of the progressive harmonization of safety requirements and criteria in order to provide an equivalent and satisfactory degree of protection of the population and of the environment against the risks of radiation resulting from nuclear activities and at the same time to assist the development of trade on the understanding that such harmonization should not involve any lowering of the safety level already attained; taking into account the state of industrial development in the respective families of

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(¹) OJ No C 128, 9. 6. 1975, p. 24.

high-power nuclear reactors, these stages involve listing and comparing the requirements and criteria applied and drawing up a balance-sheet of similarities and dissimilarities; formulating as soon as possible recommendations pursuant to the second indent of article 124 of the Euratom Treaty, and subsequently submitting to the Council the most suitable draft Community provisions;

3. agrees to strengthen Community efforts to coordinate applied research programmes in order to make the best possible use of the resources available in the Community and the Member States both technically and financially whilst avoiding as far as possible unnecessary duplication; these efforts shall be aimed at improving systematic exchanges of information, promoting concerted action and cooperation between specialized bodies and institutes and stimulating where appropriate the development of Community programmes;

4. approves of the methods used and advocated by the Commission, namely, meetings of working parties of specialized experts, exchanges of information on specific operational problems and analytical studies and syntheses with which these experts are associated;

5. notes that the measures described above may require appropriations in order to finance analyses and syntheses and the appropriate technical secretariat;

6. requests the Member States to notify the Commission of any draft laws, regulations or provisions of similar scope concerning the safety of nuclear installations in order to enable the appropriate consultations to be held at Community level at the initiative of the Commission;

7. requests the Member States to seek common positions on any problems concerning the harmonization of requirements and criteria and the coordination of research into nuclear safety being dealt with by international organizations;

8. requests the Commission to submit annual reports on the progress made and the Member States and the Commission to continue and strengthen their efforts to ensure that the public is given the best possible information about both national and Community action in the field of nuclear safety.

0427
19.8

p1 of 13

Berkeley Nuclear Laboratories

Ch

URGENT DEX

18th August 1986

To: J. Gittus SRD

copy: P. Bonnell
A. Hall
P. Clough

From: S.J. Board, BNL

Questions on Chernobyl

Revised format questions on section B + C (now 2 + 3) on Accident Evolution - Short term and Accident Evolution Long term and recovery, to add to those already sent by John Appleby on Sections A + B (now 1 + 2). Any additions, improvements, and extra briefing material will be very welcome.

S.J. BOARD

BNL/SJB/SG

B4.4 Initial Major Damage

B4.4.1 Circuit Failure

What part of the cooling circuit ruptured initially, producing the depressurisation?

- At what time relative to the power surge did this happen?
- What was the physical mechanism causing failure?

Subsidiary Questions

- How many assemblies were damaged in the power surge?
- If the pressure tubes failed, how many, and was the failure in the reactor vault, or the steam separator compartment of the containment?
- Was there evidence of molten fuel at this stage?
- Any evidence of a molten fuel/water steam explosion e.g. from fuel debris showing signs of liquid phase fragmentation to ~100 micron diameter?

Brief.

The intention is to establish whether circuit rupture was a [illegible] ([illegible] a cause of the surge) and whether the rupture was such as to also fail the containment (Q.4.4.2)

The circuit rupture would be a result of either overpressurisation or a thermally induced failure (either weakening due to overheating or thermal shock) Various scenarios are possible depending on the energy deposited ~~in~~ during the ~~[illegible]~~ power surge. A power surge of 8-12 f.p.s needed to heat the fuel adiabatically to ~900°C when there is a possibility of ~~overheating~~ failure due to overheating of either the zirconium pressure tubes or the stainless steel extensions. If the energy was somewhat greater ~~than~~ so that the clad reached ~1200°C (~13-18 fps) the exothermic zirconium steam reaction would take off. This could generate large amounts of hydrogen and also release sufficient energy to melt significant amounts of fuel. In fast transients the pressure tube temperature will significantly lag behind that of the fuel. ~~[illegible]~~ // If the transient is terminated by a normal trip ~~which~~ ~~[illegible]~~ then it is possible that circuit failure may be a result of thermal shock induced by ~~[illegible]~~ water rentering overheated channels. If molten fuel is present this may be accompanied by a pressure rise or even a steam explosion. The amounts of hydrogen generated and released will ~~[illegible]~~ depend not only on the energy deposited but on the

[illegible] The

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B.4.4.2 Containment Failure

Where and when did the containment first fail?
- What was the failure mechanism?

Subsidiary Questions

- If by a hydrogen explosion, what are the sources (and quantities) of hydrogen and oxygen (see Q4.4.3 below).
- If by steam overpressure, how did the loading compare with design basis?
- If by crane toppling what caused the collapse?

Brief

The reactor vault is designed to withstand the pressure resulting from a single channel rupture, (27 psig) and it is inerted (IAEA document Chernobyl 4 - General plant description). Containment failure could result either from multiple zircalloy pressure tube failure within the vault, or from circuit failure outside the vault which released hydrogen into one of the non inerted compartments. The most vulnerable region appears to be the steam separator compartment above the vault and on either side, housing the existing coolant channel tubes. This compartment is not hermetically sealed due to multiple joints in the reactor building floor for refuelling access; and there are no provisions for releasing a pressure surge in this compartment to the pool or other compartments (IAEA Chernobyl 4 Plant description).

propagation of this sequence would depend on the position of the failure. If the pressure tubes fail the release would be into the inerted vault but multiple failures may overpressurise this. If the steel exit section fails then the release would be to an air filled region so hydrogen explosions may be possible.

If the power surge was locally much larger and faster, sufficient to melt fuel whilst water was still present (this requires ~ 60-90 f.p.s.) it is possible that a steam explosion could be the primary failure mechanism. Evidence for steam explosions under such conditions is provided by the US Power Burst Facility test

RIA-ST4. The occurrence of a steam explosion could possibly lead to failure of the refuelling plugs (the channel acting as a "gun barrel") giving a direct containment bypass route for hydrogen to be discharged to the charge hall. (The SL-1 reactor was destroyed by a steam explosion - it is also a credible containment failure route for Sizewell 'B' via the creation of an energetic missile as a result of ~~vessel failure~~ steam explosion induced vessel failure)

B.4.4.3 Hydrogen Explosion

When and where did hydrogen explosions occur?
.What were their consequences?

Subsidiary Questions

- Can you confirm that hydrogen was from zirconium/steam reaction rather than graphite steam?
- Do you have any quantitative estimates of the amounts of hydrogen involved in the individual explosions?
- If a hydrogen explosion occurred in the reactor vault, what was the source of the oxygen?

Brief

Assumes that the answer is not provided under Q4.4.2 above. Useful to confirm publically that the graphite steam reaction was not the source of hydrogen. Also that a hydrogen explosion rather than steam drum failure was the primary cause of the visible structural damage.
Note: Hydrogen explosion (by itself) will not lead to containment failure for Sizewell 'B'. The maximum pressure for hydrogen explosion from all the zircalloy in the core is 65 psi compared with containment failure pressure 120 psi.

P5/13

Section C Longer term Accident Evolution (after the main explosion)

C1 Extent of initial damage

C2 Propagation of failure to rest of core

C3 Graphite fire

C4 Longer term meltdown

and Emergency Actions

C5 Present condition of plant

p6.13

C1 Extent of initial damage

C1.1 Primary circuit

What was the assessed state of the fuel and both coolant circuits after the main explosion?

- How many assemblies were damaged?
- Was any fuel ejected?
- Was it possible to supply ECCS to either half circuit?

C1.2 Containment failure

How badly damaged was the containment?

- What was the state of the pile cap and the upper biological shield?
- Was the moderator exposed?
- Was fuel and or zirconium ejected from the containment?
- Did the collapse of the pile cap crane significantly contribute to the magnitude of the accident, and if so how?
- Were the steam drum cells and/or the drums themselves damaged by the explosion?

C2 Propagation of failure to the rest of the core

How much of the core was damaged subsequent to the main explosion.

- What was the cause of this damage?
- Over what length of time was damage (e.g. new fuel failure) propagating?

Subsidiary Questions

- Was the reactor subcritical immediately after the initial explosion, and did it remain so?
- What cooling was available from a) the failed half circuit
  b) the other half circuit
  c) the ECCS system
- How much of the core was effectively cooled and for how long?

P9.1.3

C3 Graphite Fires

How long after the power surge did the graphite fire start, and what was the route for continued air access?

- Was the rate of graphite combustion substantial compared with the decay heating of the core?

Subsidiary Questions

- What was the graphite temperature at the time of the power surge?
- What temperature was reached subsequently, and how did it vary?
- What is judged to be the rate limiting process during the fire?
- Was there any evidence of catalytic enhancement of graphie oxidation?
- If the graphite exceeded 1000°C did the graphite steam reaction contribute significantly to the development of the accident?

Brief

The graphite/air reaction is much less than decay heat for graphite temperatures below 550°C. Heating to that point would be rather slow (hours) by decay heat alone. If the fire started rapidly this could be evidence either of continued fission heating (criticality), or of extensive zirconium/steam reaction, which can provide sufficient energy to raise the graphite to the runaway point (by radiation. Heat conduction time constant for bulk graphite is ~15mins.) Above ~700°C the graphite oxidation rate is likely to be limited by the air supply rate, due to oxygen depletion in the gas boundary layer. A path for natural circulation flow is needed to allow air to enter the channels whilst hot gasses escape in order to sustain the fire. Graphite is reported to be 'difficult' to burn, but for a very large mass of graphite high temperatures can be achieved because heat losses are relatively low, viz: Windscale fire. A graph of reaction rate for various channel flows for magnox is shown.

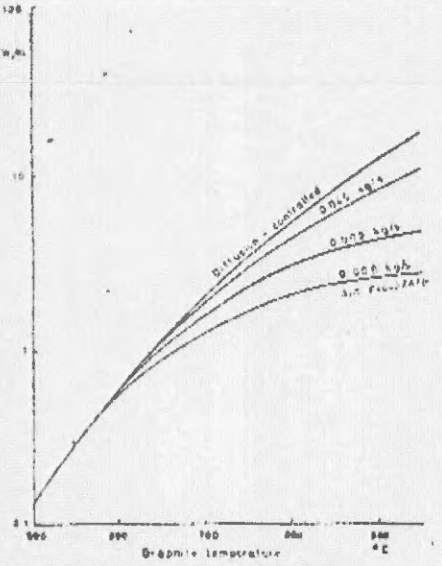

FIG. 46 Oxidation Heat Generation

At low temperatures (diffusion control)
$C+O_2 \rightarrow CO_2$+390 kj/Mole (= approx. 3MJ/cu.mtr air or 2.5MJ/kg air)
At higher temperatures (boundary layer control)
$2C+O_2=2CO$ + 2x109 kj/Mole is more likely.

Note: The graphite steam reaction (8 ltrs/ton graphite/hr at 700°C) is endothermic. (For comparison $Zr+2H_2O=ZrO_2+2H_2$ + 495 kg/mole (=5.4 kj/gm zirconium). Decay heat (~1% of thermal power) = 30MW) p10-13

C4 Long term meltdown/Emergency Actions

C4.1

What fraction of the core is estimated to have melted?
.How far is it thought to have slumped before re-freezing?

Subsidiary Questions

- How was the core cooled during this period, and particular what cooling process produced the eventual freezing?
- Why was a water spray not used to extinguish the fire and cool the core as at Windscale? Was it concern over hydrogen from graphite/steam, zirconium steam, a molten fuel/steam explosion or other reasons?
- Where and how were core temperatures measured or deduced?
- What was the level of activity in the water drained from the suppression pools?
- What long term cooling arrangements are being made?

Brief

See C5.

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C4.2

Over what period of time was the escape of activity brought under control, and how effectively?

Subsidiary Questions

- How much sand, limestone, dolomite, lead and clay were used to cover the pile cap?
- In what form were the materials and in what order were they applied. When was the decision taken and what was the dominant reason for the choice of materials?
- How quickly was the supply and drop implemented?
- Did these materials make it more difficult to re-establish core cooling?
- Was the suppression pool drained because of the danger of a molten fuel/steam explosions?
- Was there any evidence of such explosions.

<u>Brief</u>

Similar measures could conceivably be applied for some severe accidents in CEGB plant (e.g. magnox vessel failure).

p12-13

(no p13)

C5 Present conditions of plant

What is the present location and condition of most of the fuel and fuel debris?

Subsidiary Questions

- . Are there measurements available of temperatures:-
- . Beneath the core.
- . In the pressure suppression pool area.
- . Of the core temperature itself.
- .. What evidence is there of core-concrete attack. Is this regarded as a significant issue?
- . Has there been any recent structural collapse?
- . How far beneath the reactor is the water table?

Brief

Useful to demonstrate a relatively safe end state of the core. The event may point up the need for appropriate instrumentation for severe accidents (not currently provided for any UK reactor). For Sizewell many calculated core melts will progress to core-concrete reaction, unless a coolable debris bed is formed. Generation of steam, hydrogen, CO and CO_2 will contribute to containment pressurisation, and unless otherwise cooled it is likely that the melt will penetrate through the basemat, possibily releasing contaminated water from the containment into the sub soil. Contact between the fuel and groundwater is unlikely until the fuel has cooled to 100°C ($\sim$ 1 year). Diffusion of groundwater through the (sandstone) sub soil is very slow, taking many years to reach the site boundary. This allows adequate time to build a concrete 'dam'.

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18th August 1986

The Background to Chernobyl

Dear Terry,

I enclose my contribution to the 2nd September Seminar. I have discussed it with John Dunster, who will be dealing with the rest of the section on Health and Environmental Physics. I will talk for about 10 minutes, covering the main points in the written paper, (which you may like to circulate to those attending).

John will talk for about 20 minutes, leaving 10 minutes for discussion. John Gittus is happy with this arrangement.

Yours sincerely

Peter Saunders

PAH Saunders
Head, Environmental Impact Assessment

c.c Mr H J Dunster NRPB
Dr J Gittus SRD

United Kingdom Atomic Energy Authority

H.8074

URANIUM INSTITUTE SEMINAR 2 SEPT 1986
THE BACKGROUND TO CHERNOBYL
HEALTH AND ENVIRONMENTAL PHYSICS: RADIATION AND ITS EFFECTS

PAH Saunders. Head, Environmental Impact Assessments,
Harwell Laboratory, UKAEA

Public anxiety about nuclear power is centred on the possibility of harm, in particular cancer and genetic effects, resulting from exposure to radiation.

DAMAGE MECHANISMS

As radiation interacts with matter it loses some of its energy and produces ionisation - the ejection of an electron from an atom leaving it positively charged. This ionisation can lead to chemical changes which, in living tissue, can result in biological damage. The critical targets appear to be the DNA molecules, present in every cell of the body, that carry the information required for the development and division of the cell, and for the growth, proper function and reproduction of the organism. The radiation may alter a small part of the molecule, or it may break one or both of the strands of the DNA, the chromosomes that are visible under a microscope, destroying or altering some of the information carried. Damaged DNA can to a considerable extent be repaired by enzymes in the cell. However, in some cases the DNA survives in an unrepaired state, which can then be transmitted to large numbers of daughter cells by the normal processes of cell replication. Cells that have been changed in such a way are not necessarily dangerous - indeed many such changes occur normally during the lifetime of any organism. However, in some cases the altered cells can multiply in such a way that a cancer results or, if the damage occurs in a germinal cell that is itself later involved in the reproductive process, effects may be seen in later generations. Another possibility is that the cell is so seriously damaged that it dies. This is significant only if very many cells are killed, since cells are dying and being replaced all the time and most organs contain far more cells than are needed to maintain normal function.

UNITS

Before discussing the numerical relationships between different doses of radiation and their biological effects we need to introduce the units that are used to measure radiation. Since it is the transfer of energy from the radiation to the target that causes the damage the first unit is a measure of that energy transfer - it is the quantity of energy transferred from the radiation to a unit mass of the target material. The unit is the gray, after a physicist who studied under Rutherford and devoted much of his life to the medical uses of radiation. It is a unit of absorbed dose, and one gray is equal to one joule of energy per kilogram of target matter. Absorbed dose was formerly expressed in a unit called the rad, and one gray equals 100 rad.

However, equal absorbed doses do not necessarily have equal biological effects. A given amount of energy in the form of alpha particles, for example, is about 20 times as effective at causing biological damage as the same amount of energy in the form of beta particles, gamma rays or X-rays. To take such differences into account we use a unit called the sievert, after the Swedish scientist Rolf Sievert. It is a unit of dose equivalent which is equal to the absorbed dose (in joules per kilogram) multiplied by a factor that takes into account the different effectiveness in causing damage of the different types of radiation. Dose equivalent was formerly expressed in a unit called the rem, and one sievert equals 100 rem. The term dose equivalent is frequently abbreviated to dose. The sievert is a very large unit, so the unit commonly used is the millisievert, which is one thousandth of a sievert or the microsievert, which is one millionth of a sievert.

A useful measure of radiation dose to a group of people or a whole population is the collective dose; this is just the average dose times the number of people receiving that dose. The unit is the man sievert.

THE NATURAL BACKGROUND AND OTHER SOURCES OF RADIATION

The best way to get a feel for the size of these units is to consider the doses received from the natural background or from common practices such as medical X-rays. The average dose in Britain from natural background radiation is about 2 millisieverts (one five-hundredth of a sievert) a year. This radiation comes from outer space (cosmic radiation); from rocks, soil and building materials (terrestrial gamma radiation); from the air we breathe, which contains the naturally radioactive daughter products of the gases radon and thoron that are emitted from the ground (radon decay products); and from the naturally radioactive materials such as radionuclides from the uranium and thorium decay series and potassium-40 that are present in what we eat and drink and irradiate the body tissues internally (internal radiation).

Natural background radiation differs considerably in different parts of the world. Many parts of Britain have levels over twice the average and in some houses in which there are particularly high radon concentrations individuals may get as much as 100 millisieverts a year, 50 times the average.

Other typical figures are 20 microsieverts from a chest X-ray, 10 microsieverts a year from the debris from the atmospheric testing of nuclear weapons during the 1950s and 60s, 4 microsieverts a year (in Britain) from the natural radioactivity dispersed into the environment with the fly ash that is released during the burning of coal, and 1.5 microsieverts (average in Britain) from discharges from the nuclear power industry. A representative figure for the annual dose received from the nuclear power industry by the most highly exposed individuals in Britain is 1 millisievert, or about half the average natural background dose. The average annual exposure of radiation workers in Britain is about 1.4 millisieverts.

RISK ESTIMATES

The three kinds of effects of radiation to be considered are cell killing, cancer and genetic.

Cell killing

Cell killing is only important if sufficiently large doses of radiation are received in a sufficiently brief period. An absorbed dose of 10 gray or more delivered to the whole or a substantial part of the body within a few minutes is almost invariably fatal. A single absorbed dose of about 4 gray will result in a one in two chance of death in the absence of medical treatment. The same dose delivered gradually over a year, however, would probably be tolerated because of the action of the body's natural repair processes. The ability of radiation to kill cells is, of course, the basis of radiotherapy where localised doses of tens of grays are used to treat cancers and other growths. Cell killing effects are characterised by a threshold below which no significant effects occur; there are in general no observable effects below about 1 gray.

Radiation-induced cancer

Unlike the cell killing effects, which in general appear within a relatively short time after exposure and exhibit a threshold, cancer and genetic effects are delayed and it must be assumed that there is no threshold below which one can be certain that no harm will result. However, there is no evidence of effects at low doses (below a few tens of millisieverts), and the universal and inescapable natural radiation background and the 'natural' prevalence of cancer and genetic defects are such that it will probably never be possible to prove the existence or absence of a threshold.

There is a vast amount of data on the effects of radiation on cells and animals and there are a rather limited number of cases where a small excess cancer incidence has been found in groups of people exposed to sufficiently high doses of radiation, mostly above one sievert. However, the chain of events leading from radiation-induced damage in a cell to a developed cancer is far from well understood. Even when a link has been established between a radiation exposure and a subsequent cancer the radiation exposure itself may be only a necessary and not a sufficient cause of the cancer. Subsequent radiation exposures, exposures to chemicals, or metabolic changes may be required before a tumour results. Such processes take many years; latent periods are typically 5-10 years for leukaemias and 15-30 years for solid cancers.

While most but not all cancers can be induced by radiation, it is not possible to distinguish between a radiation-induced cancer and any other cancer. The only way in which the number of cancers that may be caused by an exposure to radiation can be predicted is on the basis of epidemiological studies of groups that have been exposed to radiation in the past. These are the survivors of the Hiroshima and Nagsaki bombs, patients who have received large doses of radiation for therapeutic or diagnostic purposes, and workers who have been exposed to high levels of radiation, such as radiographers, watch-dial painters using radium, and uranium and other hard-rock miners. The distribution of doses and the number of people exposed as a result of the Chernobyl accident are not yet known in sufficient detail to enable any reliable estimates to be made of the possible long-term consequences. Preliminary indications, however, suggest that a sufficient number of people may have received high enough doses to result in detectable increase in cancer incidence. It will clearly be of great importance to monitor the health of these people carefully over a long period.

The evidence has been exhaustively reviewed and assessed by national and international scientific bodies such as the International Commission on Radiological Protection, the United Nations Committee on the Effects of Atomic Radiation and Biological Effects of Ionising Radiation Committee of the US National Academy of Science. The consensus view of these bodies is that there is about a one in a hundred risk of a fatal cancer developing for each sievert of radiation dose received (over and above the doses received from the natural background), with an uncertainty in this risk of a factor of two; for safety purposes this uncertainty is of no significance.

Genetic effects

The basic process that can ultimately lead to a cancer or a genetic defect is similar - damage to a DNA molecule. As with cancer, however, the mechanism by which a mutation in a cell leads to a genetic defect is complex and not fully understood. If the mutated cell dies or is not actually involved in the fertilisation process there will be no genetic effect. Also if the new individual created at conception is not viable and dies at an early stage of embryonic development, it will probably not be detected. Most species seem to have evolved a protective mechanism by which faulty embryos are rejected; chromosome alterations are frequently found in spontaneous abortions. Genetic effects of radiation, ranging from trivial to lethal, have been observed in studies of animal populations. No unequivocal evidence of similar effects in humans has yet appeared at any dose level. Even in the Hiroshima and Nagasaki studies, no genetic defects that can be ascribed to the radiation from the bombs have been observed in any of the children subsequently concieved by the exposed parents. All estimates of possible genetic effects in humans, therefore, have to be based on extrapolation from results obtained with other species, notably mice. Such extrapolation involves considerable uncertainties.

The ICRP, UNSCEAR and BEIR analyses suggest that for humans there would be about a one in fifty risk of a genetic defect occurring for each sievert of radiation dose received (over and above the doses received from the natural background). This risk would be spread over all subsequent generations. These estimates refer to the risk of a genetic defect occurring following exposure of a hypothetical population of fertile individuals irradiated prior to conception of their offspring. in practice, some of the dose to which a real population is exposed will have no genetic significance because it will be received when no more children are likely to be conceived. Taking this factor into account reduces the risk, expressed in terms of a given total lifetime radiation dose to a given real population, to one in 125 per sievert.

In summary, a dose of one sievert is associated with a one in a hundred risk of fatal cancer in the exposed individual and a somewhat lower risk of a serious genetic defect appearing, spread over all subsequent generations. These figures are unlikely to be in error by more than a factor of two.

Extrapolation to low doses

Most of the evidence of radiation-induced cancer relates to doses of one sievert or more. There are a few cases where excess cancers have been found following doses of about one tenth of a sievert, but there is not enough data to provide quantitative risk estimates. There is no evidence of any effects associated with the doses received from the natural background, which results in lifetime doses of about 130 mSv in the UK.*

There are many parts of the world where background radiation levels are higher than the UK average, as a result of local geology or high altitudes. Attempts have been made to find correlations between natural cancer incidence and background radiation levels in such areas and no statistically significant effects have been found.

There have also been detailed studies of cancer incidence among workers in the nuclear industry, where typical radiation exposures are 1.4 mSv a year, or less than one tenth of a sievert in a working life, which is less than the natural background dose. No consistent pattern emerges from these studies, an indication that any effect from radiation is too small to be detectable.

These negative results confirm that the risk estimates derived from observations following doses of one sievert or more, are unlikely to seriously underestimate the risks at much lower levels. The question remains, what is the true risk at low levels? Does a dose of a few millisieverts, a typical annual occupational dose, result in a risk of one thousandth of that at a few sieverts, typical of the doses at which cancers have actually been observed? And does a dose of a few microsieverts, the average dose received by members of the UK public from the activities of the UK nuclear industry, result in any risk at all? Such questions may never be answered by observation, because of the size of the population that would have to be studied to give statistically significant results. They can only be answered indirectly through an understanding of the basic processes involved in radiation damage and its repair. The simplest assumption to make is that harm is directly proportional to dose, with no threshold. This is known as the linear hypothesis and is widely accepted as the correct basis for radiological protection purposes.

*It has recently been reported that Dr Alice Stewart is about to announce results which suggest a link between natural background radiation and childhood leukaemia incidence. This work will have to be carefully assessed.

On the basis of this hypothesis, in the UK about 1000 cancer deaths per year and about 300 genetic defects per year might be ascribed to natural background radiation, although there is no evidence that such effects occur. It is worth noting that cancer kills about 140,000 people in the UK each year. On the same basis, just over one cancer death per year and, if the exposure continued for enough generations for an equilibrium to be established, about one genetic defect a year might be ascribed to the exposure of the population to the activities of the UK nuclear industry. The existence of repair processes within the body probably means that the true risks are even lower, and at such low levels of exposure a zero risk is not incompatible with the evidence.

18th August 1986

Char. Misc

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ACTION

EMERITUS PROFESSOR J.H. FREMLIN
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18th August 1986

Dr J.H.Gittus,
Safety and Reliability Directorate,
UKAEA,
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Warrington WA3 4NE

Dear Dr Gittus,

I was very pleased to get your friendly letter of 30th July.

The data which I want most badly are:

1. The approximate total collective radiation dose received in the USSR, from which one can make sensible guesses as to the number of delayed cancers probable.
2. The extent of the contamination of agricultural areas in the Ukraine; whether in the form of the areas contaminated to specific numbers of Bq/m^2 of specific radionuclides; or in terms of the areas contaminated to specific ranges of dose risk to the would-be inhabitants; or in terms of areas no longer suitable for specific crops.

I enclose a bit of speculation which Nature shows so far no signs of printing, hopefully helpful in explaining the power surge initially reported. I am not doubting the Soviet reports of inadequate emergency power while working on the turbine, but it is not obvious (to me) how this should lead to a power surge in the reactor.

Yours sincerely,

John Fremlin

John Fremlin.

Jean Pl. send him
✓ my Vienna report sent 12.9
1 The Russian report + Annexes
2 my CNRG paper (new one) ✓
P. 42.
2nd Draft

INTERNATIONAL ATOMIC ENERGY AGENCY (IAEA)
WAGRAMERSTRASSE 5,
P.O. BOX 100, A-1400 VIENNA (AUSTRIA)

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OUR REF. NO. J2.SSR.41
271-689

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TELEX: 1-12645

PAGES: 9
T.O.D. 86-08-13

TO:
NAME: B. Edmondson
ORGANIZATION: Central Electricity Generating Board
HEAD OFFICE
CITY/COUNTRY: London, UK
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FACSIMILE NO. (WITH COUNTRY/CITY CODE) 0044-163-457-47
10 NEWGATE ST

FROM:
NAME: E.M. Yaremy
DEPT/SECT: NE/NENS/SNI

FURTHER TO YOUR CHAIRMANSHIP INVOLVEMENT IN THE CHERNOBYL POST ACCIDENT REVIEW MEETING ATTACHED FOR YOUR INFORMATION ARE:

(1) LETTER BY DG IAEA TO MEMBER STATES WITH ATTACHED PROGRAMME

(2) LIST OF EXPERTS AVAILABLE TO YOU IN WORKING GROUP SESSION AND IN INSAG REPORT PREPARATION

(3) POSSIBLE DISCUSSION AREAS FOR THE WORKING GROUPS DESIRED FROM DICUSSIONS WITH USSR EXPERTS

(4) PLEASE NOTE CHAIRMEN OF THE OTHER WORKING GROUPS ARE:

MR P TANGUY

MR H RABOLD

MR D BENINSON

a MRJH

via DHL

1986 -08- 14

DRAFTED BY E.M. Yaremy
EXT. 2698

AUTHORIZED /BY E.M. Yaremy
CLEARED

DATE 86-08-13

M-27 (Oct 83)

Sir,

I have the honour to refer to my letter of 7 July, 1986 on the forthcoming Chernobyl Post-Accident Review meeting taking place from 25 to 29 August, 1986 at the Agency's Headquarters. I should now like to give you some more details about the meeting.

The meeting will start at 10.00 a.m. on Monday, 25 August 1986 in the UNIDO Board Room at the Vienna International Centre. The programme is attached.

We expect that the USSR will supply the documentation (a summary report of 80 pages, a detailed report of 300 pages) in sufficient time that the Agency can supply the summary report in all languages and the detailed report in English to the Member State missions on Friday, 22 August. The detailed report in other languages will follow as quickly as translation resources permit.

The plenary session on Monday will be devoted to an overview presentation of the plant design, accident description, emergency measures, radiological consequences, recovery measures etc. to give the audience a broad perspective of the accident at Chernobyl.

The technical working group sessions proposed for Tuesday, Wednesday and Thursday will explore the accident and the phenomena and factors associated with it to a greater depth and to discuss any correlations with other experiences, both nuclear and non nuclear.

On Tuesday detailed presentations of the accident and its radiological aspects will be made by the USSR experts in two parallel sessions. On Wednesday and Thursday discussions of the accident and associated phenomena/factors will take place. The discussions for each Working Group will be based on written questions submitted by the meeting participants. These questions will be discussed in a structured fashion via a panel of experts by both the USSR experts and member state participants based on their own experience from plant operation, accidents, reseach and analysis. There will be a period of time at the end of each discussion session for additional direct questions from the participants. For this purpose I would like to request that the participants prepare themselves to contribute to the discussions their experience from accidents and their management.

For the plenary sessions simultaneous interpretation into English, French, Spanish and Russian will be provided. The technical working group sessions will be conducted in English only.

Registration for the meeting will take place on Sunday, 24 August 1986, 3.00 - 7.00 p.m., Monday, 25 August 1986, from 8.00 a.m. in the Rotunda, Building C, VIC. Your specific attention is drawn to the fact that only participants, including Members of Permanent Missions, who have been designated by their authorities in writing will be admitted to the sessions. In view of the large number of participants expected to attend, it is urgently requested to use the Sunday afternoon for timely registration.

It should also be noted that due to seating limitations in the main conference room (UNIDO Boardroom) additional entrance cards valid for this room for the plenary sessions (Monday and Friday) will be forwarded to the Missions in advance. The overflow of participants will be accommodated in the adjacent Agency Board Room where the plenary proceedings will be shown by audio/video presentation.

Accept, Sir, the assurances of my highest consideration.

Hans Blix
Director General

Enclosure

cc MRH
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1986-08-13

PROGRAMME FOR
CHERNOBYL POST-ACCIDENT REVIEW MEETING

25 - 29 August 1986

Monday, 25 August Plenary Sessions

10.00 - 11.00	Opening of the meeting	DG - IAEA Meeting Chairman Head - USSR delegation

Session 1

11.00 - 13.00 15.00 - 18.00	Overview of the accident (including plant description, accident sequence and its consequences, and response measures taken.	USSR experts

Tuesday, 26 August Technical Working Group Sessions (parallel sessions)

Session 2A Room A Working Groups 1 & 2

10.00 - 13.00 15.00 - 18.00	Detailed presentations of the plant design and safety analysis, and accident description. (Cause, sequence of events radioactive releases, short term stabilization and longer term arrangements)	USSR experts

Session 2B Room B Working Groups 3 & 4

10.00 - 13.00 15.00 - 18.00	Detailed presentations of Emergency Measures and Radiological consequences (evacuation, environmental protective actions, decontamination, environmental effects, health effects)	USSR experts

Wednesday, 27 August Technical Working Group Sessions continued (parallel sessions)

morning	No sessions (Preparation of questions for working group discussions)

<u>Session 3A</u> Room A Working Group 1

15.00 - 18.00	Discussion of phenomena and factors associated with the short term accident sequence. (Included are initiating cause, sequence of events, reactivity excursion, containment response, instrumentation, operator response, stabilization measures etc.)	Panel of experts All participants

<u>Session 3B</u> Room B Working Group 3

15.00 - 18.00	Discussion of emergency measures taken. (Included are decision basis for evacuation, sheltering, use of prophylactics; criteria for medical treatment; control of foodstuff and water; prevention of groundwater contamination; decontamination of people, material, soil etc; radiological conditions for plant re-entry.)	Panel of experts All participants

<u>Thursday, 28 August</u> Technical Working Group Sessions continued (parallel sessions)

Session 4A Room A Working Group 2

* 10.00 - 13.00 15.00 - 16.30	Discussion of phenomena associated with the long term accident sequence, plant recovery measures and radioactive releases from the plant. (Included are graphite fire, core damage, use of robotics, long term reliability of safety systems, recovery actions, radioactive release characteristics).	Panel of experts All participants

<u>Session 4B</u> Room B Working Group 4

* 10.00 - 13.00 15.00 - 16.30	Discussion of the radiological consequences of the accident. (Included are formation of plume, dispersion of aerosols and gases, environmental effects, dose assessment (internal and external) for operational personnel and the public, acute health effects, late health effects.)	Panel of experts All participants

* Working Groups 2 and 4 will commence after Working Groups 1 and 3 are completed.

Friday, 29 August   Plenary Session

10.00 - 11.30	Summary of the results of the Working Group discussions	Working Group Chairmen
12.00 - 12.30	Closing of the Meeting	

Doc. 6918n
1986-08-13

Possible Discussion Areas at the Chernobyl Post-Accident Review Meeting
Working Group Discussion Sessions

(1) Operator performance (incl. training of operators, written procedures etc.)

(2) Design against operator errors, automation instead of operator actions.

(3) Reactivity excursions

(4) Fire hazards, fire protection

(5) Soil contamination/decontamination

(6) High dose health effects or long term health effects

(7) Fuel or core melts

(8) Hydrogen generation during accidents (inerting, recombination, explosion)

(9) Filtered or vented containments

(10) Evacuation (problems encountered, solutions, experiences)

(11) Dispersion of aerosols and gases at high levels (models, calculation, prediction)

(12) Protecting groundwater from contamination

Items 1 - 6 are probably the more important

6926n
1986-08-13

List of Experts for Post-Accident Review Meeting

(1) Operation of pressure tube reactors
Mr. Alan Brown
Ontario Hydro
700 University Avenue
Toronto, Ontario M5G 1X6
Canada
Tel: (416)-592-4535

(2) Instrumentation and control, use of computers in NPP operation
G.M. Frescura
Ontario Hydro
700 University Avenue
Toronto, Ontario M5G 1X6
Canada
Tel: (416)-592-3134

(3) Reactor physics reactivity excursions in large cores
Mr. J. D. Young
Central Electricity Generating Board
Berkley Nuclear Laboratory
Berkley
Gloucestershire
U.K.
Tel: 0453-810-451

(4) Thermohydraulics, containment in particular pressure suppressed containment
Mr. E.F. Hicken
Gesellschaft für Reaktorsicherheit
Forschungsgelände
D8046 Garching bei München
FRG
Tel: 89-3291-569

(5) Chemistry of graphite, high temperature reactions
Mr. Dana Powers
Sandia National Laboratory
Alburquerque
New Mexico
USA
Tel: 505-844-4392

(6) Severe accident, core damage, source term
Mr. Thomas Kress
Oak Ridge National Laboratory
Oak Ridge
Tennessee
USA
Tel: 615-624-0561

(7) Structural dynamics aspects, explosions
Mr. A. L'Homme
DAS-SASR
IPSN
B.P. No. 6
Fontenay-aux-Roses
France
Tel: 654-7080

(8) Medical aspects of radiation exposure, high does effects, epidimiological studies
Mr. J. Liniecki
Dept. of Nuclear Medicine
Czechoslovakia 8/10
PL-92-216 Lodz
Poland
Tel: Lodz 78-36-84

(9) Environmental impact, dispersion in air and water, pathways to man
Mrs. Marian Hill
National Radiation Protection Board
Chilton, Didcot, Oxon OX11 ORQ
UK
Tel: 0235-831-600

(10) Emergency preparedness
Mr. G. Boeri
ENEA
Viale Regina Margherita 125
Rome
Italy
Tel: 85-28-2863

(11) Occupational aspects in high dose rate situation, decontamination
Mr. W. Jeschki
Nuclear Safety Division (ASK)
CH-5303 Würenlingen
Switzerland
Tel: 056-993-938

Note for Record

The BNES Post-Chernobyl Conference Seminar

Mr John Dunster telephoned to say that he wanted to avoid overlap between what he will say in his session and what I will produce at my session.

His session apparently is concerned with radiological consequences. Mine is concerned with activity release (or so he said).

He will begin by introducing the derived emergency reference levels (DERLs) and problems for foods. Then, Marion Hills will speak on radiological protection. She will have been at Vienna for two weeks. Jane Simmons also of NRPB will then talk about NRPB's experience when they were getting together information from Europe on dose rates. She will include, for example, the remote installation of radiation measurement devices at British Embassies overseas.

I said that my material would be taken from my AEX paper, paper 50 which would have been updated following the Vienna meeting. I confirmed that I would avoid overlapping any of the information which he had mentioned (listed above).

J H GITTUS

13 August 1986

cc Dr M R Hayns

MEMORANDUM

To DR P CLOUGH, DR A N HALL
MR P BONELL, DR W NIXON

Your Ref.
Our Ref.
Tel Ext. 7206

Subject CONTRIBUTION TO LORD MARSHALL'S BRIEF

As I explained to two of you (Clough and Nixon), Eric Carpenter of the CEGB has asked us to make a contribution to the brief which he is preparing for Lord Marshall and which we shall present to the latter on Saturday, 23 August, in Vienna. I would like the four of you to help with this please.

To that end I attach CIMRG 37 which is the present version of the questionnaire that has been submitted by the UK to the Russians. We hope they will answer these questions at the Vienna meeting (25-29 August).

Carpenter is preparing the Marshall brief and I am to send him our contributions on Monday (18 August) by facsimile. He will write down an answer to each of the questions in the questionnaire if an answer can be found from documents at our disposal. He will reference the source document in each case. We are not required to help with that task.

Carpenter will supply Lord Marshall with paragraphs of briefing material concerned with each question and I have said that we (that is to say, you) will help with that task. The background briefing paragraphs will indicate why this or that particular question is being asked, what its importance is, and in particular whether it is of central importance to the future of nuclear power in the United Kingdom.

I would like you to pay particular attention to this second issue in the case of every question please.

To give an example of what I would like you to produce, take question B1 on page 2 of the attached paper CIMRG 37 which is:

"1. What is the possible range of void coefficients for the Chernobyl fuel cycle?".

The briefing material, if I were writing it, would probably read as follows.

"It is believed that the Chernobyl reactor has a positive void coefficient. This means that a loss of cooling will actually increase the amount of heat being generated by the uncooled channel. SGHWR has a negative void coefficient. CANDU has a negative void coefficient. MARVIKEN and GENTILLY, both of which had positive void coefficients, were shut down partly because this condition was thought dangerous."

You should consult each other concerning which question each of you is going to deal with this and let Mike Hayns have a copy of the material that you produce.

pp JH Gittus

J H GITTUS

cc Dr M R Hayns

13 August 1986

PS I would like to hold a meeting to discuss progress on MONDAY, 18 August.

8376
13.8

Copy to Dr Low, Dr Holmes, Mr Blumfield, Dr Gittus

cc RS Peckover
MR Hayns

Note of a meeting on nuclear emergency planning in Room 1553 Thames House South at 11.00 AM on Monday 23 June.

PRESENT

Mr D I Morphet	AE Division D/Energy
Mr B Hampton	AE Division D/Energy
Mr P Agrell	AE Division D/Energy
Mr J Challis	AE Division D/Energy
Mr J Cooke	AE Division D/Energy
Mr M Granatt	INF Division D/Energy
Dr S Harbison	NII
Dr M Hill	NRPB
Mr P W Mummery	BNFL
Mr P Parkman	CEGB
Mr F Chadwick	UKAEA
Mr B Carpenter	UKAEA

Introduction

1. Mr Morphet confirmed that as envisaged in the meeting on 19 May the Department had been given a number of tasks relating to emergency planning by the Cabinet Office Working Party into the Lessons of Chernobyl. Mr Morphet invited comments on the notes of the previous meeting and after a brief discussion they were agreed.

2. Mr Morphet invited each organisation to outline what steps they had in hand to review their emergency plans.

CEGB

3. Mr Parkman noted that the Board were maintaining their ongoing programme of station exercises, and a further meeting was being set up with NII to consider arrangements for their next *OSC exercise. Mr Parkman considered that they were however not able to make much sensible progress in addressing the implications of the accident at Chernobyl until they actually had some hard facts to work with.

4. In the interim, Mr Parkman reported that the Chairman had set up a working party to look at aspects that can be put in hand in advance of the Vienna presentation by the Soviet Union. This included rationalisation and uniformity of OSC arrangements in the light of the change from the separate CEGB regional structure, and identifying source terms for Beyond Design Basis Accidents (BDA).

* OSC = Operational Support Centre
i.e. an exercise involving the "interface" with Government, local authorities etc.

5. Mr Parkman noted that they had been reviewing the outline emergency plan document that they had put into local libraries in 1978. The basic plan document related to a hypothetical gas cooled reactor rather than the specific local magnox or AGR station and had attracted some criticsm. In view of current policy of openness they hoped to replace it by a more complete/site specific document. However difficulties arose because the site emergency plan document was the only formally approved site specific document and moreover these varied from site to site.

6. Mr Parkman reported that the Board had considered delaying the exercise (for about a year) to permit all site plans to brought as near as possible into line but considered it important to respond to increasing public pressure following Chernobyl to make available further information. They intended to put to the Board shortly, versions of the site plans which had been prepared on the lines of those presented to the Sizewell B Inquiry by omitting any sensitive detail - eg phone numbers. It remained for the Board to decide whether they were willing to accept the inevitable criticism about inconsistencies between current plans. As the exercise had implications for other operators and the NII, Mr Morphet invited them to urgently meet and exchange copies of existing/proposed documents to avoid any unfortunate precedents.

UKAEA

7. Mr Chadwick noted that they were continuing to update site plans and handbooks. They too had issued indicative summaries of the emergency plans to local libraries some time ago. Responsibility for the plans rested with each site and they were aiming to complete their updating of the outline plans in about two months. Mr Chadwick warned that although the outline plans were site specific it would take time to prepare edited versions of the site plan on the lines proposed by the Board.

BNFL

8. Mr Mummery noted that the Board's proposal clearly need to be looked at on an industry wide basis. He reported that BNFL plans varied from site to site because the risks varied for instance at Capenhurst and Springfields they were basically designed to deal with a chemical hazard, whilst Chapelcross and Calder Hall(including Sellafield) plans reflected the possibliity of a release from a reactor. BNFL were in the process of reviewing the equipment/location of OSC/PBC facilities and wished to avoid issuing any new public information until this exercise was complete. They had however checked the availability of the current outline

plans in main county libraries, and were also in the process of producing updated versions.

OUTLINE PLANS

9. Mr Morphet considered it essential that the industry adopted a consistent approach and ensured that any proposed documents were cleared with the NII and D/Energy, and stressed that the interests of SSEB/Industry Department for Scotland were not overlooked. Mr Mummery noted that different sites had different Design Basis Criteria and it was therefore to be expected that plans would differ. Industry representatives agreed to meet at an early date together with SSEB.

CHERNOBYL FOLLOW UP WORK

10. Mr Morphet pointed out that it was inevitable that there would be limitations on attendance at the presentation by the Soviet Union about the accident at Chernobyl and it might therefore be necessary to identify the most appropriate attendance from the UK industry. Mr Parkman noted that as part of their long term safety review (LTSR) work, they were looking to see whether there were any "cliff edge" accident scenarios which might lie just beyond the probability cut off point for the DBA, where the consequences might be markedly greater than those of the DBA. They hoped to be submitting final LTSR papers to NII on Bradwell and Berkley shortly, and a paper on probability assessment for magnox stations would be put to ACSNI in July.

11. Dr Harbison noted that they had only limited information about Magnox stations when compared to the full probability safety assessment done for the Sizewell B Station. They considered that about 90% of Beyond Design Basis Accidents could however be coped with by only a modest extension of current detailed emergency plans. Dr Harbison noted that they had yet to identify source terms for such accidents, and this had already been commented on by the Irish premier. Mr Parkman noted that the NRPB were working on source terms for concrete and steel vessel magnox reactors and hoped to provide these by September. Mr Parkman expressed concern over the lack of detailed county level planning in certain nuclear free zone areas, and were approaching the Home Office to clarify what if anything counties were required to do.

12. Mr Mummery considered it important for any beyond design basis planning to be considered at the highest political level. Noting that any change would effect not just the

evacuation zone but a whole panoply of measures including crop bans etc.

REPORTING CHAINS

13. Mr Morphet pointed out that he considered it essential that plans envisaged realistic reporting chains including the fact of direct contact at Chairman/Secretary of State level and the probability of the appointment of a Minister to take charge of central government co-ordination of the incident. One implication being that the GTA might not undertake the role of press spokesman.

14. Dr Hill warned that Chernobyl had revealed an enormous need for the public to obtain personal reassurance about their safety from technically qualified personnel. This had stretched NRPB resources from an incident 1000 miles away and considered that a UK incident would probably generate even greater demands. Mr Mummery suggested that the role of the GTA to brief the public needed to be studied.

FOLLOW UP MEETING

15. In discussion it was agreed that a further meeting should be arranged once more information about the Soviet presentation was to hand in order to identify participants, and to report progress made in discussions about international warning systems and safety standards.

Copies to: Those present. (received 11/8/86)
Mr Manley
Brigadier Budd - Cabinet Office
Dr Hill - MOD
Mrs G Howden - BNFL
Mr Brady - Industry Department Scotland

14 Aug 86. **Edmonton.** 1.

Vienna. **Monday**: Plenary. USSR will make presentation on 80 page English Summary document available on arrival.

Tuesday: Workshops commence.

a.m. USSR presentation & parallel Workshops.
no question.

Workshops: 1 Accident sequences short term
2 " " " medium term
3 Action taken on site.
4 Source Term
5 Dispersion
6 Emergency Measures
7 Radiological effects

am Tuesday

pm Tuesday Free time for delegates to frame questions based on am Workshops → Secretariat.

Wednesday Questions → USSR. Q+A

The Session 12. Experts take lead (Maroi Hills etc)
Includes discussion of WX + other accidents.

Thursday am Workshops. "Discussions"

pm ??

Friday am. PLENARY. Chairmen of WG's report.

15 Aug 56 D Hicks · S   CX 863 826 1

Ron MacPherson Improve Loss of flow accident by prolog[illegible] use of main circulator using inertia of trapped turbine, running on 20-25% power = start 12 h before accident. Then [illegible] [illegible] → 70% power when all rods in reactor, only 6 h was available for shutdown, need 12 in their own regulation [illegible] [illegible] except deflected steam from turbine. Should [illegible] 5 t condenser or suppression pool. Did not check so reactor went up in pressure by 75 psi. [illegible]. Showed in 5-King normal circuit from water → core SIS cooling. Reactor power now 2% [illegible]. Critical heat flux in many channels. PIS [illegible]. [illegible] water stopped, reverse flow. Turned on more pumps, still reversed flow. Water at graphite. Got to 3000 cal/g → fuel disrupted — Blew top off reactor. RIA check with colleague
Steam explosion like TBF
Xenon transient built up so that 6 rods fell into a poisoned part of the core

48 sec / 3 p
15 min total!

From Dr J. H. Gittus
Director

SRD
Safety and
Reliability
Directorate
UKAEA, Wigshaw Lane, Culcheth
Warrington, WA3 4NE, England
Telephone (0925) 31244 Ext. 7206
Telex 629301 ATOMRY G

15 August 1986

Mr F Chadwick
Principal Officer
Commercial Policy and External Relations
UKAEA
11 Charles II Street
LONDON SW1Y 4QP

Dear Frank

CHAIRMAN'S LETTER TO EMPLOYEES ON CHERNOBYL

Thank you for your letter of 8 August and the copy of Harry Shalgosky's letter concerning the Annex to the Chairman's letter to employees. I would like to respond to the various points raised.

Firstly, I see nothing wrong with our statement in the Annex that "in areas of Europe furthest away from Chernobyl, radiation levels were only fractionally above background". It is quite clear from the monitoring data that increased levels in, for example, Spain were only a fraction above background. All we were trying to do here was to get over the point that the effects of the radioactive plume were experienced across Europe and that close to Chernobyl the dose rates were more than 100 times background, whereas further away the increased doses fell to only a fraction of background. In other words, we were trying to indicate the range of levels. In fact the words in the text replaced some coloured maps (produced at SRD) showing radiation levels across Europe, which were in the first draft of the Annex but had to be removed because of reproduction problems.

Secondly, I should comment on our statement in the Annex that the ICRP believe the linear hypothesis to be pessimistic. This was based upon some statements in ICRP 26. For example, in para 30 of ICRP 26 it is stated that ".... radiation risk estimates should be used only with great caution and with explicit recognition that the actual risk at low doses may be lower than that implied by a deliberately cautious assumption of proportionality". It is, of course, true to say that following the publication of ICRP 26, after their 1978 meeting, the ICRP stated "these risk factors are intended to be realistic estimates of the effects of irradiation at low annual dose-equivalents (up to the Commission's recommended dose-equivalent limits)". However, it must be appreciated that this latter statement reflects some uncertainty over the relative biological effectiveness of neutrons. Briefly, this means that if one is dealing with a radiation field with a significant neutron content (as can be the case for radiation workers), ICRP 26 recommendations may underestimate the risks. However, for relatively low doses, ie less than the Commission's dose-equivalent limits, where the ICRP originally suggested their recommendations may overestimate risks, it was felt these two factors may cancel to some extent. This is the basis of the Stockholm statement. It should be emphasised, however, that for low LET radiation (eg -rays), the above argument does not apply and the ICRP still believe that the linear dose-response relationship provides a cautions estimate of risk; my staff recently confirmed this with some colleagues at the NRPB. Our calculations as reported in the Annex relate to low LET radiation and our reference to the ICRP is therefore correct and is not subject to the criticism levelled by Harry.

Thirdly, concerning comments on our comparison of exposure from Chernobyl with background; it must be emphasised that the doses to the UK from Chernobyl are neither large nor short term, since population exposure at low dose rates will continue for decades to come. The reason we integrated doses to 50 yr was to allow us to obtain an estimate of the possible number of cancers in the UK resulting from the accident. We then compared the resulting dose with that from background and weapons testing, and went on to compare the estimated health effects with cancer statistics. It is clearly difficult to construct a single definitive way of putting radiation dose in context; however, we think that the above three comparisons (with background, weapons testing and cancer statistics) put the total dosimetric impact of Chernobyl on the UK in some perspective. There are, of course, other ways of comparing radiation risks, etc, and we note Harry Shalgosky's suggestion that we compare with variations in background; indeed, we are aware of the value of such a comparison and have used it in other cases.

Finally, I note with interest the suggestion that the Environmental and Medical Sciences Division would be pleased to make a contribution to further Chernobyl related information activities. Perhaps it would be most useful if some sort of collaboration could be established between them and my staff.

Of course SRD and E&MSc must help to provide information for public and employee consumption. Alan Eggleton of E&MSc is in fact coming with me to the Vienna meeting on Chernobyl. He and Peter Saunders are very active members of my HSSC, so there is an excellent working relationship.

Yours sincerely

John

J H GITTUS

cc Mr M A W Baker
Mr A W Hills
Mr W McMillan

sc Dr M R Hayns
Dr W Nixon

Safety and Reliability Directorate

Wigshaw Lane
Culcheth
Warrington WA3 4NE

Telex 629301
Telephone Warrington (0925) 31244
Extension 7270

A.8.
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19 AUG. 1986

URGENT – IMMEDIATE FAX PLEASE

TO DR E. W. CARPENTER
CEGB BERKELEY NUCLEAR LAB.

COPY TO DR S. J. BOARD, " " "

FROM A. N. HALL, SRD.

QUESTIONS ON CHERNOBYL

ADDITIONAL BRIEFING MATERIAL ATTACHED, FOR REVISED FORMAT QUESTIONS (SECTION C).

(PAGE 1 OF 7)

SRD United Kingdom
Atomic Energy Authority

C1

What was the assessed state of the fuel, etc.?

Brief

If it were possible to supply ECCS to either half circuit and the initial damage were sufficiently localised, it might just be possible to prevent initially undamaged fuel in the damaged half circuit overheating by thermal conduction through the moderator to the intact half circuit. This assumes decay heat to be the only heat source — if zirconium oxidation or recriticality augmented this, the region of core damage would grow.

C 1.2

How badly damaged was the containment, etc.?

Brief

The reported fire at the top of the core could only have occurred if the pile cap and biological shield were disrupted, allowing air access to the zirconium and graphite and/or fuel was ejected into the reactor hall.

C2

How much of the core was damaged subsequent to the main explosion etc.?

Brief

If the initial core damage was localised, it would take about 3 days for decay heat to raise the rest of the core to 1300C at which temperature zirconium/steam interactions would become important, due to the thermal capacity of the graphite. Thus if the initial core damage was localised and a large fraction of the inventory of volatile fission products was released within about one day, the decay heat must have been augmented by either heat from zirconium burning or recriticality.

C4.2

Over what period of time was the escape of activity brought under control, etc. ?

Brief

The sand, limestone etc. could simply have been building materials on-site for the construction of Units 5 and 6. They might however, have been chosen for their capability to filter and trap fission products, as well as smother the fire.

If the moderator was exposed by the explosions, dumping materials onto the core would make cooling more difficult, as they would tend to thermally insulate the core. It should not be assumed that core cooling was or has been re-established.

If the materials were chosen to filter and trap fission products, their effectiveness in doing so could bear upon arguments for filtered|vented secondary containment buildings.

C4.1

What fraction of the core is estimated to have melted?

- How far is it thought to have slumped before re-freezing?

Brief

It would be unwise to assume that the core has refrozen – see C5.

Dumping materials onto the core might have caused steam/vapour flows to be diverted through the suppression pool, raising its activity.

It is difficult to see how long-term cooling of the core could be established/maintained – see C5. If core/concrete interactions and basemat penetration occurred, scoping calculations indicate that the distance separating molten fuel/concrete from a cooling surface at 100 C would be no more than a few inches. Thus any network of pipes installed beneath the reactor to arrest basemat penetration would have to be very closely spaced to be effective.

CS

What is the present location and condition of most of the fuel and fuel debris?

Brief

The concrete walls of the reactor vault are efficient thermal insulators - SRD ~~estimates~~ that they could only conduct 1.2 MW per 1000 deg. C temperature drop. Unless water could be supplied to the fuel, it is hard to see how widespread core meltdown over a period of days could be averted. It seems unlikely that the core could be cooled using an inert gas - over 1 Te of nitrogen per minute blown through the core would remove the decay heat only if its temperature rose by 500 C.

Without cooling, molten fuel would fall from the moderator and collect on the floor of the reactor vault. The mass of fuel, decay heat and floor area would all be within a factor 2 of those calculated for large modern PWRs. Core/concrete interactions and basemat penetration could be expected.

If core cooling were lost and the core heated up, collapse of the steel structure supporting the moderator would be expected and the consequent fall of the moderator might have been observed from above the core.

Safety and Reliability Directorate

Wigshaw Lane
Culcheth
Warrington WA3 4NE

Telex 629301
Telephone Warrington (0925) 31244
Extension 7270

19.8
9

19 AUG. 86

URGENT - IMMEDIATE FAX PLEASE TO

DR E. W. CARPENTER, CEGB BERKELEY
NUCLEAR LABS..

COPY TO DR S. J. BOARD " "

FROM A. N. HALL, SRD

QUESTIONS ON CHERNOBYL

PLEASE FIND ENCLOSED BRIEFING MATERIAL ON SECTIONS IF AND IG (ORIGINAL NOTATION).
(FIRST PAGE OF 16).

from ANH

(1)

F. POWER SURGE

1. The cause of the initial power surge has not been described. Was it directly associated with

- control rod withdrawal, manual or automatic
- xenon decay
- coolant flow reductions in all channels, for example due to pump cavitation
- voidage consequent upon pressure reduction
- flow pattern instability in fuel channels

Brief

The cause of the power surge must bear upon whether such an event could occur in UK reactors and it would affect the characteristics (eg local or widespread, rate of reactivity insertion) of the surge. This in turn would bear upon the challenge that the surge would present to the safety systems.

Possible answer – any of causes listed

Technical background

The possible causes associated with changes in coolant conditions are related to the positive void coefficient of the reactor. Flow reduction and pressure reduction could both increase power through the positive void coefficient. Flow pattern instability could also increase power through the void coefficient and could occur if the reactor were operating at low (SRD estimate 9%) power with reduced flow through the core. At low power, the coolant flow regime at the fuel channel exits could normally be bubbly flow. At full power, the coolant at the channel exits would be annular flow. If the coolant flow to the core were reduced to increase the steam quality for turbine experiments and the reactor power remainded low, the transition from bubbly to annular flow could be approached and instability arise. Following the transition to annular flow in one channel, liquid coolant would be entrained in the steam flow and swept from the channel increasing the void coefficient and the fission power through the positive void coefficient. Furthermore, the resistance to flow of coolant is less for annular flow than it is for bubbly flow so coolant would be diverted from adjacent channels in bubbly flow conditions to that in annular flow. This and the increased power in the adjacent channels due to neutronic coupling with the channel in annular flow would tend to cause flow in the adjacent channels also change from bubbly to annular flow in a coherent manner. Consequen a core-wide rapid transition from bubbly to annular flow might occur, resulting in a power surge through the positive void coefficient.

Relevance to UK

Western thermal nuclear reactors do not have positive void coefficients under normal conditions, so if the cause were related to the positive void coefficient, it should not be relevant to Western reactors. The flow pattern instability related cause would only be relevant to boiling water reactors with positive void coefficients - no Western examples of such reactors are known.

F. 2. What was the maximum channel power (neutron flux level) reached in the power surge, as recorded by:

(i) ex-core instrumentation
(ii) in-core detectors

Brief

Fuel damage depends on actual channel power rather than average core-wide power level. Neutron flux level significant because instantaneous rate of fission can be derived – steam conditions mask rapid power rises due to thermal time constants for heat transfer through fuel, etc..

Possible answer – for step rise of power, new level would have to be at least 3× full power to cause fuel melting in 20 s (time thought necessary to insert control rods).

Technical background

SRD calculations of thermal radiation heat transfer in dried-out fuel channels indicate fuel temperature would rise from 323 C to 1850 C in about 17 s if power were 3× nominal. At this power level, pressure tubes would fail through high temperature weakening at about the same time as the fuel clad melted. At higher power levels, the fuel would melt before the pressure tubes failed.

Relevance to UK

Perhaps relevant to clad failure during overpower transients in AGRs.

F 3. Why did the reactor protection system fail to detect and safely terminate the incident. Was is because of

- equipment failure
- human error
- modifications to the plant or safety system as part of an experiment
- the incident was outside the design criteria

Brief

The protection system should have detected and terminated the accident. It will be important to demonstrate that its failure to do so does not signify oversights in Western safety studies.

Possible answer - any of causes listed, with incident outside design criteria perhaps favourite.

Technical background —

Relevance to UK

Could be great if human error or events not foreseen in safety studies were crucial.

F 4. Do the physical models and computer codes available to the designer adequately represent the course of the event, once the circumstances are defined?

If so, was it an event which had been considered and was believed to be protected against?

Brief

The results of probabilistic safety studies depend on the ability to model with acceptable accuracy the development of hypothetical severe accidents. Without such an ability, the results of the safety analyses cannot be credible. The Chernobyl accident should enable Russian analysts to validate their models of severe accident development.

If the events at Chernobyl were not foreseen in the safety analyses of the plant, the possibility that the accident was beyond the design basis of the engineered safety systems would arise.

Possible answer – designer might well have access to codes and models that could be combined to adequately represent the course of the accident once the sequence of events was defined, but sequence might either not have been considered or was believed to be protected against.

Technical background —

Relevance to UK

If accident sequence were not considered by the designers, it would be difficult to prove "completeness" of the range of accidents considered by Western analysts.

F 5. To what extent is the capability of the protection systems dependent upon operator action?

- manual adjustment of trip settings
- power/flow matching
- fuel management - burn-up distribution within core
- control rod withdrawal sequence

F 6. What action did the operators take? Did it improve the situation or make it worse? Did they fail to take any action? Were actions relevant to the event described in the operational guidance available to the operators?

Is there any previous operational experience of related incidents on this or other RBMK reactors?

F 7. Are different protection systems active under different power levels? Which system was active at the time of the initiating event?

Brief

These questions focus on the scope for operator error.

Possible answers —

Technical background —

Relevance to UK

Automation of UK systems and training of operators should reduce scope for operator error.

F 8. Are there separate protection systems for local and whole core events?

Brief

If there are separate protection systems for local and whole core events, there might be a "window" at the interface through which unexpected accidents might pass unprotected.

Possible answer —

Technical background —

Relevance to UK —

F9. Was the initiating even slow enough to have benefitted from a diverse trip and protection system or was it so fast that no conventional protection system would have been effective?

Brief —

{ Question appears to be related to the character and cause of the initial power surge as much as to the protection system }

Possible answer

– probably so fast that no conventional protection system would have been effective.

Technical background

The positive void coefficient and perhaps other characteristics of the RBMK reactors appear to present the potential for rapid increases of power at rates far in excess of those acceptable in Western reactors. Thus protection systems that would be ~~saf~~ satisfactory for Western reactors could be inadequate for RBMK reactors.

Relevance to UK

The reliability of Western engineered safety systems might in the public's eyes be tainted by association with those of the RBMK reactors, for the different challenges that the different reactors would present to their safety systems would probably not be recognised.

F 10. Was the reactor shut down manually or by the protection system in spite of the damage?

Brief

The initial damage might have occurred so rapidly and been so extensive that the protection system might not have been able to shut down the reactor automatically.
A delay in shutting down the reactor manually might have exacerbated core damage.

Possible answer –

Technical background

The initial explosion(s) were reported to be in the reactor vault and could therefore have damaged control rod drive mechanisms.

Relevance to UK –

F 11. Did the reactor (after damage and initial shut down) regain criticality?

Brief

The Germans have suggested that a recriticality occurred and this could indicate relocation of fuel and/or control rods.

Possible answer – recriticality is thought unlikely, as measurements of short-lived radionuclides do not show the second peak that would be expected from a recriticality. A second peak could not be resolved from the first release however, if recriticality occurred soon (order day?) after initial shutdown and it might in addition be attenuated by the sand etc dumped onto the reactor.

Technical background –

Relevance to UK

Might draw attention to ability to maintain safeguards beyond 24 hours after ~~shut~~ accident initiation.

F12. Did the control rod outer sheath material eventually melt - if so, was this a contributory factor to the severity of the damage?

Brief —

Possible answer —

Technical background —

Relevance to UK —

G. COOLANT CIRCUIT FAILURE

1. What part of the coolant circuit ruptured during the initial power surge?

   - pressure tube
   - coolant pipe
   - seal region

   How many channels were affected?

Brief

The location of the initial circuit rupture would affect the part of the system damaged by the rupture (eg core, space between core and pile cap etc), it would affect the size of the breach and could also affect flow conditions within fuel channels (eg produce flow stagnation). The number of channels affected would influence the rate of pressurisation of the cell surrounding the ruptured pipework and the initial extent of core damage.

Possible answer – the pressure tubes would probably be weakened by heat transfer from the fuel and might be the most likely parts of the circuit to fail.

Technical background – see question F2. Furthermore, note that the location of the breach could affect the capability to inject emergency coolant to the core – indeed, emergency injection might promote flow stagnation in fuel channels in some circumstances (which is why emergency coolant is sprayed directly onto fuel in SGHWR).

Relevance to UK

Probably limited, although opponents of nuclear power might draw a parallel between RBMK pressure tube failure in an inadequate containment building and steam generator tube failure leading to containment bypass for PWRs.

G 2. What was the physical mechanism causing the pressure circuit failure during the initial power surge, for example

- overheating due to contact with hot fuel
- pressure from a steam explosion due to molten fuel/water reaction

Brief

A rapid reactivity insertion could lead to fuel melting before pressure tube failure (see question F2) and the pressure tubes might then fail due to molten fuel relocating and causing hot spots in the tube walls. Alternatively, if molten fuel were to come into contact with liquid water once more, a steam explosion could occur.

Possible answers – either mechanism given above, or perhaps a steam spike.

Technical background – for overheating due to contact with hot fuel, see question F2. For a steam explosion, note that the mass of zirconium in fuel clad alone in a single RBMK channel (~ 33kg) exceeds the mass of 'fuel' released into water in the Winfrith SUW experiments (24 kg) and that in one SUW test, the steam explosion stretched the bolts on the test vessel. The free volume in a single RBMK fuel channel is only about 1% of that in the SUW test vessel, so the maximum pressures generated by steam explosions in RBMK fuel channels would be expected to be much greater than those in the SUW test vessel. Furthermore, the ratio of fuel to coolant in an RBMK fuel channel would be close to the theoretical optimum for the conversion of heat to mechanical energy. Nonetheless, it is generally thought that it would be difficult to trigger a steam explosion at the high operating pressure (~7 MPa) of an RBMK reaction (but see the RIA-ST4 explosion). It is also difficult, though not impossible, to imagine coherence between separate steam explosions in separate fuel channels of an RBMK reactor.

If the necessary conditions for steam explosions were produced but steam explosions were not triggered, a steam spike could occur that might nonetheless be capable of breaching the pressure circuit. It it worth noting that one reason why steam spikes are not of great concern for PWRs is that heat transfer from fuel to coolant is significantly reduced once the critical pressure (22 MPa) is exceeded ~~and~~ (the coolant is then single phase) and the critical pressure is not much greater than the PWR safety relief valve setpoint (about 17 MPa).

The critical pressure is 3x the normal operating pressure of a BWR however, so the integrity of a BWR pressure circuit is more likely to be threatened by a steam spike than that of a PWR.

Relavance to UK

Given core meltdown in a PWR, the primary circuit has been considered much more likely to fail due to contact with hot fuel than due to in-vessel steam explosions or a steam spike. If the Chernobyl pressure circuit failed due to a steam explosion or steam spike, the validity of current assessments of these phenomena could be called into question. If a large steam explosion were to occur in a PWR pressure vessel, both the vessel and secondary containment might be breached.

G3. What were the loadings on the structures surrounding the core resulting from any pressure tube failures during the power surge?

Brief

The vessel containing the core was designed to withstand only single tube failure. Multiple tube failures could fail this vessel and perhaps disrupt the core.

Possible answers —

Technical background —

Relevance to UK —

JHG
15.8

TECHNOLOGY PLANNING AND RESEARCH DIVISION

BERKELEY NUCLEAR LABORATORIES

1 PAGE

DEX

EWC.DF

15 August 1986

✓ cc MR Hayns
✓ cc P Bonell – to do.

To: Dr. J.H. Gittus

From: E.W. Carpenter

John,

P Bonell has this

When you get the revised questions could your team go through the IAEA/INSAG document circulated under cover of Bryan Edmondson's note of the 8th August and annotate the margins with the relevant questions (CIMRG 37 questions would do for starters!).

Could you then bring your master copy to Vienna - it would be marvellous if you could earlier send me a quick list of page and paragraph v question (even with CIMRG 37 question numbers). We'll be doing the same exercise.

Similar treatment of the expected Russian document would help, but I doubt there'll be time before Vienna.

Ewc

Copies: Mr. J. Appleby
Dr. S.J. Board
Dr. T. Healey
Dr. J.D. Young

IMMEDIATE FAX

To: Mr R N Simeone - on leave LHQ
Mr M A W Baker
Mr A W Hills
Mr W McMillan
Mr R L R Nicholson
Mr F Chadwick
Dr T N Marsham Risley
Dr G G E Low Harwell

cc MRH

From: Dr J H Gittus, SRD

PRE-VIENNA CHERNOBYL SPEAKING-BRIEF

From next Monday (18 August) we can expect the media to question us about the coming meeting in Vienna at which the Russians will give more information on the Chernobyl accident. Accordingly, I have prepared the following speaking-brief and would welcome immediate suggestions for its revision.

15 August 1986

PRE-VIENNA CHERNOBYL SPEAKING BRIEF

1. Q What do you hope to learn in Vienna?

   A The answers to five key questions

   - i) What initiated the accident?
   - ii) What have you done to ensure it doesn't happen again?
   - iii) What harmful effects has the accident had?
   - iv) What are your Emergency Plans? Are you amending them?
   - v) What are your Institutional Arrangements?

2. Q What do you guess the answers will be?

   A
   - i) An unauthorised experiment which caused the reactor to overheat.
   - ii) Banned such experiments.
   - iii) 30 accidental deaths (15,000 later deaths), 200,000 evacuated. 2% loss of "GNP" for Bello Russia and South Russia.
   - iv) In accord with ICRP doses for sheltering and evacuation. Will not be amended.
   - v) Were almost non-existant. Will in future be like ours, involving an independent Nuclear Inspector.

3. Q What steps have been taken following Chernobyl to ensure that ~~such an~~ a similar accident does not happen in the UK?

   A Such steps were taken long before Chernobyl. All our reactors have emergency equipment to prevent them from overheating. However, we have readied ourselves to re-evaluate these provisions in the light of the answers that the Russians give to "the five key questions".

4. Q What will you do in Vienna?

   A Question the Russians and prepare a report on their answers.

5. Q What actions will be taken following Vienna?

   A Much depends on the Russian answers. If the answers are what we think they are going to be then there will be no need for any substantial changes to UK reactors or practices.

6. Q Could you, if necessary, make our reactors safer if only to allay fears roused by Chernobyl?

   A Yes. It would be wasteful and if carried too far would render nuclear power too costly, but it could be done.

19.8

C V

FACSIMILE

TO: DR. J.H. GITTUS, SRD CULCHETH

CC: ✓ DR. T.N. MARSHAM, RISLEY (FAX) 71 3395
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MR. R.N. SIMEONE, o.r.
MR. R.I.R. NICHOLSON, o.r.
MR. F. CHADWICK, o.r.
MR. A.W. HILLS, o.r.
– MR. W. MCMILLAN

18 AUG 1986

ACTION
✓ a MR Haynes

FROM: B.C. CARPENTER, AHSS, LHQ

18/8/86

Pre Vienna Chernobyl Speaking Brief

I have the following comments on the question and answer brief circulated with your fax of 15 August.

On Question 2 - what do you guess we will be told in Vienna - I would advise against being drawn into an answer other than to say "we had better wait to hear what the Russians have to say". Speculation into eg. delayed death figures could easily produce headlines in the tone of "British expert estimates 15,000 deaths" which would both upset the Russians and put the figure into tablets of stone.

One Question 5, I would suggest that the second sentence of the answer should be more on the lines of "we shall have to analyse carefully what the Russians tell us before we can decide whether action is necessary in this country". Additional comments may be hostages to fortune.

I understand from the CEGB that press enquiries may be expected about what is in the 400 page account of what happened which is to be tabled by the Russians. The Department of Energy has told me that the Russians have asked that the document be embargoed until the Conference starts. It would be better to let the Department deal with press enquiries. The line taken would be that the UK has received a copy in Russian and that it will be translated for use at the Conference but no comment can be made on it until then.

C4

From Dr J. H. Gittus
Director

SRD

Safety and
Reliability
Directorate

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14 August 1986

Mr P Wood
Newbold Farm
Duntisbourne Abbots
CIRENCESTER
Glos. GL7 7JN

Dear Mr Wood

I apologise for not having repled earlier to your Telecom Gold message. It seems unlikely that I shall be able to find a space in my diary for the personal discussion which you request, before the Vienna meeting. However, I can confirm that I shall be in Vienna and I believe that there will be a UK "media briefing room" in the Imperial Hotel. I shall be pleased to meet you there and give whatever help I can.

Best regards.

Yours sincerely

M. O'Hara

p.p. J H GITTUS

ps: I was unable to obtain access through your Telecom Gold number.

READING LIST

UNITED KINGDOM ATOMIC ENERGY AUTHORITY

**Information Section,
Risley Nuclear Power
Development Establishment,
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Warrington, WA3 6AT
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3. Analysis of the accident using mathematical model.
4. Causes of the accident.
5. Priority measures for improving the safety of nuclear power plants with RBMK reactors.
6. Containment of the accident and alleviation of its consequences.
7. Monitoring of environmental radioactive contamination and health of the population.
8. Recommendations for improving nuclear power safety
9. The development of nuclear power in the USSR.

Annexes:

1. Water-graphite channel reactors and operating experience with RBMK reactors.
2. Design of the reactor plant.
3. Elimination of the consequences of the accident and decontamination.
4. Estimate of the amount, composition and dynamics of the discharge of radioactive substances from the damaged reactor.
5. Atmospheric transport and radioactive contamination of the atmosphere and of the ground.
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Accident event sequence, p.4-5.
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A. J. White
November 1986

1st August 1986

The Editor,
Nature,
4 Little Essex Street,
London WC2E 3LF

Chernobyl - more speculation

There seemed to be some confusion in the report in Nature last week (322, 399, 31/7/86) between the heat output from residual radioactivity when the chain reaction was shut down, which after a day or two might well have been about 4%, and the 7% usually quoted by the Russians which is likely to have been the proportion of normal output to which the chain reaction had been reduced.

When it is desired to reduce output for only a short period, it is essential to avoid a complete stoppage of the chain reaction because of the undesirable properties of xenon-135. This absorbs neutrons, to form xenon-136, with an efficiency about 4000 times the efficiency of absorption by the uranium-235 on which the reactor depends.

Xenon-135 is a fission product with a half-life of 9.2 hours, decaying by beta emission to caesium-135, and if it is allowed to accumulate will make it impossible to re-start the reactor until practically all has decayed. During normal operation it is changed by absorption of a neutron to xenon-136 (which does not absorb neutrons) as fast as it is produced, so that there is never a serious accumulation. When the chain reaction is shut down for maintenance there should therefore be none left to prevent re-starting; but unfortunately it is not produced only by the direct fission of uranium-235. It is also created as a secondary product from the beta decay of the 6.7 hour half-life product iodine-135 (itself a negligible absorber of neutrons). During normal running, the xenon-135 from the iodine-135, which can accumulate without adverse effects, will also be removed as fast as it is produced; but if the reactor is completely shut down it will rapidly accumulate as the iodine-135 decays, until both it and the iodine-135 present have decayed to negligible proportions. Until this has happened, which may take a couple of days or more, the reactor cannot be re-started.

Accordingly, a complete shut-down is avoided as far as possible, a sufficient chain reaction being allowed to continue to prevent accumulation of xenon-135. As extra heat output produced by this is little more than the output of heat from residual radioactivity, this is of little inconvenience, although requiring careful adjustment of the controls.

It seems possible that the behaviour of xenon-135 plus human error was responsible for the Chernobyl catastrophe. This would fit with the Politburo statement that the power station crew was attempting to operate the reactor at a slower power than that for which it was designed, and a possible scenario could be as follows.

In lowering the power from the normal level a technician could have pushed in a small group of control rods, or even a single rod, further than necessary, and shut down completely the chain reaction in the region of the reactor involved. He could easily fail to realise that the power output from the section involved was then due only to residual radioactivity - initially not very far below the target figure. At some later time, perhaps only a few hours, the technician (or his relief) could have noticed that the heat output from the section was still falling, as the shorter-lived fission products decayed, faster than it should have been falling if the low-level chain reaction was operating correctly.

At that point of course the technician concerned should have reported the whole pattern of events and asked for instructions. It is entirely believable however that he did not wish to admit to the earlier fault, and tried to compensate it by withdrawing the control rods for the section concerned. Some xenon-135 would by then have built up locally to a serious extent; the chain reaction would not have re-started; he would find little response (which would be due entirely to peripheral regions of the section in which xenon-135 had been suppressed by neutrons from surrounding sections). Encouraged by at least a little response, he might then withdraw the control rods of the section as far as they would go. Slowly at first, but then at increasing speed, the preipheral xenon-135 would begin to be transformed to harmless xenon-136. As the xenon-135-limited region got smaller, the transformation would go faster and faster and ultimately too fast for any reintroduction of the withdrawn control rods, and the heat output of the section could flash up to a level far above the designed maximum.

At this point the multichannel construction of the RMBK reactor becomes important; the sudden temperature rise of a few fuel units could explode the heat-removing water into steam. The zirconium alloy fuel holders would then run up to melting point and react with the steam to form hydrogen, and in the absence of liquid water would by thermal radiation raise the surface temperature of the surrounding graphite blocks to white heat.

The steam explosion could have been powerful enough at least to break the core containment of the reactor and release hydrogen to mix with air and explode to remove the roof of the containment building.

It is impossible to calculate such important quantities as the final rate of rise of local reactivity, but the positive feedback in the later stages of removal of xenon-135 could in principle produce very fast rates indeed; and while I do not know enough about the degree of independence of controls in different parts of the reactor core in the actual Chernobyl reactor, nothing in what has been reported would preclude such a scenario.

If this explanation is correct, there are two features which give hope for the future. Firstly, changes in procedure and improved localised monitoring could preclude a repeat of the pattern in other RBMK reactors. Secondly, neither PWRs nor our own gas-cooled reactors have the confined water channels around the fuel rods that could lead to so rapid and localised a temperature rise, and our reactors cooled by carbon dioxide have neither zirconium nor water in their reactor cores.

J.H.Fremlin

15.8

CHERNOBYL

~~cc PCto~~

REVISED QUESTIONS

FOR

VIENNA PRESENTATIONS

JA
13/8/86

A. Design, Safety and Operation

This section of the questions and briefs concentrates on what was and what should have been. That is it concentrates on the design as built, the safety basis for the plant and its intended operating conditions and operating arrangements.

Section B will consider what was the state of plant, operation etc at the time of the accident.

The purpose of this section is to provide background which will aid an understanding of the accident sequence and the assessment of its implications for a UK PWR and other types of reactor.

Contents

Section

A1. General Background

Question

No specific questions at present.

Background to Question

Notes

Section included for completeness.

Some general background briefing (eg. overall parameters) might be useful.

References

Section

A2 Reactor

Question

A2.1 What is the range of void coefficients over which operation of the Chernobyl reactor is allowed; what limits the allowable range; and how are void coefficients expected to vary as a function of fuel cycle history, absorber loading and control rod insertion patterns and reactor power

Background to Question

The response of a reactor to fault conditions is a function of the inherent characteristics of the reactor and the associated protection provided.

The potentially positive void coefficient of the RBMK reactor will aggravate the response to faults worse whereas the negative fuel temperature coefficient will help limit the response

The purpose of this question is to establish expected values of this coefficient as a function of reactor state and to establish the intent with regard to avoiding operation with unacceptably high values.

Notes

SXB can have positive void and moderator temperature coefficients

PCSR chapter 4 plot of MTC v coolant temp + boron ppm could be provided.

References

Section

A 2 Reactor

Question

A2.2 To what extent is the void coefficient controlled to lie within the allowable range by:

- design (enrichment, graphite density, core geometry etc)
- control of burn-up distribution
- control of absorbers and control rod patterns
- other means
- limiting reactor power

Background to Question

The void coefficient is a function of design choices and the mode of operation of the reactor.

The purpose of this question is to establish the relative importance and extent of control of the various factors which affect this coefficient.

In particular this question aims to establish the extent to which this coefficient is limited by operation

Notes

References

Section

A2 Reactor

Question

A2.3 What is the operators role in ensuring operation with acceptable void coefficients and what means does he have available for establishing the actual value of the coefficient

Background to Question

This question is a follow-on from A2.2. Its purpose is to further define the importance and the nature of the operators task in ensuring that the void coefficient is within the range intended by the designers and assumed in the safety case

Notes

References

Section

A2 Reactor

Question

A2.4 What are the sequences and speeds for control rod insertion and withdrawal during normal operation and following faults (insertion only); what limits, if any, are placed on the extent of control rod insertion and withdrawal either generally throughout the core or in local regions of it; and what are the reasons for the choice of these sequences, speeds and limits.

Background to Question

Control rods can terminate faults by insertion and cause faults by withdrawal, generally or locally. The proper choice of control rod sequences and speeds ensures that fault termination is effective and withdrawal, either deliberately or inadvertently, does not lead to unacceptable consequences.

Also the pattern of control rod deployment throughout the core can affect the response of the reactor following faults (it can affect void coefficient(?) and power distribution) and the effectiveness of the rods when tripped (it can affect shutdown margin - generally and locally).

The purpose of this question is to understand the characteristics of the control rods and the limits placed on their use.

Notes

References

Section

A 2 Reactor

Question

A2.5 What parameters are used, and in what combinations, to protect against general and local reactivity faults, ~~where~~ and how are they measured; and how do the parameters used vary with reactor operating regime. Additionally how many different parameters, or parameter combinations, are required to protect against faults

Background to Question

Control rods will not trip into the reactor unless they are 'told' to. It is, therefore, necessary to monitor the plant state to establish when a fault warranting tripping has occurred or might be about to occur.

The purpose of this question is to establish what is monitored on RBMK reactors to protect against reactivity faults; ~~and~~ how the need for tripping is derived from these parameter or combinations of them and what is the extent of trip parameter redundancy and diversity

Notes

References

Section

A2 Reactor

Question

A2.6 What is the basic implementation of the reactor trip system which uses the input parameters and generates the necessary signals for tripping rods and initiating other safeguards actions.

For example, what logic is used (2 out of 4?); ~~and~~ how is it implemented (relays, transistors, integrated circuits and/or computer); and what is the time delay between detection and trip signal generation.

Background to Question

The purpose of the question is to understand the nature of the trip hardware.

Notes

References

Section

A2 Reactor

Question

A2.7 To what extent is the effectiveness of the reactor trip system dependent on operator actions, such as setting trip margins as power changes and changing parameter as power changes and to what extent is effectiveness established by automatic actions

Background to Question

Reactor trip systems may rely on certain operator actions for their effectiveness and may be rendered ineffective by incorrect action.

The purpose of this question is to establish the extent to which this is the case for RBMK reactors.

Notes

References

Section

A3. Thermal Hydraulics

Question

A3.1 What are the thermal-hydraulic conditions of the reactor coolant system as a function of load (for example, channel flow, coolant temperatures and pressures and channel exit quality); what limits are placed on these conditions for power operation, start up and shutdown etc; and why are these limits imposed.

Background to Question

The possibility of faults occuring and the response of the system to faults may be a function of the thermal-hydraulic conditions of the reactor coolant system

The purpose of this question is to establish expected conditions and limits placed on operation.

Notes

References

Section

A3 Thermal Hydraulic

Question

A3.2 To what extent are acceptable thermal hydraulic conditions established and maintained by operator action and to what extent are they established by automatic action

Background to Question

The purpose of this question is to establish the importance and nature of the operators task in ensuring acceptable thermal hydraulic conditions and the extent to which automatic actions are relied upon.

Notes

References

Section

A4 Turbine Generators

Question

A4.2 Do the turbine generators contribute to grid frequency control. If so, is it achieved automatically; what are the characteristics (the droop characteristic, for example) of the controller; and how is the reactor protected against unacceptable effects due to the response of the turbine-generators to grid frequency variations

Do the turbines have electronic governors

Background to Question

It is desirable that a reactor contributes to grid frequency control by increasing power output as the grid frequency falls and vice versa. It is essential that this is done in a way which does not prejudice reactor reliability and safety.

The purpose of this question is to explore whether the RBMK reactors are expected to operate in this way and, if so, how the reactor is protected against unacceptable effects

Notes

What is relevance of electronic governors.

References

Section

A4 Turbine Generators

Question

A4.1 What requirements and limits are placed on turbine-generator control and operation so as to ensure safe and reliable operation of the reactor; and to what extent and how is satisfaction of these requirements and limits ensured by automatic actions and by the operator.

Background to Question

Thermal - hydraulic conditions in the reactor are affected by the way the turbine-generators are operated and controlled.

The purpose of this question is to establish to what extent and how such effects are limited.

Notes

References

Section

A5 Containment

Question

A5.1 What is the extent of containment provided in RBMK reactors of the Chornobyl 4 type and what are its design conditions and design bases.

Background to Question

Whatever containment the Chornobyl 4 reactor had was not effective. As the accident was probably well beyond the design basis this is not suprising.

The purpose of this question, therefore, is more a matter of clarification than of crucial importance to understanding the accident sequence.

Notes

References

Section

A6 Safety Design Bases

Question

A6.1 What are the limiting design basis faults for the design of the equipment and structures which protect against reactivity faults and pressure parts failure.

Has hydrogen generation due to zirconium-water reaction been considered in the design and, if so, how.

Background to Question

The purpose of this question is to clarify the safety design basis of the plant.

Notes

References

Section

A7. Operation

Question

A7.1 what is the staffing structure of the Chernobyl nuclear power station and, in particular, what is the structure of the team which operates a reactor, the relative responsibilities within the team and the relationships between the team and rest of the station staff particularly the management.

Background to Question

Notes

References

Section

A7. Operation

Question

A7.2 What are the professional qualifications and experience, required for the reactor operator(s) and what is the extent of training given particularly for dealing with accident situations. For example would the operators have a good understanding of the reactor physics and thermal hydraulics of the RBMK reactor and have had training on a simulator

Background to Question

The purpose of this question is to explore the extent to which the operators were equipped to operate a 'sensitive' reactor such as the RBMK.

Notes

References

Section

A7 Operation

Question

A7.3. How should abnormal operations, such as experiments, be ~~authorised, verified and supervised~~ defined, documented, verified, authorised, conducted and supervised.

Background to Question

The purpose of this question is to establish what is the laid down procedure for defining and controlling experiments.

Notes

References

B. Short Term Accident Sequence

This section of the questions and briefs concentrates on what was the state of the plant immediately prior to the accident an on the course of the accident until 'the roof fell in'.

Contents

B1. Initial Conditions

- B1.1 Operating History
- B1.2 Operating Intentions
- B1.3 Reactor Conditions
- B1.4 Thermal and Turbine Generator Conditions

B2 Precursors

B3 Initiating Event

B4 Short Term Sequence

- B4.1 Before Power Surge
- B4.2 Power Surge
- B4.3 Effects of Power Surge
- B4.4 Initial Major Damage

Section

B1·1 Initial Conditions - Operating History

Question

B1·1·1 What was the power history of the reactor before the accident.

Background to Question

The purpose of this question is to establish a base line for long term decay heat and source terms

Notes

References

Section

B1·2 Initial Conditions – Operating Intentions

Question

B1·2·1 At the time of the accident what operations were being undertaken and why.

For example;

- why was the reactor at 7% power;
- what experiments were being conducted, and why;
- was refuelling taking place;
- was any maintenance being undertaken, and if so, what.

Background to Question

The purpose of this question is to establish what was been done to the reactor at the time of the accident

Notes

References

Section

B1.3 Initial Conditions - Reactor

Question

B1.3.1 At the time of the accident what was the state of the following core conditions:

- fuel enrichment and type
- fuel burn-up and its distribution
- absorber pattern
- control rod pattern
- reactor power

Background to Question

The purpose of this question is to establish a base line for the physics characteristics of the core at the time of the accident.

Notes

References

Section

B1.3 Initial Conditions – Reactor

Question

B1.3.2. Were all reactor trips appropriate to the reactor power level operational and correctly set at the time of the accident or had some been overrided and were control rods adequately withdrawn to ensure effective shutdown on tripping

Background to Question

The purpose of this question is to establish the state of the protection system at the time of the accident.

Notes

References

Section

B1.4 Initial Conditions - Thermal and Turbine.

Question

B1.4.1 What were the thermal-hydraulic conditions of the reactor at the time of the accident and were these within normal operating limits. In particular what was:

- the reactor power and how much of the power was nuclear heat, fission product heat and pump power;
- the pressure in the separators;
- reactor coolant pump flow and inlet temperature;
- graphite temperatures;

Background to Question

The purpose of this question is establish a base line for the thermal-hydraulic state of the reactor at the time of the accident.

- the steam flow from the separators and its destinations
- the feed flow to the separators and its source(s) and ~~conditions~~ temperature.

Notes

References

Section

B1.4 Initial Conditions - Thermal and Turbine

Question

B1.4.2 What was the state of the turbine plant at the time of the accident.

In particular;

- how many turbines were running;
- was the feed heating train being used;
- what form of turbine control was implemented (eg manual or automatic; pressure or grid frequency control)
- what operations were being undertaken on the turbines.

Background to Question

The purpose of this question is to establish the state of the turbine plant, its potential for affecting the reactor and the operations being undertaken

Notes

References

Section

B1.4. Initial Conditions - Thermal and Turbine

Question

B1.4.3 To what loads were the turbine generators connected at the time of the accident (the grid and/or station auxiliaries) and what power were they ~~[illegible]~~ supplying to these loads

Background to Question

The purpose of this question is to establish a base line for ~~[illegible]~~ assessing the potential for external effects, such as grid frequency variations, ~~and turbine effects~~ to affect the reactor and the potential for adverse coupling between the turbine and auxiliary loads, such as the reactor coolant pumps

Notes

References

Section

B2 Precursors

Question

B2.1 Were there any precursors to the fault (for example: loss of electrical supplies, reactor coolant pump trip or pressure tube leak) and were there any similarities between the events which caused the Chernobyl accident and any faults previously experienced by RBMK reactors.

Background to Question

The purpose of this question is self evident.

Notes

References

Section

B3 Initiating Event

Question

B3.1 What was the event which initiated the accident and did it occur as a result of a plant fault, an operator error or outside effects (such as loss of the grid)

Background to Question

This is the 64 000 dollar question.

Notes

References

Section

B4·1 Sequence Before Power Surge

Question

B4·1·1 What events, if any, followed from the initiating event and preceded the power surge and during this period what actions, if any, were taken by the operators to mitigate the effects of the initiating event. For example was the initiating event aggravated by plant faults (eg pump trippings) or loss of the grid.

Background to Question

The initiating event may not have led to the power surge and what followed from it. There may have been further factors such as plant faults and operator error.

Notes

References

Section

B4·2 Power Surge

Question

B4·2·1 what was the cause of the power surge.

Was it, for example, initiated by:

- control rod withdrawal
- changes to coolant conditions
- refuelling

Background to Question

Notes

References

Section

B4.2 Power Surge

Question

B4.2.2 Did the reactor protection system detect the power surge and initiate reactor trip; if so, why was it not effective in acceptably limiting the severity of the accident; if not why not.

what effects did it have and

Background to Question

Basically there are two possibilities - it worked and was not effective or it failed to work.

Notes

References

Section

B4·2 Power Surge

Question

B4·2·3 What is the variation of reactor and thermal-hydraulic parameters from before the initiating event to and beyond the end of the power surge and has any attempt been made to model the course of the events to understand the accident further and/or to demonstrate the adequacy of the computer codes available.

Background to Question

Notes

References

Jean f.

8881
13.8

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Your reference

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Date 12 August 1986

Dear Dr Edmondson

CHERNOBYL: POST ACCIDENT REVIEW MEETING 25-29 AUGUST

We have received from the US Embassy a copy of the list of questions concerning the Chernobyl accident which has been prepared for US use at the post accident review meeting. I enclose a copy of this list for your information.

Copies of this letter and the list go also to Dr Gittus (UKAEA), Mr Dunster (NRPB), Mr Ryder (NII), Mr Pilling (BNFL), Dr Feates (RCI), Mr Gray (SSEB).

Yours sincerely

cc MR Hayns

A J Daniels

CONSOLIDATED LIST OF QUESTIONS
U.S. AGENCIES WOULD LIKE THE SOVIET UNION
TO ADDRESS AT THE AUGUST 25-29 MEETING AT THE IAEA

PLANT DESIGN FEATURES

1. THERE ARE A NUMBER OF REPORTS IN THE PUBLIC LITERATURE THAT DISCUSS THE DESIGN OF THE RBMK. HOWEVER, WE UNDERSTAND THAT THE BASIC DESIGN HAS A NUMBER OF VARIATIONS AND IMPROVEMENTS. WHAT HAS BEEN THE DESIGN EVOLUTION OF THE RBMK? IN WHAT WAYS IS CHERNOBYL-4 DIFFERENT FROM ITS PREDECESSORS? WILL IAEA MEMBERS BE ALLOWED TO REVIEW DETAILED DRAWINGS AND PRINTS OF CHERNOBYL-4?

2. WHAT ARE THE DESIGN BASES AND CRITERIA FOR CHERNOBYL-4? OF PARTICULAR INTEREST ARE THE FUEL, THE REACTIVITY CONTROL SYSTEM, THE FLOW CONTROL SYSTEM FOR THE INDIVIDUAL PRESSURE TUBES, THE ELECTRICAL SYSTEMS, SYSTEMS TO ACCOMODATE HYDROGEN PRODUCTION DURING AN ACCIDENT, THE EMERGENCY CORE COOLING SYSTEM, THE REACTOR BUILDING, THE CONTAINMENT SYSTEM INCLUDING LEAKAGE, PRESSURE CAPABILITY AND RESPONSE TO SEISMIC AND SUDDEN IMPACT EVENTS AND, FINALLY, ANY SYSTEMS OR PROVISIONS THAT EXIST FOR FILTRATION OF RADIOACTIVE MATERIAL FROM EXHAUSTS OR RELEASES.

3. WHAT FACILITIES AND SYSTEMS ARE SHARED BETWEEN CHERNOBYL UNITS 3 AND 4?

4. THERE IS INTEREST IN SCIENTIFIC KNOWLEDGE OF THE INTERACTIONS OF DAMAGED CORE DEBRIS WITH SURROUNDING CONCRETE AND METAL STRUCTURES AND THE RESULTING EFFECTS ON CONTAINMENT INTEGRITY AND FISSION PRODUCT EVOLUTION AND RELEASE. IN THIS REGARD, COULD THE FOLLOWING INFORMATION BE PROVIDED:

- A. GEOMETRY OF CONCRETE STRUCTURES IMMEDIATELY SURROUNDING AND CONTAINING THE DAMAGED CORE AND THE CONCRETE CHEMICAL COMPOSITION (INCLUDING PIPING PENETRATIONS IN THE CONCRETE FLOORING.)

- B. AVAILABLE ESTIMATES OF THE TIMING AFTER REACTOR SHUTDOWN OF CORE DAMAGE AND OF CONCRETE ATTACK.

- C. AVAILABLE ESTIMATES OF THE FRACTION OF THE CORE THAT MAY HAVE CONTACTED SURROUNDING CONCRETE.

- D. ESTIMATES OF OTHER MATERIALS THAT MAY HAVE ALSO REACTED WITH THE CORE DEBRIS SUCH AS STRUCTURAL STEEL, WATER, AND MATERIALS (SAND, ETC.) ADDED AFTER THE ACCIDENT.

5. WHAT WAS THE DESIGN BASIS FOR THE VARIOUS PRESSURE RETAINING COMPARTMENTS SURROUNDING THE PRIMARY SYSTEM COMPONENTS? WHAT WAS THE DESIGN BASIS FOR THE BUBBLER PONDS UNDER THE REACTOR?

SYSTEM OPERATION

1. WHAT HAS BEEN THE SOVIET EXPERIENCE WITH THERMALHYDRAULIC AND REACTIVITITY CONTROL AT LOW POWER? HOW ACCURATE AND RESPONSIVE IS THE INSTRUMENTATION? DOES THE INSTRUMENTATION AND CONTROL SYSTEM AFFORD ADEQUATE CONTROL OVER SPATIAL EFFECTS DURING STARTUP? ARE SPECIAL PROCEDURES USED FOR OPERATION AT LOW POWER?

2. WHAT SIGNALS TRIGGER AN AUTOMATIC REACTOR SHUTDOWN? WHAT REDUNDANCY AND COINCIDENCE ARE INCORPORATED IN THESE SIGNALS? WHICH OF THESE SIGNALS, IF ANY, CAN BE BYPASSED AT THE OPTION OF THE OPERATOR, AND UNDER WHAT CONDITIONS? ARE THESE CONDITIONS ADMINISTERED THROUGH PROCEDURE, OR ARE THEY A PART OF THE AUTOMATIC SYSTEM?

SAFETY ANALYSIS

1. WHAT ARE THE DESIGN BASIS ACCIDENTS FOR CHERNOBYL-4? WHICH OCCURRENCES DURING THE ACCIDENT FELL WITHIN THESE ASSUMED ACCIDENTS? WHERE PLANT BEHAVIOR DEVIATED SUBSTANTIALLY FROM EXPECTATIONS, WAS THAT BEHAVIOR PREDICTABLE BUT DETERMINED TO BE LOW PROBABILITY, OR DID IT APPEAR TO REPRESENT UNEXPECTED OR UNANALYZED PHENOMENA?

2. DO SAFETY ANALYSES ORDINARILY INCLUDE THE EFFECTS AN ACCIDENT AT ONE UNIT OF A MULTI-UNIT FACILITY MIGHT HAVE ON THE OTHER UNITS? WHAT SHARED SYSTEM (BETWEEN CHERNOBYL-4 AND CHERNOBYL-3) FAILURES ARE INCLUDED IN SAFETY ANALYSES?

3. WILL IAEA MEMBERS BE PROVIDED WITH RESULTS OF THE SAFETY ANALYSES CONDUCTED FOR CHERNOBYL-4?

4. HOW WAS THE PLANT STABILIZED AND THE EVENT TERMINATED?

5. WHAT, IF ANY, "BALANCE OF PLANT" COMPONENTS ARE INVOLVED IN THE SEQUENCE AND HOW DID THEY PERFORM? WAS THERE SIGNIFICANT DEGRADATION OF PERFORMANCE OF OPERATING COMPONENTS CALLED UPON TO FUNCTION DURING THE SEQUENCE?

6. WHAT FRACTION OF THE FUEL WAS INVOLVED IN THE INITIAL RELEASE OF FISSION PRODUCTS, AND WHAT FRACTION IN THE LONGER TERM RELEASE? WAS THE FUEL STORAGE POND INVOLVED IN ANY WAY? WHAT FRACTION OF AVAILABLE FISSION PRODUCTS IN THAT FUEL WAS RELEASED IN THE INITIAL RELEASE AND WHAT FRACTION IN THE LONGER TERM RELEASE? (SOME CHARACTERIZATION AS TO THE CHEMICAL ISOTOPE OR RADIONUCLIDE, AND THE FORM, SIZE AND SOLUBILITY WOULD BE MOST HELPFUL.)

7. WHAT PORTION OF THE GRAPHITE BURNED? WHAT FRACTION OF THE TOTAL ENERGY RELEASED CAME FROM BURNING GRAPHITE, FROM BURNING HYDROGEN, AND FROM BURNING ASPHALT AND PLASTIC MATERIALS?

8. WHAT WERE THE CHARACTERISTICS OF THE EXPLOSION, I.E., DURATION OF PULSE AND PEAK PRESSURE?

OPERATOR RESPONSIBILITIES AND TRAINING

1. WHAT REACTOR AND PLANT CONTROL FUNCTIONS ARE HANDLED BY AUTOMATIC OR COMPUTERIZED SYSTEMS, AND WHAT FUNCTIONS ARE HANDLED BY THE OPERATING CREWS?

2. WHAT TRAINING AND EXPERIENCE ARE REQUIRED FOR THE OPERATING CREWS? ARE THEY TRAINED ON ANY KIND OF A TRAINING SIMULATOR?

3. HOW ARE EMERGENCY PROCEDURES USED BY OPERATING PERSONNEL? FOR EXAMPLE, IS VERBATIM COMPLIANCE REQUIRED, OR ARE PROCEDURES CONSIDERED GUIDELINES? TO WHAT EXTENT MUST EMERGENCY PROCEDURES BE COMMITTED TO MEMORY?

CONDITIONS AT THE TIME OF THE ACCIDENT

1. WHAT WAS THE FUEL LOADING AND ACCUMULATED EXPOSURE AT THE TIME OF THE ACCIDENT?

2. PLEASE PROVIDE DETAILS OF THE EXPERIMENT THAT CAUSED THE ACCIDENT: WE UNDERSTAND THAT AN INFREQUENT TEST OR EXPERIMENT WAS UNDERWAY AT THE TIME OF THE ACCIDENT.

3. WHAT WERE THE REACTOR AND PLANT CONDITIONS AT THE TIME OF THE ACCIDENT? WAS THE NEUTRON DISTRIBUTION OR THERMAL HYDRAULIC CONDITIONS UNUSUAL, OR WERE ANY UNUSUAL COOLING CONFIGURATIONS IN USE? WHAT INSTRUMENTATION WAS AVAILABLE?

EMERGENCY RESPONSE - ON-SITE

1. WAS THE DIRT REMOVED TO SOME DISTANCE, OR WAS IT TURNED OVER IN PLACE?

2. WHAT TECHNIQUES WERE USED TO IMMOBILIZE OR FIX SURFACE CONTAMINATION (SPRAYED PLASTIC, SHEET METAL, WASHING DOWN, ETC)?

3. WITH THE REACTOR BURIED UNDER SAND AND OTHER SHIELDING MATERIAL, WHAT ARE THE MAJOR SOURCES OF ONSITE RADIATION? IS IRRADIATED FUEL IN THE SPENT FUEL POOL A SIGNIFICANT FACTOR?

4. WAS THE HAZARD IN THE UNIT 1 AND UNIT 2 CONTROL ROOMS DUE TO AIRBORNE RADIOACTIVITY OR DUE TO GROSS EXTERNAL RADIATION? IS THERE MAJOR CONTAMINATION INSIDE THE BUILDINGS OF UNITS 1 AND 2? IF SO, HAS ITS NATURE BEEN IDENTIFIED AND MEANS TO REMOVE OR IMMOBILIZE IT ESTABLISHED?

EMERGENCY RESPONSE - OFF SITE

1. WHAT POPULATION GROUPS WERE EVACUATED, AND WHAT WERE THE CRITERIA USED TO ESTABLISH THE NEED FOR EVACUATION?

2. WERE THE EVACUATIONS PRE-PLANNED OR PERFORMED ON AN AD-HOC BASIS? TO THE EXTENT THAT THEY WERE PRE-PLANNED, DID THE EVACUATIONS PROCEED ACCORDING TO EXPECTIONS, AND IF THEY DID NOT, WHAT WERE THE DIFFICULTIES?

3. WHAT PUBLIC PROTECTION MEASURES WERE TAKEN OTHER THAN EVAUCATION (E.G., PROPHYLACTIC DRUGS, SHELTERING), AND HOW EFFECTIVE WERE THEY?

4. WHAT CRITERIA WERE USED FOR THE CONFISCATION OF CROPS? FOR THE CONFISCATION OF FOOD? FOR DECONTAMINATION AND SUBSEQUENT USE OF FOODSTUFFS?

5. WHAT STEPS ARE BEING TAKEN TO DECONTAMINATE THE FARM LAND?

6. WILL THE USSR SHARE THE INFORMATION AND KNOWLEDGE REGARDING THE PROTECTIVE ACTIONS TAKEN? FOR EXAMPLE:

   A. HOW MANY PEOPLE WERE ACTUALLY EVACUATED, IN WHAT TIMEFRAME, AND BY WHAT MODES; E.G., BUSES, TRAINS, PRIVATELY OWNED VEHICLES, ETC.?

   B. DID THEY ENCOUNTER ANY PROBLEMS IN THE EVACUATION? IF SO, OF WHAT NATURE?

   C. WERE THERE ANY COMPLICATIONS ARISING FROM, E.G., SPONTANEOUS, OR UNORDERED, EVACUATIONS?

   D. WHAT IS THE TECHNICAL BASIS BEING USED TO DETERMINE THOSE AREAS WHERE PEOPLE ARE ALLOWED TO RETURN TO THEIR HOMES AND THOSE AREAS FROM WHICH PEOPLE MUST BE RELOCATED?

7. HOW WAS THE CHERNOBYL FACILITY MANNED AND CONTROLLED DURING THE ACCIDENT? IS THE CONTROL ROOM HABITABLE; IS THERE A REMOTE SHUTDOWN PANEL?

8. HOW AND FROM WHAT DISTANCE WAS THE EMERGENCY MANAGED WITH RESPECT TO PLANT ACTIONS AND OFFSITE ACTIONS?

9. CAN WE OBTAIN A COPY OF THE EMERGENCY PLANS AND ANY POST ACCIDENT EVALUATION BY THE USSR OF THESE PLANS?

METERORDLGY & RADIONUCLIDE TRANSPORT

1. IS THERE A DATA BASE OF SURFACE/LOCAL AND UPPER AIR METEOROLOGICAL CONDITIONS DURING THE EVENT AND ALONG THE PLUME PATH TO WHICH IAEA MEMBERS WILL HAVE ACCESS?

2. WERE ANY MEASUREMENTS MADE OF THE PLUME? IF SO, WILL THAT DATA BE MADE AVAILABLE TO IAEA MEMBERS?

LESSONS LEARNED

1. WHAT TYPES OF EXISTING ACCIDENT ANALYSIS AND RESPONSE CAPABILITIES WERE MOST HELPFUL? WHAT ADDITIONAL CAPABILITIES WOULD HAVE BEEN MOST HELPFUL?

2. ARE THERE MEASURES THAT WERE TAKEN IN RESPONSE TO THE ACCIDENT THAT, IN RETROSPECT, PROVED TO BE OF LITTLE VALUE, OR TO BE COUNTERPRODUCTIVE? IF SO, WHAT WERE THEY?

3. WHAT CHANGES OR ADDITIONS TO DESIGN, PROCEDURES, STANDARDS, OR REQUIREMENTS WOULD YOU RECOMMEND BE ADOPTED FOR NEW REACTORS AND FOR EXISTING REACTORS.

ACCIDENT SCENARIO

1. PLEASE DESCRIBE THE OPERATING CONDITIONS (INCLUDING THE RELEVANT OPERATING HISTORY) AT THE CHERNOBYL PLANT AT THE TIME OF THE ACCIDENT.

2. PLEASE DESCRIBE YOUR PRESENT UNDERSTANDING OF THE NATURE AND TIMING OF THE SEQUENCE OF EVENTS THAT LED TO THE VAIOUS PHASES OF THE ACCIDENT. A CHRONOLOGICAL LISTING OF SIGNIFICANT EVENTS AND ACTIONS BEFORE, DURING, AND SHORTLY AFTER THE ACCIDENT WOULD BE HELPFUL.

3. WHAT IS KNOWN ABOUT THE NATURE (SOURCE AND MAGNITUDE) OF THE EXPLOSIONS (WE HAVE BEEN TOLD THERE WAS MORE THAN ONE) AND FIRES?

4. DO YOU BELIEVE THAT THE STORED ENERGY OF THE GRAPHITE (WIGNER EFFECT) WAS SIGNIFICANT IN THIS ACCIDENT?

5. PLEASE PROVIDE YOUR EVALUATION OF THE DAMAGE AND CONSEQUENCES THAT RESULTED FROM THE EXPLOSIONS AND FIRES, AND DESCRIBE THE EMPLOYED FIRE SUPPRESSION MEASURES.

6. PLEASE DESCRIBE YOUR PRESENT UNDERSTANDING OF THE CONDITION AND LOCATION OF THE CORE MATERIALS AND COMPONENTS AT VARIOUS STAGES OF THE ACCIDENT. PLEASE DESCRIBE THE NATURE AND LOCATION OF MATERIALS ADDED TO THE CORE REGION DURING THE ACCIDENT.

7. PLEASE DESCRIBE (TO THE EXTENT POSSIBLE AT THIS TIME) THE NATURE OF AUTOMATIC EQUIPMENT OPERATION AND OPERATOR ACTIONS THAT TOOK PLACE DURING THE ACCIDENT INCLUDING THE EXTENDED PERIOD UNTIL THE SITUATION WAS STABILIZED.

8. PLEASE DESCRIBE THE PRESENT LOCATION OF THE REFUELING MACHINE. HOW AND WHEN WAS IT RELOCATED? WHAT DAMAGE DID IT CAUSE WHEN IT WAS RELOCATED?

9. WHAT WAS THE CAUSE OF THE POWER SURGE REFERRED TO IN PRESS REPORTS?

10. IF, AS REPORTED, AN EXPERIMENT WAS IN PROGRESS, WHAT WAS THE NATURE OF THE EXPERIMENT THAT WAS BEING CONDUCTED AT THE TIME OF THE ACCIDENT?

11. IF ANY DAMAGE WAS INCURRED AT ANY OF THE OTHER THREE REACTORS, PLEASE DESCRIBE THE NATURE OF THAT DAMAGE AND ACTIONS TAKEN TO COPE WITH IT. WERE THERE PERIODS OF TIME DURING THE ACCIDENT AT UNIT 4 THAT THE CONTROL ROOMS OF UNITS 13 WERE NOT HABITABLE?

12. THE POWER AND TEMPERATURE DISTRIBUTION TIME HISTORIES FOR THE REACTOR FROM SHORTLY BEFORE THE ACCIDENT FOR AS LONG AS IT WAS AVAILABLE WOULD HELP US CONSIDERABLY IN UNDERSTANDING THIS ACCIDENT. WE WOULD APPRECIATE AS MUCH OF THIS TYPE OF INFORMATION AS POSSIBLE.

13. WAS THERE A GRAPHITE FIRE ASSOCIATED WITH THE ACCIDENT AND IF SO, DO YOU HAVE ANY ESTIMATE OF HOW MUCH OF THE GRAPHITE BURNED?

14. REPORTS HAVE LED US TO UNDERSTAND THAT A THERMAL PLUME THAT EXTENDED UPWARDS OF 1500 METERS WAS THE PRIMARY RELEASE MECHANISM FOR RADIOACTIVITY TO THE ATMOSPHERE. WE WOULD LIKE TO KNOW IF YOU HAVE ANY ESTIMATES OF THE THERMAL PLUME HEIGHT OR ANY OTHER INSIGHTS ON THIS PHENOMENON AS THE PRIMARY RADIOACTIVE RELEASE MECHANISM.

15. OPINIONS HAVE BEEN REPORTED THAT THE FUEL STORAGE POOL MAY HAVE BEEN INVOLVED IN THE ACCIDENT. IS THERE EVIDENCE OF SUCH INVOLVEMENT? IF SO, WHAT IS KNOWN ABOUT THE ORIGIN, NATURE, AND THE CONSEQUENCES OF FUEL-POOL INVOLVEMENT?

16. HOW DID THE INFORMATION CONCERNING THE ACCIDENT UNFOLD TO THE OPERATING STAFF? WHAT SYMPTOMS AND INFERENCES AS TO WHAT WAS HAPPENING WERE EVIDENT TO THE OPERATING STAFF AS THE ACCIDENT EVOLVED?

RADIOLOGICAL RELEASES AND HEALTH EFFECTS:

1. WHAT WAS THE MAGNITUDE OF RADIONUCLIDE RELEASE DUE TO THE ACCIDENT? WE WOULD LIKE TO UNDERSTAND THE ISOTOPIC COMPOSITION OF THE RELEASE OF VOLATILE SPECIES SUCH AS IODINE AND CESIUM AS WELL AS INFORMATION ON SPECIES SUCH AS THE LANTHANIDES AND THE ACTINIDES. KNOWLEDGE OF THE PHYSICAL AND CHEMICAL CHARACTERISTICS OF THE RADIOACTIVE CLOUD FROM THE REACTOR BUILDING SUCH AS TEMPERATURE, VELOCITY, DIMENSIONS AND CHEMICAL SPECIES WOULD ALSO BE USEFUL.

2. WHAT ESTIMATES ARE AVAILABLE OF RADIONUCLIDE RETENTION AND TIME-DEPENDANT DOSE RATES WITHIN THE FACILITY?

3. WHAT WERE LOCAL METEOROLOGICAL CONDITIONS ONSITE AND OFFSITE (UP TO 30 KILOMETERS DISTANT) DURING AND FOR SOME TIME FOLLOWING THE ACCIDENT?

4. WHAT WERE TIME DEPENDANT GROUND LEVEL DOSE RATES (BETA AND GAMMA) AND ISOTOPIC CONCENTRATIONS AS A FUNCTION OF DISTANCE AND DIRECTION FROM THE FACILITY TO A DISTANCE OF 30 KILOMETERS? WAS THERE SIGNIFICANT RESUSPENSION OF MATERIAL THAT HAD SETTLED OUT ON THE GROUND?

5. WHAT ISOTOPE RATIOS (SUCH AS I-131/I-133) WERE MEASURED IN THE SOVIET UNION, AND WHAT WERE THE DATA OBTAINED, AS A FUNCTION OF TIME?

6. WHAT WERE THE LEVELS OF CONTAMINATION IN NEARBY RIVERS AND LAKES, AND WHAT WAS THE BEHAVIOR OF THE RADIONUCLIDES IN THE WATER AND THE SEDIMENTS? WHAT ARE THESE LEVELS NOW?

7. WAS THERE A REAL THREAT TO THE WATER SUPPLY, OR WAS IT JUST A NORMAL CONSERVATIVE CONCERN RELATIVE TO A LOW PROBABILITY EVENT? IF THERE WAS A REAL THREAT, WHAT WERE THE RELATIVE RISKS FROM SURFACE RUNOFF OF CONTAMINATED WASHDOWN OR FIRE FIGHTING WATER, FROM SURFACE RUNOFF OF RAINWATER, FROM CONTAMINATED WATER SOAKING INTO THE WATER TABLE?

8. HOW WAS THE RADIOLOGICAL MONITORING PROGRAM STRUCTURED AND CONDUCTED?

9. HOW LONG DID IT TAKE TO DECIDE TO EVACUATE PEOPLE?

A. HOW LONG DID IT TAKE TO ACCUMULATE ESSENTIAL INFORMATION?

B. HOW LONG DID IT TAKE TO ARRIVE AT A DECISION?

10. WHAT PROTECTIVE ACTIONS WERE TAKEN FOR EMERGENCY WORKERS, AND THE PUBLIC? WAS POTASSIUM IODIDE (KI) DISTRIBUTED?

11. WERE THERE OBSERVED SIDE EFFECTS FROM ADMINISTRATION OF POTASSIUM IODIDE? WOULD YOU RECOMMEND THIS TREATMENT, AND IF SO, UNDER WHAT CONDITIONS?

12. WHAT RADIATION EXPOSURE GUIDELINES WERE USED (DIRECT AND INGESTION)? IS THIS INCLUDED IN TRAINING PROGRAMS FOR LOCAL OFFICIALS ON HOW TO TAKE PROTECTIVE ACTIONS FOR THE PUBLIC?

13. HOW WERE RADIATION VICTIMS IDENTIFIED, SORTED AND MEDICALLY TREATED?

14. WERE DOSIMETERS OF HIGHLY EXPOSED INDIVIDUALS ADEQUATE FOR ESTIMATION OF THEIR DOSES? IF NOT, WHAT OTHER TECHNIQUES WERE USED?

15. WAS THE CLINICAL COURSE OF HIGHLY EXPOSED PERSONS COMPATIBLE WITH THEIR ESTIMATED DOSES?

16. WHAT DEPOSITION PATTERN AND METABOLIC BEHAVIOR OF RADIONUCLIDES WERE OBSERVED IN CONTAMINATED INDIVIDUALS?

Washington, D.C.
August 7, 1986

ORGANISATION FOR ECONOMIC
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STEERING COMMITTEE FOR NUCLEAR ENERGY

COMMITTEE ON THE SAFETY OF NUCLEAR INSTALLATIONS

Summary Record* of an Extraordinary Session on the Technical Aspects of the Chernobyl Accident, held at the Château de la Muette, Paris on 27th June 1986

I. GENERAL

1. The main conclusions of the discussion on the possible impact of the accident on CSNI activities are summarised in Annex I. A list of participants in the meeting is given in Annex II.

II. OPENING REMARKS

2. On behalf of OECD, Mr. Stadie, NEA's Deputy Director, Safety and Regulation, welcomed the participants, in particular the members of the Enlarged Bureau of the Committee on Radiation Protection and Public Health and two representatives of the IAEA. He then reminded the participants that the Extraordinary Session of CSNI had been decided at the Special Meeting held on 9th May 1986 [summary record SEN/SIN(86)20], the objectives being to review available information on the progression of the accident and to discuss the possible impact of the accident on CSNI activities. Prof. Birkhofer had agreed at the end of the 9th May meeting to take the lead in the preparation of a paper, to be drafted jointly by interested Member countries, on what had happened at Chernobyl. Because of pressure of other work, Prof. Birkhofer had not been able to fulfill this task, which Mr. Cogné and his staff at IPSN had kindly agreed to carry on. They had been assisted by a small ad hoc group of experts who had provided information from other countries.

3. Mr. Stadie reminded the Committee that NEA fosters co-operation in nuclear science and technology and is non-political; he hoped that Chernobyl would not change this and urged all concerned to limit their comments to technical and scientific questions posed by the accident.

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* incorporating participants' comments on an earlier version

III. REVIEW OF THE AVAILABLE INFORMATION ON THE PROGRESSION OF THE ACCIDENT

4. A brief report summarising the current state of knowledge regarding the Chernobyl accident had been prepared by Mr. L'Homme (IPSN) with the assistance of Dr. Hayns (UKAEA), Mr. Jahns (GRS), Mr. Petrangeli (ENEA/DISP), Mr. Sandervaag (Studsvik Energiteknik), and Dr. Speis (USNRC). It was presented by Mr. Cogné, who stressed that what was really known was still very limited and that a number of conjectures had been made. Mr. Cogné assumed that the main features of the RBMK design were now sufficiently well known not to have to repeat them at the meeting.

5. Regarding RBMK safety aspects, Mr. Cogné presented the following points:

- with respect to neutronics, this type of reactor was characterised by radial and axial power oscillations due to the xenon effect in a large core;
- it was also characterised with respect to neutronics by a positive void coefficient of reactivity;
- as a consequence, the monitoring, control and protection systems were very complex; this complex instrumentation had probably played a role in the accident (e.g. its efficiency might have been low at the 7% power level reported for the time at which the accident had begun);
- core component cooling was very variable; control rods, contained in pressure tubes similar to those of fuel channels, were cooled by low temperature water (50°C); local Wigner effects could not be ruled out;
- the graphite stack was cooled poorly; its average temperature was in the order of 500°C, while the local maximum temperature reached some 760°C;
- large quantities of zirconium (some 150 tons) were present in the core; in the presence of steam and a high temperature this could lead to the formation of large quantities of hydrogen;
- fission product confinement was not effected through a large unique containment but through several compartments of small volumes and variable dimensions; as in BWRs, water pools, located underneath the core cavity, were destined to reduce pressure peaks in the case of steam pipe rupture.

6. Regarding accident sequence progression, Mr. Cogné said that the only facts known for certain were that an explosion had destroyed the upper part of the reactor building on 26th April 1986 at 1.23 a.m. (local time); it had been followed by a fire which had raged for several days and which had been put out by massive quantities of sand and clay dropped from helicopters. It was also certain that large debris, some of them very active, had been dispersed into the environment; that the upper part of the core cavity had been destroyed, that fuel had melted down and an interaction had taken place between the molten core and the floor of the core cavity; and that Chernobyl-1, 2 and 3 had been shut down safely. Mr. Cogné then mentioned several less certain pieces of information, provided by the Soviets but unconfirmed. Finally, he described briefly a few facts which could be deduced from various observations:

- at the time of the accident, the average fuel burnup was in the order of 10,000 MWd/t;
- a large fraction of the radioactive products in the fuel had been released into the environment, over a period of several days;
- small amounts of radioactive products, released in the USSR, had been detected in Sweden several times before the accident.

7. All this information did not allow identification of the initial cause of the accident nor an accurate description of its progression and its consequences. The following remarks could be made:

- it seemed that the only possible explanation of the initial explosion was the ignition of a pocket of hydrogen located under the refuelling slab; the most likely explanation for this hydrogen was oxidation of zirconium in fuel clads and pressure tubes by high-temperature steam; this led one to postulate overheating of several channels, either as a result of neutron control failure, or because of loss of coolant;
- the helicopters had bombarded the burning core not only with sand and clay but also with boron and lead; this could mean that the core had remained supercritical a long time after the start of the fire;
- the Soviets had applied various counter-measures designed to slow down or stop core debris/concrete interactions; it was not clear whether the core had melted through the basemat.

8. Concerning radiological measurements made in Western Europe and source term evaluations, Mr. Cogné stressed that although a large number of measurements had been made, many of these could not be used with a high degree of confidence because there were many uncertainties with regard to methods of measurements, conditions of measurement, calibration of measuring devices, etc. He also stressed that no accurate estimation of the source term could be made in the absence of Soviet information on activities at a short distance from the reactor site. Finally, he recalled that large uncertainties affected long-distance atmospheric transfer coefficients, atmosphere dispersal, and meteorological conditions. Radiological observations led to the conclusion that the release plume had reached a high altitude, maybe between 800 and 1500 or even 2000 meters. Source term estimations could only be very rough as long as no Soviet information was available; for instance, for the volatile products they could range at this stage from a few percent to several tens percent.

9. By way of conclusion, Mr. Cogné said that, at the moment, it was impossible to draw from the Chernobyl accident any lesson regarding the safety of reactors built in OECD countries: the safety conditions were very different, and the accident itself was insufficiently known. One general lesson had been learned, however: the necessity of managing better future large nuclear crises. In order to make real progress, it would be indispensable to have accurate, detailed documents on the reactor, the programme of the accident, environmental effects (fallout, doses, etc.). A meeting would be held at the IAEA during the last week of August at which the Soviets were expected to provide information. Mr. Cogné said that such a meeting would be fruitful only if written material on what had happened were made available by the USSR.

10. Several technical issues were discussed after Mr. Cogné's presentation of the brief situation report prepared by the ad hoc group; they can be summarised briefly as follows:

- in reply to a question by Mr. Sato, Mr. Cogné said that a 760°C peak temperature for graphite had been mentioned to French engineers during a visit to the USSR; it was also consistent with limitations on specific power per channel in RBMK reactors; there was however no official confirmation of that value; Dr. Hellstrand said that he had read in Atomnaya Energiya that the reactor usually operated at a temperature of 560°C but that temperatures up to 760°C could be allowed, and that there was an alarm signal when the temperature exceeded 700°C;

- Prof. Alonso asked what the nitrogen/helium ratio in the box enclosing the graphite stack was and the influence of this ratio on the graphite temperature, formation of carbon 14 through nitrogen activation, and importance of possible reactions between nitrogen and hot graphite; no-one had accurate information on this but it was said that the ratio might be 6/4 or 4/6; Prof. Teague pointed out that this proportion was adjusted in order to achieve whatever graphite temperature was required; it was connected with reactor physics, notably the size of the void coefficient, and therefore it might be very relevant, especially if there had been some error in filling the box;
- the reaction between nitrogen and hot graphite did not appear to be important;
- no-one had information on the possible formation of carbon 14; this isotope had not been observed on Swedish filters analysed in France;
- while the amount of zirconium in an RBMK was in the order of 150 tons, it was only 17 tons in a French 900 MW PWR, 25 tons in a French 1300 MW PWR, 60 tons in a typical BWR;
- it was certain that the void coefficient of reactivity was positive but no figure had been given in Soviet literature; calculations had been made in France and in Japan;
- Dr. Haga described in some detail the results of the Japanese reactivity calculations; these had led to the conclusion that the accident might be due to normal control rod withdrawal; Dr. Haga pointed out that RBMK control rods were very long, and that the scram speed of the emergency shutdown rods was quite low;
- in reply to Mr. Petrangeli, who asked what fraction of the core could have been affected by an erroneous movement of control rods, Mr. Cogné said that such an incident in the Saint-Laurent-des-Eaux gas-graphite reactor had involved 50 to 100 channels out of a total of 3,000; RBMKs had approximately 1700 pressure tubes, and it was therefore conceivable that 50 tubes had been affected;
- as some participants felt that hydrogen production from 50 pressure tubes would not be sufficient to overpressurise the reactor building, Mr. Cogné said that French calculations showed that hydrogen from a few tens of channels (20 to 50) would be sufficient to cause hydrogen detonation and to destroy the rather thin refuelling slab;
- the control rods had been destroyed by the explosion (probably ejected through the top of the building); they were clad with aluminium and cooled down to 50°C; considering the high temperatures around them, they could not have survived anyway;
- Prof. Hicken said he had discussed the accident with a Soviet expert and that he could confirm that the withdrawal of four control rods was sufficient to make the core critical; this information was consistent with the possible failure of some 50 pressure tubes as one rod covered approximately ten channels;
- Prof. Hicken also said that there was some doubt as to whether the ECCS had worked or not during the accident;
- finally, he said that the official Soviet philosophy was that only one pressure tube could rupture at a time; this was what the reactor was designed for, in particular the containment system; Soviet literature seemed to imply that pressure tubes were replaced rather frequently;
- diverging views were expressed as to the effectiveness of the RBMK containment system; it was not clear, for instance, whether steam separators were within or outside the pressure boundary; Mr. Cogné said that Soviet literature showed that recent RBMKs were designed to cope with rupture of 900 mm diameter pipes, while the diameter of

the steam separators was 2 m; this interpretation was disputed by Mr. Giuliani (on the basis of IAEA work) and by Mr. Valtonen who considered that the containment was quite complete although it had several weak points (such as the refuelling slab, the reactor cavity where 1600 pipes went through the pressure boundary, etc.); Mr. Giuliani added that the containment was compartmentalised, with design pressures ranging from 2 to 5 atmospheres; this corresponded to the rupture of a single pressure tube;

- in reply to a question about the possible generation of coal gas during the accident (from reactions between hot graphite and water), Mr. Sato and Prof. Teague said that this had been considered but this mechanism seemed unlikely to them for the following reasons: the reaction was highly endothermic and therefore needed some continuous source of heat (about 1000°C); initially, the steam temperature was 280°C while the graphite surface temperature was some 500°C; it seemed therefore that the only possibility of heat source was the zirconium-water reaction; it was doubtful, however, that such a mechanism would happen with a random rearrangement of materials in a reactor following major core damage;
- Dr. McPherson raised several issues linked to the design of RBMKs, in particular with respect to steam separators; he also said there were indications from the USSR suggesting that Chernobyl-4 was used for district heating; if so, the thermal power should be higher than 3200 MWth;
- Dr. McPherson pointed out that this indicated that the Chernobyl operators were dealing with a reactor different from other reactors, and which was undergoing changes with time; this suggested a few questions about operating control procedures and the ability of operators to understand complex phenomena taking place in the reactor;
- for instance, at start-up, an RBMK core contained some 1500 fresh fuel rods and 200 absorber rods; these absorber rods were progressively removed as fuel was burnt up; it was not clear what condition the core was in at the time of the accident, and whether operators understood local reactivity phenomena; Mr. Sato, Dr. Haga and Prof. Teague explained a number of issues linked to the absorber rods; these were used to better control the reactivity of the core and had stabilising effects; however, it was clear that reactivity control was very complex in RBMK-type reactors, especially before the core was equilibrated; this transient phase lasted four years, and therefore Chernobyl-4 was not yet at equilibrium;
- another point raised by Dr. McPherson was that enrichment might have been 2.2% rather than 1.8% (the generally accepted value), apparently to reduce the degree of positive void coefficient; this conjecture was supported by Mr. Sato and Dr. Haga who said that enrichment might have been 2% and discharge burnup in the order of 20000 MWd/t (this would have an obvious impact on source term evaluations); Dr. McPherson pointed out that, conceivably, enrichment could be changed with time;
- Dr. McPherson then said that, according to some reports, there was a change of fuel going on at the time of the accident and that only one operator was performing this change whereas proper operation of the fuelling machine required more than one operator;
- Dr. McPherson asked if anybody had information about the way local zonal control rods were calibrated; this was done by moving the control rods and measuring the effect on the overall power; the

results were then factored in the computer control of the plant; Dr. Hellstrand said that power was supervised locally by in-core detectors, made of silver and rhodium; none of these were prompt detectors, however, and control was therefore difficult;
- at this point, Dr. McPherson emphasised the large number of RBMK features which could be controlled independently and/or manually by the operators (with numerous associated possibilities of error or unforeseen consequences): flow to each pressure tube, fuel enrichment, on-line refuelling (and associated perturbations), change of one fuel element at a time, zonal controls, etc.; on the other hand, there was little control of graphite temperature;
- finally, the discussion showed that interpretation of some photographs released by the Soviets was difficult.

IV. NATIONAL STUDIES ON THE CHERNOBYL ACCIDENT

11. the following three reports were distributed for the information of the participants:
- STUK-B-VALO 45: Second Interim Report - Radiation Situation in Finland from 5th to 16th May 1986 (May 1986);
- Radiological Consequences in Italy of the Chernobyl Accident - Report at May 27, 1986; ENEA-DISP: DOC/DISP(86)1 (June 1986);
- IPSN Report no. 2/86-Revision 2: The Tchernobyl Accident; CEA/IPSN (June 1986).

V. DISCUSSION OF THE POSSIBLE IMPACT OF THE CHERNOBYL-4 ACCIDENT ON CSNI ACTIVITIES

12. Mr. Stadie said that the Bureau of CSNI had met on 25th June 1986 and had decided to put forward the following proposal for consideration by the Committee at the Extraordinary Session. The Bureau had suggested that the ad hoc group of experts which had prepared the brief report on current technical knowledge regarding the accident, augmented by the Chairman of the Senior Group of Experts on Severe Accidents (Prof. Teague) and the Chairman of the Special Task Force on Source Terms (Dr. Torgerson), should continue its work with a view to preparing a report covering the following aspects:

(i) to highlight the relevant differences, especially those related to safety, between the Chernobyl-type reactors and power reactors licensed for electricity generation in OECD Member countries;

(ii) to explain the combination of factors (e.g. reactor physics, selection of materials, safety provisions, etc.) of the Chernobyl reactor, which were believed to have played a role in the accident.

13. The Bureau had stressed that it was essential that the report should distinguish between those aspects which were based on solid scientific facts and those less well known. The report would also describe the insights gained from severe accident research and studies in OECD countries and summarise the measures introduced in OECD reactors as a result of the TMI-2 accident.

14. The Bureau had further recommended that the ad hoc group should produce a first draft by mid-August 1986, prior to the meeting foreseen at the IAEA at which the Soviet Authorities were expected to describe the root causes and the evolution of the accident. The document should subsequently be improved in the light of information received at the IAEA meeting and during September. A final report should be issued by the ad hoc group for consideration at the regular meeting of CSNI in November 1986. To the extent possible, the ad hoc group would work by mail and telephone; if necessary, a meeting would be held in late September or October.

15. Mr. Sennis said he fully agreed with the Bureau's proposals, and with any suggestion for intense CSNI follow-up work, considering the technical and political importance of the Chernobyl accident. Recalling how the Committee had reacted after the TMI-2 accident, he said that detailed information would need to be requested from the USSR and he welcomed IAEA efforts in that direction.

16. Dr. Speis said that he also was in general agreement with the proposal, stressing the importance of gathering all facts on the accident, its evolution and its consequences, in order to be able to assess the implications of these facts for safety and regulation issues. The right place for contacts with the Soviets was of course the IAEA, and Dr. Speis recalled that the USSR had committed to provide information at the Agency meeting to be held at the end of August. It was important, however, to pursue in the CSNI framework technical issues raised by the accident -- source term, thermal-hydraulics, RBMK characteristics, etc. -- in order to identify collectively the most needed and relevant questions to be addressed to the Soviets. Stressing that the expertise of CSNI groups was unrivalled in the fields of severe accidents and source terms, Dr. Speis said that this should be offered as a contribution to the IAEA as part of the worldwide effort to exchange views and information on the Chernobyl accident. He therefore suggested that the report proposed by the CSNI Bureau be expanded to include further identification of the important information which would be needed in order to make a full assessment of the accident, and that the first draft of the report be offered to the IAEA in order to make the August meeting more fruitful.

17. Dr. Speis then described the United States' own programme of work in this area. The US was planning to produce a report on the Chernobyl accident and its implications in two phases:

- phase 1 would be devoted to the accumulation of facts about the reactor, the accident, environmental consequences, etc.; this part of the report would be prepared jointly by the NRC, DOE, EPA, FEMA, and other agencies;
- in a second phase, NRC would evaluate the implications of these facts.

18. The US Congress had requested that this work be completed before the end of 1986. Dr. Speis closed his remarks by saying that the success of this effort would depend on information provided by the Soviets through the IAEA, and that collaboration with NEA countries in the framework of CSNI would be most useful.

19. The Bureau proposal was supported by several other participants, in particular Mr. Cogné, Prof. Hicken, Dr. Högberg, Mr. van Daatselaar, Mr. Vuorinen and Mr. Weehuizen. They also endorsed Dr. Speis' suggestion to the effect that the ad hoc group should establish for mid-August 1986 a list of questions to be addressed to the USSR via the IAEA.

20. Some concern was expressed by Mr. Vuorinen, Dr. Högberg, Prof. Teague, Mr. Weehuizen and Mr. Woods as to the scope and purpose of the first aspect to be covered by the report proposed by the CSNI Bureau. They felt that it would not be very proper for the report to highlight the differences between RBMKs and power reactors operated in OECD countries, all the more so as there were also (smaller) differences among OECD reactors themselves -- especially with respect to containment -- and that a complete analysis of all these differences would entail a considerable amount of work and need careful

presentation. Rather, the report should highlight the relevant safety characteristics of RBMKs. Also, it would be unwise for CSNI as a technical body to try to formulate technical conclusions and recommendations regarding RBMK reactors without having obtained sufficient information on this type of reactor. The delegates hoped that the USSR would provide all necessary data.

21. Mr. Petrangeli and Dr. Herttrich pointed out in different ways that the main purpose of the report should be to try to explain what had happened at Chernobyl, notably the combination of typical characteristics which had led to the accident. Stressing that it was in everyone's interest to prevent another Chernobyl-type accident, all the more so as earlier RBMKs were believed not to have all the safety features which had been implemented in Chernobyl-4, Mr. Petrangeli and Dr. Herttrich said that OECD Member countries should generate information which it would be useful for the Soviets to consider in future attempts to upgrade the safety of RBMKs. This type of reactor should therefore be examined in the light of the safety philosophy applied to power reactors licensed in OECD Member countries, and the results of this examination should be made available to the USSR.

22. At this point, Dr. Cairns said that OECD countries should be prudent and take care to avoid impairing desirable future Soviet co-operation on international conventions on exchange of information in the event of a nuclear accident and on mutual assistance in the event of a nuclear accident. Mr. Finzi added that OECD countries should not appear as if they were trying to teach the USSR how to prepare a safety assessment report. Mr. Cogné, supported by Mr. Naschi and Prof. Hicken, disagreed with these views and saw efforts by the USSR to export their own difficulties. In his view, the real issue was not to avoid prejudicing information the Soviet Union might be willing to submit at a later date; what mattered was to obtain information rapidly on radioactive release and radiological measurements taken close to the reactor site (less than 100 kms). It was regrettable that, two months after the accident, the USSR had not yet provided even fragmentary information on this issue.

23. Mr. Stadie recalled that the role of NEA was purely scientific and technical and that the report to be prepared by the ad hoc group would be based on these objectives only.

24. Finally, the Bureau proposal as amended in discussion was approved by the Committee with the expansion suggested by Dr. Speis. Important information to be requested from the Soviet Union -- probably in the form of a structured list of questions -- would be identified before mid-August 1986 and made available to the IAEA prior to the meeting planned for the end of the month. As much progress as possible would be made during the Summer on a technical explanation of the Chernobyl accident and of the combination of typical factors which had led to the accident; this part of the report would also contain a brief description of RBMK-type reactors. These reactors would then be examined in the light of the safety philosophy applied to reactors in OECD countries, in order to identify information useful for understanding and evaluating measures taken in the USSR to upgrade the safety of existing and future RBMKs; it was not expected that this part of the work would be examined in any detail before the November 1986 meeting of CSNI as the Committee might wish to discuss further its scope and purpose. Finally, the report would summarise the improvements made to reactor safety in OECD countries since TMI-2.

25. Mr. Giuliani described the arrangements which were being made for the IAEA meeting planned for the end of August. The meeting would last a whole week (25th-29th August), and some 400 participants were expected. The USSR would send a certain number of technical experts to discuss the accident, and it was believed they would give relevant information. At a recent INSAG meeting, though, the Soviet participant had just described the RBMK reactor system, repeating information available in the literature and refusing to answer questions on the accident. In contrast to TMI-2, the Chernobyl accident had taken place in a reactor for which information was not readily available. The IAEA was compiling data on RBMKs, with the assistance of Soviet members of staff. This information would be checked with the Soviet Union for completeness and accuracy prior to the meeting. The IAEA would not be in a position to prepare itself a paper on the accident, but the Agency was working on a list of questions to be addressed to the USSR. The members of INSAG would be asked to play a role in the August meeting, and to provide a summary of its conclusions to the IAEA Board of Governors and the forthcoming General Conference. Finally, Mr. Giuliani mentioned two papers which had been presented by IAEA staff members at a Seminar on Operating Procedures for Abnormal Conditions in Nuclear Power Plants which was being held in Munich.

26. Mr. Cogné questioned the usefulness of a meeting as large as the one planned for the end of August. He also said that, in the absence of a detailed written description of the accident and of its consequences in the vicinity of the plant, distributed well in advance, participation would offer little interest. He was supported in this statement by Prof. Hicken.

27. Mr. Cogné then stressed that, although the entire field of reactor safety should not be reconsidered as a result of the Chernobyl accident, a number of lessons were to be learned. He therefore proposed the following programme of work for CSNI, in addition to the proposal made by the Bureau and approved earlier in the meeting:

- the crisis had been greater than most experts had predicted (although health consequences seemed to be smaller than expected); this would need to be considered carefully, both at national and international levels; the Committee should devote time to think about Chernobyl-type crises and their management;
- the use of the Incident Reporting System should be reinforced; in particular, the most significant incidents, which could be precursors of severe accidents, should be carefully analysed (as was done a few years ago);
- the role of the containment should be defined more clearly; while in the past this role was entirely in the realm of design basis accidents, the current attitude was to consider that the containment should withstand hydrogen combustion, fission products released in a core melt accident, etc.;
- fission product transfer modelling should be understood better; radiological measurements made during the weeks following the Chernobyl accident should be compiled and compared, as a first step;
- the whole question of reactor safety R & D in OECD Member countries should be discussed again by CSNI (against a background of decreasing safety budgets in some countries).

28. Mr. Cogné's suggestions were endorsed by the participants in the meeting; the following decisions were taken:

- Mr. van Daatselaar mentioned that a meeting on feedback of operating experience had been held in May; when he would present a report on this at the next meeting of CSNI, he would recommend that a few selected incidents be analysed in detail;

- the Senior Group of Experts on Severe Accidents would be invited to discuss the role of containment; members would be helped in this by the conclusions of the Task Force on Containment Performance, whose report would be completed during the Autumn;
- PWG4, and in particular its Group of Experts on Accident Consequences, had already discussed the question of collection and evaluation of radiological data from the Chernobyl accident [SEN/SIN(86)30]; a plan of action would be submitted to CSNI in November;
- Mr. Sato, Chairman of the ad hoc Group on Priorities in LWR Safety Research, said he would be willing to continue discussion of this question in his group; the Secretariat had undertaken to collect information on safety research budgets in the Member countries.

29. Mr. Finzi said that the CEC had established a Task Force on the consequences of Chernobyl, associated R & D and other actions. This would cover the data collected by the CEC on the atmosphere and the ground since the accident, atmospheric transfer codes, foodchain contamination, etc. Mr. Finzi stressed the importance for the CEC to participate in the work of CSNI and expressed satisfaction with the spirit of collaboration between the Commission and NEA in this area.

30. As a subject for consideration for possible future activities, Mr. Dopchie reminded the meeting that human factors had been mentioned as one of the likely causes of the Chernobyl accident and that these should also be an important consideration with respect to the export of nuclear plants as the human, educational, and cultural context varied from country to country. Should the design of reactors intended for exportation be identical to that of domestic reactors?

31. In reply to questions, Mr. Stadie confirmed that the Bureau of the Steering Committee for Nuclear Energy would be informed in September 1986 of the decisions taken by CSNI. These are summarised in Annex I.

Annex I:

Summary of the Decisions Taken at the Meeting

The Committee decided that the ad hoc group of experts, which had prepared a report on the current technical knowledge regarding the Chernobyl accident, augmented by the Chairman of the Senior Group of Experts on Severe Accidents and the Chairman of the Special Task Force on Source Terms, should continue its work with a view to preparing a report covering the following aspects:

- identification of important information needed from the USSR in order to to make a full assessment of the accident; this part of the report -- perhaps in the form of a structured list of questions -- will be made available to the IAEA in advance of the Chernobyl meeting to be held in Vienna at the end of August 1986;

- brief description of RBMK reactors and their safety characteristics, and explanation of the combination of factors which are believed to have played a role in the accident; as much progress as possible will be made during the Summer on the technical explanation of the accident;

- examination of RBMK reactors in the light of the safety philosophy applied to reactors in OECD countries with a view to identifying information useful for understanding and evaluating measures taken in the USSR to upgrade the safety of existing and future RBMKs; only preliminary consideration will be given to this aspect during the Summer; CSNI will discuss further the scope and purpose of this work at its November meeting;

- summary of the improvements made to reactor safety in OECD countries since TMI-2.

A first draft of the report will be prepared by the ad hoc group before mid-August 1986, covering primarily the first two aspects mentioned above. An intermediate report will be completed for consideration at the next regular meeting of CSNI to be held in November 1986. To the extent possible, the ad hoc group will work by mail and telephone; if necessary, a meeting will be held in late September or October.

The Committee also decided to propose strengthening current CSNI activities in the following areas:

- reflection on Chernobyl-type crises and their management;

- Incident Reporting System: the data base should be expanded and the analysis deepened, notably by examining a few significant incidents in detail each year, in particular with a view to identifying possible precursors to severe accidents;

- reflection on the role of the containment and discussion of its ability to cope with accidents beyond the design basis; this work may include studies and examination of current R & D programmes;

- modelling and assessment of the consequences of reactor accidents;

- review of current reactor safety R & D in OECD Member countries, notably in the light of budgetary restrictions.

Annex II:

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11. ?

ACTION?

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Telephone: 01-930 5454

~~Nixon will supply a letter for me to send.~~

8th August, 1986

Dr. J. H. Gittus,
Director,
SRD,
Wigshaw Lane,
Culcheth,
Warrington.
WA3 4NE

✓ cc MR Hayns } any
W Nixon } comment pl.

Dear John,

Chairman's Letter to Employees on Chernobyl

In view of the continuing interest in the Chernobyl accident on a number of fronts, I think that you will be interested in the comments in the enclosed copy of Harry Shalgosky's letter of 24th July about the Chairman's Letter to employees.

Yours sincerely,

Frank

F. CHADWICK

c.c. Mr. M. A. W. Baker
Mr. A. W. Hills
Mr. W. McMillan

Ch/F JHS

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To: Dr. J.H. Gittus (2) ✓ 1 → MRH
Mr. D. Smith
Mr. J. Appleby
Mr. J.G. Collier
Dr. E.W. Carpenter
Mr. J.D. Young
Dr. J.K. Wright

RP 3078

Our ref NO/BE

Your ref

Date 8 August 1986

Herewith Chernobyl documents provided by IAEA to INSAG members. These items were produced rapidly by Agency staff and are obviously short of editing, but nevertheless are of value. The sections headed Chapters 2, 3, 6, 9 and 10 are translations from the Russian of a book by Dollezal and Yemilianov published in Moscow in 1980. The item called "Chernobyl 4" was produced by Agency staff.

Yours sincerely,

B Edmondson

1 → MRH.

Phil Bonell. 1?

from J. Gittus

(re updating AEX(86)50)

JAG 13-8

Note for the Record

Approach from BBC Newsnight for Assistance in the Programme of 8 August 1986.

A Mr Richard Clemmow telephoned Dr Gittus' office to say that the BBC have obtained a Russian television documentary programme on the Chernobyl accident which they intend to show this evening and they wished to have Dr Gittus view the documentary and then appear in a discussion afterwards. Dr Gittus is on leave and Mr Clemmow was passed to me.

Mr Clemmow explained that they were seeking advice on whether we thought the information being presented to the Russian people was realistic. First of all from the point of view of whether the consequences in terms of dose and effects on crops and the like were being under or over played and secondly as to whether the technical information given concerning the cause and progress of the accident seemed reasonable. It was my view that we should not appear on this programme for the following reasons:

1. Insufficient information was available prior to the appearance because of the extremely short timescale given. (The fact that they were asking me to travel down to London from Warrington only added to the difficulty on this score). No information was made available as to when this programme had been presented in Russia or anything concerning its background or its reception in the Soviet Union.

2. Concerning information on the accident itself, the timing could hardly be worse because we have been promised the full many hundred page Russian report by 15 August. It would be very unfortunate if we were asked to comment on Russian statements in what might well be a heavily propaganda-biased programme which could then be shown to be ill-founded on such a short timescale after the screening of the programme.

3. We would find ourselves almost inevitably in the position of arguing that the Russians were playing down the accident and I do not believe that it would be a viable position for anyone being interviewed to try and either argue that what the Russian people had been told was wrong when we ourselves are not in the position to know precisely what the right answer was.

For these reasons I put off agreeing until I had had a chance to discuss this matter with others. I managed to speak to Dr Gittus whilst on leave, and he was of the opinion that we should not treat this with high priority and that he himself would not wish to appear. I also spoke to contacts in the CEGB to see whether they had been approached to appear because I had been given no information as to who else might be on the programme and they confirmed, first of all that they had not been approached at that time and that their response was likely to be negative too because of the proximity of the Vienna meeting.

I attempted to contact Bill McMillan in LHQ and Peter Vey of the CEGB but they were both out to lunch and because of the sort time available I telephoned Newsnight and told them that because of the very short notice and the proximity to the Vienna meeting, that we must regretfully decline their invitation.

The Newsnight team then said that they would contact CEGB to see if they would contribute and I left it at that. I got the impression that the Newsnight team were not unduly unhappy that we had turned them down.

After this I managed to speak to Bill McMillan to appraise him of the situation and to forewarn CEGB that they might be approached by this person from Newsnight.

There was a suggestion that the reporter for this programme who will be Steve Bradshaw might wish to contact me during the afternoon for background, unattributable information concerning our view of what might have caused the accident and I agreed that I would speak to him on that basis.

M R Hayns

cc Mr R Simeone
Mr M A W Baker
Dr J H Gittus
Mr W McMillan

8 August 1986

<u>Note Added</u>

I now understand that the CEGB have reluctantly agreed to field Brian Edmondson on the Newsnight programme. Further, the programme is being transmitted in Russia this evening - only edited highlights will be shown on the Newsnight programme.

CENTRAL ELECTRICITY GENERATING BOARD

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RP 3078

To: Mr. J. Appleby
Dr. E.W. Carpenter
Dr. J.H. Gittus ✓
Mr. D. Smith
Mr. J.D. Young

Our ref NO/BE Your ref Date 8 August 1986

You should note the enclosed. I received it from John Gaunt with the caveats indicated in his letter. He has agreed that you should see these documents, but that I should insist you take account of the privileged position. The problem is that this material is not public in the US as yet, and there would be extreme difficulty if it became known that it is available in the UK. Eventually of course such material will be published, but until then I would be grateful if you would restrict its use appropriately.

Yours sincerely,

B Edmondson

✓ Doc to MRH

7th August 1986

9622 C ✓

To: Lord Marshall
Mr. J. G. Collier
Dr. J. K. Wright
Mr. L. M. Davies
Dr. E. W. Carpenter
Mr. H. McDonald
Mr. J. Appleby
Mr. R. Coleman

a MRH
JE.

From: P. N. Vey

IAEA Post-Chernobyl Conference

I set out below aspects of administration and communications support for the CEGB team attending the IAEA Conference and which also may be of interest to the UK delegation generally.

I will be taking my secretary Miss Karen Lock. I understand that an additional CEGB secretary will also be going. I have asked Travel Section to extend my accommodation at the Imperial Hotel to include a sitting room which can be used as an office by the two secretaries and also to investigate the provision of typewriters. Travel Section will also establish what photocopying facilities are available for us in the hotel. The two secretaries will need to take paper/carbons, notebooks etc. The two secretaries will of course be available to provide secretarial support for members of the UK delegation. In total, therefore, including Dr. Gittus' secretary, there should be ample secretarial support.

The Editor of Power News, Dick Coleman, will also go to Vienna. This is because there will be a need to give coverage to the Conference in Power News and also to provide me with Press Officer support.

Communications

The Department of Energy has established that there are, surprisingly, no facsimile facilities in the IAEA building but a facsing facility is available in the UK Mission offices, five miles away. There is a regular car run between the IAEA building and the Mission offices and material for facsing can be sent in this way. The offices can be manned in the evening provided the Mission is advised each morning of this need. The Mission have been given the telephone numbers of the facsimile receiver in the CEGB Press Office (01 634 6628), that availabile to Mr. L. M. Davies (01 634 5747) and this communications link has been tested. If important information has to be sent to CEGB on August 25th (a Bank Holiday in the UK), Mr. A. Clark or one of his colleagues in Nuclear Co-ordination Group will be advised by telephone at home as will the Duty Press Officer. Information, once received in Sudbury House, can be transmitted by the Nuclear Co-ordination Group to the Chernobyl Technical Review Group Network and by DIPA on the British Telecom Gold System to the information departments of interested organisations.

The Department of Energy is of course making its own arrangements to communicate information to Thames House, but it is possible that the nuclear industry and the Department will wish to communicate different aspects of the Vienna Conference.

The Media

Although we do not know for certain, it is unlikely that the media will be allowed to attend either the plenary sessions or the working group meetings. It is likely that the Agency with the Russians participating will hold a Press Conference after the plenary session on 25th August and on Friday 29th August. The Agency are also considering daily briefings possibly without Russian participation. Accredited journalists will be allowed into the IAEA headquarters where the meeting is being held. Because they have to be accredited we will know in advance which UK journalists will be covering the Conference (note the list should be made available to DE and CEGB Press Office).

It was agreed at the Chernobyl Technical Review Group meeting on Tuesday that it should be made known to UK journalists that the UK delegation is available for comment and reaction. This will be arranged on an informal basis as appropriate through Mrs. Shah (DE) and myself. It is also possible that as journalists file their stories their offices in London will seek additional comments and reactions from the Industry. Where possible they should be referred back to contact the UK delegation since they will have the most up-to-date and accurate information on what has been discussed at the Conference.

The delegation will wish to be kept informed of UK media coverage of the Conference. This will be done by myself telephoning the CEGB Press Office at the start of each day. UK papers are also available in Vienna the same day.

I shall try and arrange a visit to Vienna during the week before the Conference to meet with appropriate members of the IAEA's Information Division to brief myself on media arrangements. Mr. L. M. Davies will go to Vienna on Thursday August 22nd for a meeting with Agency officials on Friday August 23rd. Mr. Davies will be available to meet Lord Marshall when he arrives in Vienna sometime on Saturday 24th. I plan to travel to Vienna on Sunday August 25th.

Bleepers are being made available for Mrs. Shah, Messrs. Coleman and Davies and myself for use during the Conference.

I shall be staying at the Hotel Imperial, 16 Kaerntnerring, A-1015 Vienna ([0222] 651765) together with other CEGB staff. Mrs. Shah will be at ETAP Hotel Belvedere, Am Heumarkts 35-37, A-1030 Vienna ([0222] 752535.

Copy to Mr. G. H. Hadley
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covering RESTRICTED

7 August 1986

DECLASSIFIED

Mr E Ryder
NII
Thames House South

✓cc M R Harris

Dear Eddie,

You may like to see the attached minute from FCO sources.

Yours ever

D I MORPHET

cc Dr Edmondson, CEGB
Dr Gittus, AEA, Culcheth

Reference...

DECLASSIFIED

Mr Longrigg, Soviet Dept

CHERNOBYL: FIRINGS AND HIRINGS

1. This minute lists and comments on the personnel and organisational changes made by the Politburo at its special session when it considered the report of the Government Commission (Pravda, 20 July reported in Moscow Telno 894).

2. People

(i) Out

a) E V Kulov (57), Chairman of the State Committee for the Supervision of Safety in the Atomic Energy Industry. The Committee was set up in 1983 with Kulov at its head, apparently to supervise all stages of the process of nuclear power generation, from design of reactors to their operation. Both Kulov and the Committee have always kept a very low profile. After the Party Congress (March 1986) we were struck by the fact that Kulov was one of only 4 members of the Council of Ministers not to be elected to the Party's Central Committee. We presumed that this was because all four were due to be retired or sacked. The other three duly were in April/May, but Kulov has only now got his marching orders. The inference must be that there were grave doubts about Kulov's competence before the Chernobyl disaster and that he was probably about to be replaced when it occurred. Kulov was a former Deputy Minister of Medium Machine Building (see para 4 below).

b) G A Shasharin (51), described as Deputy Minister of Power and Electrification USSR, though we have an authoritative reference to him as First Deputy Minister (for Questions of Atomic Energy - Collection of Government Laws No 22/1983). At all events he was evidently the senior man under Maiorets (see below) concerned with nuclear energy.

c) Meshkov, First Deputy Minister of Medium Machine Building (see para 4 below). We think he is identical with A G Meshkov, formerly (until at least 1980) a Deputy Chairman of the State Committee for the Use of Atomic Energy.

d) I Ya Emelyanov, Deputy Director of the Scientific Research and Design Institute of Power Engineering (according to the Neue Zürcher Zeitung the Institute was responsible for the development of Chernobyl-type reactors) and a Corresponding Member of the Academy of Sciences. Emelyanov was present at the first Soviet press conference following the disaster on 6 May and then and subsequently answered technical questions from Western journalists. He was at one point, therefore, evidently not slated for removal. Given that Emelyanov

/is

is a leading specialist in atomic energy and in the RBMK reactor in particular, the obvious conclusion to be drawn from his removal would be that the investigation had indeed found the fault to be in the reactor design. Since however the Soviet authorities have ruled this out it must be inferred that Emelyanov was in some way implicated in the unauthorised experiment which led to the explosion. (This would give a degree of credence to an item in the Dutch press, picked up by the emigre paper Russkaya Mysl, recording a Polish scientist as having been told in Dubna that Aleksandrov, President of the Academy of Sciences and himself a nuclear engineer, had authorised the experiment.)

Might not..

e) V P Bryukhanov, former Director of the Chernobyl power station. Like Emelyanov, Bryukhanov was initially at least not on the hit list. He was referred to as Director in a neutral piece of reportage in Komsomolskaya Pravda on 15 May, but by 15 June (Pravda) he was already the "former" Director. Now he has been expelled from the Party, which makes it look as if he is one of those against whom criminal charges might be preferred. The same may go for the former Chief Engineer, N Fomin, and Deputy Directors R Soloviev, I Tsarenko and V Gundar, all of whom were accused in Pravda of 15 June of dereliction of duty - though only in the context of the aftermath of the accident.

(ii) Pending

A I Maiorets (57), Minister of Power and Electrification USSR, was deemed to have "deserved removal from his work", but was let off with a warning, since he had not been in the job long. Maiorets (an electrical engineer, not a nuclear scientist) had been Minister for just over a year, since March 1985, having previously been a successful Minister of Electrical Engineering. Ironically, on or around the same day as the Politburo session on Chernobyl, Maiorets' successor at that Ministry, G P Voronovsky, who had been in his new office no longer than Maiorets, was retired (ie sacked - he is only 62) following criticism for errors which were minor in their consequences compared with Chernobyl.

(iii) In

a) N F Lukonin (56), appointed Minister of the new Ministry of Atomic Energy USSR (Pravda 22 July). According to the brief TASS biography Lukonin was appointed Director of the Leningrad nuclear power station in 1976 and of Ignalina (in Lithuania) in 1983. Both have RBMK-type reactors.

/b)

b) E N Pozdyshev (about 50), new Director of Chernobyl nuclear power station. Like Lukonin, he has worked in RBMK stations - Leningrad, Kursk and latterly Smolensk, of which he was Director until summoned to Chernobyl "in the second half of May" (Pravda, 22 July).

3. Undoubtedly this list does not exhaust the personnel changes resulting from the accident. More heads can be expected to roll: the Politburo enjoined 3 Party bodies to look for further culprits: the Committee of Party Control, the Ukrainian Central Committee and the Moscow Town Party Committee (because it supervises the Party Committees of Moscow-based Ministries and Research Institutes - another illustration of the range of its influence and that of its First Secretary, Eltsin - see Mr Murrell's letter of 24 July (not to all) on Eltsin's speech to the Moscow Gorkom Plenum).

4. Institutions

(i) Government

a) The newly-formed Ministry of Nuclear Energy, USSR, is an All-Union Ministry, ie there are no equivalent Ministries at the level of Union Republics. The Ministry for Power and Electrification, previously responsible for Chernobyl, is a Union-Republican Ministry, and there is for example a Ministry of Power and Electrification of the Ukraine (whose Minister, Sklyarov, is currently visiting the UK). All nuclear power stations will thus be controlled from now on from the centre (though it is not clear how much control Sklyarov and his Ministry had over Chernobyl - the lack of scapegoats from his Ministry suggests that it was not great). We presume that the bulk of the new Ministry's responsibilities will be hived off from the Ministry of Power and Electrification, though it may also absorb some or all of the State Committee for the Supervision of Safety and the State Committee for the Use of Atomic Energy (cf para 3J of Moscow TUR. We would, however, expect the increased international load on that Committee to give it plenty of business - Petrosyants is currently heading the Soviet delegation at the experts' talks on CTB with the US, and the IAEA special session is coming up. And it has escaped without censure over Chernobyl).

b) The Ministry of Medium Machine Building, as one of the 9 defence industry ministries, is rarely in the public firing line, and the sacking of its First Deputy Minister is a considerable stain on its escutcheon, made worse by the fact, noted above, that one of its former Deputy Ministers, Kulov, has also been sacked. It is intriguing that the Minister himself has been spared, though in his case newness to the job cannot be prayed in aid: he is E P Slavsky, Minister since 1957 and 87 (sic) years old. One can only speculate as to what powers of inertia or patronage keep him in place.

/(ii)

(ii) Party. The only reorganisation has been the creation of the post of Party Organiser (partorg) of the CC, CPSU in Party organisations of nuclear power stations "to strengthen Party influence". The Partorg is an unusual institution, which according to the Soviet Encyclopaedia belongs to history: it existed between 1933 and 1961 in enterprises and construction sites which were of special importance to the economy. Its re-creation is self-evidently a centralising measure: the Partorg at Chernobyl, for example, will presumably report direct to the Central Committee, bypassing the usual geographically based Party channels, which lead up through the Ukrainian Party organisation.

5. Conclusions. The personnel measures are quite rigorous by Soviet standards - dismissals reached into a defence industry Ministry and the Academy of Sciences - though Ministers with high Party status, ie membership of the Central Committee, have been spared. It is noteworthy that no high level Party officials as such have been sacked, but this was to be expected at this stage - the initial price is usually paid by the executive arm. The appointment of a specialist in RBMK reactors as the Minister with overall control of nuclear energy confirms that this type of reactor will not be abandoned. The organisational measures show a strongly traditional bent - the creation of new layers of administration and a reassertion of central control. This is in flat contradiction with the declared policy of the leadership to encourage devolution of responsibility. At the Party Congress, Ligachev boasted that the Politburo under Gorbachev had taken unconventional (nestandartny) steps, a term which has become popular in the Party press to describe the new type of leadership style. It must be said, however, that in its organisational measures following Chernobyl, as in its initial publicity policy, the leadership has reverted to type.

MB. Nicholson

M B Nicholson
Soviet Section
Research Dept
OAB 3/76 210 6255

1 August 1986

cc: Mr Kos, Information Dept
NED ✓
PUSD
Mr Wordsworth, Assessments Staff
Miss M Lewis, DI 72A, MOD
Mr Murrell, Moscow
UkMis Vienna

ORGANISATION FOR ECONOMIC
CO-OPERATION AND DEVELOPMENT

NUCLEAR ENERGY AGENCY

RESTRICTED

Paris, drafted: 1st August 1986
dist: 6th August 1986

NE(86)16
Scale 4

Or. Eng.

DECLASSIFIED - FOR INFORMATION

STEERING COMMITTEE FOR NUCLEAR ENERGY

ACTIONS TAKEN BY NEA IN THE FIELD OF NUCLEAR SAFETY FOLLOWING THE CHERNOBYL ACCIDENT; PRELIMINARY ASSESSMENT OF THE LIKELY IMPACT ON THE CSNI PROGRAMME

I. SPECIAL SESSIONS OF THE COMMITTEE ON THE SAFETY OF NUCLEAR INSTALLATIONS (CSNI)

1. Following consultations with the Chairman of the Steering Committee, the Bureau of the Committee on the Safety of Nuclear Installations (CSNI) and individual members of that committee, a Special Meeting of the CSNI was held on 9th May 1986. The meeting was devoted to a first review of the possible impact on OECD countries of the accident which occurred at the Chernobyl nuclear power plant in the USSR. Some members of the Committee on Radiation Protection and Public Health (CRPPH), from the countries most affected, were invited to attend the meeting.

2. The main objective of the meeting was to allow CSNI to make a preliminary assessment of the impact of the Chernobyl reactor accident in OECD countries. The committee noted that the RBMK reactors (Chernobyl) were substantially different from those in use in OECD countries and on the basis of preliminary information it was believed that they would not be licensable in our Member countries. In particular there was general agreement that the concept of RBMK reactors presented several different safety problems which did not seem to have been solved with a stringency comparable to that required for reactors built in OECD Member countries.

3. The meeting also emphasized the value of the long-standing and intimate co-operation undertaken within NEA countries in the nuclear safety field during the past twenty years, and the importance of learning from operating experience. There was a large consensus to recommend a further integration of safety efforts in the OECD area, and general agreement that the exchange of information on nuclear accidents and incidents should be enhanced, and that NEA should act as a clearinghouse for fast exchange of technical information between OECD countries during nuclear emergencies. The Committee went on to emphasize that this type of co-operation should serve as an example for worldwide co-operation in this field.

4. Preliminary reports were exchanged on radiological measurements in those countries most affected by the fall-out, as well as on implemented or envisaged counter-measures. The range of data presented spanned from very small levels above normal to significant fractions of national emergency reference levels, depending on locations and measurements. It was found that the data available were still too preliminary to allow any definitive assessment of the radiological impact and the potential health consequences of the accident. Several participants thought, however, that no traceable health effects were to be expected in their country. It was suggested that the CRPPH should, in due course, carry out a comprehensive review of the radiological and health impact of the accident, and consider the lessons learnt.

5. Following the Special Session, a press conference was arranged, with the participation of the Bureau of CSNI, some key committee members, and the Secretariat. A press communiqué, of which the Steering Committee received copy, was read and commented at this press gathering which was attended by some 120 representatives from the international trade and general press, radio and television networks.

6. A further Extraordinary Session of CSNI was held on 27th June 1986, in conjunction with a regular meeting of the CSNI Sub-Committee on Licensing, with the objective of reviewing all available information on the initiation and progression of the accident and discussing its possible impact on the Committee's programme.

7. Various national reports compiling available information on the accident were discussed. It was found impossible, however, to draw any lessons at this stage regarding the safety of reactors built in OECD countries, recognizing that the safety conditions were very different and the accident itself was insufficiently known. However, the need clearly emerged for better management of large nuclear crises in future. Availability of detailed information, such as on reactor characteristics, accident sequence and environmental effects was regarded as an essential prerequisite.

It was noted in this connection that the IAEA would host a meeting in late August, at which Soviet authorities were expected to provide information.

II. INTERIM ACTIONS

8. At its Special Meeting on 9th May, CSNI decided that interested countries should keep in permanent contact, in order to exchange views on the evolving situation. As a result, an Ad hoc group of experts was formed which, in the first instance, was charged with collecting all relevant information about the Chernobyl reactor, the accident initiation and progression, as well as radiological data. A report on the current state of knowledge was presented by this group at the second special meeting of the Committee on 27th June.

9. At that meeting, CSNI also decided that the Ad hoc group of experts remain in existence until the plenary meeting of the Committee at the end of November. The group would be augmented by the chairman of the Senior Group of Experts on Severe Accidents, and the chairman of the Special Task Force on the Source Term, and was charged with the following tasks:

i) to identify important information needed from the USSR in order to make a full assessment of the accident. For this purpose a structured list of questions should be prepared by the end of July, which would be transmitted by the NEA Secretariat to the IAEA in advance of the Chernobyl meeting to be held in Vienna at the end of August 1986;

ii) to prepare a brief description of the RBMK reactors and their safety characteristics and to explain the combination of factors which are believed to have played a role in the accident. This part of the work would begin after the Information Meeting at IAEA during the summer;

iii) to examine RBMK reactors in the light of the safety philosophy applied to reactors in OECD countries, with a view to identifying information useful for upgrading the safety of existing and future RBMKs. Only preliminary consideration would be given to this aspect, prior to the plenary meeting of CSNI in November;

iv) to summarise the improvements made to reactor safety in OECD countries since the TMI-2 accident.

III. PRELIMINARY SUGGESTIONS FOR FUTURE ACTIONS

10. At its session on 27th June, the Committee decided to strengthen current activities in a number of areas:

i) The Committee intends to reflect on Chernobyl-type crises and their management. This reflection would be initiated by a number of consultant reports which would provide a basis for a special meeting of CSNI, or its Sub-Committee on Licensing, during 1987.

ii) The Incident Reporting System (IRS) should be strengthened. As a first step, the data base should be expanded by covering a wider range of incidents, including reactor scrams. Reporting delays should be reduced and improved means of communication should be envisaged (e.g. telefax). The analysis of the IRS reports should be deepened, notably by examining the more significant incidents in detail. In addition, all reports should be carefully scrutinised to identify possible precursors of severe accidents and general problems should be examined in different working groups. In order to accomplish this task, the competence of the Nuclear Safety Division should be extended in this area, and the NEA Data Bank enabled to support the data handling efforts.

iii) The Committee should appoint a multidisciplinary group of senior experts to reflect on the role of containment in nuclear safety. This assessment would cover the containment's ability to cope with accidents beyond the design basis and may also include studies and reviews of current R&D programmes. If needed, joint projects could be envisaged.

iv) In the light of the outcome of the meeting of the CSNI Group of Experts on Accident Consequences on 12th June 1986, work should be undertaken to improve the modelling and assessment of the consequences of reactor accidents on the basis of the data compiled.

v) A special group of CSNI should review current reactor safety R&D in OECD Member countries and make suggestions on how best to carry out the necessary work in the light of budgetary restrictions. Special emphasis should be put on developing international projects in which a maximum number of Member countries participate.

11. It should be emphasized that the above list of preliminary suggestions will be further refined - and amplified if neceesary - for discussion and possible adoption at the next meeting of CSNI in November, having regard to their man-power and budgetary implications. The resulting proposals would be submitted to the Steering Committee at the earliest opportunity.

12. The Steering Committee is invited:

i) to take note of the actions taken by CSNI in the field of nuclear safety following the Chernobyl accident; and

ii) to endorse the preliminary suggestions made by CSNI for strengthening nuclear safety co-operation among NEA Member countries.

Action ... Wed

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12·8

CONFIDENTIAL

Mr. D.M. Levey

4pm Wed
Ring AEJE on hols

c.c. Mr. R.N. Simeone
Dr. J.H. Gittus
Mr. F. Chadwick
Mr. B.C. Carpenter
Dr. M.R. Hayns, SRD
Dr. J.E.R. Holmes, Winfrith
Dr. W.M. Lomer, Culham
Dr. G.G.E. Low
Dr. T.N. Marsham, Risley

Chernobyl: Post Accident Review

Thank you for copying your letter of 4th August addressed to John Gittus. Following our telephone conversation of to-day, I write to confirm that I could make a presentation at Vienna on the Windscale fire of 1957, assuming that this would be helpful in resolving the difficulties with the Russians to which you refer.

As I am going on leave tomorrow for two weeks, it would not be possible to provide a written presentation before the meeting, but I would have no difficulty in making an oral presentation dealing mainly with the environmental aspects of the Windscale accident and based entirely on already published material. I will provide myself with a suitable set of view-graphs/slides which I will take to Vienna.

Barbara Williamson

pp A.E.J. Eggleton,
Atmospheric Pollution Group,
Environmental and Medical Sciences Division,
Building 551,
Harwell.

Ext. 4722/5530

5th August 1986.

(Dictated by Dr.Eggleton and signed in his absence)

ACTION

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CONFIDENTIAL

DECLA

Dr. J. Gittus

IAEA MEETING IN VIENNA - CHERNOBYL POST-ACCIDENT REVIEW

After our several unsuccessful attempts to speak to each other, I thought it desirable to put my thoughts in writing.

You will by now, I am sure, be aware that my attendance at the conference has been approved and I intend to travel to Vienna on flight BA600, 1000 hours, from Heathrow on the 24th August. I understand the whole of the British delegation will be accommodated in the Hotel Belvedere.

I learned today that the Russians are requesting that the meeting should not be confined to discussions of the Chernobyl accident, but also should include other accidents in the West. I understand there is political resistance to this Russian requirement but, if it would be useful, I am prepared to make an oral presentation mainly on the environmental effects of the 1957 Windscale fire. This would be based on published material and I will bring with me appropriate view-graphs or slides.

Thank you for sending me the two papers on contamination and decontamination aspects of the Chernobyl accident. I found them comprehensive and a useful summary of the position, with the proviso that, not unnaturally, our recent work is not included. I therefore take this opportunity to enclose a copy of a paper which was presented at a workshop on methods for assessing the off-site radiological consequences of nuclear accidents, held in Luxembourg in April 1985. The paper describes the joint programme on urban decontamination funded by UKAEA, NRPB and NII. We were responsible for the work on forced decontamination, while NRPB were responsible for the preparation of some of the test aerosols and natural decontamination. The work was concerned entirely with removal of radio-caesium from urban surfaces, caesium-134 and caesium-137 being considered the most important isotopes for times beyond a few months.

Two important conclusions from the work were:-

(1) That the nature of the aerosol containing caesium was not very important, since once the surfaces had been wetted the caesium behaviour was similar to that when it was applied directly in solution.

(2) Dilute solutions of ammonium salts were surprisingly effective in reducing levels of contamination.

Depending on the nature of the urban surface material tested, removal of up to 90% of the caesium activity could be obtained by simply spraying on a solution 0.05 molar ammonium nitrate. It would appear that the drastic methods for decontamination described previously in the literature can be avoided in many cases. It follows from these results that the emphasis on particulate contamination in both the literature and your review papers is probably unrealistic for the Chernobyl situation. We feel that these rather simple experiments can be of considerable value to the Russians and one hopes that they have spotted our paper in the literature, though press reports of decontamination procedures being used suggest this may not yet be the case.

I have, so far, received comparatively little information on the Vienna meeting and, in particular, I am not clear what may be expected of me as a UK representative. Unfortunately, I shall be on leave from tomorrow, 6th August, returning on the 21 August. However, should you wish to contact me during that period I shall be in Scotland and can be reached by telephoning Fossoway (05774) 339. You are more likely to reach me if you 'phone early in the day. Any less urgent information can be posted to my office.

I look forward to seeing you in Vienna.

Barbara Williamson

for A.E.J. Eggleton,
Atmospheric Pollution Group,
Environmental and Medical Sciences Division,
Building 551,
Harwell.

Ext. 4722/5530

5th August 1986.

(Dictated by Dr.Eggleton and signed in his absence)

Enc.

The Uranium Institute

Twelfth Floor, Bowater House, 68 Knightsbridge, London SW1X 7LT Telephone 01-225 0303 Telex 917611

IB(86)8
5.8.86

INFORMATION BULLETIN

Seminar on the Background to Chernobyl

At the suggestion of two producer members, a special seminar is being arranged as part of the annual week of meetings, with the purpose of giving people who are not themselves reactor experts sufficient of the scientific and engineering background to be able to understand the arguments relating to Chernobyl. It will take place in the Nash Room, Institute of Directors, Pall Mall, London SW1, starting promptly at 0900 hours on Tuesday 2 September. The first half-hour is intended for those with no previous knowledge of reactor physics. The programme is still evolving, but at the time of issue of this Bulletin it seems likely to take the form shown on the next page.

All members are invited to attend the seminar. It would help the organisers if members intending to be present could send a telex to the Secretariat registering that intention, preferably before August 20th.

Lunch will be served after the Seminar, and before the Annual General Meeting. MEMBERS REQUIRING LUNCH SHOULD TELEX THE SECRETARIAT TO RESERVE A LUNCHEON PLACE BEFORE 20TH AUGUST.

Meeting programme

The programme during the week of the Annual Meeting is as follows:

Monday 1 September	0900	Executive Committee, Spears Room, Institute of Directors, Pall Mall
Monday 1 September	1400	SD, ITU and NEPA Committees, in the Burton, Waterloo and Spears rooms respectively
Tuesday 2 September	0900	Seminar: Background to Chernobyl
Tuesday 2 September	1255	Buffet lunch for all members, Burton Room, Institute of Directors
Tuesday 2 September	1415	Annual General Meeting, followed by Council in Mountbatten Room, Royal Automobile Club, Pall Mall (200 metres west of IOD)
Tuesday 2 September	1830	Symposium Reception, British Museum
Wednesday 3 September	0900 to 1730	Symposium technical sessions
Thursday 4 September	0900 to 1730	Symposium technical sessions
Thursday 4 September	1920	Reception, Guildhall followed by Banquet

PROVISIONAL PROGRAMME OF SEMINAR ON THE BACKGROUND TO CHERNOBYL

0900	INTRODUCTION TO REACTOR PHYSICS	TP + IG
0935	THE SAFETY OF GAS-COOLED REACTORS	JW
1005	THE SAFETY OF PRESSURIZED WATER REACTORS	PT
1050	COFFEE	
1105	HEALTH AND ENVIRONMENTAL PHYSICS	JD + JG
1145	CHERNOBYL - WHAT HAPPENED AND ITS IMPACT	JG + PT
1200	THE IMPACT OF THE ACCIDENT ON REACTOR DESIGN AND MANAGEMENT	PT + JG
1225	DISCUSSION	
1250	SEMINAR ENDS	

The following have agreed to take part:

Mr John Dunster, Director, National Radiological Protection Board, UK
Dr Ian Gibson, AEE, Winfrith, UK
Dr John Gittus, Safety and Reliability Directorate, UKAEA
Mr Terence Price, UI (Convenor)
Dr Pierre Tanguy, EdF
Dr John Wright, CEGB

~~ACTION~~ 2-9 11-8

The Uranium Institute

Twelfth Floor, Bowater House, 68 Knightsbridge, London SW1X 7LT Telephone 01-225 0303 Telex 917611

4 Sept Dinner - Guildhall
7.30pm

7th August 1986

Dr John Gittus
Safety and Reliability Directorate
United Kingdom Atomic Energy Authority
Wigshaw Lane
Culcheth
Warrington WA3 4NE

Dear John

UI Seminar on The Background to Chernobyl, 2 September 1986

Having now had discussions with all the people who will be taking part in this seminar, I feel that we have arrived at a reasonable division of tasks. I have therefore sent out the enclosed Information Bulletin to Institute Members.

I will try to complete the text of my own contribution before I go to Vienna on 24 August, and if so I will let you have a copy. The intention is at least to mention the concepts needed during the remainder of the morning.

As regards illustrations, several speakers have opted for transparencies projected with an overhead projector. If you need any other equipment (16mm film, or 35mm slides) this can be provided if you let me know in good time. No

I am most grateful to you for agreeing to help the Institute in this way, and look forward to seeing you in the Nash Room of the Institute of Directors a little before 0900 hours on Tuesday 2 September.

Yours sincerely

Tony Price

Terence Price

United Kingdom Atomic Energy Authority

From the Comptroller of Finance and Administration
R.N. Simeone C.B.E.

11 Charles II Street
London SW1Y 4QP

Telephone: 01-930 5454

Dr. Gittus

8339

5-8

1st August 1986

Dear David,

Implications of Chernobyl

You asked in your letter of 25th June to be kept in touch with progress on a number of the points which we have been considering following the accident at Chernobyl. Inevitably, several of these will be long-term tasks but I thought it would be helpful to summarise the position we have now reached.

2. Some progress has been made on the production of summary documents on major plant in the Authority. A document on the MTRs at Harwell should be available before too long. Winfrith are preparing a note on the safety of the SGHWR which would provide the basis for a talk or an article. They have also produced, for internal use at this stage, notes comparing the Winfrith Reactor and the RBMK (SGHWR Tech Note 608) and considering the possible significance of the Chernobyl accident for the Winfrith Reactor (SGHWR Tech Note 610). Copies of these are enclosed. Dounreay are considering the scope to amend for publication some existing documentation on emergency provisions for their plant.

3. Winfrith's "Annual Report on Radioactive Discharges and Monitoring the Environment 1985" (copy enclosed) marked a significant and successful shift towards presenting this information in terms accessible to the layman. This report is being considered by other establishments as the basis for adopting a similar approach in their reports. This may, however, take some time, not only because of the effort involved, but also because establishments will naturally wish to discuss such a change with their Local Liaison Committees. On a separate but related point, work is also under way on putting together a set of layman's definitions of common nuclear terms.

4. You will already have received copies of John Gittus' paper on the Chernobyl accident and the brief on intrinsically safe reactors.

5. As I mentioned in my earlier letter, it is difficult to draw any detailed conclusions about work the Authority should undertake in the light of the Chernobyl accident until we have a fuller picture of the nature of that accident. For this reason, we have agreed with your Division that full consideration of possible adjustments to the GNSR programme should wait on information which we hope will become available at the IAEA post-accident review at the end of August. At present, we envisage that work in the following general areas is likely to be relevant: analysis of the accident and the lessons to be learned for UK reactors (to some extent, this work is, of course, already under way); application of existing consequence codes to overseas reactors to assess the potential impact of accidents overseas; longer-term work using epidemiological data from Chernobyl (when available) to check accident consequence models; and the identification of any promising features of so-called intrinsically safe reactors.

6. Good progress is being made on the preparation of the site emergency handbooks for Harwell, Dounreay and Winfrith in a form appropriate for publication and this should go ahead before very long.

Yours sincerely,

Reggie

(R.N. SIMEONE)

Mr. D.I. Morphet
Atomic Energy Division
Department of Energy
Thames House South
Millbank
London
SW1P 4PJ

s.c.c. AEX/EDC Members
Mr. B.C. Carpenter
Mr. F. Chadwick
Dr. J.H. Gittus
Mr. A.W. Hills
Dr. G.I.W. Llewelyn

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6.8

MR. McMILLAN

c.c. Mr. Saunders (on return) ✓
Mr. Carpenter
Dr. Gittus ✓

"CHERNOBYL"

Thank you for the draft paragraph on Chernobyl for inclusion in our 3 leaflets "Effects and Control of Radiation", "Nuclear - Safe Power", and "Radiation and You".

2. As we have now waited three months since the accident before revising the leaflets it would be foolish to print revised versions covering Chernobyl a few weeks before the Vienna meeting at which the causes of Chernobyl are supposed to be made clear.

3. I attach a redraft of the Chernobyl paragraph. Reprinting of the leaflets to include this paragraph should however now wait until after the IAEA meeting in Vienna in the week beginning 25 August. Mr. Carpenter will be able to advise, on his return from that meeting, whether anything has emerged to require amendment of the paragraph.

F. CHADWICK

4 August 1986

In a major accident in April 1986 at Chernobyl in the USSR an experiment by the operators which had not been authorised correctly led to a sudden surge of power while the reactor was at low power; a steam/hydrogen explosion occurred which destroyed part of the containment building and was followed by a fire. Radioactive material was released causing about 30 deaths in the first few months after the accident and increasing risks of death from cancer in future years. Although the reactor was of a unique USSR design details of the event are being studied worldwide.

At the Three Mile Island reactor accident in 1979 in the USA, the built-in protective features ensured that only small doses of radiation were received and no-one was killed or injured.

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CONFIDENTIAL

Dr. J.H. Gittus

c.c. Mr. R.N. Simeone
Mr. F. Chadwick
Mr. B.C. Carpenter
Dr. A.E. Eggleton, Harwell
Dr. M.R. Hayns, SRD
Dr. J.E.R. Holmes, Winfrith
Dr. W.M. Lomer, Culham
Dr. G.G.E. Low, Harwell
Dr. T.N. Marsham, Risley

Chernobyl : Post Accident Review

The UK Mission in Vienna report that the IAEA Secretariat have said that the response to Blix's letter to the Soviets is unsatisfactory. The Russians are still insisting that the review meeting should explicitly cover other nuclear accidents as well as Chernobyl.

2. The Mission say that UK indignation at this attempt to change the basis for the meeting is widely shared by Western Missions and is fully understood by the Secretariat. Rosen is visiting Moscow on 3rd August to complete preparatory arrangements for the meeting and has been briefed to explain the depth of concern.

D.M. LEVEY

Overseas Relations Branch
4th August, 1986

5-8

United Kingdom Atomic Energy Authority

Central Services Administration

11 Charles II Street
London SW1Y 4QP

Telephone: 01-930 5454

4 August 1986

Dr J H Gittus
Director
Safety and Reliability Directorate
Wigshaw Lane
Culcheth

Dear Dr. Gittus

Chernobyl Review Meeting, Vienna, 25-29 August

In her letter to you of 18 July, Mark Baker's secretary omitted to mention that we will require receipts against the expenditure of up to £150 for possible entertainment in connection with the above meeting. If you think this may present you with any difficulties, perhaps you could give me a ring (I am absent on leave from 7 August, in which case I suggest you deal directly with John Peat).

Yours sincerely

P. Anderson

for R N JAMES

cc Mr J A Peat
Mrs E E Stoneham

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CIMRG 43

CEGB IN CONFIDENCE

Technical Aspects of Hypothetical Reactivity Accidents

1. Introduction

This note has been prepared to address the following issues:-

(1) Under what circumstances (if any) could prompt criticality occur in Magnox or AGR reactors? What energy would be deposited in the fuel?

(2) What are the physical processes for conversion of thermal energy in the fuel into mechanical work? /To include a brief review of the early American reactor experiments and accidents./

(3) What are the likely consequences of a prompt critical incident in a Magnox or AGR reactor? /Items 1 and 3 for PWRs are covered in a separate note prepared by the PMT./

ask [illegible]

Each of the above has been addressed in a series of appendices (prepared by GDCD and TPRD staff), whose conclusions are summarised below.

2. Prompt Criticality in Magnox and AGRs (Appendix A)

The reactivity investment in bulk control rods in a typical Magnox reactor is some 6 niles, but at start-up criticality is obtained with a rod worth in the core of about 1 nile. The fuel provides a negative reactivity effect and the moderator a slow acting positive one. The work outlined in the appendix concludes that in the event of an uncontrolled rod withdrawal, there would be a major collapse in the fuel geometry before prompt criticality was achieved; of course this would normally be prevented by the reactor protection systems. The transient develops very slowly, giving the opportunity for operator action in the event of failure of the automatic trip.

For AGRs the fault studies show for certain reactivity faults that peak fuel and can temperatures at trip can be approaching the melting limit, and at that point that the rod reactivity is more than ½ nile. The faster power excursions are those around start-up, but these can only lead to prompt criticality for events beyond the design basis, such as withdrawal of all rods with failure to trip. The nuclear reaction would eventually be terminated following fuel disruption by fuel relocation into a sub-critical configuration. The consequences are not significantly different (see Section 4 below) from other beyond-design basis accidents involving gross power to flow mismatch.

3. Mechanisms for Causing Violent Disruption (Appendix B)

The appendix discusses the various substantial reactor disruptive incidents in the early history of reactor technology - in all of these a steam explosion caused by fuel melting into the coolant (water) is believed to have been the key transition between modest releases of thermal energy and violent disruption of the reactor structure. A further consequence of the presence of water is that it provides an effective means for transmitting the energy to the walls or structure of the reactor. Whilst fuel has been severely disrupted without being molten (in very fast transient experiments) it has not produced a steam explosion when water was present, and indeed it appears unlikely that it could do so, as substantial energy would be required to disperse the solid fragments very rapidly through the water.

In gas filled systems there appears to be no practical analogous mechanism for relatively efficient and rapid conversion of thermal energy in the fuel into damaging pressure pulses.

4. Consequences of Reactivity Accidents in Magnox and AGR Reactors

For Magnox (Appendix C1) the consequences of a severe reactor reactivity fault with failure to trip would be unlikely to lead to prompt criticality, but could lead to clad and fuel melting. Magnox ignition would be likely in damp CO_2, but may not occur if the CO_2 is dry. If Magnox ignition occurred, then CO_2 would be consumed and circuit gas pressures would fall, despite gas temperature increases. Slumping of molten uranium to the bottom of the channel would be likely to occur, with the potential for eventual melting through of the pressure envelope and subsequent release of fission products; this is more likely for the case of steel pressure-vessel reactors than for concrete vessels.

For AGRs (Appendix C2) bounding assumptions have been made giving very rapid heat transfer from the fuel to gas, which is believed to be unrealistic. If the energy in the fuel is shared with all the gas in the circuit the gas pressures would rise to just below the ultimate strength of the vessel at about 2.5 x normal working pressure, and the safety valves would lift with a potentially very significant release of activity. If (more likely circumstance) the energy of the fuel is shared rapidly with the gas in the coolant channels, this may generate disruptive pressures within the core, but the overall effect on circuit pressure would be small. As a judgement it is likely that only a fraction of the fuel could be finely dispersed such that the heat is given relatively rapidly to the gas, and in this case it would be unlikely that pressure increases would be sufficient to lift the safety valves. Mechanisms for dispersal of a significant fraction of the fuel from the core have been identified which provide the ultimate means of core shut-down.

Ultimately molten fuel could reach the vessel liner. It is currently not possible to assert that vessel integrity will be maintained if it is subject to thermal attack from significant quantities of molten fuel.

Conclusions

For Magnox reactors, even with assumptions of certain failures going beyond the design basis, it seems very unlikely that the transients will give a prompt critical excursion. For AGR, failures of protection systems going beyond design basis assumptions (e.g. failure of two redundant and diverse protection systems), could produce a prompt critical event, but this does not appear likely to produce consequences more severe than other hypothetical beyond-design basis events involving large power to flow mismatches.

R. S. Hall,
GDCD
12 September 1986

Appendix A

MAGNOX REACTIVITY FAULTS

By N.A.J. Butt and T. Williams

1. Consider some basic physics facts of Oldbury (typical of MAGNOX reactors):

    i) Number of control rod groups = 6; 4 Bulk, 1 Sector and 1 Safety. (Safeties play no part in any fault transients since they are out except when dropped in on reactor trip).
    Worth of Bulks in respective lift groups are 1.3, 3.7, 1.0 and 1.0 Niles.
    Sector rods are worth about ½N.

    ii) Criticality at S.U. is obtained with 3 bulks lifted (6N removed) the sectors at some half insertion, and bulk 4 also partially lifted. At this stage the rod worth in the core is about 1 Nile.

    iii) Moderator temperature coefficient of reactivity is 10 to 14mN/°C. This is what accomodates the Xe poisoning (1½N) as power is raised. In contrast the fuel temperature coefficient is -1.5mN/°C.

    iv) The maximum withdrawal rate of Bulk Group 4 is limited to a low rate. The rate of reactivity insertion by this means is about 0.1mN/sec.

2. What we have done is to look at 2 faults for Oldbury in the symmetric reactivity fault regime:

    i) Bank withdrawal at S.U. from a low, effectively zero, reactor power

    and ii) Bank withdrawal from an at-power condition when temperatures in the core are appreciably higher.

    The results of these KINAX studies are attached as figures 3 and 4 [(a) and (b) refer respectively to the peak and mean channels]. Plots of clad, fuel and moderator temperature are given.

    To interpret these graphs we note that for the pressurised reactor case the temperatures at which fuel and clad are liable to melt are 1120°C and 630°C. In a fault study assessment allowances would be made for randoms and uncertainties on these temperatures. For the purposes of assessing the rate of the transient effect as either limiting temperature is reached ignoring temperature randoms and uncertainties is a pessimism.

From the temperature plots in figures 3 and 4 it is clear that in either fault, when the lines of trip protection fail, that clad melt temperatures are reached before fuel melt temperatures. Furthermore, a pessimistic estimate can be made of the reactivity injection rate, by calculating the rate of rise of graphite temperature and ignoring any fuel feedback effects. Investigations of the KINAX output allows an estimate of total net reactivity injection to be made at the corresponding point. Thus we have:

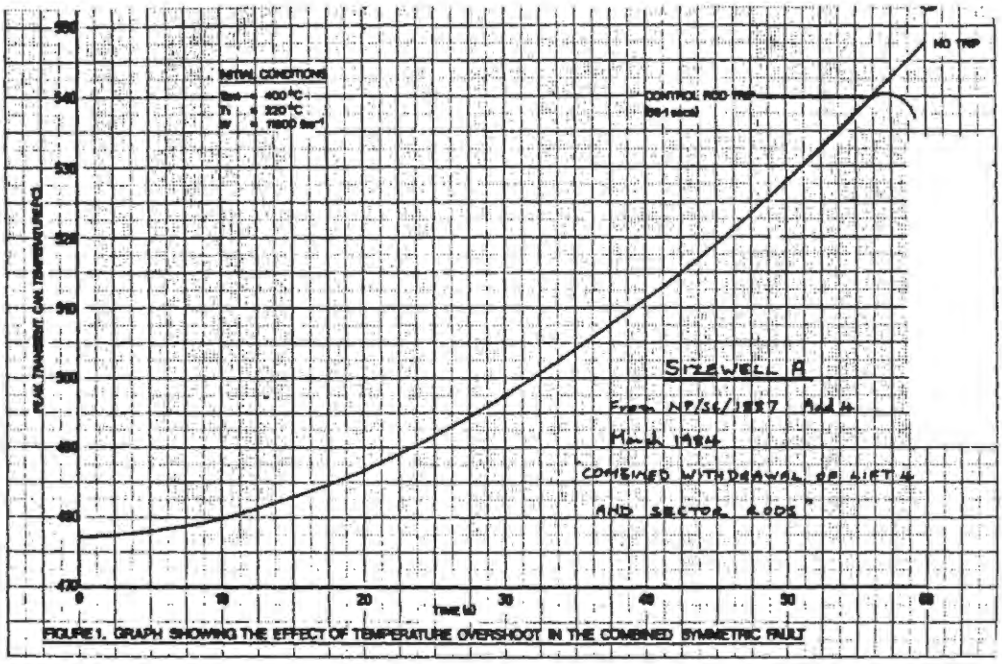
i) Start-up fault: net injected reactivity 70mN, rate of reactivity injection 3mN/sec

ii) At-power fault: net injected reactivity 200mN, rate of reactivity injection 3mN/sec.

These results straight away provide an indication that at the onset of clad and subsequent fuel melt the reactivity injected and the rate of reactivity insertion (even neglecting fuel feedback) is nowhere near prompt critical conditions, nor would those conditions pertain for a considerable time.

The Oldbury faults studied are not typical of other stations in which rod groups can move faster. Two of the faster start-up and at-power faults have been found and shown in figures 1 and 2. It is evident that the transients are similar except in timescale, to the Oldbury faults. To infer fuel and moderator temperatures we therefore compress the timescale of the Oldbury faults. We can thus take as general over the magnox reactors the conclusion that gross clad and subsequent fuel melting would occur well in advance of prompt critical conditions being achieved.

However, we will be dependent on reactor protection systems to avoid risk of clad ignition and widespread uranium melting following certain reactivity faults.



SIZEWELL A

From NP/SC/1887 Add 4

March 1984

"COMBINED WITHDRAWAL OF LIFT 4 AND SECTOR RODS"

FIGURE 1. GRAPH SHOWING THE EFFECT OF TEMPERATURE OVERSHOOT IN THE COMBINED SYMMETRIC FAULT

WYLFA

START UP FAULT AXIALLY FLATTENED CHANNEL

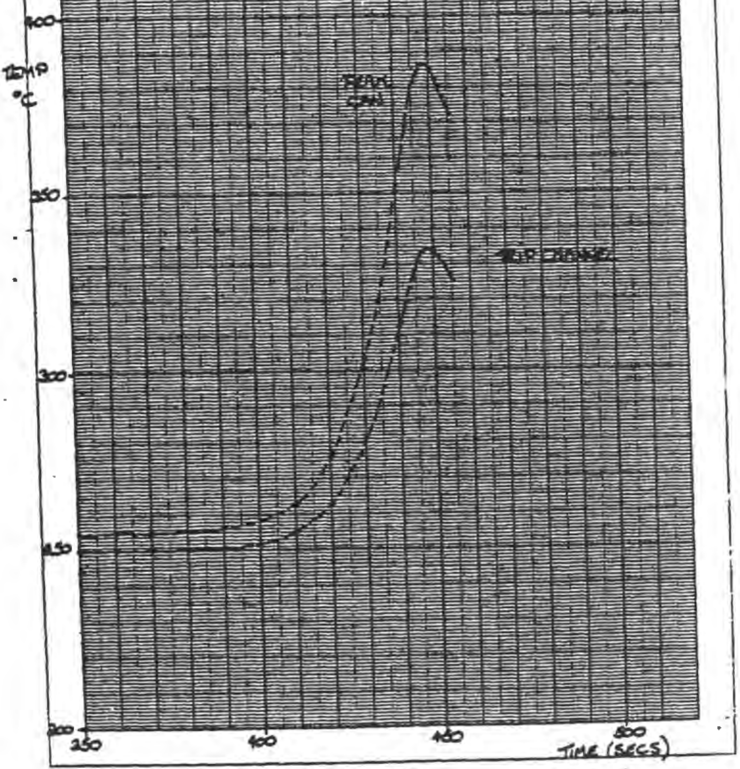
NO XENON RUN-OUT OF LIFT 4 RODS

F.C.S. SERVO RESET TRIP

COARSE RODS 1 & 2 USED FOR TRIPPING

TIME AT PEAK 448.5 s

TEMP AT PEAK 386.7 °C



From Wylfa Report 4333
July 1979.

FIG. 2

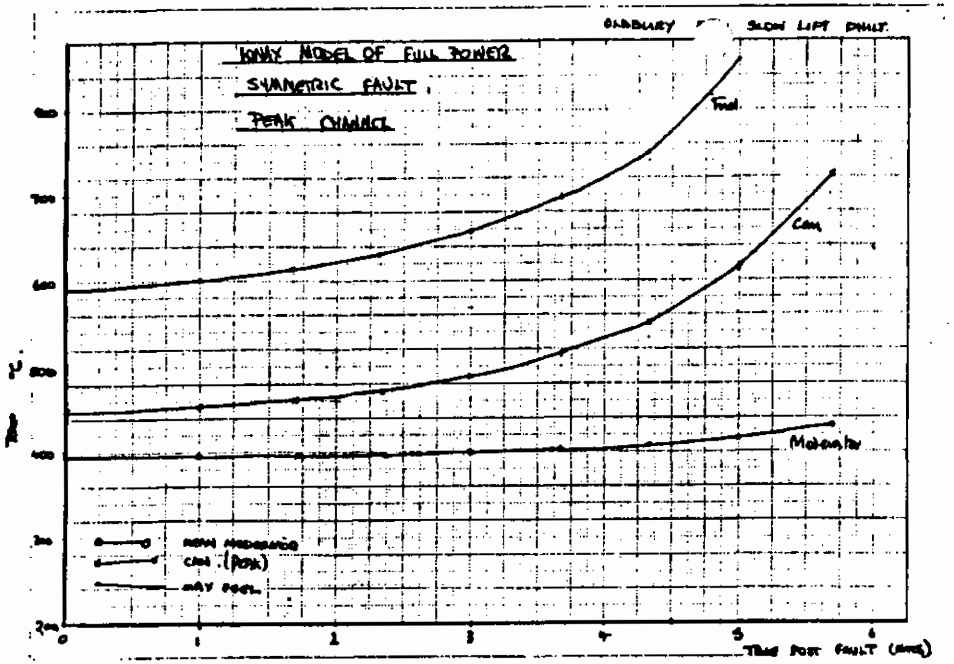


FIG. 3a

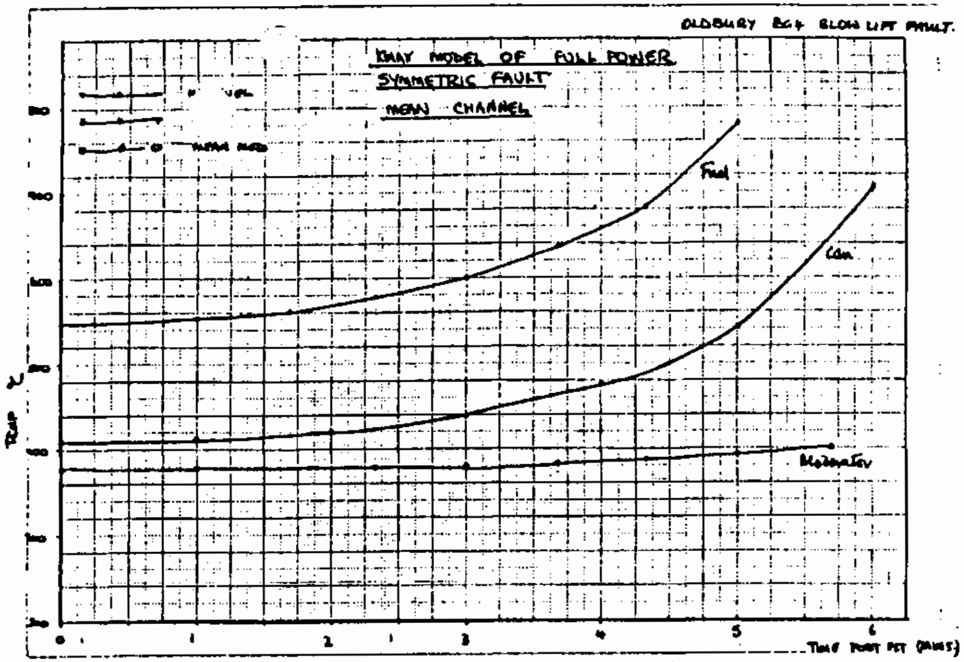


FIG 3b.

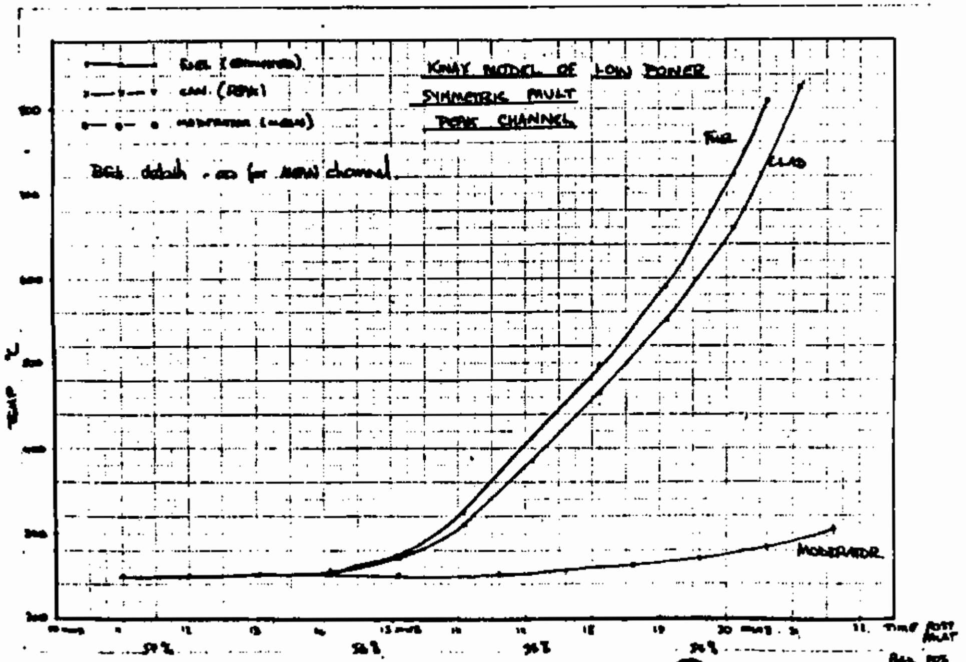


FIG. 4a.

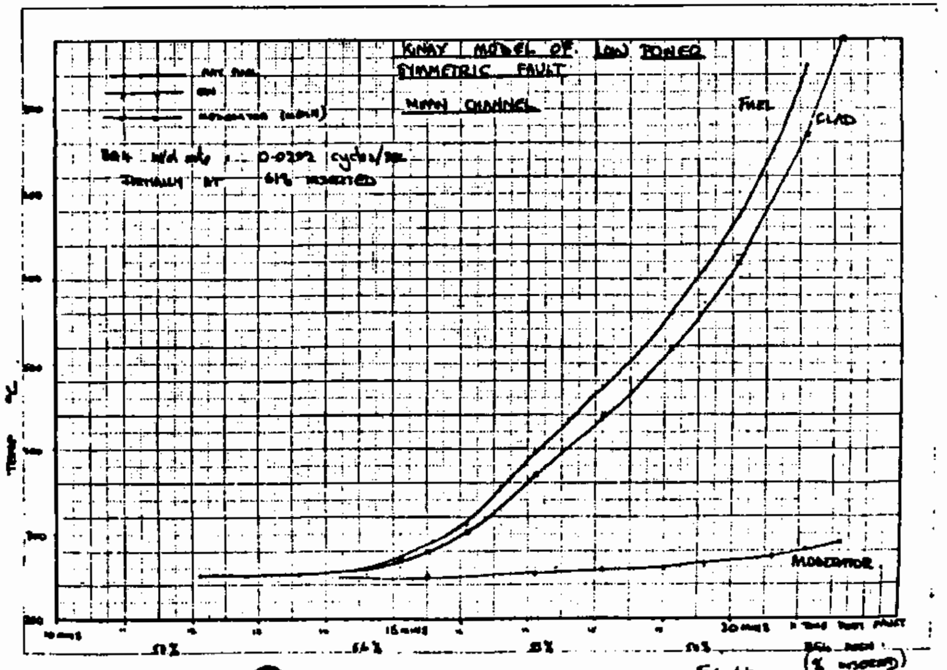


FIG 4b

AGR Reactivity Faults

Typically the total worth (all rods in to all rods out) of the control rods in an AGR is 11 niles. The control rods are divided into 4 groups, 3 groups of black 'bulk' rods (worth 3½, 3½ and 2 niles) and one group of 'grey' regulating rods (worth 2 niles). At reactor start-up, criticality is achieved with the control rods holding down 4 niles of reactivity (ie. their withdrawal would release 4 niles). At power the reactivity held down by control rods is normally some 1 to 1½ niles.

We have considered results of calculations of faults in which continued motoring of control rods is assumed at the built-in control rod speeds. Two typical cases, one with the fault occurring when the reactor is at full power and the other with the fault occurring when the reactor is at low power (10%). Quite evidently if the reactor protection system failed to operate so that the transients were allowed to develop as shown in the figure, ultimately fuel clad would melt, fuel gemotry would be disrupted and there could be melting of UO_2 - the transient could only terminate through loss of reactivity due to collapse of the fuel gemoetry in this hypothetical situation. However, it is also evident that the rates of rise of temperature are very slow indeed relative to those which must have occurred in the Chernobyl incident.

More generally, from fault studies of this type for all the stations in particular for Heysham 2, it is apparent that:

i) Avoidance of prompt criticality is dependent on reactor protection systems, but, with the negative fuel coefficient and the very slow response of moderator temperatures to power changes (mitigating the significance of the positive moderator temperature coefficient) this is not crucial for these rod withdrawal faults.

ii) The considerations resulting from the transients in Fig. 5 are of general applicability over all the AGRs.

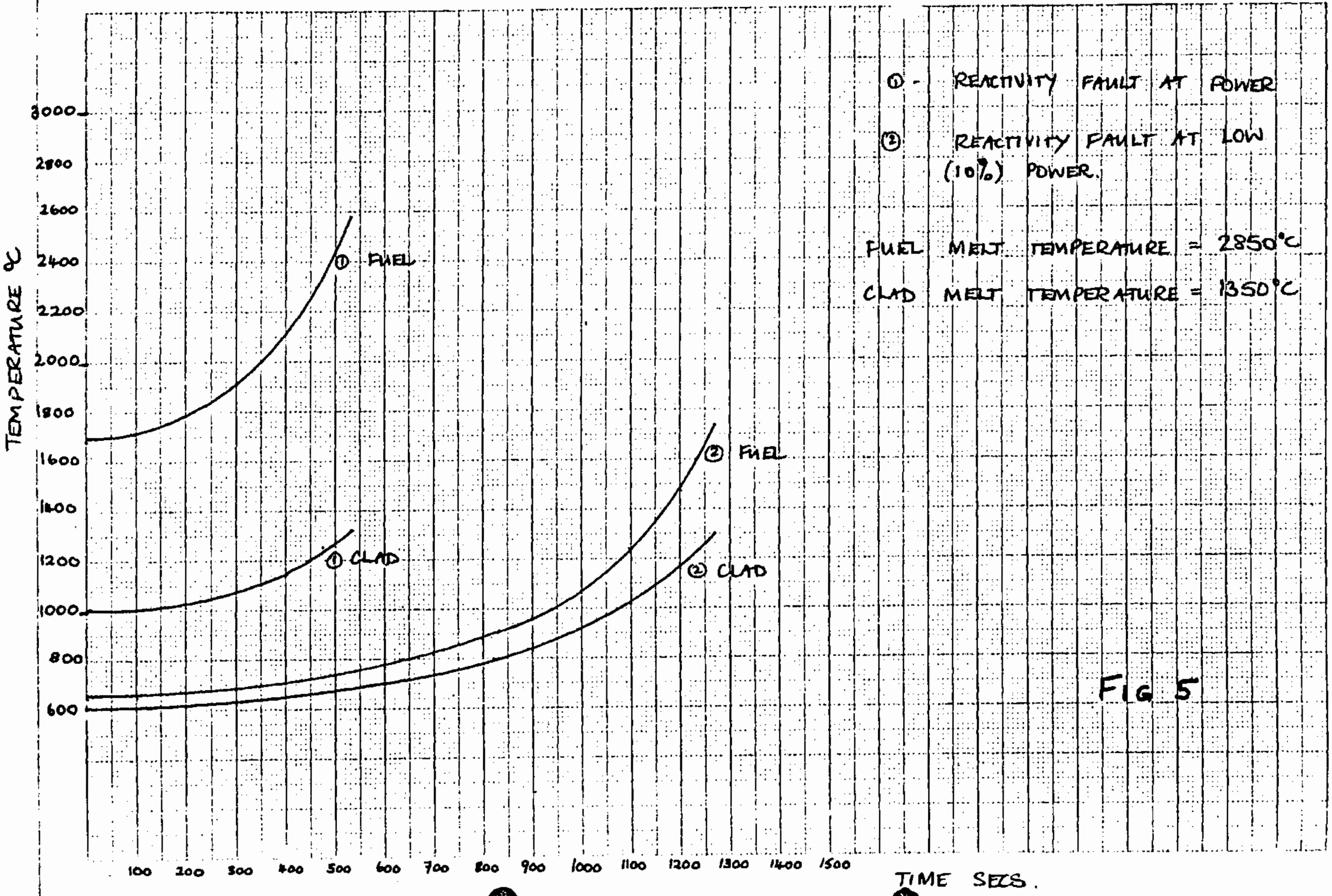


FIG 5

TYPICAL FAULT TRANSIENTS

APPENDIX B

MECHANISMS FOR VIOLENT DISRUPTIONS

M. Baines, N.E. Buttery, S.J. Board, BNL

There are several well known incidents in which reactivity excursions have led to the destruction of reactors. The best known are BORAX 1 (1954), SL1 (1961) and SPERT ID (1961). These were all water reactors with Uranium/aluminium alloy fuel in aluminium cladding immersed in light water coolant which was also the moderator.

In the BORAX 1 incident (1954) a planned 4% k_{eff} rod withdrawal produced a power pulse with reactor period approx. 2.6 m sec. The total nuclear energy release was 135 MJ over approx. 30 m sec, with peak power reaching approx. 20 GW. A pressure of approx. 700 bars destroyed the reactor vessel and breached the bunker housing, and a 1 Te structure was thrown 10 m into the air.

In the SL1 accident (1961) an uncontrolled (manual) control rod withdrawal added 2.4% excess reactivity which caused a 20 GW peak power pulse with a total nuclear energy release of approx. 130 MJ. The resulting explosion accelerated a fluid slug which hit the reactor vessel roof producing pressures of 700 bars. The vessel did not fail, but it jumped 3 m into the air shearing off all pipework.

In the SPERT-ID experiment, \$3½ of reactivity was intentionally added with a reactor period of 3.2 m sec; a total of 31 MJ of nuclear energy was released with peak power approx. 2.3 GW. The pulse was deposited in 17½ kg. of U/Al alloy, corresponding to approx 1.8KJ/gm fuel. SPERT was an open pool reactor and explosion pressures of 250 bars blew water out of the vessel and destroyed the core and associated hardware.

In all these cases the reactivity transient was terminated by voiding of the coolant (which was also the moderator). The energy deposited was sufficient to produce substantial fuel melting. Very high pressures were recorded: it is generally accepted that molten fuel and water interacted producing a vigorous steam explosion, and this was the primary cause of the damage. The explosive yield has been estimated by a number of authors, though with considerable uncertainty. Values range from 1% to 20% of the thermal energy in the fuel.

Following these events a great deal of research was undertaken by the nuclear industry into steam explosions. Transient heating of solid materials under water demonstrated that the rapid steam generation requires a very large interface area to be produced during the explosion. This suggests that the fuel must be initially molten. Oxidation and thermal shock may lead to solid fuel fragmentation. Dispersive fuel fragmentation in the solid state has been observed in transient overpower experiments, but only very fast transients. (Radial temperature gradients of $>$ 2800K/mm are required). There is no evidence that a true steam explosion is possible with solid fuel since this would require a shock initiated mechanism which could disperse and/or further fragment solid material, see below. However, it is difficult to completely rule it out.

Experiments in which molten metals and molten oxides including UO_2 have been poured into water at scales up to 25 kg have led to a better understanding of the conditions required and some of the basic mechanisms. Essentially there are three stages:-

1) Initial coarse mixing of molten fuel and coolant usually requiring film boiling.
2) A triggering event, which locally collapses the vapour film, causing
3) fragmentation/fine mixing with a high interface area. This is believed to generate sufficient steam to produce a shock wave which propagates through the coarse mixture, collapsing the vapour blankets, leading to more fragmentation.

A number of possible fine scale fragmentation and steam generation process have been proposed but there is currently insufficient evidence for a reliable theoretical prediction of the energy yield. Experimental results show significant variability, with values typically $\leq 4\%$ of the thermal energy in the fuel. There is some evidence that at high ambient pressure a more energetic trigger is required (step 2). (Note: there was no steam explosion when molten materials contacted water in TMI).

In fast reactivity excursions, it is possible for the fuel to melt whilst water remains in the channels. In this situation the initial mixing and possibly the triggering stages may be achieved when the fuel pins rupture. A series of power excursion experiments were carried out on single water reactor fuel pins in a water filled channel at 64.5 bar in the PBF reactor at Idaho. For an energy deposition of 1 kj/gm, the fuel failed without melting, and no explosion occurred. In the final test which deposited 2 kj/gm in 76 ms the fuel failed at 1.5 kj/gm (when it was mostly molten) and an explosion occurred about 1 ms later, generating a peak pressure of 500 bar, with an energy yield of 1% of the thermal energy in the fuel. There has been some debate over the nature of this event, which ocurred at a higher ambient pressure than other steam explosions. The experimentalists have examined the alternative possibility of rapid hydrogen generation from zirc/water reaction, and concluded that even allowing for fragmentation of the zirconium, the chemical reaction rate would be insufficient to explain the observed yield.

It appears to be generally accepted that a steam explosion occurred during the accident at Chernobyl. One (Western) estimate of the yield was 200 MJ. The Russian analysis of the event suggests that a prompt critical excursion deposited at least 1.2 kj/gm in the fuel (this is sufficient for melting). The explosion was modelled by fragmenting 30% of the fuel and allowing rapid heat transfer to water. The estimated yield thus corresponds to 0.3% of the thermal energy in the fragmenting fuel - a value well within the range of likely yields for a steam explosion. A major uncertainty is the quantity of water present in the channels at the time of pin rupture. The high power channels may have been largely voided, but lower power channels may have contained substantial water at the time of prompt criticality.

The experimental evidence suggests a liquid phase, vapourisable coolant is a necessary requirements for propagating steam explosions. This is probably because of the character of boiling, which allows a sudden switch from stable, low heat transfer (film boiling) to high heat transfer with mechanical agitation for fragmentation and mixing (nucleate and transition boiling). The switch can be initiated by an increase in pressure. These characteristics allow the slow initial mixing of stage 1, and ensure that only a relatively modest trigger is required (stage 2). However a propagating gas phase explosion is possible in principle. This would rely on hydrodynamic fragmentation of liquid fuel drops in the high speed gas flow behind a shock.

Hydrodynamic fragmentation becomes ineffective as the mass ratio of gas/liquid becomes less than unity. Hence a very large initial volume dispersion of fuel would be required, and because there are no other fragmentation processes to give escalation, a large gas shock would be needed to initiate the explosion. It should also be noted that dynamic effects in a gas system with heavy walls are likely to be much less important than in a liquid system.

BNL/PS/THSS/SJB/MSG
11.9.85

Appendix C, Part 1

Assessment of the Consequences of a Severe Reactivity Fault in a Magnox Reactor

It is not possible to generate a prompt critical transient by withdrawing control rods even in a fault in which the reactor trip system failed to operate. Fuel melting would occur and result in termination of the transient before the reactor became prompt critical. The consequences of a severe reactivity fault with fuel melting are described in GD/PE-N/1362. The conclusion is reached that the pressure vessel would fail and molten uranium fuel would be ejected in the case of a steel vessel reactor. In a reactor with a CPV, it is possible the molten fuel may be held within the vessel.

EXTRACT FROM GD/PE-N/1362 "Combating Fires in Magnox and AGRs", August 1986

4.1.2 Pressurised Faults

There can, of course, also be magnox fires arising from pressurised faults which are beyond the design basis. A reactivity fault from low power (at which condition some black rods are usually deeply inserted) could for example occur with failure to trip from flux signal protection, one reason for which could be that, in some stations, the operator had not set down the trip levels (the latter reason could not occur where auto-reset flux protection is installed). There is, of course, also temperature protection which on some reactors might not have been set down, or there could have been a failure of the guard-line system. Clad temperatures would rise quickly and widespread magnox melting would result. Magnox ignition may not occur if the CO_2 was dry. But if it did, CO_2 would be consumed and circuit gas pressures would fall, despite the gas temperature increases. It is likely that uranium metal would melt and, as described above, would slump to the bottom of the channels; the reactor would almost certainly become sub-critical. Graphite temperatures would increase with the core acting as a heat sink, but with no exothermic reaction. However, if the molten uranium falls to the bottom of the pressure vessel and subsequently penetrates the pressure circuit then molten uranium could be ejected. Fission product release would depend on the pressure at the time of ejection.

Assessment of the Consequences of a Prompt Critical Transient on an AGR

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and N.E. Buttery, M. Baines (BNL),

Safety Technology Section

1. Introduction

The fastest power excursions are caused by reactivity faults at startup in which control rods are accidentally or inadvertently withdrawn from the reactor core. Prompt criticality in start-up faults is only possible if events beyond the design basis are postulated to occur, e.g. withdrawal of control rods with failure to trip or ejection of a control rod from the reactor core.

In faults within the design basis there will be no melting of the UO_2 fuel. However, gross melting and disruption of the fuel is possible in the beyond design basis faults referred to above.

In order to examine the inherent capability of the AGR to withstand extreme conditions, the consequences of a prompt critical transient leading to fuel melting have been considered. There is a lack of experimental data and theoretical models relating to fuel failure induced by a rapid power transient and the consequent interaction between fuel and coolant. Therefore, in the following description of the likely consequences a considerable element of judgement is unavoidable.

Prompt critical transient

The peak power generated in the fuel pins in a prompt critical excursion is limited by the negative reactivity feedback due to the fuel temperature rise (Doppler coefficient). The power rises in a few seconds from zero to several times the normal full power rating in a fault caused by control rod withdrawal. At Dungeness B there is also the possibility of prompt criticality following a rod ejection fault. Up to 20 times the normal rating could occur in the power spike. Although negative feedback limits the amplitude of the transient the subsequent power generated in the fuel is substantial and melting will occur. The nuclear reaction will be terminated by insertion of control rods.If for any reason the rods fail to insert the reaction would also be terminated following fuel disruptionand relocation into a subcritical configuration. This would require fuel to melt and slump or be ejected; if the stainless steel clad were to melt first and disperse then in the short term the reactivity could be increased. The heat generation in the fuel would subsequently consist of decay heat from fission products. The level of decay heat at start-up would be less than that in operating fuel depending on the duration of the previous shutdown.

Melting of the fuel will commence within a few seconds of the power peak in the highest rated fuel. Temperatures are rising very rapidly and melting will spread to the rest of the fuel within a further few seconds.

Fuel pin failure

If energy is deposited at rates in excess of 40kW/g rapid heating up of the fuel in a pin could conceivably cause explosive fragmentation of the UO_2 before melting (Ref. 1).This mechanism could result in the termination of the nuclear reaction without the occurrence of immediate gross melting. Such rates of energy deposition could not be achieved in AGR faults. It is anticipated that gross melting will inevitably occur.

There are two possible modes of fuel melting which must be considered depending on whether the UO_2 fuel melts before the stainless steel cladding or vice versa. Melting of the fuel before the clad is only possible in extremely fast transients but has been postulated to occur in the most severe rod ejection faults. Melting of the cladding before or simultaneously with the fuel will occur in most prompt critical transients according to theoretical predictions. Both modes of fuel melting have been considered below.

The main consequences of fuel melting are that the coolant gas is exposed to very hot fuel and the molten fuel will relocate itself inside and/or outside the core. The short term pressure transient in the coolant due to heating by the fuel must be examined in relation to the integrity of the concrete pressure vessel, and the lifting of safety relief valves allowing the escape of radioactivity. In the longer term, the possibility that fuel relocation could jeopardise the pressure vessel integrity has to be addressed. In the following analysis bounding pessimistic calculations have been carried out initially, followed by an assessment making use of the limited experimental data on a best judgement basis.

2. Limiting Calculations of the Coolant Pressure Increase as a Consequence of Molten Fuel Release

This section presents limiting calculations of the increase in reactor coolant pressure resulting from the release of molten fuel. It should be recognised that these are upper bound calculations and are based on gross pessimisms.

If molten fuel is released into the fuel channels it could be further fragmented by hydrodynamic forces. The quantity of fuel which could be fragmented in this way is, however, likely to be small given the relatively low mass of gas. (The energy available in the gas flow is insufficient to create the large amount of surface area implied by fragmentation of the bulk of the fuel.) For example over a period of about one second only about 4 tonnes of CO_2 would be injected into the core. This would be capable of fragmenting only a few percent of the fuel into the very fine particles ($\leq$1mm) which would be necessary for rapid heat transfer to the gas.

In the following calculations it is nevertheless assumed that the whole UO_2 inventory instantly fragments into very fine debris. The increase in gas pressure is calculated for two extreme possibilities i.e. either the heat is transferred to the gas in the fuel channels or it is shared with all the gas in the vessel.

i) The heat is instantaneously transferred from the UO^2 to the gas in the fuel channels. The channel pressure would rise to about 16MPa (c.f normal circuit pressure of 4.1 MPa). If the gas is assumed to expand isothermally (since more heat is available in the fuel) this would lead to an equivalent shock overpressure of about 0.3 MPa. A pressure increase of this magnitude would not pose a direct threat to the structural integrity of the reactor vessel. Such a small pressure increase would not lift the safety relief valves.

ii) All the heat from the fuel is shared with all the CO^2 in the vessel. By bringing the UO_2 heat content into thermal equilibrium with the CO_2 and ignoring any heat and mass losses it is possible to generate an upper limit on the pressurisation. The maximum pressure on AGR reactor vessel can withstand is 2.5 times the design value i.e just below 11 MPa. Making pessimistic assumptions, the calculated pressure can be shown to be not greater than 11 MPa. Taking into account heat lost to structures the pressure would be less than 11 MPa. In his limiting consideration it is, however, clear that the safety relief valves would open and a massive amount of radioactivity would be released to the environment.

The above two sets of calculations are limiting since they are based on the entire UO_2 inventory fragmented into very fine particles. Whilst it is clear that the overall pressure transients would not compromise the vessel integrity there is the risk of structural damage in the core, due to local overpressurisation and overtemperature. This could result in disruption and/or have the potential for missile generation.

3. Mechanism of Dispersion of Molten Fuel

The relocation and cooling of the fuel after melting are critically dependent on the way which melting progresses. In very fast transients it is conceivable that the fuel will melt before the clad. For internally pressurised fuel it has been postulated that as the clad fails, the internal gas pressure can drive the molten fuel out of the breach in the clad as a high velocity jet. Dependent on the velocity, this jet will break up into droplets on impact with surrounding surfaces.

Latent heat effects of fusion have not been taken into account in this assessment. Such effects are potentially beneficial, but this has not been quantified.

In slightly slower transients, the fuel and clad might melt approximately simultaneously, and the "columns" of liquid so formed would break up primarily under the action of coolant gas inertial forces.

Both of these mechanisms are considered below:

i) Jet Impingement

It is first necessary to estimate the internal gas pressure at the time of clad failure. Under normal operation, internal gas pressure and temperature within the clad are approximately 1 MPa at 1300K. Assessing the gas to be at fuel melt temperature at the time of rupture of the clad, the internal pressure is about 2.4 MPa. This is lower than the coolant pressure. Therefore, unless there is rapid release of fission gas during the transient, the 'jetting' of the molten fuel under internal gas pressure is not a plausible mechanism for dispersion.

(Incidently, we have reviewed some Culham work (Ref. 3) on the thermal attack on steel by a molten debris stream. Based on this, it is our judgement that the short duration and incoherent nature of jets arising from failing fuel would be unlikely to cause significant damage to the graphite sleeve.)

ii) Hydrodynamic Droplet Formation

Analysis of the disintegration of columns of liquid fuel into droplets is extremely complex. The analysis given below is considered to be indicative of possible behaviour, but is subject to very considerable uncertainties.

Estimation of largest stable drop size

As the fuel melts and forms into globules it will tend to be broken up by the gas flow. The upperbound to the size of stable droplets is set by a balance between surface tension and inertisl gas forces. For stable drops this ratio, termed the Weber number, must be less than about 10, giving a maximum stable diameter of about 2 mm. Break-up of the liquid columns into droplets of this size would take place within about 0.05 sec. In practice, as noted in Section 2, there is probably insufficient mass flow of gas in the channel to break up a major fraction of the fuel into droplets as small as this.

Drop size spectrum

As well as the larger drops, a spectrum of smaller droplets would be generated, for example by localized high gas velocities entrainingfluid from the surface of the larger drops. No data on the break up of liquid UO_2 by such mechanisms has currently been identified but considerable data exists for the entrainment and break up of water drops by air flows. For example, Komabayasi, Gonda and Isono (Ref. 2) measured the size spectrum of droplets produced on the disintegration of marginally stable water drops of 0.005 - 0.01 m diameter by air flow. Their data suggest that less than 10% of the initial mass resides in drops smaller than 1mm, and less than 1% below 0.1mm. These figures cannot be applied with confidence to UO_2 fuel.

Relocation of molten fuel

The terminal velocity of the largest stable drop of liquid UO_2 in CO_2 at 4 MPa is approximately $7.5ms^{-1}$. This implies that all drops formed will be levitated. Of course it should be noted that a relatively small reduction in the gas velocity ($10ms^{-1}$) would reverse the position.

A possible mechanism for reducing channel flow is restriction of the outlet by accumulation of refreezing fuel, for example in the CIC. It is also possible that a trip signal had occurred initiating a circulator trip.

Much of the liquid fuel would be expected to impinge and remain on the channel wall. A counter-current two-phase "flooding" analysis suggests that if this fuel remained as liquid, it would flow downward to the channel inlet.

4. More Realistic Calculations of the Coolant Pressure Increase.

In section 3 it is concluded that less than 10% of the molten UO_2 particles will have a radius of less than 1mm (and about 1% of particles will have a radius of less than 0.1mm). Only these very fine particles can transfer their heat, quickly enough, such that a rapid pressure increase could be generated. Larger particles would lose their heat more slowly and would not pose a threat in terms of rapid overpressurisation.

The calculations described in section 2 have been repeated for 1% of the total UO_2 mass. With the UO_2 heat instantaneously shared with all the gas the consequential increase in coolant pressure is negligible. With 10% of the total UO_2 mass safety relief valve pressure could be reached.

The local pressure increase, considering only the mass of CO_2 in the channel, has also been calculated for both UO_2 masses. With 10% of the total UO_2 in the core the pressure increase (about 14 MPa) is still potentially damaging. For 1% of the available UO_2 the channel pressure increases to only about 6 MPa. It seems unlikely that this pressure increase would result in significant damage to the channel.

. Ultimate Fuel Configuration

The nuclear reaction will cease after a significant proportion of the fuel has been relocated. The processes described above, in section 3, identify mechanisms for the relocation of significant quantities of UO_2. It is judged that sufficient UO_2 would be relocated such that the nuclear reaction would cease a few seconds after the inception of gross melting and within about 20 seconds of the start of the power excusion.

Some molten material will be relocated to the upper parts of the core. (A limited quantity of material may even be blown out of the core onto the top dome). It is, however, inevitable that significant downwards flow freezing of material will occur.

Ultimately molten fuel could eventually reach the vessel liner. It is currently not possible to assert that vessel integrity will be maintained if it is subject to thermal attack from significant quantities of molten fuel.

. Conclusions

The consequences of a prompt critical transient producing gross fuel melting have been examined. The lack of experimental data on the behaviour of fuel pins under these conditions has required an approach in which bounding pessimistic assessments were initially made followed by assessments based on a best judgement of how the available experimental data should be interpreted. Conclusion drawn must, however, be regarded as speculative.

The pressure transient produced by rapid heating of coolant by the fuel could not jeopardise the integrity of the concrete pressure vessel even if the bounding assumption is made that heat transfer from all the fuel occurs instantaneously. However, this calculation indicates that the vessel safety relief valves would lift allowing massive amounts of radioactivity to escape. It is also indicated that a severe overpressurise transient would occur in the fuel channels leading to core damage. There is a possibility of local overpressures destroying the top dome and the possibility of missiles.

If account is taken of the limited degree of fragmentation which is likely to occur and the resulting delay in heat transfer to the coolant the safety relief valves would not lift and it is highly unlikely that significant core damage could be caused by overpressurisation in the fuel channels.

If prompt criticality occured as a result of a rod ejection fault then of course radioactivity would directly escape through the failed penetration and be driven out as the reactor depressurised.

The relocation of fuel following melt out is a complex process and fuel may be widely dispersed around the gas circuit. However, it is certain that some molten fuel would reach the floor of the pressure vessel. In this eventuality it is not possible to claim that the pressure vessel integrity would be preserved.

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Sudbury House (Room 9.02).

Mr. G. H. Hadley,
Sudbury House (Room 1501).

From Dr J. H. Gittus
Director

SRD

Safety and
Reliability
Directorate

UKAEA, Wigshaw Lane, Culcheth
Warrington, WA3 4NE, England
Telephone (0925) 31244 Ext. 7206
Telex 629301 ATOMRY G

30 July 1986

Emeritus Professor J H Fremlin
46 Vernon Road
Edgbaston
Birmingham
B16 9SH

Dear Professor Fremlin

Yes, of course I will supply you with information about the Chernobyl disaster and will certainly send you a copy of our report immediately after the Vienna meeting, together with anything else which we pick up and which seems likely to be of help to you.

Yours sincerely

M. O'Hara

p.p. J H GITTUS

cc Lord Marshall of Goring

ACTION

(7242 28·7 Mac Dn)

United Kingdom Atomic Energy Authority

11 Charles II Street
London SW1Y 4QP

Telephone: 01-930 5454

X2232
AERE

✓ 479

Dr. John Gittus,
Safety and Reliability Directorate,
Wigshaw Lane,
Culcheth,
Warrington,
WA3 4NE.

am — 4 Sept at AERE end.

25th July 1986.

Wed 8pm dinner

am → 3pm

7.20pm Guildhall

Dear John,

Chernobyl Video

We are keen to get on with the preparations for your programme about Chernobyl. Although it is sensible to wait until after the Vienna meeting for final studio work there are, nevertheless, some actions we can be starting on in the next few weeks. We will then be held up at the post production stage for only a few items.

The AEA has first-class staff for graphics and photography. Your programme will be visual so we may as well take advantage of our facilities such as the electronic painting devices and the technical illustration and graphic skills in the Design Studios and Photographic Groups.

Essentially the things we can be assembling now are diagrams and photographs. Could you let me have copies of any sketches, diagrams and photographs you think you may need to enhance the explanation of the accident? We will then start thinking about how to present them as video/graphics.

Your presentation will probably look best in the form of an interview and we will need to go outside the AEA for the professional skill. I am looking into the possibility of using Barry Westwood or someone of his calibre.

The interviewer will need two things: at an early stage, documentary briefing material from which he can learn about the topic; and later a meeting with you to establish the ground rules. We can supply ample background material to remind the interviewer of the Chernobyl story as it is seen by the general public.

Could you let me know a range of preferred dates to meet the interviewer - perhaps just before, or just after, the Vienna meeting?

Barry Westwood

Yours sincerely,

G Gibbons

20 minutes

Gerry Gibbons

ccs. Mr. Chadwick, Mr. McMillan, Mr. Mullane

P.S. I am on leave from today until 12 Aug. Please reply to Nicholas Mullane (Ext 320)

JHG back at SRD 14 Aug.

BRIEF FOR THE SECRETARY OF STATE FOR ENERGY

THE INTRINSICALLY-SAFE REACTOR: A CONCEPT

John H Gittus
Director, Safety and Reliability Directorate

United Kingdom Atomic Energy Authority
Culcheth

25 July 1986

INTRODUCTION

If a nuclear reactor overheats it may give off radioactive "fumes". This is what happened at Chernobyl. In theory overheating can be prevented by intrinsic safety features such as thermal convection. In practice engineered safety features such as water-pumps are also used.

This brief explains some intrinsic safety features and the manner in which they are incorporated into designs of Intrinsically Safe Reactors. No such reactors have been built and no detailed designs exist - just concepts.

Numbers in the text refer to paragraphs and illustrations in the attached "child's guide" to intrinsically safe reactors.

The Safety Task

1. In all reactors, the reactor core generates heat (by fission) and this heat is removed by using it to boil water (1 and 2). If the water is insufficient to remove the heat from the core (3), it will overheat and radioactive fumes will be released. The safety task is to ensure that this cannot occur.

2. In a practical power reactor the steam produced is used to drive the turbine and so a more complex system has to be designed to remove the steam in an efficient manner. This introduces another step in the process: in addition to supplying sufficient water to remove the heat, the heat also has to be transferred from the core to the steam producing system.

3. Two heat production processes are involved in the core. The chain reaction produces the majority of the heat in normal operation, but a small proportion (roughly one twentieth) is produced by the radioactive decay of the products of the fission process. The chain reaction can be controlled and turned off if necessary by the insertion of control rods. These control rods are an ENGINEERED SAFETY FEATURE. Decay heat production cannot be turned off, although it reduces gradually with time after the chain reaction is stopped. Thus shutting down the reactor turns off the chain reaction and considerably reduces the amount of heat needing to be removed. If the reactor is both moderated and cooled by water then, should it boil dry the production of fission-heat will cease spontaneously: this is an INTRINSIC SAFETY FEATURE (4).

4. The reactor loses heat to its surroundings by natural processes (radiation, conduction, convection). This natural cooling is an intrinsic safety feature. It is possible to remove all of the decay heat by these natural processes providing that the reactor is small (5&6). If such a reactor is too large then it may overheat and release radioactivity, supposing that we rely exclusively upon natural processes to cool it (7).

5. Another basic concept employed in some designs of "intrinsically safe" reactor is shown in 9. Here fission is occurring. If due to poor cooling the core heats up the resultant increase in temperature of the core slows down the fission process and so less heat is generated. Also heat is lost to the surroundings by natural processes as the core heats up. At some temperature the heat loss will balance the heat generation rate. If the core remains undamaged at this temperature it would be "intrinsically safe".

Attractions of Intrinsic Safety

6. Intrinsically safe designs, if achieved, might be attractive for four reasons. Safety assurance might be easier and less reliant upon, for example, the plant operators. If complex safety systems were not required this might reduce the cost of the plant. Intrinsically safe plant might be permissible in urban or near-urban areas and so district heating opportunities could open up. Finally, and perhaps most attractive, intrinsically safe reactors might be better understood by and therefore more acceptable to the public.

Designs for Intrinsically Safe Reactors

7. A number of designs have been developed claiming intrinsic safety. The main ones are listed in Table 1.

TABLE 1

REACTOR	POWER (MW(e))
Pressurised Water Designs	
PIUS (Process Inherent Ultimate Safety)	250
SECURE (Safe and Environmentally Clean Urban Reactors)	500
Gas Cooled Designs	
Modular High Temperature Reactor	100
Fast Reactor Designs	
PRISM (Power Reactor Inherently Safe Module)	415
SAFR (Sodium Advanced Fast Reactor)	350
For Comparison:	
Sizewell 'B' PWR	1200

They have several features in common - they are all small units and in addition in most cases they do not generate so much heat in relation to their size as is achieved in conventional design. This is because it is easier to cool a small reactor than a large one using natural processes. However, this leads to a significant disadvantage: the smaller reactor will be a more expensive source of power than the larger one. Some cost savings may be possible if the safety-related systems used in conventional plant can be simplified or even removed in the intrinsically safe design, but this may not completely offset the less efficient design of the plant. Thus there may well be an economic penalty in adopting an intrinsically safe design.

8. A recent design is the PRISM concept shown at 17 and 18. (The SAFR design (not illustrated) is similar to PRISM.) This is close to the basic concept of 1 to 9. On loss of all normal cooling the reactor would normally be shut down by the safety system but if this did not work, thermal expansion of the core and related structures would reduce reactor power to a low level, the concept illustrated in 9. The heat would be removed by natural convection of the air around the vessel and no core damage would result (the concept of 6). We see that PRISM embodies two of the intrinsic safety features described in this brief: it shuts down if it starts to overheat and it can get rid of decay heat by natural processes. Figure 18 shows PRISM in greater detail and includes the normal heat removal loop which includes a heat-exchanger through which flows sodium (the coolant: PRISM is a fast reactor) that has been heated in the core. If this cooling system fails then the core heats up until it spontaneously shuts down. Then the emergency air cooling removes decay heat by natural convection.

9. The PIUS reactor concept developed in Sweden is perhaps better known. It is shown in 19. The reactor core is surrounded by an enormous tank of water at high pressure, containing a reactor "poison" which absorbs neutrons. The poisoned water, if it enters the core, will switch off the chain reactor and transfer the heat from the core by natural convection. Heat can be removed by allowing the water to boil away. As there is a large amount of water it may take weeks to boil it all away. The reactor operates by the main pump pumping clean water into the core to keep out the poisoned water. If the pump stops the reactor is automatically shut down by the entry of the poisoned water.

Drawbacks

10. The basis of intrinsic safety is that a fundamental property of the reactor will protect it from overheating at all times. However, great care is needed in applying this. it might be thought, for example, that to make a reactor reduce power strongly as the temperature rose would always be an advantage, 9. However, in fact, this would make it vulnerable to accidents in which it was cooled too much, say by a steam line breaking leading to rapid cooling so that the power rose

to too high a level and the core was damaged (10). Engineered systems can have their response closely tailored to meet the safety requirements and can in a last resort be switched off by the operator if they are making the situation worse. Intrinsic features require very careful consideration to ensure that they are truly intrinsic safety features under all circumstances.

11. The intrinsically safe designs mentioned above are all novel designs. None of them has been built to date; none are under construction. This contrasts with the relatively long experience with all the currently-used reactor types. It would be a very long time before adequate experience has been built up on the novel systems, in addition it might be that prototype operation would reveal unforeseen problems which comprised the intrincally safety characteristics of the reactor. Finally, being small they would probably be relatively costly for a given output, as noted earlier, in paragraph 7.

12. The main thrust of intrinsically safe designs is to protect against faults occurring within the plant - pumps stopping, loss of water feed, etc. However, these faults are already well protected-against by the safety systems provided in existing designs. It is thought that the safety of modern designs is so high that the risk from these plants is very largely determined by events outside the plant, such as earthquakes. Whilst the intrinsically safe designs offer some advantages in these areas (such as not relying on on-site or off-site power supplies) the case for intrinsic safety against, for example, major structural failure, is by no means obvious. Thus a large earthquake or the impact of a heavy aircraft might split the tank of sodium coolant in PRISM, or the tank of pressurised water in PIUS, in either case the reactor would overheat and give off radioactivity.

Developments of Existing Design with Intrinsic Safety Features in Existing Designs of PWR, AGR, HTGR and LMFBR

13. The concept of intrinsic safety is not ignored in the main stream of reactor development. Several developments of current systems are under way which to varying degrees incorporate features having a degree of intrinsic safety. Advanced PWR and BWR concepts still rely heavily on engineered safety features but the natural capability of water coolant as both moderator and coolant is being exploited to the full. In the AGR, as the temperature of the fuel rises its reactivity diminishes. The passively safe HTGR is a development of existing technology using the high temperature capability and high thermal capacity of the core to enable passive removal of decay heat.

14. PFR, the fast reactor at Dounreay, possesses a number of inherent safety features which provide considerable assurance. It has for example been demonstrated that, in the event of a

failure of forced circulation of the primary coolant, natural circulation will prevent fuel and coolant temperatures from exceeding their normal operating levels. Even in the extreme case whereby, given the above considerations the reactor failed to trip, the reactor's measured negative power co-efficient will automatically reduce the reactor's power level and thereby confine the incident to within the primary containment. A further example which illustrates the PFR's robustness against loss of heat removal incidents is the case of loss of the steam plant and failure to trip, in this instance the reactor power will be returned to zero whilst the primary sodium temperatures rises to a uniform pool temperature of about 600°C.

15. The CDFR design by NNC has many intrinsic safety features such as using the heat transport capability and thermal capacity of sodium to minimise the reliance on external power sources for decay heat removal. Experiments at DFR and WAGR during their concluding phases of operation, and also at PFR, have demonstrated that many of these intrinsic safety features of current designs are effective in practice and provide a valuable and resilient safety margin which is intrinsic in the basic design of the relevant system.

16. Evidently designs of intrinsically safe reactors are still at a formative stage. No plants have been been built or operated. The concept of intrinsic safety is appealing but it may not prove easy to realise in practice: there is no experience of the reactors proposed and the designs may not be proof against the complete spectrum of initiating events considered for developed designs. Also there may be an economic penalty.

17. It is likely to be more fruitful to continue the development of existing designs which incorporate some intrinsic safety features already. These developed designs have a balance between intrinsic safety features and carefully designed engineered safety features so that the plant does not rely entirely on either for its safe and reliable performance.

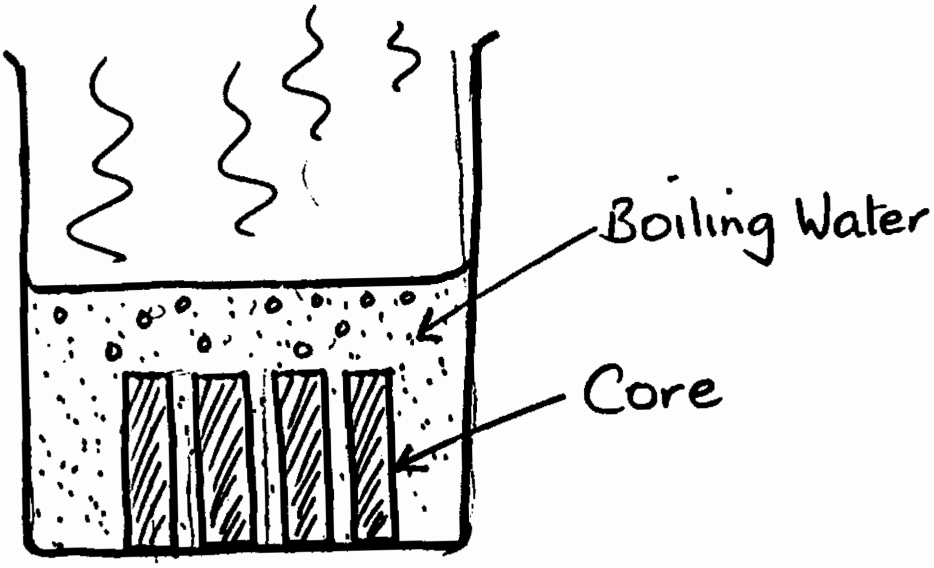
CONCLUSIONS

1. There is a view that intrinsic safety features are better than engineered safety features. For example, shut-down absorbers might not be dropped into the reactor when needed but if the coolant is the moderator then fission-heat ceases when the coolant is lost (no coolant but nothing to cool ...).

2. Unfortunately intrinsic features cannot be switched off which lead to limitations and could in extreme situations even be dangerous. Thus they may not be truly intrinsic safety features under all circumstances.

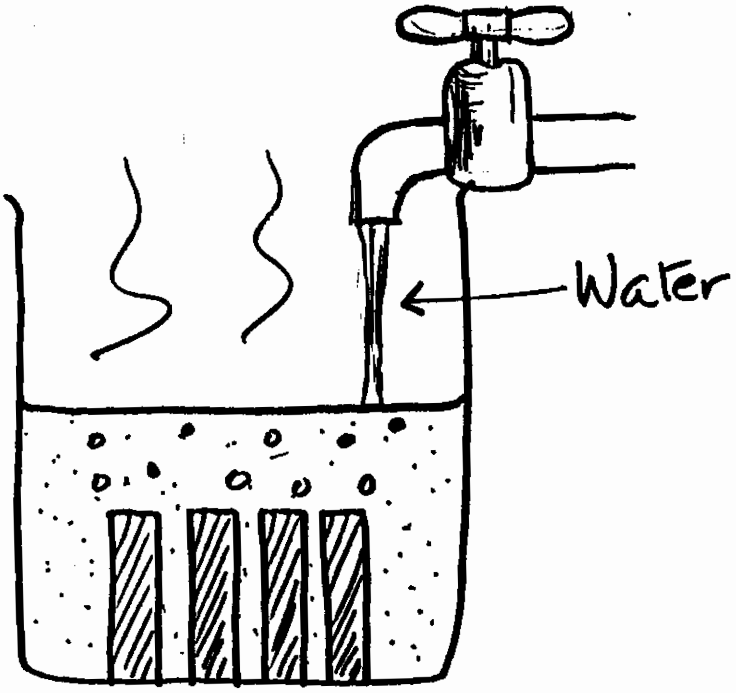
3. We therefore need to employ both intrinsic and engineered safety features. This is done. The UKAEA is re-examining existing reactors to see whether the right balance is struck between the two.

1.



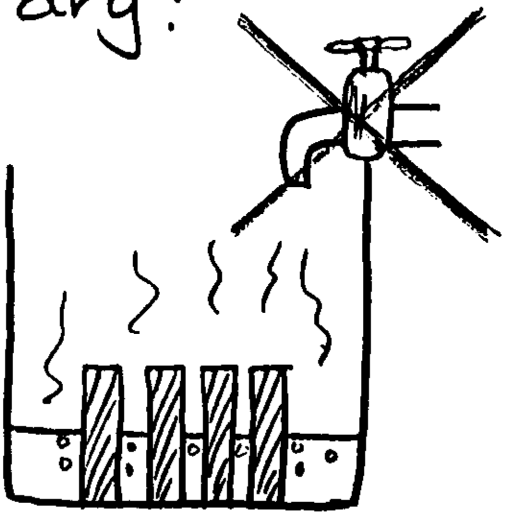
Simple intrinsically-safe reactor.
Heat from the core boils water.
The water is the moderator, too.

2.



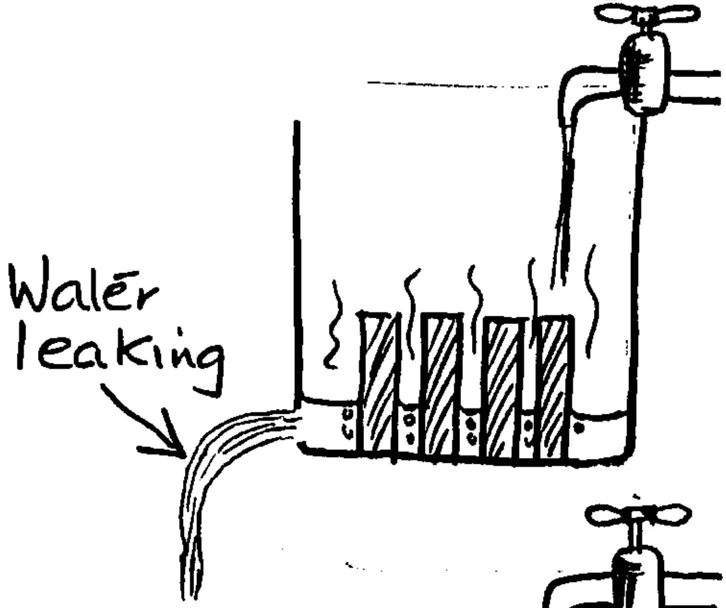
Water must be added to make up for the water boiled away.

3. Three things may allow it to boil dry:



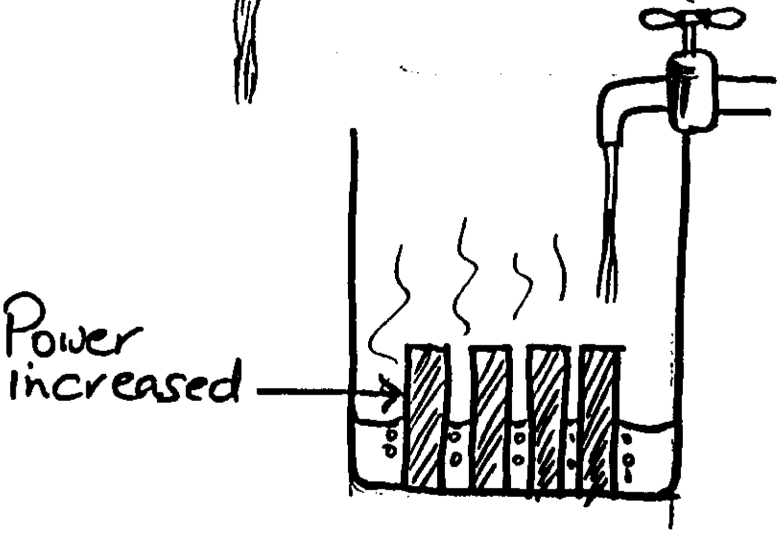
A.

Too little water added.



B.

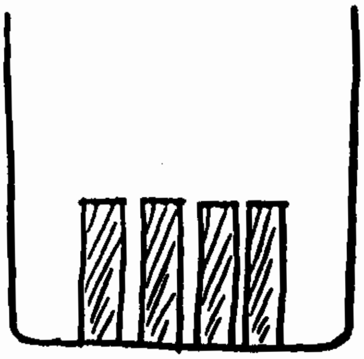
Water leaks away faster than it is added.



C.

Too much heat evolved.

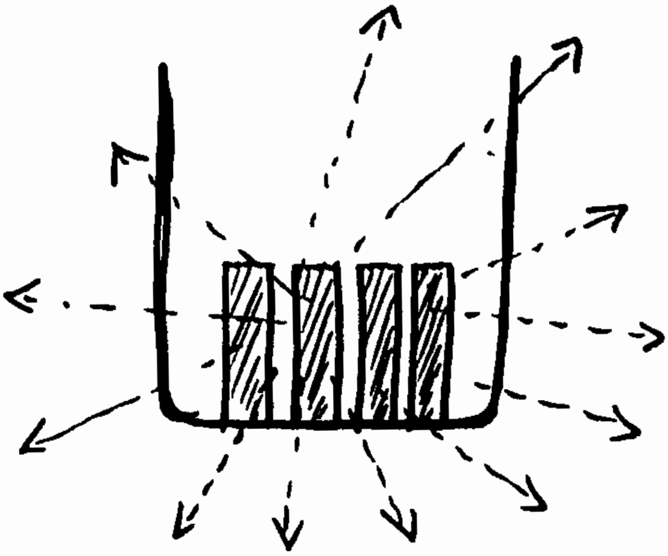
4. When it has boiled dry the generation of FISSION HEAT stops. This is because the water was the MODERATOR:



No moderator
so
No fission.

This is an INTRINSIC SAFETY FEATURE

5.

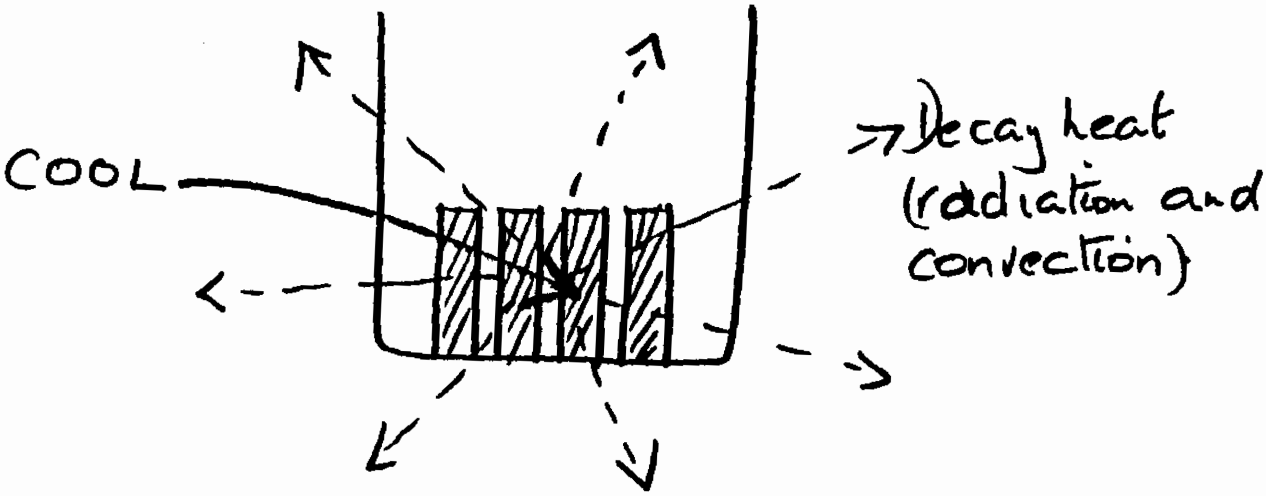


Decay heat radiated and convected

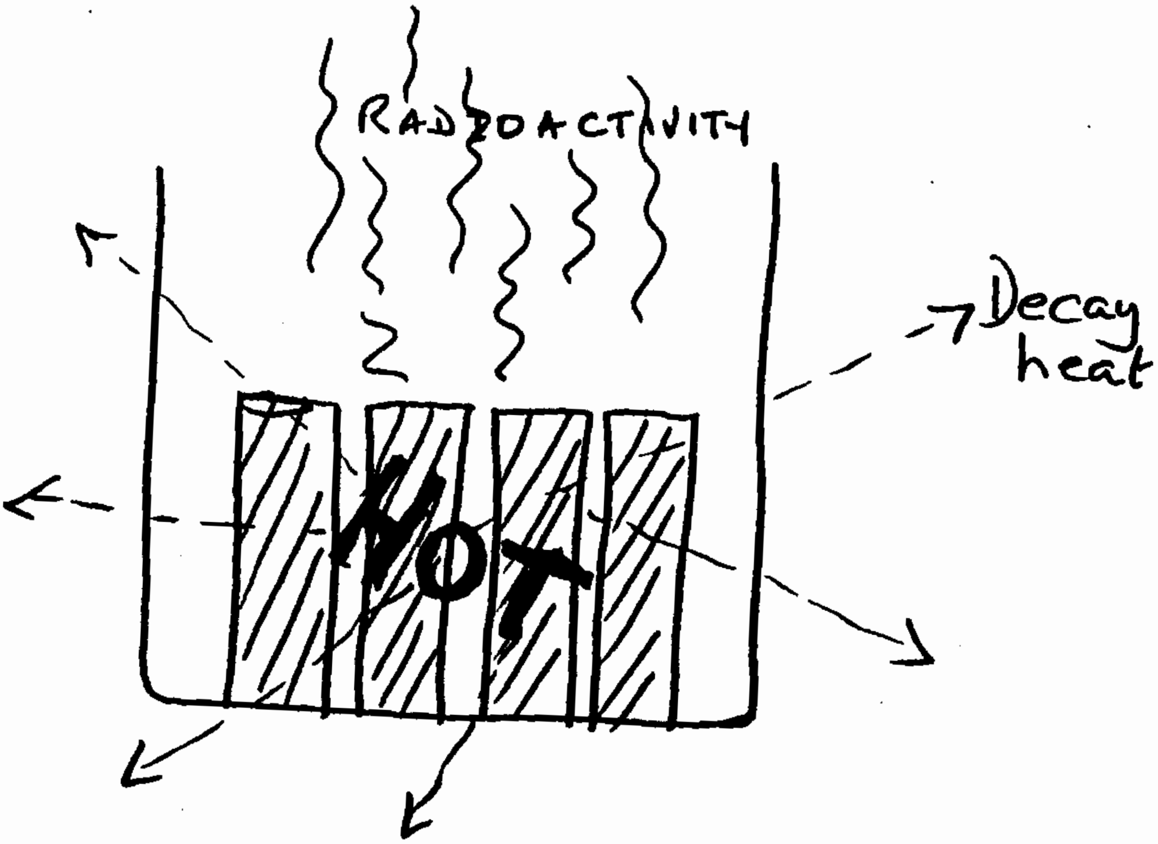
The DECAY HEAT is dissipated to the surrounding environment

This is another INTRINSIC SAFETY FEATURE.

6. If the core is small then it will remain cool:



7. If the core is large it will get too hot in the centre and will give off radionuclide aerosols:



8.

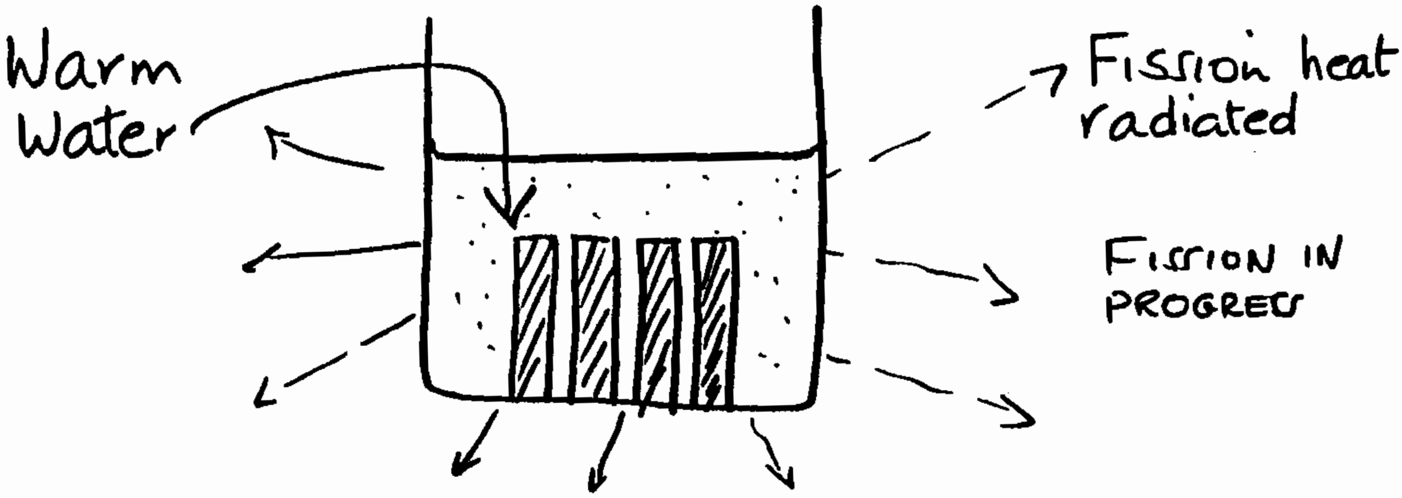
We conclude that a Simple, INTRINSICALLY-SAFE REACTOR could:

i) Use water as both coolant and moderator. The PWR does this.

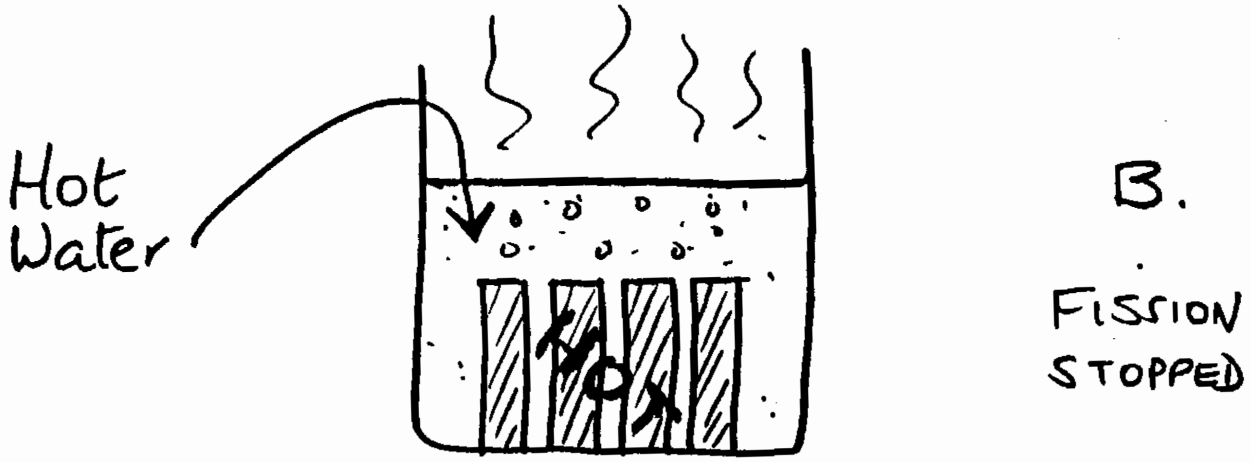
ii) Be small so that it dissipates decay-heat without getting too hot. A conceptual reactor, PRISM, is like this.

9. Another INTRINSIC SAFETY FEATURE is a core in which fission ceases when the temperature rises:

A.



B.



10. However if we accidentally over cool the core, fission may start up again unexpectedly: the INTRINSIC SAFETY FEATURE has led to an UNSAFE CONDITION.

11. Evidently INTRINSIC SAFETY FEATURES can be dangerous. And unlike ENGINEERED SAFETY FEATURES (such as a water-pump) they cannot be 'switched-off," if they are unhelpful.

12. We need to incorporate the best of both, in fact.

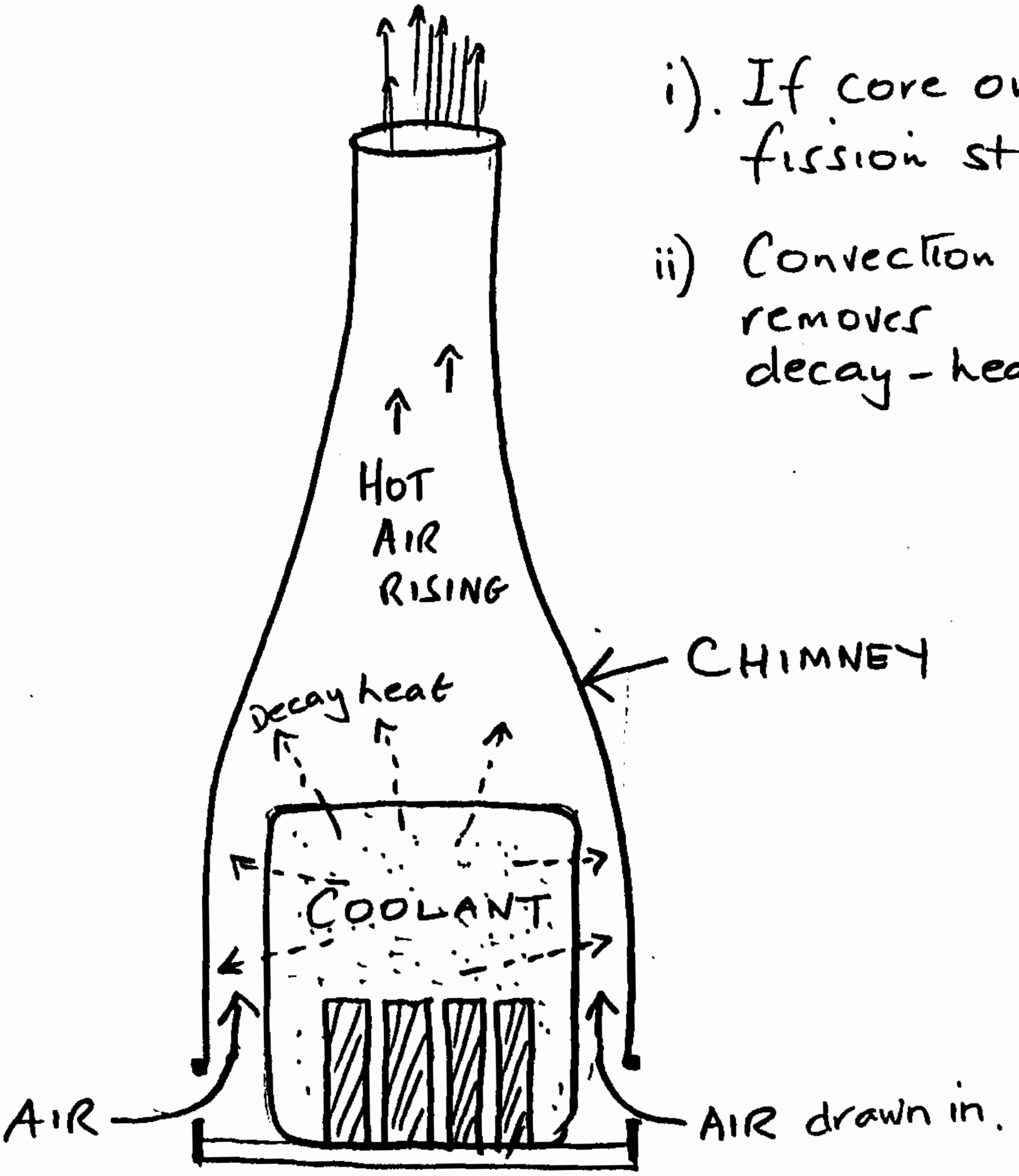
13. This is done; here are 3 examples:

14. Thus the WINDSCALE AGR shut-down when it over-heated.

15. Again the DOUNREAY PFR can dissipate decay heat to the enviroment by natural convection processes.

16 And in a PWR the water coolant is also the moderator, as we have seen above.

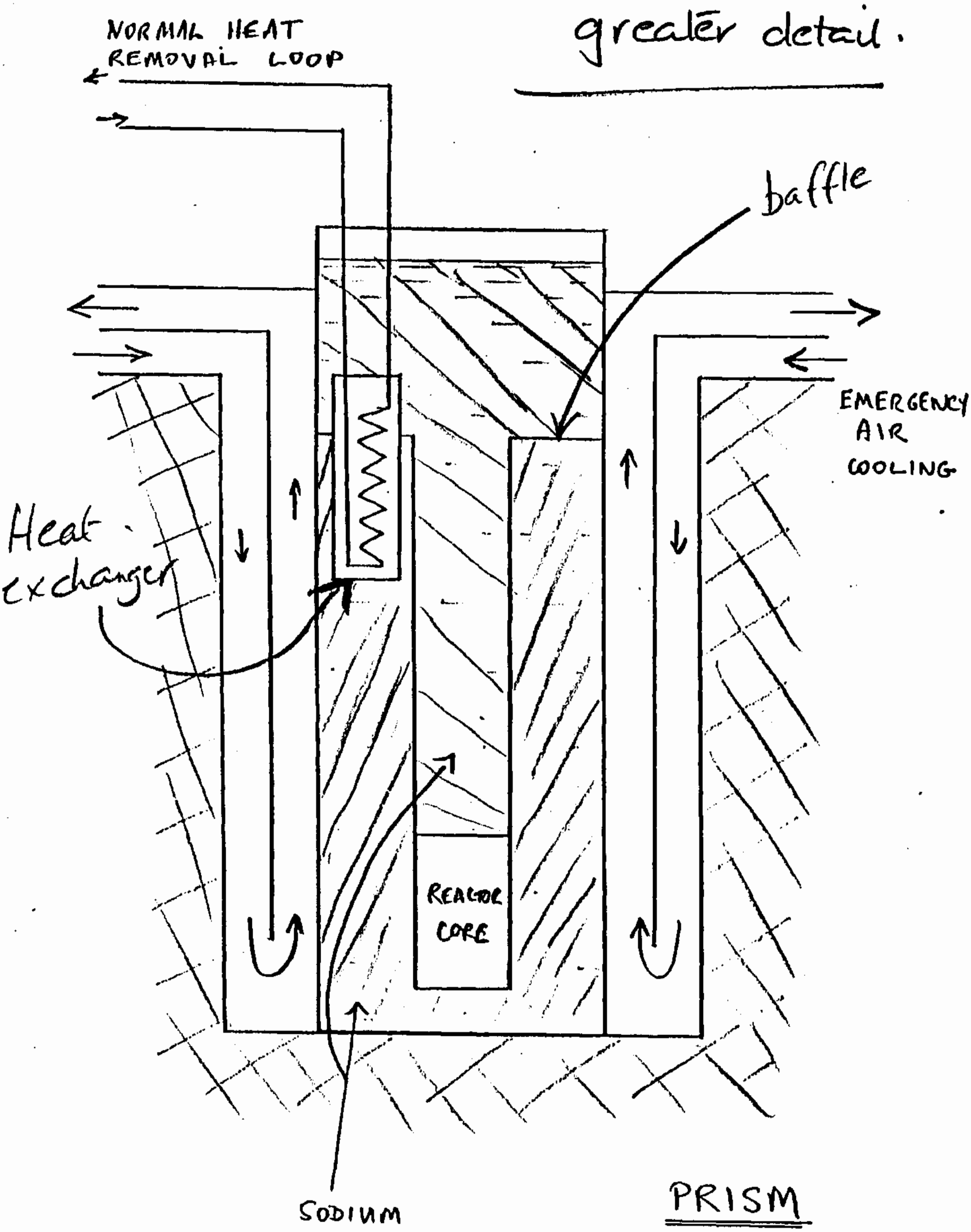
17. One conceptual reactor that relies totally on INTRINSIC SAFETY FEATURES is the US device called PRISM:



i). If core overheats, fission stops.

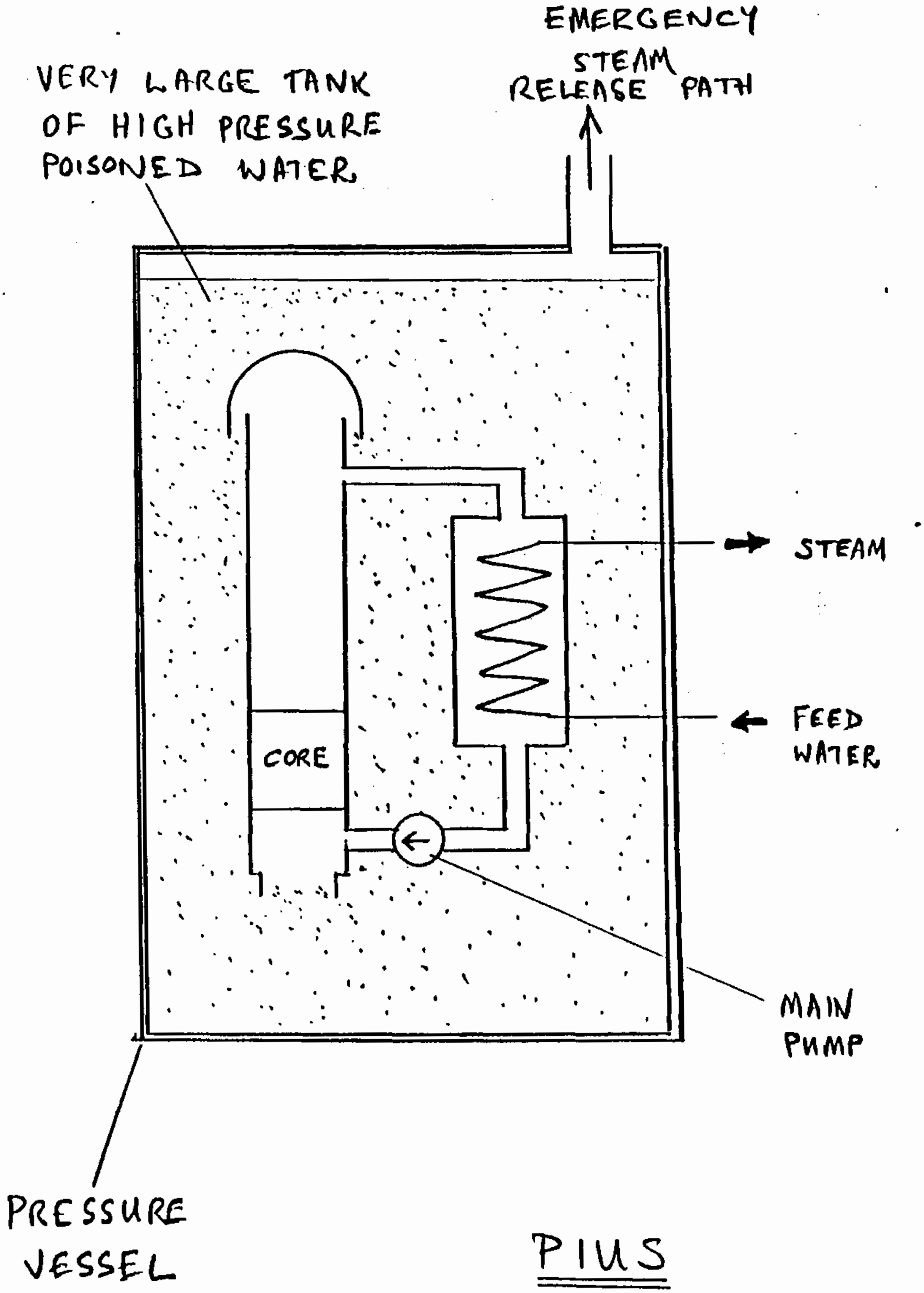
ii) Convection then removes decay-heat.

18. PRISM in greater detail.



PRISM

19. Another concept is PIUS



PIUS

28·7

CENTRAL ELECTRICITY GENERATING BOARD

Sudbury House, 15 Newgate Street, London EC1A 7AU. Telephone 01-634 5111

From the Chairman
The Lord Marshall of Goring Kt, CBE, FRS

23 July, 1986

Emeritus Professor J H Fremlin
46 Vernon Road
Edgbaston
Birmingham
B16 9SH

/cc → JHS

Dear John,

The man who can best help you understand Chernobyl is I think John Gittus. He will be coming with me to the conference in Vienna in August and he has the responsibility to write up the British report on the conference. I also think he would enjoy helping you. I have therefore copied your letter to him with the suggestion that he gets in touch with you.

The statement that came from the Russians yesterday explains that they were doing experiments with the turbine generator so that it looks as though my guess that they were looking at mixed oxide fuels was incorrect. I do hope the Russians explain everything clearly in August, else we shall all be left very frustrated and puzzled.

Your second question is easily answered. There are several specific parts of the Chernobyl design which would have prevented it getting a licence in this country. So that you can understand that, I attach to this letter several notes which I have put out in recent weeks. I am also asking NNC to send you a copy of their review report of the RBMK design written in 1976. John Gittus could best answer your questions about collective dose.

Yours sincerely,

Walter

Marshall of Goring

ccs: Dr J Gittus ✓
Mr C H Davies
Mr R W Clarke

15.7.86.
8147

EMERITUS PROFESSOR J.H. FREMLIN
46 Vernon Road
Edgbaston
Birmingham
B16 9SH

Telephone: 021-454 0314

14th July 1986

15/7 ✓ cc A W Clarke } draft reply for
LM Davies } Chmn's consid.
asap pl.

Lord Marshall,
CEGB,
15 Newgate Street,
London EC1

Dear Walter,

To whom should I write to ask for the latest data on Chernobyl, so that I do not have to bother you again?

The Oxford University Press is to bring out a paper-back edition of my book, and have said I can write a postscript on Chernobyl, and will allow me 3000 words if get it done by the beginning of October. Although I need it badly within the next two months I have as yet seen no definitive statement from the USSR of the initiating cause of the accident itself. Your suggestion that experiments with U-238 and Pu-239 could have been responsible sounds very likely if the experiments involved only a small - perhaps separately cooled and monitored - section of the core, especially if the change of cross section for Pu-239 with moderator temperature is different from that of U-235. Whatever the cause was it seems likely that an operator error or a monitoring failure was involved.

My second question would perhaps more properly go to the Nuclear Installation Inspectorate. I would like to know of any specific part or parts of the Chernobyl design that would have prevented the granting of a licence, and if possible how one of such parts could have contributed to the accident. If any such part could be identified it would be of very great value in a discussion of the effects of Chernobyl on our own estimates of risk.

The other thing that I badly need to know is the Soviet estimate of the total collective dose received in the Ukraine or elsewhere, and any data available on the areas with local dose rates to people in the open above 20 rem/year, 5 rem/year and 1 rem/year, or any other quantitative data on, more realistically, any figures on the dose rate criteria used to control the return from evacuation and the numbers of people involved.

Data on dose criteria for evacuation may be difficult to get, because some very silly things seem to have been done. It seems to me highly probable that evacuation from Kiev was a response to frightened people rather than to important radiation doses; and the idiot advice to women not to have children for three years looks like a party boss wanting to look extra careful of his people and with a complete ignorance of the difference between congenital damage to babies in utero at the time of the irradiation and the much less likely genetic damage for which the risk of expression or transmission would last for the rest of a woman's life.

I had some good reports from friends in our audience at the House of Commons, suggesting that each of us satisfactorily complemented the other.

Yours sincerely,

FOR YOUR INFO.

Dr Gittus.

Enclosures sent to John Fremlin by Lord Marshall included:

Diagram of Chernobyl RBMK Type Reactor
" " SGHWR
" " AGR

A Note from CEGB re: Chernobyl Nuclear Accident.

The Accident at Chernobyl - The Containment Issue

WM's speech to BNF Annual Luncheon on 1 May '86

Nuclear Power: Energy of Today and Tomorrow.

Issue No: 5

Date: 6th June 1986

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CHERNOBYL ACCIDENT NEWSLETTER

****

This newsletter is issued by The Director
Nuclear Operations Support Group,
CEGB,
Sudbury House,
15, Newgate street,
London EC1A 7AU.

(Edited by the Nuclear Operations Services Engineer)

Introduction

This is the fifth issue of a newsletter on the Chernobyl nuclear accident. The purpose of the newsletter is to provide a concise account of what is currently known and, where appropriate, what can be reasonably surmised about the station, the event itself and its radiological and political aftermath both in the UK and abroad.

The newsletter is compiled from all available sources by representatives of NOSG, GDCD and BNL in the CEGB and by SRD in UKAEA.

The newsletter is revised and reissued weekly. In advance of a new issue, daily updates are provided, as appropriate.

The weekly newsletter and daily updates are available to organisations within the UK nuclear power industry. See attached list. Copies which are mailed (rather than electronically distributed) will have new and changed material side-lined.

PART 1. PLANT DESIGN

CHERNOBYL RBMK 1000 REACTOR DESIGN

1. DESIGN SUMMARY

The basis of a nuclear station containing RBMK reactor units is provided by two units of electrical power 1000 MW each, with a common fuelling machine hall. Each unit is a reactor of a graphite-moderated, pressure tube, boiling water type with direct cycle to two 500 MW turbines. The reactor fuel is contained inside pressure tubes, which are located in the graphite in vertical columns. The reactor water passes through the pressure tubes and starts to boil. The steam leaves the pressure tubes as a two-phase mixture with a void content of 15%, is directed to common steam lines, and is then transferred to the turbines.

Thirteen units containing RBMK-1000 reactors are now operating: 4 at Leningrad nuclear power station, 4 at Chernobyl, 3 at Kursk, 2 at Smolensk, and 1 unit containing an RBMK-1500 at the Ignala nuclear power station.

Fairly extensive information has been presented in Russian and Western technical literature, however where specific reactors have been considered these have generally been those at Leningrad or Smolensk.

The reactor involved in the incident at Chernobyl is the most recently constructed fourth reactor, ie second half of the second station. This is thought to be part of the same series and thus similar to the Smolensk reactor. The information presented here should thus not be considered a precise description of Chernobyl No 4 reactor, but has been taken from all the available sources on RBMK 1000 reactors.

It should be noted that because Part I of the newsletter is a concatenation of several sources rather than a written paper some repetition of information has been inevitable in attempting to cover as much detail as is available.

2. LARGE RBMK UNITS IN SERVICE AND UNDER CONSTRUCTION

Status at 31.12.85	Station	Unit Output MWe (net)	No of units	Commercial operation
In Service	Leningrad	950	4	1974-1981
	Kursk	950	3	1976-1983
	Chernobyl	950	4	1978-1984
	Smolensk	950	2	1983-1985
	Ignala	1450	1	1984
Under Construction	Kursk	950	1	1986
	Ignala	1450	1	1986
	Chernobyl	950	2	1987-1989
	Smolensk	950	2	1988-1989
	Kostroma	1450	2	1988-1989

Figure 1 shows the location of these stations in the USSR.

3. STATION LAYOUT

Two different arrangements of the reactor and turbine halls have been adopted for the RBMK stations. Fig 2, attached, shows the arrangements of the main buildings in the first stages (units 1 & & 2) at Kursk & Smolensk, and Fig 3 is an artist's sketch of the Smolensk plant. The dates of construction might suggest that Chernobyl 1 & 2 resembles Kursk, whilst the two later units resemble Smolensk as shown in Figure 3.

In the Smolensk layout the buildings A, B, C & F of Fig 2(a) have been replaced by a single block measuring 72 m x 162 m. The reactor blocks face each other with their transport entrances. The space between the reactor blocks is occupied by auxiliary systems and repair services. The reactor section also includes the pump station & evaporation plant of a liquid waste storage facility, and a gas-activity suppression plant which is located directly under the central span roof. The stack is located on the roof of the reactor section.

4. REACTOR VAULT

The graphite structure forming the core and reflector is supported on a welded metal structure. There is concrete shielding 3 m thick above the core and 2 m thick below the core. Water tanks provide the inner radial biological shielding and there is an annulus filled with special sand between these water tanks and the outer concrete of the reactor vault. The space immediately round the graphite core is sealed and contains a helium/nitrogen mixture (40% He/60% N2).

The space outside the inner volume is filled with nitrogen at 22 mm WG higher pressure than that of the He/N2 mixture. If a pressure tube should burst and increase the pressure in the gas space there are special bursting discs which are designed to relieve pressure at 1.8 kgf per square cm (26.5lb per square in).

5. THE REACTOR CORE AND REFLECTOR

The core is 12 m in diameter and 7 m high. The graphite assembly is formed from graphite columns consisting of blocks of graphite 250 mm squared x 600 mm high with openings for channels 114 mm diameter. There are also 20 openings 45 mm diameter in the graphite assembly for temperature channels (situated along ribs of the columns) and in the outer columns of the graphite stack are positions for the reflector cooling channels. The total number of columns is 2488 and the total weight of the graphite is 1700 te (density of 1.67 g/cc).

The graphite columns rest on steel slabs placed on steel structure and they are centred by shielding slabs and connecting pieces. Radial movement is prevented by rods located in the peripheral columns of the reflector.

The heat generated in the moderator is transferred to the fuel channels by conduction and radiation via 'piston ring' type graphite rings, one mounted tightly on the fuel channel and the other fitting tightly in the graphite column (Fig 4). The maximum temperature in the graphite stack is 700 degrees C.

The core is enclosed by a radial graphite neutron reflector 1 m thick and top and bottom neutron reflectors each 0.5 m thick. It contains the uranium fuel elements, the moderator, coolant, reactor control rods, radial and vertical neutron-flux sensors, and thermocouples for measuring the graphite temperature.

6. FUEL CHANNELS

The RBMK-1000 graphite-channel boiling-water reactor has 1693 fuel channels (FC) arranged in vertical holes in the graphite stack (see Fig 5). Each channel has a body of tubular construction within which is located a fuel stringer.

The coolant is boiling light water circulating in the vertical zirconium channels which pass through the graphite moderator.

The part of the pressure tube inside the moderator is made of a zirconium alloy and has the form of a tube 88 mm in diameter with a wall thickness of 4 mm.

The upper and lower ends of the zirconium 2.5 Nb alloy tubes have extensions made of alloy steel which are connected by special transitions pieces (see Fig 6) to ensure they are leak-proof at operating temperatures, when transition sections transfer steam to steam separators. The upper end of each channel has a sealing device to meet the requirement of the refuelling machine (Fig 7).

The joining of the Zr-2 1/2 Nb tube to the stainless steel sections is achieved by means of transition joints (Fig 5). The Zr-2 1/2 Nb is welded to a zirconium alloy transition piece (zircaloy-2 or zircaloy-4) by means of an electron beam weld and the transition piece is then joined to the stainless steel by means of a diffusion weld. There is then a further weld, argon arc, between the stainless steel piece and the connection to the upper and lower steel structures of the reactor. The condition of the Zr-2 1/2 Nb pressure tubes on installation was believed to be 45% cold worked followed by stress relief at 550 degree C, a condition for low growth under irradiation. The fuel channel assembly is welded directly to the header (ducting the steam water mixture to the drum separator) and via a thermal expansion joint (stainless bellows) sub-assembly to the water feed lines.

7. THE FUEL

Each of the 1693 fuel channels contains two fuel sub-assemblies held together by a central supporting rod and suspended from a plug in the upper duct (see Figs 8 & 9)

The sub-assemblies are each 3.5 m long and are made up of 18 fuel pins (called elements by the Russians) spaced by ten stainless steel cellular spacer lattices. The fuel pins are of 1.8% enriched uranium dioxide pellets in a zirconium-niobium (Zr + 1% Nb) cladding 13.6 mm od and 0.9 mm thick. The inner space of the fuel pin is filled with an argon-helium mixture.

Details of the fuel elements and their thermal parameters are given in Tables 1 and 2 respectively. The design dryout margin for the sub assembly under steady operating conditions with continuous refuelling is reported to be 1.38.

The design limit of damaged fuel pins for normal operation (in terms of number and size of fuel pin defects), which determines the level of activity which may be reached in the primary coolant, is as follows (primary damaged fuel pin design limit):

> 1% of fuel pins with gas leaks, and 0.1% of fuel pins in which there is direct fuel/coolant contact.

8. CONTROL ROD DESIGN

The channels for the control and shut-down rods and the in-core instrumentation run through the central holes in the graphite columns. The square lattice of 211 control rods and 12 vertical power profile sensors has a pitch of 700 mm and is at 45 degrees to the fuel lattice.

The control rods are divided functionally into groups covering radial control of the power distribution, maintenance of the required radial field profile (local automatic regulators, automatic regulation of mean power level), emergency interruption of chain reaction (safety rods), and regulation of axial power distribution. The rods of the first four groups are withdrawn from the core upwards; the shorter absorber rods of the last group are withdrawn downwards. The control-rod channels are made of the same zirconium alloy as are the fuel channels and are 88 mm in diameter and 3 mm thick. They too are fitted with graphite rings on the outside. The rods are built up from standard absorber elements with articulated joints.. In each element a 65 x 7.5 mm boron carbide sleeve is contained in the leak-proof annulus formed by a 70 x 2 mm outer tube and a 50 x 2 mm inner tube, both made of aluminium alloy.

The control rod channels are cooled by a separate water cooling circuit. Water from a circulation tank is pumped by electric pumps to the top of the reactor where it enters the control channels at 40 degrees C. It leaves the channels at a maximum temperature of 76 degrees C and passes via heat exchangers back to the tank. When the rods are withdrawn from the core they are replaced by graphite displacers to reduce parasitic absorption caused by the coolant.

The rods are divided by function as follows.

(a) 89 manually operated rods.

(b) 12 automatically operated rods for power variation.

(c) 57 emergency shutdown rods.

(d) 21 shortened absorber rods. These, and the manual rods are used for controlling the power distribution in the reactor.

The power distribution control, radial profile control, power-level control and safety rods consist of six elements and have an overall length of 6170 mm, while the axial profile control rods consist of three elements and have an overall length of 3050 mm.

9. REFUELLING

The RBMK reactors are designed to be refuelled at full load. Fig 2 illustrates a refuelling machine operating from a gantry running the full length of the common fuelling machine hall.

Recharging fuel on the first and second units at the Leningrad power station with the reactor operating was carried using the charging-discharging machine.

After assembly the machine was adjusted and tested on a special rig.

For one recharging cycle which takes 3 hours, the machine carries out the following operations semi-automatically:

- loading of new fuel sub-assemblies into the machine on the rig;
- accurate approach to the fuel channel being recharged and linking up with it;
- breaking the seal of the fuel channel and removal of irradiated fuel sub-assembly;
- checking fuel channel with special gauge;
- placing new fuel sub-assembly;
- sealing fuel channel;
- unloading of irradiated fuel sub-assembly from charging-discharging machine into the storage pond receptacle.

During the recharging process the water in the recharging machine is maintained at a pressure slightly in excess of the pressure in the fuel channels which creates an excess flow of cold water up to 1 cu m/hour and prevents contamination of the machine by circuit water.

During the reactor operating period the charging-discharging machine carried out more than 200 recharging cycles with the reactor on power. No events requiring observation occurred.

Before the charging-discharging machine was brought into operation removal of supplementary absorbers and fuel sub-assemblies on the shutdown reactor was carried out using the protective casing of the central hall crane.

10. THE COOLANT SYSTEM

The coolant circuit is shown in Fig 10. It consists of two parallel loops each of which cools half of the reactor.

Water at 270 degrees C enters the bottom of each fuel channel individually through a 53.5 mm diameter pipe. On leaving the top of the fuel channel the steam water mixture is passed via an individual 72 mm pipe to a drum separator. Each loop has two drum separators linked by steam and water connectors. The drums are made of carbon steel lined with stainless steel. Saturated steam at 284 degrees C, 70 kgf/sq cm is passed to a general collector supplied by both loops from which it enters two 500 MW turbines. Condensate from the turbine is returned to the drum separators by electric pumps.

A feedwater collector is located along the bottom of each drum separator. From these collectors feedwater is taken via 12 312 mm downcomers to a 1020 mm pump inlet header. Each loop has 4 main circulation pumps (3 operational, one standby) which pass the feedwater to a pump outlet header. From the outlet header the feedwater passes via 22 325 mm lines to the pipes which feed the individual channels.

The water is maintained by deaeration and anion/cation beds at:

O_2 = 0.1 - 0.2 mg/kg
Cl < 0.1 mg/kg
Cu < 0.05 mg/kg

Under boiling conditions and in the absence of measures to suppress radiolysis the quantity of radiolytic gases in the steam is 15-25 normal ml/kg H_2 and 8-12 normal ml/kg O_2 .

(Comment: This may be of some importance since it suggests a mechanism for the production of explosive gases which does not require any Zr/H_2O or H_2O/graphite reaction).

The specific conductivity of the feedwater is 0.1 micro Siemens/cm while that of the circulation water is 1.0 micro Siemens/cm.

The silicic acid content in the reactor water is less than 0.5 mg/kg.

The corrosion products of iron (calculated as iron) are standardised at < or = 0.2 mg/kg.

11. MODERATOR He/N_2 CIRCUIT (see Fig 10 and Fig 13)

The space immediately round the graphite core is sealed and contains a helium/nitrogen mixture (40% He/60% N_2)* which is circulated through the core and inner structures. This is at a pressure of 150 mm WG and the flowrate is 500 cubic m/h. It is fed into the inner chamber below a membrane under the core and flows through the gaps between the graphite blocks.

* Composition from other references gives 60:40 and 80:20. The purpose of the nitrogen is unknown although one technical paper stresses that it has been 'optimised.' Helium is inert with good heat transfer and low neutron cross section capture properties. The negative reactivity worth of the nitrogen at such a low pressure and core voidage is not thought to be of significance in overall reactivity calculations.

Gas is removed from the reactor through 12 mm pulse tubes from each channel of the reactor. The channel integrity monitoring system monitors the gas for increased relative humidity and increased temperature. A leak in one of the channels causes an increased humidity signal which identifies the group with the faulty channel and an increased temperature signal identifies the individual channel. The gas is then dried and purified and returned to the space below the graphite core from which it is distributed via annular gaps in the channel graphite blocks. Any impurities are discharged via the stack. The circulation and drying of the gas also ensures that water vapour (and hence water) is removed from within the moderator envelop. The space outside the inner volume is filled with nitrogen at 22 mm WG higher pressure than that of the He/N2 mixture.

12. SHUTDOWN HEAT REMOVAL

The residual power production in the core when the reactor has been shut down is fairly substantial. For example, after a day it is 0.4% of the nominal power (Nnom), ie, 12.8 MW. After 30 days, this falls to 0.12% Nnom and then remains virtually constant for a long time. This makes clear why it is not permissible to drain the core even after shutdown. Therefore, in conducting servicing on the forced multiple circulation loop (FMCL), it is necessary to organise core cooling.

One of the basic specifications required by USSR designers for such a cooling system is that the cooling should be reliable and that safe access should be provided to the Forced Multiple Cooling Loop for examination or repair. This is attained by installing shut-off valves at various parts of the circuit to provide for draining, and also for organising various core cooling modes.

During the design of the RBMK, three conditions of service cooling were provided for in order to facilitate servicing, as shown on Fig 15.

1) natural circulation with nominal water levels in the separators and the FMCL valves open;

2) interrupted natural circulation with the separators drained and the FMCL valves open; and

3) bubble mode with nominal water levels in the separators but with the pressure-regulating valves (PRV) at the inlet to the fuel channel (FC) closed.

Natural circulation in the Forced Multiple Cooling Loop is provided by cooling the water in the outlet section of the loop, for which one uses the ordinary flushing and cooling system. The coolant heated in the core is transferred by the cooling pumps from the water tapping points in the separators to the flushing cooler, where the temperature is reduced by heat transfer to the water in the intermediate circuit. The cooled water passes to the feed pipelines and then to mixers at the inlet, which thereby cools the circuit. This condition is used for ordinary reactor cooling, in repairing the main circulation pumps (MCP), and also in servicing the pressurised and suction pipes, as well as for preliminary cooling of the reactor and FMCL before the start of servicing.

In the state of interrupted natural circulation, the separators are drained and communicate with the atmosphere. The core is supplied by spontaneous flow from a servicing tank connected to the pressurised collectors in the Forced Multiple Cooling Loop (FMCL) by special pipes.

The gate valves in the main circulation pumps may be closed, ie, it is possible to drain the FMCL as well. In this state, one can service the separators, the pipelines, the suction collectors, and the MCPs' pipelines with their valves. Here, to provide for safety, special rubber-metal plugs are inserted in the pipelines from the collectors and the main circulation pumps.

In the third state, the pressure regulating valves (PRV) at the inlet to the FC are closed, and the level in the separators is nominal. Under these conditions, one can repair the equipment and the FMCL pipes on the section from the inlet gate valves on the MCP to the PRVs. This mode of cooling is widely used in general replacement of failed transducers in the flowmeters and PRVs. In the latter case, a special freezing system provides ice plugs in the water pipelines.

If the circulation ceases and parts of the Forced Multiple Cooling Loop (FMCL) are drained, the following technical specifications have been inserted in "Engineering Rules for Operating Nuclear-Power Station Units Containing RBMK Reactors."

Transfer of the fuel channels to bubble mode, ie, closing the valves at the inlet, is allowed not earlier than 72 hours after shutting down the reactor in order to reduce the residual power to a permissible level if the following conditions are met:

(a) water levels in the separators are above the ends of the upper series of steam-water pipes (SWP);

(b) the water temperature in the separators should be not less than 80-90 degrees C in order to avoid hydraulic shocks in the SWPs; and

(c) the pressure in the separator is atmospheric.

It is forbidden to reduce the water levels in the separators below the ends of the SWP if the fuel channels have closed inlet valves.

In all cases where parts of the forced multiple circulation loops (FMCL) are drained, the water level should not fall more than 1 m below the heads of the fuel channel (FC), and then it is necessary to provide a constant supply of cold water to the core. Also, studies on servicing conditions involving water level reduction in the loop have enabled the limiting positions to be established for the upper and lower water levels in the servicing tank, which is connected to the FMCL to supply the core when the outlet system is drained. Results obtained with interrupted natural circulation experiments have enabled specifications to be formulated for the forced cooling system operating during servicing without boiling.

13. EMERGENCY FEED AND COOLING SYSTEM

Safety of the installation with complete stoppage of feed water fed into the power units is achieved by switching off the reactor by the emergency safeguarding system according to a signal for decreasing the flow rate below 50% of the instantaneous value. In this regime, the input of water into the circulation loop by emergency feed pumps constitutes approximately 10% of the nominal value; they are switched on 10-20 sec following cessation of feed water inflow. As investigations showed, cessation of feed water flow leads to a decrease in the level in the separators. This can cause an undesirable entrapment of steam in the down-drop part of the loop and cavitation failure of the main circulating pumps, and inhibits the development of natural circulation. Lowering the level in the separators is avoided by switching off the main circulating pumps, which decreases the rate of decrease in the steam content in the active zone and the output pipelines of the reactor. As a result of this, less water is required from the separators for replacing steam in the circulation loop.

The regime in which input of feed water ceases with switching off of the main circulating pumps is similar to the shutoff regime for the unit, namely:

the rate of decrease of heat energy is greater than the rate of decrease in the flow rate of water over the entire transient process, which indicates reliable cooling of the active zones; maximum decrease in the level in the separators is observed after 75 sec, and then it begins to increase; the steam pressure in the separators at the beginning of the process decreases and then becomes somewhat greater than the nominal value, and after 72 sec stabilizes at the nominal level.

The main circulating pumps are switched off after triggering of the emergency safeguard systems according to a signal showing a decrease in the flow rate of feed water below 50% of the instantaneous value with a decay of approximately 9 sec. The active zone is cooled by natural circulation of the heat carrier.

It is assumed by USSR designers that most serious emergency situations can arise with rupture of the large pipelines in the power unit. In the event of depressurisation of the primary circuit, the emergency cooling system must guarantee the following (secondary damaged fuel pin design limit):

fuel pin cladding temperature not greater than 1200 degrees C;

local depth of cladding oxidation not greater than 18% of the initial wall thickness;

fraction of reacted zirconium not greater than 1% of the mass of fuel pin claddings of the channels of one main distributing header.

The design includes technical means that do not permit the emission of the steam gas mixture into the operation area and especially outside the limits of the nuclear power plant, which are described in Section 16. The most characteristic damage of the circulation loop is rupture of the small pipelines (drainage, pulsed lines, etc). Rupture of the large pipeline was thought most unlikely. Experiments on natural specimens showed that at a pressure of 8.5-9.0 MPa in pipelines with a diameter of approximately 800 mm, leakage is possible if the depth of the fatigue cracks is approximately 0.75 of the thickness of the wall, and length approximately 470 mm. Monitoring the metal guarantees elimination of sudden pipeline rupture, since the critical dimensions of the defects are large and must be revealed with planned shutdown of the units. During inspection, the metal is examined and monitored by special methods (ultrasonic flaw detection, acoustic emission). In spite of this, the design of nuclear power plant includes measures which ensure its safety with sudden transverse rupture of the largest pipeline.

Initially, leakage is about 6 tons per sec in the case of total sudden rupture of a pipe with diameter 300 mm and approximately 40 tons per sec with the same rupture for a pipe with a diameter of 900 mm. As a result of an analysis of emergency situations, two independent signals have been chosen for triggering the emergency safeguard for the reactor: pressure increase in enclosures where the pipelines of the loop are located and decrease in the level in any separator to values exceeding its deviation from the nominal value in the transient regimes.

The most dangerous is a rupture of a pipeline at the head of the main circulation pump, since in this case there is a sudden cessation of input of heat carrier into the channels of the emergency path of the reactor. This particular hypothetical accident determines the fast response of the emergency reactor cooling system, its maximum capacity (about 1.1 tons per sec), and minimum time for removing all of the heat carried from the emergency loop (10-12 sec). In order that the fuel elements are not damaged, the heat carrier is introduced into the channels of this half from the emergency reactor cooling system.

The water from the emergency reactor cooling system is input to each distributing group collector, and in order to avoid its loss through the rupture section in the head collector non-reverse valves are provided at the inlet to the distributing group collector. The emergency reactor cooling system consists of two subsystems: a main subsystem with a hydroaccumulation unit and a subsystem with prolonged cooling with special pumps and water storage in tanks. The cooling water from the tanks, and after their discharge with the help of pumps, is input to the collector of the emergency reactor cooling system of each half of the reactor and further along the pipelines in each distributing group collector. The lines for bringing water into the collectors include fast-acting valves, which are opened with a pressure increase in the enclosures. At the same time, the water enters into that reactor loop in which the level in the separators has dropped or pressure differential between the head collector and separators has dropped. This method for including the main subsystems of the emergency reactor cooling system provides for cooling of the active zone with complete and partial rupture of large diameter pipelines and excludes false triggering with emergencies that are not related to loss of hermetic seal in the loop.

Investigations have shown that for any rupture of pipelines up to maximum diameter, due to the rapid action and capacity of the emergency reactor cooling system, there is an acceptable temperature regime for the fuel elements.

14. REACTOR CONTROL SYSTEMS

Because of the special features of the reactor and its large size and high power, and with a view to more efficient and safer operation, the power control and monitoring systems have been improved. This has involved the following items:

First, the control system, which regulates the total power of the reactor and its average neutron flux from the far sub-critical state to normal operating level. The startup apparatus enables the reactor power to be controlled from (10 to the -10) of the nominal level. A further increase in power is controlled by the automatic protection regulator operating over the reactor power range 0.1% to 5%. Automatic control of reactor power over the range 5% to 100% is provided by two automatic controllers. An emergency signal operates if a set signal is exceeded and recorded on not less than two measuring channels of different groups. This gives protection against power excursions for the reactor as a whole and also for local power excursions. The rate of power increase and the power distribution on the periphery of the reactor are also monitored from the signals of the radial reflector ionization chambers. Provision is also, made for manual regulation of the power distribution and reactivity, and automatically maintaining the power level and ensuring protection of the reactor in an emergency. This system includes as sub-systems localized automatic regulation and localized emergency protection. These work on the signals from in-core ionization chambers. The localized automatic regulation system automatically stabilizes the radial and azimuthal power distribution, while the localized protection system ensures the protection of the reactor in an emergency and shuts off the local regulation system if this goes out of order.

There are five emergency danger categories requiring reductions to 80%, 50%, 40%, 30% and complete shutdown.

Secondly, nuclear monitoring of the radial power distribution, which works on the power level of 130 fuel assemblies uniformly distributed over the core, using in-core detectors. The vertical monitoring system measures the neutron density at seven points along the length of each of 12 fuel assemblies. The detector signals are passed to a computer in the control complex.

Thirdly, a data-processing program which calculates the power of all fuel assemblies from the detector signals and from calculated reactor physics data, the safety margins to maximum allowable power for the particular flow through each channel, the maximum permissible levels of the detector signals, the void fraction, the power generation of each channel, etc.

Fourthly, a computer at a centre outside the reactor installation, which periodically carries out nuclear and optimisation calculations.

Thus the monitoring, control and protection of the reactor are effected by several independent systems.

At the joints of the graphite blocks of the moderator there are 20 vertical holes 45 mm in diameter 17 of which contain thermocouples at three different heights to monitor the temperature of the graphite.

During the life of the fuel in the reactor the flow of water into the individual channel is adjusted twice by means of a regulating valve placed at the entrance to the channel. This maintains the proportion of steam in the water.

15. ENGINEERING MONITORING

The RBMK is provided with engineering monitoring systems to transmit to the operators visual and recorded information on the values of parameters which describe the operating conditions of the reactor and the state of the following components of its structure.

(a) fuel channels; a more detailed description is provided under this heading below;
(b) control and safety-system channels;
(c) reflector cooling channels;
(d) graphite stack;
(e) metal structures.

There are systems for local monitoring of water flowrate through the fuel channels and the control and safety-system channels, for detecting fuel-pin failures, and for monitoring the integrity of channel tubes.

Fuel Channels

Leakage monitoring of fuel element claddings during operation of the nuclear power station is carried out by the following monitoring systems:

(i) Individual channel system for monitoring gamma radiation of coolant leaving the pipework from each fuel channel using scintillation spectrometric detectors.

The basic constituent of the power gamma spectrum recorded by detectors is radiation of short-lived products originating from fission.

The advantage of the channel scintillation spectrometric detector system used is the possibility of using it for a qualitative determination of the presence of coolant flow in the fuel channels in the event of the ball-type flowmeter failing, based on the nitrogen-16 activity;

(ii) System for continuous monitoring of gamma activity of steam leaving the drum separators using gamma spectrometric analysis of condensate steam samples having:

- gaseous fission products passing into steam on separation;

- decay products of fission fragments (caesium and rubidium);

(iii) systems for laboratory analysis of reactor circuit water activity.

The activity of water in the operating reactor varied between 1 x (10 to the -4) and 1 x (10 to the -5) Ci/litre.

A case occurred of leakage of a fuel channel containing supplementary absorber.

The cause of the leak turned out to be inadequacy in the design of the supplementary absorber which suffered vibration in the flow of water.

The leaking channel was unambiguously detected using the fuel channel integrity monitoring system and the reactor was shut down and cooled.

Using special equipment the faulty channel was replaced with a new one. All the supplementary absorbers were replaced by improved ones and the fuel channels were inspected before recharging and allowed to continue operating. No other cases of leakage were found.

During the operating period of the Leningrad Nuclear Power Station, 30 stringers were removed from the first unit due to leaking fuel element claddings and 5 from the second unit.

Examination of 11 stringers from the first unit in the "hot" cell showed the presence of defects in the first and second fuel elements in each stringer having a burn-up level of 10 MWD/kg uranium.

There was whitening of the weld zone in the region of the closure on the fuel elements of the stringer and cracks on the weld of the lower closure of the upper fuel sub-assemblies.

Analysis of the results of examining corrosion product deposits on the fuel element cladding showed that for the first year of operation of the reactor of the first unit, a film of corrosion products formed on the fuel element surface (basically consisting of 90% iron oxide deposits) with a thickness up to 40 microns. The maximum thickness of the film is in the zone where coolant starts to boil, ie on the fuel elements in the lower fuel sub-assemblies. The data obtained confirms the thermocouple readings recording the variation of temperature of the internal surface of the fuel element cladding in the zones where boiling starts and in the coolant boiling zone. In the period preceding the acid flushing of the reactor of the first unit the thickness of the film of deposits was found in a preliminary examination in the hot cell to be 50-60 microns.

There are systems for local monitoring of water flowrate through the fuel channels and the control and safety-system channels, for detecting fuel-pin failures, and for monitoring the integrity of channel tubes.

16. SAFETY SYSTEMS

The RBMK was designed to provide protection against radiation for service staff and the population and also to prevent contamination of the surrounding locality of radioactive substances, both under conditions of prolonged operation and in emergency situations which may arise. The design was believed to fulfil the following conditions

(a) terminate the chain reaction in an emergency;

(b) cool the core reliably under emergency conditions resulting from the breakdown of various equipment;

(c) prevent the failure of fuel cladding with any possible failure of the reactor coolant pipework;

(d) prevent the discharge of radioactive coolant outside the power station or of specialised localised equipment in quantities exceeding permitted standards.

The plant items and systems required to achieve these objectives are:

- reactor control and protection system;
- system for physically controlling the energy distribution throughout the core volume;
- technological process monitoring and control system;
- reactor emergency cooling system;

- accident localisation system for receiving discharges of radioactive coolant, described more fully under the subheading 'Accident Localisation', below.
- burst can detection system, and a series of other systems;
- a vent stack some 150 metres high (492 ft) through which off-gases from the turbine condenser and other gases can be discharged to atmosphere.
- plant to hold up and clean the gases if necessary, before discharge.

Accident Localisation

As was mentioned earlier, the maximum credible accident is usually associated with the instantaneous full cross-sectional fracture of a pipeline with the maximum diameter in the reactor cooling system (see fig 13) involving outflow of coolant from both sides. In the RBMK-1000 type reactor the maximum inside diameter of pipes and collectors in the multiple forced circulation system (see fig 14) is very considerable (see fig 11).

In order to prevent the destruction of a building when such large pipes fracture, and at the same time ensure that radioactive products contained in the coolant are retained, large diameter pipes and collectors, together with their valves, are contained in a hermetically sealed chamber under the reactor (fig 12). The chamber is designed for a gauge pressure of 4.5 kgf/sq cm (see footnote 2).

The group distribution manifolds and pipework of the lower water lines, whose inside diameter is equal to 300 and 50 mm respectively, are arranged in another hermetically sealed room (the lower water line room) designed for a gauge pressure of 0.8 kgf/cubic cm.

An important task resides in achieving an all-round reduction in the pressure in the chamber and the room housing the lower water lines in the event of bursts involving the largest pipes in them, ie the pressure collector of the lower water lines and the group distribution manifold. This problem is solved by the provision of a set of measures. The principal measures involve the installation of inserts (leak limiters) at the inlet to the group distribution manifolds, the use of a sparge pond arranged at the bottom of the reactor building, and the division of the hermetically sealed buildings into sections, the partitions between which have check valves.

The inserts (leak limiters), which are constructed in the form of Laval type nozzles, hardly disturb the normal operation of the reactor and cause only a slight increase in the hydraulic resistance of the pipework (by 0.3 - 0.4 kgf/cm sq). At the same time, in the event of a burst pipe the inserts reduce by several times the process of the coolant entering the hermetic chamber room, because a critical flow rate of the medium is formed in their flow section.

The sparge pond contains approximately 3000 cubic m water. In the event of a pipe bursting in the reactor plant the steam caused by the escaping coolant will not only fill the hermetic chamber room, but will also pass, together with the air filling the hermetic chamber room, into the sparge pond through several hundred stand-pipes, 400 mm dia downcomers in the floor of the reactor building. Upon entering the pond, the steam bubbles through a 1 m deep layer of water, condensing in the process. After it has passed through the water, the air displaced from the chambers will fill the air in the space above the pond, thereby raising the pressure. This rise in pressure will open the check valves arranged in the inter-storey floor between the sparge pond and the non-emergency sections of the chamber and will by-pass some of the air into these sections; this reduces the overall pressure in the localization system.

In addition to the above-mentioned system for reducing the pressure in case of accidents, fig 12 shows, likewise in simplified form, the sprinkler-cooling system, which serves to cool the air filling the chambers and remove radioactive aerosols and iodine from this air. A particular feature of this system is that it operates not only during a post-accident period, but also during normal working, performing those functions which, in re-circulation systems for ventilating hermetically sealed rooms at nuclear power stations, normally rest with water-air heat-exchange equipment and filters, ie aerosol and iodine filters. The pumps belonging to this system draw water from the sparge pond, the water being cooled in the heat-exchangers and treated in normal water filters with ion-exchange units before it is fed to a sprinkler arranged in a permanent cell. The water screen thus created in the path of the circulating air ensures that the air is cooled and aerosols and iodine are removed from it.

Footnotes

1. One of the systems developed in conjunction with two institutes, Gidroproekt and VTI, is examined here.

2. In fig 12 the outlines of the chamber are shown by a thick line.

17. FAULT STUDIES

The list of design basis accidents for RBMK type reactors includes:

- situations leading to a change in reactivity;
- accidents involving the tripping out or failure of equipment at a nuclear plant;
- accidents caused by a burst in main circulation pipework, steam lines and feed piping.

Fault studies have been carried out by the Russians on this reactor. These have led them to conclude that:

(a) If one of six main circulation pumps fails power must be reduced by 20%.

(b) If one of the two turbogenerators is tripped power must be reduced by 40%.

(c) If both turbine generators trip power must be reduced by 70%.

These load reductions will be carried out automatically (see section 14).

It was shown that in these situations the basic plant parameters do not exceed their permitted values.

In the event of turbine trip steam is passed by safety valves to "bubblers" and after these have exhausted their capacity secondary steam is sent to the condensers.

If all the main circulating pumps fail natural circulation can be established via pump bypass lines and will adequately cool the shutdown reactor.

Leakage of coolant circuit pipework was also considered.

In the event of a small pipe burst (including a channel tube) the flow of coolant through the channel affected would increase to greater than normal values. It was calculated that the fuel would not burn out. Bursting discs would allow the steam-gas mixture to escape from the core.

Failures of pipework up to 900 mm diameter have also been considered. This would cause an increase of pressure in reactor areas and a reduction of water level in the separators which would trigger the highest level emergency signal. A sharp deterioration of core cooling would occur. An emergency cooling system will automatically come into operation. This system is shown in fig 10. Initially water is fed from a hydroaccumulator and the deaerators directly to the header at inlet to the half of the reactor affected. In the longer term a prolonged reactor shutdown cooling sub-system using pumps powered by an emergency diesel generator supply and drawing water from station reservoir can be brought into action.

All equipment and pipework of the recirculation loop of the reactor is located in closely sealed compartments preventing the discharge of a steam-gas mixture from the nuclear power station into the atmosphere in the event of pipework ruptures, since the steam-gas mixture is removed via special tunnels into a localisation unit where the steam is condensed. The compartments are designed to withstand an overpressure of 0.4 MPa, which is not exceeded even with a full instantaneous rupture of the largest pipework.

(Comment: It should be noted that this does essentially constitute a containment system.)

The total loss of electrical power of the nuclear plant has also been considered in fault studies.

For all the above transients arising from equipment failures the criterion of nuclear power station safety that is taken is the absence of dryout on the fuel pin surface.

18 GENERAL SPECIFICATION

Thermal power, MW	3140
Electrical power (at generator terminals), MW	1000
Core diameter, m	11.8
Core height, m	7
Lattice pitch, mm	250 x 250
Number of channels in lattice	2044
made up of:	
- fuel channels	1693
- control and safety system channels	195
- reflector cooling channels	156
Number of channels outside lattice	18
made up of:	
- temperature channels	17
- gas sampling channels	1
Constant uranium dioxide charge, t	204
Uranium enrichment, %	1.8
Mean power of fuel channel, kW	1850
Power of most highly loaded channel, kW	2700
Coolant flow, t/hour	37.5 x (10 to the 3)
Mean bulk steam content	0.15
Saturated steam temperature, deg C	284
Coolant temperature at fuel channel inlet, deg C	270
Saturated steam pressure in drum separators, kgf/cm sq	70
Feedwater temperature, deg C	160
Maximum graphite temperature, deg C	700
Burn-up MWD/kg uranium	18.5
Mean channel power rating MW/te	15.4 (cf 13.6 at HYB)
Peak channel power rating MW/te	22.4 (cf 17.4 at HYB)

Coolant Circuit	- Two parallel loops, 4 pumps per loop. Coolant enters the fuel channels from below (supplied by individual feeder pipes) and the steam-water mixture from the top of the channels passes along individual riser pipes to steam drums (2 drums per loop) The coolant pressure at the steam drums is 68.6 bar (994lb/sq in). Feedwater temperature is 160 degree C.
Refuelling	- On load, up to 5 channels/ 24 hours.
Turbine generators	- 2x500MWe capacity each at the generator terminals.
Reactor building	- (See Fig 2) The reactor core is in a concrete vault and the main primary circuit components (piping, pumps, steam drums) are in separate cells with concrete biological shielding round them. In the bottom of the reactor building is a 'bubbler pond' (suppression pool) into which steam can be discharged if it cannot be passed to the turbine condenser.

TABLE 1

CHARACTERISTICS OF RBMK-1000 FUEL SUB-ASSEMBLY AND FUEL ELEMENT

Distribution of fuel elements in fuel sub-assembly	2 rows of 6 and 12
Spacer grid	Stainless steel cellular type
Supporting central rod	Zr alloy with 2.5% Nb
Length of fuel element	3644 mm
Weight of uranium dioxide (mean)	3.59 kg
Length of fuel column	3430 mm
Volume of gas collector	17.4 cubic cm
Filler gas	Helium at 1 atm
Fuel element cladding	Zr alloy with 1% Nb in fully annealed condition
External diameter of cladding	13.6 mm
Wall thickness of cladding (min)	0.825 mm
Diametral gap between fuel and cladding	0.18-0.38 mm
Fuel enrichment	1.8%
Fuel density	> or = 10.3 g/cubic cm
Height of fuel pellet	12.0 mm
Diameter of fuel pellet	11.52 mm
Volume of indentation on pellet	3%

TABLE 2

THERMAL PARAMETERS OF RBMK-1000 FUEL SUB-ASSEMBLY AND FUEL ELEMENT

Maximum power of fuel channel		3000 KW
Coolant pressure	- at inlet	80 kgf/square cm
	- at outlet	73 kgf/square cm
Coolant temperature	- at inlet	265 degrees C
	- at outlet	284 degrees C
Maximum steam content		27 wt.%
Maximum velocity of steam-water mixture		20 m/sec
Rate of flow of coolant through fuel at maximum power		21,200 kg/hour
Maximum thermal flux from surface of element		83 W/square cm
Maximum linear thermal power		350 W/cm
Maximum fuel temperature		1800 degrees C
Mean burn-up		19,500 MWD/t uranium
Duration of operation of fuel element at rated power		1190 days

PART 2. STATE OF THE PLANT AND RECOVERY MEASURES

Diary of Events on Site

Date	Statements	Source
26 April	The reactor was at 200MW (6%) which was a shut down condition. This was the usual bottom point when the intention was to take the reactor to full power again. Going below this point causes a build up of Xenon from the fission by-products and the reactor has to wait for the Xenon to decay. The reactor had been at full power. It went through its shut down procedures which took 2 1/2 hours. Main coolant pumps were in service. The power surged from 6% to 50% in 10 seconds before the reactor shut down automatically. (The reason for this surge is as yet unknown). At 01.23 h local time, a hydrogen explosion occurred, (the time interval between the power excursion and the explosion is not yet known). Gorbachev stated on 14 May that "the considerable emission of steam and subsequent reaction resulted in the formation of hydrogen, its explosion, damage to the reactor and the associated radioactive release". The explosion took the roof off the reactor hall and caused the overhead crane which weighed 200 te to fall on to the reactor causing further damage. Fires started which carried the radioactive gases to height of 1500m. The temperature of the fuel exceeded 2500 degrees C (inferred by Sweden from their detection of small spherical particles of ruthenium). The Commander of the fire team reported that the reactor hall flames were raging on various floors, fire centres also broke out in the turbine hall. The fire in the buildings was extinguished in three hours and the fire team evacuated at about 05.00h. Meanwhile at 03.20h a senior electrical foreman and others were called to the plant. The small group (about 7 in number) entered the strictly prohibited area. An eyewitness from this team reported that on arriving at the reactor "the graphite had fallen out and was lying around the floor; the background radiation level was very high." The team leader set about working on the transformers to restore power to the unit. Shutting off the hydrogen feed valves was a particularly hazardous operation and there was also concern with the rise in temperature within the cable ducting.	Dr Blix's briefing to missions at IAEA on 12 May.

M Rosen (IAEA) who visited the Chernobyl site on 8 May stated that, "the accident appears to have been caused by a steam explosion in the core, which in turn, was the consequence of an increase in reactivity. The lack of precursors tended to rule out a coolant failure in one or more channels as this would have been seen in the control room data. This incident was virtually instantaneous and probably caused by the withdrawal of the control rods."

204 site workers and fire fighters received radiation exposures in excess of 100REM, of these, 18 were in a serious condition, 49 people were later discharged after medical examination. Two people were killed in the explosion, an instrument technician and a plant operator, one from steam burns and the other from falling debris. Dr Blix's briefing. TASS 8 May Many Sources

Confirmation that the chain reaction stopped at the moment of the accident was given by medical examinations of people affected. These indicated that there was no evidence of neutron irradiation.

An Investigating Commission headed by the Deputy Premier Shcherbina was set up within hours of the explosion. One of its first decisions taken within a few hours after the explosion, was to shut down Number 3 reactor housed in the adjoining building. Associated Press - interview with Yemelianov 20-05-86

A helicopter reconnaissance flight was made over Reactor 4.

27 April Helicopters commenced the dropping of material on to the damaged reactor.

27-29 April The serious casualties in hospital were transferred to Moscow. About 25,000 people were evacuated from a 10km zone within 36 hours of the accident. This evacuation included the township of Pripyat.

Date not specified Hundreds of fire-fighting appliances were used to pump out the suppression pool. The water was channelled away to a special secure place. (Vaporizers are being made to purify this water).

3 May 49,000 people were evacuated from a 30km zone within 7 days of the reactor accident.

7 May	Work started to build embankments along the Pripyat river to prevent contamination of water supplies to a wide area.	Pravda 7 May
8 May	Lyashko (Chairman of the Council of Ministers of the Ukraine) said that the plant situation was under control and that the temperature of the damaged reactor had fallen to 300 degrees C (this is believed to be the graphite). The other three units on the site are being supervised by rotating shifts of workers.	
9 May	Rosen stated that the objective now was to encase the fourth reactor in concrete.	
	Ilyin reported that workers inside the zone were observing a 25R exposure limit.	
10 May	Velikhov reported that the soil under the reactor is being frozen. Work begins to decontaminate the territory. TASS report stating over 5000 Tonnes of sand, boron, dolomite and lead had been dropped by helicopter to close the crater.	BBC Monitoring broadcast
11 May	Velikhov reports situation no longer represents a major threat.	TASS 11 May
	Soviet TV reports that in short time, Sets 1, 2 & 3 will be put into action.	Soviet TV - 11 May
13 May	Velikhov reported that reservoir under the reactor had been pumped out.	TASS 13 May
	Work is in progress to provide a cooled base plate for the damaged reactor when it has been encased in concrete. The work is being carried out from a huge trench by the wall of the Number 3 unit. The most difficult first metres of the collector tunnel have been laid at a depth of over 6 metres in solid sand stone with permanent radiation monitoring. There are over 400 people taking part in the round-the-clock work.	

15 May	Soviet correspondents taken to visit Chernobyl power station in armoured personnel carriers. There are 50 workers on shift at the first three generating units. Fire and radiation safety were being closely monitored. Lorries bringing concrete to Unit 4.	TASS
25 May	Several thousand tonnes of materials have been used to seal the reactor and the "breathing" is now described as becoming shallower. However, heaps of contaminated fragments and debris still litter the site.	
30 May	Russia is ready to accept global safety standards for nuclear reactors, Mr Valentine Falin, director of the Novosti news agency, said in Bonn on 30 May.	
2nd June	Officials in charge of cleaning up the Chernobyl nuclear disaster aim to start up two of the power plant's four reactors from October, a local Communist Party official said on 2nd June	

PART 3. CAUSE OF THE ACCIDENT

Joint CEGB (BNL) and UKAEA (SRD) View on Possible Accident Sequences

1. INTRODUCTION

More information is starting to become available on the possible course of the accident at Chernobyl unit 4, but it is still too early to be able to make definitive statements about exactly what happened. Indeed it is clear from statements made by the Russian scientific team that they are not yet in a position to be able to give a definitive account of the course of the accident. This is not surprising in retrospect if one considers that it took some time for the course of the TMI-2 accident to be determined under circumstances which must have been more straight-forward, in that access to the plant was much easier in that the off-site consequences were small. Therefore, this note must, by its very nature, be to a great extent speculation. As more information has become available, some of the possibilities have begun to appear less likely. Nonetheless, the reliability of information that could exclude certain possibilities has not yet been fully established, so the range of possibilities discussed in this paper will not be completely limited by it. The next section reviews some of the information available. Based on this, some generalised scenarios have been developed. It should be recognised however, that they are based upon very limited information and their merits could easily change as more information becomes available.

2. INFORMATION AVAILABLE ON THE COURSE OF THE ACCIDENT

The information available on the incident at Chernobyl has tended to be contradictory and has been confused by possibly misleading reports put out by interested parties, which have, in effect, been largely speculation. The "hard" facts are that the reactor building has been destroyed by fire and/or explosion, a core/graphite fire ensued and a significant quantity of the fission product inventory has been released. Reports available from the IAEA team which visited the area as well as Tass and Pravda are starting to paint a more consistent picture. A more detailed chronology of events is being built up by NOSG but this assessment is largely based on the following.

The "initial" incident appears to have been an explosion or explosions which occurred at 1.23 am on Saturday 26 April. This resulted in a fire in the reactor building, which may have spread to the turbine hall roof. There have been unconfirmed US reports that intercepted Soviet communications traffic indicated that there was a problem on the Friday but this is not borne out by the IAEA reports. Blix and Rosen (IAEA) have reported that the event occurred when the reactor was at a low power (200 MW th), which is normal for a routine short-term shutdown, and that all pumps were running at the time. Rosen stated that he had seen control room data which supported the theory that the reactor had been at full power prior to the "shutdown". The shutdown itself was said to be uneventful until the accident occurred, this appeared to be a spontaneous event. It was reported that there was an explosion which "took the roof off the reactor" and caused the 300 te overhead crane to fall into the reactor causing further damage. At some time prior to the explosion, the power of the reactor suddenly surged from 6% to 50% in ten seconds. Soviet scientists are still analysing the data but believe they are close to identifying the cause of the explosion. They are confident that the accident originated inside the reactor and was not a consequence of an event from outside. It has also been reported that the design of the Chernobyl reactor has been reviewed and no design flaw has been identified. However, operating procedures are being reviewed at similar plants and stringent alert procedures are being adopted. This strongly suggests an element of operator error.

Gorbachev in his 14 May statement on Soviet television, reported that information provided by specialists indicated that "the reactor's capacity suddenly increased during a scheduled shutdown of the fourth unit. The considerable emission of steam and subsequent reaction resulted in the formation of hydrogen, its explosion, damage to the reactor, and the associated radioactive release". However, he went on to say that it was still too early to pass final judgement on the causes of the accident.

The release itself appears to have been a relatively prolonged one. There are reports that the firemen were evacuated from the site at 5 am and that some helicopter sorties to drop sand were flown on the Saturday. Rosen has reported that the fire was extensive, encompassed one quarter of the top of the core at one stage and produced temperatures high enough to melt fuel rods. It has also been reported that suppression pools beneath the reactor have been drained to eliminate the possibility of steam explosions should molten debris fall into them. Concrete is being injected into the empty pool vaults to provide additional support for the reactor building over the vaults and to provide an additional impediment to basemat melt through.

3. PHENOMENOLOGY OF THE INITIAL STAGES

The common element in the descriptions we have available is that the incident started with an explosion which may well have been in the reactor vault. This led to a release of steam as well as a fire. The first two casualties were a reactor operator and an instrument technician who were killed by steam and falling debris. Parts of the circuit in a boiling water reactor lie outside the containment. This includes the steam mains, deaerator, off-gas plant, refuelling stand-pipes and turbine. A fracture of one of these items, either spontaneously or in the case of the stand-pipes as a result of a dropped load, cannot be ruled out and turbine failure has been suggested as a possibility since the alternator is hydrogen-cooled and so a consequential failure of this would lead to additional explosions and fire. Normally these external steam lines can be isolated in case of failure but consequential damage may prevent this or lead to additional failure which may cause the fault to develop further. Failure to isolate would result in the containment being bypassed. One sequence in this class which would not require any additional failures to be postulated is steam drum failure. This event is regarded as "incredible" and would lead not only to failure of the steam drum cells but also a LOCA beyond the capacity of the ECCS system. The IAEA experts have reported that the first explosion was within the core and have explicitly denied steam drum failure as an initiating event. This would rule out an explosion as the original initiating event, as indicated below.

Under normal conditions, none of the materials in the core have the potential to cause explosions. For an explosion to occur, either chemical reactions must reduce water to produce hydrogen, which can then explode if it mixed with air, or fuel rod materials must melt and then mix with liquid water to provide the initial conditions for a steam explosion or steam spike. In either case, this would require greatly elevated core temperatures as significant reduction of water by either the zirconium cladding or the graphite moderator requires temperatures of 1000 degrees C or above and large-scale melting of the fuel cladding could not occur until a temperature of 1850 degrees C was reached (though some local fuel liquifaction might occur at temperatures above 1300 degrees C). For such temperatures to be attained, either the coolant supply to a fuel channel would have to be reduced or departure from nucleate boiling would have to occur. The latter could result from an overpower transient, a reduction of coolant pressure or some combination of the two. Indeed, as the core appears to have a negative coolant density coefficient of reactivity, an overpower transient could arise as a direct result of a fall in pressure increasing the void fraction of the coolant.

Overheating of fuel however, does not by itself provide the necessary conditions for an explosion. As already noted, to produce a hydrogen explosion the gases produced by the reduction of water must mix with air to produce an explosive mixture, and to produce a steam explosion molten materials and water must be intermixed.

The graphite moderator of the Chernobyl reactor was inerted by a He/N2 mixture which was in turn surrounded by a nitrogen blanket prior to the accident, so failures of these blanketting systems would have had to occur to allow air access to the core if a chemical explosion occurred. The He/N2 blanket boundary might have been breached by rupture of its bursting disks by steam released from failed pressure tubes. It is not clear, however, where the boundary of the nitrogen blanket lay. It may well have extended throughout the pressure cells since these are interlinked by blowdown tunnels; in which case a pressure rise would simply cause venting to the suppression pool and it would be difficult to envisage means by which air could gain access to the core.

If hydrogen is produced in the circuit due to overheating then it is possible that it may be removed via the deaerator and accumulate in the off-gas treatment plant. An explosion in this region may well set fire to roof structures since it is quite high in the plant. The failure could cause consequential damage as well as bypassing the containment. This, however, does not accord with the description of an in-reactor explosion.

A steam explosion could not arise unless liquid coolant re-entered the channel. Thus, there would have to be water remaining in other parts of the primary circuit that could re-enter the channel at some stage, or emergency injection to the channel would have to occur to reflood it. If fuel melting occurred as a result of a reactivity transient, then although water would be forced out of the channels by the increase in heat transfer, the pumps would restore the flow as the transient subsides. The general geometry of a long tube containing molten material is reminiscent of some of the configurations which have been used in experiments to promote such interactions (eg a "shock tube"). The resultant explosion may displace the stand-pipe closure expelling steam, hydrogen and molten material into the reactor hall. The hydrogen may ignite and, in addition, if the interaction involved unoxidised Zr, expelled particles of this may burn rapidly. In thermal explosions involving molten Al, chemical explosions involving the rapid oxidation of finely divided Al are often observed. The combination of steam pressure, hydrogen and Zr burning would probably collapse the relatively light reactor hall. The accident would then develop as a LOCA with the containment bypassed. This progression will be discussed in the next section since it is common to many of the postulated sequences.

A further difficulty in interpreting the in-core explosion as a steam explosion arises if, as appears likely, the circuit pressure were close to its normal value or about 7 MPa at the time of the explosion. Various studies have concluded that a steam explosion is difficult to trigger at high pressures (>1 MPa). There is, however, evidence that a steam explosion occurred during a reactivity transient in an in-pile experiment at EG & G Idaho at a pressure of 6.4 MPa, so a steam explosion in the Chernobyl reactor at normal operating pressure is a possibility. Furthermore, if pressure tube failure occurred during the melting transient the resulting depressurisation would reduce the local system pressure.

4. DEVELOPMENT OF LOCAs WITH BYPASSED CONTAINMENT

Since many of the events described above lead to a LOCA with a breach outside the containment, it is worth examining how this may proceed. Any extended event has many possible variations because operator actions or attempted recovery operations may affect both the timescales and the course of the events. For simplicity, the postulated sequence here will ignore any external action. It will also be assumed that the safety systems function normally; further failures will simply speed up events.

Following the breach, the ECCS system should be activated. Part of the core may be uncoolable because the explosion may have damaged the inlet pipework. However, the rest of the core would be cooled, provided the resultant damage did not exceed the ECCS capacity, although the water will gradually be lost through the breach. Normally for breaches inside the containment the ECCS water would run back into the pressure suppression pool from whence it could be recirculated. However, for a breach outside the containment, this water is lost and eventually the ECCS pumps will be starved of supplies and the core would uncover and melt. It should be noted that the reactor has two separate circuits but it is not clear that the suppression pool is similarly divided so both halves could be affected. This would mean that the core may effectively be treated as three different zones: the initial damaged area (the size of which will be sequence dependent) which may not be coolable even when ECCS water is available; the rest of that circuit which will undergo a LOCA with long-term failure of ECCS and the other circuit which will undergo an intact circuit fault with long-term failure of feed. Each would have a different time constant which may help to explain the apparently rather extended timescale of the releases. Replenishing the water supply would extend the timescale but the meltdown and possible growth of the local damaged region would still be a potential problem. This or the possibility that the damage exceeded the ECCS capacity may explain why the Russians were worried about the advisability of maintaining a water pool below the reactor.

One would expect that the high temperatures generated would lead to degradation of the roof and its penetrations. At some stage this would allow air access to unoxidised Zr and graphite leading to a fire. There may be significant amounts of Zr left both because of the relatively large quantities and because the heat-up could be under steam-starved conditions if the thermal capacity of the graphite significantly delays the onset of oxidation after uncovering the fuel. Oxidation of Zr in air would give a very intense fire.

5. POSSIBLE INITIATORS

So far the discussion has concentrated on the course of the accident following the explosion. The question arises as to what caused the explosion in the first place? Some are initiators in themselves (eg turbine failure or steam drum failure) but the others require the production of either molten material or hydrogen. There may be many ways to postulate this happening but to remain undetected (or ignored if operator error is postulated) a local fault seems the most likely. These may be under-cooling or over-power faults.

Examples of under-cooling faults would include such things as a dropped stringer with consequential damage. One might postulate a scenario in which a stringer was dropped whilst the reactor was at power. The "routine shutdown" may have been to recover from this but holding the power level at 7% may have been too high for adequate cooling, resulting in fuel melting. Failure of the pressure tube and subsequent depressurisation may then have promoted coolant re-entry. One might, however, have expected the initial event to have been in the control room log as the reason for the shutdown.

A start up fault is also possible since one of the modes of cooling allowed in RBMK and used to enable certain maintenance operations to be carried out is to cool the fuel channels by recirculation with the channel inlet valved shut. If the reactor went back to power with a channel inlet valve either completely or partly shut this may lead to melting as well as hydrogen production. Since there are flow meters on each channel this should be detected, but there are indications that these may not be very reliable since it has been remarked that a more accurate value for the flow is often obtained from the quality meters than the flow meters. If this is the case the operator may ignore the low reading for a while. The shutdown may then have been to check the instrumentation, which would explain the presence of the instrumentation technician. However, this may also not be consistent with the lack of indications of a precursor in the control room logs.

A reactivity transient may be particularly serious if the reactor is operating close to local instability, as it may be at low power. In this case a reactivity change due to say a dropped stringer, (the power at which refuelling is carried out is not known but the intention was to do this at full power), failure of a bottom entry control rod, withdrawal of control rods or a control system fault could drive the reactivity rise rate beyond the capability of the control system and lead to a local criticality. If the channels remained voided for long enough then melting may take place before coolant re-entry.

The sequence has been considered in terms of a local criticality fault but is may be fairly extensive compared with a single-channel meltdown. If a significant part of the core is affected, then it may be possible that a steam explosion, in the true sense, is unnecessary in that the pressure build-up from non-explosive steam production and rapid hydrogen generation as a result of molten zirconium/water reactors may pressurise the system at too fast a rate to be relieved, except by failing the circuit. Such failures could include the roof penetrations and roof structure.

6. CONCLUSIONS

Various sequences can be postulated which fit the known facts. The propagation of an undetected local fault or local criticality seem the strongest possibilities, particularly the latter in view of the increase in power. Propagation of these events could be either via steam or hydrogen "explosions", with the former being more probably in reactor and the latter affecting out-of-reactor plant.

All the sequences considered here lead to complete meltdown. This may not be the case in reality but since it is operator action to recover the situation which is likely to be the limiting factor, it is not possible to predict this without details of the actions taken. The current estimates of the fission product release could be interpreted as indicating only a local meltdown. However, the use of sand and other materials to smother the fire may also have effectively introduced a "filter bed" which has held up activity. Given this and the other uncertainties, it is not possible to reliably estimate how much of the core is involved.

PART 4. RADIOLOGICAL CONSEQUENCES

CURRENT SRD VIEW FOR CHERNOBYL RELEASE

Some Preliminary Conclusions about the Source Term

Measurements from a wide range of sources around Europe present a fairly consistent picture. Only the characteristic nuclide distribution has been examined, with no regard to the absolute magnitudes of activity. To date, data from the Netherlands, Sweden, Denmark and Hungary, collected over the period 28 April to 4 May, have been examined. At all sites, most members of the following list of radio-nuclides had been detected: Nb 95, Mo 99/Te 99, Ru 103, I 131, 132, 133, Cs 134, 136, 137, Te 132, Ba 140/La 140, Ce 141. A very few measurements of Np 239 have been reported from Sweden and Finland, the activity ratios have been compared with the shut-down core inventories calculated by FISPIN for a 1000 MW(e) RBMK reactor at various burn-ups. A fairly consistent picture of the relative release fractions of different fission products emerges:-

Element	Relative Release Fraction
Cs	1.0
I	0.2-0.3
Te	0.3-0.5
Ru	0.03-0.07
Ba	0.02-0.03
Ce	<0.005
Nb	<0.005
Np	0.001-0.07

From this the following conclusions can be drawn

a) The Cs 137/Cs 134 ratio is everywhere consistent at about 2.0, corresponding to an average fuel burn-up of 1 year to 500 days.

b) Measurements over a period extending over 1 week after the accident initiation on 26 April, after half-life corrections, all point to the same shut-down inventory, ie there was no significant continuing reactivity in the core generating short-lived fission products after 26 April. This is in line with USSR statements.

c) Relating to b), the radionuclide 'finger print' at a variety of locations and times is much the same. This suggests that either the release did not continue for long (ie more than a couple of days), or if it did, then the release characteristics from fuel were fairly constant over the period. The former seems more likely.

d) The iodine to caesium ratio is generally found to be about 0.3. This suggests that iodine has deposited from the cloud faster than caesium, assuming that the original release fractions were closely similar. A mixed gaseous and particulate iodine release seems likely - computer runs show that Cs I would be largely decomposed in air at 1500K, for example, in a fire (graphite or hydrogen). Note, however, that an air sample measured in Finland (Nurmijarvi, 28 April) incorporating a charcoal filter gives a ratio Cs/I = 1.0, with 85% of the iodine on the charcoal. Other glass-fibre filters probably missed the gaseous component, or were subject to desorption. Cs/I ratio on ground samples are also much closer to unity than in air samples.

e) The Te release fraction is comparable with that for iodine, fully consistent with expected behaviour in an oxidizing regime, ie Te hold-up on Zircalloy is not a dominant feature.

f) The ratio of release fractions of volatiles (Cs, I, Te) and non-volatiles (Ba, Ce) is what we would expect for release from PWR fuel which has got very hot, probably attaining eutectic (Zr-U-O) melting temperature (2200-2400 degrees C).

g) There is evidence for enhancement of Ru release above the level of Ba, Ce. This is consistent with an oxidizing regime within the core, probably associated with the air ingress which would be necessary to promote a graphite fire. Computer runs point to major volatility of RuO3 in air above 1500K.

h) The evidence for actinide release is limited and erratic. Press reports of Pu detection have appeared. Only Np 239 has been reported to date in the data we have received, and that only in Sweden and Finland. Some Swedish surface samples are consistent with large fractional Np 239 releases, several % of inventory. However, a Finnish air sample suggests approximately 0.1%, consistent with non-volatiles. There is no mechanism for enhanced Np release - the chemical affinity to Pu is near exact. At present, the Swedish surface measurements must be considered suspect. Np 239 and Te 132 share one common gamma energy, although they should be readily distinguishable.

Implications for Accident Scenario

A scenario being considered is that an in-core local transient overpower during power increase led to local pressure-tube dry out, gross fuel overheating, and a steam explosion on reflood which blew a hole in the pile cap. This meant that air could get into the graphite pile very early on. An uncontrolled LOCA ensued, with the damaged channels rapidly overheating, and undamaged channels possibly heating up much more slowly.

All remote measurements, and even closer-in results now available, support the original SRD position that at most a few % of volatile fission products escaped from the plant. This could arise in two scenarios:

a) There was limited initial damage to the core, the damaged channels rapidly overheated to fuel melting temperatures and released all of their volatile fission products, but cooling was maintained in much of the undamaged core.

b) As a) but with loss of coolant to all channels and a large differential heat-up rate between the damaged and undamaged channels. By the time the originally intact channels had reached dangerous temperatures, sufficient sand and other materials had been dumped on top of the reactor to filter out most of the fission products released from them - possibly a few days after accident initiation. This is consistent with the USSR admission that the whole core was 'white hot' one week after the accident started.

It is probable that the in-core graphite fire had little effect in promoting fission product release compared with decay heat, except in terms of stimulating core ventilation. Ex-core the fires were probably even more effective in the latter respect.

Radioactivity Measurements and Dose Assessments After the Chernobyl Accident

The Central Electricity Generating Board regularly monitors the environment around its nuclear plant in order to determine levels of radioactivity. The routine power station measurements are very sensitive and the radioactivity carried into the UK from the Chernobyl reactor by the prevailing weather conditions was rapidly located. The radioactive cloud was first detected as the Dungeness nuclear power station. Subsequently, the environmental monitoring equipment at all the CEGB's nuclear stations recorded levels of increased activity above the natural background which varied widely according to the local weather conditions. All the measurements were made available to the National Radiological Protection Board for assessment.

The incident has demonstrated the high sensitivity and reliability of the CEGB's monitoring facilities. Although the increased radioactivity was readily detectable, it remained below the level at which precautionary action in the context of health effects was required. Nevertheless, it is emphasised that the CEGB's operations would have been subject to a searching and stringent local inquiry if such levels had arisen at one of its own stations.

At the CEGB's Nuclear Research Laboratories at Berkeley, Gloucestershire, an environmental sampling programme was set up using exceptionally sensitive equipment to measure activity and composition of the radioactive material in the cloud. Whilst many radionuclides were detected, the isotopes of main radiological significance were those of iodine and caesium. The Berkeley measurements showed a transient 15 per cent increase in the gamma radiation level during passage of the cloud. Some radionuclides were deposited from the air onto the ground surfaces, and background levels have now returned virtually to normal.

A preliminary assessment has been made by Laboratory staff of the radiation dose to a member of the public in the Berkeley area. The main contributions appear to arise from the consumption of foodstuffs containing traces of iodine and caesium, and from long term irradiation by caesium deposited onto the ground. With regard to the latter contribution, it may be noted that the local deposition of caesium (in terms of the amount of radioactivity deposited per unit area) is approximately ten to twenty per cent of the caesium deposition from the atmospheric weapons tests.

The estimates of radiation dose made at BNL indicate that the total dose to be received by an adult over his lifetime will be unlikely to exceed 400 microsieverts. This corresponds to 0.5 per cent of the dose received from natural background radiation over the same period. These estimates would be doubled for infants under one year old who consume fresh cow's milk. This is well within the natural background variability, and the extra radiation dose could, for example, be acquired by taking annual holidays in areas of higher natural background such as Cornwall.

An analysis of the components of the activity release has made it possible for the CEGB's scientist to make some deductions about how long the fuel had been in the reactor, and about the condition of the core when the release occurred. Had this information been more directly available to the international community, then the process of assessment would have been substantially improved. (Note: HSD Report on CEGB NPS site dose measurements to be issued.)

A meeting was held on 20th May at Thames House South and hosted by NII. Representatives from NII, NRPB, NNC, CEGB, BNFL, MOD, Imperial College and SRD attended. The purpose of the meeting was to hear a presentation by Helen ApSimon of Imperial College concerning a preliminary analysis of doses in Europe resulting from the Chernobyl accident, using the computer code MESOS.

The nature of the analysis is that the code splits the release into 3-hourly "puffs"; trajectories are followed using a synoptic wind field derived from surface pressure data. The depth of the mixing layer is interpolated from radiosonde measurements; rainfall is interpolated from routine meteorological recordings of "current weather". A spatial mesh of 100km x 100km is used (thus allowing only a coarse representation of close-in details). Average doses over 24 hours were calculated.

The following meteorological aspects are considered to be important:-

a) A radiosonde measurement near the release point indicated that the mixing layer would be around 3000 m deep, which is untypically large.

b) Fortunately for the Russians, there appears to have been no local rain during the first couple of days.

c) A frontal system on Wednesday 30th caused fairly high wet deposition in France, Germany and Scandinavia.

d) A high pressure system on Thursday 1st May caused a bi-furcation in the concentration pattern, the division of material further South eventually led to the UK contamination.

The release was assumed to start at 1 am Russian time on Saturday 26 April (2100 GMT Friday). Analysis so far has concentrated on noble gases and iodine 131. Noble gas release was assumed to be dominated by Xenon 133, with the whole inventory released as a short burst immediately. The iodine release was spread over four days. A multi-step time profile was assumed with a decrease in release rate by a factor of three on Monday 28th and a further decrease by a factor of 3.3 on Tuesday 29th. (A decreasing profile was found to give the most consistent fit to the data). The total magnitude of the iodine release was a free parameter to be chosen to give the best overall agreement with measurements.

The success of the analysis can be judged from the following conclusions:-

a) Calculated trajectories appear fairly accurate judged against the arrival times in various countries, and the timing of peaks, etc.

b) A single nomalising factor for the total iodine release (approx 2 x 10 to the power 7 Ci) appears to correlate a large amount of data over the whole of W Europe, both air concentrations and concentration in rainwater.

c) The rather complex, and at first sight, anomalous, time development of dose in W Germany is quite well predicted in terms of the complex meteorological pattern.

d) The spatial pattern of I 131 wet deposition correlates well with observations; the pattern for the UK is particularly well predicted.

e) A single early dose measurement in Southern Scandinavia ties in reasonably well with the hypothesis of an early, near total, release of noble gases.

The inferences for the source term based on this analysis are:-

a) Total Iodine - 131 release of 2 x 10 to the power 7 Ci (within a factor of 2) spread over 4 days. This represents about 20% of the core inventory at shutdown.

b) Release tails off after about 2 days.

c) Large prompt noble gas release (little direct evidence).

It is the intention to carry out a similar analysis on Cs - 137 again using MESOS.

CHRONOLOGY OF RADIOLOGICAL ASPECTS

Saturday 26th April

- The chain reaction automatically stopped at the time of the accident. This was subsequently confirmed by the fact that medical examination of persons affected showed no evidence of high neutron flux exposure.

- Firemen and some nuclear power station personnel were among those injured by radiation.

- Most residents in adjacent areas were indoors at the time of the accident thus reducing their exposure.

- In the early morning of the 26th, monitoring equipment (location not specified) registered increased radioactivity.

- The Ukrainian Minister of Health ordered hundreds of teams from all regions in the Ukraine; each team comprised doctors, radiation monitors and laboratory technicians. By mid-morning, most of those who had been called had already arrived in Kiev.

- It was later reported that the helicopter pilots and station staff did not know the radiation levels in detail on this first day.

- TASS

Sunday 27th April

- According to Mr. Shcherbina, the peak radiation levels in the immediate proximity of the Chernobyl site were recorded today, although he did not give this figure.

- Washington Post 7th May

- Evacuation began.
  About 25,000 people were evacuated from a 10 km zone within 36 hours of the accident. This evacuation included the township of Pripyat.
  (The evacuation was subsequently extended to a 30 km zone around the power station).

- As a preventive measure, potassium iodide tablets were widely distributed inside as well as outside the 30 km zone.

- TASS

Monday 28th April

- Radiation readings on the central and east coast of Sweden were 14x normal, and on the west coast were normal. Readings in Stockholm were 3x normal. At noon in Stockholm, readings revealed:

  Caesium - 134, 137
  Iodine - 131
  Niobium - 99
  Rubidium - 103
  Cerium - 143

  In southern Sweden, ground concentrations measured were:

  Lanthanum - 140, 60 Bq/sq m
  Zirconium - 95, 60 Bq/sq m
  Iodine - 131, 83 Bq/sq m
  Neptunium - 239,300 Bq/sq m

  Neptunium 239 was also detected on the Danish island of Bornholm with winds from the south and southeast.

  \- Atomic Industrial Forum (AIF)

Tuesday 29 April

- Radiation readings in Sweden and Denmark have fallen due to a shift in wind direction.

  \- TASS/AIF

- Radiation dose rates in Scandinavia in excess of normal background levels as follows:

Stockholm	2-3x
Finland	6-10x
Denmark	5x

  also Cs -137 levels 100 x background, and I -131 levels of "300-800 counts/sq m" reported at Ringhals.

  \- Memo from Berkeley Nuclear Laboratories

- Information from L Devel, Studsvik (the Swedish energy research station 75 km south of Stockholm), 2.00 pm.

Tuesday 29 April, continued

Airborne concentrations have been relatively steady since early Sunday morning, and still are (even though the wind has shifted to the west). Values are:-

I -131	approx 5	Bq/cu m
I -133	1.25	Bq/cu m
Cs -137	1.0	Bq/cu m
Cs -134	0.5	Bq/cu m
Np -239	1.0	Bq/cu m
Te -132	0.5	Bq/cu m
Zr -95, Nb -95	0.25	Bq/cu m
Ru -103, Ru -106		
Ba -140		
Ce -141, Ce -144		

Deposition samples over this period give:-

I -131	600	Bq/sq m
Cs -137	100	Bq/sq m
Cs -134	50	Bq/sq m
Np -239	1500	Bq/sq m

- Dex SRD to HSD

Wednesday 30th April

- As a result of measures taken in the past 24 hours, the emanation of radioactive substances decreased. Radiation levels in the area of the power station and the settlement have fallen. Work is under way to clean polluted sections of the adjoining locality.

- The state of the air basin over the remaining territory of the Kiev region and the city of Kiev evoke no concern. The quality of drinking water, as well as water in rivers and reservoirs is in keeping with standards.

- TASS

- In Switzerland, the first increase in radiation level was observed in the N/NE part of the country on the morning of 30th April. External dose rates increased to about 3 to 4 times normal.

- Information received from SRD

Friday 2nd May

- The interagency task force established by the White House has released the following information :

  It is believed that air containing radioactivity now covers much of Europe and a large part of the Soviet Union. The distribution of radioactivity is likely to be patchy. Air containing radioactivity detected by aircraft at 5000 feet about 400 miles west of northern Norway is believed to have moved westward and now appears to be heading south or southeastward perhaps to return to western Europe. There is no independent confirmation of the radioactivity in the air moving eastward across Asia.

  Environmental monitoring data have been provided by the Swedish government for the Stockholm area for April 28-30. Extrapolations of those data suggest that radiation exposure levels at the Chernobyl site would have been in a range from 20 rem to hundreds of rem whole-body for the two-day period over which most of the radiation release probably took place. Radiation doses for the Thyroid gland have been estimated to be in a range of from 200 rem to thousands of rem for the same period. Those doses are sufficient to produce severe physical trauma including death. IT SHOULD BE EMPHASIZED THAT THESE ARE ESTIMATES SUBJECT TO CONSIDERABLE UNCERTAINTY. The US has as yet no information from the Soviet Union as to actual radiation levels experienced at the accident site.

  - AIF

- Moscow party chief Boris Yeltsin is reported to have said in a television interview in West Germany today that the radiation level in the vicinity of the plant was "200 roentgen per hour, or 300 times the lethal dose".

  - Washington Post 7th May

- Activity was first detected in the UK (south)

Friday 2nd May/Saturday 3rd May

- The peak concentrations in air were measured in the UK during this period.

  - HSD memo HS/RBP/3.10

- It is believed that by now, 49,000 people have been evacuated from a 30km zone around the power station.

  - TASS

Sunday 4th May

- Boris Yeltsin is reported as saying that the level of radiation in the vicinity of the plant has dropped to 150 Roentgens/hr.

  - Washington Post, 7th May

- Radioactivity believed to have resulted from Chernobyl has reached Japan. A one litre sample of rain which had fallen in Chiba by Saturday (3rd May) was found to contain 4000 picocuries of I -131. The reading increased to 13,300 picocuries for the same amount of rain collected at the same spot from 10.30 pm Saturday (3rd May) to 8.10 am Sunday (4th May).

Sunday 4th May

- Levels of Iodine 131 in rainwater in Scotland reached 9,400 Bq/litre. The derived initial concentration in drinking water for substituting fresh supplies (assuming a 2 day substitution time is necessary) = 11,000 Bq/litre.

  - Press Cutting

Monday 5th May

- The 30km zone radiation level has fallen to 2-3 m rem/hr.

  - TASS

Tuesday 6th May

- In the UK, MAFF began delivery of samples of milk to all District Survey Laboratories and also to some individual stations for gamma-spectrometry analysis. MAFF have also delivered a few samples of vegetables to laboratories for determination of activity in Bq/kg.

  - HSD memo HS/RBP/3.10

Wednesday 7th May

- Work has started to put up embankments along the Pripyat river to prevent contamination of water supplies.

  In the US, the Washington Post reports Mr Shcherbina as giving the first official figures on radiation levels which he said now registered 10-15 milliRoentgens/hr in the immediate proximity of the Chernobyl site. He said that the figure had dropped two to three times, and that the high had been recorded on April 27, the day after the accident. Shcherbina did not give that figure.

  - Washington Post/Pravda

Wednesday 7th May, continued

- In the UK, the Department of the Environment set up an emergency information centre.

- A further 'cloud' reached the south of England between the 7th and 8th of May but this contained relatively little activity and was barely detectable.

- HSD memo, HS/RBP/3.10

Thursday 8th May

- Report received from collective farm about 30-40 km from Chernobyl; doses were small, amounting to 50 or 40 milliRoentgen.

- The level of background radiation in Kiev (0.35 mRem/hr) is gradually falling, and currently within the 'norms recommended'. In the last few days, 20,000 inhabitants of Kiev including more than 5,500 children have been examined; no adverse effects attributable to Chernobyl were found.

- A third victim has died in a Kiev hospital due to radiation.

- All persons resident in the vicinity of the station and evacuated within a 30 km radius have been examined; except for a group of people who had been close to the place of the accident, no changes were found in them.

- Systematic measurements of contamination throughout the Soviet Union are being taken. Higher levels of radiation have been recorded in Poland, Rumania, Hungary and Yugoslavia. In the Soviet Union, higher radiation has been recorded among other places in Kiev and in the south of the country, but this 'presented no danger'.

- Radiation level at the perimeter of 30 km zone has dropped to 0.15 m rem/hr.

- TASS

- During the course of a helicopter flight over the damaged plant the personal dosimeters worn by Dr Blix and his companions registered 350 mrem/hr at a height of 400 m above the plant and at a distance of 800m.

- Nature, Vol 321, 15 May

Wednesday 9th May

- The level of radiation in some places adjacent to Chernobyl power station reached 1015 milli Roentgens/hr. As a result of decay, it has reduced by several times.

- The radiation levels in Zhlobin and Gomel were given as 0.5m rem/hr and 0.3 m rem/hr respectively.

- 92,000 people have been evacuated from the 30 km zone.

- TV warnings have been given to the local populace in Kiev to beware of drinking milk, eating lettuce etc. It was reported that the population of Kiev were not adhering strictly to the rules of protection against radiation.

- The radiation level in the zone within a radius of 30km from the site continues to decrease.

- According to the Polish Government Commission, the latest radiological readings are:-

  Concentration of Iodine in the atmosphere = 1.5-6.5 Bq/cu m

  Radioactivity levels(whole body?) = 0.01-0.05 m rem/hr

  Contamination of water, in pipes = 1.0-10.0 Bq/litre

  Surface water = 2.3-31.7 Bq/litre

  Milk = 7-493 Bq/litre

- BBC Monitoring Service

Saturday 10th May

- In a statement given on 10th May, Mr Ilyin, Vice president of the USSR Academy of Medical Sciences reported that no one in the area of the nuclear power station is being exposed to more than 25 Roentgens.

- Radiation levels in Kiev do not exceed 0.35-0.4 milliroentgens per hour.

- EEC ban the import of fresh agricultural produce from 6 Eastern Block countries and Yugoslavia.

- There has been a sharp reduction in the emission of radioactive substances.

- Work has begun on a large scale to decontaminate the territory.

Saturday 10th May, continued

- The rate of the dose of radiation in Kiev has dropped by a factor of 2 from the previous day.

- Monitoring of the Kiev's water reservoir is being carried out several times daily.

- Blood tests have been taken from all those involved in first aid.

- Radiation levels = 0.33 milliRoentgen/hr, 60 km from station.

- BBC Monitoring Service/TASS

- In the United States, precipitation samples collected 9-10th May in Salt Lake City, Utah; Jacksonville, Florida; Santa Fe, New Mexico; Albany, New York; Cheyenne, Wyoming, contained radioactivity from the Chernobyl accident. Values of I -131 ranged from 7 to 360 picocuries per litre. The rainwater samples from Santa Fe also contained low concentrations of Ruthenium-103 (28 picocuries per litre) and Caesium -137 (18 picocuries per litre).

- AIF

Sunday 11th May

- It was reported on the 11th that 204 people had received radiation doses higher than 100 rem but 50 were able to leave hospital after a few hours.

- TASS

Monday 12th May

- Izvestiya reports on the ban of street sale of food and water in Kiev.

- TASS

- In a despatch from Kiev, it was reported that radiation levels in the 30 km zone have fallen 2.5 to 3 times, and now stand at about 0.4 milliRoentgen/hr.

- BBC Monitoring Service.

- In Finland, the situation remains unchanged over the last 24 hours. The highest figures are 10 times normal. Some restrictions have been imposed on foodstuffs.

- BBC Monitoring Service

Tuesday 13th May

- Returning from Kiev, foreign journalists reported that water and soil samples were being taken every day. All the evacuees constantly undergo medical check ups.

- Radiation levels adjacent to Chernobyl are 10-15 milli Roentgens/hr and 0.3-0.4 milliRoentgens/hr in Kiev.

- TASS

Wednesday 14th May

- In the regions outside the 30 km zone, agricultural work is going on, and industrial enterprises are functioning normally.

- AIF

Mr Ivan Silayev, a deputy prime minister, said it might take months to decontaminate the area around Chernobyl because "there are radioactive substances at the power station and the zone around it." Soviet press reports say there is no real danger to health in most of the forbidden zone, but they add "it's a different matter close to the fourth block" where the original explosion occurred.

Mr Silayev revealed that workers at the Chernobyl plant are covering some 360,000 sq yds (300,000 sq m) of contaminated surfaces a day with a neutralising membrane. The decontaminating film would prevent radioactive dust and particles polluting the soil or water.

Smaller fragments of radioactive dust littering the site are deactivated in a different manner. A plastic material is sprayed on to the debris, which then hardens allowing removal to burial sites.

- Press Cuttings
14th May.

Friday 16th May

- Dr R Gale (US bone marrow transplant specialist) reported as saying, 11 people have now died from the affects of radiation (plus two initial fatalities); of the 28 people in the initial fire team 5 were now dead.

- UK Press D/Telegraph

Wednesday 21st May

- The Times reports that a Communist paper admitted "the extent of the mass radiation panic" in Kiev. Western observers believe that 250,000 children between the ages of 6 and 13 and all breast feeding mothers have now been evacuated for the duration of the Summer.

- In parts of Sweden a ban on milk has been imposed (This restriction will last for some months).

- The Times

Friday 23rd May

- Following concern in other countries over radioactivity levels in Beef, MAFF are anxious to establish a correlation between grass and beef activity levels in this country. CEGB have been asked by MAFF to assist in the analysis of grass samples, particularly with respect to Caesium levels.

- HSD TELEX

Monday 26th May

- Mr Velikhov is reported to have said, during a Moscow news conference, that the death toll has risen to 17 (plus the initial two). The 17 were among 35 people, mainly firemen, brought to hospital in Moscow suffering from radiation burns.

- Radioactivity in the immediate vicinity of the Chernobyl site "still measured hundreds of Roentgen per hour and work could only be done there using robots or thick protective suits. At a distance of 38 miles away, the level was only 15 milliRoentgen.

- The Guardian (27th May)

Wednesday 28th May

- The Soviet Government news agency Novosti indicated that as many as 1000 people were injured in the accident, including some from Communities surrounding the disaster site. The agency's report on the Moscow hospital, where the most serious cases have been treated, was the first to suggest that such a large number of people were affected by radiation.

- D/Telegraph (29th May)

Thursday 29th May

- Dr Gale said that the death toll from the accident had risen to 23, including 21 deaths from radiation. About 55 others in hospital were in a serious condition.

Thursday 29th May, Continued

- Dr Yevgeny Chazov, Deputy Health Minister said that 210 people were still receiving treatment, and 30 were in a serious condition. Reacting to Soviet news reports that a total of 1,000 people had been injured, Dr Chazov explained that this figure related to the total of medical investigations. He acknowledged that the size and magnitude of the Chernobyl accident had at first been underestimated by the local authorities.

  \- The Guardian (30 May)

Monday 2nd June

- Report received that a new West German reactor at which a radioactive leak went unreported during the Chernobyl events has been shutdown. At the time the high radiation level in the district was blamed on Chernobyl, but an independent ecological institute claims that 70% of the elevated radiation level measured on 4th May had nothing to do with the Soviet accident.

  The institute said it detected 50,000 Bq/sq m in samples of soil.

  \- The Guardian

Tuesday 3rd June

- The death toll has risen to 25 in total, and 30 people are in a critical state.

- The London Standard (4th June)

Wednesday 4th June

- The Soviet authorities have admitted that the evacuation programme was much more widespread, and that the radiation zone extended much further to the north than was previously acknowledged. 60,000 children were evacuated from the Gomel region of the republic of Byelorussia. Gomel has 350,000 inhabitants, about 100 miles north of Chernobyl. The Deputy Prime Minister of Byelorussia said that they were surprised to find that there were some clean zones within 30 km limit, and some dirty sports outside; some of the original evacuees were permitted to return whilst it became necessary to evacuate other areas.

- An earlier report which erroneously claimed that a second evacuation zone had been established around the city of Gomel, was withdrawn by Reuters.

- It was clear however that the evacuation plan had been greatly extended. Of the original 92,000 evacuees, 26,000 had come from that part of the evacuation zone within the republic of Byelorussia. The evacuation of a further 60,000 children indicates the scope of the second phase of evacuation. Many adults accompanied the children. Although earlier official statements had said food from outside the 30 km zone was safe, it was now believed that people throughout the Gomel region of Byelorussia, an area the size of Southern England, were being warned not to touch food from their private plots.

  Some wells have had to be closed, and new wells sunk into deep arresian water. Streets are periodically being washed, new asphalt laid, and a chemical film is put on land bordering the roads.

- The Guardian (5h June)

PART 5. REGULATORY ISSUES AND POLICY MATTERS

1. NPC REPORT ON RBMK-1000 REACTORS - Unclassified
2. CEGB STATEMENT ON CONTAINMENT - Unclassified
3. IAEA EMERGENCY SESSION 21 MAY 1986 - Unclassified
4. SRD COLLABORATION - CEGB in Confidence
5. OVERSEAS REACTIONS - Unclassified

1. NPC REPORT ON RBMK-1000 REACTORS

In March 1976 a report (NPC(R) 1275) entitled "The Russian Graphite-Moderated Channel - Tube Reactor" was produced by the Nuclear Power Company Limited, (this being the forerunner of the National Nuclear Corporation). It is important to recognise the purpose of the report and the background at that time. Active measures were then in hand to promote Anglo-Soviet relations and nuclear power was judged to be a suitable area for fruitful interchange. A British Nuclear Forum delegation, including NPC staff, therefore visited Russia in October/November 1975 and there was also a return Russian visit. The main objective of the visit was to see what could be learnt from the very significant progress that the Russians were making in the design and construction of the RBMK pressure-tube type of reactor. The UK was then in the middle of an extensive design study to see whether it should adopt the Steam Generating Heavy Water Reactor as a commercial power producer, and the superficial similarities between the two concepts suggested that closer collaboration could be beneficial.

The assessment of the Leningrad reactor by NPC after these visits was therefore a fairly detailed comparison with the commercial SGHWR design as it existed at the time, and represented a genuine attempt to try to gain benefit from the Russian collaboration. However, at the end of it, it was concluded that various features, including the approach to safety, would make it very difficult to transplant the Russian ideas into the UK grid system. These features are discussed in more detail in this report.

The Russian data was not always comprehensive or easily understood and therefore presented NPC with difficulties in analysis and assessment. Subsequently, design changes, including the provision of vented containment, have been incorporated into later RBMK stations, such as Chernobyl. Thus, the assessment was based on limited information and was essentially a "snapshot" at that point in time. The report has not been altered to try and update the information and views within it, so that readers should bear these provisos in mind in comparing it with current information.

Nevertheless, NNC believe that whilst, with hindsight, it may be imperfect and inaccurate in parts, the views in it are still substantially valid and there would be difficulty for many safety-related aspects to gain acceptance in the UK.

In the light of the great interest surounding the incident at Chernobyl and in the absence of much technical data on the reactor, it has been decided to publish the above report for general information.

2. CEGB STATEMENT ON CONTAINMENT, ISSUED BY LORD MARSHALL

The Accident at Chernobyl - The Containment Issue

The nuclear accident at Chernobyl has understandably led the public to ask questions about the safety of our own reactors. One major issue is containment. In the accident at the Three Mile Island nuclear power station, Pennsylvania, USA, there was a partial core meltdown, but there was no significant harm to the public because virtually all the radioactivity was retained inside the containment building when the primary pressure boundary was breached. The Chernobyl reactor accident on the other hand has led to a large release of radioactivity and does not have similar containment. People, therefore, naturally ask what containment do we have on our own Magnox and advanced gas cooled reactors? This note compares the containment features of different types of reactor systems. We hope that this will reassure the public about the safety of our own reactors.

Unfortunately the word "containment" can have either a general or a specific meaning depending on reactor type or national habit - the objective of all safety devices in a reactor is to "contain" the radioactivity. To avoid confusion we shall refer to physical boundaries or buildings as "barriers".

All nuclear fuel is enclosed inside sealed cans, often referred to as the fuel cladding. These cans are the first barrier against the escape of radioactivity and are common to all reactor types.

The fuel together with the other components of the reactor core and the primary coolant, whether it be gas or water, are enclosed within a primary pressure circuit, which provides the second "barrier" to the escape of radioactivity. In a light water reactor like the PWR or BWR, this second barrier is provided by the pressure vessel and the main coolant circuit, made of extremely thick, tough steel. In the early Magnox reactors the pressure vessel is also made of steel. Although not so thick because the gas pressure in a Magnox reactor is only modest compared to a light water reactor we are nevertheless confident that it too will not fail catastrophically. In the later Magnox reactors and in all the Advanced Gas Cooled reactors, a concrete pressure vessel is used. Sometimes in the UK this second barrier is colloquially referred to as "primary containment".

For all the reactor systems mentioned above, the pressure vessel "contains" the pressure of the system. In practice, this barrier connot be complete, it cannot be a totally closed cylinder or sphere, otherwise there would be no way to get the coolant, either water or gas, in and out. There must be pipes penetrating this barrier so the heat can be removed, so the control rods can get in and out and so that instruments can be inserted and taken out.

The golden rule of safety in the Western world is that we must be pessimistic and assume Murphy's law applies to all pipes breaching a steel pressure vessel or a concrete vessel. That is, we assume that they can fail completely and we must then prove that no harm comes to the public nevertheless. Sometimes it is also necessary to protect the public by providing a third barrier, the "containment building". This a large sealed building surrounding the reactor, the primary circuit, and all the pipes and apparatus connected to it. Sometimes, depending on the nature of the technology, it is not necessary to provide that third barrier because of the precautions we take to ensure that significant radioactivity does not escape in the first place from the first or second barriers.

In the Western world, for water reactors like the PWR or the boiling water reactor, where there is a breach in the primary boundary for whatever reason, steam will escape from the primary circuit. That steam will be radioactive because water borne corrosion products are irradiated in the reactor core, and there are sometimes failed fuel elements in the reactor. That steam must be contained so that the radioactivity is not released into the environment. For this reason all water cooled reactors must have a third barrier in the form of a containment building. In the event of such an accident, the steam trapped inside the containment building is automatically sprayed with cold water and thereby condensed back into water.

In our gas cooled reactors the situation is very different. Again, our safety rules insist upon Murphy's law, namely, we assume a breach in the primary circuit and that therefore the CO2 gas will escape through the hole. However, the gas escaping from the gas cooled reactors is relatively free of radioactivity.

The reason is that radioactive corrosion products are not readily transported by the gas, and great care is taken to ensure that no fuel with damaged cladding remains in the reactor.

Gas cooled reactors also behave very differently from water reactors in the event of a loss of coolant accident. In gas cooled reactors the gas will simply stream out and the pressure inside the primary circuit will steadily drop, but nothing much else will happen. Gas cannot change suddenly into something else as water can change into steam. Consequently, the environment of the fuel elements changes relatively slowly and there are numerous devices which ensure that we can keep the coolant circulating past the fuel. In those circumstances, we know that leakage of radioactivity from the fuel, if any, into the coolant will only occur to a limited degree and the coolant will remain relatively clean.

Therefore, in these accidents, in contrast to the water reactors, there is no harm in releasing the CO2 gas directly to the environment and there is no necessity to provide a containment building.

For both water and gas cooled reactors we can imagine even larger accidents. The worst credible accident in the UK system might require an evacuation of the public from within a radius of about 1.5 miles.

The discussion given earlier should make clear the essential task of the primary circuit to hold the coolant IN. In gas cooled reactors it serves a second equally important role, to keep air OUT and thus prevent graphite fires.

We can also look at how these general principles apply to pressure tube reactors. The principle of a pressure tube reactor is that the second barrier will not be provided by a steel pressure vessel or a concrete pressure vessel, but by a stout pressure tube. The pressure tube therefore surrounds either a single fuel element or small number of fuel elements and is then connected up to steel pipes and steam drums. The Canadians in their safety assessments assume that a failure in the primary circuit can occur, and they put their entire primary circuit inside a containment building which can withstand the failure so that, in broad principles, their safety arguments are somewhat similar to those for light water reactors, though, of course, they are different in points of detail.

In the RBMK reactors in the Soviet Union they use pressure tubes, water cooling and a graphite moderator, a very different concept from any commercial plant in the West.

We do not know in detail the safety principles followed in designing that reactor but from fundamental principles this design needs a "barrier" with a unique function. This barrier need not be robust enough to contain the primary pressure (that is done by the pressure tubes) but it needs to have sufficient strength to "contain" the pressure if a tube fails (as the Canadians do) and to surround the graphite to prevent the air getting IN. It is this unique "barrier" which appears to have failed at Chernobyl - because it did have a graphite fire and therefore air did get in. In UK reactors this second function (preventing air getting IN) is achieved automatically by the robustness of the primary circuit (i.e. second barrier).

We must avoid jumping to hasty conclusions and we must learn what we can from this unfortunate accident, but present evidence suggests that it would be wiser to have a graphite moderator cooled and contained within the primary circuit rather than have a graphite moderator hot, outside the primary circuit and contained only within a weaker containment building.

The provision of a "containment building" or the use of graphite as a moderator - has no intrinsic value or importance at all as an isolated fact. Neither is the choice of water or gas as a coolant itself an important fact. What is ESSENTIAL is that each reactor concept is provided consistently with whatever the technology demands.

3. IAEA EMERGENCY SESSION 21 MAY 1986

The full 35-nation board of the IAEA, including the Soviet Union, agreed in emergency session at Vienna on 21 May 1986 to seek building accords on coping with nuclear disasters. The day-long meeting which was requested by Bonn in the wake of the Chernobyl disaster, called unanimously on Dr Hans Blix, the IAEA head, to set up expert groups to draft a world agreement commiting countries to report promptly any nuclear accidents that crossed national frontiers. A second binding convention to be drafted would provide for co-ordination of the emergency response and aid in event of a nuclear accident. September was set as a target date for both drafts. A separate IAEA conference will be held in Vienna within three months to hear a detailed account by Soviet experts on the cause and development of the accident which is still being extensively analysed.

4. SRD COLLABORATION

Assessments by the UKAEA in support of the Industry Task Force, set up following the Chernobyl Accident are being coordinated by the Director of SRD, Dr J H Gittus. An office has been set up at Culcheth, headed by Dr M R Hayns, (contact M A H G Alderson 0925 31244 ext 1361).

SRD are collating and assessing the radionuclide dose measurements made in the various European countries following the accident. The object is to obtain a measure of consistency and therefore accuracy, so that an attempt can be made to more closely define the source characteristics of the radioactive release with respect to the neutronic shutdown and irradiation history of the fuel in the reactor. The collection and dispersal of this information is being closely coordinated with the National Radiological Protection Board, who have the national responsibility in this area.

SRD and the CEGB have collaborated in an exercise to review possible scenarios for the progression of the accident at the Chernobyl reactor. This will be based on the latest available information emanating from the IAEA and elsewhere, and also on the interpretation of the radionuclide dose measurements from all known sources.

The Directorate has commenced a review of decontamination procedures for land and buildings. Since SRD maintains strong links with many overseas countries, close cooperation has been possible, leading to a rapid exchange of views and data. The Deputy Director of SRD, Prof H J Teague along with Mr P B Woods of HMNII attended an extra-ordinary meeting of the NEA CSNI on the 9th May, where the accident was discussed at a technical level. Contact has been established with the appropriate branch of the USNRC.

5. OVERSEAS REACTIONS

SWEDEN

The Swedish Government is committed by the terms of a 1980 Referendum, and a subsequent vote in Parliament to the phasing out of nuclear power plants by the year 2010. Anti-nuclear organisations have now attacked the government for not accelerating the phasing-out plans and for insisting the Barsebaeck reactors are safe. The two Barsebaeck BWRs are fitted with unique systems for containment venting through filters. The Swedish Parliament is expected to devote a full day's debate, probably this month, to the subject of Chernobyl, with participation expected from the Prime Minister Ingvar Carlsson and Energy Minister Birgitta Dahl.

ITALY

The Italian Government does not intend to abandon its nuclear energy programme nor to close down existing nuclear plants as a result of the Chernobyl disaster, the inner Cabinet has decided. However the Government favours holding a national conference on nuclear energy, and wants there to be a "pause for reflection" while new safety standards for future nuclear plants are considered. The decision means that the country's three existing nuclear plants will stay open. This includes the magnox station at Latina whose premature closure has been requested by the Socialist Party which is part of the Government.

Radiation Consequences

The Italian province of Como has reinstated bans on milk following recent rainfall and an increase in radioactivity following the Chernobyl disaster, a nuclear energy spokesman said on Sunday.

Officials in Milan, the capital of the region, prohibited the sale of milk produced from local sheep and goats and reinstated a ban on giving milk to pregnant women or to children under 10.

George Armstrong of the Guardian stated in Rome on Monday that Sixty-thousand rabbits that have eaten fresh grass in the past month in an area round Lake Como encompassing the towns of Leggo, Erba, and Ballano, must be handed over to the authorities to be killed. The order comes from the Lombardy region health office, which has found radioactivity two to four times higher than the permitted level in rabbit meat.

FRANCE

The head of nuclear safety in EdF, Pierre Tanguy stated that following the Three Mile Island accident, EdF completely re-examined the safety of its magnox reactors and concluded that the "containment function" was assured by the prestressed concrete vessels. The Chinon-A3 plant is different from the rest, as its caisson does not envelope the entire primary circuit. This reactor has been shut down since May 1984 for major repairs to the internal structures, and the French environmentalists are demanding that it should be decommissioned. M Jacques Leclercq, head of the Nuclear and Fossil Generating Group at EdF has said that they will have to satisfy the national safety authorities about starting-up Chinon-A3 in November. However, if the analysis of the Chernobyl accident calls into question the safety of Chinon-A3 or even the other French magnox reactors and if solving the problem proves too costly, then EdF could shut down all the magnox stations.

USA

The US Nuclear Regulatory Commission is re-examining "its decision on non-containment" at the Fort St Vrain plant. Fort St Vrain is a graphite-moderated high-temperature reactor operated by Public Service of Colorado and is the only commercial reactor operating in the USA which does not have an air-tight containment building. The "confinement" structure consists of a pre-stressed concrete reactor vessel which houses the core. The vessel is 49ft wide, 107ft high and the walls are more than 9 ft thick. Its ceiling and floor are 15.5 ft thick.

On 13 May, the staff of the USNRC told the commissioners that they would recommend no changes in the safety and licencing regulations of US commercial nuclear plants based on what was known to date from the accident at Chernobyl. The staff said a chimney effect appeared to have thrown the plume so high that it was carried over the immediate area and dispersed. The NRC estimates that about half the radioactive isotopes in the core were released. They recommend setting up through the auspices of the IAEA an international early warning system for reporting such accidents and the need for a system of rapid international data collection and exchange.

CHINA

The Chernobyl nuclear accident is accelerating concern in China over the safety of its own nuclear development programme. There are worries about carelessness in atmospheric testing, the storage of nuclear waste and the operation of its own nuclear reactors which include small experimental plants (probably more than ten in number).

GEC (UK) is expecting to supply the turbines for the proposed 1800 MW nuclear plant at Daya Bay in Guangdong province. Chinese officials have sought to reassure Hong Kong opinion by stressing the safety of the nearby Daya Bay reactor to be supplied by Framatome (France).

YUGOSLAVIA

The official Tanjug news agency announced on 21 May it has put off building a nuclear power station in the main wheat growing area. This is the second cancellation of a nuclear plant this month. Officials say the Government is backing away from its nuclear development plans until the Chernobyl disaster can be assessed properly.

FINLAND

The Finnish government were reported on 27 May to have said that as a result of the Chernobyl accident they would postpone a decision on whether to build a fifth reactor.

HOLLAND

Daily Telegraph, 27 May, reported that the Dutch government has decided to suspend its plans for a major expansion of its nuclear power programme in the 1990s.

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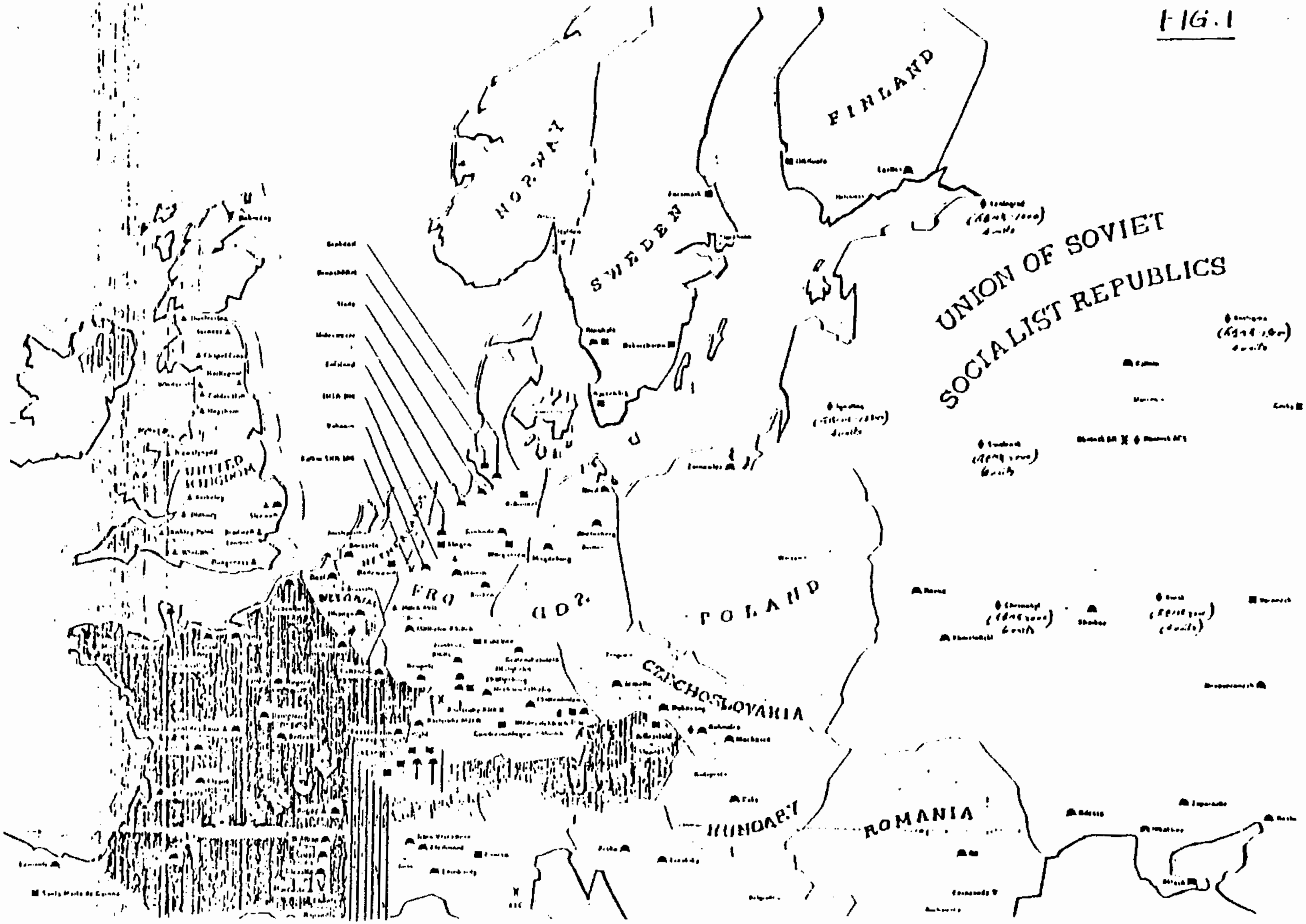
FIG.1



FINLAND
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UNION OF SOVIET SOCIALIST REPUBLICS
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POLAND
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HUNGARY
ROMANIA

KURSK-1&2

A & B - Reactors

C - Auxillary systems

D - Turbine Hall

E - Deaerator mounting

F - Repair service compartment

SMOLENSK-1&2

See Fig. 3.

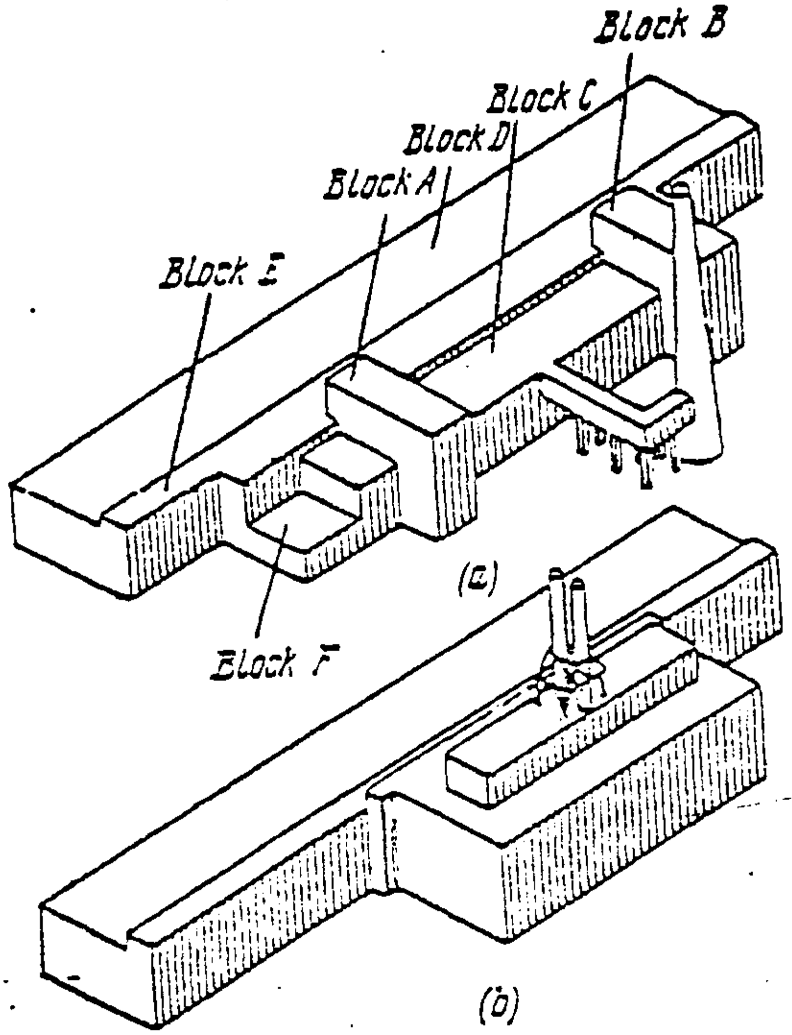


Fig. 2 Layout of the first stages at (a) Kursk and (b) Smolensk

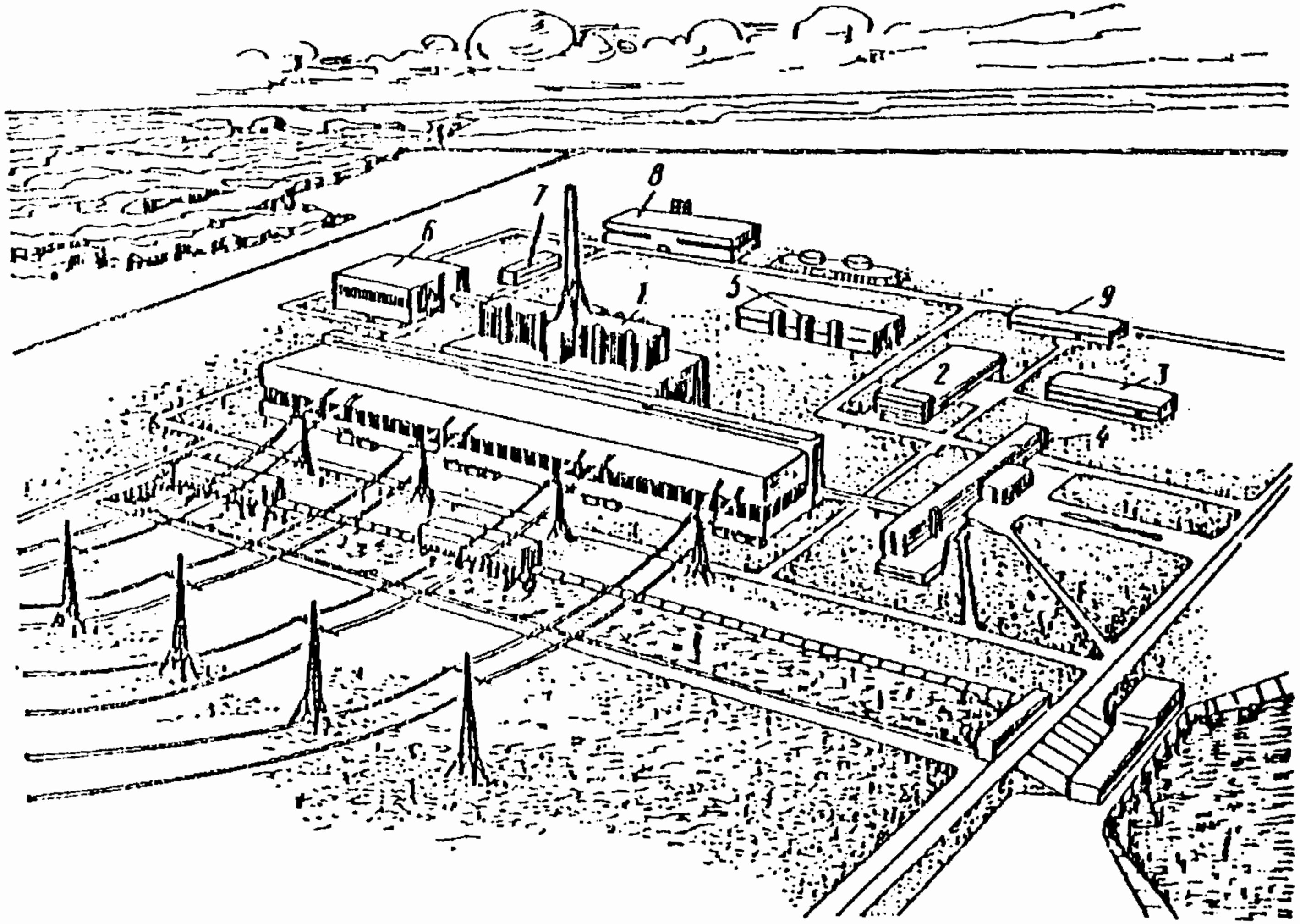


Fig. 2 General view of the Smolensk nuclear power plant

1—main building; 2—auxiliary building and chemical water clean-up building; 3—chemical storehouse; 4—administrative and welfare building; 5—Diesel-generator station; 6—liquid- and solid-waste storage facility; 7—nitrogen-oxygen station; 8—stand-by boiler; 9—new fuel storage facility

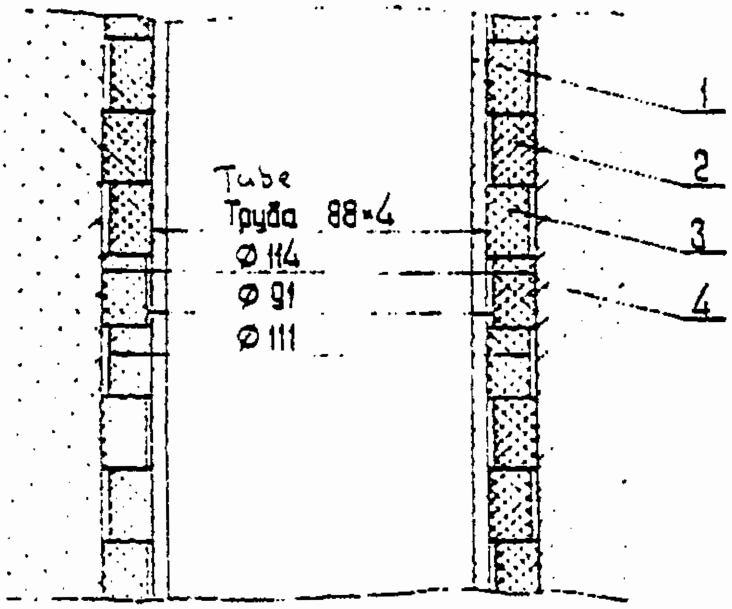


Fig. 4. Fitting of fuel channel in graphite stacking:
1 - tube - zirconium alloy; 2 - graphite ring - outer; 3 - graphite ring - inner;
4 - graphite stacking.

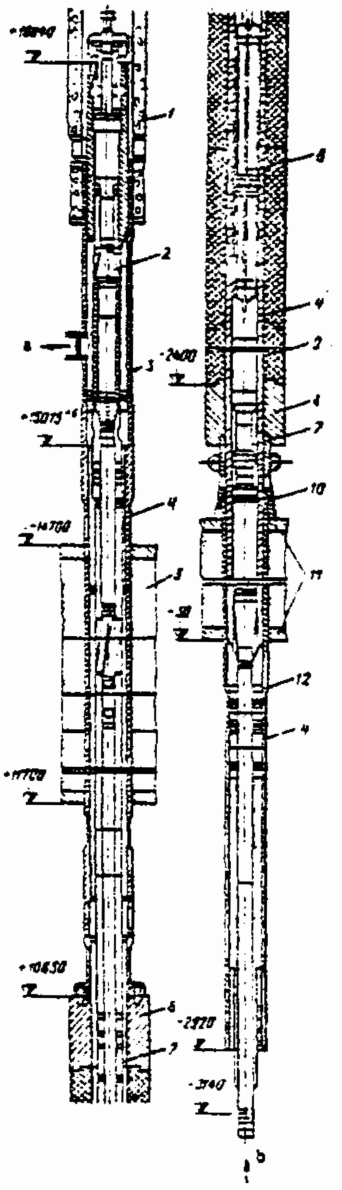


Fig.5 . A fuel channel: 1) protection unit; 2) FA suspension; 3) FC head; 4) pressure tube; 5) upper protection plate; 6) thermal shield; 7) steel—zirconium joint; 8) FA; 9) stack block; 10) supporting vessel; 11) lower plate; 12) channel section; a) steam-water mixture outlet; b) water inlet.

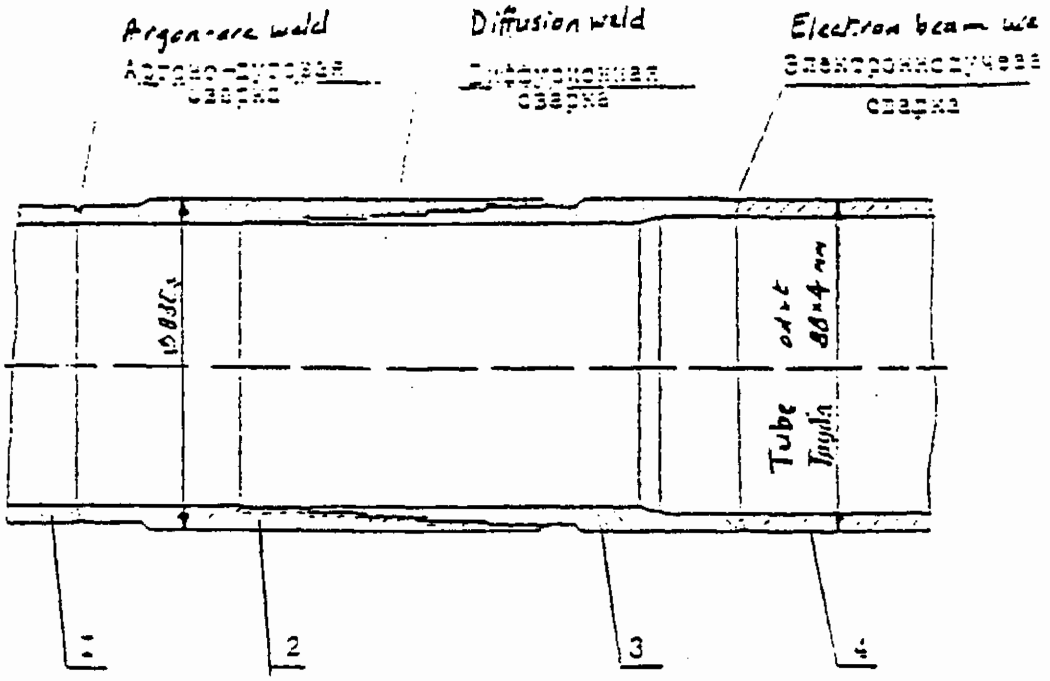
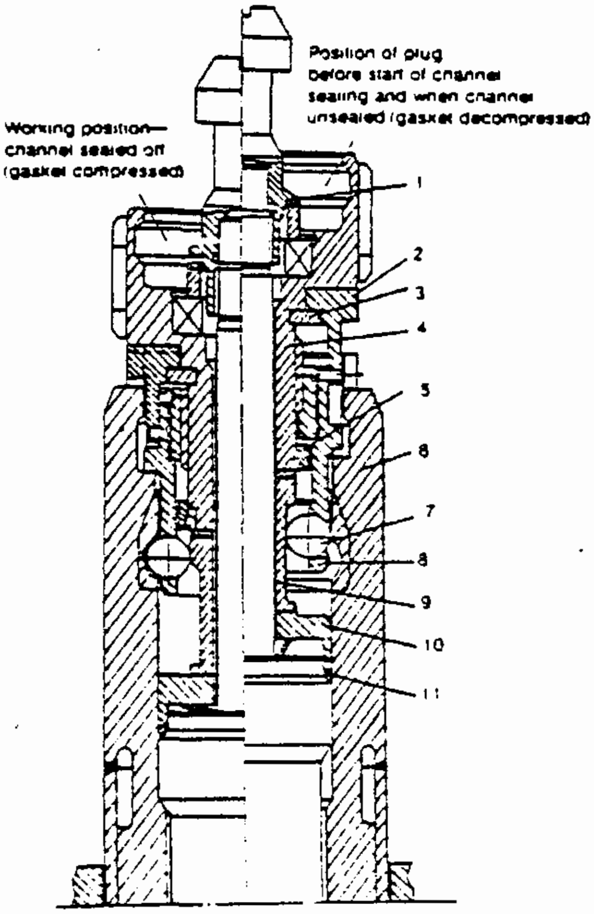


Fig. 6. Junction of zirconium alloy tube with stainless steel tube: 1 - tube - stainless steel; 2 - nipple - stainless steel; 3 - nipple - zirco alloy; 4 - tube - zirconium alloy.



1	Stem	7	Ball
2	Flange	8	Plug casing
3	Half-ring	9	Spacing sleeve
4	Screw	10	Pressure sleeve
5	Support ring	11	Gasket
6	Casing		

Fig 7 Top-end closure unit (fuel changing)

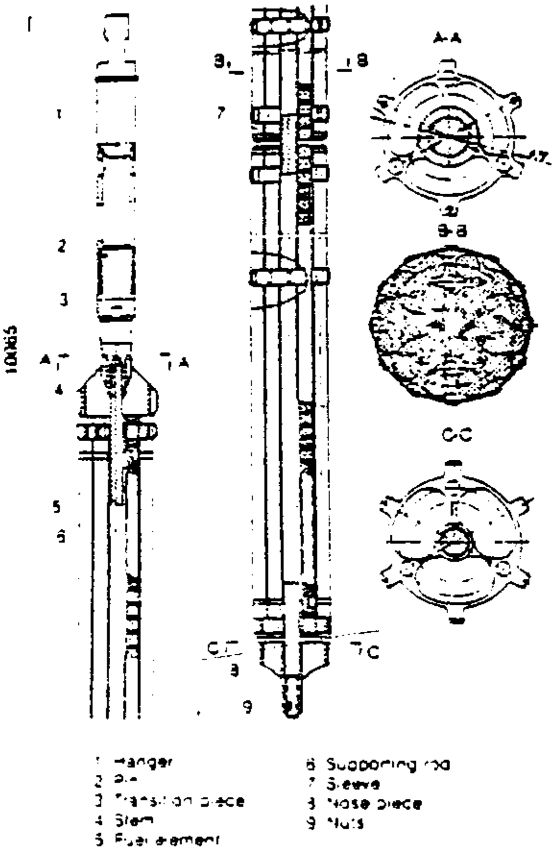


Fig. 8 RBMK fuel assembly

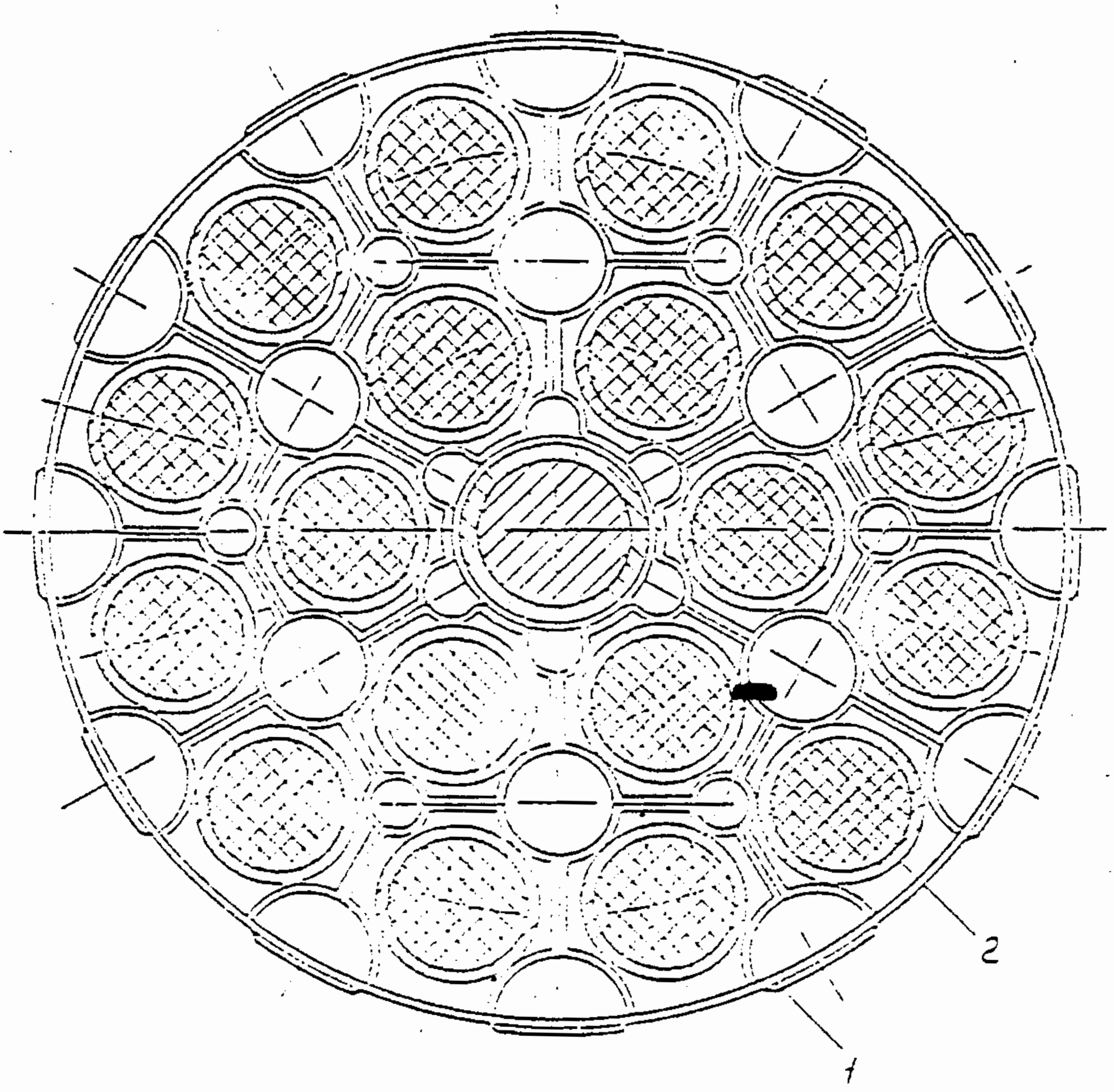
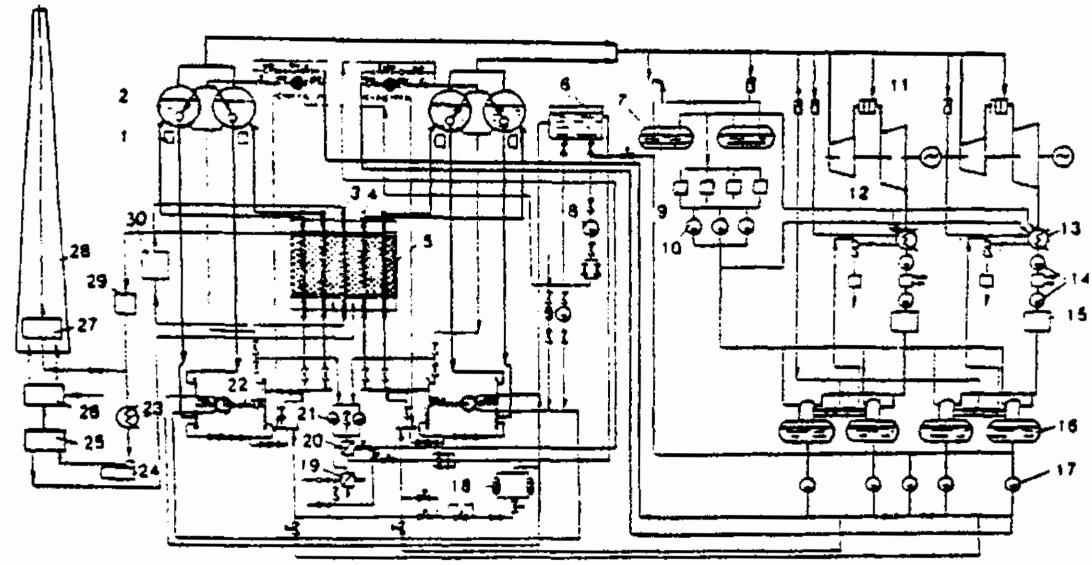


Рис. 2 Сечение ТВС. 1-Дистанционирующая решётка,
2-Твэл

Fig 2 Section through fuel sub-assembly
1 - Spacer grid
2 - fuel pin



1 Cladding failure detection system
2 Steam separator
3 Monitoring channel
4 Fuel channel
5 Reactor
6 Emergency feed-water tank
7 Sparging tank
8 Emergency cooling pump
9 Condensers
10 Condensate pumps
11 Separator and superheater
12 Turboalternator
13 Condenser
14 Condensate pumps
15 Low-pressure preheaters (five in series)
16 De-aerator
17 Electric feedpumps
18 Pressurizers of emergency cooling system
19 Aftercoolers
20 Regenerators
21 After-heat removal hose
22 Main circulating pump
23 Gas circuit condenser
24 Compressor
25 Helium cleaning plant
26 Buffer gasholder
27 Wet gasholder
28 Ventilation stack
29 Fuel channel failure detection system
30 Pumps and heat exchangers of control rod system

Fig. 10Schematic of RBMK-1000 generating unit

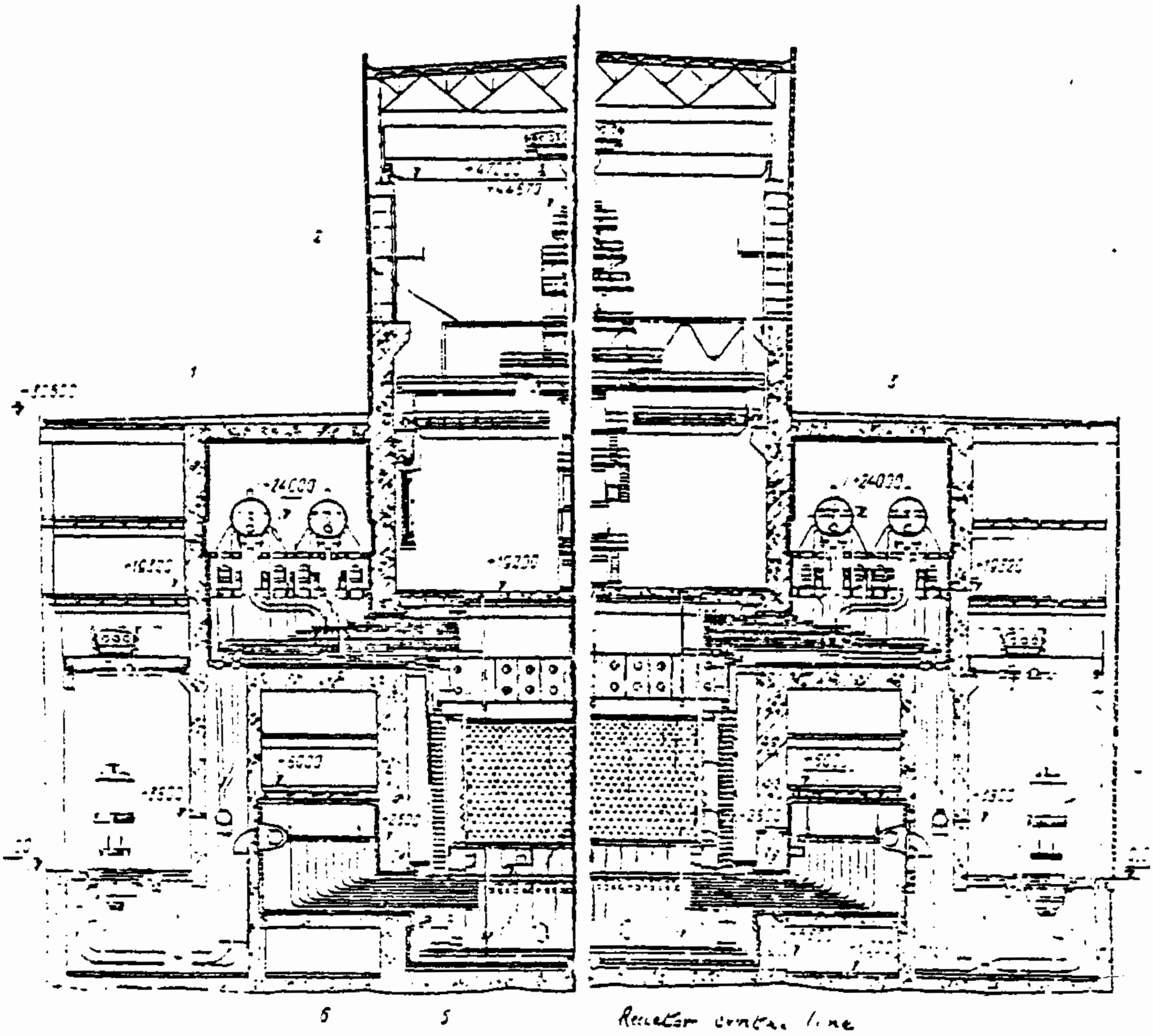


Fig. 11 Sectional view of RBMK-1000 type reactor

1. Pipes for removing steam and water mixture
2. Re-fuelling machine
3. Drum-separator
4. Main circulation pump
5. Core
6. Water feed lines

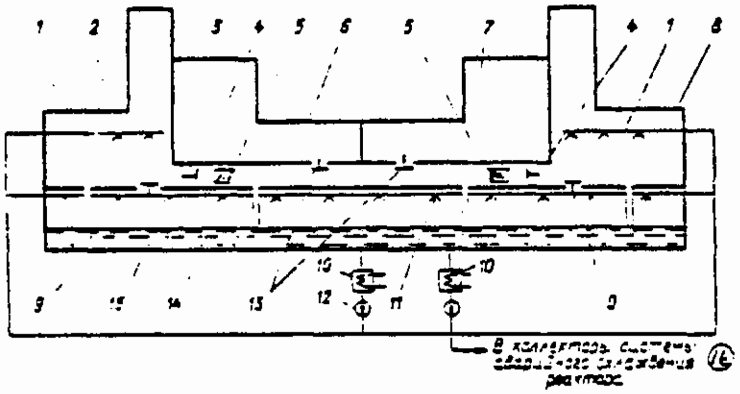


Fig. **12** Schematic diagram of the system for retaining and localizing radioactive products in the event of an accident involving an RBMK-1000 type reactor

1, 11	-	sprinklers
2, 8	-	left and right hand halves of the hermetically sealed chambers
3, 7	-	left and right hand halves of the rooms housing the lower water lines
4	-	valve panels in the partitions separating the chambers and the corridors
5	-	surface type condensers
6	-	steam distribtion corridor
9	-	relief valves
10	-	heat-exchanger
12	-	pump
13	-	check valves
14	-	air space above sparge pond
15	-	depth to which sparge pond is filled with water
16	-	To emergency reactor cooling system collectors.

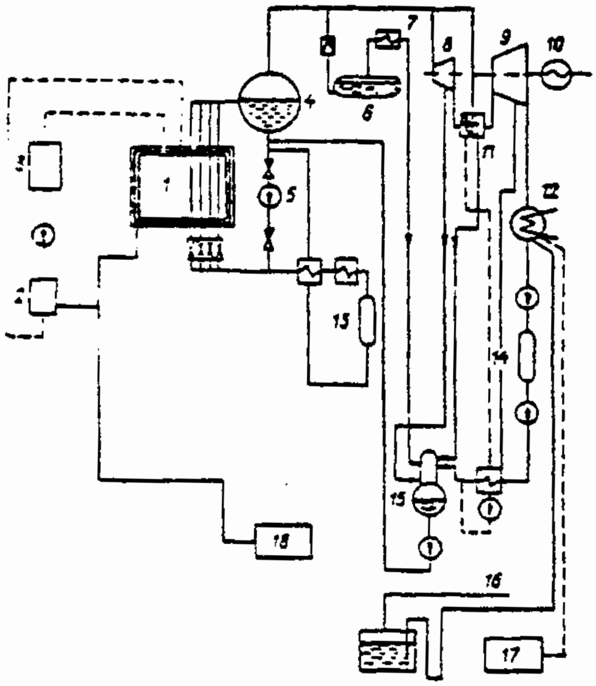


Fig. **13** Schematic flow diagram of a generating unit at an RBMK-1000 type nuclear power station

1. Reactor
2. Helium purification plant
3. System for monitoring the moisture in the reactor graphite blocks
4. Drum-separator
5. Main circulating pump
6. Sparger
7. Process condenser
8. Part of h.p. turbine
9. Part of l.p. turbine
10. Power generator
11. Separator-steam superheater
12. Main turbine condenser
13. Filter
14. Condensate polishing unit
15. Deaerator
16. Chemically treated make-up water
17. Gas cleaning plant
18. Nitrogen plant

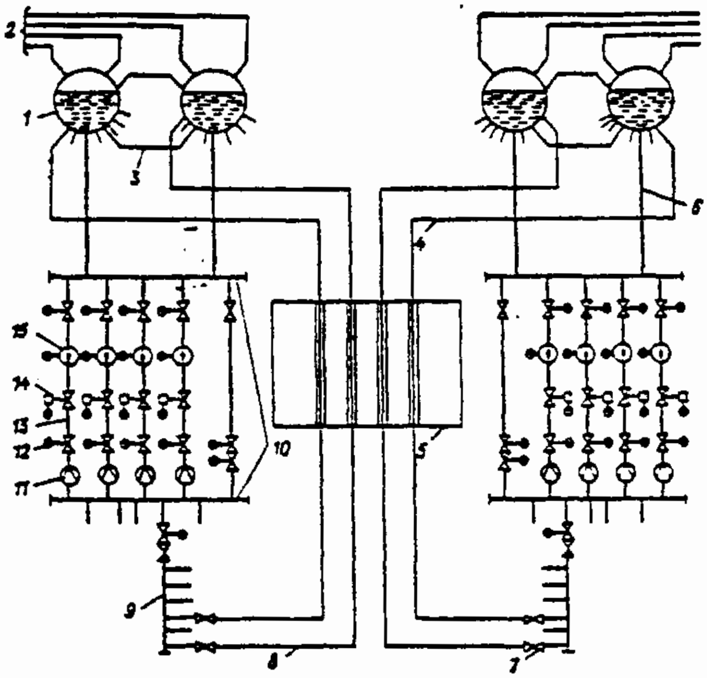
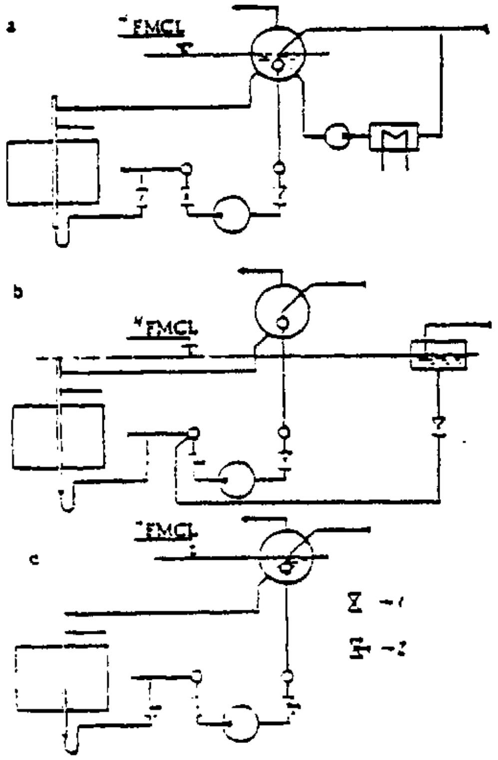


Fig. 14 Diagram of multiple forced circulation loop of an RBMK-1000 type reactor

1. Drum-separator
2. Steam to turbine
3. Compensation line
4. Steam-water lines (76 x 4 mm, n = 1693)
5. Reactor
6. Downcomers (nom. dia. 300, n = 48)
7. Control valve
8. Lower water lines (57 x 3.5 mm, n = 1693)
9. Group distribution manifold (nom. dia. 300, n = 44)
10. Suction and pressure headers (nom. dia. 1000, n = 4)
11. Check valve
12. Main shut-off valve
13. Connecting pipes (nom. dia. 800, n = 10)
14. Throttle valve

Figure 15



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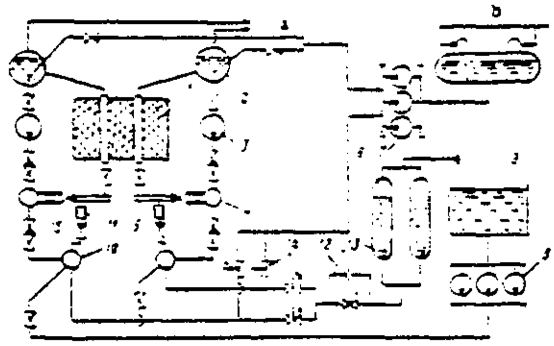

Header

Essential scheme for circulation loop and ECS: 1) reactor; 2) separator; 3) MCP; 4) pressurized collector; 5) DGC; 6) hydraulic accumulation unit in ECS; 7) feed pump; 8) ECS pumps; 9) water stock in condensation device. 10) ECS collector; 11) restriction nozzle; 12) intermediate throttling link; 13) cutoff float valve; 14) fast ECS valve; 15) DGC insert; a) steam to turbines; b) condensate return.