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MINISTRY OF SUPPLY

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MINISTRY OF SUPPLY.

istered Number

STAFF

[redacted]

Operation Hurricane –

Radiation Dosage

RC 256

4723

28–1–85

0149

26/11/51

or Numbers and Subjects of former and subsequent papers e inside of cover.

REFERRED TO	DATE	REFERRED TO	DATE	REFERRED TO	DATE	REFERRED TO	DATE
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P.A. HE	29/5/63						
...TED IN BRANCH REGISTRY							
Dept of AtEn							

NOTATION of decisions, etc., in Branch precedent book or records.

BRANCH	INITIALS	DATE

P.A.

Category for Retention (Routine or Permanent)

SIGNED [redacted]

proceed north as far as is consistent with complete radiation safety. During this stage information should be continuously received by the telemetry system. The movement of the vessel will be determined both by this information and by that available from instruments on board. An estimate, necessarily without any accuracy, is that the period will last about one hour and that the vessel will go to a position about six miles south of the target. At about this time the H.C.V., will be required to meet the 'evacuation boat' carrying all staff from H.1, who will have embarked, with their records, about ½ hour after the explosion. This procedure is necessary since the party and any material they are carrying must be checked and passed as 'clean' before going to the Base Ship.

Having received the party from H.1 and proceeded to a position determined by the radiation conditions the H.C.V., will despatch two boats for reconnaissance. The 'evacuation boat' can be used for this purpose. In approximate terms one will take a northerly direction and make for T.1 if practicable and the other will take a north easterly direction with a view to approaching T.5 and N.1 from the east. It will not however be the function of these expeditions to recover the records accessible from these positions but to obtain information on radiation levels, thus enabling the pattern to be plotted on the H.C.V. The question arises whether an escort and appropriate group ~~number~~ member should travel with these expeditions to collect records if conditions chance to be favourable. This is still an open matter but S.R.M's opinion is against such a course. The main requirement will be to establish the safe 'edge' of the radiation field. In determining this contour, and returning, the personnel may be subjected to the maximum safe dose and so not be available to accompany further attempts. A party with a dual object might be encouraged to make an effort to get the records if conditions seem reasonably good, find recovery impracticable, and be forced to return without having succeeded in either mission. In this case, and also in the case where conditions are worse and no attempt at recovery is made, staff will have been unnecessarily exposed. If conditions are good very little is lost by delaying recovery. If conditions are on the borderline the above risks occur, and in some cases the records might be equally safe, or more safe, in situ than they would be in transit through a contaminated region. If conditions are bad it is clearly desirable to keep the reconnaissance party to a minimum.

It is anticipated that this first boat-survey of the radiation field will occupy about three hours, i.e., that the parties will have returned to the H.C.V., and radiation contours for a given level will be available four hours after the explosion. This information will of course be supplemented by knowledge of the level at particular positions from the telemetry system. The action to be taken at this stage depends on the pattern revealed and the decision will presumably be given by the Officer in charge of Group H on the H.C.V. It may be necessary to arrange a further survey or it may be possible to start recovery of records. It is probable that there will be an overlap with period (iii). For example, recovery of records and apparatus from H.2 and H.1 might well be possible before other sites, particularly A.4, can be revisited. The likelihood is therefore that the two boats used for survey will continue to be used for the same purpose after giving their initial report. Possibly a third will be used to survey in some other region west of Hermite.

(iii) <u>Recovery of material and continuation of survey</u>

Five regions will be revisited for recovery of apparatus and/or records. In order of urgency from the aspect of records these are:-

South Trimouille (Multiplication rate and radiation data at site T.1)
Alpha Island (Cine photographs at A.4)
North Trimouille) (Radiation data at T.5, cine records at N.4,
N. West Island) photographic record by flashes triggered by
Hermite) shock wave at H.3)

A substantial amount of apparatus will also need collection from most of the sites, particularly Hermite and Trimouille. In the latter case non photographic records will require collection in addition to apparatus. No account has been taken so far of requirements which may arise if A.E.R.E., include a station on Trimouille near the target for initial multiplication rate measurements. Such an undertaking will probably raise difficult problems in several aspects, including recovery. Neglecting any special provision for this project it seems likely that

[redacted] /over

[redacted]

over a period of several days five boats will be required in addition to the two which continue the survey.

All boats should be of a type which gives cover from spray, whether merely by their size or by a superstructure. For the same reason, i.e., avoidance of unnecessary contamination risks, dry landings must be made and gas masks should be available. A minimum of one escort must be carried on each trip. In conditions such as those on Trimouille where parties may divide on landing sufficient escorts must be available to accompany each sub group. The seven or eight boats engaged may thus vary in size according to number of personnel to be carried and bulk of stores to be evacuated. There is no point in sending a small boat to H.1 or a large one to H.3 on a survey. The boats employed in this way will be regarded as 'dirty' boats throughout and will not be interchangeable with those used for transport to and from the Base Ship.

(3) Facilities required on H.C.V.

[redacted] confirmed that his requirement was confined to a room for telemetry reception and associated apparatus, with an aerial system as near as possible directly above. The type of aerial now envisaged was simpler than that first proposed. It was envisaged that it could be erected over the bridge without spoiling visibility, and by using individual swivels would place no limitation on the orientation of the ship. [redacted] will supply both a sketch of the aerial structure required and a block plan showing disposition of apparatus in the telemetry room. An attempt was made to define a suitable lay-out of the facilities required by S.R.E., on the vessel. It was, however, agreed that S.R.E., would forward a plan after giving further consideration.

(4) Staff requirements

The staffing arrangement proposed b[redacted] is shown in the attached Table. This gives a total of 79 personnel. Notes on each group shown in the Table are given below.

(1) Directing and administrative staff.

1 S.P.S.O.
1 Service Officer (Suggested rank: Lt. Col.)
1 Typist) It is not essential that these personnel should be
1 Clerk) drawn from H.E.R. staff. They could possibly be
2 Messengers) supplied by the Navy. A suitably qualified individual could serve both as typist and clerk.

(2) Neutron measurement section.

1 P.S.O. 1 A.E.O. 1 A/S.

This section will measure neutron activity in capsules of chemicals distributed over Trimouille. One week would be an ample allowance of time before the event. Afterwards they will require access to Trimouille as soon as possible, and may require continued access for about two weeks.

(3) Gamma ray measurement section.

1 S.S.O. 2 A.E.O.

This section, which will travel with the H.C.V. will be responsibl for the maintenance, calibration and siting of the rate meters and for the collection of pen records after the event. They will be concerned only with the radiation aspect and not the electronic.

(4) Instrument section.

1 S.E.O. 1 E.O. 6 Assistants (Tech. Grade?)

The electronic aspect of instruments used by Group H. will be covered by this group. In particular they will be responsible for the apparatus linking the rate meters to the telemetry system. They will

[redacted]

also provide maintenance for the electronic instruments used by the Radio Chemical Group.

(5) Contamination survey section

A large number of staff will be controlled by this section and will be subdivided as follows:-

(i) Adminstration	1 Service Officer (Suggested rank : Major) 2 Assistants for records and to act as messengers (These may be supplied by Navy)		
(ii) Ground survey	1 Service Officer.	6 Assistants.	
(iii) Escorts.	1 Service Officer.	30 Assistants.	
(iv) Decontamination.	1 " "	3 "	
(v) Air sampling.	1 S.O.	1 A.E.O.	2 A/S.

This group will visit sites after the event in order to obtain filter samples which can be subsequently examined to determine whether it is necessary for gas masks to be worn.

Items (ii), (iii) and (iv), are self explanatory as regards function but it is not clear what method is best suited to staffing them

It was suggested by [redacted] that the assistants should be Army personnel, preferably N.C.O's and that they and the Service Officers should be obtained from the Joint School of Chemical Warfare (Winterbourne Gunner, nr. Porton). This method would ensure a suitable type of staff and would give them excellent training for subsequent instructional duties.

If this scheme is followed there will be a need to accommodate about forty personnel whose duties do not start until after the event and who are not necessarily suitable for any duties in the earlier phases. Since the amount of training required by the assistants is small it would be more economical to use as far as possible staff who will necessarily be present before the event but who have so far no assigned duties afterwards. This possibility will be discussed in the report dealing with staff requirements as a whole.

(6) Personnel monitoring and film dosage section.

This section will be subdivided as follows:-

Supervisor.	1.S.E.O.	
Personal films.	1 E.O.	3 Assistants.

This group will issue, process and interpret all films carried by staff for radiation checking, and will also be responsible for keeping records. The three assistants are required almost exclusively for photographic work. Since the checking does not start until after the event three Photographers can be released from Team O to provide the three assistants.

Chambers and electroscopes. 1 A.E.O. 1 A/S.

Gamma dosage and film survey. 1 E.O. 1 Assistant.

This group will measure integrated doses from films exposed at various localities. The assistant can in this case also be provided by Team O.

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[redacted]

Report No. H.18

The gross requirements for staff are thus:-

Scientific Staff		Service Officers		Assistants (A)		Assistants (B) Rank Unspecified	
S.P.S.O.	1	Lt. Col.	1	Tech. Grades	6	Contamination Survey	39
P.S.O.	1	Maj.	1	Photog.	4		
S.S.O.	1	Others	3			Secretarial and Messengers (Available from Navy)	5
S.O.	1						
S.E.O.	2						
E.O.	3						
A.E.O.	5						
A.S.	4						
Totals	18		5		10		44

Gross total: 77

Min. nett total 18+5+6 = 29
Max. nett total 18+5+6+44 = 73

20th April, 1951.

[redacted]

[illegible]

1 [illegible]
1 Lt. Col.
1 Typist/Clerk
2 Messengers.

Neutron Measurement Section

1 P.S.O.
1 A.E.O.
1 A/S.

Gamma Ray Measurement Section

1 S.S.O.
1 A.E.O.

Contamination Survey Section

1 Major
2 Assistants

Ground Survey

1 Service Officer
6 Assistants

Escorts

1 Service Officer
30 Assistants

Decontamination

1 Service Officer
3 Assistants

Air Sampling

1 S.O.
1 A.E.O.
2 A/S.

Instrument Section

1 S.E.O.
1 E.O.
6 Assistants

Personnel Monitoring & film dosage section.

1 S.E.O.

Personal films

1 E.O.
3 Assistants*

Chambers & Electroscope

1 A.E.O.
1 A/S.

Gamma dosage & film survey

1 E.O.
1 Assistant*

* Photographer available from Team O.

[redacted]

Health Control Vessel for "Hurricane"

(Submitted by [redacted], on 18.5.51).

(1) With reference to para.3 of the minutes of the meeting held on 4th April at Fort Halstead (Report No. H.18), I now enclose a sketch of the layout required in the Health Control Vessel.

(2) The sizes of rooms are approximately those given at the meeting on 28th February, with some minor adjustments to fit things together and with the addition of a store for decontaminated equipment. The overall dimensions of the space required are 80 feet x 35 feet: it is noted that the dimensions of an L.S.T. are 347½ ft. x 55½ ft.

(3) It is realised that the layout shown may well have to be modified to suit the general layout of the ship but the following points should be catered for:-

(a) All persons wishing to proceed to the contaminated area must first report to the control room (1) for briefing. They will then collect film badges and other personnel monitoring devices from hatch A (in the photographic lab. (3)), protective clothing from hatch B (in the clothing store (5)), and monitoring instruments, as necessary, from hatch C (in the instrument lab. (6)). They will then change their clothing in the clean changing room (7) and depart for the contaminated zone by some exit X.

(b) All persons returning from the contaminated zone will arrive at entrance Y. They will hand over film badges and personnel monitoring devices to a waiting representative of the film monitoring section and any instruments and equipment to a member of the decontamination squad. They will then strip off their protective clothing and put it straight into a bin, whence it will be dumped in the contaminated waste store for ultimate disposal without any attempt at decontamination. They will then take a shower (10) and pass into room (9) for monitoring. When clean they will be allowed to pass to the clean change room and once dressed they will report out at the control room before finally leaving at X.

(c) All equipment will be monitored and decontaminated if possible by the decontamination squad in room (13). Equipment which has been satisfactorily decontaminated will be stored in room (8) pending instructions from its owners, with the exception of radiation instruments which will be returned to the instrument laboratory via hatch D. Equipment which cannot be satisfactorily decontaminated will be placed in the contaminated waste store to await sea dumping in a suitable form.

(d) The telemetry reception room must for obvious reasons be adjacent to the control room and the photographic lab., instrument lab., and clothing store must also be on the clean side.

(4) The following services will be required:-

(a) Electrical supply points (230-250 volts A.C.)

Instrument lab. (room 6)	6 x 15 amps.
Photographic lab. (room 3)	1 x 15 amps.
	2 x 5 amps.
Personnel monitoring (room 9)	2 x 15 amps.
Dirty Equipment (room 12)	2 x 15 amps.

plus normal lighting.

/ (b) Water Supply

[redacted]

(b) Water Supply

(i) Distilled water for film processing unit in dark room of photographic lab. (room 3).

(ii) Sea water for decontamination sumps in dirty equipment room (13) and for showers (10): for the latter, some fresh water also is desirable for rinsing but may be impossible to provide..

(iii) A sink is necessary in the instrument lab. (room 6) for flushing out of counters with alcohol etc., but no actual water supply is required.

(c) Cooling

(i) Some means of maintaining a temperature of 65°F for the processing unit in the dark room will be necessary: sea water cooling should be adequate for this.

(ii) A total of 6 cubic feet of refrigerated accommodation is required in the instrument laboratory (6) for battery storage.

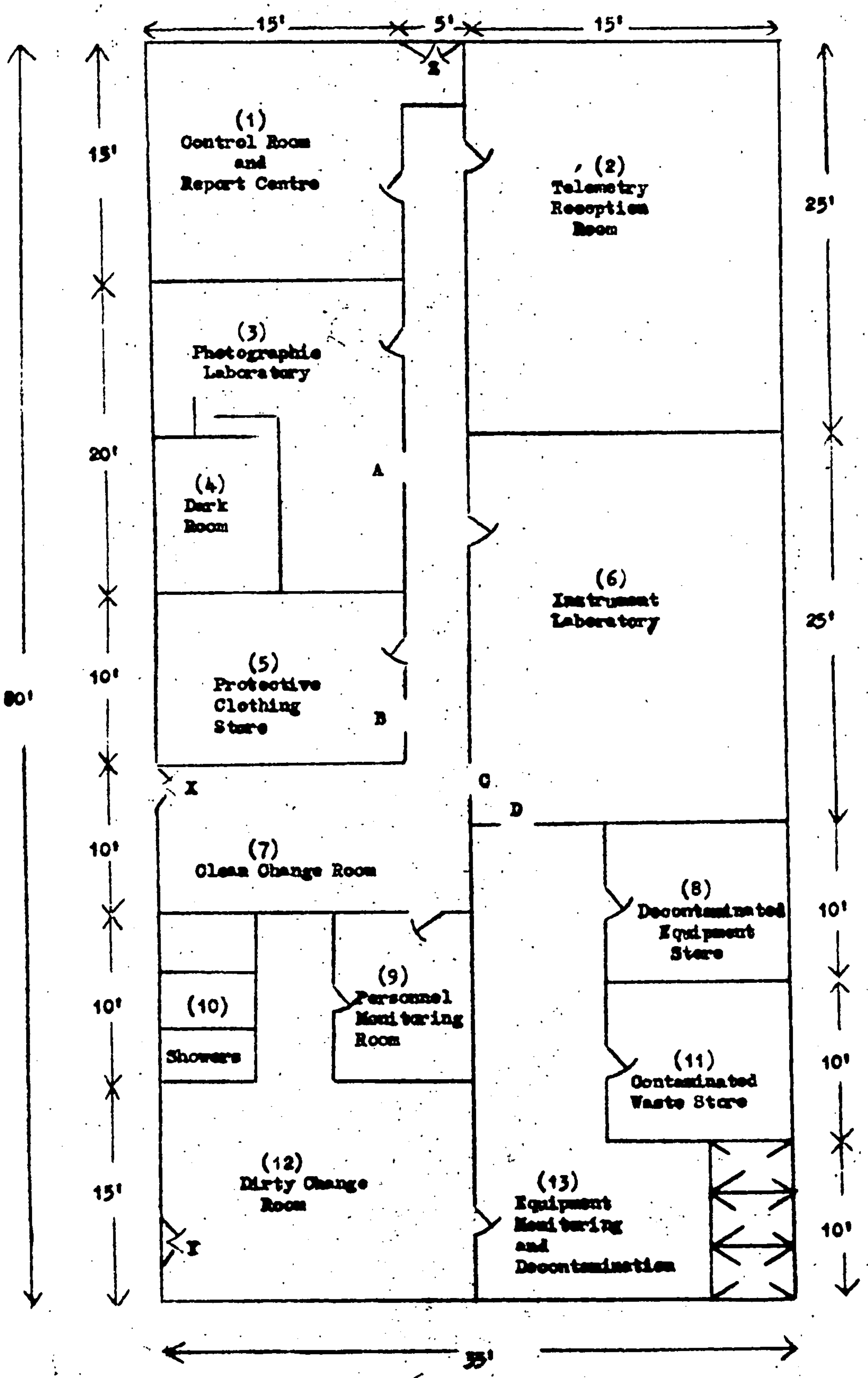
(d) Requirements for the Telemetry Reception Room (2) are not included nd should be provided by [redacted].

18th May, 1951.

H27

LAYOUT OF HEALTH CONTROL VESSEL
for "HURRICANE"

(for detailed explanation see covering letter)



0149 [redacted] Copy No. 2 of 6 copies H32

A note on the Radiation Hazards in Operation Hurricane, with particular reference to the Safety Distances to be laid down in advance for various stages of the Operation

1. The object of this paper is to consider the factual basis for the safety distance to be laid down in advance for each stage of Operation Hurricane.

2. There are four distinct stages to be considered.

Stage I. During assembly of radioactive components and up to commencement of loading.

Stage II. During loading of R.A. components and up to commencement of detting-up.

Stage III. During detting-up and up to but exclnding H hour.

Stage IV. At H hour and after.

The actual and potential radiation hazards and the consequent safety distances during each of these four stages are considered in detail below. A distinction is drawn between "minimum safe distances" and statutory "safety distances".

3. Stage I. During assembly of radioactive components and up to commencement of loading.

(a) It has not yet been decided whether this shall be done on site or in the U.K.

(b) In either case the hazard is small and entirely local. It consists in -

(i) An internal hazard for the person carrying out the assembly due to the possibility of inhalation or ingestion of material that has been exposed as a result of scratches on plating etc.

(ii) An external hazard due to the background neutron and gamma emission from the components. For the assembled components the order of magnitude of this hazard at 30 cms. is -

neutron	-	1 x tolerance
gamma	-	1 x tolerance

(c) The only possibility of a more general hazard lies in -

(i) The possibility of the assembly being super-critical in which case there would be an instantaneous flash of mixed radiation of unpredictable intensity before thermal expansion brought the assembly back to sub-criticality. This is stated to be mathematically impossible.

(ii) The possibility of fire involving the assembly. The consequent vaporisation and oxidation of Q would result in a widespread inhalation hazard. This hazard could be dealt with by the immediate use of respirators and evacuation of the area. The relevant figure is that assuming complete vaporisation there is sufficient material present to produce long-term breathing tolerance (i.e. a concentration that could be safely breathed for 50 years) over an area of approximately 80 miles in radius and a one hour breathing tolerance (i.e. a concentration that could be safely breathed for 1 hour) over an area of approximately 2 mile radius. The chance of such a fire however would be no greater than at any time during the manufacture of the various components.

(d) To sum up - NO SAFETY DISTANCE is necessary during this stage.

4. Stage II. During loading of R.A. components and up to commencement of detting-up.

(a) The small internal hazard for those handling the components (see 3(b)(i) above) is now negligible as the assembly is completely enclosed in the cartridge.

(b) The external hazard (see para. 3(b)(ii) above) is now reduced by the inverse square law to a total of -

.3 x tolerance $(n + \gamma)$

at the surface of th[redacted]. This might be increased by a factor of two

/due.....

[redacted]

due to the assembly now being more nearly critical.

(c) The following additional possibilities call for consideration.

(i) The possibility of the assembly going supercritical on insertion in the H.E. This would probably cause the same hazard as described in 3(c)(i) above. It is however considered to be theoretically impossible: the fully assembled weapon is stated to be only 75% critical. In view of the fact that this will be the first time ever it is for serious consideration whether some preliminary remote-control test in the U.K. should be carried out. For the moment however the theoretical findings must be accepted and the possibility ignored.

(ii) The possibility of fire (involving NO explosion). In this case the hazard would be as described at 3(c)(ii) above.

(iii) The possibility of fire or any other cause causing the weapon to explode. This could cause an actual atomic explosion with the hazards that are considered in detail in para. 6 below. It would, almost certainly, not be a full scale explosion: something of the order of 1/40th full scale has been suggested. But this cannot be counted on and, in any case, although the external hazard would be much reduced, the internal hazard due to unfissioned material would be greatly increased. The minimum safe distances therefore would be the same as are given in para. 6, but on account of the improbability of such an explosion, the statutory safety distance need not be so great.

(d) To sum up - a SAFETY DISTANCE of 5 miles should be laid down for all personnel whose presence on the weapon ship during this stage is not essential; and in addition a danger zone downwind should be defined, which will depend on meteorological conditions at the time.

5. Stage III. During detting-up and up to but excluding H hour

(a) The small external hazard described at 4(b) above remains unchanged.

(b) The possibility of fire with NO explosion and the consequent hazards is also unchanged (see 3(c)(ii) and 4(c)(ii)).

(c) The possibility of explosion and its consequences as described in 4(c)(iii) above is now increased but the magnitude of the potential hazards is unchanged.

(d) To sumup - the SAFETY DISTANCE of 5 miles stipulated for Stage II remains unchanged.

6. Stage IV. At H hour and after

(a) No known explosions of an exactly similar type have taken place and estimates of the hazards must therefore be based on the results ofthe Bikini tests. Some allowance might also be made forthe possibility of an increase in efficiency, although the mathematicians consider that there is no possibility of any significant increase.

(b) For planning purposes it is essential to know the probable minimum safe distances for personnel during the explosion, anchorages after the explosion, approach of aircraft afterthe explosion etc., and these minimum safe distances must depend on estimates of:-

(i) the intensity of the initial flash of γ and neutron radiation.

(ii) the possibility and probable extent of a base surge.

(iii) the areas covered by the fallout of airborne contamination.

(iv) the intensity of the radiation from the atomic cloud.

(v) the movement of seaborne contamination.

/(c)........

[redacted]

[redacted]

(c) The initial flash

It is probable that the initial flash will be considerably less intense than that from an airburst but the amount of water present is small and this cannot be stated with certainty.. We should therefore work on the figures for the Bikini Able burst where the dose was negligible outside two miles.

(d) The base surge

There is no agreement on whether or not a base surge will take place and the matter is likely to remain undecided until afterthe event. It is therefore essential to assume that there will be a base surge and that its extent might be as great (but almost certainly not greater) than that at Bikini Test Baker.

The outer limit upwind of the base surge at Bikini is quoted as 2000 yds.: the outer limit downwind was some two to three times greater: the outer limit at right angles to the wind direction was not more than 1½ miles: the total area covered was 7 square miles. This was for a low wind speed of 7 knots: it is generally considered that any increase in windspeed would reduce the spread upwind but increase the total spread, mainly in a downwind direction.

It can therefore be said that the minimum safe distance for the base surge will depend on windspeed at the time but should not be greater than 2000 yds. upwind and at right angles to the wind direction.

(e) The fall out of airborne contamination

It can be safely assumed that the inner area of gross contamination due to the rapid fall out of the larger particles will not be of any great extent and will come well within the limits necessitated by (c) and (d) above. There will, however, be a rather wider area of contamination, in which the dose-rate may be quite considerable (15 R/HR after 1 hr. has been quoted) due to the fall out of smaller particles which have been carried some distance by the wind. It will be possible roughly to predict this area given the necessary meteorological data, i.e. wind speeds and directions up to approximately 40,000 ft. It is likely to be a sausage-shaped area about 2 miles wide and 10-15 miles long stretching roughly, but notnecessarily exactly, downwind from the centre of the explosion. It must be remembered that the wind direction at higher altitudes is not always the same as that at ground level. It is reported that predictions of this kind were made with success at New Mexico and at Bikini. Lest the possibility of this hazard from "fall-out" be underestimated it should be noted that some cattle 10 to 15 miles from the New Mexico explosion were sufficiently irradiated to cause loss, and subsequent graying, of hair and other apparently superficial injuries.

(f) The atomic cloud.

No accurate estimate of the dosage to be expected from the Atomic cloud is either available or possible. It would appear that the minimum safe distance from it for aircraft initially would be about 2 miles with a statutory SAFETY DISTANCE for at least the first day of twice this figure. It is for consideration whether the subsequent course of the cloud should be followed.

(g) The movement of water-borne contamination

Whatever the nature of the burst there will be a large area of contaminated water. From a knowledge of the tides in the area and from the Bikini data it will be possible roughly to predict the movement of the water-borne contamination. In the event this will be established by direct measurement but it is obviously important from the planning point of view to know at what minimum distances the water can be expected to be completely safe. In this respect there are two aspects to be considered: firstly the external dosage received on a ship anchored temporarily in a particular area: and secondly the possibility of

[redacted]

/activity....

[redacted]

activity appearing in drinking water etc. As far as the former is concerned the figure (based on a maximum dose rate at any time of .1 R/day) is likely to be of the order of 5 miles: as far as the latter is concerned (accepting zero activity in drinking water etc.) it is more likely to be 10 miles.

(h) To sum up we can predict for this stage -

(i) A distance outside which the initial flash of radiation will be innocuous - 2 miles.

(ii) A distance beyond which the base surge, should it occur, cannot be expected to extend - 2,000 yds. upwind and at right angles to wind, with anything from 6,000 yds.+ downwind depending on windspeed.

(iii) A zone within which the fall out of airborne contamination may cause a hazard, at least for some time after H hour - a sausage-shaped area approximately 2 miles wide stretching for 10 to 15 miles roughly downwind from the centre of the explosion.

(iv) A distance from the atomic cloud within which no aircraft must go for a period of at least 24 hrs. after the explosion - 4 miles.

(v) A distance outside which it will be safe for ships to anchor for an unlimited time provided condensers and evaporators are closed down - of the order of 5 miles.

(vi) A distance outside which it will be safe for ships to anchor for an unlimited time without closing down condensers and evaporators - of the order of 10 miles.

It should be remembered that (iii) (iv) and (v) can only be guessed at until the necessary information re meteorological conditions and tides is made available.

(i) In the light of these factors and making a generous allowance for unforeseen factors, it is recommended that the SAFETY DISTANCE within which no-one must be, unless absolutely essential, at the time of the explosion, should be 10 miles.

Radiation Safety Section,
Radiological Branch.
28th June, 1951.

[redacted]

[redacted]

Ref: 8/51/123 [redacted]

ADMIRALTY S.W.

RECORD OF A DISCUSSION ON RADIATION SAFETY HELD AT WOOLWICH ON 12TH SEPTEMBER, 1951.

Present:

[redacted]

22.1.85 [redacted] DECLASSIFIED

[redacted] would be the Radiological Safety Officer and responsible for advising the command on all matters concerning the Radiological safety of personnel concerned in the Operation. [redacted] would be responsible for the organisation and training of the Radiological Team in the Health Ship.

2. Arrangements would be made for the radiation situation to be portrayed graphically in the Health Ship.

3. It was necessary that a decision should be given as to:-

(a) the normal total dose permissible;

(b) the maximum permissible for volunteers.

This was a medical question and [redacted] agreed to ask C.S. H.E.R. to approach the Medical Research Council for figures.

4. It was agreed that the question of compensation to individual scientists who suffer injury, whether as volunteers for special risk or not must be taken up with the Ministry of Supply. The Services appeared to be catered for by existing regulations. [redacted] agreed to put this matter to the "Hurricane" Executive after consulting C.S. H.E.R.

5. [redacted] felt that there were various duties of a Naval flavour which he had envisaged as being the business of the Safety Officer but which neither [redacted] nor [redacted] could be expected to perform. He therefore required a Naval Radiological Staff Officer on his staff who would attend to the Naval side of Radiological Safety. This would mean such matters as the Naval implications of safety planning, training of Naval personnel, organisation of any Naval trials etc. This Naval Officer would have to work very closely with the Safety Officer and with [redacted] and it was therefore desirable that he should be attached to Woolwich. It was agreed, however, that first the selected officer should do a course in H.M.S. PHOENIX and possibly further training at Porton. [redacted] undertook to seek C.S. H.E.R.'s concurrence to the Naval Officer working with the Health Team at Woolwich.

6. Discussion took place regarding the possibility of ships condensers, firemains (and similar machinery wherein seawater circulates) becoming contaminated to an extent which would make them a danger to anyone required to strip them. [redacted] agreed to make further investigations of this matter; also on the degree of safety given by distilling to drinking water produced from sea water of various contaminations.

/7.

[redacted]

[redacted]

7. After some consideration of the problem of obtaining air or water samples [redacted] undertook to obtain further information of the possibilities of a miniature radio controlled aircraft as being developed by the Auster Company.

8. It was also agreed that the Naval Staff would obtain details of large inflatable merchant ship type rafts. These might be used as platforms for sampling up to several miles downwind.

9. [redacted] described what he had learnt concerning the trials which the Admiralty would like to include in the Operation. These were Service Trials on Radiological instruments, measurement of depth and rate of water contamination, provision of contamination in ships by use of water sprays, measurement of risk to personnel from boiler-room forced draught and decontamination problems as applied to ships.

10. It was agreed that the provision of a hulk would assist such trials and [redacted] will investigate the possibility of obtaining some old ship from Australian sources. A ruling has already been given that a hulk is not to be towed out from England.

[redacted]

[illegible] 1951

Distribution

T.P.S.

[redacted]

[redacted]

Ref. No:8/51/124

D.C.N.S.,

[redacted] Trials Planning Section,
Room 144 Citadel,
Admiralty, S.W.1.

20th September, 1951.

Dear [redacted]

Radiological safety must be one of the chief concerns of the Naval Commander but, equally evidently, some degree of risk must be run by some people if we are to achieve the full purpose of the trial.

2. I would therefore be glad of [redacted] remarks under the two following heads and his concurrence that the two matters should be taken by the "Hurricane" Executive.

Permissible Dosage

3. Our plans cater for the measurement of radiation levels and for recording the integrated value of doses received by people. We can in advance estimate, up to a point, what contamination is likely and we will be able in the event to discover the facts. We cannot however make sensible plans now, nor later carry them out, unless we have standards of permissible doses laid down by the competent authority.

4. I understand that this authority would be the Medical Research Council. If so this leads me to suppose that they would, naturally, play for safety to such an extent that we might be quite unable to achieve the scientific purpose of the trial.

5. Could it be put to the M.R.C. that they should lay down more than one standard, for instance, a general standard and a special (once only) standard for volunteers?.

6. If C.S.H.E.R. agrees, as I am sure he does, that we must get something laid down; I suggest that he might perhaps prepare a draft letter to the M.R.C. which could be taken by the "Hurricane" Executive.

State Liability for Compensation

7. My second point concerns the position of a man who is injured during the operation or who subsequently falls ill from causes attributable to the operation.

8. As Naval Commander I must expect to have to order or approve the acceptance of some degree of risk. This is a customary Service obligation, but it is performed in the knowledge that the Admiralty accept liability for those killed or injured on duty.

9. I want to be quite certain that the same applies to all who take part in Operation "Hurricane", whether or not they are volunteers for any or all of their duty.

/10.

[redacted],
Armament Research Establishment,
Fort Halstead,
Nr. Sevenoaks.

[redacted]

10. I believe that all Government servants are in fact entitled to compensation for injury on duty. But the particular points to be covered in "Hurricane" arise from the facts that:-

(a) the ill effects may be long delayed;

(b) illness unconnected with the operation might have caused the same symptoms.

11. It is not suggested that any one who took part, and subsequently suffers from a disease which <u>might</u> be due to the Operation, should automatically be compensated. I do feel however that some formula might be accepted by Ministries which would dispose any tribunal in favour of a claimant ex "Hurricane".

12. Again as the matter is a technical one, perhaps [redacted] would be prepared to draft the necessary paper to bring the subject to the <u>Executive's</u> notice.

[redacted]

Trials Planning Section.

[redacted]

MEMORANDUM

C.I.O. Form 16.

From: ACS/HER.

Ref.

To:- [redacted]

Ref.

/ /195

Subject: Radiological Safety discussion 12/9/5, minutes of

Para 3 Who should take action for C.S.H.E.R. with M.R.C.?
If you confirm that it is Greatbatch, please forward this to him & ask him to do so.

Para 4 This is dealt with in a separate letter from Torlesse to me

Para 5 Presume no objection but this is also raised vide remarks under para 4 above.

Para 9 Is it clear what staff are involved. presumably the Sc + Tech staff will come under you & must therefore be shewn in your lists of numbers. Can they be organised to help in their duties, if so perhaps they would enable us to reduce our numbers.

[redacted]

2/9

21 Sept-51

LCT/JG. [redacted]

C 149

C.I.O. Form 16

28 / 9 /195 1

From:- S.S.I.R.

Ref.

To:- A.C.S./H.E.R.

Ref.

Subject Minutes of Radiological Safety Discussion - 12/9/51

With reference to the above Minutes and your memorandum of 21st September, 1951, the following comments are offered:-

Paragraph 3. I understand you have taken up this matter with A.E.R.E. and that the M.R.C. has already issued a statement whicl can be used as a basis for this decision.

Paragraph 4)
Paragraph 5) Noted

Paragraph 9 This is, in the main, a new major request, which is rather nebulous in character. The first item - service trials on radiological instruments - is simply provided for by, say, attachment of a signals expert to the "Instrument Section " (Team R.H.2).

The other items are largely consequential requirements arising from the occurrence of a base surge, the creation of whic is regarded as doubtful. The measurements, although perhaps involving only a few additional staff, provide a major problem, and one which will have to be tackled by a new team, presumably Admiralty, working in parallel with our Radiation Hazard people. If a hulk is obtained, the problem becomes more tangible and it is suggested that [redacted] be asked to be much more concrete in his proposals. At the moment I can foresee no likelihood of this new team taking over duties now scheduled for the existing party, on the contrary, I expect its inclusion will result in an increase in the number of health surveyors required.

19 [redacted]

Plastpeel 'A' [illegible] ethyl cellulose [illegible] in solution

20.3.52 0149.

[redacted]

[redacted]

MEMORANDUM

From:- [redacted] Woolwich. To: (See below)

Ref: H/RS/15

Operation Hurricane - Decontamination

So that we may know what complexing agents etc. to stock on H.M.S. TRACKER for use for decontamination, it is necessary that we should have answers to the following questions. It would also help if you would add any other remarks you may think relevant.

1. Records

(a) What is the total number of records to be brought in?

(b) How many will be brought in per day?

(c) What is their physical form?

(d) What is the nature of the container which may be contaminated?

(e) Can the records be photographed if decontamination is impossible?

(f) What is the finish of the surfaces which may be contaminated?

In answering the last question full details should be given. For example if the finish is paint you should state if it is stove finish, oil paint, cellulose lacquer etc., and if possible give the specification. In the case of paint or other applied finishes the type of metal or other material under the finish should be stated.

2. Salvage of Equipment

(a) What equipment do you expect to salvage which may need decontamination? (see para.3).

(b) What is the physical form? (Shape, weight, size).

(c) Is there an outer cover which can be discarded? (Every effort should be made to provide such a cover).

(d) What is the finish of the surfaces which may be contaminated?

3. Policy for recovery

The following extracts from draft H.T.Os. are given for guidance.

"....... All records brought out of a contaminated area are to be decontaminated by Health Control. Records which cannot be decontaminated are as far as possible to be analysed on the spot and then destroyed. If they are required for further study they are to be sealed in a suitable container by Health Control and certified safe for return to laboratories in the U.K. ....

20

[redacted]

[redacted]

..... As much equipment as possible is to be salvaged subject to:-

(a) Time and effort available.
(b) Radiological conditions.

No equipment in contaminated areas is to be salvaged unless there is a reasonable hope of successful decontamination.

As far as possible no equipment is to be abandoned on site which might reveal classified information in the event of its falling into the hands of unauthorised persons. ....

..... All salvaged equipment is to be handed over for decontamination to Health Control.

Decontamination is to be carried out as far as possible on H.C.V. Health Control is to be prepared to establish a decontamination centre ashore to deal with equipment which cannot be handled on the H.C.V. ....

..... Additional labour as required by Health Control is to be provided by the scientific teams concerned. ......

4. Exact answers (except where specially noted) are neither required nor necessary, and I would appreciate your early replies covering all the activities of your various groups.

[redacted]

20th March, 1952.

To:- [redacted]

Copy to: [redacted]

[redacted]

21

0149.

7 ACS/HER.

[redacted]

Copies to [redacted]

'HURRICANE' Radiation Safety Dosage.

I attach (to [redacted] only) copies of two Medical Research Council confidential reports on Allowable Doses of Radiation.

My suggestion now is that H.E.R. should write to the Under Secretary Establishments (M.O.S.) enclosing copies of the above reports, to propose a maximum dosage which should not be exceeded during HURRICANE, and to ask for official acceptance by Ministry of Supply and Admiralty of this proposed limit in respect of their participating staffs.

I have confirmed from the Ministry of Supply that this approach is regarded as the correct channel, and that necessary discussions with Chief Medical Office and Chief Scientist will be undertaken by the Establishment Division.

Similarly M.O.S. Establishment Division will consult Admiralty Establishment Division in order to obtain an agreed solution.

Would you please therefore draft a letter from CS/HER to [redacted] (E.O.) setting out our proposals and the reasons for them, and let me have it.

I am sending copies of this minute to [redacted] and [redacted] so that they may be informed of the procedure being followed.

[redacted]

ACS/H R.

C.I.O. Form 15.

MEMORANDUM

From:- ACS/HER

Ref.

To:- [redacted]

Ref.

/ /195

Subject: Hurricane Damage

Please ~~see~~ see attached draft by Greatbatch & return with any comments by 0915 Thursday 22nd Oct (as [redacted] then wants to deal with it)

If the draft is approved my recommendation would be to send copies, officially, to U.S. Af Em. ? [redacted] [redacted] & internally to [redacted] [redacted]

You agree? [redacted]

[redacted]

(prob Aug '51 / pre 22 Oct '51 / (prob ~ mid Oct 51))

DRAFT

OPERATION HURRICANE - RADIATION DOSAGE

9

U.S.(E2)

In the absence of precedent and of any statutory regulations on the subject it is necessary to ask for official acceptance, both by the Ministry of Supply and by the Admiralty, ~~for~~ of the maximum permissible dosages of ionising radiation which it is proposed to adopt in Operation Hurricane.

In framing our proposals, outlined below, we have been guided by data given and recommendations made in recent papers of the Medical Research Council (P.A.B.E. 26 and P.A.B.E. 39 - copies attached) in which this problem has been considered in detail, with particular reference to Civil Defence operations. Due allowance is made for the fact that Hurricane is essentially a peace-time operation and that it will be possible to carry out the work under accurately known conditions and under strict control of experienced Radiation Safety Officers.

The effects of beta and gamma radiation are regarded as completely additive. In the case of beta radiation however, only the face and neck will be exposed, the remainder of the body being completely covered by suitable protective clothing.

Apart from accidental injuries the problem of internal radiation will not arise, since gas-masks will be worn for all operations which involve exposure to any airborne hazard. They will be worn automatically in the first instance until such time as measurements prove that their general use is unnecessary.

Approval is sought for the use of a set of three dosage levels to be applied under various conditions, these levels being:-

(1) An intermittent or continuous dosage up to 0.1 r/day of gamma-radiation (together with an accompanying beta-radiation of up to 1.2 rep/day on 10% of the body surface, which is taken as equivalent to 0.12 rep/day whole body).

This is the normal working limit which will be applied generally and it is estimated that it will be possible to carry out the greater part of the operation under these normal conditions.

(2) An integrated dose, received in one or a few exposures, of up to 3 r. of gamma-radiation (accompanying beta 36 rep).

This ~~dose will~~ may be applied in a limited number of cases where necessary to ensure the smooth running of the operation and

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[redacted]

[redacted]

will require the express permission of the Radiation Safety Officer. Personnel receiving such a dose will not be subjected to any further exposure during the remainder of the operation. It is considered that under these conditions such a dose is innocuous.

(3) An integrated dose of 15 r. of gamma-radiation (accompanying beta 180 rep).

This may be applied only in cases of extreme urgency, in order to recover vital records that might otherwise be lost, and will require the express personal permission of the Commander of the Operation who will have expert medical and radiological advice at hand. Personnel receiving such a dose will not be subjected to further exposure for a minimum period of 12 months. It will be noted from the M.R.C. Report Table I that the risk involved by this exposure is ~~small~~ slight.

Finally it should be noted that all personnel who are to be subject to any of these levels will undergo a pre-exposure medical examination and no person will be allowed to accept the radiation exposure until the Medical Officer has approved him as fit for such work.

Encl. C.S.H.E.R.

E. 1.

11KK/10. 128/10.

Register No [redacted] Minute Sheet No.

U. S. (E. O.)

OPERATION HURRICANE - RADIATION DOSAGE

In the absence of precedent and of any statutory regulations on the subject it is necessary to ask for official acceptance, both by the Ministry of Supply and by the Admiralty of the maximum permissible dosages of ionising radiation which it is proposed to adopt in Operation Hurricane.

In framing our proposals, outlined below, we have been guided by data given and recommendations made in recent papers of the Medical Research Council (F.A.B.E. 26 and F.A.B.E. 39 - copies attached) in which this problem has been considered in detail, with particular reference to Civil Defence operations. Due allowance is made for the fact that Hurricane is essentially a peace-time operation and that it will be possible to carry out the work under accurately known conditions and under strict control of experienced Radiation Safety Officers.

The effects of beta and gamma radiation are regarded as completely additive. In the case of beta radiation however, only the face and neck will be exposed, the remainder of the body being completely covered by suitable protective clothing.

Apart from accidental injuries the problem of internal radiation will not arise, since gas-masks will be worn for all operations which involve exposure to any airborne hazard. They will be worn automatically in the first instance until such time as measurements prove that their general use is unnecessary.

Approval is sought for the use of a set of three dosage levels to be applied under various conditions, these levels bei

(1) An intermittent or continuous dosage up to 0.1 r/day of gamma-radiation (together with an accompanying beta-radiation of up to 1.2 rep/day on 10% of the body surf which is taken as equivalent to 0.12 rep/day whole bo

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M41805/9203 8/45 800M Ko.(403)

[P.T. Over

This is the normal working limit which will be applied generally and it is estimated that it will be possible to carry out the greater part of the operation under these normal conditions.

(2) An integrated dose, received in one or a few exposures, of up to 3 r. of gamma-radiation (accompanying beta 36 rep). This may be applied in a limited number of cases where necessary to ensure the smooth running of the operation and will require the express permission of the Radiation Safety Officer. Personnel receiving such a dose will not be subjected to any further exposure during the remainder of the operation. It is considered that under these conditions such a dose is innocuous.

(3) An integrated dose of 10 r. of gamma-radiation (accompanying beta 150 rep).

This may be applied only in cases of extreme urgency, in order to recover vital records that might otherwise be lost, and will require the express personal permission of the Commander of the Operation who will have expert medical and radiological advice at hand. Personnel receiving such a dose will not be subjected to further exposure for a minimum period of 12 months. It will be noted from the M.R.C. Report Table I that the risk involved by this exposure is very slight.

Finally it should be noted that all personnel who are to be subject to any of these levels will undergo a pre-exposure medical examination and no person will be allowed to accept the radiation exposure until the Medical Officer has approved him as fit for such work.

[redacted]

Fort Halstead
22nd Oct. 1951

C.S.H.E.R.

Copy to: U.S.At.En., [redacted]

AL DRAFT

MEDICAL RESEARCH COUNCIL

[redacted]

MRC 50/795
PABE 26.

ALLOWABLE DOSES OF RADIATION

A request has been received for a decision on "the maximum allowable dose of gamma radiation for members of the Civil Defence Corps".

Single Doses of Radiation

[redacted] Panel has considered this problem. The conclusion was that no single figure for dose in röntgens could be quoted. This decision was arrived at from the following considerations.

(i) Varying conditions of operation. The Home Office Manual of Basic Training Volume II Atomic Warfare envisages these varying conditions and envisages scales.

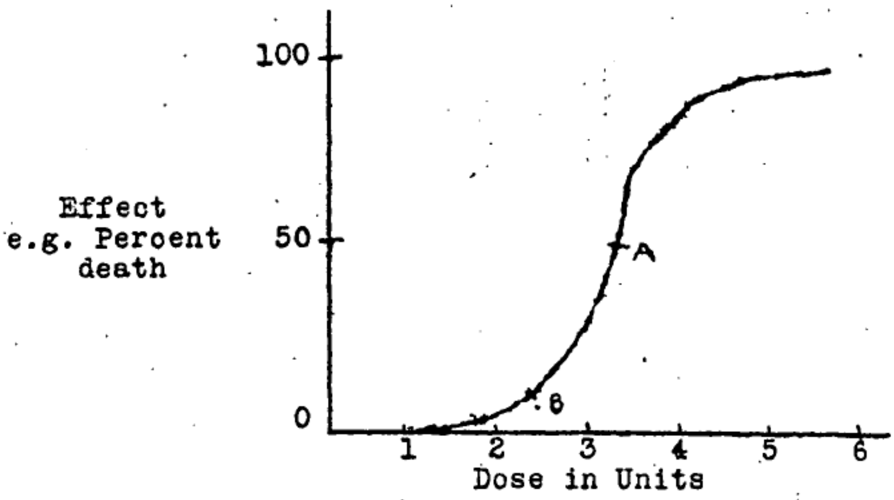
(a) for the general public,
(b) for the Civil Defence Corps and associated services such as the police and fire brigade, and
(c) for special categories such as rescue squads.

(ii) Paucity of reliable clinical data in man. The clinical response of normal man to exposure to ionising radiation applied to the whole body is known only from occasional accidents and from the Hiroshima and Nagasaki incidents when reliable and carefully controlled observation was not possible. The responses, therefore, have largely to be inferred from experiences in radiotherapy. However, radiotherapists deal almost exclusively with sick subjects and in addition radiation applied to the whole body is in this country in particular unusual. The great majority of cases treated with radiotherapy receive the radiation only to very limited parts of the body. Usually the local doses are very large and the part irradiated is very small compared with the whole. However, the total tissue-dose given can be assessed from the product of the dose given and the mass irradiated. This is the 'integral dose' and is expressed in gram-röntgens. Unfortunately for this purpose not all parts of the body are equally sensitive to radiation so that the same integral dose given say to the abdomen and to the limbs gives very different general clinical reaction.

In the face of all these limitations estimates have already been given (PABE 8, 13, fig. 1) of the expected effects, in terms of mortality, from a range of integral doses (5-40 megagram-röntgens). From these the surface doses, which might be received when the whole body is irradiated, to give the same effect were calculated and quoted.

When one considers a general reaction like radiation sickness rather than death, while reliable data are at present lacking, (but are being compiled), this much is qualitatively known. A very small proportion of people appear to be very highly 28 sensitive and with small doses get undesirable symptoms. Probably an equally small proportion are unduly resistant. This is in line with the usual experience of pharmacologists in the reaction of man and animals to drugs. When a graph is made of dose of a drug against effect (e.g. the percentage dying or giving some other measurable, positive response) this graph is usually not a straight line but S shaped.

Figure 1



This type of graph is obtained when experimental animals are given large doses of radiation to the whole body and the percentage dying is scored.

More frequently, however, the relationship is not as simple as this example and the S shaped curve is obtained only when the percentage effect is plotted against the logarithm of the dose.

This indicates a very much wider range of sensitivity. This was the type of curve found by [redacted] (PABE 5 and 8) when man was given therapeutic doses of X-radiation and the percentage dying was scored. This wider range of sensitivity in man is to be expected on other grounds - very mixed stock and a wide variety of clinical states.

For practical purposes obviously one required to know several important points on such a graph - the figure of dose for a 50% positive effect (point A on the graph) and that figure at which the S curve takes its sharp vertical ascent (point B on graph).

When mortality was considered [redacted] and 8) the 50% point (median) was taken to be 500r and point B was found to be 300r. If radiation sickness is now considered one finds estimates for the median ranging from 100-200r. (Radiological Defense Vol. iii, compiled by U.S. Armed Forces Special Weapons Project p. 105). No reliable data exist at present which would fix point B. The best opinion that can at present be obtained from radiotherapists is that this latter point is probably, but not certainly, above 50r. The following table summarises the best opinion at this time but is open to revision in the light of further evidence.

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TABLE I

Effects of a Single Exposure

Single dose, range in r.	Mortality at 24 hours.	Mortality at 6 weeks	Number incapacitated within 24 hours	Probable time of* unfitness for any duties of those showing symptoms
0- 25	0	0	Negligible	2-3 days
25- 75	0	0	A few	2-3 days
75-100	0	less than 0.1%	Up to half	1-2 weeks
100-150	0	less than 0.5%	At least half	About 3 weeks
150-200	0	up to 5%	At least three-quarters	Not less than 3 weeks: some very ill
200-400	unlikely to be any	About a third	Probably all	Not less than 3 months
400-600	Perhaps a few	About half	Probably all	Not less than 3 months
over 800	Likely to be some	Almost all	Probably all	-

* It is likely that a small proportion of people will require considerably longer peiods off duty.

This table thus has the following uses:

(1) A dose of gamma radiation having been unavoidably received by a body of men, as from an atomic bomb flash, the officer in charge should be able to gauge what is the outlook for his men.

(2) A dose of gamma radiation has to be risked, as in going into contaminated ground. The officer in charge can assess the result of the risk. He should note that

(a) for men receiving doses above 50r the amount of incapacity for any physical or mental work rises rapidly.

(b) in the absence of urgency it would not be desirable to expose men to more than 25r.

Spaced Repetition of Single Dose

A man having received unavoidably or from calculated risk a measured dose, his officers will naturally wish to know when he can legitimately be exposed again in the course of duty.

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This problem requires an understanding of the methods by which radiation adversely affects the body and of the principles on which "tolerable" amounts of radiation are fixed.

Practicably one can say that ionising radiation has always a destructive and deleterious effect. There are two main types of effect.

(i) Effect from which there is no recovery. All doses of radiation whether given intermittently or continuously have to be added together in assessing the effect in producing irrecoverable damage. The damage of genetic material is known with certainty to be of this type (see Effects of Atomic Weapons, U.S. Govt. Printing Office 1950, p. 363: also [redacted] American Scientist, Jan. 1950. p. 33). Other effects of this type may be shortening of life span and induction of cancer. It is notable that these effects are delayed and do not immediately manifest themselves as impaired physical ability. Knowledge on the part of the individuals of these additive effects may, however, result in loss of morale.

(ii) Effects from which there is apparent recovery. Radiation sickness, be it manifested as subjective symptoms of nausea, vomiting, fatigue, etc. or as objective signs like depression of the blood count is a clinical state from which there is a considerable measure of apparent recovery. For such effects a consideration of the dose-rate is most important. A single exposure of 500r in say an atomic bomb burst may result in death. The same dose spread evenly over a 50 year working life would probably lead neither to symptoms nor physical signs.

The peace time "tolerance" or maximum permissible dose of 0.5r per week was set at this level with two considerations in mind:

(a) The individual receiving such a dose for an indefinite period of time should not suffer clinically any adverse effects.

(b) Provided that less than 1% of the population were so exposed, the genetic and other effects from which there is no recovery should not create any sociological problem. In practice in well run establishments the doses actually received are kept to 10% or less of the maximum permissible.

Under these peace time conditions those who have been inadvertently exposed to doses above tolerance are required to take "time out", that is if a single dose of 10r has been accidentally received a rest period free from all exposure to radiation (but not off work) of 10/0.5 i.e. 20 weeks is demanded. It would have been logical to have required more, because as stated above, the acute dose is more damaging than the same dose given over a long period of time.

In war, however, while the peace time principles should be adhered to whenever possible, some allowance must be made for operational necessity and certain risks may have to be taken.

Granted that an individual has once received say between 10 and 50r, how soon can a second exposure above tolerance be given if the emergency persists? Broadly speaking within a matter of a day or two, the second dose may be considered to be completely additive to the first dose, not only for the effects for which there is no recovery but for those for which recovery is to be expected. On the other hand within a matter of months apart from the cumulative effects one may consider that there has been almost complete recovery. The actual rate of recovery is not certainly known: but some animal experiments, in which time of death was the indicator of biological effect, the residual effect within the first few weeks appeared to decline between 5 and 10% per day. For this paper, the median figure of $7\frac{1}{2}\%$ is taken. The residual effective dose (d) at any time (t) in days up to 3 weeks from an original dose (d0) can be calculated from an equation $d = do\Sigma - 0.075t$. This can be expressed graphically as an exponential curve, or in the form of a table(Table II)

TABLE II

Estimated Residual Effective Dose (d) at t days in % of initial dose (do)

Time in days	Residual effective dose	Time in days	Residual effective dose
0	100	12	40
3	80	16	30
7	60	21	20
10	50	30	10

After a month the rate of decline of the residual effect may be slower than this equation suggests but biological measurements at this level are very difficult to make. It may be safest, therefore, to postulate that there is always some persistent residual effect say equivalent to 10% of the original dose.

Another factor that must be taken into account is what total dose one can allow an individual to accumulate in a life time. This question has been considered for peace time occupations lasting a working life-time but no figure has been set. 300r was a figure which was suggested. Under emergency conditions, greatly shorter than working life-time, say a matter of a few years, this suggested figure would have to be still further reduced to 200r or less. If 200r is accepted and a 2 year period postulated, doses of 50r might if necessary be repeated at intervals of six months, and doses of 25r at intervals of 3 months. It should be stressed that these figures are speculative and these doses may produce symptoms of intolerance.

Continuous exposures

Where exposure to radiation is not a single acute event lasting minutes or hours, but is chronic and spread over periods greater than one day up to two or three weeks, the sum of the fractionated doses, equivalent in effect to a single acute dose are given in Table III. These figures are based on the results of radiotherapeutic doses - the observed affects being skin erythema or the reaction of tumours. In equating the effects of a number (x) of fractional doses (each = d) to those of a single dose (K) the following equation was used.

$$\log dx = a \log x + \log K$$

where a is a constant = 0.36

For one period of exposure extending over a matter of days, as in working in an area contaminated with aged fission products, the following table derived from the above equation can be used for assessing the total accumulated dose over a period of days to give similar effects to a single acute dose of 25 or 50r. These figures have been adversely criticised and rightly since they were derived from experiences in local radiotherapy. They may not be applicable to man given radiation to the whole body, but no alternatives are at present available.

/Table III

Table III

Dose accumulated from a more or less constant source to give effects similar to single doses of 25 and 50r

No. of days continuous exposure	Approximate accumulated dose in r equivalent to a single dose of 25 r	50r
1	25	50
2	~30	~ 60
3	~35	~70
4	~40	~80
5	~45	~90
7	~ 50	~100
9	~55	~110
11	~60	~120
14	~65	~130
17	~70	~140
20	~ 75	~150

General Summary

Single Exposure   For exposure up to 24 hours, it is recommended that Table I be consulted for possible clinical effects from a range of doses.

Repetition of Single Exposures   At least a month should elapse before the residual effect of the first dose should be considered to have fallen to 1/10 of the original value. If a second acute exposure has to be given within this time the residual to the first dose can be estimated from Table II. The sum of the residum of the first dose and the second dose might be expected to give results as in Table I.

Key personnel may have to be repeatedly exposed. If 4 single exposures of 25r or 2 single exposures of 50r per year for 2 years be taken reasonable freedom from ill effect is to be expected.

Continuous Exposure.   The determination of a permissible dose of radiation to be taken daily for a period up to a few weeks can be estimated from Table III.

ADDENDUM

Consideration is now being given to permissible doses of β rays. At first sight it would appear that the likely figures for doses (i.e. almost certainly not damaging) are likely to be more restrictive in practice than those of γ-rays estimated above.

July 1951.

[redacted] 22-1-85

[redacted] DECLASSIFIED

PABE/39

MEDICAL RESEARCH COUNCIL

[redacted] Panel

The eleventh meeting of the Panel was held at the Headquarters office of the Medical Research Council, 38 Old Queen Street, London, S.W.1., at 3.30 p.m. on Wednesday, 15th August 1951.

Present: [redacted]

Apologies for absence were received from [redacted] and [redacted].

11.1. Matters arising from the minutes

(a) Action on PABE/26 The latest amended version of PABE/26 had been issued but without the addendum on beta irradiation to the skin as recommended in 10.2 and 10.3 (see PABE/38).

The Joint School of Chemical Warfare had written a training manual which had been received at Harwell for comment by [redacted] and [redacted]. The Navy and Civil Defence Service had apparently not been consulted in the preparation of this manual. The Panel agreed that the first recommendation of [redacted] and [redacted] might be that the manual be sent to the Navy and Civil Defence for comment.

Action [redacted] and [redacted]

(b) Dextran. Data had been received from [redacted] on the effects of dextran in rats. The final unlike the preliminary results had not shown any deleterious effects of dextran. It had been agreed therefore that the dextran investigation should be dropped.

11.2. Probable effects of acute whole body gamma radiation doses (PABE 35)

[redacted] committee had submitted data in PABE/35 drawn from Report of the (U.S.) Army Field Forces Board No.I. Examination of material quoted therein showed some discrepancies when compared with PABE 26. The only real discrepancy from the militar[y] point of view was in the range 50-150r. It was noted that this was the early steep part of the dose-effect curve. It could be attributed to the general uncertainty of this part of the curve, to differences in the subject material (e.g. fit men or cases for radiotherapy) or to a difference in expressing the doses (e.g. measured in air or measured with backscatter).

Action [redacted]

It was agreed that Harwell enquire from the U.S. about the methods of measurement and the sources of material on which the report was based. The Secretary was instructed to ask [redacted] for data promised in 8.2. (PABE 25). [redacted]s asked to survey available data for the degree of incapacity and rate of recovery following whole body radiation that could be derived from the British radiotherapeutic centres

Action [redacted]

Action [redacted]

....

Probable effects of chronic whole body gamma radiation doses

There were also discrepancies between PABE 26 and the American figures for chronic doses. It was agreed again that Harwell should enquire about the basis of calculation of the acute dose equivalent for chronic doses quoted in the American document.

Action [redacted]

11.3. Maximum Permissible level for β radiation of the skin in an emergency (PABE 38)(see 10.3.) [redacted] noted that the 50 rep of beta radiation permitted by 10.3 would in the case of fresh fission products, be received by the surface of the body with 4r gamma rays. It was agreed that at the last meeting the figure of 50 reps of β rays referred to whole body exposure. [redacted] pointed out that the figures of Low Beer quoted were for areas of skin 5 cm^2 and that the effect was very dependent on the area of skin irradiated. The Panel decided it was justifiable to permit a dose of 300 rep of β rays, averaged over 1 mm. depth and excluding the first 7 mg. per cm^2, for the hands and face only, that is the normally exposed areas of the body, the rest of the body being presumed to be covered in a dust proof outfit and not to be receiving any beta rays. In a grave emergency an extra factor of three would be permissible. The panel agreed that, because of uncertainties in the clinical responses to irradiation of large areas of the skin by beta rays, a clinical trial should be considered. [redacted]l was asked to advise on this.

Action [redacted]

11.4 Radioactive dust hazards (PABE 37 and PABE 31)

The Panel supported the conclusions reached in PABE 31 and 37. It was noted that owing to retention of dust in the nose there might be a high dose to the nasal mucosa. The Secretary was instructed to write to [redacted] asking for data on the rate of removal of dust from the nose. [redacted]l noted that ciliary action of ciliated epithelium was not abolished until the cells were so severely damaged as to be almost dead.

Action [redacted]

E.2.

6. [redacted]

[redacted]

Room 829,

21st November, 1951

Chief Superintendent,
H.E.R.,
Fort Halstead,
Nr. Sevenoaks, Kent.

Operation Hurricane - Radiation Dosage

We asked the Chief Medical Officer for his views on the subject of the maximum permissible dosages of ionising radiation raised in your minute to U.S.(E.O) dated 22nd October, 1951, and I attach a copy of his reply.

It would appear that if these precautions and safeguards are practicable in the circumstances under which the Operation will be carried out, the risk to which the staff concerned will be exposed is very slight in the worse possible circumstances visualised, short of an accident, and that the greater part of the Operation will be carried out within "the normal working limit".

Unless you have any comments to make on C.M.O's minute it seems to me that the proposed dosages may be accepted.

[redacted]

[redacted]

Reference...

[redacted] 22.1.85

DECLASSIFIED

1

C.M.O.

Will you please refer to the enclosed minute by C.S./H.E.R. and the accompanying papers.

We shall be glad of your views as to whether approval may be given to the dosage levels mentioned by C.S./H.E.R. We should like to know also whether analogous questions have arisen at the atomic energy establishments and if so how they have been settled.

Adelphi.
27th October 1951

[redacted]
A.S./Est.3.

2.

A.S./Est.3.

There is no objection to the use of the levels of radiation exposure for Operation Hurricane as put forward by [redacted] in his minute 144/10 of 22nd October subject to the following reservations:-

(1) Personal ionisation chambers and monitoring films must be worn by all personnel entering the radiation area, so that individual exposures will be known in every case. Where it is necessary to subject the hands to high exposure wrist films should be worn. The Maximal Permissible Exposure to the hands is 1.5 r or its energy equivalent per week.

Radiation workers for whom regular exposure records are maintained elsewhere must have their Operation Hurricane exposure duly entered subsequently in their permanent record.

(2) When personnel working at dosage level (i), as described in the minute, receive a dose of radiation in excess of the generally agreed maximum permissible exposure of 0.5 r per week,

/a.

(1439) Wt41894/1033 2/51 1,000,000 JC&S Ltd. Gp736/210 (REGIMITE) Code 5-35-0 a compensation period of non-radiation work must be arranged when the excess dose reaches the equivalent of 3 r of gamma radiation and 36 r of beta radiation.

This provision is to cover accidental over-exposure which might accrue during the weeks over which the operation is being carried out or by a single unforeseen high exposure. The dosage chosen brings it into line with level (ii).

The compensatory period is calculated on a basis of one week for every 0.5 r of over exposure [redacted] D.At.En.(P) Report No.5006-49 1951).

(3) It is agreed for the purposes of this operation, that provided that rubber gloves, protective clothing and respirators are worn, beta ray exposure as measured on personal monitoring films may be considered as being one tenth of the biological value of an equivalent dose of gamma rays. Where these conditions are not in force beta ray exposure must be reckoned at one third of the gamma rays.

Level (iii) is noted and it is emphasised that exposure of this kind should be avoided if possible. The compensation period for recovery at 0.5 r per week is, of course, much less than one year.

Analogous situations have had to be foreseen in atomic energy establishments and the question of permissible levels is dealt with at length by [redacted] in the report to which reference has been made above.

(4) I would add these further suggestions:

(a) In the pre-operational medical examination there should, if possible, be three blood counts done on those whose work is likely to involve higher dose rates.

(b) If possible, a proportion of those exposed should wear more than one monitoring film, on different parts of the body, e.g., chest (standard), lower leg, cuff or wrist, and lower abdomen. This comparison of recorded doses would be of interest to both present and future operations.

L.2.

Shell Mex House, Room 967,
Ext.1087,
14.11.51.

[redacted]

[redacted]
Chief Medical Officer.

L.H. 158

Telegrams: SPLYMIN, WIRE, LONDON
Tel. No.: GERrard 6933
Extn. 1087

Our Ref. L.2.

Your Ref.

MINISTRY OF SUPPLY
Room 967 [redacted]
SHELL MEX HOUSE,
STRAND,
LONDON, W.C.2.

16th November, 1951.

[redacted]

Dear [redacted],

Operation Hurricane

I have recently minuted A.S./Est.3. regarding some of the queries which you put to U.S./E. and O. and in this minute I refer to a memorandum by [redacted], Atomic Energy (Production).

I am not sure whether you have a copy of this and [redacted] is not sure whether one was sent to H.E.R.

In case you have not got a copy by you, [redacted] has let me have a spare one to send you and I am attaching it. → Annex

You will perhaps want to refer to this when you see my minute to A.S./Est.3.

Yours sincerely,

[redacted]

Chief Medical Officer.

[redacted],
[redacted],
Armament Research Establishment,
Fort Halstead,
Nr. Sevenoaks, Kent.

Tel. [illegible]-Sevenoaks 5211
Extn.

Any communication on the subject of this letter should be addressed to:
THE CHIEF SUPERINTENDENT
and the following reference quoted:

Your Ref.

1395/23

MINISTRY OF SUPPLY
ARMAMENT RESEARCH ESTABLISHMENT
FORT HALSTEAD
SEVENOAKS, KENT

CONFIDENTIAL

[redacted]

4th December, 1951

[redacted]
A.S./Est.3.,
Rm. 829, The Adelphi,
London, W.C.2.

Operation Hurricane. Radiation Dosage.

Your memo of 21st November. The reservations in C.M.O.'s minute are acceptable.

With regard to para.4 of C.M.O.'s minute, 4(a) has been arranged to be carried out by Naval Medical authorities and para.4(b) will be complied with where practicable.

[redacted]

41

[redacted]

6

UNCLASSIFIED

MINISTRY OF ... 22.1.85 [redacted] LONDON ...

E4

1/Staff/13379/Est.3

EST. 3,

THE ADELPHI,

JOHN ADAM ST.,

LONDON, W.C.2.

For the attention of [redacted]

14 January, 1952.

Dear Sir,

I am directed by the Minister of Supply to inform you that the following arrangements relating to the permissible dosages of ionising radiation have been approved for the staff of this Ministry who will be employed on Operation Hurricane.

2. The proposals take account of the data given and the recommendations made in recent papers of the Medical Research Council (P.A.R.E. 26 and P.A.R.E. 39) in which the question of allowable doses of radiation has been considered in detail, with particular reference to Civil Defence operations. In the arrangements due allowance is made for the fact that Operation Hurricane is a peace-time operation and that it will be possible to carry out the work under accurately known conditions and the strict control of experienced Radiation Safety Officers. The effects of beta and gamma radiation are regarded as completely additive. In the case of beta radiation, however, only the face and neck will be exposed, the remainder of the body being completely covered by suitable protective clothing. Apart from accidental injuries the problem of internal radiation will not arise since gas-masks will be worn for all operations which involve exposure to any airborne hazard. They will be worn invariably in the first instance until such time as measurements may prove that their general use is unnecessary. Personal ionisation chambers and monitoring films will be worn by all personnel entering the radiation area so that individual exposures will be known in every case. Where it is necessary to subject the hands to high exposure wrist films should be worn. The maximum permissible exposure to the hands is 1.5r or its energy equivalent per week. Radiation workers for whom regular exposure records are maintained elsewhere will have their Operation Hurricane exposure entered subsequently in their permanent records.

3. Approval has been given for the use of a set of three dosage levels to be applied under various conditions, as follows:-

(i) An intermittent or continuous dosage up to 0.1 r/day of gamma-radiation (together with an accompanying beta-radiation of up to 1.2 rep/day on 10% of the body surface which is taken as equivalent to 0.12 rep/day whole body). This is the normal working limit which will be applied generally, and it is estimated that it will be possible to carry out the greater part of the operation under these conditions. If any officer receives a dose of radiation in excess of the generally agreed maximum permissible exposure of 0.5r per week a compensation period of non-radiation work will be arranged when the excess dose reaches the equivalent of 3r of gamma radiation and 36r of beta radiation. The compensatory period will be calculated on a basis of one w[eek] for every 0.5r of over exposure. This provision is to cover accidental o[ver] exposure which might occur during the weeks over which the operation is being carried out or by a single unforeseen high exposure.

(ii) An integrated dose, received in one or a few exposures, of up to 3r gamma-radiation. (accompanying beta 36 rep). This may be applied in a limited number of cases where necessary to ensure the smooth running of [the] operation and will require the express permission of the Radiation Saf[ety]

/Of[ficer]

The Secretary,
Admiralty.

42

Copy sent to [redacted]

Officer. Any officer who receives such a dose should not be subjected to any further exposure during the remainder of the operation. It is considered that under these conditions such a dose is innocuous.

(iii) An integrated dose of 10r of gamma-radiation (accompanying beta 150 rep) This may be applied only in cases of extreme urgency, e.g. in order to recover vital records that might otherwise be lost, and will require the personal authority of the Commander of the Operation who will have expert medical and radiological advice at hand. Any officer receiving such a dose will not be subjected to further exposure for a minimum period of twelve months. According to the Medical Research Council's Reports the risk involved by this exposure is very slight.

4. For the purposes of the Operation and provided that rubber gloves, protective clothing and respirators are worn, beta ray exposures as measured on personal monitoring films will be considered as being one tenth of the biological value of an equivalent dose of gamma rays. Where these conditions are not in force beta ray exposure will be reckoned at one-third of the gamma rays.

5. If possible, a proportion of those exposed should wear more than one monitoring film, on different parts of the body e.g. chest (standard), lower leg, cuff or wrist, and lower abdomen. This comparison of recorded doses would be of value.

6. Any officer who is likely to be subject to any of these levels should undergo a pre-operational medical examination and no person should be allowed to accept the radiation exposure until the Medical Officer has approved him as fit for such work. In the medical examination there should be, if possible, three blood counts done on any officer whose duties are likely to involve exposure to the higher rates.

7. I am to enquire whether the above arrangements and proposed dosages are accepted for the purposes of Operation Hurricane so far as the naval personnel and civilian staff are concerned.

I am, Sir,
Your obedient Servant,

[redacted]

[redacted]

[redacted]

E5.

L.P.—No. 8

Any further [redacted]
should be addressed to
The Secretary of the Admiralty,
London, S.W.1
quoting "N1/T.S.D.30/52"

Admiralty, S.W.1

20th February, 1952.

MINISTRY OF DEFENCE
22.1.85
[redacted] DECLASSIFIED
LONDON S.W.1

Sir,

With reference to your letter of 14th January, reference 1/Staff/13379/Est.3., I am commanded by My Lords Commissioners of the Admiralty to inform you that the proposed arrangements and dosages detailed therein are acceptable for the Naval and Admiralty Civilian personnel participating in Operation "Hurricane".

It is understood that Army personnel will also be taking part in the Operation and I am to suggest that the War Office should be similarly consulted and informed of the Admiralty agreement to the proposed dosages.

I am, Sir,
Your obedient Servant,

[redacted]

The Secretary,
Ministry of Supply,
Est. 3,
The Adelphi,
John Adam Street,
W.C.2.

BP
CCB/20

E6a. [redacted]

2019

[redacted]

1/Staff/1337/Est.3.A.

29 February 1952.

E4

Sir,

I am directed to forward, for your information, the attached copy of a letter, dated 14th January 1952, addressed to the Secretary, Admiralty, about the arrangements relating to the permissible dosages of ionising radiation which have been approved for the staff of this Ministry who will be employed on Operation Hurricane.

2. Notification has just been received from the Admiralty that the proposed arrangements and dosages detailed in the letter are acceptable for the Naval and Admiralty Civilian personnel participating in Operation "Hurricane". It would be appreciated if you would please confirm that the proposals are also acceptable for the Army and War Office Civilian personnel participating in the operation.

3. A similar letter has been sent to the Director General of R.A.F. Medical Services, Air Ministry.

I am, Sir,
Your obedient Servant,

[redacted]

The Director General of Army Medical Services,

The War Office,
Whitehall, S.W.1.

E 7

TEL. No GRO 8040

EXTN. 464.

Further correspondence on this subject should be addressed to:
The Under-Secretary of State (A.M.D.7.)

THE WAR OFFICE,
LONDON,
S.W.1.

Please quote in any reply:
86/Gen/5290.A.M.D.7.

[redacted]

6th March, 1952.

Sir,

I am directed to acknowledge receipt of your letter 1/Staff/1337 Est 3A dated 29th February, 1952 and the enclosed copy of a letter 1/Staff/13379/Est 3 dated 14th January, 1952.

I am further directed to confirm that the proposed arrangements relating to the permissible dosages of ionising radiation for staff employed on Operation Hurricane are acceptable for Army and War Office Civilian personnel participating in the operation.

I am, Sir,
Your obedient Servant,

[redacted]

Army Medical Services.

22-1-85 [redacted] DECLASSIFIED

The Secretary,
Ministry of Supply,
The Adelphi,
London, W.C.2.

[redacted]

E6

/Staff/13379/Est.3A [redacted]

29 February 1952.

MINISTRY OF DEFENCE
22.1.85
DECLASSIFIED

[redacted]

Sir,

E4

I am directed to forward, for your information, the attached copy of a letter, dated 14th January 1952, addressed to the Secretary, Admiralty, about the arrangements relating to the permissible dosages of ionising radiation which have been approved for the staff of this Ministry who will be employed on Operation Hurricane.

2. Notification has just been received from the Admiralty that the proposed arrangements and dosages detailed in the letter are acceptable for the Naval and Admiralty Civilian personnel participating in Operation "Hurricane". It would be appreciated if you would please confirm that the proposals are also acceptable for R.A.F. personnel participating in the operation.

3. A similar letter has been sent to the Director General of Army Medical Services, War Office.

I am, Sir,
Your obedient Servant,

[redacted]

Air Ministry,
Adastral House,
Kingsway, W.C.2.

Temple Bar 1216,
TEL.: ~~HOLBORN 3434~~ Extn. 3523.

Correspondence on the subject of this letter should be addressed to :—
THE UNDER SECRETARY OF STATE,
AIR MINISTRY
and should quote the reference :—
DGMS/752

Your ref.

E8

AIR MINISTRY,
LONDON, W.C.2.

[redacted]

5th March, 1952.

Sir,

I am directed to refer to your 1/Staff/1337/Est.3A. dated 29th February 1952, and to state that the proposals contained therein are acceptable for Royal Air Force personnel attending Operation "Hurricane".

I am, Sir,
Your obedient Servant

[redacted]

Air Commodore,
for Director-General of Medical Services.

The Secretary,
Ministry of Supply,
The Adelphi,
London,
W.C.2.

Copy to: Medical Director-General of the Navy.
Director-General of Army Medical Services.

[redacted]

C.S.H.E.R.

Fall-Out of Contamination. Criteria for Firing

I am in entire agreement with the modifications you have introduced in Part V of this document.

With regard to Part IV on Maximum Permissible Dosages, I would like to make some comments. As you know, further facts which have come to light since this was first formulated have shown that the assumptions then made are not applicable to the conditions of the operation. I have dealt with this in more detail in a separate note attached.

From the discussion in Part II it would seem that the conditions you anticipate as most probable will give a heavy contamination on the Islands and with the β-dosages limited as in the present agreement it seems likely that for a high proportion of the records it would be impossible to recover them within the period available before the expedition leaves. An increase in acceptable β-dose by a factor of four would, in critical circumstances, make a difference of weeks in the waiting time before recovery was possible. I therefore recommend that a new agreement be sought.

For the purposes of the present document, I would suggest that, unless you regard it as a necessary part of the whole, Part IV should be omitted. If you do regard it as essential then I would suggest the addition of a note to the effect that :-

> Further investigation has shown that the ratio of β-dose to γ-dose for the body as a whole will probably be considerably greater under the conditions of the operation than that used above. Nevertheless if any changes are made in details of the dosage levels they will be such as to maintain an overall physiological effect similar to that given by the levels stated.

[redacted]

[redacted]

[redacted] 22.1.85 DECLASSIFIED

Copies to:

S.S.M.R.
File (2)

Health Physics Group,
Building [redacted].,
Aldermaston,
Nr. Reading,
8th April, 1952.

Minute [redacted]

Missing

Discussões β : ∇ vetor
in

[redacted] D.I.O. Form 16.

E12

MEMORANDUM

22/5 /1952

From:- S.S.I.R.	To:- C.S.H.E.R.
Ref.	Ref.

Subject Fall out of Contamination - Criteria for Firing

[redacted] raises two important points.

The first is that the effects of contamination, particularly the beta dose, will be much more severe than had been anticipated and hence the recovery of records and salvage will take considerably longer time than has been reckoned so far. This, in itself, is not very serious, it may mean that the expedition has to stay at the site a little longer but clearly this condition can be met. I do not think we need worry ourselves unduly about it at this stage, since there must be a large element of speculation in assessing the phenomena which will occur and the times assigned to post event duties are, admittedly, no more than guesses.

22.1.85 [redacted] DECLASSIFIED

The question of maximum permissible dosages is more important but it would not seem unreasonable to accept the levels suggested by [redacted] although they would seem well above those agreed by the Ministry. No specific figures have been included in the Ministry of Supply Plan of the Operation and hence our Staff have not been given figures for dosages which will have to be altered. However, I understand you have discussed this matter further with [redacted] and decided to await further results from his experiments before reaching a decision.

[redacted]

Wait till [redacted] produces some further results [redacted]

[redacted] 78/1
L.H. 102 SP.

E.16

Tel. No.: WOOLWICH 4261
Ext. 55

MINISTRY OF SUPPLY

Chief Superintendent,

H.E.R.,

WOOLWICH, S.E.18.

Our Ref.

2

[redacted]

MEMORANDUM

23rd July, 1952.

To [redacted]

C.S./H.E.R.,

FORT HALSTEAD.

Your Ref.

Subject OPERATION HURRICANE - RADIATION DOSAGE

Please see attached minute (unsigned) to US(E) which you might like to use unaltered or as a draft if you wish to modify it.

I have discussed the new levels with [redacted] and [redacted] and they agreed very readily with the proposals.

Paragraph 4 refers to them but it can easily be detached if required.

[redacted]

1/3 23/7/52 [redacted]

DUP.

OPERATION HURRICANE - RADIATION DOSAGE

U.S.(E)

Further to my minute 144/10 of 22nd October, 1951:-

1. Since our previous correspondence on this subject, my staff have been able to make a more thorough experimental investigation of the β and γ doses likely to be received on the operation. As a result of these investigations we now see that it is possible to improve the regulations controlling the doses which can be allowed. It is true that our original regulations could have been successfully applied but they would have imposed limitations which we now know can be avoided.

2. The main findings which emerge from our investigations are:-

(i) Proportions of the dose attributable to γ-rays and to β-rays will not be a fixed ratio but will vary from time to time and place to place.

(ii) The clothing which can be used in this climate (effective thickness about 20 mg/sq.cm) will afford only a limited protection to the body.

3. Approval is therefore sought to re-define the dosage levels previously agreed so as to allow for these conditions whilst giving the same general physiological effect as originally envisaged.

The effects of β and γ radiation will be regarded as additive and both will be whole-body radiation. They will be separately evaluated by means of personal film badges.

Three dosage levels will be applied under various conditions viz:-

(i) Normal Working Rate

An intermittent or continuous dosage up to 0.3 rep per day of which the γ-ray component is not to exceed 0.1 r/day.

This is the normal working limit which will be applied generally and it is estimated that it will be possible to carry out the greater part of the operation under these conditions.

(ii) Lower Integrated Dose

An integrated dose, received in one or a few exposures, of up to 15 rep of which the γ-ray component is not to exceed 3r.

This dose will be applied only with the express permission of the Radiation Safety Officer, which will be given only where he regards it as necessary for the smooth running of the operation. Except as provided for under (iii) below personnel who have received this dose will not be subjected to further exposure during the remainder of the operation.

(iii) Higher Integrated Dose

An integrated dose of up to 50 rep of which the γ-ray component is not to exceed 10r.

This dose will be applied only in cases of extreme urgency in order to recover vital records which might otherwise be lost, and will require the express personal permission of the Commander of the Operation who will have expert medical and radiological advice at hand. Personnel receiving this dose will not be subjected to further exposure for a minimum period of 12 month

4. These proposals have been discussed with [redacted], [redacted] (M.R.C) and [redacted] (Health Physics) at A.E.R.E. Harwell. They consider that the levels suggested are safe and the conditions under which they are to be applied are ~~reasonable~~ sensible.

[redacted]

CSHER

TS.75/13
file
[illegible]·18

5211

[redacted] 30th July, 1952

[redacted]
Rm. [illegible], Shell Mex House,
Strand, W.C.2.

Dear [redacted]

For the past few months, the Health Physics Group in H.E.R. has been making investigations into the hazards to health of the contamination expected at the Hurricane Trial. The Health Physics Group has now prepared a new instruction sheet. The main decisions are summarised in para.3 of the attached Minute.

Will you please give formal agreement for me to use the Radiation Dosage Levels, defined in the present Minute; and to regard them as superseding the earlier Dosage Levels, defined in my Minute of 22nd October 1951.

Yours sincerely,

Copy to: [redacted]

[redacted]

MINISTRY OF DEFENCE 22.1.85 DECLASSIFIED [redacted] 3/81 E9A

Reference

U.S. (E.O.) [redacted]

Operation Hurricane - Radiation Dosage E1

Further to my minute ~~111/10~~ of 22nd October, 1951:-

1. Since our previous correspondence on this subject, my staff have been able to make a more thorough experimental investigation of the β and γ doses likely to be received on the operation. As a result of these investigations we now see that it is possible to improve the regulations controlling the doses which can be allowed. It is true that our original regulations could have been successfully applied but they would have imposed limitations which we now know can be avoided.

2. The main findings which emerge from our investigations are:-

(I) Proportions of the dose attributable to γ-rays and to β-rays will not be a fixed ratio but will vary from time to time and place to place.

(II) The clothing which can be used in this climate (effective thickness about 20 mg/sq.cm.) will afford only a limited protection to the body.

3. Approval is therefore sought to re-define the dosage levels previously agreed so as to allow for these conditions whilst giving the same general physiological effect as originally envisaged.

The effects of β and γ radiation will be regarded as additive and both will be whole-body radiation. They will be separately evaluated by means of personal film badges.

Three dosage levels will be applied under various conditions viz:-

(i) Normal Working Rate

An intermittent or continuous dosage up to 0.5 rep per day of which the γ-ray component is not to exceed 0.1 r/day.

This is the normal working limit which will be applied generally and it is estimated that it will be possible to carry out the greater part of the operation under these conditions.

(ii) Lower Integrated Dose

An integrated dose, received in one or a few exposures, of up to 15 rep of which the γ-ray component is not to exceed 3r.

This dose will be applied only with the express permission of the Radiation Safety Officer, which will be given only where he regards it as necessary for the smooth running of the operation. Except as provided for under (iii) below personnel who have received this dose will not be subjected to further exposure during the remainder of the operation.

(iii) Higher Integrated Dose

An integrated dose of up to 50 rep of which the γ-ray component is not to exceed 10r.

This dose will be applied only in cases of extreme urgency in order to recover vital records which might otherwise be lost, and will require the express personal permission of the Commander of the Operation who will have expert medical and radiological advice at hand. Personnel receiving this dose will not be subjected to further exposure for a minimum period of 12 months.

40) Wt41896/1035 2/51 850,000 JC&SLtd Gp736/211a REGIMERE CODE 5-30-0

4. These proposals have been discussed with [redacted] (M.R.C.) and [redacted] (Health Physics) at A.E.R.E. Harwell. They consider that the levels suggested are safe and the conditions under which they are to be applied are sensible.

[redacted]

Fort Halstead
30th July, 1952

C.S.H.E.R.

Reference 1/Staff/13379

3

C.M.O.

Please see C.S./H.E.R's letter and minute at E.9 & E.9.A.

Your comments on C.S./H.E.R.'s original proposals on radiation dosage for "Operation Hurricane" are at minute 2 and were conveyed to C.S./H.E.R. in our minute of 21.11.51 (see E.2).

We should be glad to have your views on the revised proposals.

[redacted]

Est.3.G.
, August 1952.

\- 4 -

Est. 3.G.

I have no objections to the revised [redacted]

2/8/52

\- 5 -

File transferred to the Department of Atomic Energy w.e.f. 1.1.54

[redacted]

[illegible] SUPPLY.
Est. 3.G.
ROOM 613
[illegible] HOTEL,
[illegible], S.W.1
TRAFALGAR [illegible] 301

(5757) Wt. Y21079—4121—10/51 450m A.O.St.
REGIMITE
Code 5-35-0

EB.

E10

[redacted]

EST. 3.

1/Staff/13379/Est. 3.

[redacted]

7 August, 1952.

Dear [redacted]

In reply to your letter No. TS 75/13 of 30th July to [redacted] and your minute No. TS 73/13 of the same date, I have to say that you have our formal agreement to use the radiation dosage levels defined in your minute No. TS 73/13.

We assume that in the case of (iii), the Higher Integrated Dose, the risk involved by this exposure is very slight.

On the previous occasion, when we received your minute of 22nd October 1951, we told the Admiralty, War Office and Air Ministry of the arrangements and proposed dosages.

We will do so on this occasion; I hope you have no objection.

Yours sincerely,

[redacted]

H. S. R.
Fort Halstead,
Nr. Sevenoaks,
Kent.

EB.

1/8

?.H. 209

..LEGRAMS: SPLYMIN WIRE, LONDON
TELEPHONE: GERRARD 8081

Extn.............................

Our Ref....1/Staff/13379/Est. 3.

Your Ref..................................

MINISTRY OF SUPPLY

EST. 3.

THE ADELPHI,
JOHN ADAM STREET,
LONDON, W.C.2.

7 August, 1952.

[redacted]

Dear [redacted]

In reply to your letter No. TS 75/13 of 30th July to [redacted] and your minute No. TS 73/13 of the same date, I have to say that you have our formal agreement to use the radiation dosage levels defined in your minute No. TS 73/13.

We assume that in the case of (iii), the Higher Integrated Dose, the risk involved by this exposure is very slight.

On the previous occasion, when we received your minute of 22nd October 1951, we told the Admiralty, War Office and Air Ministry of the arrangements and proposed dosages.

We will do so on this occasion; I hope you have no objection.

Yours sincerely,

[redacted]

[redacted],
H. E. R.
Fort Halstead,
Nr. Sevenoaks,
Kent.

Copy fwdd. to: [redacted]

18/8/52. H79

60

(E11

8-8-1952

Our ref. 1/Staff/13379 (Est.3.A)

Your ref . N.I./T.S.D.30/52 (Admiralty)
86/Gen/5290 A.M.D.7. (War Office)
D.G.M.S./752 (Air Ministry).

[redacted]

Sir,

With reference to -
Admiralty letter, dated 20th February 1952
War Office letter dated 6th March 1952
Air Ministry letter dated 5th March 1952.

I am directed to forward, for your information, the attached copy of a revised note by our Chief Superintendent, High Explosives Research, on Radiation Dosages for personnel taking part in Operation Hurricane. E9a

2. The revised dosage levels given in this paper supersede those formerly communicated to your Department and this Ministry has formally agreed that they may be used.

I am, Sir,
Your obedient Servant,

[redacted]

The Secretary,
Admiralty (N.I./T.S.D.)
Whitehall, S.W.1.

[redacted]

The War Office,
Whitehall, S.W.1.

The Director General of R.A.F. Medical Services,
Air Ministry,
Adastral House,
Kingsway, W.C.2.

22.1.85
DECLASSIFIED

E.7A

[redacted] [redacted]

IN

[redacted]

MESSAGE

DISTRIBUTION OF THIS MESSAGE IS TO BE LIMITED TO THOSE OFFICERS WHO ARE CONCERNED WITH ITS CONTENTS

050951Z July

From [redacted]

Date: 5.7.52

Recd: 1454

To [redacted]

BY [redacted]

EXCLUSIVE.

Request I may be informed before arrival Fremantle regarding policy in the unlikely event of monitoring by aircraft indicating any dangerous contamination on Australian mainland.

2. As planned Harwell Monitoring Team will send their reports which are not self evident, to me.

3. If these reports indicate that further survey is required in any area I intend to order it to be done by same Harwell Team during aircraft and/or land transport as appropriate. (using)

4. Such survey would be desirable for scientific purposes if any significant contamination is detected although this may not constitute a danger to life.

5. It is recommended that Australia should beadvised that further monitoring surveys may be called for after initial surveys results have been examined and that these further surveys would be for scientific purposes.

6. If danger to life should exist anywhere it is proposed to report by Op. signal to Admiralty only. Request information before event what level should be regarded as dangerous.

[redacted]

21/3/

[redacted]

050951Z

[redacted]

AB/64/19

[redacted]

E.977
8A

To: C.T.F.4.

From: Admiralty.

From D.C.N.S. Policy outlined in your 030931 paragraphs three, (comma) four and six is confirmed.

2. Your paras 5 [redacted] states that Appendix B of his paper to U.K. S.L.5 dated twenty first March (of which you have copy) envisaged further search by R.A.F. aircraft after initial surveys and therefore further advice on this point is unnecessary.

3. Re danger level C.S.H.E.R. remarks as follows:-

(a) Scientists making coastal survey expect to make continuous measurements from twenty four to eighty hours after explosion. They will express contamination in MICROCURIES PER SQUARE METRE.

(b) Since contamination decreases with time they will extrapolate backwards in time to one hour after explosion.

(c) A contamination level calculated as in (b) above less than FORTY THOUSAND (R) FORTY THOUSAND MICROCURIES PER SQUARE METRE is considered safe, but slight risk begins above this level.

(d) Please see page 35 of C.S.H.E.R. report T.S. 75/20 on Fall Out of Contamination of which TYTE holds copy.

(e) Sensitivity of measuring instruments is such that three days after explosion they can measure fifty times less contamination than level quoted in (c) above.

[redacted]

[redacted] Copy No.1 of 2 copies

TS 75/20

14th July, 1952.

Dear D.C.N.S.

In reply to [redacted] letter to me dated 7th July, I attach [redacted] suggested reply to C.T.F.4's 030931.

Recommend that U.S.(At.En.) is on distribution of both signals and request [redacted] may have a copy of this reply as sent.

Yours sincerely,

[redacted]

D.C.N.S.
Trials Planning Section,
Citadel,
Admiralty,
Whitehall, London.

---Encl.

[redacted]

[redacted] Copy No.1 of 2 copies

15th July, 52

[redacted],
A.E.R.E.
Harwell.

TS.75/20

HURRICANE. COASTAL SURVEY

Herewith for your information and retention a copy of a signal from Re[redacted] (C.T.F.4) to D.C.N.S. Admiralty together with C.S.H.E.R's suggested reply.

[redacted]

for Chief Superintendent, H.E.R.

[redacted]

65

E.27

WHItehall 9000
Extension 629

DEPUTY CHIEF OF THE
NAVAL STAFF

[redacted]

7th July, 1952.

[redacted]

D.C.N.S. asks me to send you the attached copy [redacted] signal which has just come in from [redacted]. He would be grateful if you would go into this problem and advise him as to how he should reply.

As you probably know, [redacted] is due to arrive at Fremantle on 31st July.

We have not referred this to Mow, as it seems to be a matter of detailed planning in which you are better able to give the answer, but if you think he should be consulted, may I leave it to you to do so?

[redacted]

[redacted]

Fort Halstead,
Sevenoaks,
Kent.

[redacted]

[redacted]

TRIALS PLANNING SECTION

No. of Paper /

File No. /

Subject:

Referred to:-

REMARKS AND ACTION PROPOSED

BY S.MET. O.

From a meteorological point of view it would be preferable to impose slightly more severe restrictions on firing since by so doing we arrive at a simple and practical meteorological condition.

2. It is suggested that the restriction on firing should be:-

'No particles of any size must fall south of lines drawn 080° and 270° from ground zero.'

In other words we have a sector in which no fallout is permitted.

3. This condition is more severe than that proposed in para.4 of letter 16/52/533 but in practice this means very little. Fallout is only permissible in the sector 080°-120° in very light winds. Such situations may occur but they are very difficult to forecast and are hardly to be recommended.

Restrictions (a) and (b) of para.3 are automatically included in the new condition.

After action

4. Situations which satisfy the new restriction are apparently associated with a definite recognisable 'type' of weather map. They persist for 2-3 days and may be expected to occur about twice in a month.

Reference restrictions on meteorological conditions for operation, following limits are imposed:-

(1) Winds from direction 090 degrees to 300 degrees through North are to be excluded.

(2) Winds from direction 300 degrees to 270 degrees not to exceed 10 knots.

(3) Winds from direction 270 degrees to 260 degrees not to exceed 15 knots

(4) Winds from direction 260 degrees to 250 degrees not to exceed 25 knots.

(5) Winds from direction 250 degrees to 090 degrees through South. No limit imposed.

2. Each of these limits are to be imposed separately on:-

(a) Surface wind

(b) Mean wind surface to 5000 feet

(c) Mean wind surface to 30,000 feet.

Satisfactory conditions are such that all three of (a), (b) and (c) conform to all of the limits defined in paragraph one.

Extract from Hurricane 55 (TS.75/10)

[redacted] Reference

U.S.(E.O.)

Radiation Dosage - Operation Totem

1. The Maximum permissible doses which people were allowed to receive under varying conditions were defined and accepted for the Ministry of Supply prior to operation "HURRICANE". It will be necessary to define the doses which can be received for operation "TOTEM".

2. From the experience on "HURRICANE", no change is recommended in the three categories of permissible dose which were previously recommended. A draft of the proposed regulations suitable for operation "TOTEM" is attached at Appendix "A".

3. Just as for Hurricane, I suggest that you act formally for the Ministry and agree that I, as the responsible officer, should work to this charter. When you have given this formal approval, I will notify [redacted] and ask the Chairman to inform the Australian authorities of our dosage regulations and ask them to agree that Australians who are to work in contaminated areas should obey the same regulations.

[redacted]

M.O.S. Establishment,
Aldermaston, Berks.
11th February, 1953.

Copy: [redacted] [redacted] [redacted] [redacted] [redacted]

(1793)WtY32685/4230
11/51 800,000 JC&S
Ltd. Gp736/210
(REGIMITE)
Code 5-35-0

[redacted]

E/A

[redacted]

APPENDIX "A" ~~TO HPG/3907 DATED 5th FEBRUARY 1953~~

1. The effects of β and γ radiation will be regarded as additive and both will be whole-body radiation. They will be separately evaluated by means of personal film badges.

2. Three dosage levels will be applied under various conditions, viz:-

(a) Normal Working Rate

An intermittent or continuous dosage up to 0.3 rep per day of which the γ-ray component is not to exceed 0.1 r/day.

This is the normal working limit which will be applied generally and it is estimated that it will be possible to carry out the greater part of the operation under these conditions.

(b) Lower Integrated Dose

An integrated dose, received in one or a few exposures, of up to 15 rep of which the γ-ray component is not to exceed 3r. This dose will be applied only with the express permission of the Radiation Safety Officer (AD/RH) which will be given only where he regards it as necessary for the smooth running of the operation. Except as provided for under (~~iii~~ c) below personnel who have received this dose will not be subjected to further exposure during the remainder of the operation.

22-1-85

[redacted] DECLASSIFIED

(c) Higher Integrated Dose

An integrated dose of up to 50 rep of which the γ-ray component is not to exceed 10r.

This dose will be applied only in cases of extreme urgency in order to recover vital records which might otherwise be lost, and will require the express personal permission of CSHER who will have radiological and medical advice available. Personnel receiving this dose will not be subjected to further exposure for a minimum of 12 months.

[redacted]

C.F. No.	5006/49
Sub. Ref.	
Copy No.	59

002010

MINISTRY OF SUPPLY
DIVISION OF ATOMIC ENERGY
(PRODUCTION)

RISLEY, NR. WARRINGTON
LANCASHIRE

22-1-85
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PRODUCTION REPORT

TITLE. Recommendations on maximal permissible exposures to radiation for the Division of Atomic Energy (Production).

AUTHOR [redacted]

Passed for Circulation

[redacted]

Assistant Controller

Date 14.3.51.

Circulation

Name	Copy No.	Name	Copy No.	Name	Copy No.

[redacted]

Spr. M/1804

ADDENDUM NO. 1 to REPORT 5006-49.

A list is provided of further M.P.C.'s or modified M.P.C.'s for radioactive substances in air and water. The figures are provisional recommendations of the Internal Hazards Panel of the M.R.C., submitted by [redacted] and [redacted]. These recommendations should be added to (or in the asterisked cases substituted for) those given in Col. II of Appendices IX and X of Report 5006-49 (March 1951) and in the summary of recommended M.P.C.'s later issued to staff members concerned.

22.1.85 DECLASSIFIED

AIR

Estimated MPC's of Radioisotopes in Air, under working conditions. (μc/cc air)

Ca^{45}	4×10^{-8}
Sb^{125}	7×10^{-8}
Cs^{134}	2×10^{-6}
Cs^{135}	1×10^{-5}
Cs^{136}	4×10^{-6}
Ce^{141}	4×10^{-8}
Pr^{143}	6×10^{-8}
Pm^{147}	4×10^{-9}
Sm^{151}	2×10^{-9}
Eu^{155}	6×10^{-9}
Tl^{204}	2×10^{-8}

WATER

Estimated M.P.C.'s of Radioisotopes in Water or other ingested media. (μc/gm)

	Ca^{45}	1×10^{-4}	
xx	Y^{91}	8×10^{-4}	xx
xx	Zr^{95}-Nb^{95}	8×10^{-4}	xx
	Sb^{125}	2×10^{-4}	
	Cs^{134}	2×10^{-3}	
	Cs^{135}	1×10^{-2}	
	Cs^{136}	4×10^{-3}	
xx	Ce^{141}	2×10^{-3}	xx
xx	Ce^{144}-Pr^{144}	4×10^{-4}	xx
xx	Pm^{147}	3×10^{-3}	xx
	Sm^{151}	2×10^{-3}	
	Eu^{155}	7×10^{-2}	
	Tl^{204}	1×10^{-4}	
	Po^{210}	5×10^{-7}	

All other figures quoted in Report and Summary remain unchanged. Further copies of this Addendum are available, on request.

[redacted]

Principal Medical Officer

Medical Department,
Springfields.
20th August, 1951.

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

Distribution (for further issue):

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C O N T E N T S

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Note: Further copies of this report are available, if required, from [redacted], Medical Department, Springfields Factory, Salwick, Preston, Lancs.

RECOMMENDATIONS ON MAXIMAL PERMISSIBLE EXPOSURES TO RADIATION FOR THE DIVISION OF ATOMIC ENERGY (PRODUCTION).

Introduction and Summary.

The Production Division is a large-scale employer of industrial and non-industrial manpower, and the continued protection of its employees from occupational injury is an important commitment. Protection of the outside community from any untoward effects of Divisional operations has similar importance. One of the most valuable factors to these ends is prior knowledge of the maximal permissible exposures recommended for the potentially injurious materials used, based on the principles of toxicology and preventive medicine as applied to Industry. Such knowledge permits reasonably quantitative hazard control to be adopted in factory design, operations and protection programmes. Data of this type are fairly readily available for most non-radioactive substances. This report provides similar information, based on the best available evidence for exposures to ionising radiations and radioactive substances.

Since no formal report has previously been issued within the Production Division on this subject, opportunity is taken of providing a somewhat historical introduction, followed by a brief outline of the methods by which estimates have been made for maximal permissible exposures to radiations and radioactive substances, and discussion on certain important aspects such as additivity of exposures, averaging of values, and radioactive effluent disposal values. Many members of the staff are already aware of these aspects: others, especially new-comers, may find this background helpful. It is emphasised, however, that the report is not a treatise on how to estimate maximal permissible exposure values, and for further information on any detailed point recourse should be made to the author or the quoted literature.

Throughout the report attempts have been made to strike a balance between theory and reality, and certain recommendations are made which really come under the heading of 'recommended Divisional policy on radiation protection'.

The Appendices separately consider specific radiations (X, γ, β, neutron and mixed exposures), a group of important materials (U, Ra, Pu, Po) and, in tabular form, a number of important radioisotopes including fission products. As far as is known, every isotope for which an authoritative recommendation has as yet been made is referred to, but there still remain many others which have as yet not been considered or on which biological information is lacking. The final appendix is a glossary of terms used in radiobiology and radiation protection, which has frequently been requested within the Division.

Steps have been taken to issue more concise lists of the recommended values of this report to staff concerned with radiation protection, and will be issued through Works Health Panels; this also applies to any amendments or additions which may from time to time be necessary.

It is recommended that the values quoted in this report should now supersede values previously used in the Production Division.

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

EFE/BA
Medical Department,
Springfields.
2nd March, 1951.

[redacted]

RECOMMENDATIONS ON MAXIMAL PERMISSIBLE EXPOSURES TO RADIATION

FOR THE DIVISION OF ATOMIC ENERGY (PRODUCTION).

1. Purpose of Report.

1. To describe the origin and basis of recommendations on maximal permissible exposures to radiation.

2. To provide a list of recommended maximal permissible exposures to ionising radiations and maximal permissible concentrations of radioactive substances in air, drinking water, foodstuffs or human tissues.

3. To make recommendations on the interpretation of these maximal permissible levels in the practice of radiation protection at Production Division establishments.

Origin and bases of maximal permissible exposure recommendations.

2. In other industries, the potential health risks from toxic materials are legislated for by the adoption of specific maximal allowable concentrations (MAC) for toxic gases, fumes and dusts in the atmosphere.(8) Maximal exposures to external radiation (MPE), and maximal permissible concentrations of radioactive substances in air or water (MPC), are simply extensions of the above principle.

3. From 1925 to 1947, official recommendations for radiation protection in Britain were made by the British X-ray and Radium Protection Committee (1) whose views were generally accepted and adopted by the Ministry of Health, Ministry of Labour, hospitals, and research laboratories. During this period most organisations with a potential radiation hazard commenced to avail themselves of the advisory and monitoring film service provided by the National Physical Laboratory of D.S.I.R., which remains in active operation.(2)

4. In 1946, it became apparent that the number of persons occupationally or incidentally exposed to radiation was likely to increase rapidly in Britain, as it had done in America. This resulted from progress in nuclear physics research, in the production of fissionable materials, in the production of radioisotopes for scientific research or therapy, in the use of high energy radiation for radiotherapy, radiography and research, and from other expansions in the field of radioactivity. This led to the formation by the Medical Research Council of the "Committee on the Medical and Biological Applications of Nuclear Physics", one of whose Sub-Committees considered solely Protection problems, which in turn created a specialist group called the "Tolerance Doses Panel". The function of this Panel was to make recommendations to the Protection Sub-Committee on MPE's and MPC's for radiations and radioactive substances, on a much wider programme than had been hitherto found necessary. The Tolerance Doses Panel has held approximately 30 meetings and discussed about 150 papers on its special subject in the past three years.(3)

/5.

5. In America, official views on maximal permissible exposures were first given by the Safety Committee of the Röntgen Society, and then by the Advisory Committee on X-ray and Radium Protection (Bureau of Standards). The latter continues to operate, on an expanded basis.(4) During the war, the Manhattan and Plutonium Projects, committed to work with materials causing great and diverse health risks, found that existing official recommendations did not cover the new field adequately. At the same time as initiating an ambitious biological research programme on radiation hazards and protection, provisional recommendations were made to cover the new hazards, by extrapolation of the small amount of basic knowledge which existed from pre-war recommendations, and experimental animal research.

6. In 1947, the two wartime U.S.A. Projects were replaced by the civilian Atomic Energy Commission, which included in its Division of Biology and Medicine a Medical Physics branch. This body smoothed out some of the local variations in MPE's and MPC's which had arisen due to the dispersed nature of American laboratories and plants, and co-ordinated American views through the Bureau of Standards Advisory Committees.(5) In the post-war years several opportunities have arisen for discussions between the British, Canadian and American authorities concerned with MPE's and MPC's, and in the past two years considerable agreement in principle and detail has been found possible.(6)

7. In addition to these national bodies, the 1927 International Congress on Radiology established an International Protection Commission, which proceeded to issue recommendations on radiation protection and MPE's, especially for X and γ-radiation exposures occurring in medical radiology. The infrequent meetings of the Congress resulted in occasional disparity between current national views and previous international recommendations. At its 1950 meeting, the International Protection Commission was presented with the current recommendations of British, American and Canadian groups, and arranged to issue a series of new recommendations on 1st January, 1951. The values given in this Report are in line with those issued internationally. The Commission felt that although the existing evidence justified certain amendments to its earlier recommendations on external radiation, the data on which national groups had framed MPC's for certain isotopes were not substantial, and decided to refer to such recommendations solely as nationally-used values.(7, 33)

8. The Radioactive Substances Act (1946) empowered the Ministries concerned (Supply and Health) to create an Advisory Committee on Radiation Protection. This group first met in 1949, and has since formed certain Sub-Committees to discuss specific aspects of radiation hazards, with a view to framing statutory legislation under the Act. This legislation will probably be delayed for some time, however, as the problems are notably difficult. At present the only statutory requirement in Britain is applicable to the luminous paint industry (Factories, Luminising, Special Regulations, S.R.O. 865, 1947) and does not therefore apply specifically to Production Division establishments. The general provisions of the Factories Acts (1937 - 1948) do, however, apply to Production Division establishments.

9. A further step indicating more wide-spread interest in existing standards of radiation protection has been made by the International Labour Office at Geneva, which includes in its latest edition of "Model Code of Safety Regulations for the guidance of Governments and Industry, 1950", a section on "Dangerous Radiations", including penetrating radiations and radioactive substances. The recommendations presented are largely based upon those of the Medical Research Council.

/10.

10. At the present time the official arrangements concerning radiation protection in this country are being reorganised. The M.R.C., the International Commission on Radiological Protection, and the Advisory Committee under the Radioactive Substances Act, have recently tended to go over the same ground separately. This proves inadvisable, since the total number of suitably experienced scientists and medical authorities in the field remains very small. The future organisation is expected to be based upon the need for permanent official interest in radiation protection, both for occupational exposures and as applying to the entire community.

Principles underlying maximal permissible exposures.

11. A maximal permissible radiation exposure level (hitherto termed a tolerance) may be defined as "an exposure level which, under specified conditions connected with existing health, duration of exposure, type of radiation, etc., may be assumed in the light of available information, to be unlikely to result in detectable injury by its recipients". The nature and clinical courses of radiation injuries have been described elsewhere.(35, 36, 16)

In general, the principle adopted has been to estimate initially, by the best available means, the so-called "injury threshold amount" for a radiation or radioactive substance, i.e. that level which would be likely to cause the first signs of biological response in man on continuous exposure for the majority or entirety of his working life or his full life-span. The figure for the injury threshold level is then reduced by an appropriate safety factor to form the "maximal permissible exposure" level. The numerical value of the safety factor applied varies in different types of exposure, but is, in most cases, at least 10.

12. When dosage for exposure to a toxic substance is plotted against the proportion of the exposed group affected, most biological responses show an S-shaped curve, since certain individuals are more sensitive or less sensitive than the average. The "injury threshold" is usually taken as that applying to the more sensitive subjects in the exposed group. The deliberate safety factor of (e.g.) 10 therefore gives more safety for the group as a whole than its numerical order implies. (Fig. 1)

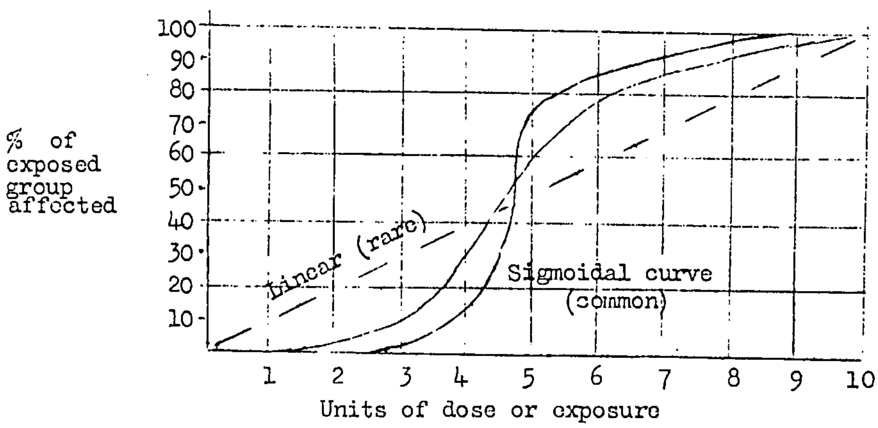

Fig. 1. Examples of types of Biological Responses in exposed groups.

/13.

13. In addition to this deliberate factor of safety, it has been a matter of policy that wherever experimental evidence appeared inadequate or otherwise unsatisfactory, the greater hazard should be assumed rather than the lesser possibility. Since the biological evidence has often appeared unsatisfactory, this may have led to some multiplication of safety factors in estimates of certain injury thresholds.

"Standard Man".

14. It is a matter of common experience that what is safe for one man is not necessarily safe for all men. Official estimates and subsequent recommendations could hardly cover the whole range of human variabilities in health, diet, disease, and modes of exposure. Some standard human had to be devised as a yard-stick for estimating purposes. The so-called "standard man" originated from the average dimensions, chemical composition, and physiology of man obtained from previous medical investigations.(9) It is, however, assumed that the standard man is in normal health for his age, and free from existing disease or disorder which would be likely to render him more susceptible to radiation injury than the average of the exposed group. Although inherent factors of safety do permit some latitude in respect of minor variations in health, significant abnormality of individual health, nutrition or physiology would in certain cases logically demand a lower MPE or MPC than applies to the majority of persons. Since this would be a difficult commitment within the Production Division, certain "medical standards" are applied for persons required to undertake occupational exposure to radiation or radioactive substances.

15. The expected total duration of exposure to a risk does to some extent dictate what MPE is permissible, i.e. the shorter the total occupational exposure, the greater the MPE possible. It has been assumed that occupational exposures involve very lengthy employment periods, and the figure of 20 years or more of occupational exposure has been used for estimations of MPE's or MPC's. In non-occupational exposures, such as would result for example from persistent consumption of drinking water or inhalation of air containing added radioactivity, a 70-year lifetime of exposure has been used. Both assumptions are arbitrary, but favour safety.

16. It may be taken that the recommendations are generally applicable to both sexes at all ages. In view of the long latent period usually required for chronic radiation injuries to develop in man, occupational exposure to radiation commencing for the first time in the later years of life, e.g. at 55 or over, carries a fortuitous added safety factor. This is in part offset by the known probability at such ages of existing deviation from 'standard' health, e.g. incidental developing diseases of the lungs, bone, blood, or skin. (There have been general recommendations that radiation exposure in the first three months of pregnancy should be avoided as far as possible, in view of the rapid cell division occurring in the developing foetus.)

17. It has been the policy of the M.R.C. to base its recommendations solely upon the biological and safety aspects of radiation exposures, without any real consideration of attendant difficulties in monitoring, instrumentation, engineering, operational convenience, productivity or costs. These latter factors vary very much in different situations and with time, and authoritative long-term recommendations on preventive measures should not be obviously influenced by short-term difficulties.

18. It has been the policy of formal recommendations to allow the 'user' to devise the exact methods of ensuring radiation safety at his establishment; this is implied by the use of the word 'recommendations'. Different types and multiplicity of radiation risks, duration of working

/periods

periods, health physics facilities and instrumentation, operational convenience, health supervisory services, urgencies and costs must all be considered in devising a radiation safety programme in its fine detail. It will be found that certain detailed procedures have been advised in the Appendices to this Report.

Methods of estimation of Maximal Permissible Levels.

19. About 1200 isotopes, of nearly 100 elements, are now known. The maximal permissible exposures of man to each radioactive isotope would be slightly or greatly diffrrent, depending upon the isotope's comparative radioactive characteristics, and the metabolism of the parent element in the human body. Relatively few of the 700 have as yet been considered, and it will probably never be necessary to obtain an MPC for all of them. The list of isotopes for which MPC estimates now exist is however much greater than it was a few years ago, although a considerable number of isotopes of potential importance remain to be considered. Although calculations of MPC's are not themselves difficult, some previous knowledge of the element's behaviour in the body is imperative. This usually demands large scale animal experiments, with more than one species, and with chronic exposures, usually for the major part of the animals' life-span. The urgent requirement for official recommendations of MPE's and MPC's has in the past decade outstripped the pace of biological investigations, as is occasionally indicated by the indirect methods used to estimate MPC values. Four main methods have been used up to the present time.(10)

I. Direct evidence based on human exposures.

20. The long latent period usually associated with occupational radiation injuries permits this approach to be used only for agents which have already been handled for a considerable number of years. This now limits the method to X-rays, γ-rays, radon in air, and radium in the body. In each of these instances additional animal experiments have been found necessary to give a firmer basis for the estimates to be made.

II. Direct comparison between biological effects of a 'known' and 'unknown' radiation or radioactive substance.

21. This has obviously been limited to planned biological experiments. Comparison has been made between the biological responses to measured dose-rates of external X or γ radiation, and alpha, beta or neutron irradiation. Similar radiations, but of different energies, have been compared in the same way. The radiotoxicity of radium has been compared with that of polonium, plutonium, radio-strontium and X-radiation.

22. The biological response selected as the criterion of injury in such tests varies with the circumstances. In animals, comparative lethality is the simplest index, but it demands far greater dose-rates than those in the MPE range, and is therefore not entirely suitable. Skin response, blood changes, weight variation, defective growth, induction of malignant (cancerous) growths, shortening of life-span, and other criteria have also been used in whole animal experiments. In tissue culture and plant tissue experiments, growth restriction, microscopic changes in cellular or nuclear detail, reduction in biochemical (enzymatic) activity, and many other indices, have been used. Tests on the lower organisms or isolated tissues are of much value, but difficult to apply or extrapolate to man. They cannot often be co-ordinated with the capacity of normal body tissues to recover from injury, or the complexity of the processes by which radiation injury is brought about in mammals and in man especially.

/III.

III. Estimates based upon a basic MPE for living cells, and the radiation dosage calculated to occur in tissue from a known amount of deposited isotope.

23. This method has been widely used. The MPE for healthy living cells is regarded as .3 rep/week of x or γ radiation, equivalent to an energy absorption of 31 ergs/gm/week. It is possible, from knowledge of an isotope's radioactivity characteristics, to calculate the amount which, uniformly distributed through tissue, would cause 31 ergs/gm/week energy absorption. If experimental data also exist for the bodily metabolism of the element, especially 'turnover' rates in the body, it is then possible to calculate what (MP) daily intake would maintain this (MP) concentration of isotope in tissue. Next, from data concerning 'standard' man's air or water intake, with a knowledge of the proportion absorbed from gut or lung, it is possible to calculate what concentration of the isotope may be present in air, food or water, in order to keep within the MP daily intake of the isotope.

24. Data on the radioactive characteristics of isotopes are usually adequately known. The information on human bodily metabolism of the more common elements is reasonably well-known, but for rare elements human data is usually negligible. Data obtained from animal investigations are therefore necessarily used, but with due caution.

This method has had to be applied for the majority of isotopes formed in nuclear fission. It is capable of extension to β-γ emitting radioactive gases in the atmosphere, by assuming that the skin surface is the critical tissue, the MPC of such an isotope being the concentration in air causing a dose-rate at the surface of the body not exceeding the MPE for skin.

There are usually several multiplying safety factors in calculations of this type, but the total factor of safety can never be accurately evaluated.

IV. Estimates based upon safe dilution of radioactive isotope in stable isotope of the element within the body.

25. This method can be used only for isotopes of elements which are normally present in and essential to the human body, in known concentration and tissue locations, at known average daily intake rates. It is therefore only applicable to the determination of MPC's in air or water for isotopes of the following elements:-

C, H, O, N, P, S, Fe, I, K, Na, Cl, Ca, Mn, Cu, Mg.

Other non-essential elements are occasionally present in tissues, but only inconstantly, and at concentrations and intake rates which are very variable, e.g. Sr, rare earths, Ra, U, etc. The body burdens of such non-essential elements are related more to incidental factors such as food or water contamination, or previous occupations, than to a bodily requirement.

The MP tissue dose-rate of .3 rep/week will be caused by a calculable tissue concentration of a radioisotope of any of the essential elements listed above. This MPC for that isotope in tissue may then be expressed as a fraction of the existing concentration of the element's stable isotopes in the same tissue. (The chemical and biochemical behaviour of the isotopes of an element in a biological system is virtually identical.) Thus, the MP daily intake of the isotope will be that same fraction of the total daily intake of the parent element. From the MP daily intake of the isotope may be estimated the MPC in air or water.

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The principles outlined above have been dealt with in considerably greater detail in at least two special reports(32, 11) to which reference should be made for further information.

General problems arising from all recommended values and estimates.

26. There remain three very important considerations on which no formal views have as yet been expressed by outside authorities. These are, the additivity of external and internal radiations of different types, the safely allowable variation around the mean maximal permissible exposure or concentration, and the maximal permissible radiation exposure levels for non-occupational exposure, e.g. in air, food or drinking water containing traces of radioactive wastes. In view of the great practical importance of these three issues, a guiding policy is required for Divisional purposes.

"Additivity"

27. The "additivity" of different types of radiation is biologically important where two or more types of radiation exposure co-exist.

Considering a specific small volume of tissue in the body, the expected biological response, i.e. the degree of injury, will be proportional to the total energy absorption in that tissue volume. That is, x, γ, neutron, α and β-radiation of that tissue, whether from external sources or from deposited isotopes, will cause intracellular ionisations whose effects would be expected to summate. Considering the body as a whole, however, it is well known that x and γ-radiation tends to cause scattered ionisations through large depths of tissue: neutron-irradiation of different energies gives a varying degree of initial penetration into the body, with terminal α, β, proton, or γ-radiation; β-radiation causes scattered ionisations over a relatively short path in tissue, rarely of more than one centimetre depth; α-radiation causes very dense ionisations along a very short track, usually of 50 microns or less. Additivity of all external and internal radiation exposures would thus be markedly limited by the ranges of the types of radiation concerned, or by the site of preferential deposition of isotopes in the body.

28. For the purposes of health physics procedures, the following recommendations appear reasonably operable and of adequate safety:-

(a) All external radiation is to be considered additive; except that external α-rays may be regarded as not normally contributing to irradiation of living cells.

(b) All concentrations of radioactive substances in air or water should be considered additive.

(c) External radiation exposures and concurrent exposures to radioactive substances in air or water do not require to be regarded as additive.

29. The theoretical effect of this recommendation, which is made admittedly on the grounds of expediency to allow for the impracticability of measuring and accounting full detail of every exposure to radiation in large scale industrial work, would be to permit two concurrent MPE's to be received by a worker, one from external radiation, one from internal radiation. To a certain extent this will be offset by safety factors inherent in MP levels; and by the general recommendation, and general finding in properly conducted operations, that average occupational exposures to radiation are normally well below the MP recommendations.

/"Averaging"

"Averaging" of values for MPE's and MPC's.

30. Maximal permissible exposure estimates should more correctly be termed "recommended maximal permissible average occupational exposure" (or concentration). In the case of MAC's for non-radioactive toxic agents in industry, it is generally accepted that the MAC is to be regarded as an average value. A certain amount of temporary upward range may usually be allowed without harm, provided that the average value over a certain period complies with the recommendation, and that the concentration does not extend into the acutely toxic range.(8) This may legitimately be taken to apply also to MPE's and MPC's for radiation and radioactive substances. It is hardly ever possible to maintain an industrial or occupational exposure constant over a long period. Industrial operations, in varying themselves, naturally result in fluctuations in radiation intensity and atmospheric contamination.

The MPE's and MPC's quoted in the Appendices restrict radiation energy absorption in selected deep tissues to not more than 31 ergs/gm/week, i.e. .3 rep/week. A temporary ten-fold increase in tissue irradiation would increase the energy absorption rate to 3 rep/week. This would be expected to have little biological significance, if any, provided that such a dose-rate is not continued for long periods.

31. Provided, therefore, that the average maximal permissible exposure or concentration of isotope in air or water is brought down to below the maximum permissible recommendation within a period of a few minutes, hours, or days, operations may reasonably continue in spite of a temporary ten-fold increase above recommended average values.

The decision to permit work to continue depends largely upon the expected duration of exposure at these high values; and each instance can only be properly considered on its merits and features.

It should be specifically noted, however, that certain chemical compounds of radioactive elements, such as uranium hexafluoride, UF_6, or uranyl fluoride, UO_2F_2, are likely to be chemically injurious at ten times the recommended MPC/air. The above recommendations on the interpretation of average atmospheric concentrations concern solely potential radiation risks. Every chemical hazard and exposure has its own special features for consideration.

Non-occupational exposures (effluents).

32. The MPC's for isotopes in air/given in the Appendices have all been adjusted from formal official figures(7, 6), and figures given in other reports(32,10,11), so that they apply specifically to occupational exposures. Most formal values issued have assumed inhalational exposure for 24 hours per day, while in fact occupational exposures are for eight hours per day. Since 'standard man' is assumed to breathe $10m^3$ air in his eight-hour day at work, and $20m^3$ during his total 24-hour day, the MPC in laboratories or other purely occupational environment may be doubled by comparison with that for the 24-hour exposure. The listed values of MPC's in the Appendices are appropriately defined for occupational or non-occupational conditions, i.e. 8 or 24 hr/day exposure.

33. The community outside an Atomic Energy establishment, but still within range of radioactivity in air or drinking water due to gaseous or aqueous effluents, differs in certain important ways from the employees within the establishment. The outside community has virtually no means of recognising the existence or degree of raised activity in air or water in the neighbourhood; it has no means of securing specific protection, other than that through legal or statutory channels: it includes persons in abnormally low states of health, and in some cases, of nutrition: it is not subjected to any

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specific health supervisory service for exclusion or earliest detection of radiation injury: many members of the community are already exposed to the potential risks of their own chosen manner of employment. Furthermore, in some instances it is a large and densely populated community. Views have been expressed that in such circumstances extra safeguards from radiation exposure should be insisted upon and should run parallel with the size of the community.(12)

Public health requirements from this Division should be adequately served if the average MPC of radioactive substances in air or ingested material (water or food) applying to the outside community, should be not higher than one-twentieth of the 8-hr. values applying occupationally within the Establishment, and thus one-tenth of the 24-hr. exposure values recommended. The previous recommendations regarding additivity and permissible averaging for the MPC apply also to exposures of the outside community.

34. It is perhaps at this stage appropriate to quote from the 1950 recommendations of the International Commission on Radiological Protection(7,33):-

> "Whilst the values proposed for maximum permissible exposures are such as to involve a risk which is small compared with the other hazards of life, nevertheless in view of the unsatisfactory nature of much of the evidence on which our judgments must be based, coupled with the knowledge that certain radiation effects are irreversible and cumulative, it is strongly recommended that every effort be made to reduce exposures to all types of ionising radiation to the lowest possible level."

Current authoritative medical opinion is that the present generation is not that in which appreciable relaxation of maximal permissible values should occur. Relaxation may eventually be regarded as legitimate and logical, but it seems likely that only the results of a full generation carefully observed may provide the necessary evidence.

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X AND GAMMA RADIATION

Maximal permissible exposure ---- 0.5 rep/week.

1. Official recommendation.(7, 33)

(Note: Röntgen is here synonymous with rep, see Appx. XI.)

"In circumstances under which the whole body may be exposed over an indefinite period to X or gamma radiation of quantum energy less than 3 MeV, the maximal permissible dose received by the surface of the body shall be 0.5 röntgens in any one week. This dose corresponds to .3 röntgens/week measured in free air."

2. This new MPE replaces the previous figure adopted by the Production Division, of .3 rep/week, and all recommendations based upon that figure.

3. The value of 0.5 rep/week refers specifically to the surface dose, including back-scatter. Since backscatter from γ-radiation in the relevant γ-energy range ($\frac{1}{2}$ - 2 MeV) amounts to only 5 - 10% (not the 40% indicated by the official recommendation in para. 1 above) the MP dose-rate measured by survey instruments in free air is to be .5 rep/week, i.e. 500 mrep/week, 100 mrep/working day, or 12 mrep/working hour, irrespective of X or γ energy.

4. The MPE of 0.5 rep/week is irrespective of brevity of exposure during that week. A dose of 0.5 rep may thus be received in a period of seconds, minutes, hours or days, with identical biological significance.

5. Films or other personal monitoring devices should be worn in such a position, on the trunk of the body, as gives the maximum probability of recording the full radiation exposure of the body under the particular conditions of exposure and work.

6. The dose thus recorded by monitoring device is assumed, for health physics purposes, to represent total body exposure.

7. Each establishment at which personal monitoring devices are issued is required to maintain indefinitely an up-to-date record, in suitable form, of individual radiation exposures for all persons to whom monitoring devices have been issued.

8. Where a radiation dose of more than 0.5 rep is recorded by film or other personal monitoring device worn for one week or shorter period, or where the derived dose-rate in a longer period of wear exceeds 0.5 rep/week, the wearer is to be regarded as having been over-exposed to radiation.

9. Over-exposure to radiation justifies being regarded as a potential injury, from a breakdown in safe practices, necessitating enquiry.

10. An employee should be regarded as significantly over-exposed to radiation when his total recorded radiation exposure for the past thirteen weeks exceeds the MP dose for that period, i.e. exceeds 6.5 rep (13 x .5 rep).

/11.

11. If and when this occurs, exposure in excess of 6.5 rep during the past thirteen weeks is to be mitigated by a period of radiation-free employment, sufficient to cancel the over-exposure at the rate of 0.5 rep per week.

12. This 'compensatory' procedure is required in order to ensure that the individual's average exposure is reduced as quickly as possible to the MPE, and is to be regarded as a preventive medical measure.

13. Radiation exposure assessed as "less than 0.05 rep" should be shown as such on the individual's record of exposure. In summating maximal possible exposure in a period, e.g. for medical or statistical purposes, "less than .05" should be regarded as ".05". In summating probable over-exposure in a period of thirteen weeks, for calculation of time compensation requirements (paras. 10 - 11 above), recordings of "less than .05" may be ignored, as being technically arbitrary and of negligible biological importance compared with the over-exposure under investigation.

14. As far as reasonably practicable, all occupational exposures to radiation in significant amounts, e.g. over .1 rep in a week, should be assessed by the use of personal monitoring devices. Under no circumstances should it be possible that individual exposures over 0.5 rep in a week are unrecorded.

15. The above recommendations apply not only to gamma radiation but also to X-radiation exposures from industrial, medical or experimental procedures with X-ray generating equipment.

16. Attention is drawn to the mutual additivity of external β, X, γ and neutron radiations (Report, paragraphs 27 - 29).

17. For special duties known to involve exposure at high radiation dose-rates during operational emergencies, the maximal permissible X or γ radiation dose during a single continuous exposure is 13 rep, equivalent to six months' maximal permissible exposure.

The provisions of paragraphs 8 - 12 above, concerning over-exposures, should apply promptly after such exposure.

Wherever possible selection of personnel required for such special duties should be based upon their freedom from comparatively high exposure-rates and temporary over-exposures in the past.

18. It is strongly recommended that recording should be made of the radiation exposures received by all visitors, supervisory, scientific, research, development and Headquarter staff entering 'radiation areas' at Divisional Works, and that entry to such an area without wearing a monitoring device should be forbidden.

19. There may be occasions where it is felt desirable to declare an area not a 'radiation area' in the above sense, in view of the very low order of radiation or air contamination present. An example may well be formed by certain parts of the Capenhurst process areas, handling exclusively uraniferous materials by enclosed processes. It is, however, recommended that exemptions from these general recommendations be granted only through the Divisional Works Health Physics Committee, in order that full consideration may be given to the occupational features of the area.

20. The major biological hazards from over-exposure to X and γ-radiation are the production of chronic inflammatory, degenerative or even malignant (cancerous) changes in superficial tissues, e.g. the skin, and the production of injuries to the blood-forming tissues of the body, resulting in reduction of the numbers of circulating white blood cells, or in excessive production of both normal and markedly abnormal white cells (leukaemia).

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Appendix II.

BETA-RADIATION

Maximal permissible exposure ---- 1.5 rep/week.

1. Official Recommendation.(7)

"In the case of high energy beta rays, the maximal permissible exposure of the surface of the body in any one week shall be the energy flux of beta radiation such that the absorption per gramme of superficial tissues is equivalent to the energy absorption from 1.5 röntgen of hard gamma rays.

For purposes of calculation, the superficial tissues concerned shall be assumed to be the basal layer of the epidermis, defined conventionally as lying at a depth corresponding to 7 mg/cm^2."

2. The major biological hazard from over-exposure to β-radiation is the production of chronic inflammatory, degenerative and possibly malignant changes (carcinoma) in the exposed skin. The radiosensitive cells lie beneath the inert epidermis, which varies in thickness from 70 to 1000 microns in different areas of the body: 7 mg/cm^2 corresponds to a depth of 70 microns below the surface. Since the range of beta-radiation from the vast majority of β-emitters in wet tissue is measured in millimetres, it is not necessary (for present purposes) to make any allowance for the depth of sensitive cells.

3. β-radiation is to be regarded as fully additive to γ-radiation. If, therefore, the recorded β and γ doses occurring during a period of mixed β-γ exposure are expressed as fractions of their respective MPE's (19.5 rep and 6.5 rep respectively, in a three month period), then the sum of the fractions should not exceed unity. For example, if in a three month period a worker's β-dose is 10 rep, and his γ-dose is 3.2 rep, then -

$$\frac{10}{19.5} + \frac{3.2}{6.5} = .5 + .5 = 1 = \text{unit MPE} ;$$

the individual has thus received one MPE for β-γ radiation.

In most circumstances such a calculation should be found unnecessary, in view of the desirable control of all exposures to well below the relevant MPE.

4. Similar principles apply to the prevention of over-exposures from β-radiation as are laid down in Appendix I for γ-radiation.

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Appendix III.

LOCAL EXPOSURES OF HANDS AND FOREARMS TO X, γ AND β-RADIATION.

Maximal permissible exposure --- 1.5 rep/week.

1. Official recommendation.(7, 33)

"In the case of exposure of the hands and forearms to X, gamma and beta-radiation, the maximal permissible dose shall be 1.5 r (or its energy equivalent) in any one week, at the basal layer of the epidermis, defined conventionally as lying at a depth corresponding to 7 mg/cm^2."

2. The implication of this MPE, as contrasted with those for X and γ, and for β-radiations separately, is that it is considered permissible for a three-fold increase to occur in the X or γ-radiation dose-rate to the hands and forearms. This relaxation is based upon practical experience among radiotherapists and others. It is acceptable in theory, since only local, not total body exposure, is concerned.

3. The MPE has been mainly based upon dose-rates obtained from wrist-films, with some evidence from finger-bases, i.e. ring films.

4. Under certain conditions, the dose to the finger-tips may be materially greater than that shown by wrist or finger films. Where this is considered likely to occur, it is recommended that the wrist or finger-base dose-rates should be proportionally less than the MPE of 1.5 rep/week.

5. Every opportunity should be taken to evaluate finger-tip, hand and forearm exposure dose-rates in work involving manual and digital operations. Wrist films should be worn wherever there is a reasonable probability that exposures over 1.5 rep/week may result.

6. Similar principles apply to the prevention of over-exposures of the hands to mixed radiations as were suggested for x-γ, and β-γ exposures in Appendices I and II respectively.

7. The major biological risks from over-exposure of hands and forearms are acute or chronic inflammatory or degenerative changes and eventual malignant (carcinomatous) changes in the skin.

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NEUTRONS

Maximal permissible exposure	2 to 20 MeV	..	30 n/cm²/sec
	0.5 to 2 MeV	..	50 n/cm²/sec
	less than 0.5 MeV	..	1200 n/cm²/sec

1. Official recommendation.[7]

"Whole body exposure of individuals to neutrons.

The International Commission on Radiological Protection considers that the maximal permissible energy absorption per gramme of tissues exposed to fast neutrons should not be greater than one-tenth of that permitted for high energy quantum radiation." (i.e. MPE of .03 rep/week in the tissues for fast neutrons)

The numerical values quoted above are those of the Medical Research Council (1950) and are based on total body exposure.[15]

2. The major biological risks from over-exposure to neutrons are likely to be both local changes (skin effects, ocular lens cataracts) and internal effects (depression of blood-cell formation, leukaemia, induction of tumours). These potential risks arise from the physical fate of neutrons of different energies absorbed in tissue.[13, 14]

3. The "relative biological efficiency" of neutrons, i.e. capacity for producing biological injury in tissue, at unit physical dose-rate, is higher than that of X or γ or β-radiation by a factor varying from 10 (in the cases of neutrons of 2-20 MeV) down to 5 (thermal neutrons of about .025 eV energy). The radiation dose in a small volume of tissue from a standard neutron flux varies considerably with the neutrons' energy; with a flux of 10^{10} n/cm²/sec, at 0.5 MeV the tissue dose is 17 rep/sec, at 5.0 MeV it is 47 rep/sec.

4. Neutron exposures are to be regarded as biologically additive to exposures to external X, γ, or β-radiation, and where necessary, similar calculations made for additive dose-recording as have been suggested for βγ-radiation (App. II, 3).

5. Wherever reasonably possible, occupational exposure to slow and fast neutrons should be detected and assessed by the use of individual monitoring devices. Where occupational exposure to neutrons is likely, but individual monitoring is not found possible, the neutrons' flux in the work area is to be determined by the use of appropriate monitoring instruments. This flux, as a fraction of the MP flux, should then be assumed to have been received continuously by all employees in that work area, and individual exposure records suitably amended.

6. The MPE's for neutron exposure are notably difficult to estimate, and neutron dosimetry in tissue is so complex that the precision of the quoted MPE's is not likely to be of a high order, even though they remain safe values.

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Appendix V.

RADIUM

Maximum permissible continuous body burden for Ra	--	.1 µg (.1 µc)
MP Concentration of Ra in air at work	--	1.6×10^{-11} µc/cc.
MP Concentration of Ra in water	--	4×10^{-8} µc/cc.
MP Concentration of RADON in air at work	--	5×10^{-8} µc/cc.

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1. The MPBB is based mainly on evidence from health histories of persons having worked with radium or mesothorium in the luminous dial painting industry. Recent evidence suggests that some of these cases of radiation injury may have been due not to radium but to mesothorium; and if this proves to be the case, an amendment to the above recommended levels may eventually be made.[6]

2. The major biological risks from over-deposition of Ra in the body appear to be thr production of inflammatory, degenerative or eventually malignant (sarcomatous) changes in bone, since Ra is preferentially deposited in the skeletal structures. In addition, severe depression of blood cell formation may occur (leucopenia, anaemia), due to irradiation of the blood-forming tissues within the bones. Furthermore, inhalation of excessive concentrations of particulate radium may lead to local changes in the lung (possibly to lung cancer), in addition to causing excessive deposition in bone due to absorption from the lungs.[18, 19]

3. Assuming that 45% of the radon emanated from Ra fixed in the body is exhaled in the breath, the concentration of radon in breath, equivalent to .1 µg Ra in the body, is 1×10^{-12} curies/litre (1×10^{-9} µc/cc).[20]

4. The MPBB of .1 µc of radium undergoes 2.2×10^5 α-dis/min within the body. If, six months after its deposition in the body, .01% of this amount is being excreted in the urine daily, the α-activity in a 24-hr urine specimen would give 22 dis/min. If, after several years' deposition, the urinary excretion rate fell to .0005% per day, a 24-hr urine specimen would then give 1 dis/min. It is probable that the normal unexposed person's natural radium burden[21] is maximally .005 µg (equivalent to 10^4 dis/min), which, excreted at the rate of .0005% per day, would result in a urinary activity of .01 dis/min or thereabouts, rising to .04 dis/min at radioactive equilibrium. This method of determining the radium body burden of exposed persons has already been proposed.[17]

5. Assuming that 25% of all inhaled Ra is transferred to bone, that the effective half-life of deposited radium is 20 years, that the MPBB is .1 µc, and that the standard worker inhales 10m^3 air/8-hr day, the <u>MPC for Ra in air at work has been calculated to be 1.6×10^{-11} µc/cc</u> (or .54 dis/sec/m^3).[10]

/6.

Counters — Generic term covering instruments devised for quantitatively recording electrical changes due to ionising radiations entering a suitably prepared chamber; usually involve amplification of electrical pulses collected on conductor at high potential: in other forms loss of potential measured by sensitive electrometer: in others ionisations cause scintillation of ZnS or other fluorescent material on screen, counted by photomultiplier tube: others use special crystals to collect pulses. Each variety has special virtues and vices; none is universally useful.

Curie — Unit of measurement of radioactivity; one curie (c) is the amount of a radioactive isotope which decays at the rate of 3.7×10^{10} disintegrations/second: hence millicurie (mc) 3.7×10^{7} dis/sec; microcurie (μc) 3.7×10^{4} dis/sec: micromicrocurie (μμc) 3.7×10^{-2} (0.037) dis/sec. The slower the decay rate of an isotope, the greater the mass required to produce 1 curie of activity: thus Ra (arbitrary standard) 1 c = 1 gm: Pu 1c = 16 gm: U^{238} 1 c = 2.8×10^{6} gm: reverse obviously also applies.

Cyclotron — Produces positively charged particles of extremely high energy (protons, deuterons, α-particles) by causing low-energy particles to progressively accelerate in a strong electromagnetic field applied to 'dees', particle track being an increasing spiral ending at a final deflection plate: energies up to 400 MeV have been obtained with α's and protons, 200 MeV with deuterons.

Cytoplasm — Protoplasm of living cells, inside cell membrane, surrounding nucleus; colloidal system of inorganic ions, nutrient and organic molecules, enzymes and protein in water vehicle.

Daughter product — Isotope, stable or radioactive, of another element, produced when a radioactive parent isotope disintegrates by α or β-decay; progressive chain of successive daughter products forms radioactive series: formed in body, radioactive daughter product energy contributes quota to effective energy of irradiation.

Decay — Exponential decrease in amount of radioactive isotope in consequence of α or β disintegrations; decay rate (expressed by decay constant) highly specific for every isotope.

Deposition — Removal of an element or substance from the circulating blood and its incorporation in a restricted volume, tissue or organ, either prior to excretion (e.g. in the liver prior to excretion in bile) or by adsorption or ion-exchange processes in (e.g.) bone. Most elements undergo at least some such deposition after entry into the blood stream; certain elements, e.g. Ra, Pu, remain more or less in situ for years; others are more rapidly removed by remobilisation, then excretion; other terms, selective fixation, preferential deposition, etc.

Dose — Usually, the amount (of an injurious agent) administered: in radiation exposures, the energy absorption (converted from ergs/gm to roentgens) occurring during such exposure; hence <u>dose-rate</u>, units of dose administered or supplied in units of time, e.g. roentgens/second, or rep/hour, or rep/3 months: <u>dosage</u> (correctly) the total of a series of successive doses: <u>fractionated dosage</u>, amount administered in separate known fractions at known intervals: <u>protracted dosage</u>, administration or exposure over a prolonged period of time (by implication, at low dose-rates); <u>intermittent dosage</u>, administration or exposure to usually irregular small doses at irregular intervals: <u>lethal dose</u>, the amount which results in death: <u>LD 50</u>, the amount which causes death in 50% of the exposed group: <u>MLD</u>, median lethal dose (obsolete).

Dosimetry — Estimation (from theoretical considerations of type and energy and dosage of radiation, and properties of irradiated medium) or determination (by experiment) of the radiation energy absorption occurring at different depths or locations in irradiated tissues.

Electromagnetic radiations — A related series of radiations, including long and short radio, radar, infra-red, visible light, ultraviolet, X and gamma-rays (in order of decreasing wavelength): all travel at same velocity (3×10^{10} cm/sec, or 186,000 miles/sec): undergo reflection and exhibit diffraction and interference effects. Emitted in wave-form as energy quanta (photons): only X and gamma-radiations cause ionisation of material lying in their path; the longer wavelength (and thus less energetic) radiations cause only excitation of molecules along their paths.

Electron — Electrically charged particles, with negative charge of 4.8×10^{-10} electrostatic units, weight (O = 16) 0.000548 (one eighteen hundredth of hydrogen atom): fundamental smallest constituents of all material atoms: in such atoms electrons circulate in orbits round nucleus, number of electrons specific to every element (≡ atomic number, Z). Cathode rays and β-particles consist of electrons.

Electron volt — (eV); "the kinetic energy acquired by one electron when accelerated in the electric field produced by a difference in potential of 1 volt"; thus, a very small energy unit, used where the erg (6.3×10^{11} eV, the work done when a force of 1 dyne moves a mass of 1 gm through a distance of 1 cm) would be too large for usefulness; hence MeV (million eV), KeV (kilo or thousand eV): energies of γ-rays from natural radioactive substances may reach 2 MeV: β-particles up to 3 MeV: α-particles up to 10 MeV.

Energy) Erg) — See eV.

Enzyme — Specific biological catalysts, present in large variety but usually minute concentrations, in all biological systems: probably catalyse all chemical change in protoplasm: capable of aiding syntheses as well as breakdown reactions: activity high, able to promote up to average of 300 molecular reactions/sec/enzyme molecule: sensitive, beyond a specific threshold, to toxic influences, e.g. irradiation: chemistry unknown, but believed to be very large complex reactive molecules.

Epidermis — Inert outer layer of skin; consists of strata of dead flattened cells: thickness varies from 20 - 1200 microns in different areas: average thickness arbitrarily 70 microns, i.e. 20 μ deeper than range of 5 MeV Pu α-particle: see Skin.

Epilation — Loss of hair from the skin, due usually to interference with hair-forming cells of the follicles, often from restriction of blood supply: follows dermatitis caused by radiation: see Skin, radiodermatitis.

Excretion — Removal of waste materials from the body via the urine, faeces, exhaled air, sweat, sputum: in general, a material is excreted when (a) it has no specific purpose for bodily processes, or (b) although of usable nature, it is present in excess and cannot be stored.

Fission product	Radioactive isotopes of elements formed by the fission (splitting) of U^{235}, Pu , or U^{233} by a fast neutron, along with (a) spare neutrons (b) gamma ray photons. Uranium fission results in fission products ranging from ${}_{31}$Gallium^{71} to ${}_{64}$Gadolinium^{158}: fission yield for an isotope is a % representing the proportion of all fissions occurring which result in the production of that isotope; for isotopes of mass number around 90 (Kr) and around 140 (Xe), fission yields may reach almost 10%. Approximately 200 isotopes of about 34 elements are formed in fission: the majority undergo β-decay (often with γ-emission) forming a stable isotope after (often) three such decays: fission product half-lives are mostly very short and decay proportionately rapid: residual activity from isotopes of long half-life produces major protection problems in disposal, however.
Gamma rays	Electromagnetic radiation, emitted from certain isotopes during β, or rarely α-decay, as quanta or photons, having the same type of properties as but shorter wavelength and greater energy than X-rays: having no mass and no electrical charge, penetrate materials more readily than other radiations (save cosmic): cause comparatively low density of ionisation along their tracks: when emitted by internally-deposited α or β-emitter, do not usually add significantly to the radiation dosage, especially true for α-emitters.
Geiger counter	(Geiger-Muller counter: Geiger tube): sealed tube containing a gas under reduced pressure with cylindrical cathode and central wire anode; really a triggering device in which a voltage pulse is produced by the discharge initiated by an ionising particle: same voltage pulse is produced by either α, β or other particle; pulses produced then counted by connection to appropriate electronic instruments. Design, size, filling gas, materials of construction vary according to purpose intended.
Gene	Hereditary characteristic of a species, passed from parent to offspring as a component (gene) of chromosome structure of parent germ cell; is a minute nucleoprotein moiety (less than 1/20 micron diameter): chromosomes (48 in man's germ cells) may each bear thousands of genes, each specific for some hereditary trait; thus genes are raw material of biological evolution. In their effect, some genes are dominant, i.e. their effects, good or bad, shown in first generation; others are 'recessive', i.e. effects latent or hidden, unless both germ cells carry same recessive, which then shows in first generation. Genes undergo occasional though rare 'spontaneous' mutations, or change in nature of trait produced: rate of mutation of genes may be speeded up artificially, e.g. by ionising radiation, nitrogen mustards. Thus, rate of change in biological characteristics, good or bad, apt to be higher in inbreeding irradiated community than inbreeding non-irradiated community: hence so-called "genetic effects of radiation"; no evidence in man to date.
Geometry	Expresses geometrical relationships between source of radioactivity and sensitive area of counter tube or other absorbent of radiation; often referred to as solid angle subtended at counter tube by source; if poor gives inefficient counting; if good, gives higher counter efficiency.

Gonads	Reproductive organs, inclusive of both male (testes) and female (ovaries).
Haemopoietic tissues	Blood forming tissues: red marrow (bones), spleen, liver, and lymph nodes; from primitive parent cells, progressively more specialised cells develop by cell multiplication, culminating in formation of mature red and white cells which are then extruded into circulation; since normality of blood formation is vital, and h. tissues are highly cellular and active, these tissues are regarded as one of critical tissues in radiation dosimetry and protection.
Half-life	1. Radioactive: time required for the radioactivity of a given amount of an isotope to decay to half its initial value; thus after one half-life, 50% activity remains, 2-25% etc.: if accurately determined, specific to individual isotope: varies tremendously, from 10^{-6} sec to 10^{10} years, in different isotopes. 2. Biological: time required for the amount of an isotope fixed in the body to fall to half its initial value as a result of excretion processes: correctly, does not cater for early excretion within first few days of absorption (e.g. Ra, 10% gut contamination absorbed, but about two-thirds of absorbed amount excreted in few days; residue fixed in bone, with b. half-life of order of 20 years); varies with element from days to many years; if element (e.g. Na) has no selective fixation in body, b. half-life refers to 50% loss of all element taken into body. 3. Effective: radioactive or biological half-life of isotope (whichever is shorter) as further reduced by excretion or radioactive decay occurring in same time in residual amount: correctly, sum of radioactive and biological decay constants.
Ion	Electrically charged particle of matter, either atom, radicle or molecule: formed when photon or ionising particle frees orbital electron from atom in its path by collision, in effect leaving atom with one surplus positive charge: freed electron attaches to an adjacent atom, adding thus one negative charge; thus ion-pair formed: ions are attracted in field of electric potential, negative ions to positive (anode), positive to cathode: may be accelerated in the process, with increase in energy; this permits either transfer of energy to molecules collided with in travel, or ionisation of other atoms in path by collision, especially under reduced pressures.
Ionisation chamber	Sealed or gas-flow chamber provided with electrodes operating at controlled potential difference, serving to collect ions formed by incident ionising radiation but without causing further ionisation, i.e. insufficient acceleration of ions to cause ionisation by collision: ionisation occurring in chamber then detected by measurement of voltage produced by flow of charge through resistance, or measurement of rate of change of voltage as charge is collected: one form is parallel-plate condenser, another is thimble chamber (with central collecting rod); can detect all types of radiation, energetic ionising particles by counting circuit, less ionising radiations (γ, β) by charge collected/unit time. Very diverse applications, therefore, and many special varieties.
Inhibition	Reduction of activity of e.g. an enzyme system, blood cell formation, etc.: typical first effect of toxic agent on living processes, in some cases reversible and recuperable, in others irreversible and permanent.

6. Assuming that 10% of all ingested Ra is absorbed and all is deposited in bone, that the effective half-life in bone is 20 years, that the MPBB is .1 μc, and that a person ingests 2.5 litres of water as food or drink daily throughout life, the MPC for Ra in drinking water or ingested materials has been calculated to be 4×10^{-8} μc/cc (or 1.5 dis/sec/litre or kg).(10)

7. As regards radon in air, a concentration of 2.5×10^{-8} c/litre of Rn in air in uranium mines has apparently resulted in a very high incidence of lung cancer in workers (approximately 50%), and animal experiments have verified this order of radiotoxicity for inhaled radon.(16) The recommended MPC for radon in air at work is therefore 5×10^{-11} curies/litre (or 5×10^{-8} μc/cc,(1) equivalent to 1800 dis/sec/m^3).

8. Assuming that 50% of the radon emanating from .1 μc of deposited radium in the body is exhaled (and therefore contributes no further to internal irradiation of tissues), it is calculated(10) that .1 μc of Ra distributed in the skeleton causes to adjacent bone cells a dose-rate of .07 rep/week. Since α-radiation has a relative biological efficiency of 10-20 when compared with X and γ-radiation (for which the MPE is .3 rep/week), the MP α-radiation of cells would be .015 - .03 rep/week; which would be caused in theory by .04 - .02 μg Ra distributed in the skeleton. Clinical judgments have suggested that .1 μg is permissible, and that value has been accepted. There is, however, commendable agreement between the clinical and theoretical assessments of maximum permissible body burden in this instance.

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(RaF) POLONIUM (Po^{210})

Maximal permissible continuous body burden --- .005 μc.

Maximal permissible concentration in air, at work --- 1.2×10^{-10} μc/cc. (4.5 dis/sec/m^3)

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1. The MPBB of .005 μc for Po^{210} is based largely on direct comparisons between the radiotoxicity of radium, plutonium and polonium on rats and dogs.[22] These experiments investigated only acute toxicity, of high intake rates; in the present absence of evidence to the contrary, their implications must be assumed to extend also to chronic exposures at low intake rates. There is, however, very little real evidence on which to frame the MPBB, and .005 μc probably represents an extremely safe value.

2. Polonium, unlike Ra and Pu, does not deposit firmly and selectively in the skeleton, but undergoes only temporary storage in the liver, spleen and to a certain extent, the bones. It is rapidly excreted in the urine, its effective half-life being of the order of 60 days, compared with 20 years for Ra or Pu.[6, 23]

3. The high radiotoxicity and hence the very low MPBB of .005 μc Po^{210} (compared with .1 μc for Ra^{226}) would result mainly from its short half-life (138 days) and consequent rapid disintegration rate, compared with the 1622 year half-life and slower disintegration rate of Ra^{226}. This rapid energy-release more than offsets the lower energy per disintegration of Po^{210}. The MPC for Po^{210} in air is approximately 10 times higher than that for Ra^{226}, however, due to the fact that Po^{210} is excreted from the body far more rapidly than occurs with Ra^{226}.

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URANIUM COMPOUNDS

Maximal permissible concentration, in air, at work ------------ 50 μg/m³ (1.7×10^{-11} μc/cc)

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1. No international recommendations have been issued on the MPC for U compounds in air, water or in the body. The value of 50 μg/m³ is now accepted both in this country and by the A.E.C.[24, 16, 25] The official view expressed is that "as the specific activity of natural uranium is so low, it is considered that the hazards arising from its use are mainly chemical".[33]

2. The major biological risks from over-absorption of uranium ion by the body lies in the production of damage to the excretory cells of the kidney, as is known to occur with other heavy metals. There is also some injury to the liver and to other internal tissues after high dosages. Semi-permanent deposition of unexcreted U occurs in skeletal bone.[26, 27, 28] It is thought improbable that inhaled U dusts will cause specific lung injury, although this is not yet certain.

3. Injury from the chemical toxicity of the U-ion occurs at far lower tissue concentrations than those required to cause radiation effects. U is an α-emitter, and the injury threshold dose-rate would therefore be .03 rep/week of alpha radiation, assuming a relative biological efficiency of 10 for α-rays. Calculations show[28] that 25 μg U/gm. tissue are required before that dose-rate is attained. Experiments on dogs and rats indicate that this concentration of U-ion in tissues is very difficult to produce, and demands extremely high intake rates. In chronic exposures of animals at 50 μg U/m³ of inhaled air, the concentration of U in lungs, blood, bone or kidney did not attain 25 μg/gm. At this concentration there is also believed to be an adequate safety factor from the chemical toxicity of the U-ion.

4. The factor of safety in the MPC of 50 μg/m³ varies somewhat, according to the 'solubility' or 'insolubility' of the particular compound concerned. 'Insoluble' U compounds, such as UO_2, high grade ore, U_3O_8, UF_4, have a higher safety factor at this MPC than the more soluble compounds, such as UO_2F_2, UF_6, $UO_2(NO_3)_2$. The most chemically toxic compound of uranium so far known is uranyl fluoride, UO_2F_2, arising from the hydrolysis of UF_6.[30]

5. On the basis of radiotoxicity, the MPBB for U in the body (skeleton) has been quoted as .01 gm (10 milligrammes).[10] That for the lungs, weighing 1000 gm. in standard man, has been quoted as 25 milligrammes, i.e. 25 μg/gm of tissue.[28]

6. Assuming that standard man inhales 10m³ air at work daily, he could thus inhale (50 x 10) or 500 μg of uranium. Assuming in the light of experiments on animals, that one-eighth of that inhaled

/is absorbed

is absorbed into the bloodstream, (the remainder being removed from the lungs by normal mechanisms applying to dusts), the daily absorption rate would be about 60 μg of U. Assuming further that only one-fifth of the absorbed amount is retained semi-permanently in the skeleton, the remaining four-fifths, or about 50 μg, would be excreted, predominantly very rapidly, in the urine. Since the normal daily urine volume is 1500 cc, the concentration of U in urine could thus be about 30 μg U/litre urine as a result of inhalation at MPC levels. If the compound is a soluble one, perhaps one-quarter of the inhaled dust would be absorbed; in that case, the urinary concentration of U could be doubled, i.e. 60 μg U/litre.

7. From the above, it will be seen that the urinary uranium excretion reasonably compatible with inhalation at the MPC level in air is from 30 to 60 μg U/litre of urine, depending upon the U compound concerned. It is recommended that the MPC for U in urine is regarded as 60 μg/litre; levels in excess of this should be taken to imply over-exposure to uranium from some occupational source, unless this can be excluded.(29)

8. The alpha-activity of air corresponding to 50 μg U/m^3 (1.7×10^{-11} μc/cc) gives 70 α-dis/min/m^3, since there are effectively two α-disintegrations per atom of U^{238}.(25)

9. The MPC of 50 μg/m^3 gives an adequate order of safety from concurrent intake of the impurities present in crude ore, e.g. lead (6%), SiO_2 (10%), radium (1 curie per 3×10^6 gm U, or 1 curie/3 tonnes).

10. Certain of the chemical compounds of uranium, e.g. UF_6 and others, are directly corrosive to the skin, eyes, nose, lungs and all tissues. The MPC of 50 μg U/m^3 of air provides adequate safety from these local effects. However, the corrosive properties of such compounds, and in the case of UO_2F_2, its high solubility (18 gm %) and toxicity, are so marked that the safe permissible range of concentration around the MPC is very limited indeed.(30) This aspect is mentioned in paragraph 31 of the main report.

11. Although there is no doubt that the toxicity of inhaled particles increases rapidly with decreasing particle size, the MPC of 50 μg/m^3 is based already upon the toxicity of very fine particles (.5 - 1 μ diameter). No allowance therefore needs to be made for particle size distribution in industrial uranium dusts.

12. No official figure exists for the MPC of U in drinking water. On the bases that 50 μg/m^3 is safe for inhalation; that standard man breathes 4000 times more volume of air at work than he ingests water in a day (10m^3 : 2.5 litres); that he absorbs only 1/250 as much uranium from the gut as from the lung (25% : .1%); then the MPC of U in water could be (4000 x 250) times that for an equal volume of air, i.e. 50 μg/cc. This would give the same order of safety as that provided by the MPC in air. Since this 50 μg/cc would be a theoretical "occupational" exposure, a further reduction by a factor of 20 should be made for an outside community having uranium contamination of its drinking water supplies. The value could thus become 2.5 μg/cc (2.5 p.p.m.).

/13.

13. The above paragraphs refer to chemical compounds of U^{238} or of natural U in radioactive equilibrium. They also refer to uranium enriched in the isotopes U^{235} or U^{233} and give an adequate factor of safety for pure U^{235} or U^{233}. They do not, however, necessarily apply to uranium contaminated with fission products, e.g. uranium recovered from pile-irradiated cartridges. A further specific MPC may eventually be required for such material, imposed by the degree of residual contamination with fission products or plutonium.

Appendix VIII.

PLUTONIUM

Maximal permissible continuous body burden	.... 0.6 μg (.04 μc)
Maximal permissible concentration of Pu in air, at work	.... 4 x 10^{-12} μc/cc
Maximal permissible concentration of Pu in drinking water, etc.	.... 1.5 x 10^{-6} μc/cc

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1. The major biological risks arising from occupational over-exposure to particulate Pu^{239} in the atmosphere appear to be the production of eventual bone changes similar to those due to over-deposition of radium (App. V). Similar blood changes are also possible. There is also a possibility that specific lung injury (lung cancer) could follow chronic over-exposure to inhaled Pu dusts, from persistent intense α-irradiation of lung cells, such as is believed to have occurred with over-exposure to radon (App.V).

2. The basis for the MPBB of .04 μc (.6 μg) for Pu^{239} is mainly direct experimental comparison between the radiotoxicity of Ra, Po and Pu in rats and dogs.(22, 24) It appeared that the manner of deposition of Pu in microscopic relation to the bone cells was likely to cause Pu to be several times more injurious than Ra, when compared on an activity (curie/curie) basis. This is offset, in comparisons by mass, by the fact that Pu requires 16 gm. per curie.

3. A proportion of all absorbed Pu is excreted in the urine, and the approximate order of daily excretion is known both in animals and in man.(31) Excretion rate decreases rapidly after the causative over-exposure. If, as a result of occupational over-exposure, a person has the MPBB of .04 μc Pu in the body (causing 1500 α-dis/sec, or 90,000 α-dis/min), it is possible to calculate the subsequent α-activity of 24 hour urine specimens from certain assumptions regarding the excretion rate of Pu following absorption.

Estimated α-activity in urine at increasing times after absorption of one MPBB (.04 μc) of Pu^{239}; assuming 100% analytical chemical efficiency. (% excretion based on animal and human studies)

% of MPBB excreted in urine per day, at various times after absorption — Delay	Excretion	Urinary Pu excretion per day (α-dis/minute)	Urinary α-count assuming 33% counting efficiency. (α -c/minute)
day 1	1%	900	300
month 1	.1%	90	30
month 6	.01%	9	3
year 1 (and after)	.001%	.9	.3

/4.

4. It is probable that the normal human body burden of Ra and U will give α-activity of the urine reaching at times up to .1 c/min/24 hourly sample, and this imposes some restriction on Pu determinations at very low count-rates. The difficulty of detection of absorbed Pu increases rapidly with increasing time after the exposure, although it is reasonably straightforward within a few days or weeks of first absorption. Ease of detection is also obviously proportional to the actual body burden of Pu.

5. Inhalation of Pu at concentrations below the MPC will result in some Pu absorption and will give some increase in urinary α-activity. If, for example, a person inhales the MPC for Pu in air on each working day, the total absorbed Pu (assuming 10% lung absorption) will be 4×10^{-6} μc/day, equivalent to 8 α-dis/min. If, in the next 24 hours he excretes 1% of that absorbed, the day's urine will thus give .08 dis/min. To this must be added the exponentially decreasing excretion from previous days, months and years of exposure. The additive excretion in such a case may amount to at least 1 dis/min/24 hr. urine specimen. It is therefore conceivable that a worker occupationally exposed to Pu at atmospheric concentrations within the MPC may have up to 1 c/min in any day's urine specimen.

6. It is recommended that if the daily urinary activity exceeds 1 c/min in an exposed worker, it is presumed that over-exposure may have occurred, and this possibility must be excluded.

7. It will be noted that if a single very severe exposure some months previous to a urine test had caused the MPBB of .04 μc to be absorbed, this would still result in urinary activity of at least 3 c/min/24 hr. specimen, even 6 months after absorption, and would theoretically be detected on the basis of the recommendation in para. 6.

8. It is calculated that the MPC of 4×10^{-12} μc/cc (9 α-dis/min/m^3) provides a satisfactory standard of protection against the build-up of Pu both in the skeleton and in the lungs. The recommendation applies to all Pu compounds, irrespective of chemical combination, and to Pu aerosols irrespective of particle size distribution.

9. The MPC for Pu in drinking water (1.5×10^{-6} μc/cc) is considerably higher than that for the MPC of Ra in water (4×10^{-8} μc/cc). This is because 10% absorption of Ra is assumed to occur in the gut but only .1% absorption of Pu. Furthermore, the effective available energy of the Ra chain of elements in the tissues is considerably greater (15 MeV) than that of Pu^{239} (5 MeV).

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Appendix IX.

ESTIMATED MAXIMUM PERMISSIBLE CONCENTRATIONS OF RADIOISOTOPES IN AIR, UNDER WORKING CONDITIONS.

Preliminary Notes.

i. All values have been specifically adjusted for occupational exposure, i.e. 8 hours/day.

ii. For 24 hours/day (continuous) exposure, the values should be halved.

iii. For continuous environmental exposures of arbitrarily 'large' communities, the values should be reduced by a factor of 20.

ISOTOPE	ESTIMATED MPC IN AIR (μc/cc)			REMARKS
	International	British	American	
Col. I	Col. II	Col. III	Col. IV	Col. V
H^3	1×10^{-4}		5.4×10^{-5}	MPBB 10 μc
C^{14}	2×10^{-6}		9×10^{-7}	As $C^{14}O_2$
N^{16}		1.2×10^{-2}		
O^{19}		2×10^{-6}		
Na^{22}			4.8×10^{-7}	
Na^{24}	6×10^{-6}		3.4×10^{-6}	MPBB 15 μc
P^{32}		2×10^{-7}	7.1×10^{-8}	MPBB 10 μc
S^{35}			1.1×10^{-6}	
Cl^{36}			1.2×10^{-6}	
K^{40}			2.3×10^{-7}	
K^{42}			6.5×10^{-6}	
A^{41}		2×10^{-6}		See Note 1.
Ca^{45}			4.8×10^{-9}	
Ca^{47}			1.4×10^{-7}	
Ca^{49}			4.7×10^{-5}	
Mn^{52}			1.3×10^{-6}	
Mn^{54}			6×10^{-7}	
Mn^{56}			5.9×10^{-5}	
Fe^{52}			1.1×10^{-5}	
Fe^{55}			5.3×10^{-7}	
Fe^{59}			3×10^{-8}	
Co^{60}				MPBB 1 μc
Cu^{67}			2.1×10^{-6}	
Kr^{85}		2×10^{-5}		See Note 1.
Kr^{85}		4×10^{-6}		"
Kr^{87}		4×10^{-6}		"
Kr^{88}		2×10^{-6}		"

Cont.........

ISOTOPE	ESTIMATED MPC IN AIR (µc/cc)			REMARKS
	International	British	American	
Col.I	Col.II	Col.III	Col.IV	Col.V
Sr^{89}		2 x 10^{-8}		MPBB 2 µc
Sr^{90} Y^{90}	4 x 10^{-10}	1.6 x 10^{-10}		MPBB 1 µc
Y^{91}		6 x 10^{-9}		
Zr^{95} + Nb^{95}		6 x 10^{-9}		
Ru^{103} + Rh^{103}		8 x 10^{-8}		
Ru^{106} + Rh^{106}		3 x 10^{-9}		
Te^{*127} + Te^{127}		2 x 10^{-7}		
Te^{*129} + Te^{129}		8 x 10^{-8}		
I^{125}			9.1 x 10^{-9}	
I^{126}			3.6 x 10^{-9}	
I^{130}			2.7 x 10^{-9}	
I^{131}	6 x 10^{-9}		3.2 x 10^{-9}	MPBB body .3 µc, thyroid .18 µc. See Note 3.
I^{133}			1.1 x 10^{-8}	
Xe^{133}		2 x 10^{-5}		See Note 1.
Xe^{135}		6 x 10^{-6}		See Note 1.
Cs^{137} + Ba^{137}		1.6 x 10^{-6}		
Ba^{140} + La^{140}		4 x 10^{-8}		
Ce^{144} + Pr^{144}		1 x 10^{-9}		
Pm^{147}		2 x 10^{-9}		
Po^{210}		1.2 x 10^{-10}		See Appx. VI.
Rn^{222}		5 x 10^{-8}		See Appx. V.
Ra^{226}	1.6 x 10^{-11}			See Appx.V. MPBB .1 µc
U^{238}	1.7 x 10^{-11}			See Appx.VII (≡ 50 µg/m³)
Pu^{239}	4 x 10^{-12}			See Appx. VIII. MPBB .04 µc or .6 µg

Note 1. Isotopes of inert gases Argon, Xenon and Krypton present mainly an external radiation. The MPC's quoted restrict external radiation to the correct MPE (0.5 rep/week at the surface): these are so-called "immersion" conditions.(10)

Note 2. The American values in Column IV are estimates stated to possess no 'deliberate' safety factors. The American author(11) recommends a plant safety factor of 100. However, where comparison is possible, it will be seen that his values are already 'safer' than those of Col. II.

Note 3. I^{131} is adsorbed or absorbed by herbage, possibly selectively. In order to ensure safety of grazing animals, a special 'agricultural' MPC of 2 x 10^{-12} µc/cc has been recommended.(32)

Note 4. Literature references. Col. II - 33, 7, 6, 10.
Col.III - 10, and various M.R.C./T.D.P. papers.
Col. IV - 11.

ESTIMATED MAXIMUM PERMISSIBLE CONCENTRATIONS OF RADIOISOTOPES IN DRINKING WATER, ETC.

Preliminary Notes

i. All values have been adjusted for continuous exposure, i.e. standard daily water intake for a full lifetime. (No obvious need exists to refer to 'occupational' exposure in this Appendix.)

ii. For exposures of arbitrarily 'large' outside communities the values should therefore be reduced by a factor of 10.

iii. For lack of evidence to the contrary, the values may be taken as also applying to other ingested materials, e.g. foodstuffs, of both man and (in the absence of other data) animals.

iv. Where more than one isotope is present in an ingested medium, additivity of effect is envisaged. If, therefore, the actual concentration of each isotope present is expressed as a fraction of its MPC, the sum of all these fractions should not exceed unity.

v. The values quoted do not necessarily apply where significant dilution of the radioisotope may occur due to the concurrent presence of stable isotopes of the element in the same medium.

ISOTOPE	RECOMMENDED MPC IN WATER (μc/cc)			REMARKS
	International	British	American	
Col. I	Col. II	Col.III	Col. IV	Col.V
H^3	.4			MPBB [illegible]0 μc
C^{14}			3.1×10^{-3}	As $C^{14}O_3$ radical.
Na^{22}			1.6×10^{-3}	
Na^{24}	8×10^{-3}		1.1×10^{-2}	MPBB 15 μc
P^{32}	2×10^{-4}		2.4×10^{-4}	MPBB 10 μc
S^{35}			3.8×10^{-3}	
Cl^{36}			4.1×10^{-3}	
K^{40}			7.7×10^{-4}	
K^{42}			2.2×10^{-2}	
Ca^{45}			1.6×10^{-5}	
Ca^{47}			4.8×10^{-5}	
Ca^{49}			1.6×10^{-1}	
Mn^{52}			4.3×10^{-3}	
Mn^{54}			2.1×10^{-3}	
Mn^{56}			.2	
Fe^{52}			3.8×10^{-2}	
Fe^{55}			1.8×10^{-3}	
Fe^{59}			1×10^{-4}	
Co^{60}	1×10^{-5}			
Cu^{67}			7×10^{-3}	

Continued....

ISOTOPE	ESTIMATED MPC IN WATER (μc/cc)			REMARKS
	International	British	American	
Col. I	Col. II	Col. III	Col. IV	Col. V
Sr^{89}		2 x 10-5		MPBB 2 μc
$Sr^{90} + Y^{90}$	8 x 10-7			MPBB 1 μc
Y^{91}		3 x 10-3		
$Zr^{95} + Nb^{95}$		5 x 10-3		
$Ru^{103} + Rh^{103}$		4 x 10-1		
$Ru^{106} + Rh^{106}$		8 x 10-2		
$Te^{*127} + Te^{127}$		1 x 10-3		
$Te^{*129} + Te^{129}$		3 x 10-4		
I^{125}			3.1 x 10-5	
I^{126}			1.2 x 10-5	
I^{130}			8.7 x 10-5	
I^{131}	3 x 10-5		1.1 x 10-5	MPBB .3 μc in body, .18 μc in thyroid. See Note 3.
I^{133}			3.8 x 10-5	
$Cs^{137} + Ba^{*137}$		1 x 10-3		
$Ba^{140} + La^{140}$		6 x 10-5		
Ce^{141}		4 x 10-2		
$Ce^{144} + Pr^{144}$		8 x 10-4		
Pm^{147}		2 x 10-3		
Ra^{226}	4 x 10-8			See Appx. V. MPBB .1 μc.
U^{238}		8 x 10-6		See Appx. VII. (≡ 25 μg U/cc water)
Pu^{239}	1.5 x 10-6			See Appx. VIII. MPBB .04 μc (.6 μg)

Note 1. Literature references.

Col. II : refs. 33, 6, 7, and 10.
Col. III : 10, and various M.R.C./T.D.P. papers.
Col. IV : 11.

Note 2. The values quoted in Col. IV are stated by the American author to possess no deliberate factors of safety. Where comparison is possible, however, these values already approximate very closely to those quoted in Cols. II and III. The originator's suggestion, that a safety factor of 100 be superadded to Col. IV figures, is therefore considered very conservative indeed.

Note 3. I^{131} in vegetation. The I^{131} concentration in vegetation, likely to result in thyroid gland dose-rate of 1 rep/day, is estimated to be 2 x 10-4 μc/gm vegetation, i.e. a higher value than the MPC in drinking water for man, by a factor of almost 10.(32, 34)

Appendix XI.

GLOSSARY OF SELECTED TERMS USED IN RADIOBIOLOGY AND RADIATION PROTECTION.

Preliminary Note. This series of definitions or explanations is given in response to requests for such information from both medical, health physics and other staff. The definitions may well be found somewhat or quite inaccurate by specialists in that field; they however are intended to serve the general purpose of indicating what other staffs' terms mean when encountered in discussions, reports or literature. I am naturally much indebted to many textbooks for their help. - E.F.E.

Absorption

1. Transmission of a substance, usually in solution, across a membrane at a body surface, e.g. lungs, gut, skin, eye, nose: usually specific and selective for different elements or compounds.
2. Loss of energy of radiation in penetration of irradiated medium, energy being transferred to atoms in or alongside path of radiation; common indices of absorption are absorption coefficient, and "half-value layer".

"Acute" Marked and rapid response of tissue to injury, usually with very short latent period, sudden onset of effects and implication of severity. (cf. "chronic")

Alpha-radiation Streams of α-particles from an α-emitting isotope; each particle a helium nucleus (4 nuclear mass units, 2 positive charges); characterised by short range of penetration (centimetres in air, less than 100 microns in tissue), dense ionisation tracks in path, and high relative biological efficiency (RBE, q.v.).

Anaemia Deficiency in quantity or quality of the circulating blood; most commonly, deficiency in haemoglobin (oxygen-carrier) content of red blood cells: late effect of severe over-exposure to radiation.

Angstrom unit (Å) 10^{-8} cm, or 10^{-7} mm, or 10^{-4} micron. Most atomic radii fall between .5 and 2.5 Å. Optical resolution of microscope 10^3 Å.

Atom The smallest portion of an element that can be found in a molecule of any of the element's compounds: comprises central nucleus (itself consisting of neutrons and protons) with electrons circulating in orbits; numbers of these electrons specific to particular element.

Atrophy Reduction in size, thickness or elasticity of living tissues following some types of injury or diseases.

Autoradiograph Photographic demonstration of tracks of ionising particles from radioactive substance in ore, biological tissue or other material kept in contact with photographic emulsion, usually requiring lengthy exposure time.

Backscatter Radiation reflected or deflected from external or internal surfaces of an irradiated medium.

Beta-rays	Streams of β-particles from a β-emitting isotope, each being an electron (mass 1/1800 that of neutron, 1/7600 that of α-particle) possessing one negative electrical charge: characterised by comparatively low penetration of matter (about one hundred times that of α-particle, i.e. few metres in air, 1 cm. or less in tissue, depending on energy), low density of ionisation along tracks (about equal to γ-rays), ease of deflection (tortuous tracks), and low relative biological efficiency (equal to γ-rays, 1/20 of α-rays RBE).
Blood	Disperse phase (50:50) of blood cells in blood plasma (a solution of nutrients, inorganic ions and proteins): amounts to about 1/13 weight of body in mammals: formed in haemopoietic tissues (marrow of ribs, sternum, pelvis, vertebrae , long bone ends, liver, spleen, and lymph nodes): circulates through all body tissues in closed system of vessels and semipermeable capillaries: transports required materials to cells (oxygen, nutrient molecules, chemical messengers, etc.) and transports wastes to excretory organs (breakdown products, carbon dioxide, etc.).
Blood cells	Two types, white and red. Red cells function as O_2-carriers; white cells mainly anti-infection defence. White cells of several types, e.g. multilobed nuclear cells (neutrophil, eosinophil, basophil) discrete nucleus cells (lymphocyte, monocyte); also platelets (concerned with blood clotting) in addition. Average life red cells 120 days; white cells only few hours or days.
Blood count	Investigation of number, type and normality of cells in circulating blood; of value in conditions where changes in these give first detectable body response to injurious agent (lead, benzene, radiation, etc.); "normal" count varies with individual, recent physical activity, infections, and other factors, which must usually be taken into some consideration.
Body burden	"Maximal permissible body burden" implies that amount of a toxic substance which may be present, permanently deposited, in the body, and will in that situation cause a maximal permissible radiation dose-rate to adjacent cells.
Bone	Consists of (i) mineral structure (cortex, containing mainly elements Ca and P, with network of capillary canals, interspersed living cells) enclosing (ii) lattice structure of bone spicules (matrix) serving as framework for bone marrow cells. Most cell activity occurs at inner and outer surfaces of cortex; many heavy elements, rare earths and other elements are selectively deposited in or on bone structure, site varying with element.
Bone marrow	Non-bone cells lying inside bone structure. Yellow marrow mainly special fat storage; red marrow is highly cellular blood-forming tissue, extruding the formed mature cells into blood stream.
Cancer	Serious local abnormality of tissue of the body, in which normal continuous pattern of cell-division and cell function gives way (due to mechanical, chemical, physical or other stimulus) to abnormally rapid tissue growth and abnormal cells; involves invasion of local normal tissues in all directions, with possibility of spread to distant areas via blood or lymphatic drainage: occupational cancers include those due to over-exposures to tar derivatives, dyestuffs, mineral oils, nickel, arsenic, radiation and radioactive substances, and other agents.

Carcinoma	Cancerous changes arising in highly cellular tissues or organs of the body; (c.f. sarcoma).
Cataract	Opacity of the ocular lens, caused by inflammatory changes following physical, chemical or other injury; occupational cataract has occurred due to infra-red or ionising radiation (X, γ and neutron exposures above MPE's).
Cathode rays	Streams of electrons (β-particles) emitted from the cathode of an evacuated tube operating at a high electrical potential difference.
Cell	A discrete, usually minute, mass of living material (protoplasm) consisting of a visible wall (in plants) or a membrane (in animals) enclosing a semi-fluid mass (cytoplasm) in which is suspended the nucleus. Cells vary not only in size, but in composition, contents, function, structure, reproductivity.
Chemotoxicity	Property possessed by most elements or compounds, if in adequate dosage, of causing injury to living cells from chemical reactions with constituent molecules of nucleus of cytoplasm; chemotoxicity is thus a property of ions, radicles or whole molecules.
Chromosome	Dense nuclear material carrying hereditary characteristics of parent cells; on cell division (by mitosis) form strands, each strand dividing in length, thus duplicating itself and its burden of 'genes', and providing the two nuclei to be formed with identical characteristics of parent. At times strands break (e.g. under influence of ionising radiation) and may mis-unite, disturbing hereditary pattern of cells thence onward. In division by meiosis (q.v.) chromosome number is halved, prior to fusion of reproductive cells.
"Chronic"	Implies gradual, insidious, slowly-developing or prolonged response to injury or disease, as distinct from "acute" (q.v.); implication also of being unresponsive to natural healing or medical treatment; in sense of prolonged, applied also to radiation exposures, e.g. chronic exposure.
"Compton effect"	Scattering (first described by Compton) of X and γ-rays impacting on an electron in their path; the X or γ-photon is deflected from its previous path and undergoes reduction in energy (thus increase of wavelength): the recoil electron, by increase in its velocity, accounts fully for the lost energy of the photon; effect is most important process for γ-ray absorption at high energies (.5 - 5 MeV), but negligible at low energies where photoelectric effect predominates; accounts for degraded energy and scattered angles of X or γ beam passing through absorber.
Cosmic rays	Ionising radiation, originating somewhere in outer space, causing about 1 particle/cm^2/min. to hit the earth's surface; arbitrarily two components, hard (mesons, with some protons, neutrons, atomic nuclei, electrons and photons) all with intense energy, average 6 billion electron volts, and tremendous penetration, greater than 1400 metres of water, for example; and soft, less energetic (circa 200 MeV) positive and negative electrons, photons, protons, neutrons, stopped by 10 cm lead. Contribute perhaps 5 - 10% to natural background radiation.

Isomeric transition — Special type of radioactive decay, in which one isotope (of a certain rate of radioactive decay) changes its rate of decay without however changing its atomic number, mass number or place (therefore) in the Table of Isotopes; appears to arise from production of first 'isomer' in a highly excited state of energy, causing rapid release of a γ-photon (without particle emission) thus forming second isomer in "ground state" of energy: over 70 examples known; few cases of triple isomerism (double transition) are known: examples UZ:UX2, Te^{*127} - Te^{127}, Sb^{**124} - Sb^{*124} - Sb^{124}.

Isotopes — Atoms of the same element, having the specific number of orbital electrons for that element (atomic number) and therefore chemically indistinguishable, but varying in the atomic mass number (neutron/proton total in the nucleus), some being therefore heavier than others, e.g. $_{92}U^{235}$ (light isotope) $_{92}U^{238}$ (heavy isotope). Each and every element of the 98 thus far known, has chemically indistinguishable but lighter or heavier isotopes prepared or found; nearly 1200 isotopes have now been discovered; capable of being divided into two groups, <u>stable</u> (non-radioactive) and <u>radioactive</u> (either naturally or artificially prepared). Most natural forms of elements actually consist of two or more stable isotopes of the elements. Separation of isotopes depends upon utilisation of some property of different masses, e.g. electromagnetic deflection, thermal diffusion, gaseous diffusion, centrifuging, distillation, electrolysis: for the lighter elements (up to $_{16}S^{34}$) there are in fact slight differences in chemical behaviour of isotopes of the same element, and chemical separation can be used: this has not yet been shown to feature in any biological reactivity of the light element's compounds. The nuclear and radioactive properties of every known radioisotope are specific to that isotope: loosely, radioactive isotopes (radioisotopes) of an element may be termed radio-elements, e.g. radiostrontium, radioiodine, etc.: since such elements often have several dissimilar radioisotopes, confusion occurs at times.

Isotopic dilution — Dilution (i.e. of radioactivity) of a radioactive isotope by mixing with appropriate quantity of stable isotope of same element; since chemically indistinguishable, radioactive and stable isotope will proceed in parallel throughout all subsequent chemical changes: basis of all 'tracer' methods for biological and chemical investigations: usable to reduce dangerous levels of activity (e.g. in water supplies, food materials, living tissues) to innocuous levels.

Keloid — Abnormal condition of skin, due to excessive formation of dense fibrous tissue deposits, sometimes apparently spontaneous (or congenital), otherwise from abnormal formation of scar-tissue, e.g. in wounds, after burn-healing; occasional trend towards malignant change (cancer-development).

Kidney — Bilateral organ (mammals) concerned with excretion (as solution in urine) of traces or excesses of material which other body tissues have not selectively absorbed or taken up: consists of about 10^6 (in man) highly cellular twisting tubules ending in collecting duct to bladder; copious blood flow through organ, particularly the selective filtration-bed (glomerulus); concentration of urinary constituents by re-absorption of water; kidney cells apt to be injured during excretion of high concentrations of toxic agents, e.g. lead, uranium, ruthenium, organic molecules, bacterial toxins.

Leucocytes	White blood cells: function mainly anti-infective, engulfers or dissolvers of foreign bodies, including germs, throughout body: occur in several specific forms in circulating blood; formed in haemopoietic tissues: total numbers in blood vary between 4000 - 12000 /cu.mm. in normal individuals: numbers reduced by injury to formative tissues, e.g. by radiation, toxic molecules of organic compounds (some): increase in numbers in most infections, exercise: malignant increase in numbers in leukaemia: types, numbers, normality important in health supervision of persons exposed to some chemotoxic and most radiotoxic risks.
Leukaemia	Malignant over-activity and abnormal activity of white cell-forming tissues, occurring spontaneously as 'natural' disease, also notably apt to occur following consistent over-exposure to radiation, especially of blood-forming tissues; incidence nine times higher in medical radiologists than other medical men of same ages: occurred in persons over-exposed to radium/mesothorium as dial painters: usually fatal, precise mode of causation doubtful: may run course of many years or few weeks, depending on type.
Lymphocyte	White blood cell, present in circulating blood (1000-5000/cu.mm.) formed by lymphnodes scattered throughout body; one form of leucocyte: probably most sensitive of all white blood cells to radiation over-exposure, if affecting sites of production.
Lymph nodes	Lymph glands; discrete usually small masses of lymphocyte-forming tissues located at fairly definite positions throughout body: serve to collect and usually detoxify foreign chemical molecules arising in organs, e.g. in tonsils, lung, gut, skin, etc.
Liver	Large highly active and cellular organ in abdomen: functions multitudinous, including foodstuff conversion, detoxification of abnormal or injurious blood contamination, temporary storage of unwanted substances (e.g. certain heavy elements) or foodstuffs (e.g. fat, glycogen), blood cell and haemoglobin formation; best regarded as hardworking physiological chemical laboratory of the body.
Lung	Sponge-like elastic mass of minute air-sacs, providing about $60m^2$ area of absorptive cell surfaces; connecting with nostrils via bronchioles, bronchi, trachea and nose (successively): abundant blood flow in capillaries between air-sac walls, permitting exchange (by diffusion plus accelerating catalysts) of waste CO_2 for atmospheric O_2: breathing process, in expanding chest, expands lung volume; elastic contraction of lungs aids exhalation: bronchioles and wider ducts lined with special mucus-secreting cells equipped with minute brush-like 'ciliae', intended to sweep deposited air contaminant particles upwards for expectoration or other removal: serves, rather incidentally, as excretory organ for gaseous or volatile blood contaminants, e.g. alcohol, ether, argon, helium, krypton, radon. Lungs probably far the most important portal of entry of injurious materials into body, in industry.
MeV	Million electron volts: thus, multiple of minute energy unit eV (q.v.).
Malignant	Abnormal growth of living tissues, synonymous with cancerous growth; involves tendency towards spread of abnormal tissue throughout organ (slow or fast, depending on type of malignancy) ulceration and bleeding (due to erratic blood vessel formation) spread of abnormal cells via lymph drainage or blood circulation, involvement by invasion or pressure (etc.) of adjacent previously-normal organs.

Meiosis Form of cell division in sexual reproduction of organisms, reducing number of chromosomes (therefore of genes) to half number present in normal, non-reproductive cells: daughter cells of meiosis are thus prepared for union with reproductive cell of other parent, giving zygote (or product of union) normal double or diploid number of chromosomes, contributed equally by both parents.

Metabolism Chain of events between intake (of a foodstuff, inert or toxic material) into a living organism, and its final disposal: involves therefore factors, specific to each substance (metabolite), of solution, absorption, distribution, utilisation, concentration, temporary or permanent storage, detoxification and finally excretion.

Mucous membrane Lining cell-layer of a hollow part or organ of body, e.g. nose, mouth, bronchi (etc.), bladder, gut, stomach, uterus: so-called from presence of cells secreting mucus (colloidal nucleoprotein): often has specific function in absorption of materials across cell membranes into blood capillaries: usually fair amount of cell multiplication occurring, to provide replacement for injured or freed cells.

Mutation Change in type or arrangement of hereditary characteristics borne on chromosomes by genes, leading thenceonward to detectable or latent alteration in biological characteristics of progeny: two main causes gene mutations, where gene itself undergoes spontaneous or induced alteration, possibly in its molecules, and chromosome mutations due to re-orientation of chromosomes or their fragments during cell division; regarded as raw material of evolution, in that mutations alter characteristics of species, either early or later, and thus lead to change in form, function, habits, survival or development of species.

Negatron (Also negaton): alternative name suggested for electron, to distinguish this from positron (positive charged electron, q.v.).

Necrosis Degenerative changes in cells which have died, recognisable in cell by shrinkage or swelling, nuclear deformation or disintegration change is cytoplasm and staining reactions, etc.: in tissue, by gross appearances, e.g. change in colour, elasticity, liquefaction: exemplified by slough of deep burn, core of boil, gangrene of extremity, etc.

Neutron Nuclear particle, of unit mass but no electrical charge; producible by α-irradiation of Be, Bo, Li, N, F, Mg, Na, Al; best yield from Ra-Be or Po-Be or Rn-Be sources (α, n reaction); also producible by irradiation of Be, Li or deuterium with deuterons (hydrogen nuclei) e.g. Be^9 (d, n) B^{10}: also by proton on e.g. Li (Li^7 (p,n) Be^7): also by photonuclear reaction (γ,n), using γ-rays of Na^{24} (etc.) on Be or deuterium: also emitted spontaneously by certain heavy isotopes, e.g. of uranium: also emitted as prompt and delayed spare neutrons in fission of U^{235}, Pu^{239}, U^{233}, e.g. in nuclear reactor (pile). Produce but little primary ionisation along path (ca. 1 ion-pair/m in air), but detection and measurement aided by secondary particle emissions after reaction with (mainly) light atoms in path, e.g. C, H, O, B, Li, N; these reactions produce in specific cases, either α, β, proton or γ-photon, detectable by orthodox methods: certain elements (In, Rh) absorb neutrons of limited energies with (n, γ) reaction and formation of measurable amounts of β-isotope of element. Slowed down by elastic ("billiard ball") collisions, especially with light atoms, initial energy of neutron transferred, and neutron slowed down (moderated) to thermal energies, i.e. about same as energies of surrounding atoms, which are

/temperature

Neutron (cont.) — temperature (thermal)-dependent, about .025 eV at normal temperatures. Slowed-down neutrons able to enter any atom nucleus; apt to undergo 'capture', adding mass (equivalent to energy) but no charge, e.g. $_{92}U^{238}$ - U^{239} (which by β-decay gives rise to $_{94}Pu^{239}$). "Epithermal" neutrons intermediate in energy and velocity between thermal n. and fast n. Biologically, energy is transferred to cell constituents in proportion to neutron energy; thus fast neutrons more hazardous in equal flux (arbitrarily expressed in $n/cm^2/sec$); relative biological efficiency varies with energy, from about half that of α's (for fast n.) to about a quarter of that of α's (thermal n.).

Neutrino — Minute particle, about 1/200 mass of electron, hypothetically emitted during β-decay; neutron liberates β- and also neutrino in β-decay, leaving +ve proton in nucleus: postulated to obtain balance of energy equation in process; not yet demonstrated to exist, but assumption firm.

Nucleus — 1. In cell, dense specialised mass of protoplasm, essential to life of cell, initiating cell-divisions and (by assumption) integrating all cellular activities; demonstrable by staining reactions of special constituents; varies in size from minor to major fraction of entire cell volume.

2. In atom, composite lattice structure of neutrons and protons, bound together by cohesive forces, surrounded by fields of force in which the atom's orbital electrons circulate; radius 10^{-12} - 10^{-13} cm.

Nucleon — Inclusive term for nuclear particles (neutrons and protons).

Nuclide — Proposed expression for species of atom characterised by composition of its nucleus, i.e. number of protons and neutrons therein; almost but not quite synonymous with isotope; put forward (1947) to clarify interpretation of isotope: not yet in popular use.

Organ — Anatomically discrete part of an animal or plant, structurally and functionally a unit: examples - heart, lung, brain, kidney, thyroid, etc.: but not muscle, fat, lymphatic cells, bone, which are types of tissue widely spread through body, not discrete.

Osteogenic sarcoma — A malignant (cancerous) overgrowth arising from bone, the malignant cells retaining power to form new (but erratic) invasive bone tissue: spontaneous 'natural' occurrence, as one of whole group of bone cancers: occurred with abnormal frequency among dial painters with heavy radium deposition in bones: thought therefore major hazard from excess fixation of radioactive elements in bone, especially α-emitters of long biological half-life (or more correctly, effective half-life, q.v.).

Pathological — State of abnormal type or order of activity, function or structure of cell, tissue or organ which is sufficiently marked to be recognisable by investigation, and is believed to be harmful: diseased, in effect.

Photoelectric effect — (Photon-electron effect): ejection of orbital electron of atom by impact of γ-photon, causing full absorption (loss) of photon's energy, and transfer of that unused (in ejection process) to ejected electron; major manner of absorption of γ-radiation of low energies, e.g. .5 MeV or below, or soft X-rays of about same energy; at higher energies Compton effect predominates (q.v.).

Photomultiplier tube	Electron-multiplier tube with photoelectric sensitive cathode; light (e.g. single weak scintillation from particle or γ-photon on fluorescent screen, e.g. Zns, Ca tungstate, naphthalene, etc.) falls on cathode, liberating some electrons, which are greatly multiplied by successive stages of tube, producing finally a measurable pulse of current; best for α's, under development for β and γ-rays.
Physiology	Normal physiology implies smoothly integrated processes by which living organism maintains life, functions and form up to the stage of senile degeneration for the species; abnormal physiology means deviation (temporary or permanent) from the smooth integration of normality, due to injury, disease, or degeneration.
Positron	Particle with same mass as electron but with unit positive charge; formed by interaction of very high energy rays (e.g. cosmic or hard γ) with matter and by certain artificial radioisotopes: very short survival, combines with any available negative electron, usually within 10^{-9} second of formation, liberating finally its annihilation radiation, of γ type.
Proportional counter	Correctly, an electronic counter operating at such differences of potential (between anode and cathode) that there is a nearly linear relation between the output pulse size and the total ionisation produced in the counter by one charged particle: thus possible, with care, to distinguish between different kinds and energy levels of incident particles, or to register only particles of over a chosen size or energy: useful in discrimination between the components of mixed radiation.
Proton	Single positive charged particle, of unit mass: thus is hydrogen ion $_1H^1$ (cf. deuteron $_1H^2$ α-particle or He nucleus $_2H^4$), or hydrogen atom minus one electron: constituent of atomic nucleus (nucleon) along with neutron: can undergo 'capture' (as slow neutrons) in lighter elements; producible by ionisation of hydrogen in discharge tube: acceleration to high energies (in linear accelerator, cyclotron, or Van der Graaff high voltage generator, e.g.) of frequent research value: biological and penetrant properties similar to those of other heavy positive particles, e.g. deuteron and α-particle, i.e. short range, high specific ionisation along short paths, easy 'stopping', high relative biological efficiency (p = 5; α = 20; γ, β, X = 1).
Radiation	Radiant energy; the form in which energy can be transferred from one point to another through space; emissions of energy outwards into space or surrounding medium, from a source.
Radiation sickness	Sudden distressing illness (raised temperature, loss of well-being, loss of appetite, nausea and vomiting) occurring few hours after exposure of body (either whole or a relatively large part) to penetrant radiation: as after radiotherapy, accidental high over-exposure: severity proportional to radiation dose: not usually seen unless more than 100 r (total body dose) has been absorbed; of itself not fatal.

Radiation syndrome (acute)	Syndrome (characteristic series of occurrences) of sudden, severe, possibly fatal illness commencing within a few hours or days (in milder cases) of total body irradiation by penetrant radiation, e.g. in atomic bomb casualties, accidental gross over-exposures, accidents in radio-therapy: includes firstly radiation sickness of severe and prolonged type, then progressive weakness, cessation of blood formation, haemorrhages (e.g. of gums, skin, gut) vomiting and diarrhoea, incapacitation and possibly death: recovery possible, but slow and uncertain; relapses due to infection likely in later weeks.
Radioactive series	Chain of isotopes (radionuclides) produced serially by successive α or β-decay processes in members of the series; due in effect to failure to attain stable energy levels of nucleus until formation of last (stable) member of radioactive series: three naturally occurring series are thorium, uranium and actinium (actinouranium) series; termed 4n, 4n + 2, 4n + 3 series respectively, where n is integer of atomic weight of any member of series: 4n + 1 series does not occur in nature, but now known to be artificially producible neptunium series; in state of equilibrium, the rate of disintegration of any member of series is paralleled by rate of formation from parent member: thus in uranium series, at equilibrium, for every curie of Ra (3.7×10^{10} dis/sec) there is a curie of all other members of series.
Radiodermatitis	Inflammation of skin following over-exposure to external radiation: usually applied to characteristic condition developing months or years after causative exposure(s), showing skin thinning, loss of hair, loss of pigment or patchy pigmentation, loss of elasticity, loss of finger-ridge (fingerprint) detail, patches of visible enlarged blood vessels, ridged nails, tapering fingers, frequently ulcers of easy production by injury but very slow healing, often showing areas of local thickening or wart formation (papillomas) some of which (about 10% cases) develop malignant or cancerous characteristics (flat or squamous cell epithelioma).
Radiotherapy	Use of ionising radiation in medical treatment to check or cure an abnormality of tissue growth or function: involves radiation injury to abnormal cells and immediate neighbour cells, but should avoid injury to normal cells as far as possible; hence use of high energy quanta or particles, radium, radon or other isotope inserts in affected tissue, crossed-beam irradiation, selective deposition of radioisotope in tissue concerned: very high dosages need to kill cells (2000 rep or higher).
Radiography	Production of an X or γ-ray photograph of an object (e.g. chest, bone, metal, etc.) to demonstrate density patterns of irradiated material, and show up internal structure, flaws, etc.: for metals, involves high-energy quanta and often prolonged exposure periods; in Industry important method of non-destructive testing or inspection: similarly in medicine.
Radioisotope	Radioactive isotope of an element, differing specifically from other nuclides of that element only by nuclear make-up, i.e. proton/neutron (mass) number, and radiation characteristics.

Radiosensitivity — Arbitrary index of apparent injurability of different types of cells, tissues or organs to similar radiation exposures: in general, increases with frequency of cell divisions in tissue, probably due to greater probability of ionisation effects on dividing nucleus at most vulnerable stage; thus higher in bone marrow, gonads, lymphnodes, mucous membranes, germinal layer of skin, than in muscle, bone cortex, fibrous tissues, brain and inert epidermis, in which cell division or replacement is restricted or nil: also higher in cancerous than normal tissues for same reason.

Radiotoxicity — Property possessed by most radioactive substances, if in adequate maintained concentration, of causing injury to living cells from absorption of their emitted radiation energy in the substance of the cell, and (probably) the physical, chemical and metabolic sequelae of such energy-transference; substance may therefore be radiotoxic in concentrations far below chemotoxic levels, or chemotoxi at concentrations below those causing injurious radiation energy dosage, (e.g. uranium).

Röntgen (r) — Correctly, unit of radiation energy absorption in air: "that quantity of X or γ-radiation such that the associated corpuscular emissions, fully absorbed in 1 cc. of dry air at 0°C and 760 mm Hg pressure, produces, in air, ions carrying 1 electrostatic unit of electricity of either sign": more simply, that amount of X or γ-radiation producing, in air, ionisation equivalent to 1 e.s.u. of electricity: customarily used as unit of radiation intensi or dosage; order of magnitude indicated by facts that (1) 'gamma background' radiation at sea level amounts to about .0001 r/day (.04 r/year, 3 r/lifetime), (2) 1 mg Ra (enclosed in $\frac{1}{2}$ mm thickness Pt to absorb α and β rays) causes a dose-rate, at 1 cm distance from point source, of 8.3 r/hour, (3) radiation amounting to 1 r/second, absorbed fully in 1 cc air, would maintain a current of 5.3×10^{-12} amperes, (4) average X-ray dose from diagnostic chest X-ray amounts to .2 r in volume exposed, (5) LD 50 for man, single total body exposure, is about 500 r.

The röntgen can be proven approximately equivalent to the following:-

1 e.s.u. ionisation electricity/cc. of air.
2×10^9 ion-pairs produced/cc of air.
1.6×10^{12} ion-pairs produced/gram of air or wet tissue
2 ion-pairs produced/cubic micron of wet tissue.
6.7×10^4 MeV energy absorbed/cc. of air.
5.2×10^7 MeV energy absorbed/gm. of air or wet tissue.
52 eV energy absorbed/cubic micron of tissue.
83 ergs energy absorbed/gm of air.
93 ergs energy absorbed/gm of wet tissue.

Hence milliröntgen (one thousandth röntgen, mr) and rhm (röntgen/hour/1 metre distance).

"REP" — "Röntgen-equivalent-physical": "that amount of any ionising radiation which produces energy absorption of 83 ergs/cc. of tissue is 1 rep": required as extension of röntgen unit (defined for X and γ radiation) to α, β or other ionising radiations: there is a slight discrepa in that 1 rep is equivalent to 1 r (X and γ) on the basis of energy absorption in air, but (due to effects of tissue composition on absorption) 1 r is equivalent to absorption of 93 ergs/gm of tissue, which is 93/83 or rep: in practice this discrepancy is usually ignored practical advantages in adopting rep as standard unit with complete equivalence to röntgen, even for tissu synonymous with equivalent-roentgen, tissue roentge roentgen equivalent.

Relative Biological Efficiency

(RBE): comparative index of injury-producing power of different radiations when administered in similar physical dosages to standardised biological test-medium: order of accuracy probably low, due to intrinsic difficulty in measurements throughout such work: most recent values give RBE's as follow:- X, γ, β = 1 (unity), α-rays = 20 (from 4-40), fast neutrons = 10, thermal neutrons (in effect, protons) = 5: differences in RBE, in spite of physically-equivalent dosage and energy absorption/unit mass, probably related to specific ionisation of different radiations in tissue, i.e. density of ion-pair production/unit length, e.g. micron of track, since there is probably an ion density threshold for tissue above which adverse effect becomes much more likely; RBE determined by large numbers of direct experiments on animal and plant tissues.

"REM"

"Roentgen-equivalent-man", originally "roentgen-equivalent-biological"; "that dose of any ionising radiation which, delivered to man or mammal, is biologically equivalent to the dose of 1 roentgen of X or γ-radiation" : biological-equivalence implies equal injury-producing power, thus 1 rep of α-radiation, of RBE 20, is equal to 20 rem; 1 rep fast neutrons (RBE 10) is 10 rem of fast neutrons, etc.: unit used to certain extent in U.S.A. but rarely in this country.

Sarcoma

Cancer originating in cells of connective tissues, e.g. bone, muscle, fibrous tissue, cartilage: example, causable by radioactive substances, is osteogenic sarcoma (q.v.).

Scintillation counter

Disintegration-counting device, originally comprising screen coated with compound emitting visible light photon when hit by particle, with light-flash detecting, amplifying and counting circuits: first used as 'spinthariscope': still widely used now in conjunction with photomultiplier tube (q.v.).

"Scaling unit"

Electronic circuit serving to record an elected fixed proportion of pulses fed into the circuit from e.g. a Geiger-Muller tube, especially where counting or disintegration-rate of sample is very high: scales vary from e.g. 1 in 10 upwards; most have choice of scale: needed since mechanical register for count-recording is limited to 50 counts/second or less, if loss of counts is to be avoided.

Shielding

Inert radiation absorbent material inserted between source of radiation and that which requires protection from otherwise high radiation dose-rate: type and thickness of material to be used depends upon absorption coefficient for particular type and energy of radiation, reduction factor required for dose-rate before and behind shield, mobility required, costs, and availability: for highly penetrant X and γ rays, lead, iron, concrete, barium plaster, bricks, aluminium, water are most generally useful (given in order of decreasing absorptive power): for neutrons, light elements must be provided, e.g. as in hydrocarbon waxes, paraffins, water: for β-rays even of fairly high energy, few millimetres of glass, lucite (plastic), aluminium, metal foil or sheet, will usually serve: for α-rays, full absorption occurs in almost any everyday material (paper, textiles, clothing, foils), even in very thin layers: major problems of shielding may be scattered radiation, induced radioactivity in material of shield, radiation-induced loss of texture, transparency (e.g. in ordinary or lead glass), flaws in density or structure, gaps for doors, controls or panels, and misuse.

Skin

Outer covering of mammalian body: three important layers (1) epidermis (stratum corneum), dead, flattened cell-layer, mainly protective in function, thickness varying from 20 to 1200 microns in different parts of body: (2) germinal layer, underlying inert epidermis; cells in active division, forming outer layers, hair follicles, sweat and sebaceous glands: (3) dermis, supportive layer of elastic fibres carrying blood vessels, nerve endings, fat cells: critical cells, as regards radiation damage, are germinal cells, since over-irradiation may induce in them malignant overgrowth.

Specific activity

Index of radioactivity of an element or substance, i.e. disintegrations/unit time/gm: directly proportional to decay rate, inversely proportional to half-life or mass per curie. Also, in tracer work, ratio of number of atoms of a radioisotope to total number of atoms of same element present in sample.

Specific ionisation

Number of ion-pairs formed per unit length of track of ionising radiation: usually ion-pairs formed/micron of path in tissue: probably most vital factor in quantitative aspects of cell or tissue injury: not confined to tracks in tissue, but also can refer to tracks in other media, e.g. air: for the same radiation specific ionisation is inversely proportional to energy, i.e. less energetic particles cause more ionisations/micron in their (shorter) paths than do higher energy particles in their own (longer) paths:-

Approximate specific ionisation in tissue.

β-rays	.45 MeV	10	ion-pairs/micron
	1.0 MeV	8	"
X-rays	30 - 180 KV	100	"
	1.0 MeV	15	"
γ-rays	2.0 MeV	11	"
α-rays	< 5.0 MeV	6000-8000	"
	5.3 MeV	4500	"
	5.5 MeV	3700	"

Spleen

Highly cellular organ in abdomen: functions include mainly blood cell formation and maintenance of blood normality: not in fact an essential organ of body (is removed for some conditions), but may well have special importance in connection with resistance to injury from penetrating radiation.

Synchroton

A particle accelerating device involving the principles of both betatron and cyclotron: electrons are projected into the orbit from a tungsten electron gun and accelerated in the betatron-type electromagnetic field: when peak betatron type acceleration is reached, cyclotron type acceleration continues, by application of a radiofrequency voltage to the 'dees'; protons have also been thus accelerated; <u>synchrocyclotron</u> is a further modification intended to provide greater acceleration, beyond the limits of the synchrotron's performance.

Target theory

Physical theory attempting to explain rationally some of the quantitative biological aspects of irradiation of single celled organisms, viruses, possibly genes and chromosomes: postulates hypothetical vital target, of calculable dimensions, present in a cell, which, if 'hit' by an ionisation, is destroyed, and with it, the entire cell: may well apply to certain responses in minute organisms and genes, but not easily applicable to multicellular tissues or organisms: forms one of the many theories which have been held on the mode of action of radiation ırget theory ·cont.)

on living systems: does cover fairly well all effects in which a linear relationship exists between energy absorption and % organisms killed or affected, but does not cover more characteristic non-linear responses (threshold responses) in higher organisms or systems.

.ter, .ctivated, theory of

Yet another theory on mode of action of radiation on biological systems: postulates (1) production of free hydrogen and hydroxyl radicles (H, OH) in water of cell protoplasm, by several related possible reactions between H-ions and water molecules, (2) inactivation of vital enzyme-controlled processes of cell by toxic action of these H and OH radicles: considerable experimental evidence in favour of both occurrences: serves to explain many typical 'threshold' responses of cells and tissues to radiation; brings ionising radiations' effects into line with existing opinions on mode of action of other toxic chemicals and agents: combined with target theory, provides reasonable basis for assumptions on mode of action on most systems, if used with some imagination.

·-rays

Electromagnetic quanta (photons) emitted in wave form when a stream of fast electrons hits the target anode in an X-ray tube: characteristics as for γ-rays, but of longer wavelength, therefore less energy and less powers of penetration: by increase of operating potential can however be brought up to energy and down to wavelength of γ-photons, therefore (under those conditions) identical with γ-rays: occur in certain nuclear reactions in radioactive isotopes, but otherwise entirely man-made.

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TS. 75/20 E.13

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Annex B

Fall out of Contamination from the Monte Bello Explosion: Firing Criteria.

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Part I The Main Issues

Part II Contamination due to fall out from atomic bomb explosions

Part III Criteria for acceptable wind conditions at time of firing.

Part IV Maximum permissible dosages to be taken by participating teams in Operation Hurricane (see TS 75/13)

Part V Estimates of "No risk" & "High risk" levels of contamination in the environment (T/P Report 17/51 [redacted])

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Annex E

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Fall-Out of Contamination From the

Monte-Bello Explosion: Criteria For Firing.

Part I. The Main Issues.

Part II. Contamination due to Fall-Out from Atomic Bomb Explosions.

Part III Criteria for acceptable Wind Conditions at Time of Firing.

Part IV Maximum permissible Dosages to be taken by participating Teams in Operation Hurricane.

Part V. Estimates of "No Risk" and "Slight Risk" Levels of Contamination on the Mainland.

FALL OUT OF CONTAMINATION FROM THE MONTE-BELLO EXPLOSION:

CRITERIA FOR SAFE FIRING

PART I. THE MAIN ISSUES

The atomic bomb which is to be exploded in the Monte-Bello Islands will be on a 1000-ton ship, in water of depth about 40 ft. The bomb will be slightly more powerful than the "nominal" bomb of 20 kiloton TNT equivalent.

The chief items for scientific test are

(a) the proper functioning of the weapon

(b) the contamination, blast and heat effects of the weapon.

A prime consideration governing the conduct of the trial is the necessity of avoiding risks to the health of people and animals on the Mainland and of personnel taking part in the trial, due to radioactivity.

In order to get photographic records of the explosion, the preferred choice for the time of day at which the bomb will be detonated is 7 a.m. - 9 a.m. During this two hour period, haze and shimmer are least, and excellent photographs can be taken.

The men nearest to the bomb at the moment of explosion will be the scientists at Main Base, about five miles south of the bomb. The rest of the Expedition will be several miles to the south of Main Base, the exact position depending on the winds and tides. The duty of the party at Main Base is to control the firing of the bomb and to make certain photographic and electronic measurements on the exploding bomb. A boat party, and an unmanned spare boat, will be standing-by, ready to evacuate the party and their records within half an hour of the explosion, back to one of the ships.

Radioactive contamination could be carried to Main Base either by winds or by water. Accordingly, the bomb will only be exploded if the winds are directed such that no significant radioactive spray or dust can be deposited on Main Base; and similarly, the bomb will only be exploded when the movement of water within half a mile of the target vessel is such that none of it can flow to within two miles of Main Base within two hours.

The winds and movements of water in the Monte-Bello Islands are such that on most days in October the safety of the scientists at Main Base can be guaranteed, and the Base itself, after the scientists have been evacuated, will not become contaminated. The landing-point for Main Base might become contaminated from the sea water running past, a day or two after the explosion.

The safety of the rest of the Expedition during the two hours after the explosion requires no further consideration, since the ships are to be several miles further up-wind than Main Base.

Within an hour of the bomb exploding, the ships of the Expedition, led by the Health Monitoring Ship (H.M.S. TRACKER), will slowly proceed back towards the islands. A continuous check will be made on air and water samples for contamination. No risks will be taken. The ships may have to anchor two or three miles south of Main Base and it may be necessary to wait a week or so before all instruments can be collected from the land near the explosion. Every movement of ships and personnel will be made under strict control of the Radiation Safety Officer. No purely British force has yet conducted an operation of this type; but United States Forces have done it successfully several times without exposing anybody to radiological damage, and nothing insuperable is foreseen in Operation Hurricane.

Turning now to the requirements on weather conditions at the Islands, in order to be sure that the health of no person or animal on the Mainland will be affected by radioactive material from the bomb, the following considerations apply. The explosion is intermediate in type to the underwater Bikini explosion and a ground burst explosion. Tens of thousands of tons of sea water and bottom sand will be thrown upwards through the fire-ball, but this material will not go higher than 5000 ft., except for a small fraction subsequently dragged up by the rising mushroom cloud. The water and sand will fall back, and will probably make a base surge. Because the air at the Islands is fairly dry, the residual mist will quickly dry out, leaving a few per cent. of the total radioactivity on salt crystals and dust, suspended in the air.

Within half a minute of detonation the mushroom cloud will begin to rise through the "chimney" inside the water column (see Part II); and after ten minutes the cloud will be at about 25,000 ft. The diameter will be about 4 miles and the depth about 1 mile. This cloud will contain approximately 40 per cent. of the total radioactivity of the bomb. A substantial part of the radioactivity will be contained in small spherical particles, mainly iron oxide, of diameter less than 20 microns. less than 20 microns.

In order to estimate the maximum possible contamination on the Mainland it is now assumed that the wind conditions are chosen to give the worst possible results ~~conditions~~, namely when the winds at all levels are blowing direct from the Islands to the Mainland. Making the pessimistic assumptions that all the radioactivity in the cloud is carried on larger particles, with radioactivity proportional to the area of the particle, and that the largest particles are just large enough to settle to the ground by the time they first reach the Mainland, (3 hours after the explosion), the estimated maximum contamination on the Mainland is still only about one percent ~~one-seventy fifth~~ of the dose which is cautiously estimated as possibly producing mild sickness. In order to meet the categorical assurances which we have given that the health of men and animals on the Mainland will not be affected, further elements of safety are introduced in the actual specification of acceptable wind conditions at the time of firing, and for the subsequent ten hours. The winds must be such that

(1) Any particle of size greater than 75 microns in diameter (density 2.25), released at any height up to 30,000 ft. over the Islands at the time of the explosion, will fall into the sea not nearer than 5 miles from the coast of the Mainland.

(2) No air up to 5000 ft. over the Islands at the time of the explosion will be carried over the Mainland within ten hours.

The safety of the ships and personnel of the Expedition imposes a third criterion on wind conditions at the time of firing

(3) No particles, of any size, released from any height up to 30,000 ft. over the Islands at the time of the explosion, must fall either
   (a) on the ships of the expedition within ten hours
   (b) on Main Base (H.1) within two hours.

The first of these conditions guarantees that nothing from the explosion can fall on the Mainland sooner than eight to ten hours after the explosion. The second condition ensures that no contamination, carried on dust or salt crystals remaining from the "crater material", is carried over the Mainland sooner than ten hours after the explosion. The third condition ensures the safety of the Expedition itself.

Provided conditions (1) and (2) are met, any radioactivity falling on the Mainland will be so thinly spread that there is categorically no possibility of the health of any person or animal being affected. 127

It is pertinent now to enquire how many days, at times between 7 a.m. and 9 a.m., radioactive air-borne particles. The scientist-in-charge will agree with the officer-in-charge what the course for each aircraft is to be, and the scientists in the planes will make continuous readings of the level of gamma activity. Six aircraft have been assigned to the group responsible for tracking the cloud and collecting air-samples, and they will fly in relays.

At the Air-Station where the cloud-tracking aircraft are based will be two further aircraft, fully equipped with continuously recording counting apparatus adapted from equipment used for aerial surveys for uranium. Each plane will carry one scientist. The aircraft will fly very close to the ground up and down the coast, in order to obtain for the Technical Director the evidence on which he can officially inform the Australian authorities that actual measurements have confirmed that no hazards to the health of men or animals exist on the Mainland.

PART II. CONTAMINATION DUE TO FALL-OUT FROM ATOMIC BOMB EXPLOSIONS.

Part II summarises what is known about the fall-out from atomic bomb explosions in varying circumstances, and gives special consideration to the Monte-Bello explosion.

An Air Burst Bomb.

When an atomic bomb explodes, the material of the bomb is vapourised. If the explosion is some hundreds of feet or more above the ground, the bomb vapour is contained in the "ball of fire". The ball of fire, which consists mainly of air, rapidly cools, because the heat escapes as radiation; and, in a few seconds, the temperature has fallen sufficiently for the bomb material to begin recondensing. The density of the condensing vapour, however, is very small, because the bomb material has been dispersed through a volume nearly the full size of the ball of fire. Consequently, the condensation process leads to a vast number of minute particles. These particles are usually at first liquid, and therefore have a spherical shape which is retained as the falling temperature changes them into solid form. The diameter of the particles varies much less than might have been expected. Few particles are less than 1 micron* in diameter; and few are larger than 20 microns.

Although the red-hot appearance of the fire-ball soon disappears, the air in the fire-ball retains a considerable amount of heat long after the luminosity has gone. This large ball of hot air may be regarded as a gigantic hot-air balloon, whose lifting power, or buoyancy, rapidly takes it upward. Unlike a real balloon, there is no fabric to prevent the gas inside mixing with the air outside. Consequently, the rising ball of hot air leaves some of its outer parts behind, mixed with cold air. This mixture contains some of the re-condensed bomb particles.

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* The "micron" is the standard scientific unit of length for small particles. It is one millionth part of a metre, or 10^{-4} centimetres.

The rise of the ball of hot air causes strong air currents. As the ball begins to rise, a "fire-wind" can be observed at ground level. Air rushes inwards from all directions, and the air currents, meeting at the centre, turn upwards, following the rising ball of hot air. The fire-wind carries with it great numbers of dust particles, some of which have been formed from the re-condensation of vapour from the surface layer of the soil, boiled by the heat of the fire-ball. The dark appearance of the lower parts of the "column" or "stem" in the typical photograph of an atomic explosion over land is due to dust and particles of re-condensed soil gathered by the fire-wind, and carried upwards in the currents following the rising hot air cloud. The upper part of the "stem" is less dark, and is mainly the wake of the cooling fire-ball cloud.

The initial lifting power, or buoyancy, of the ball of hot air produced by the explosion is great, and is of the order 300,000 tons for the nominal 20 kiloton atomic bomb.

As the ball of hot air rises higher and higher, cooling by radiation and adiabatic expansion occurs, and a great deal of mixing of the outer layers with cold air takes place. A height is eventually reached, usually in the stratosphere, some 30,000 - 50,000 ft. above sea level, where the density is the same as that of the surrounding air. The mass of air which has been carried up into the stratosphere contains water vapour, and this vapour condenses into a fog or mist of ice droplets, thus revealing the size of volume or cloud inside which is to be found most of the air which was near to the bomb when it exploded. The air inside this cloud is at first very turbulent, and due to the turbulence, the apparent size of the cloud increases for several minutes. Gradually the turbulence decreases, and thereafter, the cloud disperses much more slowly due to more normal meteorological processes. The horizontal diameter of the mushroom cloud after ten minutes for the nominal 20 kiloton bomb is about 4 miles, and the depth or thickness is about one mile to one and a half miles. The width of the stem varies with the "dustiness" of the soil and with the wind conditions; the width after ten minutes varies between $\frac{3}{4}$ mile and one mile.

The particles formed by the re-condensing atomic bomb material in the case of a bomb exploding several hundred feet above the ground are therefore almost all carried up into the stratosphere within a few minutes from the explosion. The only exceptions are those particles which are contained in air that is torn off the rising ball of hot air. These particles are left in the stem of the mushroom, and some of them collide with much larger dust particles and stick to them.

All of the air-borne particles thrown up or created as the result of the explosion at once begin to sediment towards the ground. The rate of fall is fairly fast for large particles but very slow for fine particles. The rate of fall of a solid particle of density $2\frac{1}{4}$ gm./c.c. and diameter D is shown by the following Table.

Table I

Terminal Velocity of Spherical Particle Density $2\frac{1}{4}$ gm./c.c.

Diameter D microns	Rate of Fall U_D Ft. per sec.	Diameter D microns	Rate of Fall U_D Ft. per sec.
5	0.00551	150	3.53
10	0.0220	200	5.45
20	0.0878	250	7.36
30	0.198	300	9.09
40	0.353	500	15.5
50	0.538	750	23.1
100	1.81	1000	30.2

As stated above, the particles of bomb-debris from an air-burst bomb have diameters between 1 and 20 microns. Even the largest particles take about a day to fall from the mushroom cloud to the ground. The smallest remain air-borne for weeks or even months.

A very small proportion of the particles of bomb debris, as also explained above, are left in the stem, and a few of these may stick to a much larger dust particle. The dust particles are usually large enough to fall to the ground again in a few minutes. Contamination of the ground will therefore result. The contamination will be found mainly on the ground directly beneath the bomb due both to fall-out and induced radioactivity but there will also be some fall-out contamination in a band downwind of initial width nearly one mile. The width of the band increases steadily with the distance from the explosion, and the intensity of contamination falls.

Careful surveys were made in Hiroshima and Nagasaki, three to four weeks after the atomic bomb explosions, to distances extending 10 miles from the centres, with the object of plotting the radioactivity deposited on or induced in the ground. It was concluded that 0.025 per cent. of the radioactive materials of the exploded bombs settled on the ground within half-mile circles below the bombs, and that possibly equal amounts settled in a strip of width one mile extending downwind for five miles. Even the most sensitive instruments could not detect anything above background three weeks after the explosion except in the ½ mile circles and the 1 mile x 5 mile downwind strips. The maximum contamination corresponded with a gamma dose rate one hour after the explosions of approximately

3 r per hour in Hiroshima
15 r per hour in Nagasaki.

It has been claimed several times by United States authorities that extensive medical tests made in the period 1 month - 1 year after the explosions on people who went into the central ½ mile contaminated circles shortly after the explosion, and stayed there for several weeks, showed that no harm was done to them by radio-activity. This evidence, although useful and probably correct, cannot be regarded as completely reliable, especially as regards long-term injury to the persons concerned, or to their progeny.

To sum up, it may be said that an atomic weapon burst sufficiently high in the air to prevent the ball of fire touching the ground deposits some contamination on the ground in a circle of half a mile radius, and in a band downwind to a distance of 3 - 10 miles, depending on the wind speed; but all areas are almost certainly completely safe again for permanent occupation a few days after the explosion. Absolute certainty of complete safety, however, can only be achieved as the result of a careful scientific survey which gives satisfactory results. Instruments for surveys of this type are obviously a necessary part of the paraphernalia of civil defence in atomic war.

Bomb Near or On the Ground

The fire-ball from the nominal 20 kiloton bomb exploding in air reaches about 300 yards in radius. If the nominal bomb is nearer than 300 yards to the ground when it explodes, the fire-ball touches the ground and the ground is heavily contaminated. The facts, as far as they are known in the United Kingdom, indicate that the nominal bomb exploding 300 yards above the ground deposits about 0.2 per cent. of the fission products and unexploded fissile material in the melted surface of the soil inside a circle of radius 400 yards, while a bomb exploded 100 ft. above the ground deposits about 1 per cent. in the same circle. The degree of contamination outside the 400 yard circle, either in the immediate vicinity or at distances 10-20 miles downwind, varies enormously with the soil conditions, especially with the soil conditions over the central circle of radius 100-200 yards. When a test explosion of an atomic bomb on a tower is being staged, the surface of the soil over the central 100 yards should be "stabilized". This procedure greatly reduces the amount of dust thrown into the air, and also greatly reduces the contamination, especially in the first few miles downwind.

The nominal bomb exploded on or just above the ground (up to 300 ft.), will vapourise approximately 100 tons of ground. The bomb products and the vapourised ground re-condense within 5 seconds into particles of diameter between 1 and 20 microns. While the particles are being formed, and for the next minute or so, hundreds, or even thousands, of tons of soil are projected through the fire-ball. Whether this vast quantity of soil breaks up into its individual particles or not depends on the nature of the soil. A dry sandy or volcanic soil would probably break up into its individual particles; a wet clay would not.

Consider first the case of a dry dusty soil. Within a few seconds of the explosion of the bomb, there are approximately 100 tons of 1-20 micron particles in the fire-ball, and approximately 1000 tons of soil, broken up into individual particles, either in or above the fire-ball. The updraft of the fire-ball sweeps nearly everything up to 30,000 ft., except for the spill-off at the edges of the rising cloud, revealed by the stem. The individual particles of soil will have a range of sizes, but as a rule, there will be practically nothing smaller than 100 microns diameter and nothing larger than 1000 microns diameter.

The 100 micron particles fall at 2 ft./sec., and the 1000 micron particles fall at 30-40 ft. per second. Most of the soil thrown up into the air by the bomb therefore returns to the ground within an hour of the explosion; and probably 99.9 per cent. of the soil, not vapourised but thrown up by the explosion, reaches the ground again within 4 hours. If the bomb explodes on the ground, reasonable assumptions for estimating ground contamination are that 20 per cent. of the bomb debris becomes attached to these soil particles, and all the particles return back to earth again within 4 hours. If the bomb explodes so that the fire-ball just touches the ground, the assumptions may be made that 5 per cent. of the bomb debris becomes attached to soil particles and these particles fall-out in four hours.

Most of the bomb debris is to be found in the mushroom cloud in the particles of 1-20 microns diameter, formed as the vapourised soil re-condenses. The larger particles fall back to earth in a day or two; but the smallest remain high up in the air for weeks.

Consider now an explosion on or near the ground, when the ground is clay or rock. The main difference from the case of dusty soil considered above is that the soil thrown up by the force of the explosion will not readily break up into its individual particles. Thus the 100 tons of "fines" will still be formed, but the 1000 tons of soil thrown up into and through the fire-ball will not produce a great dust stem. Most of the soil in this 1000 tons will fall back to earth again in a few minutes. Some dust, of course, will be formed, and this dust will fall out in a few hours, but the "fines", carrying at least 90 per cent. of the bomb debris, will remain air-borne for days or even weeks.

Thus, an explosion near or on the ground, on clay or rock, will cause about the same contamination within about one mile of the explosion as a similar explosion on dry dusty fine soil; but the contamination at distances 1 mile - 20 miles downwind will be at least one order of magnitude less.

Bomb Below the Ground.

The description given above of the fall-out from the dust cloud formed by an atomic bomb exploding on the ground applies with little modification to a bomb exploding in the ground below ground level. A nominal bomb would vapourise several thousand tons of soil, and project tens of thousands of tons of soil upwards and slightly outwards from the centre. If the bomb were within 10 ft. of the surface, in dry dusty soil, a substantial part of the bomb debris would be contained in re-condensed "fines". It would be reasonable to suppose that one half of the radioactive material would be taken up into the mushroom cloud as "fines" and the other half condensed as soil particles largely to be found in the stem. If the soil were clay, there would be more "fines" and less dust. Most of the clay thrown up would fall back to earth again without being broken up into the individual particles.

If the nominal bomb were exploded 50 ft. or more below ground in dry dusty soil, a heavily dust-laden mushroom cloud and stem would form. As far as is known in the United Kingdom, an assumption which roughly agrees with the facts is that 20 per cent. of the radioactivity is carried on "fines" remaining air-borne for a week, while the remainder is carried on the individual soil particles. The pattern of the fall-out can be guessed approximately by assuming that 20 per cent. of the activity is carried on dust particles in the stem and 60 per cent. on dust particles in the mushroom cloud. The distribution of particle sizes is that of the soil.

A nominal bomb exploding at 50 ft. depth would give an air-blast about equal to that of 5000 tons of TNT exploding. The lifting power of the ball of hot air produced by this explosion is about 50,000 tons. The explosion throws approximately 100,000 tons of soil into the air. Thus the lifting power of the explosion is not enough to carry the soil upwards. Provided the soil is dry and dusty, and therefore separates into individual particles when flung into the air, the dust cloud thrown into the air will settle again and form a <u>Base Surge</u>. When this happens, three-quarters of the radioactivity of the bomb products collapses in a dust cloud which rapidly spreads over the ground. The remaining one-quarter remains mainly as "fines" in the mushroom cloud, at height 6000-10000 ft.

Explosions On or In Water

There are a great many variations in points of detail for explosions on or in water; and although it is possible to make reasonable predictions about any particular case which is closely defined, it is not possible here to do more than sketch the factors that have to be taken into account. The results which are obtained from the Monte-Bello trial will add greatly to our knowledge.

The water may be fresh (e.g. river, reservoir) or salt (sea). The water may be deep, or it may be shallow. If the water is shallow (say less than 100 ft. if the bomb is near the surface, and less than 200 ft. if the bomb is at least 100 ft. down) the nature of the bottom, especially the particle size, is important.

The only experiment so far made was that of a nearly "nominal" bomb, the second bomb, at Bikini. The bomb was exploded fairly well down in 200 ft. of water. About 150,000 tons of water and also a few thousand tons of calcareous sand were thrown in the air. The maximum height to which the water column rose was 5000 ft. The air blast was about equal to that of 5000 tons of TNT, and the lifting power of the hot-air ball was about 50,000 tons. The "water" thrown up was thrown in such a way that it gathered into a curtain of spray only a hundred feet thick, of radius 1000 ft. and of height 5000 ft. The hot air ball, containing a lot of steam and possibly 10 per cent. of the radioactivity, rose up the "chimney" inside this curtain of water spray, and emerged from the top and billowed out into the cauliflower cloud. Meanwhile, the cylindrical curtain of water spray began to collapse back on to the sea practically as if it were a single dense gas. The initial size of the water drops in the spray must have ranged from a few microns diameter up to large drops.

Mathematical arguments show that if the air is humid as at Bikini, most of the water and salt collects into large drops and falls on to the sea again within ten minutes. If the air is relatively dry, by no means all the water and salt will aggregate into large drops and fall on to the sea. The last 25 per cent. of the water will evaporate, leaving salt crystals, containing radioactivity from the bomb, of diameters 10-200 microns.

The depth of water in the Monte Bello trial will be about 35-40 ft., and the bomb will be exploded a few feet lower than the water surface. The air blast will be approximately the same as that of 12-15 kilotons TNT exploded on the ground. About 30,000 tons of water, and possibly an equal amount of bottom sand will be thrown into the air, in a cylindrical curtain or sheath as at Bikini, 5000 ft. high, 1000 ft. outer radius and one hundred feet thick. The hot air ball will have a buoyancy of nearly 200,000 tons. Most of the buoyancy will be located inside the water and sand curtain, but some will be found outside. The position is therefore extremely complicated. The hot air ball inside the water curtain will rise rapidly, the water curtain itself will fall, and the hot air near the sea just outside the water curtain will rise. A small base surge is expected, but the main feature within a few minutes will be a fully developed mushroom cloud and stem.

The water first thrown up by the explosion moves upwards and outwards, with velocity of the order 10,000 ft. per second. The rising water begins to quench part of the fire-ball and a great deal of steam is produced, but the rest of the fire-ball is unaffected and remains luminous. The shape of the residual fire-ball is strange - an inverted conical region with a cross section something like the Prince of Wales' plume. However, the luminosity of this residual fire-ball will not be apparent to observers at ground level because it will become hidden by the rising curtain of water, which is at the same time quenching part of the fire-ball. All luminosity will be hidden from observers at ground level within approximately one quarter of a second.

The rising curtain of water, and later on, of water and bottom sand, gradually develops to its full size, and probably contains at least half of the total radioactivity. Most of the water and sand in the curtain falls back into the sea, probably as a base surge. The residual "mist" will dry out, leaving some radioactivity in small salt crystals or dust, ranging in size from 10 microns up to possibly 200 microns.

That part of the fire-ball not swept by the rising water contains iron and bomb vapour which re-condenses into fine particles. The fire-ball rises up through the central chimney of the water curtain, and in doing so creates turbulence and turbulent mixing. When it emerges from the top of the "chimney", it will increase in width, and almost at once look like the normal rising "atomic" cloud. By the time the cloud reaches its maximum height of about 25,000 ft., it will have a considerable diameter and depth (4 miles x 1½ miles, judging from Bikini and other U.S. experiments). The radioactivity will be found in a wide range of particle sizes. An appreciable part of the activity will be contained in particles of re-condensed steel, of diameters 1-20 microns, but there will also be a lot of radioactivity caught on salt crystals, on pulverised calcareous sand particles, on ice crystals, etc. These particles will probably range up to three hundred microns diameter or more.

Summarising, a reasonable prediction for conditions ten minutes after the explosion is that there will be a large mushroom cloud 4 miles diameter and 1 mile deep, at a height of about 25,000 ft.; a stem, about $\frac{1}{2}$ mile diameter; and a misty cloud, rapidly drying out, about 1000 ft. high and one mile radius. Approximately 40 per cent. of the radioactivity will be in the mushroom cloud, 2 or 3 per cent. in the stem mostly on large particles, 5-10 per cent. in the low drying mist, and the rest in the sea or on the land.

PART III CRITERIA FOR ACCEPTABLE WIND CONDITIONS AT TIME OF FIRING

Part III considers the fall out from the mushroom cloud and from the stem with relation to contamination of the Mainland, assuming the worst possible wind conditions. Guided by the numerical results obtained and by the principles of the mathematical arguments, stringent criteria are postulated for deciding whether wind conditions are suitable or not for exploding the bomb.

The essential points in the mathematical arguments are

(a) The mushroom cloud starts at about 4 miles diameter (Bikini measurements)

(b) The mushroom cloud contains about 40 per cent. of the radioactivity due to the bomb. Some, possibly as much as one half, of the radioactivity is contained in very small particles of re-condensed ship and bomb. These particles will be at most 20 microns diameter, and even the largest will not settle for two or three days. We can ignore the deposition of contamination from these particles. The rest of the activity will be in the same type of particle, attached to much larger particles of salt, sand, ice, etc. Because the particle size distribution is not known, certain pessimistic assumptions have to be made, namely that the whole of the radioactivity is contained on these larger particles, and that the fall-out only starts and is worst at the nearest point on the Mainland.

(c) Not more than 5 per cent. of the radioactivity is left in the stem above 5000 ft. of initial width at least $\frac{1}{2}$ mile.

(d) All of the rest of the activity (about 50 per cent.) is trapped in the "water column" and most of this falls back into the sea. An unknown proportion of the contaminated water evaporates and leaves small contaminated salt crystals, suspended in the air.

The Mushroom Cloud

The following arguments are admittedly far from exact, but they are physically reasonable. Their sole purpose is to give the order of magnitude of the expected contamination on the Mainland, in the worst possible wind conditions.

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Let $f(D)dD$ be the fraction of the total number of particles whose diameter is between D and D + dD.

Then

$$1 = \int_{D_0}^{D_1} f(D)dD \qquad (1)$$

where D_0 is the diameter of the minimum particle and D_1 is the diameter of the largest particle.

Make the reasonable assumption that the radioactive content of the particle is proportional to the area of the particle. Then

Activity of particle = $k D^2$, where k is a constant.

The total activity of all particles A is given by

$$A = \int_{D_0}^{D_1} k D^2 f(D)\, dD \qquad (2)$$

Now make the assumption that

$$f(D) = \frac{N}{D} \qquad (3)$$

where N is a constant.

Substitution (3) in (1) we get

$$1 = N \log D_1/D_0$$

and therefore

$$N = 1/\log(D_1/D_0).$$

Furthermore, from (2) we get

$$A = \tfrac{1}{2} k D_1{}^2/\log(D_1/D_0),$$

provided we neglect $D_0{}^2$ compared with $D_1{}^2$.

The activity carried by particles of diameter between D and D + dD is therefore

$$\frac{2A}{D_1{}^2 D} dD$$

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Suppose that we take the very worst case where the wind is strong, is the same at all levels and is blowing straight from the islands to the Mainland, distance 50 miles. Combined with this most unfavourable supposition, let us assume that the cloud contains no particles of diameter greater than 120 microns and that the first particles are just reaching the ground when they first pass on to the Mainland.

The time of fall T of a particle is proportional to $1/D^2$.

Let

$$T = \frac{p}{D^2}\text{, where } p \text{ is a constant.}$$

Then we know that T = 3 hours for D = 120 microns.

Hence

$$T = 1.5 \times 10^8/D^2 .$$

The wind speed V is obviously such that the air travels 50 miles in 3 hours, and is therefore 24 ft./sec.

A particle of diameter D + dD will come to ground a time $2p\,dD/D^3$ before a particle of diameter D, and in this time the wind has moved a distance dX where

$$dX = 2pV\,dD/D^3.$$

The concentration of activity per unit length of the contaminated strip is therefore

$$\frac{A\,D^2}{p\,V\,D_1^{\,2}}$$

This concentration of course is spread over the whole width of the strip. The width at 50 miles is about 8 miles and at 200 miles is 16 miles.

The most serious contamination is where the particles first reach the ground. To estimate this, we substitute the numerical values quoted earlier, namely

$$D = D_1 = 120 \text{ microns} \qquad V = 24 \text{ ft./sec.}$$

$$p = 1.5 \times 10^8 \text{ secs./micron}^2.$$

The concentration per foot run of the contaminated band is 3×10^{-10} A. Since the band is 8 miles across, the contamination is 7×10^{-15} A per ft.^{2}.

Now A is about 40 per cent. of the total radioactivity left by an exploding bomb (namely $10^{10}\ t^{-1.2}$ curies)

Substituting this value, we get the maximum concentration as $2.8 \times 10^{-5}\ t^{-1.2}$ curies per ft.^{2}, or

$$3 \times 10^{-4}\ t^{-1.2} \text{ curies per metre}^2.$$

After a careful assessment of the risks of fission products and plutonium deposited on the Mainland, it has been concluded that there is no plutonium risk at all, but that pessimistically the fission product risk might just cause temporary mild sickness if the level were

$$4 \times 10^{-2}\ t^{-1.2} \text{ curies per metre}^2.$$

The contamination estimated when circumstances are very unfavourable (wind very unfavourable; particle size distribution very unfavourable) is therefore 133 times less than that which on extremely cautious estimates might conceivably just cause mild sickness.

Admittedly, a hill might cause a local increase of concentration, probably by a factor 3 or 4. Again, our assumptions on the distribution of particle size do not give a concentrated distribution and to be on the safe side we might allow an extra factor of 10. On the other hand, we have allowed nothing for wind shear (something which always appears to be present near the Islands) and we have assumed that nothing falls out from the cloud until it just reaches the Mainland.

The wind conditions envisaged in the above discussion are idealized and in practice will almost certainly be much more complicated. The problem now arises of framing the criterion for judging whether the wind conditions are acceptable for firing without danger to the Mainland. The arguments above give a strong indication that only in the extreme case where the mushroom cloud is quickly swept off to the Mainland and where the particle sizes are unfavourable will the contamination ever approach within an order of magnitude of the mild sickness dose. However, the arguments although strong, are not considered sufficiently certain for considerations of Health Physics.

An important feature of the arguments was that the smaller a particle is, the longer time it takes to fall, and therefore, other things being equal, the smallest particles, when they reach the ground, are spread thinnest per unit length of the contaminated band. We are guided by this principle and frame our criteria on wind conditions in such a way that all particles with a reasonable time of fall from the mushroom cloud must fall in the sea. The remainder (if there are any) stay suspended in the air for such a long time that when they do reach the ground, the level of contamination is minute compared with the acceptable concentration.

The criterion proposed for deciding whether the wind conditions are acceptable for the activity carried in the mushroom cloud is that "wind conditions in the vicinity of the Islands must be such that any particle of size greater than 75 microns in diameter, released at any height up to 30,000 ft. over the Islands at the time of the explosion must fall in the sea not nearer than 5 miles from the coast of the Mainland".

The Stem.

The stem is initially about ½ mile wide, and stretches from the misty cloud near the sea to the base of the mushroom cloud, at 20,000 - 30,000 ft. The stem above 5000 ft., the height of the "water column", contains little radioactivity, but as a safe assumption, the radioactive contents may be taken as 5 per cent. of the total. It is easy to see that the contamination on the Mainland due to the particles from the stem above 5000 ft., in the idealized example of the previous sub-section, is less than that from the mushroom cloud.

The criterion to be used on the wind conditions at the time of firing for the mushroom cloud is stringent enough to cover at the same time the radioactivity in the stem, with the possible exception of the lowest 5000 ft. The following sub-section deals with the lowest 5000 ft. of the stem.

The Lowest 5000 ft. of the Stem.

The "water column" will be about ⅓ mile wide, and will probably collapse on to the sea as a base surge. The "water column" will not be higher than 5000 ft. The column will contain about one half of the radioactivity. Although plausible guesses can be made about the subsequent movement of the radioactivity, depending on the particle size distributions, etc., it is impossible to be certain what will happen. Therefore, it is necessary to be cautious in regard to the Health Physics aspects.

The following criterion on wind conditions at the time of firing will be employed.

"The wind conditions at the time of firing in the vicinity of the islands must be such that no air over the islands up to a height of 5000 ft. must be carried over the Mainland within twelve hours".

Summary

Two conditions must be satisfied before wind conditions in the vicinity of the Islands are to be considered suitable for firing, in order to keep the contamination of the Mainland to acceptable levels.

(1) Any particle of size greater than 75 microns in diameter (density 2.25), released at any height up to 30,000 ft. over the Islands at the time of the explosion, must fall into the sea not nearer than 5 miles from the coast of the Mainland.

(2) No air up to 5000 ft. over the Islands at the time of the explosion must be carried over the Mainland within ten hours.

The safety of the ships and personnel of the expedition require the following wind conditions at the time of firing

(3) No particles, of any size, released from any height up to 30,000 ft. over the Islands at the time of the explosion, must fall either

(a) on the ships of the expedition within ten hours

(b) on Main Base (H.1) within two hours.

PART IV. MAXIMUM PERMISSIBLE DOSAGES TO BE TAKEN BY PARTICIPATING TEAMS IN OPERATION HURRICANE

The maximum permissible dosages which are to be allowed in varying circumstances for Operation Hurricane are described in the following official minute from [redacted] Under Secretary Establishments in the Ministry of Supply.

U.S.(E.O.)

Operation Hurricane - Radiation Dosage

In the absence of precedent and of any statutory regulations on the subject it is necessary to ask for official acceptance, both by the Ministry of Supply and by the Admiralty of the maximum permissible dosages of ionising radiation which it is proposed to adopt in Operation Hurricane.

In framing our proposals, outlined below, we have been guided by data given and recommendations made in recent papers of the Medical Research Council (P.A.B.E.26 and P.A.B.E.39 - copies attached) in which this problem has been considered in detail, with particular reference to Civil Defence Operations. Due allowance is made for the fact that Hurricane is essentially a peace-time operation and that it will be possible to carry out the work under accurately known conditions and under strict control of experienced Radiation Safety Officers.

The effects of beta and gamma radiation are regarded as completely additive. In the case of beta radiation however, only the face and neck will be exposed, the remainder of the body being completely covered by suitable protective clothing.

Apart from accidental injuries the problem of internal radiation will not arise, since gas-masks will be worn for all operations which involve exposure to any airborne hazard. They will be worn automatically in the first instance until such time as measurements prove that their general use is unnecessary.

Approval is sought for the use of a set of three dosage levels to be applied under various conditions, these levels being:-

(1) An intermittent or continuous dosage up to 0.1 r/day of gamma-radiation (together with an accompanying beta-radiation of up to 1.2 rep/day on 10 per cent. of the body surface, which is

taken as equivalent to 0.12 rep/day whole body).

This is the normal working limit which will be applied generally and it is estimated that it will be possible to carry out the greater part of the operation under these normal conditions.

(2) An integrated dose, received in one or a few exposures, of up to 3 r. of gamma-radiation (accompanying beta 36 rep). This may be applied in a limited number of cases where necessary to ensure the smooth running of the operation and will require the express permission of the Radiation Safety Officer. Personnel receiving such a dose will not be subjected to any further exposure during the remainder of the operation. It is considered that under these conditions such a dose is innocuous.

(3) An integrated dose of 10 r. of gamma-radiation (accompanying beta 150 rep). This may be applied only in cases of extreme urgency, in order to recover vital records that might otherwise be lost, and will require the express personal permission of the Commander of the Operation who will have expert medical and radiological advice at hand. Personnel receiving such a dose will not be subjected to further exposure for a minimum period of 12 months. It will be noted from the M.R.C. Report Table I that the risk involved by this exposure is very slight.

Finally it should be noted that all personnel who are to be subject to any of these levels will undergo a pre-exposure medical examination and no person will be allowed to accept the radiation exposure until the Medical Officer has approved him as fit for such work.

PART V. ESTIMATES OF "NO RISK" AND "SLIGHT RISK LEVELS OF CONTAMINATION ON THE MAINLAND

The general question of the maximum permissible ground contamination of populated areas due to fall-out following an atomic bomb explosion is one which has received little detailed attention hitherto. An attempt will be made in the following paragraphs to make a quantitative assessment of the problem with particular reference to the circumstances of Operation Hurricane.

The main sources of hazard arising from the deposition of fission products and unfissioned material following an explosion will be as follows:-

External Hazards

(a) Whole-body beta and gamma-irradiation by fission products deposited on ground, buildings, clothing, etc.

(b) Local beta-irradiation of tissue from fission products deposited directly on the skin of human beings and animals.

Internal Hazards

(c) Direct deposition of fission products and unfissioned material in sources of drinking water - reservoirs, rivers, water-tanks, etc.

(d) Indirect deposition in drinking water via the ground, by subsequent drainage, etc.

(e) Direct deposition on human food, crops, fruit, etc.

(f) Deposition on animal foodstuffs (grass, etc.) with consequent possibility of damage to the animal and ultimately to the human being who eats it.

(g) Inhalation while the material is still airborne, i.e. before it settles out.

(h) Inhalation of active dust which may be stirred up from the ground.

(i) Injection into the blood-stream by way of cuts, wounds, etc.

It is necessary first to decide on the maximum permissible radiation exposure levels to be adopted as a basis for calculation.

(a) External whole-body radiation

The problem of whole-body irradiation from mixed fission products is complicated by the presence of considerable beta, as well as gamma, radiation. From data calculated by [redacted] the relative beta to gamma dosages in roentgens at three feet from the ground are in the ratio of 40 to I. In northern climates where considerable 147 clothing is worn most of the beta rays may be stopped before they reach the body, but in a hot climate it must be assumed that the clothing offers little or no protection against beta rays of these energies. It is therefo clear that the beta radiation is the limiting factor. Two distinct levels may be considered:-

(i) A level at which there is absolutely no risk of any kind: 6 rep (roentgen equivalent physical).
This represents a month's dose at the continuous level of 1.5 rep/week accepted throughout the working life of radiation workers.(2)

(ii) A level at which there is a risk of some temporary sickness in a small proportion of persons exposed - but no lasting damage.
50 rep.(3)

The accompanying gamma radiation we can take to be 0.3 r. and 2.5 r. respectively. This is obtained by taking the above ratio of 40 to 1 and introducing a factor of 2 to allow for some absorption in dust etc., some protection from clothing, and a decrease in dosage with height above the ground.

(b) Local beta-irradiation of the skin

It is generally accepted that higher doses can be delivered to small areas of the body than to the whole body, the permissible dose being inversely proportional to the area exposed. If as a worst case, we assume that fission products are deposited on 50 per cent. of the body then the dosages corresponding to zero risk and risk of temporary sickness are 12 rep. and 100 rep. respectively.

(c) Internally deposited Pu 239

The maximum permissible amount of Pu^{239} fixed in the body is considered to be 0.04 μc.(2). This, however, is for occupational groups, and the M.R.C. hold the opinion that, in view of the danger, even at the normally accepted levels, of an increase in the natural rate of genetic mutations in man, a further factor of 100 should be applied where large populations are concerned.(5) Where small groups only are involved the precaution is considered unnecessary but in this case, where marriage outside the local community may be rare, it may be wise to include it . The figure adopted 148 therefore is

$$0.0004\ \mu c. \quad \text{or } 0.0064\ \mu g.$$

Owing to the long-term nature of the hazard and the fact that the Pu once fixed is never significantly eliminated, there can be no question here of degress of exposure or any acceptance of a risk of some temporary sickness.

(d) Ingested fission products

The main danger lies in the semi-permanent retention in the body of harmful amounts of the longer-lived beta-emitting fission products. Calculations indicate that a total ingestion of 3 millicurie of 1 hour fission products would represent a completely safe dose. These calculations, based on known fission yields and various biological factors(4), show that from this amount of mixed products the following amounts of the most dangerous isotopes would be retained in the various vital organs:-

Sr^{90}	0.0001 μc
Sr^{89}	0.015 μc
Ba^{140}	0.09 μc
I^{131}	0.3 μc

The maximum amounts laid down(2) are Sr^{90} - 1 μc., Sr^{89} - 2 μc., I^{131} - 0.3 μc.; nothing is laid down for Ba^{140} which has the same biological factors as Sr^{89} but a much shorter half-life. We therefore see that the amounts corresponding to a total ingestion of 3 millicurie are within the recommended maxima. The strontium figures also include the "general population" factor of 100, recommended by the M.R.C. for the long-lived isotopes.(5). The limiting case is I^{131}. Iodine however goes only to the thyroid and is short-lived. Furthermore the figure is laid down for a maintained burden. The amounts of I^{131} used therapeutically without causing radiation sickness of any sort are of the order of 100 millicuries. We might therefore reasonably accept an increase in our total fission product ingestion figure to 30 millicuries giving retention figures of

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Sr^{90}	0.001 μc.
Sr^{89}	0.15 μc.
Ba^{140}	0.9 μc.
I^{131}	3.0 μc.

In view of the relatively large dose likely to be received by the intestines prior to the excretion of the major part of the fission products, this higher figure of 30 millicuries total ingestion should be regarded as coming into the "slight risk of temporary sickness" category. It is of interest to note that the 50 per cent. lethal dose for ingested fission products has been quoted as being of the order of 7 curies.

(e) Inhaled fission products

Owing to the greater retention (25 per cent.) in the case of inhalation, and to the added danger of beta-irradiation of the lungs before the active material has been dispersed to the various sites of deposition, it is considered that the levels for "zero risk" and for "slight risk of temporary sickness" are 0.1 mc. and 1.0 mc. of 1 hour fission production respectively. The resultant retention of the more dangerous isotopes would be:-

	0.1 mc. level	1.0 mc. level
Sr^{90}	0.00001 μc.	0.0001 μc.
Sr^{89}	0.001 μc.	0.01 μc.
Ba^{140}	0.01 μc.	0.1 μc.
I^{131}	0.005 μc.	0.05 μc.

All these amounts are far below those permitted by the I.C.R.P. The limit, however, is set by the beta-irradiation of the lungs. It has been estimated(6) that 1 mc. of 12 hour fission products retained by inhalation will result in an integrated dose to the lungs of up to 20 rep. The dose from 1 mc. of 1 hr. fission products will be slightly less than this because of more rapid decay, and that from 0.1 mc. will be less again by a factor of 10. (It should be noted that a total inhalation figure of about 2 curies has been suggested as the 50 per cent. lethal dose). Having established the above maximum permissible exposures we can now apply them to the various cases assimilated above.

Whole body beta and gamma-irradiation from deposited fission products

The maximum permissible contamination in this case will clearly depend on the time at which the exposure starts. We will consider exposures that start at $2\frac{1}{2}$, 5, 10 and 20 hrs. respectively: for the purposes of calculation we will assume that all exposures continue to infinity (the major part of the dose, in any case, is received within a matter of days) and for comparative purposes we will express all results in terms of 1 hr. fission products.

For the "zero risk" dose, that is 0.3 r. gamma (plus the accompanying beta as given ~~under 15(a)~~ above) the gamma dose rates at 1 hr. for the four exposure times are as follows:-

$2\frac{1}{2}$ hrs.	0.075 r/hr.
5 hrs.	0.083 r/hr.
10 hrs.	0.097 r/hr.
20 hrs.	0.11 r/hr.

Now a contamination of 1000 curies/sq. mile is required to give a dose rate of 0.1 r/day or 0.004 r/hr. Therefore the contaminations of 1 hr. fission products necessary to give us 0.3 r. for the exposure times under consideration are :-

$0.7 \times 10^4 \mu c/m^2$

$0.78 \times 10^4 \mu c/m^2$

$0.91 \times 10^4 \mu c/m^2$

$1.04 \times 10^4 \mu c/m^2$

respectively.

For the "slight risk of temporary sickness" category (2.5 r. gamma plus 50 rep beta) all the above figures can be increased by a factor of eight, giving:-

$0.6 \times 10^5 \mu c/m^2$

$0.65 \times 10^5 \mu c/m^2$

$0.76 \times 10^5 \mu c/m^2$

$0.87 \times 10^5 \mu c/m^2$

Local beta-irradiation of the skin from directly deposited fission products

Here again the time of the exposure is important. We will consider 24 hr. exposures (a period after which most deposited material would be either washed off or worn off) commencing, as before, at $2\frac{1}{2}$, 5, 10 and 20 hours after the explosion.

For the "zero risk" dose of 12 rep we require the following dose rates at 1 hr.

$2\frac{1}{2}$ hrs. - $26\frac{1}{2}$ hrs.	7.5 r/hr.
5 hrs. - 29 hrs.	11.0 r/hr.
10 hrs. - 34 hrs.	17.0 r/hr.
20 hrs. - 44 hrs.	30.0 r/hr.

Using data given by [redacted](1) it is found that 113 beta particles/cm^2/sec. of average energy 0.8 Mev. will produce a dose-rate of 12.5 mr/hr. Therefore to produce an integrated dose of 12 rep the following contaminations in terms of 1 hr. fission products are required:-

Exposure beginning at -

$2\frac{1}{2}$ hrs.	1.8×10^4 $\mu c/m^2$
5 hrs.	1.0×10^5 $\mu c/m^2$
10 hrs.	1.5×10^5 $\mu c/m^2$
20 hrs.	2.7×10^5 $\mu c/m^2$

For the "slight risk of temporary sickness" category we can again increase these figures by a factor of 8, giving :-

Exposure beginning at -

$2\frac{1}{2}$ hrs.	1.5×10^5 $\mu c/m^2$
5 hrs.	8.3×10^5 $\mu c/m^2$
10 hrs.	1.25×10^6 $\mu c/m^2$

Direct deposition of Pu^{239} and fission products in drinking water

Let us assume that a one-thousand gallon water tank serving a homestead of 10 people is contaminated. The maximum permissible amounts of material to be ingested are:-

Pu^{239} - 0.4 μc. (assuming 0.1% absorption)(2)

1 hr. fission products 3 mc. (zero risk)

30 mc. (slight risk of temporary sickness)

If the surface area of the tank is 5 m^2 and the 10 persons drink an equal share, the maximum permissible contaminations are:-

Pu^{239} - 0.8 $\mu c/m^2$

1 hr. fission products 6×10^3, 6×10^4 $\mu c/m^2$

Indirect deposition in drinking water by drainage over the years

Let us assume that over a period of 70 years all the surface contamination is gradually drained away by the rain and appears uniformly over that period in drinking water supplies. Let us also assume that the rainfall over that period averages 12 inches a year, i.e. 840 inches total (and let us allow 25% for evaporation), so that the total volume of water per square metre is 1.6×10^7 ccs. The 70 year drinking water tolerance for Pu (I.C.R.P. 1950) is $1.5 \times 10^{-3} \mu c/cc.$, giving us a maximum permissible contamination of

$$0.24 \mu c/m^2$$

The only fission product to be considered in this case is Sr^{90} (half-life 25 years). The long term drinking water tolerance for Sr^{90} is $8 \times 10^{-9} \mu c/cc.$, so that the maximum contamination would be $0.075 \mu c/m^2$, corresponding to

$$5 \times 10^5 \mu c/m^2$$

Deposition on human foodstuffs

It is difficult here to devise a suitably realistic case. Let us imagine a fruit tree with a total spread of 2 metres radius, and that one-fifth of the contamination falling on it falls on the fruit as opposed to the leaves and branches and that one tenth of the fruit is eventually eaten by the same person without being washed. Using the same maximum permissible ingestions as before we find that our maximum permissible contaminations are

Pu^{239} - $1.7 \mu c/m^2$

1 hr. fission products - $1.3 \times 10^4 \mu c/m^2$ (zero risk)

$1.3 \times 10^5 \mu c/m^2$ (slight risk of temporary sickness)

Deposition on animal foodstuffs

This particular problem is exceedingly difficult to assess. There are two aspects: on the one hand there is the possibility of effects on humans who eat the animals, and on the other hand there is the possibility of effects on the animals themselves, which is important in districts where man's livelihood depends on the breeding of livestock. In considering the animals themselves it seems fair to ignore any factor which has been included for humans merely to guard against any increase in genetic mutations: this increase is, in any case, calculated to be exceedingly small and would be completely insignificant amongst a population of animals. The figure we will use therefore for total ingestion of Pu^{239} is

$$40\ \mu c.$$

It also seems fair to enter the region of "slight risk" in the case of fission products and to increase the total ingestion figure up to

$$100\ mc.$$

This is still only about 2 per cent. of the quoted 50 per cent. lethal dose. Only a small percentage of these amounts will, as we have seen, be absorbed from the animals' intestines, and only a small proportion - say 10 per cent. - of this might end up in edible parts of the animal; allowing also for man's own excretion it is found that the body burden retained by a man who eats, over a period of time, one whole contaminated animal would be small compared to the permissible figures and we need have no concern on that account.

Now suppose that the animal eats contaminated vegetation weighing about 300 lb. If every piece of this vegetation could be laid out flat on the ground, the total would cover about 100 m^2. This vegetation when growing would probably take up 10,000 m^2 of ground, but to be on the safe side, assume that it grows on only 1000 m^2.

When the contaminated particles are settling, a very small proportion will touch the vegetation and stick. Since the vegetation, when imagined laid out flat, covers only 100 m^2, it is inconceivable that even one particle in 100 falling on the ground sticks to the vegetation. Taking this figure, we deduce that the animal will ingest 100 mc. if the contaminations ~~were~~ are

$$Pu^{239} \quad - \quad 0.04\ \mu c/m^2$$

$$1 \text{ hr. fission products} - 10^4\ \mu c/m^2.$$

<u>Inhalation while particles are still airborne</u>

Suppose that we have a cloud of unfissioned material or fission products which is 500 metres deep, settling out uniformly over a given area over a period of 1 hour, so that anyone in that area is breathing in radioactive material for 1 hour. Assuming a breathing rate of 1 m^3/hr. and 25 per cent. retention, and using the maximum permissible amounts previously quoted, we have as our maximum permissible air concentrations :-

Indirect deposition in drinking water by drainage over the years

Let us assume that over a period of 70 years all the surface contamination is gradually drained away by the rain and appears uniformly over that period in drinking water supplies. Let us also assume that the rainfall over that period averages 12 inches a year, i.e. 840 inches total (and let us allow 25% for evaporation), so that the total volume of water per square metre is 1.6×10^7 ccs. The 70 year drinking water tolerance for Pu (I.C.R.P.1950) is $1.5 \times 10^{-3} \mu c/cc.$, giving us a maximum permissible contamination of

$$0.24 \mu c/m^2$$

The only fission product to be considered in this case is Sr^{90} (half-life 25 years). The long term drinking water tolerance for Sr^{90} is $8 \times 10^{-9} \mu c/cc.$, so that the maximum contamination would be $0.075 \mu c/m^2$, corresponding to

$$5 \times 10^5 \mu c/m^2$$

Deposition on human foodstuffs

It is difficult here to devise a suitably realistic case. Let us imagine a fruit tree with a total spread of 2 metres radius, and that one-fifth of the contamination falling on it falls on the fruit as opposed to the leaves and branches and that one tenth of the fruit is eventually eaten by the same person without being washed. Using the same maximum permissible ingestions as before we find that our maximum permissible contaminations are

Pu^{239} - $1.7 \mu c/m^2$

1 hr. fission products - $1.3 \times 10^4 \mu c/m^2$ (zero risk)

$1.3 \times 10^5 \mu c/m^2$ (slight risk of temporary sickness)

Deposition on animal foodstuffs

This particular problem is exceedingly difficult to assess. There are two aspects: on the one hand there is the possibility of effects on humans who eat the animals, and on the other hand there is the possibility of effects on the animals themselves, which is important in districts where man's livelihood depends on the breeding of livestock. In considering the animals themselves it seems fair to ignore any factor which has been included for humans merely to guard against any increase in genetic mutations: this increase is, in any case, calculated to be exceedingly small and would be

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completely insignificant amongst a population of animals. The figure we will use therefore for total ingestion of Pu^{239} is

$$40 \ \mu c.$$

It also seems fair to enter the region of "slight risk" in the case of fission products and to increase the total ingestion figure up to

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This is still only about 2 per cent. of the quoted 50 per cent. lethal dose. Only a small percentage of these amounts will, as we have seen, be absorbed from the animals' intestines, and only a small proportion - say 10 per cent. - of this might end up in edible parts of the animal; allowing also for man's own excretion it is found that the body burden retained by a man who eats, over a period of time, one whole contaminated animal would be small compared to the permissible figures and we need have no concern on that account.

Now suppose that the animal eats contaminated vegetation weighing about 300 lb. If every piece of this vegetation could be laid out flat on the ground, the total would cover about 100 m^2. This vegetation when growing would probably take up 10,000 m^2 of ground, but to be on the safe side, assume that it grows on only 1000 m^2.

When the contaminated particles are settling, a very small proportion will touch the vegetation and stick. Since the vegetation, when imagined laid out flat, covers only 100 m^2, it is inconceivable that even one particle in 100 falling on the ground sticks to the vegetation. Taking this figure, we deduce that the animal will ingest 100 mc. if the contaminations ~~were~~ are

$$Pu^{239} \quad - \quad 0.04 \ \mu c/m^2$$

$$1 \text{ hr. fission products} - 10^4 \ \mu c/m^2.$$

<u>Inhalation while particles are still airborne</u>

Suppose that we have a cloud of unfissioned material or fission products which is 500 metres deep, settling out uniformly over a given area over a period of 1 hour, so that anyone in that area is breathing in radioactive material for 1 hour. Assuming a breathing rate of 1 m^3/hr. and 25 per cent. retention, and using the maximum permissible amounts previously quoted, we have as our maximum permissible air concentrations :- 156

Pu^{239} 0.0004 $\mu c/m^3$

1 hr. fission products 0.1 mc/m^3 (zero risk)

1.0 mc/m^3 (slight risk of temporary sickness)

We can thus imagine a column 500 m. in height and of one m^2 cross-section settling out over one m^2 of ground and containing the above concentrations. This will eventually give us maximum permissible ground concentrations of

Pu^{239} 0.2 $\mu c/m^2$

1 hr. fission products $5 \times 10^4 \mu c/m^2$ (zero risk)

$5 \times 10^5 \mu c/m^2$ (slight risk of temporary sickness)

Inhalation of stirred-up dust

We can make use here of the results of the trials carried out by the Home Office and A.E.R.E.(6), which show that the air concentration per cubic metre produced by the disturbance of dust (by shovelling, clearance of debris; etc.) in a contaminated area, was a fraction of 2×10^{-6} of the contamination per sq. metre of ground.

Pu^{239} is the most dangerous possibility in this case and to be entirely safe we should assume indefinite exposure to disturbed airborne dust (e.g., this covers the case of a man who spends most of his life on horseback). The long-term maximum permissible breathing concentration for Pu^{239} is

$$2 \times 10^{-12} \mu c/cc.$$

or $$2 \times 10^{-6} \mu c/m^3$$

Using the above-quoted results this would correspond to a maximum permissible ground contamination of

$$1 \mu c/m^2$$

In the case of fission products the hazard will not be so long-lived. If we take a continuous exposure to disturbed dust of 6 months as the worst possible case and neglect any radioactive decay we find that the maximum permissible air concentrations are

5×10^{-5} mc/m^3 (zero risk)

5×10^{-4} mc/m^3 (slight risk of temporary sickness)

and the corresponding ground concentrations

$2.5 \times 10^4 \mu c/m^2$

$2.5 \times 10^5 \mu c/m^2$

Injection into the blood-stream through cuts, etc.

Ignoring direct deposition, let us consider a man falling over on contaminated ground and all the active material from, say, 10 cm^2 entering a scratch or wound and passing into his bloodstream.

The maximum amounts he should absorb by direct injection are

Pu^{239}	0.0004 μc.
1 hr. fission products	0.1 mc.

Our maximum permissible contaminations are therefore

Pu^{239}	0.4 $\mu c/m^2$.
1 hr. fission products	1×10^5 $\mu c/m^2$.

Hazards from Pu^{239}

Hazard	Max. permissible contamination in $\mu c/m^2$	Corresponding conc. of 1 hr.f.ps. based on estimate of relative amounts present. $\mu c/m^2$	$\mu g/m^2$
Direct deposition in drinking water	0.8	1.2×10^7	2.0
Indirect deposition in drinking water over years	0.24	3.5×10^6	0.5
Direct deposition on human foodstuffs	1.7	2.5×10^7	4.1
Deposition on animal foodstuffs	0.004	5.8×10^5	0.1
Inhalation of cloud before settling out	0.2	2.9×10^6	0.5
Inhalation of stirred-up dust	1.0	1.4×10^7	2.6
Injection into cuts etc.	0.4	5.8×10^6	1.0

Hazard	Maximum permissible contamination of 1 hr.f.ps.			
	$\mu c/m^2$		$\mu g/m^2$	
	zero risk	slight risk	zero risk	slight risk
Whole body beta and gamma radiation *	0.7×10^4	0.6×10^5	1.2×10^{-3}	1×10^{-2}
Local beta-irradiation of skin *	1.8×10^4	1.5×10^5	3×10^{-3}	2.6×10^{-2}
Direct deposition in drinking water	6×10^3	6×10^4	1×10^{-3}	1×10^{-2}
Indirect deposition in drinking water over years	5×10^5	-	8.0×10^{-2}	-
Direct deposition on human foodstuffs	1.3×10^4	1.3×10^5	2.2×10^{-3}	2.2×10^{-2}
Direct deposition on animal foodstuffs	-	1×10^4	-	1.7×10^{-5}
Inhalation of cloud before settling out	5×10^4	5×10^5	8.0×10^{-3}	8.0×10^{-2}
Inhalation of stirred-up dust	2.5×10^4	2.5×10^5	4.0×10^{-3}	4.0×10^{-2}
Injection into cuts, etc.	1×10^5	-	1.7×10^{-2}	-

* Figs. given are for exposures beginning at $2\frac{1}{2}$ hrs. as representing the worst case.

It can be seen at a glance that the concentrations of fission products corresponding to all the permissible contaminations of Pu are so far in excess of the limiting cases for the fission products themselves that we need consider the problem of the Pu no further.

Discussion

(a) It would appear to be a simple matter, once the acceptable degree of risk has been decided upon, to accept the lowest figure in the above tables as the maximum permissible contamination without further discussion. There are certain factors, however, that cannot be overlooked:-

(i) Many of the calculations concerning the ingestion and inhalation hazards are, of necessity, guesswork and tend, if anything, to over-estimate the hazard.

(ii) Certain hazards such as the direct deposition of activity in drinking water could be avoided by taking protective measures before the event. 159

(iii) Others, the longer-term ones, could be checked and dealt with, if necessary, by evacuation of limited areas after the event.

(iv) All the hazards described may well be additive, i.e. one individual may be exposed to all of them.

(b) The limiting case on paper for "slight risk" is the deposition on animal foodstuffs

$$1 \times 10^4 \ \mu c/m^2$$

(c) With (b) might be bracketted the "zero risk" figures for direct deposition on drinking water for humans in an uncovered tank in the open air, namely

$$6 \times 10^3 \ \mu c/m^2.$$

(d) At about $1 \times 10^4 \mu c/m^2$ we have the "zero risk" figures for whole body external beta-gamma radiation for local beta-irradiation of the skin, and for direct deposition on human foodstuffs. The former irradiation is inescapable and cannot be argued about: the figure of $10^4 \ \mu c/m^2$ is, of course, for "zero risk" and can be increased by a factor of eight before it comes into the "slight risk of temporary sicknes[s]" category, but in countenancing such an increase it is necessary to rememb[er] that we are now accumulating quite a number of hazards, the effect of all of which will be additive.

(e) It is time now to make some specific recommendations. It is suggested that -

(i) <u>$6 \times 10^3 \mu c/m^2$</u> would involve no risk at all.

(ii) <u>$4 \times 10^4 \mu c/m^2$</u> would probably involve zero risk but where an individual was exposed to more than one hazard at a time, the additivity of the effect would carry him into the "risk of temporary sickness" category.

(iii) Any significant increase in the figure of $4 \times 10^4 \mu c/m^2$ must be assumed to involve a risk of lasting or at least unpleasant injury and cannot be regarded as acceptable.

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References

(1) A.E.R.E. HP/R/551

(2) Recommendations of the International Congress of Radiological Physics - 1950

(3) Medical Research Council paper PABE 36.

(4) Radiology - September, 1947

(5) Medical Research Council paper NP/P/TD/148

(6) A.E.R.E. HP/R/737

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[redacted] T.P. Report 17/51

The Possibility of Radioactive Contamination of the Australian Mainland as a result of Operation Hurricane

002009.

by [redacted]

(with appendices by [redacted] and [redacted] and [redacted].

Summary [redacted]

If the wind comes from directions between W. and N.E. (through N), radioactive contamination may reach the Australian mainland in sufficient concentration to give some risk of injury to the civilian population. However the danger is not likely to be great and can be reduced to small proportions by taking precautions to ensure that:-

(a) Food and drink are protected from atmospheric dust so as not to be contaminated.

(b) The area of fall out is delineated as soon as possible.

Any area contaminated in this way will be of small extent and the number of people concerned in any special arrangements will be small.

At the time of year envisaged there may be a high frequency of winds from these directions and it may not prove practicable to choose a day for firing when there is no risk at all of significant contamination being deposited on the mainland.

January, 1952.

* Air Ministry, Meteorological Office.

/ Royal Naval Weather Service.

[redacted]

1. The Problem.

2. The Explosion.

3. Rate of Fall of Particles.

4. Contamination deposited on the ground.

5. Effect of the assumptions made.

6. Numerical values for the contamination.

7. Conclusions and Recommendations.
References.
Acknowledgements.

Appendix A. Note on Wind Frequency by [redacted].

Appendix B. Some notes on North West Australia by [redacted].

Appendix C. An assessment of the Meteorological Factors in the problem of Fall-out over the Australian mainland by [redacted].

Appendix D. The Products to be expected from the Explosion by [redacted]

Appendix E. The maximum permissible ground contamination of populated areas by [redacted]

Appendix F. Monitoring of the mainland by [redacted].

1. The Problem

It is proposed to explode an atomic bomb in a ship in shallow water at a point 47 nautical miles from the Australian mainland. If the wind comes from directions between W. and N.E. (through N.) some radioactive fission products will be deposited on the mainland. A note on the frequency of such winds is given in Appendix A. It is the purpose of this report to estimate the amount of contamination that could be produced in this way and to assess the hazard to the population of these regions. A brief account of the economic geography of the parts of the mainland which may be reached by the contamination is given in Appendix B.

2. The Explosion

We have no information about the spread of fission products when an atomic bomb is detonated on the surface of the ground or on the surface of the sea. It is in fact one of the objects of the experiment to fill to some extent this gap in our knowledge. At the Bikini experiments it was observed that a burst high in the air gave rise to a mushroom cloud which spread upwards to the tropopause before being dispersed by the wind. It is believed that the fission products were deposited on finely divided, condensed metal particles which were carried upwards by the mushroom cloud and dispersed. These particles fell so slowly that they were scattered over a wide area and so the fission products they carried presented no hazard anywhere. On the other hand an underwater explosion produced a column of spray about 2,000 ft. in diameter and 2,000 ft. high surmounted by a large mushroom head reaching to a height of about 8,000 ft. The column and mushroom consisted of small water droplets so numerous that in falling they dragged the air down with them, forming a "base surge" which deposited nearly all the fission products over an area of a few square miles.

Shortly after the detonation in the ship one would expect a ball of fire to be formed which would be partly below the surface of the water and partly above and would contain as vapour much of the ship, all the components of the bomb and some seawater. There is no obvious reason why most of this ball of fire should not rise to the tropopause eventually as happened after the Bikini air burst. As it cooled the ~~steel~~ metal vapour would condense out but would be expected to form such small particles that their fall out would constitute no hazard. Any water vapour which condensed would evaporate again before it could reach the mainland. As the explosion developed, a great amount of spray would be thrown up together with some sand from the sea bed and bits of ship that had not vapourised. Much of this would be in particles large enough to fall out long before they could reach the mainland. However there would almost certainly be some sea water and sand etc. thrown up to intermediate heights which might well be such that it could carry fission products to the mainland if the wind were suitable. The water would almost certainly evaporate on the way but, being sea water, there would be a particle of salt remaining which could still carry the fission products originally in the water drop.

From these ideas the following distribution of the fission products was suggested by [redacted]. A cloud would rise to the tropopause carrying, let us say, 60% of the fission products, deposited on finely divided condensed metal particles. These products would be distributed over such a wide area that the radioactive contamination produced by them would be negligible. A large amount of spray would be thrown up but would settle fairly quickly taking, say, 30% of the fission products. The remaining 10% of the fission products would be carried on solid particles of salt and sand etc. and on water droplets which, to fix the ideas, let us say would be distributed in a column of about 1,000 metres diameter. It is this 10% of the fission products which could be deposited on the mainland.

Such a picture seems physically reasonable and will be used to estimate what could be deposited on the mainland. It will certainly not give the worst conceivable contamination, as it must be borne in mind that the final answer may be in error either way. We will therefore confine our attention to the column containing 10% of the fission products.

3. Rate of fall of particles

falling, drag the air with them. We would [illegible] surge which would spread the contamination over an area of a few square miles only and would not reach the mainland. If however the particles were more dispersed they would fall relative to the air and would also be carried along with the wind. Their rate of fall relative to the air would be, to a close approximation, equal to their terminal velocity. Best (1950) has examined the terminal velocities of water droplets in air which he finds fall as rigid spheres if they are less than [illegible] mm. in diameter. From his results, making a rough estimate of the appropriate air density to use and knowing that terminal velocities of small spherical particles are very nearly proportional to their density, we can deduce a relation between the particle diameter D and its falling velocity U_D *. The results are given in Table I which has been calculated for a particle density of 2¼ grms/cc. - an approximate mean density for sand and salt particles.

Table I

Terminal Velocities
of sperical particles of density 2¼ grms/cc.

D microns	U_D ft/sec.	D microns	U_D ft/sec.
5	0.00551	200	5.45
10	0.0220	250	7.36
20	0.0878	300	9.09
30	0.198	500	15.5
40	0.353	750	23.1
50	0.538	1000	30.2
100	1.81		
150	3.53		

Particles of diameter D falling from a height h will take a time h/U_D to reach the ground. If the mean wind to height h is V_h the particles will have travelled a horizontal distance

$$R = hV_h/U_D \tag{3.1}$$

Table II gives a few corresponding values of h and V_h for different D, based on the U_D given in Table I, for values of R of 50 and 200 nautical miles, and for various mean wind speeds.

Table II

[illegible] Heights of Fall of Particles (= h)

R = 50 nautical miles

Heights in feet

Mean Wind to height h V_h (knots)	Time of fall (seconds)	Particle Diameter D				
		20 u	30 u	50 u	100 u	200 u
5	36,000	3,100	7,200	19,000	[illegible]	-
10	18,000	1,600	3,600	9,700	33,000	-
15	12,000	1,100	2,400	6,500	22,000	-
20	9,000	790	1,800	4,900	16,000	49,000
25	7,200	630	1,400	3,900	13,000	39,000
30	6,000	530	1,200	3,200	11,000	33,000
40	4,500	-	890	2,400	8,100	25,000
50	3,600	-	720	1,900	6,500	20,000

* See top of Page 3.

[redacted]

* It is not possible to give an accurate value of the terminal velocity because of the probably complex shape of the particles. The accuracy of the figures in Table I should, however, be quite adequate for our purpose.

** These heights are calculated from the falling velocities given in Table I and so do not accurately take into account the variation of air density with height. However, the error from this cause should not exceed about 10%.

R = 200 nautical miles

TABLE II (contd.)

Mean Wind to height h V_h (knots)	Time of fall (seconds)	Particle Diameter D			
		20 u	30 u	50 u	100 u
5	144,000	13,000	29,000	-	-
10	72,000	6,300	14,000	39,000	-
15	48,000	4,200	9,500	26,000	-
20	36,000	3,100	7,200	19,000	-
25	28,800	2,500	5,700	15,000	52,000
30	24,000	2,100	4,800	13,000	43,000
40	18,000	1,600	3,600	9,700	33,000
50	14,400	1,300	2,900	7,700	26,000

The figures in the body of the tables are values of the height (h) in feet.

It will be seen from these tables that particles of not unreasonable size can fall on the mainland at distances between 50 and 200 nautical miles by starting from heights which the column may well reach.

4. Contamination deposited on the ground ≠

We will assume that the fission products carried in the column are spread evenly in height between the surface and the top of the column and that particles at any given height are all of the same size. We shall discuss these assumptions again in section 5.

Suppose that the particles from a height h are deposited at a distance R downwind. Then

$$hV_h = R\,U_D \qquad (4.1)$$

where V_h is the mean wind to height h and U_D is the falling velocity of the particles.

[redacted] (1950) have shown that if a number of air trajectories are followed in the atmosphere starting from a given point during an interval of time T, the scalar standard deviation (along a particular direction) of their end points after a given time is σ, where

$$\sigma = AR^a \qquad (4.2)$$

R being the mean distance of the end points from the source and A and a being constants which obey the following empirical laws.

a = 0.875 on the average but may differ from this value, being smaller when small-scale eddies are the more common and larger when large-scale eddies are the more common. It is reasonable, in our problem, to take 'a' between 0.75 and 1.00. Also

$$A = 0.51\,T^{0.31}\,(a/0.875)^{-b} \qquad (4.3)$$

where T is measured in hours and the unit of length is the centimetre.

b is a constant which varies with height, a reasonable mean value for our problem being 4.5.

≠ The analysis in this section was originally developed by [redacted]

In order to apply these ideas to the dispersion of the column by the wind we can think of each point on the lee side of the column as a source of contamination which emits for a time T, where T is the time taken for a particle moving with the wind to traverse the column. In order to calculate the amount of contamination at a distance of 50 miles or more we can think of the column as compressed into a plane sheet lying along the direction of the wind. The error arising from this procedure is only a few per cent. Because of the finite cross-wind width of the column, however, the maximum contamination will in fact occur over a strip of width comparable with the width of the column.

On the ground therefore, the cross-wind profile of the contamination deposited will have a flat peak, nearly constant over a width of about 750 metres, and will fall away outside this zone, reaching about 1/10 of its peak value at a distance 2.15σ from the centre.

Using the assumption that the fission products are evenly distributed in height throughout the column, and supposing that the particle sizes are such that the products deposited at a distance R all come from the same height in the column*, then the contamination at distance R is greatest when all the fission products in the column are deposited at distances no greater than R. This contamination at distance R is then the same as if there were the same total deposition, per unit length down-wind, at all distances less than R from the source. So if Ⓗ is the total contamination carried by the column the peak contamination per unit area at distance R is given by

$$\phi = \frac{Ⓗ}{\sigma\sqrt{2\pi}} \times \frac{1}{R} \qquad (4.4)$$

Inserting numerical values we get the results given in Table III.

TABLE III

Values of ϕ/Ⓗ

R = 50 nautical miles

Wind Speed (knots)	T (hrs.)	a	A	σ (metres)	2.15σ (metres)	ϕ/Ⓗ (per sq.metre)
10	0.054	0.75	0.41	690	1,500	6.1×10^{-9}
10	0.054	0.875	0.21	2,600	5,600	1.7×10^{-9}
10	0.054	1.00	0.11	10,500	22,000	4.1×10^{-10}
20	0.027	0.75	0.33	560	1,200	7.6×10^{-9}
20	0.027	0.~~0~~875	0.17	2,100	4,500	2.1×10^{-9}
20	0.027	1.00	0.09	8,500	18,000	5.1×10^{-10}

R = 200 nautical miles

Wind Speed (knots)	T (hrs.)	a	A	σ (metres)	2.15σ (metres)	ϕ/Ⓗ (per sq.metre)
10	0.054	0.075	0.41	2,000	4,200	5.4×10^{-10}
10	0.054	0.875	0.21	8,700	19,000	1.3×10^{-10}
10	0.054	1.00	0.11	42,000	88,000	2.6×10^{-11}
20	0.027	0.75	0.33	1,600	3,400	6.7×10^{-10}
20	0.027	0.875	0.17	7,100	15,000	1.6×10^{-10}
20	0.027	1.00	0.09	34,000	72,000	3.2×10^{-11}

* This assumption is discussed fully in section 5.

[redacted]

These values of $\phi/(H)$ are however average values and there may be local variations in the deposition due to the topography of the ground. Particularly favourable places for a local increase of contamination are on the windward slope of high ground, and a little distance to the lee of it. The township of Roebourne* appears from the map to be so situated, and here the contamination may reach 5 to 10 times the average value.

5. Effect of the assumptions made

The contaminations represented by the last columns of table III are a first estimate of those against which precautions should be taken. However these figures have been obtained by means of a number of assumptions. The first, and perhaps most sweeping, assumption is that set out in section 2, reducing the resultant contamination by a factor 10. It may well be argued that with the uncertainty attached to this initial picture we should not make any further allowance for factors which would reduce the values of $\phi/(H)$ given in table III. Putting this aspect on one side, however, there are a number of other assumptions we have made.

In the first place we assumed the fission products were evenly distributed in height throughout the column. This may not be so and the effect of different distributions would be in general to increase the highest possible contamination, though reducing the chance that it would actually occur.

We have also assumed that particles at any given height are all of the same size. This will not be true although it may be that a narrow range of sizes is dominant. If there is a spectrum of sizes our assumption that the products deposited at a distance R all come from the same height will not be true and some of the finer particles will be carried to distances greater than R while the larger particles will fall out quickly. Thus the assumption of the same total deposition per unit length downwind will not hold, the total deposition now decreasing with distance from the source. The net result will be to decrease the highest calculated contaminations at the distances we have in mind. Without knowledge of the spectrum of sizes it is not possible to calculate a figure for this reduction but it is suggested that an estimated factor of 10 is of the right order.

In addition, when there is a spectrum of particle sizes, there will be a further factor of reduction caused by the variation of wind with height. As is shown in Appendix C, a factor 5 would be reasonable to allow for this effect. Such a wind shear would also increase the width of the contaminated zone by a factor of 5.

Altogether, therefore, if the fission products are evenly distributed in height in the initial column, we have a total factor of reduction 50, which allowing for the factor 10 suggested in section 2 for the fraction of products carried by the column, means that in table III (H) should be the total contamination produced by the explosion reduced by a factor 500. An independent estimate of this factor is given in Appendix C, which is in close agreement.

Although the value 0.875 for 'a' is probably a good average, the value of 'a' on any particular day may be quite likely near one of the extremes given in table III. That is to say that if we take the value of $\phi/(H)$ corresponding to $a = 0.875$ we may well be in error by a factor of 4 or 5 in either direction.

Bearing in mind all these uncertainties therefore, it is suggested that we use the values of $\phi/(H)$ for $a = 0.875$ together with the reduction factor 500 to calculate values of contamination to be used for the purpose of planning the precautions to take. In addition allowance should be made for topographical effects which may increase the contamination in some limited areas. The final figures will not be expected to prove very accurate and, as has been discussed above, may prove to be too low or too high, perhaps by a factor of 10.

6. Numerical values for the contamination

(H) is now defined as the total contamination produced by the explosion

* 100 nautical miles away to the E.S.E.

[redacted]

reduced by the factor 500 determined in the previous section. In Appendix D an estimate is made of this contamination which leads to the result that

$$(H) = 0.74 \text{ curies of plutonium and } 1.8 \times 10^{7}\, t^{-1.2} \text{ curies of fission products} \quad (6.1)$$

where t is the time after the explosion in hours.

Inserting these values in table III for a = 0.875 we have the following results:-

TABLE IV

Contamination which may be deposited

Wind speed (knots)	Distance R from explosion (nautical miles)	Contamination ϕ	
		fission products (μcuries/m^2)	plutonium (μcuries/m^2)
10	50	$3.0 \times 10^{4} t^{-1.2}$	1.3×10^{-3}
20	50	$3.8 \times 10^{4} t^{-1.2}$	1.6×10^{-3}
10	200	$2.4 \times 10^{3} t^{-1.2}$	9.6×10^{-5}
20	200	$3.0 \times 10^{3} t^{-1.2}$	1.2×10^{-4}

In Appendix E are given estimates of the maximum ground contaminations which it is suggested might be permitted on the Australian mainland. The conclusion is that we need not consider the plutonium risk and that, provided drinking water supplies are covered over, a contamination of $4 \times 10^{4} t^{-1.2}$ microcuries of fission products per square metre would involve a risk of no more than a slight chance of temporary sickness, but that any significant increase in this figure involves a risk of lasting or, at least, unpleasant injury. It is instructive therefore to express the figures in table IV in units of this contamination.

TABLE V

* Contamination which may be deposited in units of suggested maximum permissible contamination

Wind speed (knots)	Distance R from explosion (nautical miles)	Contamination deposited (in units of suggested maximum permissible)
10	50	0.75
20	50	0.95
10	200	0.06
20	200	0.08

* Allowing for topographical effects the contamination at Roebourne, for example, could be as high, or a little higher than that quoted for R = 50 nautical miles.

7. Conclusions and Recommendations

The discussion of the preceding sections and the figures given in table V show that there will be some risk to the civilian population, but provided that simple precautions are taken the risk should be small.

The risk would be removed, of course, if the firing took place at a time when the wind was in such a direction as to carry the products away from the mainland. In view however of the fact that in some years there is a high

[redacted]

frequency of winds towards the mainland in September and October as is shown in Appendix A, such a solution may not prove to be a practicable possibility.

We may assume therefore that there is a possibility of significant contamination being deposited on the mainland, though Table V indicates that the danger is not likely to extend beyond a distance of about 200 nautical miles. It is therefore recommended that precautions on the following lines be taken:-

(a) People within 200 nautical miles of the explosion should be warned to cover food and drink and not to partake of any that has been exposed to the air after the time of firing until they have been assured that it is safe to do so.

(b) An organisation should be set up to determine where any fall out has occurred and measure its intensity. They would then delineate any dangerous areas and take necessary action if any unforeseen circumstance should arise. A possible organisation of this type is described in more detail in Appendix F.

References

[redacted] Met. Soc. Vol. 76 p.302.
[redacted] (1950) Air Ministry M.R.P.573

Acknowledgements

I am indebted to [redacted] and [redacted] for much helpful discussion during the p[redacted]ation of this report.

[redacted]

APPENDIX 'A'

Note on Wind Frequency

by [redacted]

The upper winds at Onslow observed by pilot balloons have been summarised in Australia for two years and are published in R.A.A.F. Publication No. 252 Vol.II Part 11, page 29. In addition the winds observed at the Island during September and October, 1951, have been analysed. There are some important differences. The Onslow winds show predominantly directions from between W.S.W. and E.N.E. (through W. and N.) at 10,000 feet. On the other hand the 1951 data show a considerable frequency of winds from Easterly and Southerly directions at 10,000 feet and below, as is shown in Table I. A comparative table of the Onslow and Island observations is given in Table II. At 20,000 feet and above winds are mainly from north westerly direction.

The discrepancy is almost certainly due to the shortness of the observational periods, and it must be contemplated that there is a risk of a season in which the winds tend to be more from a W.N.W. direction than in 1951.

TRIMOVILLE ISLAND

9.00 clock time

[redacted]

Table I. Mean Winds (in knots) up to various heights at the Island

September - October, 1951

SEPTEMBER	Surface		0-5,000		0-10,000		0-15,000		0-20,000		0-25,000		0-30,000	
9	200	12												
10	180	20												
11	200	14												
12	200	09												
13	200	04	200	1.5	028	3.5	027	5.3	023	5.5	357	5.6	320	8.0
14	160	06	147	11.6	116	7.5	084	10.3	069	9.0	014	5.4	314	6.3
15	180	06	172	22	161	14								
16	200	05	199	07	301	02	061	04						
17	180	07	170	21	160	11	120	08						
18	200	12	360	24	004	16	250	5.7	266	6.2	260	9.7	261	14.3
19	200	11	243	14	287	14	297	13.7	288	13.5	286	16	283	20.7
20	200	12	263	15	291	20.5	296	21.5	296	21.5	293	25		
21	200	10	231	21	257	22	267	28	273	31				
22	200	06	167	16	157	15	172	15	187	17.7	197	21.2	204	24.5
23	CALM		064	5.5	045	10.5	031	7.1	002	4.1	306	4.8	277	8.3
24	CALM		NO ASCENT											
25	270	03	192	5	244	4.3	304	4.5	342	7.2	345	11.7	338	16.1
26	200	12	249	12.4	274	17.5	287	22	296	26	301	31	302	34.8
27	180	12	185	14	216	11	220	10	242	14				
28	200	08	133	06	113	3.1	266	4.7	281	10.3	279	10.4	297	16.6
29	250	12	222	09	273	7.5	295	12.7	297	16.1	264	11.3	293	16.3
30	180	14	NO ASCENT											

TRIMOUILLE ISLAND [redacted]

09.00 clock time

Table I. Mean Winds (in knots) up to various heights at the Island

September - October, 1951

	Surface		0-5,000		0-10,000		0-15,000		0-20,000		0-25,000		0-30,000	
OCTOBER														
1	200	10	215	13	202	12.7	233	13.3	256	20.3	264	26.8	270	32.4
2	140	10	114	16	111	15	120	12.8	132	10.7	154	9.2	183	11.1
3	180	04	078	14	076	14.5	094	8.5	129	5.8	169	6.8	187	11.6
4	180	06	150	7.5	104	3.2	020	2.4	315	3.1	267	6.5	250	11.3
5	180	04	083	3.5	030	6.5	355	9.7	330	12.7	306	14.8	287	18
6	220	11	247	11	276	15.7	280	21						
7	180	20	178	16	184	9	225	8	247	12.8	257	17.6	262	22.6
8	200	03	074	03	021	5.6	321	7	300	12.3	292	18.7	285	24.9
9	220	05	222	09	252	7.5	277	10.2	278	16.3	273	20.6	270	25.9
10	200	22	250	16.7	282	18.5	290	21.3	290	24	288	28.5	286	33.3
11	180	14	196	13	266	11	292	16.9	290	19	281	23.1	280	29.4
12	180	22	252	05	285	11.2								
13	180	17	189	10.5	248	4.5	280	08	278	10.1	278	12.4	281	17.1
14	180	20	202	09	271	9.5	291	19	295	22.2	297	22.7	295	25.3
15	180	25	222	13	271	14	280	18	280	18.2	280	23.4	280	29.1
16	180	03	159	03	279	4.3	295	10.1	295	13.2	292	16.7	291	20.9
17	200	05	198	06	222	04	292	7.3	303	12.2	298	14.2	291	19.8
18	180	22	228	14.2	256	13.5	268	15	275	17.2	280	21.4	282	26.6
19	180	12	208	21	224	23.5	233	24	243	24.3	254	27.6	263	32
20	180	21	213	16.5	227	20	238	24	249	26.2	259	29.8	235	14.6
21	200	16	196	15	194	13.7	200	13.7	212	13.2	265	34.8	252	20.8
22	CALM		NO ASCENT											
23	180	05	158	18	135	14	106	08	267	4.3	237	1.6	293	5.2
24	090	06	020	03	049	07	043	8.8	012	8	337	8.2	315	10.9
25	180	03	155	12	148	09	152	05	204	2.8	253	04	269	6.4
26	090	03	138	06	138	07	156	7.3	193	08	227	8.8	238	12.1
27	200	16	187	14.6	164	11.7	158	12	169	10.7	195	7.6	219	9.8
28	180	06	147	17.5	137	16.1	115	13.9	102	12.5	102	7.6	320	4.2
29	220	06	189	06	183	2.5	033	1.9	020	3.4	127	1.0	282	7.1
30	220	06	173	09	160	08								
31	220	14	244	12.8	263	11.5								

CALM – [illegible]

Oct 6 [illegible]

Oct 7 [illegible]

Oct 29 [illegible]

Oct 30 [illegible]

ISLAND - Black
ONSLOW - Red

[redacted]

October 1951 (Island)
1939-41 (Onslow)

Comparison number of days per 100.

	N. I	N. II	N. III	N. IV	N.E. I	N.E. II	N.E. III	N.E. IV	E. I	E. II	E. III	E. IV	S.E. I	S.E. II	S.E. III	S.E. IV	S. I	S. II	S. III	S. IV
5000'	3	2			7	7	2		2	7			3	3			14	8		
6000'	6	2	2		8								4	2			4		2	
10000'	5	2			7	3			5	2			5				8			
10000'	5	14	5	2	5	2			2					2			2		2	

	S.W. I	S.W. II	S.W. III	S.W. IV	W. I	W. II	W. III	W. IV	N.W. I	N.W. II	N.W. III	N.W. IV	Calm	Total obs.
5000'		7			15	10			5				7	60
6000'	2				8	22	6	2	8	18	2		2	48
10000'			2		10	14	10		1	16	10		0	60
10000'	2				2	5	2	2	12	12	10	5	7	43

I = 3-13 knots
II = 14-27 knots
III = 28-40 knots
IV = over 40 knots

ISLAND - Black
ONSLOW - Red

[redacted]

TABLE II

A comparison of Upper Winds observed at Onslow and at the Island

September 1951 (Island)
1939-41 (Onslow)

Comparison number of days per 100.

	N. I	N. II	N. III	N. IV	N.E. I	N.E. II	N.E. III	N.E. IV	E. I	E. II	E. III	E. IV	S.E. I	S.E. II	S.E. III	S.E. IV
5000'	7				11	3	3						11	3		
6000'	6	13	4		6	10			8				4			
10000'	16	3			10	3			3				3			
10000'	6	16	6		9	6			6				2	4		

	S. I	S. II	S. III	S. IV	S.W. I	S.W. II	S.W. III	S.W. IV	W. I	W. II	W. III	W. IV	N.W. I	N.W. II	N.W. III	N.W. IV	Calm.	No. of Obs
5000'	3	13			6	6	3		6	13	3		6	3				36
6000'	6				4	4			6	6			6	13		2	2	51
10000'	3								6		10		6	16	10	3	3	31
10000'	9	2			2	2			2	4			6	14	2		2	47

I = 3-13 knots
II = 14-27 "
III = 28-40 "
IV = over 40 knots.

[redacted]

From these figures it would seem reasonable to deduce that between 5 and 10 people live on each homestead, the rest of the population being employed either on the airfields or in the towns.

B.5 Agriculture

Crops in the area are negligible though there may be a little fruit grown.

B.6 Livestock

The following table shows the livestock in each district.

	Ashburton	Roebourne
Poultry, hens, ducks	120 hens A few ducks	584 hens No ducks
Dairy cattle	56	120
Beef cattle	2,737	1,285
Horses	920	458
Sheep	251,815	139,162

Since Ashburton is 25,210 square miles in area and Roebourne 8,452 square miles the numbers of beef cattle and sheep per square mile are:-

	Ashburton	Roebourne
Beef cattle	0.11	0.14
Sheep	10	16

B.7 Summary

There are in this area 21 homesteads at each of which there are -

5 to 10 people
About 25 hens
About 6 dairy cows
About 20 horses

and in addition there are about

1 beef cattle to 7 square miles, and about
16 sheep per square mile.

There are also 4 townships and 4 airfields.

B.8 Source of information

The above information is gleaned from the following sources:-

(a) Australian Aeronautical Map, sheet F.3.
(b) Statistical Register of Western Australia 1947-48, Part V and Part XI.
(c) Pocket Year Book of Western Australia, 1950.
(d) Population of Onslow; provided by Rear-Admiral Torlesse.
(e) Encyclopedia Britannica.

[redacted]

Appendix 'B'.

Some notes on North West Australia

[redacted]

B.1 Topography

The area to the south, southeast and east and within 150 miles of the Montebello Islands includes nearly all of the Road District of Roebourne, about a quarter of Ashburton and a little of Tableland. The nearest points of the mainland coast vary from 100 miles to the S.S.W. to 56 miles to the S.E. (the nearest point) to 90 miles to the E. There are salt marshes along much of this coast, being 5 miles wide in places, and farther inland the ground rises slowly. The 1,000 ft. contour appears, on the average, to be about 50 miles from the coast. The main range of hills has a crest 100-150 miles inland with peaks rising to over 3,000 ft. There are six main river valleys running from these hills to the coast, though presumably these are usually dry and water is normally obtained from waterholes, wells and tanks.

B.2 Climate

The whole district is classed as arid, the rivers flowing only for short periods at intervals of several years. Rainfall consists mainly of occasional heavy tropical storms giving a long term average rainfall of about 12 ins. annually. There are however large variations from this average from year to year. In 1949 the rainfall reported at Onslow was 18 ins. and at Roebourne 7 ins.

Average temperatures are about 78°F. near the coast with an annual variation from about 45°F. to 110°F.

B.3 Towns, dwellings etc.

In the area between S.S.W. and E. of the Islands and within 150 miles there are the townships of

Onslow	100 miles away	Population 350 (?)
Roebourne	116 " "	" unknown.
Cossack) Port Walcott)	119 " "	" "

There are four airfields:-

Onslow	- 100 miles away	Used by regular scheduled services
Roebourne	- 116 " "	
Minderoo	- 125 miles away	Used as required, the regular services calling there when requested.
Mardie	- 64 " "	

There are lighthouses at distances of 54, 66, 75, 89, 118 and 119 miles, though except for the last two, which are at Cossack and Port Walcott, they are probably not usually manned, probably being automatic beacons. There are 21 homesteads situated at distances of 62, 64, 86, 92, 92, 99, 99, 108, 108, 118, 122, 125, 126, 127, 128, 129, 135, 136, 140, 143 and 148 miles, all of which are occupied.

B.4 Population

Excluding full-blooded Aboriginals, for whom no statistics are available, there are:-

In the Roebourne district - 318 people (90 females), of whom 120 (29 females) are employed on the land.

In the Ashburton district - 397 people (118 females) of whom 190 (18 females) are employed on the land.

[redacted]

Appendix 'C'

Meteorological Office Investigation Division Memorandum No.33

An Assessment of the Meteorological Factors in the problem of Fall-out over the Australian Mainland

by [redacted]

In discussing this question it is convenient to do so from the point of view of discovering the range of particle sizes which affect the problem. In the assessment of possible ground contamination we need then only consider particles within the range of sizes given.

C.1 Range of Particle Size

The nearest point on the coast is 50 miles away. We shall assume that the mean wind up to the top of the cloud does not exceed 35 knots* and that the cloud reaches a height of 30,000 feet. For the present we make no assumption about wind direction. We also assume that solid particles fall with the velocity given by Stokes Law, and that liquid particles have a velocity as given by [redacted] (1). Under these assumptions it is easily found that the maximum size of solid particles which can reach the mainland have diameter 150μ, and for liquid particles diameter 500μ. This sets an upper limit to the range of size of the particles. To get a lower limit we may remark that the speed of fall of a particle is proportional to D^{-2} and thus the area of ground contaminated is proportional to D^{-4}. If we also assume that the contamination is carried on the surface area of the particle then the contamination per unit area is proportional to D^3. On this basis it seems safe to assume that particles smaller than 35μ have no effect on the problem./ It, therefore, seems reasonably certain that the fall-out problem depends on particles in the following range of size:-

Solid particles 30μ to 150μ
Liquid particles 30μ to 500μ

It is probable that no matter what the initial distribution of drop size may be, the distribution will become "gaussian" after a period of, say, a few minutes owing to coalescence and evaporation. The distribution is likely to be centred around some most favoured size and it is expected that few drops are greater than twice that size or less than ½ that size.

In the absence of any precise information as to the drop size in a cloud due to an explosion it is not possible to be certain that the favoured size will be outside the range 30μ to 500μ, but in natural cloud the favoured sizes are much below 30μ.

The formation of the drops will be largely due to (i) shattering by shock in which case the drops may be heterogeneous over a wide range of size but are probably very small, (ii) condensation as the heated air cools, in which case they will in general be of cloud particle size.

It is, therefore, expected that the number of drops in the critical range will be only a small percentage of the whole.

C.2 Evaporation of Liquid Droplets

The prevailing meteorological conditions are favourable for evaporation of droplets. The relative humidity is low and there is a substantial change of wind direction with height. In such circumstances, Best(2) has shown that drops in the size range 150μ and below will evaporate rapidly. If the droplets are composed of salt water a salt crystal will be left behind after evaporation. The diameter

* In fact no record of wind in excess of this figure was obtained in Sept./Oct. 1951.

/ Assuming the total mass of drops around 35μ is the same as of those around 150μ then in a given wind only one per cent of the surface contamination is attributable to the 35μ drops. At a place where both drops land in light and strong wind this ratio is constant but if the wind is so light that the 150μ drops fall out before reaching the coast, [illegible] the increase of contamination due to the small drops would only be equivalent to the contamination due to both drop sizes if the wind speed were reduced by a factor of 5

[redacted]

of this crystal is roughly a quarter that of the liquid drop from which it was formed. These salt particles may be of some importance since even drops as large as 400μ may be evaporated in falling and leave a salt crystal as large as 100μ. Such large drops, however, cannot remain in the cloud but might fall as rain in the immediate locality of ground zero. It now seems that the contamination to be feared arises from:-

(i) solid particles in the range 35μ to 150μ

(ii) salt crystals

while contamination of the mainland by liquid particles may be ruled out.

C.3 Origin of Solid Particles

We must now examine the source of supply of the solid matter. It is understood that the naturally occurring solid particles are composed of crushed coral, which is such that only 0.1% will pass through a fine sieve. Some surface sand and dust may be caught up by the convective processes, but it is unlikely that the amount will be large, nor are such particles likely to be carried to any great height. If we take the suggested figure of 10,000 tons of bottom sand as being thrown up, we are left with 10 tons in the size range of about 1,000μ and below, and perhaps 1 ton in the range 100μ and below. The quantity of evaporated salt is very difficult to assess, but it is unlikely to be of greater importance than the solid matter. Moreover, the degree of contamination due to salt particles is probably small.

C.4 Diffusion and Wind Shear

A feature of the problem is the effect of the change of wind direction in various layers. The minimum wind shear observed during September and October, 1951, was 35 degrees, and the average about 60 degrees. Since the angular spread of contamination by diffusion is of the order of 10 degrees at a distance of 50 to 200 miles from the source it is clear that the effect of shear in this region will decrease the concentration by at least 3½ times and probably by more than 6 times.

C.5 Examination of Data for September/October, 1951

Diagram 1 shows the distance travelled by two particles of size 150μ and 75μ which have been assumed to fall from 30,000 feet under the prevailing wind.* It will be noted that in the case of 150μ particles, no particles reach the coast because of the wind direction. In practice, therefore, we can probably limit the particle size to 100μ as an upper limit. It should also be noted that the contaminated sector almost always lies to the north of the line joining the origin to the point of fall. With winds of 15 knots or more in only two cases in a month was the contaminated sector to the south of this line. Diagram 2 illustrates the wind shear in graphical form. The safest factor from a statistical point of view is seen to be from 210 to 290 degrees.

C.6 Effect of Time and Space on Wind Estimation

In plotting diagram 1 it has been assumed that the wind found over ground zero is applicable during the time of fall-out. For the 150μ particles this time is about one and a half hours and the distance travelled less than 50 miles. In such cases the assumption is quite valid. For the 75μ particles the time of fall is about six hours and the distance travelled up to 200 miles. In such a case there is a statistical error due to the possible change of wind with time and space. An attempt has been made to estimate the magnitude of the error and it appears that the true position of the 75μ particles will lie inside a circle of about 20 miles radius around the assumed position. This, however, does not affect the value of the diagram.

C.7 Conclusions

With these considerations it is possible to make some revision of the estimates of the amount of contamination which will be deposited under the worst

* The falling velocities for these particles have been calculated from Stokes' Law.

conditions.

(a) The contamination which is associated with the water column thrown up by the bomb will be swept back into the sea by the downward surge of the solid water column. No exact estimate can be made of this amount but it is probable that 70 per cent of the total contamination will be so accounted for.

(b) Of the contamination associated with drops thrown up into the cloud at the head of the column and with spray thrown outward from the sides a considerable proportion will be brought to the sea by the fall of large drops of size greater than 200 μ to 400 μ. Probably at least 2/3 of the contamination will be so accounted for leaving not more than 10 per cent of the total contamination deposited on water still remaining to be considered.

(c) These contaminated drops will evaporate and the contamination may remain on salt particles the very great majority of which will be less than 125 μ. Particles of size below 35 μ will be carried such great distances that their effect will be negligible, so we are really concerned only with salt particles of a range 35 μ - 125 μ and in that range there is not likely to be more than 10 per cent of the contamination remaining after the washout described in (a) and (b). Hence there is not likely to be more than 1% of the initial contamination on salt particles.

(d) Now let us consider the solid matter swept up from the bottom; some of it will become contaminated by the adherence of fission products and other radioactive substances. It may be that a higher proportion of the contamination is carried by the finer particles, but it is most improbable that the proportion of contaminated matter having diameter less than 100 μ is more than one thousandth of the total matter swept up.

(e) On the estimates given above the contamination is almost certainly to be reduced by 10^{-2} from that which would be expected if all drops were of equal size and all contamination were carried by these drops.

(f) However, the shear of the wind is going to reduce the value still further by a factor of 1/3 or 1/6.

(g) These estimates, though admittedly subjective, are believed to be on the high side and in fact the factor by which the values given in Table III should be reduced is likely to be one thousandth.

Meteorological Office
Air Ministry
December, 1951.

References

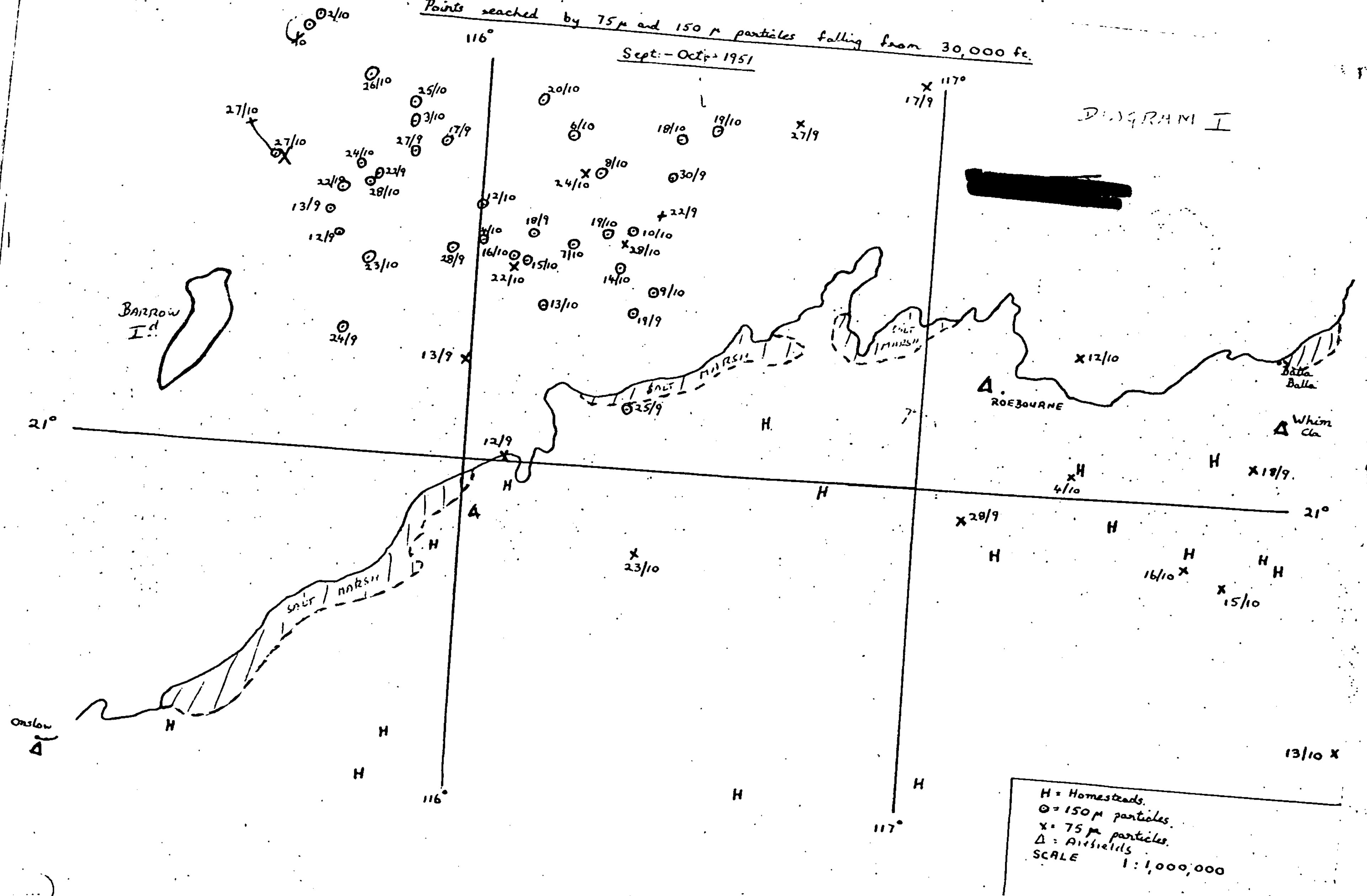
(1) [redacted] (1950) Q.J. Royal Met. Soc.
(2) (1950) M.R.P. No.603

DIAGRAM I

[redacted]

Points reached by 75μ and 150μ particles falling from 30,000 ft.

Sept.-Oct. 1951



"MRC" File

[redacted] u/c

TS. 75/20

2

C.S.H.E.R.

Maximum Permissible Dosages to be taken by Participating Teams in Operation Hurricane

1. As a result of recent investigations it is now known that certain of the bases on which these doses were fixed are not now applicable to the conditions of the operation. In particular :-

(i) the ratio of 4 r of γ-rays to 50 rep. of β-rays referred to in PABE/39 is only true at head-height from the ground.

(ii) the clothing which can be used in this climate (effective thickness about 20 mg/sq.cm.) will afford very little protection to the body against the energetic β-particles.

2. It is not yet possible to give accurate figures for the effect which these two factors will make on the total body dose. Experiments are proceeding and the present indications are :-

(i) that the ratio of β/γ at waist-height is about 40/1.

(ii) that the clothing will reduce the β-dosage by about 40%.

3. The present agreement assumes that the clothing will give complete protection to 90% of the body. If, however, we ignore this restriction and spread the β-dose over the whole body then this agreement would allow us three levels of dosage :

(i) 0.1 r of γ + 0.12 rep. of β per day

(ii) 3 r of γ + 3.6 rep. of β as integrated dose.

(iii) 10 r of γ + 15 rep. of β as integrated dose.

These β levels, if adhered to, would be a serious limitation in that they might delay recovery of records etc. If the ground contamination is heavy this would mean that re-entry to many areas might not be possible at all during the time available for the operation, whereas with a higher level more areas would be opened up. In view of this I feel that it would be advisable to re-open the question on the basis of the new information and ask for a new agreement giving higher β-dosages such that the general physiological effect would be the same as originally envisaged for the γ-doses.

In this case I would suggest the following three levels:-

(i) 0.3 rep. per day of which the γ not to exceed 0.1 r

(ii) 15 rep integrated dose of which the γ not to exceed 3 r

(iii) 50 rep. integrated dose of which the γ not to exceed 10 r.

It is likely that the β will still be the limiting factor but it is now a realistic limit and is as high as I feel it would be reasonable to go.

The ratio of β/γ within these overall doses would be unspecified and would be fixed later for the purposes of our measurements on the basis of the experiments now in hand and measurements made in the field as soon as possible after the event.

4. The dosages received by personnel will in general be estimated on the basis of the γ-ray dose recorded by the personal monitoring films adjusted in accordance with the ratio determined. If the experiments confirm the present estimates of β/γ ratio given above the permissible levels in terms of γ-ray dosage received would be approximately:

(i) 0.01 r/day.

(ii) 0.6 r integrated dose.

(iii) 2 r integrated dose.

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5. If, on the basis of the above summary, you agree that the matter should be re-opened and you are satisfied with the levels suggested, I would prepare a draft memorandum on which you could base a letter to the Ministry. If, however, you are not entirely satisfied on these points I would like an opportunity to discuss with you and [redacted] the implications of this new information and the action to be taken.

[redacted]

Copies to:

S.S.M.R.
File (2)

Health P[redacted]p,
Building [redacted]
Aldermas[redacted]
Nr. Reading,
8th April, 1952.
DEB/JMG.

182A

[redacted]

Part V Estimate of "No Risk" and "Slight Risk" levels of Contamination on the Mainland.

~~The maximum permissible ground contamination~~ ~~areas~~ on the Mainland.

Copies

~~By~~ [redacted]

B.1. The general question of the maximum permissible ground contamination of populated areas due to fall-out following an atomic bomb explosion is one which has received little detailed attention hitherto. An attempt will be made in the following paragraphs to make a quantitative assessment of the problem with particular reference to the circumstances of Operation Hurricane.

B.2. The main sources of hazard arising from the deposition of fission products and unfissioned material following an explosion will be as follows:-

External hazards

(a) Whole-body beta and gamma-irradiation by fission products deposited on ground, buildings, clothing, etc.

(b) Local beta-irradiation of tissue from fission products deposited directly on the skin of human beings and animals.

Internal hazards

(c) Direct deposition of fission products and unfissioned material in sources of drinking water - reservoirs, rivers, water-tanks etc.

(d) Indirect deposition in drinking water via the ground, by subsequent drainage, etc.

(e) Direct deposition on human food, crops, fruit, etc.

(f) Deposition on animal foodstuffs (grass, etc.) with consequent possibility of damage to the animal and ultimately to the human being who eats it.

(g) Inhalation while the material is still airborne, i.e. before it settles out.

(h) Inhalation of active dust which may be stirred up from the ground.

(i) Injection into the blood-stream by way of cuts, wounds, etc.

B.3. It is necessary first to decide on the maximum permissible radiation exposure levels to be adopted as a basis for calculation.

(a) External whole-body radiation

The problem of whole-body irradiation from mixed fission products is complicated by the presence of considerable beta, as well as gamma, radiation. From data calculated by [redacted] the relative beta to gamma dosages in roentgens at three feet from the ground are in the ratio of 40 to 1. In northern climates where considerable clothing is worn most of the beta rays may be stopped before they reach the body, but in a hot climate it must be assumed that the clothing offers little or no protection against beta rays of these energies. It is therefore clear that the beta radiation is the limiting factor. Two distinct levels may be considered:-

(i) A level at which there is absolutely no risk of any kind: 6 rep (roentgen equivalent physical). This represents a month's dose at the continuous level of 1.5 rep/week accepted throughout the working life of radiation workers.[2]

(ii) A level at which there is a risk of some temporary sickness in a small proportion of persons exposed - but no lasting damage. 50 rep.[3]

The accompanying gamma radiation we can take to be 0.3 r. and 2.5 r. respectively. This is obtained by taking the above ratio of 40 to 1 and introducing a factor of 2 to allow for some absorption in dust etc., some protection from clothing, and a decrease in dosage with height above the ground.

(b) Local beta-irradiation of the skin

It is generally accepted that higher doses can be delivered to small areas of the body than to the whole body, the permissible dose being inversely proportional to the area exposed. If, as a worst case, we assume that fission products are deposited on 50% of the body then the dosages corresponding to zero risk and risk of temporary sickness are 12 rep and 100 rep respectively.

(c) Internally deposited Pu 239

The maximum permissible amount of Pu^{239} fixed in the body is considered to be 0.04 μc.(2) This, however, is for occupational groups, and the M.R.C. hold the opinion that, in view of the danger, even at the normally accepted levels, of an increase in the natural rate of genetic mutations in man, a further factor of 100 should be applied where large populations are concerned.(5) Where small groups only are involved the precaution is considered unnecessary but in this case, where marriage outside the local community may be rare, it may be wise to include it. The figure adopted therefore is

0.0004 μc. or 0.0064 μg.

Owing to the long-term nature of the hazard and the fact that the Pu once fixed is never significantly eliminated, there can be no question here of degrees of exposure or any acceptance of a risk of some temporary sickness.

(d) Ingested fission products

The main danger lies in the semi-permanent retention in the body of harmful amounts of the longer-lived beta-emitting fission products. Calculations indicate that a total ingestion of 3 millicurie of 1 hour fission products would represent a completely safe dose. These calculations, based on known fission yields and various biological factors(4), show that from this amount of mixed products the following amounts of the most dangerous isotopes would be retained in the various vital organs:-

Sr^{90}	0.0001 μc
Sr^{89}	0.015 uc
Ba^{140}	0.09 uc
I^{131}	0.3 uc

The maximum amounts laid down(2) are Sr^{90} - 1 μc., Sr^{89} - 2 μc., I^{131} - 0.3 uc.; nothing is laid down for Ba^{140} which has the same biological factors as Sr^{89} but a much shorter half-life. We therefore see that the amounts corresponding to a total ingestion of 3 millicurie are within the recommended maxima. The strontium figures also include the "general population" factor of 100, recommended by the M.R.C. for the long-lived isotopes.(5) The limiting case is I^{131}. Iodine however goes only to the thyroid and is short-lived. Furthermore the figure is laid down for a maintained burden. The amounts of I^{131} used therapeutically without causing radiation sickness of any sort are of the order of 100 millicuries. We might therefore reasonably accept an increase in our total fission product ingestion figure to 30 millicuries giving retention figures of

Sr^{90}	0.001 μc.
Sr^{89}	0.15 μc.
Ba^{140}	0.9 μc.
I^{131}	3.0 μc.

[redacted]

For the "slight risk of temporary sickness" category (2.5 r. gamma plus 50 rep beta) all the above figures can be increased by a factor of eight, giving:-

0.6×10^5 uc/m²
0.65×10^5 uc/m²
0.76×10^5 uc/m²
0.87×10^5 uc/m²

Local beta-irradiation of the skin from directly deposited fission products

Here again the time of the exposure is important. We will consider 24 hr. exposures (a period after which most deposited material would be either washed off or worn off) commencing, as before, at 2½, 5, 10 and 20 hrs. after the explosion.

For the "zero risk" dose of 12 rep we require the following dose rates at 1 hr.

2½ hrs. - 26½ hrs.	7.5 r/hr.
5 hrs. - 29 hrs.	11.0 r/hr.
10 hrs. - 34 hrs.	17.0 r/hr.
20 hrs. - 44 hrs.	30.0 r/hr.

Using data given by [redacted] (1) it is found that 113 beta particles cm²/sec. of average energy 0.8 Mev. will produce a dose-rate of 12.5 mr/hr. Therefore to produce an integrated dose of 12 rep the following contaminations in terms of 1 hr. fission products are required:-

Exposure beginning at -

2½ hrs.	1.8×10^4 uc/m²
5 hrs.	1.0×10^5 uc/m²
10 hrs.	1.5×10^5 uc/m²
20 hrs.	2.7×10^5 uc/m²

For the "slight risk of temporary sickness" category we can again increase these figures by a factor of 8, giving:-

Exposure beginning at -

2½ hrs.	1.5×10^5 uc/m²
5 hrs.	8.3×10^5 uc/m²
10 hrs.	1.25×10^6 uc/m²
20 hrs.	2.24×10^6 uc/m²

Direct deposition of Pu^{239} and fission products in drinking water

Let us assume that a one-thousand gallon water tank serving a homestead of 10 people is contaminated. The maximum permissible amounts of material to be ingested are:-

Pu^{239} - 0.4 uc. (assuming 0.1% absorption)(2)

1 hr. fission products 3 mc. (zero risk)
30 mc. (slight risk of temporary sickness)

If the surface area of the tank is 5 m² and the 10 persons drink an equal share the maximum permissible contaminations are:-

Pu^{239} - 0.8 uc/m²

1 hr. fission products 6×10^3 } uc/m².
6×10^4 }

[redacted]

Indirect deposition in drinking water by drainage over the years

Let us assume that over a period of 70 years all the surface contamination is gradually drained away by the rain and appears uniformly over that period in drinking water supplies. Let us also assume that the rainfall over that period averages 12 inches a year, i.e. 840 inches total (and let us allow 25% for evaporation), so that the total volume of water per square metre is 1.6×10^7 ccs. The 70 year drinking water tolerance for Pu (I.C.R.P.1950) is 1.5×10^{-8} μc/cc., giving us a maximum permissible contamination of

$$0.24 \ \mu c/m^2$$

The only fission product to be considered in this case is Sr^{90} (half-life 25 years). The long term drinking water tolerance for Sr^{90} is 8×10^{-9} μc/cc., so that the maximum contamination would be 0.075 $\mu c/m^2$, corresponding to

$$5 \times 10^5 \ \mu c/m^2$$

Deposition on human foodstuffs

It is difficult here to devise a suitably realistic case. Let us imagine a fruit tree with a total spread of 2 metres radius, and that one fifth of the contamination falling on it falls on the fruit as opposed to the leaves and branches and that one tenth of the fruit is eventually eaten by the same person without being washed. Using the same maximum permissible ingestions as before we find that our maximum permissible contaminations are

Pu^{239} - 1.7 $\mu c/m^2$

1 hr. fission products - 1.3×10^4 $\mu c/m^2$ (zero risk)
1.3×10^5 $\mu c/m^2$ (slight risk of temporary sickness)

Deposition on animal foodstuffs

This particular problem is exceedingly difficult to assess. There are two aspects: on the one hand there is the possibility of effects on humans who eat the animals, and on the other hand there is the possibility of effects on the animals themselves, which is important in districts where mans' livelihood depends on the breeding of livestock. In considering the animals themselves it seems fair to ignore any factor which has been included for humans merely to guard against any increase in genetic mutations: this increase is, in any case calculated to be exceedingly small and would be completely insignificant amongst a population of animals. The figure we will use therefore for total ingestion of Pu^{239} is

$$40 \ \mu c.$$

It also seems fair to enter the region of "slight risk" in the case of fission products and to increase the total ingestion figure up to

$$100 \ mc.$$

This is still only about 2% of the quoted 50% lethal dose. Only a small percentage of these amounts will, as we have seen, be absorbed from the animals' intestines, and only a small proportion - say 10% - of this might end up in edible parts of the animal; allowing also for mans' own excretion it is found that the body burden retained by a man who eats, over a period of time, one whole contaminated animal would be small compared to the permissible figures and we need have no concern on that account.

~~Now suppose that, in the first instance, the animal had in fact swallowed one tenth of the contaminated fodder or grazing over an area of 1000 sq.metres, then the maximum permissible contaminations would be~~

~~Pu^{239} - 0.4 $\mu c/m^2$~~

~~1 hr. fission products - 1×10^3 $\mu c/m^2$.~~

[redacted]

Inhalation while particles are still airborne

Suppose that we have a cloud of unfissioned material or fission products which is 500 metres deep, settling out uniformly over a given area over a period of 1 hour, so that anyone in that area is breathing in radioactive material for 1 hour. Assuming a breathing rate of 1 m^3/hr. and 25% retention, and using the maximum permissible amounts previously quoted, we have as our maximum permissible air concentrations:-

Pu^{239}	0.0004 $\mu c/m^3$
1 hr. fission products	0.1 mc/m^3 (zero risk)
	1.0 mc/m^3 (slight risk of temporary sickness)

We can thus imagine a column 500 m. in height and of one m^2 cross-section settling out over one m^2 of ground and containing the above concentrations. This will eventually give us maximum permissible ground concentrations of

Pu^{239}	0.2 $\mu c/m^2$
1 hr. fission products	5×10^4 $\mu c/m^2$ (zero risk)
	5×10^5 $\mu c/m^2$ (slight risk of temporary sickness)

Inhalation of stirred-up dust

We can make use here of the results of the trials carried out by the Home Office and A.E.R.E.[6], which show that the air concentration per cubic metre produced by the disturbance of dust (by shovelling, clearance of debris, etc.) in a contaminated area, was a fraction of 2×10^{-6} of the contamination per sq. metre of ground.

Pu^{239} is the most dangerous possibility in this case and to be entirely safe we should assume indefinite exposure to disturbed airborne dust (e.g., this covers the case of a man who spends most of his life on horseback). The long-term maximum permissible breathing concentration for Pu^{239} is

$$2 \times 10^{-12} \ \mu c/cc.$$

$$\text{or} \quad 2 \times 10^{-6} \ \mu c/m^3.$$

Using the above-quoted results this would correspond to a maximum permissible ground contamination of

$$1 \ \mu c/m^2$$

In the case of fission products the hazard will not be so long-lived. If we take a continuous exposure to disturbed dust of 6 months as the worst possible case and neglect any radioactive decay we find that the maximum permissible air concentrations are

$$5 \times 10^{-5} \ mc/m^3 \ \text{(zero risk)}$$

$$5 \times 10^{-4} \ mc/m^3 \ \text{(slight risk of temporary sickness)}$$

and the corresponding ground concentrations

$$2.5 \times 10^4 \ \mu c/m^2$$

$$2.5 \times 10^5 \ \mu c/m^2$$

Injection into the blood-stream through cuts, etc.

~~This is very difficult to assess~~ Ignoring direct deposition, let us consider a man falling over on contaminated ground and all the active material from, say, 10 cm^2 entering a scratch or wound and passing into his bloodstream.

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The maximum amounts he should absorb by direct injection are

Pu^{239} 0.0004 μc.

1 hr. fission products 0.1 mc.

Our maximum permissible contaminations are therefore

Pu^{239} 0.4 μc/m^2.

1 hr. fission products 1 x 10^5 μc/m^2.

~~E.9~~ The results of the above assessments are summarised below:-

~~T[illegible]~~ Hazards from Pu^{239}

Hazard	Max. permissible contamination in uc/m^2.	Corresponding conc. of 1 hr.f.ps. based on estimate of relative amounts present. uc/m^2	ug/m^2
Direct deposition in drinking water	0.8	~~2 x 10^7~~ 1.2 x 10^7	~~[illegible]~~ 2.0
Indirect deposition in drinking water over years	0.24	~~5 x 10^6~~ 3.5 x 10^6	~~0.8~~ 0.5
Direct deposition on human foodstuffs	1.7	~~4 x 10^7~~ 2.5 x 10^7	~~6.8~~ 4.1
Deposition on animal foodstuffs	~~0.1~~ 0.04	~~1 x 10^7~~ 5.8 x 10^5	~~1.7~~ 0.1
Inhalation of cloud before settling out	0.2	~~5 x 10^6~~ 2.9 x 10^6	~~0.8~~ 0.5
Inhalation of stirred-up dust	1.0	~~2.5 x 10^7~~ 1.4 x 10^7	~~4.2~~ 2.6
Injection into cuts etc.	0.4	~~1 x 10^7~~ 5.5 x 10^6	~~1.7~~ 1.0

Table EII. Hazards from fission products

Hazard	Maximum permissible contamination of 1 hr.f.ps.			
	uc/m^2 zero risk	slight risk	ug/m^2 zero risk	slight risk
Whole body beta & gamma radiation *	0.7 x 10^4	0.6 x 10^5	1.2 x 10^{-3}	1 x 10^{-2}
Local beta-irradiation of skin *	1.8 x 10^4	1.5 x 10^5	3 x 10^{-3}	2.6 x 10^{-2}
Direct deposition in drinking water	6 x 10^3	6 x 10^4	1 x 10^{-3}	1 x 10^{-2}
Indirect deposition in drinking water over years	5 x 10^5	-	8.0 x 10^{-2}	-
Direct deposition on human foodstuffs	1.3 x 10^4	1.3 x 10^5	2.2 x 10^{-3}	2.2 x 10^{-2}
Direct deposition on animal food-stuffs	-	1 x 10^4	-	1.7 x 10^{-5}
Inhalation of cloud before settling out	5 x 10^4	5 x 10^5	8.0 x 10^{-3}	8.0 x 10^{-2}
Inhalation of stirred-up dust	2.5 x 10^4	2.5 x 10^5	4.0 x 10^{-3}	4.0 x 10^{-2}
Injection into cuts, etc.	1 x 10^5	-	1.7 x 10^{-2}	-

* Figs. given are for exposures beginning at 2½ hrs. as representing the worst case.

It can be seen at a glance that the concentrations of fission products corresponding to all the permissible contaminations of Pu are so far in excess of the limiting cases for the fission products themselves that we need consider the problem of the Pu no further.

E.14 Discussion

(a) It would appear to be a simple matter, once the acceptable degree of risk has been decided upon, to accept the lowest figure in the above tables as the maximum permissible contamination without further discussion. There are certain factors, however, that cannot be overlooked:-

(i) Many of the calculations concerning the ingestion and inhalation hazards are, of necessity, guesswork and tend, if anything, to over-estimate the hazard.

(ii) Certain hazards such as the direct deposition of activity in drinking watercould be avoided by taking protective measures before the event.

(iii) Others, the longer-term ones, could be checked and dealt with, if necessary, by evacuation of limited areas after the event.

(iv) All the hazards described may well be additive, i.e. one individual may be exposed to all of them.

(b) The limiting case on paper (for "slight risk") is the deposition on animal foodstuffs

$$1 \times 10^4 \ \mu c/m^2$$

~~It is clearly unreasonable that the feasibility of the whole operation should hinge on a refusal to accept some risk to a small number of animals, a risk based very much on guesswork. In any case it is a fairly long-term risk and one which could be dealt with satisfactorily by subsequent temporary evacuation of affected grazing areas, provided that the fall-out of contamination is adequately tracked and monitored, and that the contamination does not exceed the above figure by a factor of 10: this would allow three days in which to evacuate the animals. The limiting value for this case might therefore be regarded as~~

~~$$1 \times 10^4 \ \mu c/m^2$$~~

(6 x 10³ μc/m² ...) (With (b) might be ...)

~~(c) Next, at approximately 6 x 10³ μc/m² come the "zero risk" figures for direct deposition on drinking water. This hazard could fairly simply be guarded against by the covering of all water supplies before the event – this may, in any case, be normal practice.~~

(d) At about 1 x 10⁴ μc/m² we have the "zero risk" figures for whole body external beta-gamma radiation for local beta-irradiation of the skin, and for direct deposition on human foodstuffs. ~~The latter, again, is a long-term risk which could be avoided by subsequent precautionary measures such as washing of food, peeling of skins, etc.~~ The former irradiation is inescapable and cannot be argued about: the figure of 10⁴ μc/m² is, of course, for "zero risk" and can be increased by a factor of eight before it came into the "slight risk of temporary sickness" category, but in countenancing such an increase it is necessary to remember that we are now accumulating quite a number of hazards, the effect of all of which will be additive.

(e) It is time now to make some specific recommendations. It is suggested that -

(i) ~~10³ μc/m²~~ (6 x 10³ μc/m²) would involve no risk at all, ~~provided that arrangements could be made to cover all drinking water supplies.~~

(ii) 4 x 10⁴ μc/m² would probably involve zero risk but where an individual was exposed to more than one hazard at a time, the additivity of the effect would carry him into the "risk of temporary sickness" category.

(iii) Any significant increase in the figure of 4 x 10⁴ μc/m² must be assumed to involve a risk of lasting or at least unpleasant injury and cannot be regarded as acceptable.

References
(1) A.E.R.E. HP/R/551
(2) Recommendations of the International Congress of Radiological Physics - 1950.
(3) Medical Research Council paper PABE 36.
(4) Radiology - September, 1947.
(5) Medical Research Council paper NP/P/TD/148.
(6) A.E.R.E. HP/R/737.

[redacted]

Monitoring on the mainland

by [redacted]

(a) In the event of there being a possibility, however slight, of significant contamination reaching the mainland, it will be essential to obtain as much information as possible with regard to the trace and the intensity of the fall-out.

(b) In very broad outline, this would call for

(i) Tracking of the cloud by aircraft.

(ii) Fixed monitoring stations at selected points. If instruments were placed at all major homesteads within 150 miles it would appear that the total number required would not exceed 25.

(iii) Light aircraft or jeep patrols, stationed at about 5 central points, which could make a detailed survey as soon as the actual path of the cloud became known.

(iv) Collection of samples of soil and water from any suspected fall-out area, for subsequent analysis by Force H.

(v) A small Headquarters to handle information, take command of any unforeseen situation that might arise and maintain wireless communication with Force H.

(c) The framework of such an organisation, including the communications, could clearly best be supplied by the Australian Armed Services. Use could be made of existing civil communications and civilian personnel.

(d) Training

Some preliminary training of personnel involved would be necessary, particularly in the use of instruments. Assistance in this could be given by the Hurricane Radiation Safety group during the preparatory period.

(e) Radiation Instruments

All the information required could be obtained with two portable battery-operated instruments with ranges

(i) 0-200 mr/hr.

(ii) 0-30 r/hr.

Approximately 30 of each would be required. These would have to be supplied by Hurricane Radiation Safety group.

(f) In view of the fact that the contingency which makes the plan necessary might never arise, it is clear that the effort involved both in men and money must be kept to a minimum. On the other hand it is obvious that, should it arise, then the information obtained must be full and complete.