AWRE Working Group on the Peaceful Uses of Nuclear Explosives

Oil Storage beneath the Seabed in Cavities Created by Nuclear Explosives

The attached document prepared by [redacted] is a proposal for a detailed evaluation of oil storage beneath the seabed in cavities created by nuclear explosives. It is intended that the proposal should be used as a basis for approaches to Government Departments Petroleum Companies etc. To this end WGPNE(72)33 has been revised as follows:-

(a) Up-dating of technical information.

(b) Rearrangement of material to give a short statement of the proposal supported by information in several appendices.

(c) Inclusion of more detailed staffing and cost figures supplied by several members of the Working Party.

(d) Inclusion of suggestions made when WGPNE(72)33 was discussed with [redacted] formerly Technical Adviser, UKAEA London Office.

The Working Group is invited to endorse the proposal and to recommend that the UKAEA be advised to take positive action to promote the proposed feasibili study. Appendix C is included to aid the Working Group's discussion and will not form part of any final version of the proposal.

[redacted]

[redacted]
AWRE
10 August 1973

KP/873/162

A Proposal for a Detailed Evaluation of Oil Storage beneath the Seabed in Cavities Created by Nuclear Explosives

This proposal has been prepared by AWRE, Aldermaston in discharge of its responsibility to advise British public and private organisations on the potentialities of nuclear explosive engineering.

August 1973

The Motive

Offshore storage of oil is expensive. Systems already installed or on offer commercially show costs which are generally over $10 per bbl* and run as high as $30 per bbl, as against $ 2 to 4 per bbl on shore. At least half a dozen general studies have been made of oil storage in cavities/chimneys created by contained nuclear explosions and these suggest that costs as low as $2 per bbl might be achieved even beneath the seabed. Storage as cheap as this could be of tremendous help to both the countries of Western Europe and individual oil companies as an aid in the exploitation of fields on Continental Shelves and in the provision of strategic reserves close inshore. The potential economic and political benefits are sufficiently high to justify a detailed evaluation of oil storage beneath the seabed off the West European seaboard.

A more detailed assessment of the current position on offshore oil storage is given in Appendix A.

The Proposal

The sponsor should support a detailed evaluation of nuclear oil storage beneath the seabed of the West European Continental Shelf as an aid in the exploitation of offshore fields and as a means of providing strategic reserves. Terms of reference should be along the following lines:

1. To assess the feasibility, safety and economics of offshore oil storage in cavities/chimneys created by contained nuclear explosions beneath the seabed of the West European Continental Shelf for both oil field development and strategic storage inshore.

2. To identify any technical difficulties currently preventing the creation of such offshore storage indicating ways in which these might be overcome and the likely cost of the necessary work.

3. To prepare a detailed plan for the development of such storage at one particular site preferably of practical interest for current or projected oil field development.

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* 1bbl = 1 barrel (American) = 5.6146 ft^3 = 0.15899m^3. A long ton of crude oil occupies about 7½ barrels.

The Form of the Evaluation

The evaluation could probably be undertaken in 15 to 18 months. It would be likely to involve contributions from something like 50 people totalling 12 to 15 man years of effort and costing £200,000 to £250,000. The main participan would be a major oil company with good offshore experience, preferably in the North Sea, and AWRE, Aldermaston as experts in the effects of nuclear explosions. But it would also be necessary to involve Government Departments, particularly the; Department of Trade and Industry (DTI) and its Petroleum and Atomic Energy Division:

A detailed breakdown of the tasks involved and how they might be tackled is given in Appendix B. In view of the wide range of interests and disciplines involved the first month of any evaluation should be devoted to preparing a firmer plan and a critical path programme having the agreement of the sponsor, all participants and the project manager.

It should be noted that for political and security reasons the supply of nuclear explosives should be considered and funded as a separate exercise, which would include consideration of meeting the requirements from American sources. A commercial sponsor of the evaluation would (should) not be called upon to meet the costs of this separate exercise.

The outcome of the Evaluation and likely Benefits to Participants

If the evaluation proceeds in accordance with the terms of reference then after 18 months there should exist an assessment of the potential of nuclear offshore oil storage supported by fairly detailed technical data. In the event that the assessment is optimistic it should be possible to construct usable storage offshore within the following three years. The likely benefits to participants can then be seen as follows:-

1. The Sponsor

The sponsor would aquire the position and ability to act as project manager/financier of nuclear offshore oil storage projects on the basis that profits can justifiably be high for this high risk technology.

2. Oil Companies

The oil company(ies) involved would be well placed to exploit offshore fields not only in the West European Continental Shelf but throughout the world. As prospecting moves further offshore the need for offshore loading of oil will increase since pipeline exploitation will become increasingly uneconomic. The trend to seabed completion of production wells may also increase the attractiveness of storage beneath the seabed.

3. The Nation

Any means of improving the exploitation of offshore oil around the British Isles should ultimately benefit the nation. But the potential benefit is large, particularly when the possibility of inshore strategic storage is taken into account. The countries of Western Europe in general and the enlarged European Economic Community in particular are likely to regard the Continental Shelf oil as a "European" resource. Although the present North Sea discoveries may possibly meet present United Kingdom requirements (about 100 million tons per annum) by 1980 this is a long way short of meeting the then total West European requirement. In view of the present policy of the Organisation of Petroleum Exporting Countries (OPEC), now possibly to be actively aided by the major international oil companies, a major increase in European strategic oil storage facilities could be required during the next few years to strengthen the negotiating position on imports from extra-European sources The increasing demand on seaboard land for all purposes,including recreation,make storage on land increasingly unattractive - the answer could lie in storage beneath the seabed some 15 to 20 miles offshore and this would also allow the possibility of direct discharge from the largest tankers.

4. AWRE

AWRE would increase its knowledge and competence in the field of nuclear explosive engineering and could look forward to playing an important role in any project which developed from the evaluation.

APPENDIX A

Oil Storage Beneath the Seabed in Cavities/Chimneys Created by Contained Nuclear Explosions

A. INTRODUCTION

1. It is now clear that oil from offshore fields in the North Sea and possibly elsewhere on the West European Continental Shelf will play a significant role in meeting the energy and raw material needs of the United Kingdom and other European countries during the next twenty years. Despite the early apparent pessimisim of the oil companies major discoveries have been made in the northern part of the North Sea and considerable effect is now being devoted to the development of the various fields. It has recently been estimated that the total cost of developing the full capacity of gas and oil fields in the North Sea will be £1500 - 2000 million(1). At this order of expenditure there is every incentive to examine possible new solutions to the production, transportation and storage problems which are involved. Underground cavities created by contained nuclear explosions may be capable of providing suitable storage for crude oil and liquid petroleum and petroleum products either on land or beneath the seabed. Although the detonation of a nuclear explosive deep underground should not lead to any immediate release of radioactivity it will produce some seismic energy which can lead to structural damage in buildings relatively near to the explosion point. The urban character of much of Britain is therefore not generally conducive to underground nuclear explosions on land and it is in the creation of oil storage beneath the seabed that the technology of peaceful nuclear explosions may be helpful in offshore oil development programes.

2. The storage of oil in cavities/chimneys created by contained nuclear explosions has been examined in several paper studies (2,3,4,5,6,7,8,9,10). Many of the resulting costs estimates are of order $ 1 per bbl* as compared with $ 5 to 11 per bbl for conventionally mined cavity storage and $ 11 per bbl or more for seabed storage in concrete or steel vessels; indeed the only clear competitor to

*1 bbl = 1 barrel (American) = 5.6146 ft^3 = 0.15899m^3
For a typical oil specific gravity of 0.85 ,1 long ton = 7.54 barrels and 1 tonne = 7.42 barrels.

such a low figure is storage in leached-out salt cavities, where geology allows their construction. The apparent substantial price advantage of nuclear cavity storage is sufficient to warrant detailed examination of the concept notwithstandin the difficulties of feasibility, safety, public relations and the like which come readily to mind, particularly on a first encounter with the idea. Even with existing knowledge a more detailed examination reveals that many of these problems can be overcome (whilst those that remain do not necessarily arise from the use of nuclear explosives, per se).

3. In the light of this situation the time is now ripe for a detailed study of nuclear oil storage on the West European Continental Shelf - a look based on evaluations of specific sites and a realistic assessment of all the outstanding problems involving both nuclear and non-nuclear technologies, public relations, political considerations and the like.

B. PRINCIPLES OF OIL STORAGE IN OFFSHORE NUCLEAR CAVITIES AND CHIMNEYS

4. The principles involved in the storage of oil in nuclear cavities and chimneys are simple[9]. A contained nuclear explosion in the energy range 25 to 100 kt* is carried out in a suitable geological medium beneath the seabed. There results a roughly spherical cavity with a volume which may be conservatively estimated as 100,000 ft^3 (say 3,000 m^3 or 20,000 barrels) per kiloton of explosive yield for moderate emplacement depths. This may undergo partial upward collapse to give a nuclear chimney in which the equivalent void space occurs between the broken rock within the chimney. Under appropriate geological conditions the cavity/chimney provides competent storage for crude oil/liquid petroleum and petroleum products. The cavity/chimney is accessed at the top by re-entry through the emplacement hole and near the bottom by a second hole which serves as a hydraulic line. After the storage system has been flushed of residual radioactivity under controlled conditions it is operated with the help of seawater displacement. Oil driven by tanker and/or loading platform pumps displaces seawater when the storage is filled. When oil is withdrawn the differential pressure of water and

* kt = kiloton. 1 kiloton (10^{12} calories or 4.18×10^{12} joules) is the approximate energy release from the detonation of 1,000 tons of TNT.

and oil aids in the transfer process.

5. A storage system may involve several cavities/chimneys and may be sited close to the shore as a substitute for on-land store or at a distance as an adjunct to an offshore field or as an aid to tanker-tanker transfers.

C. PREVIOUS EXAMINATIONS OF NUCLEAR CAVITY/CHIMNEY STORAGE FOR OIL

6. The earliest writings on underground oil storage using nuclear cavities and chimneys appear to be those of [redacted][2,3,4]. He pointed to the apparently large cost advantage of underground nuclear storage. For a 100 kt explosion in tuff [redacted] derived an oil storage cost of about \$ 0.18 per bbl, very cheap in comparison with both surface storage at \$ 2 per bbl and mined caverns at \$ 4 per bbl, but he clearly ignored or underestimated the substantial conventional engineering costs associated with the commissioning of the storage following the nuclear explosion. The main difficulties of the concept were identified as:

(a) flow characteristics of the cavity/chimney rubble/void system

(b) residual radiation

(c) temperature of the storage cavity/chimney.

7. In 1966 the use of storage as an aid to the development of offshore fields was discussed by [redacted][5] who noted that storage capacity for 10 days average production is usually sufficient to maintain steady production of wells. Such storage may be onshore or offshore depending on the field production system. Typical costs were quoted as \$ 10 to 15 per bbl rising to as high as \$ 30 to 40 per bbl but without making clear what part, if any, of any pipeline costs were included in these figures. [redacted] suggested nuclear storage costs of less than \$ 10 per bbl based on a 100 kt explosion at 1524m depth giving 1.3 million bbl of storage (compare Carlson's estimate that 100 kt at an unspecified depth will give 7 million bbl of storage, a figure which can now be seen as a considerable overestimate).

8. A more detailed study of oil storage in nuclear cavities/chimneys was made by Lockhead Missiles and Space Company (LMSC) in 1967[6,7]. Based on explosive yields varying from 11 kt to over 1 Mt storage charges ranged from \$ 3.75

per bbl at the lowest yields (for 0.5 million bbl) down to $ 0.14 per bbl at the highest yields (for 25 million bbl). An extra $ 3 million of costs might be incurred for an offshore location leading to costs ranging between 10 dollars/bbl and 0.28 dollars/bbl. The report LMSC-699462 (6) formed the basis for a presentation made at Dallas on 26 October 1967 to about two dozen petroleum companies including British Petroleum (BP). LMSC proposed a joint $5 million experiment but this did not proceed. The principal LMSC expert on peaceful nuclear explosions (PNE) at the time was [redacted], Manager Nuclear Expolsives Applications Programs. Work appears to have continued into 1968 since reference 7 contains additional information on offshore storage. For 1 million bbl capacity costs vary from $5.2 per bbl in 100 ft of water to $7.0 per bbl in 300 ft of water; for 2 million bbl capacity the costs are $2.7 per bbl and $3.6 per bbl respectively.

9. British Petroleum have had an interest in nuclear cavity/chimney oil storage since at least 1966 when there were informal discussions between [redacted] of AWRE and [redacted] of BP. After the LMSC Dallas symposium, and the light of their discussions with representatives of AWRE and CER Geonuclear, BP made an appraisal of the possibilities and a report was prepared by [redacted] of the Civil Engineering Division under the direction of [redacted] (8). This was based on the Ketch gas storage study (11) but generally makes rather pessimistic assumptions for the available void volume (1972 data suggest at least 100,000 ft^3 per kt in competent rock). Estimated costs varied from $0.68 to 1.70 per bbl at 100 kt to $4.81 per bbl at [redacted] as against $0.9 per bbl in leached-out salt caverns at Wilhelmshaven and a slightly lower figure at Manosque, all figures relating to storage underground on land.

10. In May 1969 the Mersey Docks and Harbour Board announced plans to develop an oil tanker terminal in Liverpool Bay capable of handling million ton tankers. This involved an artificial island 11 miles off the Welsh Coast. Over the next 15 months there were a number of discussions between representatives of the Board and of AWRE on the possibility of providing the suggested 1½ million tons

or more of storage in the form of nuclear cavities/chimneys beneath the seabed[12] and a certain amount of assessment work was undertaken by the Board's engineers. A major user of the terminal would have been Shell but this company now hopes to meet its requirements using a single buoy mooring scheme near Amlwych in North east Anglesey. The Board's scheme appears to have been abandoned on cost grounds, no doubt influenced by its general financial difficulties.

11. The most comprehensive review of oil storage in nuclear cavities/chimney appears to be that published by [redacted] early in 1970[9]. They consider two types of offshore system - crude oil storage about 12 miles off the coast and close to a major oilport and a rapid access crude oil storage system for the exploitation of an offshore field that is so far from the nearest shore that a pipeline to the coast would not be an economical proposition. In the first case a 26 million bbl storage is estimated to cost $1.08 per bbl as compared with $2.80 per bbl for a 4½ million bbl tank farm facility constructed for BP in Rotterdam. In the second case, evaluated for Persian Gulf conditions, 6 million bbl of storage costs $1.28 to 1.63 per bbl as compared with $14 per bbl for a 15,000 ton steel and concrete seabed storage facility holding 500,000 bbl. Alternative systems have costs of $10 per bbl up.

12. A more recent study is that by [redacted][10] of the Explosive Excavation Research Laboratory operated by the US Army Corps of Engineers at Livermore, California. Nuclear explosion cavities involving void volumes of 50,000 to 250,000 bbl and explosions with yields in the 1 to 10 kton range are considered with the general objective of providing secure "hardened" storage facilities for petroleum products. This study does not give overall cost estimates but does contain a wealth of information on the technical problems involved, particularly storage integrity and operation.

13. The French are known to have given serious consideration to using nuclear explosives to provide under the seabed oil storage at Le Havre[13] and CER Geonuclear were apparently involved in feasibility studies during 1970. During

a conference held in Grenoble in May 1970 maximum charges of 10 kt within 10 km of the town were mentioned. Calculations of oil storage volumes, probably made in connection with this project, have been published by [redacted][14].

14. It seems likely that a number of oil companies and other organisations have already looked at the question of oil storage in nuclear cavities/chimneys in the North Sea. During a meeting organised by the Hudson Institute and held in Venice, 9-14 January 1972 [redacted] President of Geonuclear Nobel Paso said that North Sea oil storage made by nuclear explosives would cost $10 per bbl under the most pessimistic assumptions as compared with $20 per bbl for conventional storage. In private discussions [redacted] claimed that Geonuclear Nobel Paso had not yet approached any oil company but had been looking hard at the programming of possible well/store/tanker systems to take into account the lower flow rates from storage as against those from producing wells; he felt they had solved this problem

C. THE NORTH SEA OILFIELDS

15. The map in figure 1 shows the location of most of the North Sea oil and gas fields announced up to September 1972. The pace of exploration and the incidence of success are both so high that any general account is outdated in a very short time. The International Management and Engineering Group which have been employed as a consultant to the United Kingdom Government estimated in August 1972 that fields within the British sector would be producing 2.1 to 2.6 million bbl of oil per day by 1980 (about 100 to 130 million tons per year). By February 1973 they had been forced to uprate this figure to 3 to 4 million bbl/day (150 to 200 million tons per year)[15]. As is well known most of the oil fields lie north of the 55th parallel of latitude where the weather conditions are a good deal more difficult than those experienced around the more southerly gas fields.

16. The Auk field in block 30/16 (British Sector) has been discovered by a Shell/Esso partnership. Initial production is planned for mid 1974 using a production platform with facilities to load tankers from two single-buoy moorings[16]

No buffer storage is to be provided and when a tanker is not available to take crude oil the wells will be shut in. Average field production is likely to be about 40,000 bbl/day (2million tons per year) with two 66,000 ton tankers shuttling to and from Shell's Teesport refinery[17].

17. The Brent field (also Shell/Esso) is in block 211/29 some 120 miles north east of Lerwick, Shetland. Production facilities are being designed to survive storm waves 100ft high and wind gusts of 160 mph. The reserves total about 1 billion bbl and it is hoped to produce oil by mid-1975. Initially the oil will be shipped by tanker direct from the field where the platform - to be errected in summer 1974 - will be capable of producing up to 100,000 bbl/day (5 million tons per year). In this case a SPAR floating storage and loading unit will be used with a storage capacity of 300,000 bbl (3 to 4 days production) allowing for periodic loading by 70,000 ton tankers for delivery to refineries. Further production platforms - presumably of similar performance - are likely to follow in 1975 and 1976. More tentative plans include the possibility of providing platform oil storage allowing loading of oil tankers or alternatively of piping the oil to Shetland where a large tank farm would need to be operated[17]

18. The Ekofisk field in block 2/4 was the first major field to to discovered in September 1969. Phillips and Amoco are the major companies involved in what is now the Ekofisk Group of fields involving not only Ekofisk but also Torfield, Eldfisk, West Ekofisk, S E Torfield and Edda. A long debate took place on how Ekofisk should be developed but it has now been agreed that a 220 mile 36 in. diameter pipeline will be laid to a new Teeside oil terminal[18]. Initial pipeline production will be 15 million tons per year but this will increase as the nearby fields are developed. At May 1973 tanker production was running at 40,000 bbl/day (2 million tons per year) but this should increase substantially if and when the million barrel concrete storage vessel is brought into use at the field. Designed by the French firm C G Doris and built at Stravanger this vessel began its journey to the Ekofisk field on 21 June 1973. Detailed descriptions have been given by de [redacted][18] and by [redacted][19].
The total cost of the unit is at least $23 million[19] and a figure of

$28 million has been given fairly recently[20]. At $23 to 28 per bbl the storage is very expensive compared with more conventional systems on shore.

19. That part of the Forties field in block 21/10 (British sector) is an exclusively BP discovery and they have launched a £160 million first-stage development programme for the field[21]. The first stage involves production from two platforms expected to reach 250,000 bbl/day (over 12 million tons a year) by late 1975 The second stage involving a third and possibly a fourth platform should bring output to 400,000 bbl/day (20 million tons a year) by the late 1970s. The oil will be landed at Cruden Bay, near Peterhead by a 115 mile 34-inch pipeline laid in water depths of up to 420 feet. From here oil will flow through a 140-mile, 36-inch onshore pipeline to BP's Grangemouth refinery (expanded from 9 million to 19 million tons a year capacity by late 1974). A new crude oil terminal capable of handling 250,000 dwt tankers will be built on the Firth of Forth. The seabed pipeline is likely to cost £¾ million a mile[22]. There have been suggestions that BP will eventually seek to co-operate with other companies to cut this huge cost with branch pipelines linking up to the main pipeline. The Forties field extends eastward into the Shell/Esso block 22/6 and these firms may participate in the second stage of the development. It is worth noting that BP apparently gave serious consideration to a totally marine solution to the problem of exploiting the Forties field. All oil would have been produced from wells completed on the seabed, treated and loaded at sea with intermediate storage to cushion the effect of weather on loadings at sea[21,23].

20. Of the remaining fields Montrose (Amrco/Gas Council) may possibly be developed in conjunction with Forties from November 1974 onwards whilst the small Dan field in the Danish sector is being produced using tankers. There are still many fields where neither the full commercial potential nor production plans have been revealed - Argyll (Hamilton in block 30/24), Beryl (Mobil/Gas Council in block 9/13), Cormorant (Shell/Esso in block 21/26), Dunlin (Shell/Esso in block 211/24 110 miles north east of Shetland), Halibut (Signal in block 211/18) Heimdall (Petronord in Norwegian block 25/4), Maureen (Phillips/Petrofina in block

16/29) and Piper (Occidental, 130 miles N.E of Aberdeen).

D. ALTERNATIVE METHODS OF STORING OIL OFFSHORE

21. There are several existing methods of storing oil; some are well-established but others have only been developed to meet special requirements and their use is far from widespread. Experience of storage on or beneath the seabed is still very limited. Underground storage on land is more widespread but the common storage method is still epitomised by the familiar tank farm where the storage vessels are partially or wholly above ground.

22. Storage in leached-out salt caverns is available in both France and Germany. At Manosque (NNE of Marseilles) there are 20 caverns of 250,000 m^3 (1,575,000 bbl) each constructed at a cost of approximately $0.8/bbl (inclusive of 92 km pipeline). At Wilhelmshaven there are 10 caverns of 200,000 m^3 (1,260,000 bbl) each costing approximately $0.9/bbl (inclusive of 5 km pipeline). A further 8 caverns of 300,000 m^3 are planned for a salt dome at Blaxen near Nordenham in the Weser estuary and the costs are expected to be about DM25 per m^3 ($1.25 per bbl)[24]. This type of storage has also been used for liquefield petroleum gases, particularly in Canada[25] and in France, where there are three cavities for the storage of liquid propane gas in the Lavera(?) area[26]. According to reference 9 leached salt storage costs between $1 and 2½ per bbl.

23. Mined underground caverns are used quite extensively for oil storage in Scandanavia[25, 27, 28, 29]. Of particular relevance to the use of nuclear cavities/chimneys for oil storage are the techniques developed to use caverns which are not particularly fluid tight. The cavern is sited far enough below the water table so that small amounts of water seep slowly into the storage space through fractures and fissures. Since the density of the stored product is less than that of water, only minor amounts of product are lost. Fluid levels are maintained by removing leakage water at required rates.

The development of this technique means that fluid tight storage can be developed both in competent impermeable rock or in certain types of permeable rock below the water table as discussed in reference 10.

In Sweden, home of Sentab, the leading firm in the field, mined underground caverns provide a cheaper form of storage than above ground tank farms at volumes of about 30,000 m^3 (or 200,000 bbls). Svenska Shell have a 500,000 m^3 installation at their Gothenburg refinery. Acccording to reference 9 mined cavern storage costs between $5 and 11 per bbl.

24. A comprehensive review of floating and submerged offshore storage systems has been made on behalf of the Construction Industry Research and Information Association (CIRIA) Underwater Engineering Group[19] 13 major floating units had been installed by mid-1972; capacities range up to 1800 million bbl. These systems are unsuitable for bad weather areas such as the North Sea.

25. Small submerged storage units have been operating in the Gulf of Mexico for ten years or more. The only operational or near operational units of any size are those at the Dubai field in the Persian Gulf and at the Ekofisk field in the North Sea.

26. A completely self-contained offshore producing, storage and loading system is operational at the Fateh field, some 60 miles offshore the Shiekdom of Dubai in the Persian Gulf; water depths range from 110 to 180 ft[30]. Storage volume was based on 5 days production plus the capacity of a 70,000 dwt tanker. The storage vessel consists of a 15,000 ton steel structure 270 ft in diameter and 205 ft high which holds 500,000 bbl of oil; a central stem rises above the water surface. The tank is operated on the displacement principle with water being expelled by oil when filling and the reverse when unloading. The control of the oil-water interface to prevent pollution and the removal of sludge - a problem in all storage tanks - are satisfactorily allowed for in the design and in the operating procedure. Estimates made in 1967 show that for a producing rate of 100,000 bbl/day involving a 500,000 bbl storage vessel total capital costs are $25.76 million of which the storage vessel takes $11.66 million or $23.32 per bbl. However according to [redacted][9] the storage cost was $7 million

or $14 per bbl - a figure also quoted in the CIRIA report [19]. Two similar units were due to be added to the facility during 1972.

27. The Ekofisk storage has already been mentioned in paragraph 16. Installation was due in mind-1972 and the project is already over a year behind schedule. Reference 19 summarises proposals for other submerged storage systems including those by the Elf-Erap sponsored Sea Tank Company. Commercial versions of the latter might cost $10 to 13 per bbl.

28. In a talk to the Science and Technology Society of Scotland on 19 September, 1971, [redacted] Director, Centre of Industrial Innovation, University of Strathclyde stated that ideas for the design and construction of offshore islands were under consideration within his organisation[31]; presumably storage would be included in these studies.

APPENDIX B

Tasks involved in a Detailed Evaluation of Oil Storage in Offshore Nuclear Cavities and Chimneys

A convenient classification of problems considers five main heads:

Feasibility	-	can cavities and/or chimneys be created which will hold oil and from which oil can be conveniently recovered?
Operations	-	waht problems will arise in constructing and operation the storage?
Safety	-	can safety problems be solved?
Political and public relations	-	what governmental action will be needed and what public relations problems will arise?
Economics	-	what are the overall economics taking into account costs arising from the technical and political problems and overall oil recovery costs?

The problems which are likely to require consideration and the effort involved are as follows:-

~~COMMERCIAL IN CONFIDENCE~~

Problems	Possible Approach	Participants and Professional man - months required
1. Geology - general geology of possible sites - more detailed geology of site chosen for detailed examination	A. FEASIBILITY Evaluate known geological data Consider what further geological exploration would be required at site chosen for detailed examination.	Oil company, AWRE, DTI, Institute of Geological Sciences. 6 man-months
2. Drilling - will it be possible to drill all necessary emplacement and re-entry holes from one fixed platform which can be used in production system?	Appraisal of large diameter drilling possibilities beneath the seabed.	Oil company. AWRE to advise on likely diameters required. This question could be of wider interest than oil storage beneath the seabed. 3 man-months
3. Number of cavities Uncertainties in volume.	a. General in relation to volume of storage required. b. Detailed calculations for particular site selected for general suitability and known geology.	AWRE ½ man-month AWRE to make calculations on basis of information supplied by oil company and DTI from their North Sea knowledge. Volume uncertainties much easier to delineate for specific site. 2 man-months
4. Oil-flow dynamics of rubble filled chimneys. Can chimney be filled and emptied in reasonable time?	Investigate permeability of chimney and fluid flow through permeable media. Experiments may be required.	AWRE and oil company drawing on experience of latter in reservoir calculations. 6 man-months
5. Integrity of storage against leakage of oil	a. General b. For specific sites	Companies with experience of underground storage. AWRE to supply data on properties of nuclear cavities/chimneys. 3 man-months
6. Sludge deposit Surface tanks have to be cleaned periodically to remove waxy deposits. Similar deposits in nuclear chimney may clog the flow channels.	Combine available knowledge of sludge in surface tanks with known properties of rubble in nuclear chimneys and experience of oil storage in mined caverns.	AWRE and oil company. Although this is a potentially serious problem a solution ma[y] be possible particularly at the relativel[y] high ambient temperatures which may be attained in nuclear chimney/cavity storag[e] 18 man-months.

Problems	Possible approach	Participants and Professional man-months required
7. Operating System - pumping requirements, separators, method of operation. Interlocking of cavities.	Assessment by refinery engineers etc. Operational research study.	Oil company. 6 man-months
	B. EXECUTION	
8. Supply of Nuclear explosives - type, special requirements (e.g refrigeration)	Determine sources and costs. Adaption of UK service explosives?	This would be a separate study by AWRE in conjunction with Government Departments involving 3 man-years and paid for separately.
9. Weather effects	Examine influence on time schedule - rough seas etc and on firing conditions - prevailing winds, currents etc.	oil companies for rig operations AWRE for firing of explosives. 2 man-months
10. Control and firing system	Survey possible schemes	AWRE 3 man-months

Problems	Possible approach	Possible participants in examination
	C. SAFETY	
11. Containment of explosion	Assessment of possible sites with safety criteria. Assess stemming methods.	AWRE with geological help and help from drilling experts on stemming holes drille through seabed. 6 man-months
12. Effects of Venting	Look at blast effects, if any, and dispersion of radioactivity in sea and atmosphere. Determine safe firing conditions.	AWRE. 6 man-months
13. Seismic effects	Assess sea waves, ground motion, possible damage to ships, rigs etc. Shore installations (near shore systems).	AWRE 3 man-months
14. Purging of cavity/chimney	Assess purging by air, natural gas, sea water etc, including time taken, in relation to type of explosive used.	AWRE 15 man-months
15. Oil pollution	Assessment of possibilities under normal and abnormal operating conditions.	Oil companies. 3 man-months
16. Contamination of Stored Oil	Assessment in light of knowledge of likely residual activity and Russian/US experience on gas and oil stimulation.	AWRE and oil companies. 18 man-months

Problem	Possible approach	Possible participants in examination
	D. POLITICAL	
17. International Law relating to operations outside territorial waters.	Examine in light of Partial Test Ban Treaty etc.	AWRE/Foreign and Commonwealth Office. 3 man-months spread over 12 to 18 months
18. Safety clearance - how will this be arranged.	Look at arrangements for nuclear power stations, North Sea rigs etc.	AWRE/DTI. 3 man-months spread over 12 to 18 months
19. Supply of nuclear explosives	See under B	
20. Public Relations	Consider how project might best be explained to general public.	AWRE/Oil companies/DTI. 3 man-months spread over 12 to 18 months
21. Insurance	Consider how insurance would be arranged.	AWRE/Oil companies/DTI. 3 man-months spread over 12 to 18 months

Problem	Possible approach	Possible participants in examination
	E. ECONOMICS	
22. Competing Systems	Examine economics of pipelines, washed caverns in salt beneath seabed. Seabed and floating tanks etc.	Oil companies 6 man-months
23. Construction time	Examine timetables for pilot scheme and for routine installation.	AWRE/Oil companies. 12 man-months
24. Examination of near shore and far offshore systems	Estimate costs and benefits	AWRE/Oil companies. 12 man-months

Total effort in terms of man-months = 142½. Costed at £15,000 per man year gives a total cost of about £180,000. Allowing for contingencies and possible additional experimental equipment gives the final estimate of £200,000 to £250,000.

APPENDIX C

Basis for the Professional Man-Month Figures of Appendix B

During the second half of 1972 estimates were obtained from all AWRE superintendcies likely to be involved. The breakdown of the figures and their sources are as follows:

Appendix B Item	Effort Required, professional man-months
1. Geology	SDO 2. IGS + Oil companies. 4 estimated
2. Drilling	Oil company. 3 estimated. Small effort from SPA1 and SDO.
3. Cavity volume	SSDM 2½
4. Oil flow dynamics of rubble	SSDM 1 or 6. It seems likely that the oil company would provide the main effort here. 6 units allowed in all.
5. Integrity	SSDM estimate under 4 includes this item. 3 units allowed giving 9 units for 4 and 5 together.
6. Sludge deposit	SCE 9. A similar amount has been allocated to the oil company giving 18 units in all.
7. Operating system	Oil company 6 estimated
8. Supply of nuclear explosives	Separate study by AWRE/UKAEA etc involving 3 man-years.
9. Weather effects	SDO 2
10. Control and firing system	SPA1. 3
11. Containment	SDO 2. 6 allowed in all.

Appendix B Item	Effort Required, professional man-months
12. Venting effects	SSDM 1½ for calculation of upward extent of rock cracking. SRGS 36 - for assessment of effects if material gets into sea (will presumably cover some of work for item 14 as well).
13. Seismic effects	SSDM ½ (sea waves) SSDM 1 (ground and water shock damage)
14. Purging of cavity/chimney	SCE 9 SRC 1½ SSDM 1 SRGS 3
15. Oil Pollution	Oil company 3 estimated
16. Contamination of stored oil	SCT 12 SRC 1½ SRGS 3 Oil company say 1½
17. International Law	Arbitrary estimate of 3
18. Safety clearance	Arbitrary estimate of 3
20. Public relations	Arbitrary estimate of 3
21. Insurance	Arbitrary estimate of 3
22. Competing Systems	Oil company 6 estimated
23. Construction time	AWRE/Oil company 12 estimated Mostly oil company
24. Near and far-shore	AWRE/Oil company 12 estimated Mostly oil company

<u>Sources of information</u>

SCE	Note of 31.8.72
SCT	CTD/CRT/41
SDO	SDO/300 of 20.9.72
SPA1	SPA1/S18/12
SRC	SRC/72/41 of 15.9.72
SRGS	SRGS/850
SSD	SSD/29/3
SSDM	GCS/C/72/10 of 25.8.72

[redacted] to [redacted]

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COMMERCIAL IN CONFIDENCE

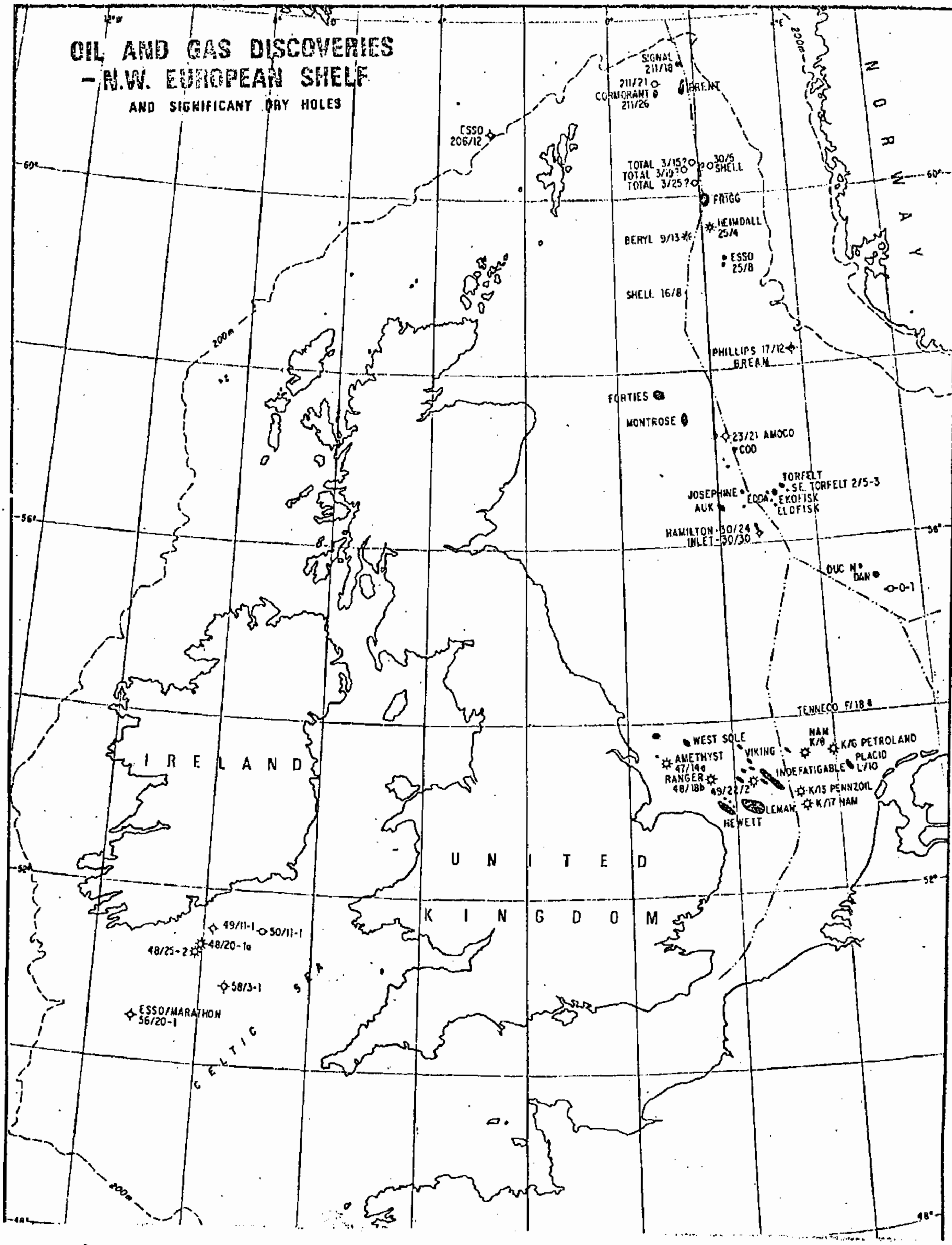

Figure 1. Principal Oil and Gas Fields in the North Sea

COMMERCIAL IN CONFIDENCE

Distribution

Members

CPA
SSDS
SBME12
SDR
SRC
SDO
WD5
SRGS
SSD
[redacted]

[redacted]
SDO
SCE
SSCT (GL/OM)
Army Element
SRC
SSDM
SSDM
SMF

Others

Director
CMP
SSCD
SSCT
[redacted]

[redacted]
SSDM
SCT
SDO