NUVIA	**MPOS Study Data Report** [redacted]	89330/PDT/TAF 6/006 Issue C Jul 2010 Page 1 of 33

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This document has been released as background information to support the Submarine Dismantling Consultation (28 Oct 2011 – 17 Feb 2012). It has been redacted in order to protect:

- **personal information; and**
- **information that could compromise UK Defence or National Security.**

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Nuvia Limited, Kelburn Court, Daten Park, Risley, Warrington, WA3 6TW
Tel: 01925 858200 Fax: 01925 811866
Email: Info@nuvia.co.uk
www.nuvia.co.uk

GLOSSARY OF TERMS

COEIA	Combined Operational Effectiveness Investment Appraisal
GDF	Geological Disposal Facility
ILW	Intermediate Level Waste
LLILW	Long-lived Intermediate Level Waste
LLW	Low Level Waste
LLWR	Low Level Waste Repository
MCDA	Multi Criteria Decision Analysis
MDAL	Master Data and Assumptions List
MPOS	MoD Proposed Option Study
RC	Reactor Compartment
RPV	Reactor Pressure Vessel
SDP	Submarine Dismantling Project
SLILW	Short-lived Intermediate Level Waste

Note: All text added subsequent to the Desk Officers' workshop is highlighted in grey boxes

CONTENTS

1 INTRODUCTION

1 The UK currently has 27 nuclear powered submarines of which 11 are still in service and 16 have left naval service. The16 redundant submarines are stored afloat, 9 at Devonport Royal Dockyard and 7 at Rosyth Royal Dockyard. Defuelling and preparation of the submarines for afloat storage is ongoing.

2 The original stated intention was to store these submarines afloat for 30 years to allow for the short-lived isotopes to decay. After this time dismantling activities would commence although a recent study has suggested that worker doses may not be unacceptably higher if earlier dismantling took place. Through the submarine dismantling project (SDP), and its precursor the ISOLUS project, the MoD has identified three feasible options for the way in which the submarine dismantling will be managed. All options have the same ultimate end point with the disposal of Intermediate Level Waste (ILW) as packaged waste in the Geological Disposal Facility (GDF). The main differences between these options relate to when and in what form ILW will be produced and the consequent requirements for its safe storage/management prior to disposal. These options are described in Section 2.

3 The GDF is planned to become available after 2040, however it is possible that submarine dismantling waste will not be accepted until many decades after this date, and hence an interim storage period of between 50 and 100 years has been assumed.

1.1 Process

4 The three identified options were first considered during the ISOLUS options study in 2008, where a wide range of external stakeholders were invited to discuss and assess the options [1, 2]. In September 2009, a decision workshop was proposed for MoD stakeholders to assess the identified options; a draft set of criteria was proposed based on the original ISOLUS study [3], which were then subject to peer review [4, 5].

5 In April 2010, the scope of the options study – now termed the MoD Proposed Option Study (MPOS) – was changed to more closely support the sub-COEIA (Combined Operational Effectiveness Investment Appraisal) approach and hence the criteria were again revisited to ensure alignment with the measures of performance. The set of criteria selected were outlined in a technical note [6] and subject to discussion with the MoD Desk Officers.

6 The MPOS utilises a two stage process, as described within the methodology statement [7]. In the first stage, Desk Officers representing the 1* personnel attended a facilitated Multi Criteria Decision Analysis (MCDA) process to assess the technical options. The output of this workshop forms one input to a 1* Approvals Board, which will also consider the investment appraisal work being conducted in parallel.

1.2 Purpose of this report

7 The purpose of Issue A of this data report was to provide relevant technical information and data to those attending the Desk Officers' workshop. This data then formed the basis of discussion at the workshop. Where applicable, some interpretation of the data was also provided. This report

was intended to be a support document to assist in, but not replace, discussion amongst those technical and other experts at the Desk Officers' workshop.

8 It should be noted Issue A [17] of this report was distributed prior to the Desk Officer's Workshop. This version of the report, Issue B, was completed subsequent to the Desk Officers' workshop and incorporates new data presented at the workshop. Where data has been added or modified following the workshop, this has been highlighted within shaded boxes within the text.

An explanation of the technical terminology used within the data report can be found in Section 5.

9 Data is presented in Section 3, organised by criteria.

2 OPTIONS

10 Each of the three options for consideration is described in detail in Sections 2.1 to 2.3, below, and are also displayed pictorially in Appendix 1. Where assumptions have been made these are clearly stated and are consistent with MoD Master Data and Assumptions List (MDAL). Section 2.4 contains summary tables highlighting the most significant points for each of the options. The sequence of activities for each of the dismantling options is based on a series of logical assumptions.

11 For all options the submarine will be transported, if required, from the afloat storage location by sea to the dockyard selected for initial dismantling. There are also three possible means of transporting the submarine by sea to the dismantling dockyard;

- Towing the submarine directly to the dockyard.
- Floating the submarine onto a heavy lift vessel. (This has been a proven method of transport of fuelled submarines in Russia and regularly for transportation of oil rigs.)
- A combination option which involves using a heavy lift ship but removing the submarine a distance form the dock and towing in. (This is a useful option where the depth of water in the dock at the dismantling site is not sufficiently deep to allow the heavy lift ship to berth successfully if this is the chosen method of transport.)

12 The submarine will be transferred to a submarine dismantling area from the sea either by the use of a dry-dock, ship-lift, floating dock or slipway, all of which are routine processes in common use on ship building and refitting.

13 For all options the radioactive and non-radioactive systems must be drained prior to cut-out. Pipework and cables protruding through the RC bulk heads must be isolated and sealed individually and contaminated systems outside of the RC will be wholly removed by cutting and sealing operations within containment tents. All radioactive material removed from the submarine will be transferred to a waste disposal facility. All items removed, will be monitored, characterised and transferred to a suitable waste processing facility for disposal. This work can be carried out utilising existing facilities.

14 For all three options either new or upgraded facilities will also be required, these will consist of; a LLW processing area with individual bays suitable for radiological work. The processing of LLW is

a routine operation utilising simple sorting and cutting techniques with all equipment necessary for this work readily available. Wherever possible the LLW will be transported to waste treatment facilities to be processed using techniques such as shot blasting and smelting to enable recycling of materials. The remaining LLW will be packaged to conform to the Low Level Waste Repository (LLWR) requirements and a robust waste characterisation and monitoring regime will be required to ensure compliance with all LLWR radioactive limits.

15 A ILW processing area will also be required, again with individual bays, suitable for remote and shielded radiological work. ILW processing will require some specialist operations e.g. wire cutting for size reduction which are well understood and practised in the nuclear industry. Mechanical handling of larger pieces of ILW may require specialist equipment which is readily available. The ILW component of the RPV will be removed; size reduced and placed in standard $3m^3$ boxes and sent for interim storage pending consignment to the GDF. A suitable container is required for all ILW box on-site movements with a shielded overpack being required for $3m^3$ ILW box transport to the GDF. Transport of the shielded overpack containing $3m^3$ ILW boxes will be via a specialist haulage contractor or by rail depending on the location of the dismantling facility and the GDF for final disposal.

2.1 Option 1 – Storage of intact Reactor Compartments

16 This option (also sometimes termed the Cut-Out Option) involves cutting out the entire reactor compartment (RC), which effectively means taking a “slice” from the centre section of the submarine, and placing it in storage until the planned national GDF becomes available. The RC would serve as the interim storage and transport container. When the GDF is able to accept the submarine dismantling waste, the RC will be dismantled and all waste which has been classified as ILW will be packaged into containers suitable for disposal in the GDF and the containers are then transported for final disposal. Processing, packaging and disposal of Low Level Waste (LLW) at the national Low Level Waste Repository (LLWR) will take place at this time also. The storage of intact RC is the approach taken by USA, Russia and France (although the latter may now be moving towards earlier dismantling). The option is summarised in Figure 2.1, below, and then discussed in more detail.

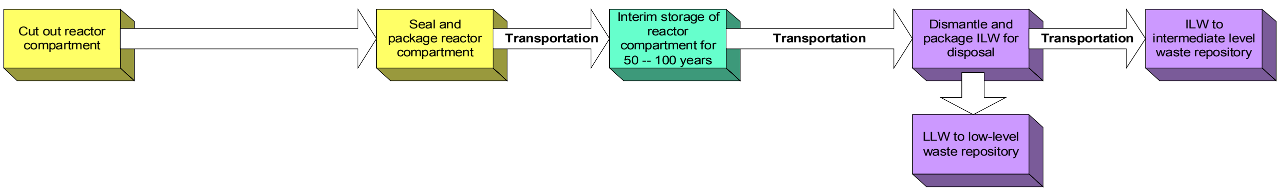

Figure 2.1 – Option 1 Storage of Intact Reactor Compartments

17 Prior to cut-out of the RC, a simple non-seismic cradle will be fabricated and welded to the underside of the RC to provide support during separation from the hull, transportation and storage. The construction of the cradle will be based on established technology with no special requirements.

18 A clear path for the hull cuts will be made by the removal of pipes, plant and equipment from the inside of the compartments adjacent to the RC and the removal of the tiles on the outside of the hull. Two cuts through the submarine hull, on either side of the RC, will be made using existing cutting techniques, including hot and cold cutting e.g. oxy/acetylene and diamond wire cutting.

This latter method was used effectively in the dissection of the sunken Russian submarine, the Kursk. The two hull sections on either side of the RC will be pulled away from the RC section using existing ship building and refitting methodologies. Metal plates will be welded onto the ends of the separated fore and aft hull sections and of the RC to seal them The two separated hull sections will be transported to a conventional dismantling site using a heavy lift submersible ship/barge. It is unlikely that the two separated hull sections will be rejoined.

19 The RC must be transported to the interim storage location. The weight of the RC is expected to be up to 1000 tonnes so transportation by road would only be possible over very short distances, possibly on specially constructed or reinforced roads. Transportation over greater distances would be by sea with the RC and its associated support structure being transferred onto a transport ship or barge using existing heavy lifting equipment, such as strand jacks. No additional shielding is anticipated as being required for transportation or storage as the RC would serve as the interim storage container – and would require to be formally justified as a transport container.

20 At the interim storage site heavy lifting/moving equipment will be required to ltransfer the RC and support structure from the ship/barge the short distance from the sea receipt to the interim storage facility. The interim storage facility only needs to be a simple weatherproof building as the RC provides all the necessary radiation shielding and containment. However, the lack of seawater which provides additional shielding around the bottom of the hull may result in higher radiation levels under the RC and access to this area may need to be controlled, similar to that associated with dry docking. The interim store should include a water run-off catchment facility to enable monitoring for contamination resulting from a loss of containment. The facility must be secure and allow the regular inspection and monitoring of the RC's to confirm integrity of hull. Table 1 summarises the RC storage process.

21 The RC's will be stored at the interim storage facility until the GDF is available to receive the waste. It is expected that the GDF will be operational around 2040 and will accept the submarine dismantling waste possibly tens of years after this date. An RC dismantling facility will require construction consisting of a simple steel framed structure with a large open area suitable for radiological work and built-in mechanical handling. The RC must be transferred from the interim store to the dismantling facility, the working assumption being that the dismantling facility will be at the same location as the interim store. Dismantling operations involve well understood remote handling, cutting, containment and lifting techniques and will entirely de-plant the RC. Removal of the Reactor Pressure Vessel (RPV) involves a heavy lift which is consistent with existing capabilities. The dismantling operation will be performed by skilled nuclear workers with the worker dose being strictly controlled throughout the procedure.

2.2 Option 2 & 3 – Removal of RPV

22 Options 2 and 3 both require removal of the RPV from the RC. Option 2 involves interim storage of the RPV prior to dismantling and packaging of ILW for disposal into the GDF. Option 3 involves the early full dismantling of the RPV and packaging of ILW. The ILW packages would then be interim stored prior to disposal into the GDF.

Option 1 Storage of RC	Option 2 Storage of RPV	Option 3 Storage of packaged ILW

23 This section of the report describes the removal of the RPV (common to both Options 2 and 3) and then the specific reqirements for RPV storage (Option 2) and storage of packaged ILW (Option 3).

24 Prior to cut-out of the RPV, a simple non-seismic cradle must be fabricated that the RPV can be lifted onto to provide support during future transportation and storage. The construction of the cradle will be based on established technology with no special requirements e.g. seismic. Environmental containment will be provided for the primary reactor systems and RPV cut out work by constructing a temporary structure that includes a high efficiency, filtered extract ventilation system around the relevant part of the submarine hull. The containment structure would also allow equipments to be removed from the RC.

25 All systems and equipments will be cut, sealed and removed from the RC, the connections to the RPV being sealed individually. All items removed from within the RC, will be monitored, characterised and transferred to a suitable waste processing facility for disposal.

26 As the RPV head is expected to be activated LLW significant size and weight reduction of the RPV is possible by head removal before the RPV is removed from the RC (this is a standard dockyard operation during a refuelling period). This has benefits in handling the RPV and in reducing the amount of material held with the RPV in an ILW store. The RPV can be readily sealed/covered to provide a contained environment. The advantage with separating these portions of the RPV is that the ILW component, requiring long term storage, is reduced enabling the larger volume of LLW to be disposed of earlier. It is important to ensure the LLW portion of the RPV is adequately characterised through sampling and analysis with particular attention being paid to the tritium/carbon-14 radionuclide concentrations as they are strictly regulated by the LLWR. In calculating storage volumes, it has been assumed that this approach is feasible. If the RPV option is preferred this approach will need to be investigated further to confirm its viability.

27 Access through the submarine hull must be made to enable the removal of the RPV. A hole will be cut into the submarine hull either on top or on the side of the RC (depending on the preferred method of removal) using existing ship building/refitting cutting techniques. If the access hole is made through the top of the RC then the RPV will be removed from the submarine using heavy lifting craneage which is routinely used in ship building dockyards. The RPV, which weighs around 50 tonnes (without head), will be craned onto the purpose built cradle. If the access hole is made through the side of the RC then the RPV will be removed from the submarine using jack lifting equipment which is also routinely used in ship building dockyards to slide the RPV out of the RC. The RPV will be transferred onto the purpose built cradle using heavy lifting equipment. Further removal of irradiated structure may be required and metal plates will be welded over all holes cut in the submarine hull to re-establish the submarine watertight integrity using existing ship building and refitting methodologies. The remaining non-radioactive submarine hull will be dismantled using conventional techniques used to dismantle marine vessels to enable the recycling of materials wherever possible after transfer to a suitable shipyard as necessary.

28 The RPV will require transportation to the dismantling facility / interim store so suitable containment for the transportation process and subsequent storage must be established. The containment/transport and storage package should as a minimum provide contamination control as the RPV could still contain some residual sludge or crud which could be released during

transportation. The contact dose rate on the RPV must conform to Road Transport Regulations so the container may require additional shielding to reduce the radiation dose rate to acceptable levels. The RPV will be transferred into the container and onto a suitable transportation vehicle using heavy lifting equipment. Transportation of an irradiated RPV has not been undertaken in the UK to date. The size reduction and dismantling of a submarine RPV has not been undertaken in the UK to date, although it has been undertaken for land-based reactors.

2.2.1 Option 2 – Reactor Pressure Vessel Storage

29 The RPV will be stored at the dismantling facility / interim store in some form of shielded environment, assumed to be the container designed for transportation to ensure compliance with the Ionising Radiation Regulations 1999 (IRR's) until the GDF is able to accept submarine dismantling waste. Table 2 summarises the RPV Storage process.

30 Once the national GDF becomes available, the RPV will be transferred from the interim store to the dismantling facility, using heavy lifting equipment to transfer it, as it is assumed that this will be undertaken at the interim storage site. The stored RPV will then be completely dismantled and the ILW generated suitably packaged and conditioned for transfer for final disposal with LLW monitored, characterised and transferred to a suitable waste processing facility for disposal.

Figure 2.2 summarises this option.

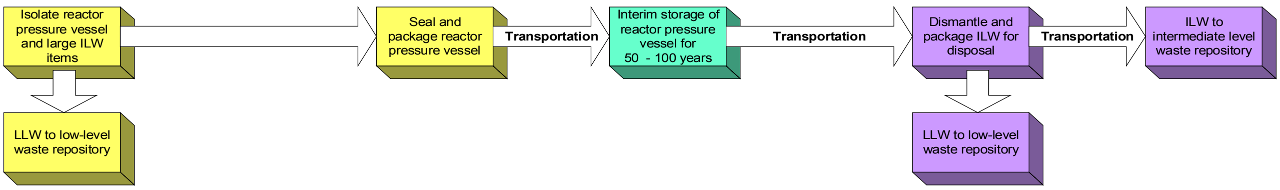

Figure 2.2 – Option 2 RPV Storage

2.2.2 Option 3 - Storage of Packaged ILW

31 This involves early full dismantling of the RPV, segregating the intermediate and low level wastes, prior to interim storage. The ILW would be suitably packaged, conditioned into ILW facility-compliant containers and stored on land before being transferred to the GDF after 2040. Then the packages will be transported for final disposal. This option (also sometimes known as the Cut-Up Option) is summarised in Figure 2.3. It is very similar to Option 2 in that the RPV has to be removed from the RC, the essential difference being that the RPV is then immediately dismantled, the ILW is packaged into disposal containers and sent to an interim storage site, with the LLW being sent to LLWR.

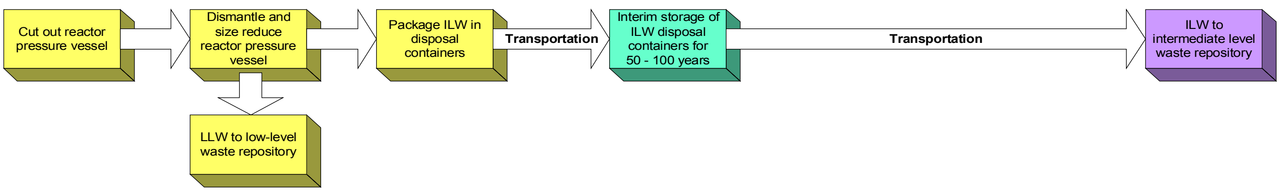

Figure 2.3 Storage of packaged ILW

Option 1 Storage of RC	Option 2 Storage of RPV	Option 3 Storage of packaged ILW

32 It is assumed that these operations will be undertaken on the same dismantling site as the removal of the RPV from the submarine, meaning that no off-site transportation of the RPV is required. Table 3 summarises the storage of the packaged ILW process.

2.3 Summary Tables

33 The following tables summarise the key stages involved for each of the options.

Table 1 : Option 1 Storage of RC

Step	Discussion
Transport to Dismantling Site	The redundant submarine may require transportation from the afloat store to the dismantling site. There are 3 possible means of transporting the submarine: • Towing the submarine directly to the dockyard. • Floating submarine onto heavy lifting vessel. • Using a heavy lift vessel for much of the journey and towing the submarine into the dock.
Dismantling	The entire RC will be cut-out, effectively taking 2 slices either side of RC through the submarine hull, using existing cutting technologies. Metal plates to be welded on ends of RC to seal for shipping.
Initial size reduction to RC	N/A
Dismantling and size reduction of RPV	N/A
Packaging for storage	The sealed RC serves as the interim storage container and will not require additional shielding.
Transport to storage site	Sea transport on barges is the only possibility for transporting the RC to the storage site. Infrastructure requires to be in place to receive the ship and transfer the RC ashore. Transportation of the RC from the dock to the interim store will be required but will only be very short distance by road
Interim storage	The interim store must be capable of storing 27 RC's with the ability to inspect the RC's at regular intervals. Storage for 50-100 years is probably required
Transport to dismantling facility	Once GDF is able to accept submarine ILW, RC to be transported to dismantling site. If the dismantling site is at the same location as the interim storage site then a short transportation by road is possible. If the dismantling site is at a different location to the interim storage site then transportation by sea will be necessary.
Dismantle and package ILW for disposal	Dismantle the complete RC including the RPV and segregate the waste into LLW and ILW. Dismantling will utilise existing technologies using a skilled nuclear workforce. The ILW will be packaged and conditioned in $3m^3$ boxes. Waste characterisation through sampling and analysis must be undertaken prior to conditioning to enable acceptance at GDF.
Transport of ILW packages to GDF	Shielded overpack likely to be required to transport $3m^3$ boxes to GDF depending on transport restrictions
Transport of LLW to LLW repository	Waste characterisation of the LLW, through sampling and analysis, must be undertaken to identify and quantify radionuclides. Packaging of the LLW must be in accordance with the LLWR requirements

Table 2 : Option 2 Storage of RPV

Step	Discussion
Transport to Dismantling Site	The redundant submarine may require transportation from the afloat store to the dismantling site. There are 3 possible means of transporting the submarine: • Towing the submarine directly to the dockyard. • Floating submarine onto heavy lifting vessel. • Using a heavy lift vessel for much of the journey and towing the submarine into the dock.
Dismantling	The RPV will be removed intact from the submarine by cutting a hole in the hull, using existing cutting technologies. All radioactive systems and components will be removed from the submarine and treated appropriately.
Initial size reduction to RPV	It is assumed that, the “head” of the RPV will be removed and the RPV sealed using well understood techniques.
Dismantling and size reduction of RPV	N/A
Packaging for storage	The RPV requires suitable containment for transportation and storage. This containment must satisfy transport regulations and as such is assumed to be also a satisfactory storage.
Transport to storage site	Transportation of the RPV from the dock to the interim store will be required. It is possible that transportation by road is possible provided suitable containment is provided, although this will be an extremely large package. The RPV could also be transported by sea if necessary again using suitable containment.
Interim storage	The interim store must be capable of storing 27 RPV’s in their associated containers with the ability to inspect the RPV’s at regular intervals. Storage for 50-100 years is probably required.
Transport to dismantling facility	Once GDF is able to accept submarine ILW, RPV will be transferred to dismantling site. If the dismantling site is at the same location as the interim storage site then a short transportation by road is possible. If the dismantling site is at a different location to the interim storage site then transportation by road is a possibility provided the containment conforms with the road transportation regulations at that time or possibly transport by sea will be necessary.
Dismantle and package ILW for disposal	Dismantle the RPV and segregate the waste into LLW and ILW. Dismantling will utilise existing technologies using a skilled nuclear workforce. The ILW will be packaged and conditioned in $3m^3$ boxes. Waste characterisation through sampling and analysis must be undertaken prior to conditioning to enable acceptance at GDF.
Transport of ILW packages to GDF	Shielded overpack may be required to transport $3m^3$ boxes to GDF depending on transport restrictions.
Transport of LLW to LLW repository	Waste characterisation of the LLW, through sampling and analysis, must be undertaken to identify and quantify radionuclides. Packaging of the LLW must be in accordance with the LLWR requirements.

Table 3 : Option 3 Storage of packaged ILW

Step	Discussion
Transport to Dismantling Site	The redundant submarine may require transportation from the afloat store to the dismantling site. There are 3 possible means of transporting the submarine: • Towing the submarine directly to the dockyard. • Floating submarine onto heavy lifting vessel. • Using a heavy lift vessel for much of the journey and towing the submarine into the dock.
Dismantling	The RPV will be removed intact from the submarine by cutting a hole in the hull, using existing cutting technologies.
Initial size reduction to RPV	N/A
Dismantling and size reduction of RPV	This takes place directly following removal from the submarine using existing cutting technologies and skilled nuclear workforce. The waste will be segregated into ILW and LLW. The ILW will be packaged and conditioned in $3m^3$ boxes. Waste characterisation through sampling and analysis must be undertaken prior to conditioning to enable acceptance at GDF. Waste characterisation of the LLW, through sampling and analysis, must be undertaken to identify and quantify radionuclides. Packaging of the LLW must be in accordance with the LLWR requirements.
Packaging for storage	ILW will be packaged and conditioned in $3m^3$ boxes.
Transport to storage site	Transportation of the $3m^3$ boxes from the dismantling facility to the interim store will be required. Transportation by road/rail is possible with the $3m^3$ boxes using shielded overpacks.
Interim storage	Storage of the $3m^3$ boxes for 50-100 years is probably required.
Transport to dismantling facility	N/A
Dismantle and package ILW for disposal	N/A
Transport of ILW packages to GDF	Shielded overpack will be required to transport $3m^3$ boxes to the GDF.
Transport of LLW to LLW repository	Packaging of the LLW must be in accordance with the transport regulations and LLWR requirements.

3 DATA AND INFORMATION

34 The criteria selected for the Desk Officers' workshop were as follows:

- Intergenerational equity
- Flexibility of location
- Industrial skill set
- Technical challenges
- Worker dose
- Adaptability
- Interim storage area

Option 1 Storage of RC	Option 2 Storage of RPV	Option 3 Storage of packaged ILW

- Volume of ILW to GDF
- Volume of LLW to The LLWR
- Accidental radiological discharges
- Radioactive discharges
- Vulnerability
- Regulatory compliance/statutory approvals
- Nuisance

> The following changes were made to the criteria set during the Desk Officers' workshop:
> - Industrial skill set was subdivided into industrial skill set and industrial submarine experience.
> - Accidental radiological discharges was replaced by accidental radiation exposure.
> - Nuisance was replaced By other non-radiological environmental impact.

35 Local acceptability and national public acceptability were also considered as criteria but a decision has been made to remove these as a full consultation exercise will be undertaken following the MPOS review and it would not be prudent to try to predict the outcome of this.

36 The criteria are discussed individually in the following sections which present and discuss the available data and information to support the scoring process during the decision workshop.

3.1 Intergenerational equity

> The IAEA radioactive waste management principles state that "radioactive waste shall be managed in such a way that will not impose undue burdens on future generations" [14].

37 Options 1 and 2 both involve deferring some of the dismantling activities for future generations. It will not be possible at the present time to fully design and gain approval for future dismantling facilities and so this responsibility will be placed on the next generation, together with the actual implementation of the dismantling work. It is noted that both the RC (at approximately 1000 tonnes) and the packaged RPV (at approximately 100-150 tonnes) will be too big to be accepted by the national repository without further size reduction (this limit is set at 65 tonnes) and so further dismantling activities will be required. Although Option 1 involves a greater extent of dismantling activities, it is the RPV itself which will present the greatest challenge and burden, and this is common to all options.

38 Option 3 results in the lowest burden on future generations as the reactor compartment will be completely dismantled and the ILW grouted into approved disposal containers pending the availability of a Geological Disposal Facility (GDF). Therefore, the only activity remaining will be the transportation of the ILW packages to the GDF (together with associated characterisation/revalidation requirements).

3.2 Flexibility of location

39 The number of available sites for dismantling and interim storage is driven by:
- Access for the necessary transport vehicles
- The required infrastructure
- The required size of the site

Option 1 Storage of RC	Option 2 Storage of RPV	Option 3 Storage of packaged ILW

40 At this stage, no decision has been made on the selection of site for the dismantling of the submarines, or for the storage of the resultant ILW. Therefore, flexibility of location is intended to judge the extent to which each option retains flexibility in that choice, or forecloses options.

Dismantling location

41 The flexibility in the selection of the initial dismantling site will be driven by the same restrictions for all three options, i.e. the ability to handle a submarine and to remove sections from that vessel. This will be common to all of the options, which will all need the fore and aft sections to be removed. Further facilities will be required for Options 2 and 3 to enable isolation or cutting up of the RPV. Depending on the location selected, it may be possible to make some use of existing maintenance facilities. However, providing there is space for the construction of any additional facilities this should not significantly affect the flexibility of dismantling location, as it is assumed that this will be a licensed nuclear site.

42 Transportation from the dismantling site should not affect the flexibility in choice of location as sea and road transportation (except for complete RCs) will be possible.

Storage location

43 The flexibility of storage location will be affected by all the issues listed above. Transportation will be a key factor as transportation of ILW can be a difficult undertaking, especially when the packages involved are of abnormal sizes and weights.

44 For Option 1, the only feasible method of transportation for any distance would be by ship or barge, requiring receiving port infrastructure able to handle the load, although very short distances (<2 miles) by road may be possible. This will place restrictions on the sites that could be selected for interim storage. This is more restrictive than the space or facility requirements that would be needed at the storage site itself; although it should be noted that this option also requires the largest footprint of the store and the most significant structure requirements in terms of handling equipment, which may also affect the flexibility in choice of location.

45 For Option 2, transportation is still a restricting issue on choice of location. Transportation by sea is likely to be the most feasible option, although road transportation may be possible, providing a suitable transportation container could be devised. Handling equipment requirements will be less onerous than Option 1 but still greater than Option 3 (RPV package could weigh approximately 100-150 tonnes).

46 Option 3 is the most flexible in terms of storage location. Approved ILW containers (3 m^3 boxes) will be used which can be transported by sea, road or rail. This option requires a much smaller store than Option 1 and handling capacity will be limited to the filled 3 m^3 box (which may weigh up to 12 tonnes) with the capability of fitting/removing the transport overpack and handling the total package of up to 65 tonnes.

3.3 Industrial skill set

47 This criterion assesses the likely availability of the required skills at the time that dismantling activities will be undertaken. In general, the longer final dismantling activities are delayed, the greater the risk that knowledge of existing processes and industrial skill set will be lost.

Option 1 Storage of RC	Option 2 Storage of RPV	Option 3 Storage of packaged ILW

At the Desk Officers' workshop, it was noted that skills can be regenerated but that experience cannot readily be replaced. As a result, a decision was taken to divide the criteria into two; industrial skill set and industrial submarine experience. Information is presented here applying to both criteria.

48 Option 1 has been carried out in the USA, France and the former Soviet Union. Therefore, skills exist in the preparation of RC's for storage, although direct UK experience is limited. Current operational expertise at the dismantling site will also be invaluable in the preparation of the RC for interim storage. With RC dismantling delayed by a number of years then current operator knowledge and experience of nuclear submarine reactors may be lost. It should be recognised that experience may exist elsewhere within the nuclear industry which could be readily transferred to the submarine reactors. However, detailed knowledge and records of each individual submarine will need to be maintained and transferred, as those who were actually skilled and experienced in the maintenance of the submarines would no longer be available.

49 Option 2 would make significant use of the existing skill set during the extraction of the RPV, and the preparation for interim storage. However, there would be concerns over the level of operator knowledge and experience for the actual cutting up of the RPV, which will be delayed by a number of years.

50 Immediate dismantling (Option 3) allows advantage be taken of existing knowledge and experience of personnel. Knowledge gained by operational staff can be utilised, including the status and operational history of all submarines.

51 It has previously been estimated [8] that approximately 100 specialist nuclear posts would be required for the full dismantling of the submarine.

52 One alternative viewpoint expressed during the original options study [2] was that delaying the final dismantling work would make it possible to take advantage of future skills and expertise advances developed elsewhere within the nuclear industry, including internationally, in the intervening period. This is certainly a possibility but is covered under the discussion of adaptability.

3.4 Technical challenges

53 This criterion considers the technical challenges across all the steps in the programme from initial submarine dismantling and size reduction right through to final disposal.

A significant amount of discussion was generated during the Desk Officers' workshop on the applicability and magnitude of the different technical challenges identified within this section. The implications of this discussion on the scoring of this criterion can be found within the workshop report [15]. The tables below serve as a useful introduction to the types of technical challenges faced, but should not be taken as a full technical assessment of the options, merely as a starting point for discussion and an indication of some of the main challenges.

54 Technical challenges include consideration of buildability, operability and maintainability. It takes account of the current level of knowledge and experience and the magnitude of the challenges faced in order to achieve each of the options. It needs to be recognised that different classes of

Option 1 Storage of RC	Option 2 Storage of RPV	Option 3 Storage of packaged ILW

submarine will present different challenges during the initial dismantling and size reduction process. Therefore, care will need to be taken when trying to draw general conclusions on the use of implementing each of the 3 options.

55 All options will involve different methodologies and possibly different technologies, depending on the option. The likely size reduction methodologies and technologies have been laid out in the option descriptions. Although similar size reduction processes will ultimately be required of all of the options, these will be undertaken on different timescales, which may influence the methodologies and technologies selected. It is possible that after a period of interim storage, the activity may have decayed to a level where a higher degree of manual handling is possible, simplifying the dismantling process. Option 1 and Option 2 involve double handling of the active areas of the reactor compartment. Processing is required both prior to and after interim storage in preparation for final disposal. This may introduce new technical challenges [4, 5].

56 For each of the option phases, the key technical challenges are identified and discussed below to enable an assessment of where the most significant technical challenges are faced. These reflect the degree of uncertainty and risk associated with the implementation of each option.

Option 1 -- Storage of the RC	
Step	**Discussion**
Initial dismantling and size reduction	The initial technical challenge will involve the cutting off of the bow and stern sections and the removal of radioactive material from outside the reactor compartment and the sealing of all systems penetrating the RC boundary. A cradle will be required to assist in separating the RC from the submarine pressure hull. However, no buildability difficulties are envisaged as this is based on established technology with no special requirements.
Dismantling and size reduction of RPV	N/A
Packaging for storage	The RC will need to be capped and sealed to produce a "package" which can be transported and stored for a number of years. This is assumed to utilise standard shipyard techniques and has been undertaken in other countries including France, USA and Russia.
Transport to storage site	In order to load the RC on to a transport ship or barge a RC support structure will be needed to interface with the vessel. The only feasible method for transportation of the RC is by ship or barge. There may be a significant technical challenge in ensuring the RC can be transported safely and in finding a suitable port where facilities can be constructed or modified to unload it.
Interim storage	During the storage period the key challenge will be to ensure that the reactor compartment retains structural integrity and prevents the loss of any mobile material contained within. The storage facility itself is likely to be a basic steel framed protective enclosure utilising standard construction techniques as the RC is expected to be a self shielding package.
Transport to dismantling facility	A further transportation step will be required to the dismantling site, after the period of interim storage. This step may involve additional technical challenges to those involved in the first transportation, as the integrity of the package may have degraded over the period of storage.

Dismantle and package ILW for disposal	Ultimate dismantling of the RC to form LLW and ILW, which will be packaged and disposed of accordingly, will present similar technical challenges to those encountered in the short term for Option 3. There is the potential for other work within the nuclear industry to have provided useful techniques and methodologies for use in the RC dismantling, which are not currently readily available. However, these advantages are anticipated to be slight as the dismantling can be undertaken using a range of cutting techniques presently available. The RC dismantling facility will be a simple steel frame structure with a large open area suitable for radiological work and built-in mechanical handling. A facility will be required for some simple remote operation in the processing of ILW. The Co-60 activity and the associated gamma dose rates will be reduced by a factor of 2 for approximately every 5 years of decay storage. The activities of Ni-63 and other long-lived isotopes will decay at a far slower rate. Therefore, the waste is likely to remain ILW, albeit with a reduced gamma dose rate.
Transport of ILW packages to GDF	Common to all the options when the ILW repository is available. Although the transportation of ILW is never without its challenges, the ILW will be contained within approved transport and disposal containers (with appropriate overpack for transport).
Transport of LLW to LLW repository	LLW will be generated at the time of final dismantling of the RC. This will be transported in standard LLW packages to the low-level waste repository (currently the repository is located at Drigg, although the timescales involved in this option mean that it is likely that this repository will be full and an alternative will be in place).
Previous experience	Both Russia and the US have effectively adopted this solution and should be a source of useful experience. However, when making comparisons with other countries, differences in the submarines being dismantled will need to be considered together with the availability of dismantling and storage sites, as well as political and regulatory environment in the relevant country.

Option 2 -- Storage of RPV	
Step	**Discussion**
Initial dismantling and size reduction (to RC or RPV)	The initial technical challenge will involve the removal of radioactive material from outside the reactor compartment, the isolation of the reactor pressure vessel and the cutting, sealing and removal of all systems and equipment within the RC with the connections to the RPV being sealed individually. All items removed will be checked radiologically and processed as LLW (for disposal to The LLWR), recycled (decontamination and re-smelting) or treated as ILW by being placed into standards 3 m^3 boxes for interim storage. All radioactive and non-radioactive systems must be drained prior to the RPV cut-out. The RPV will be removed by cutting a hole into the submarine hull to permit either removal by craneage or by sideways extraction.

Dismantling and size reduction of RPV	N/A
Packaging for storage	The RPV will need to be sealed in a way that it can be transported and stored for a number of years. This step will form a significant challenge as it has not, to our knowledge, been undertaken in any submarine dismantling programme. A significant amount of development will be required, considering all the potential risks involved in such a step. Containment of contamination and shielding to reduce dose rates will be required for handling of the RPV on site and for off-site transportation. It is assumed that the head of the RPV will be removed as this is bulky and is anticipated to be predominately LLW. The RPV will be sealed for the period of interim storage.
Transport to storage site	The RPV transport package could weigh approximately 100-150 tonnes and it is likely that sea transportation will be the most viable form of transportation, although some short distance road transportation may also be possible. Transportation of an irradiated RPV has not been undertaken in the UK to date.
Interim storage	The RPV will need to be stored in some form of shielded and contained environment. It is assumed that storage will be within the container designed for transportation which will continue to satisfy the requirements for containment and shielding and should ensure that the RPV retains structural integrity and shielding during the interim storage period. Some technical challenge exists in the development of a suitable container.
Transport to dismantling facility	A further transportation step will be required to the dismantling site, after the period of interim storage. This step may involve additional technical challenges to those involved in the first transportation, as the integrity of the transportation package may have degraded over the period of storage.
Dismantle and package ILW for disposal	Ultimate dismantling will present similar technical challenges to those encountered in the short term for Option 3. It is possible that further techniques and methodologies would have been developed to enable dismantling to be undertaken more readily. Radioactive decay occurring during the interim storage period may also mean that less remote activities are required, making dismantling activities more straightforward.
Transport of ILW packages to GDF	Common to all the options when the ILW repository is available.
Transport of LLW to LLW repository	Common to all the options. Less LLW will be generated at this later stage than for Option 1.
Previous experience	There is limited experience in the long-term storage of the RPV although most RPVs will be of the order of 35-45 years old with no significant deterioration during service and lay-up periods. Storage will be ‘dry-storage’ with the expectation of very low rates of corrosion.

Option 3 - Storage of ILW packages	
Step	**Discussion**
Initial dismantling and size reduction (to RC or RPV)	The initial dismantling step will involve the cutting out and removal of the RPV, and therefore the technical challenges faced are as that described for Option 2.
Dismantling and size reduction of RPV	The RPV will then be dismantled and size reduced to form ILW and LLW. A range of cutting techniques are available, although further development and trials work will be required to ensure the suitability of these techniques. Cutting and handling equipment will be within a containment facility, which will need to have the capability for remote handling techniques to be employed to lift and package heavy items of ILW. This is the key technical challenge for this option, but once this has been undertaken, technical challenges associated with the transportation and storage of ILW are significantly reduced in comparison to other options.
Packaging for storage	ILW produced will be placed in 3 m³ boxes and grouted in place. This is a standard technique but handling of large pieces of RPV could pose problems.
Transport to storage site	Although the transportation of ILW is never without its challenges, the ILW will be contained within approved transport and disposal containers. An appropriate overpack will be required for the transportation of 3 m³ boxes; however, this is a common challenge across the nuclear industry and is unlikely to fall under the remit of the submarine dismantling programme.
Interim storage	A store will need to be constructed for the interim storage of 3 m³ boxes. This will need to incorporate shielding as it is assumed that the shielded overpack will be removed after transportation.
Transport to dismantling facility	N/A
Dismantle and package ILW for disposal	N/A
Transport of ILW packages to GDF	Common to all the options when the ILW repository is available.
Transport of LLW to LLW repository	Common to all the options. As the LLW will be generated early in the programme for this option (at least for the earlier submarines) the current repository at Drigg is likely to be available.
Previous experience	The French dismantling programme is now thought to be adopting this strategy. There is experience within the UK nuclear industry in the use of 3 m³ boxes for the storage of ILW waste, including the construction of interim stores. A shielded overpack is not currently available but work is ongoing to develop this.

57 A technical challenge which will be faced by all the options to some degree is that of waste characterisation, which will be required principally for off-site transportation, storage and disposal of wastes. Inadequate characterisation could lead to difficulties in obtaining statutory approvals of the transport and storage and could lead to increased disposal costs. Characterisation will involve non-intrusive measurements (e.g. gamma spectroscopy) and intrusive sampling coupled with the

product analysis. A "fingerprint" of radionuclides will be established with reference to a measurable entity, probably the Cobalt 60 gamma dose rates. Measurement of these dose rates will then allow calculation of the radionuclide inventory of the waste. Waste characterisation is one of the most difficult tasks, and is often overlooked. Some major UK nuclear industry projects have failed in the past because inadequate attention has been paid to this requirement. Retaining the reactor compartment in one block will inevitably make waste characterisation harder, as it will be more difficult to reliably establish the inventory. The extent of the challenge this will pose will depend in part on the reliability of the existing submarine radionuclide data, and the extent to which this can be used to effectively estimate the inventory during transportation and storage. Waste segregation will be a technically challenging process which will need to be fully understood. However, because this is common to all options it is not regarded as a discriminating factor.

58 Overall, the most significant technical challenges are associated with the packaging of the RPV (Option 2), and the transportation of the RPV and RC (Options 1 and 2) if the interim storage locations are assumed to be other than at the initial dismantling site.

3.5 Worker dose

59 An outline assessment of worker dose was conducted by Jacobs in September 2009 to assess the likely dose implications of the three options [9]. This was subsequently refined by the Demonstrator Planning Team using actual operational data and a more realistic assessment of the required industrial process steps. The resultant draft report produced by Babcock in January 2010 [10].reassessed the collective worker dose for Option 1 and Option 3 (Option 2 was not included within this report). The findings of this report are summarised below.

Table 4: Collective dose information taken from the Babcock report

Option	**Collective Worker Dose (man mSv) HMS Conqueror**		
	Overall	**Early Activities**	**Deferred Activities**
1. Cut out and store RC	16	10	6
3. Complete Immediate Dismantling	50	50	minimal

60 These values have been calculated for one specific submarine, HMS Conqueror as the assumed “worst case”, and represent the, maximum difference in collective dose between Option 1 and Option 3 across the PWR1 fleet for a single submarine. On average, the difference in collective dose is 15 man mSv.

61 The dose assessment within the Babcock Report is based on submarine refitting experience, with particular attention being paid to de-planting of the RC, which is recognised as the most dose intensive activity. The actual collective dose has been scaled down to take account of the reduction in dose rate at time of disposal and the reduction in task duration due to no high integrity restoration activities (as there is no requirement to safeguard operational plant). Further collective dose reduction may be achieved by more effective or additional shielding. It is also anticipated that the actual doses will be reduced as experience of the disposal process increases.

62 The collective dose calculated for Option 1 does not include any additional activities that may be required to prepare the internals of the RC to satisfy the requirements of the Transport Regulations. Dose implications during the storage period are not considered to be significant compared to those incurred during that dismantling process.

63 Dose calculations have not been performed for Option 2 in the Babcock report. However, it is reasonable to assume the same relative ordering as in the Jacobs report which would have put Option 2 between Option 1 and Option 3, had comparable calculations been performed.

However, the dose calculations were then refined further and the data contained within the final report [16] was presented at the Desk Officers' workshop. This data is summarised below, together with an assessment of the estimated dose for Option 2 which was presented verbally by Babcock Marine.

Option	**Collective Worker Dose (man mSv)** [redacted]
1. Storage of RC	9
2. Storage of RPV	47
3. Storage of packaged ILW	50

These values have been calculated for one specific submarine, [redacted] as the assumed "worst case", and represent the, maximum difference in collective dose between Option 1 and Option 3 across the PWR1 fleet for a single submarine. This vessel has been selected as the 'demonstrator' which will be dismantled first to prove the techniques selected. The dose estimates associated with each individual submarine for the implementation of Option 3 range from 17 to 50 man mSv, leading to the average difference in collective dose between Option 1 and 3 of 17 man mSv.

Points noted during discussion included the assessment that the majority of the dose arises from the handling of LLW, as much of the ILW operations will be remote and the fact that all activities will be subject to ALARP assessments which will ensure that doses are As Low As Reasonably Practicable.

To give some perspective to the dose values discussed, it can be noted that the annual individual worker dose limit is 20 mSv per annum. The annual dose for the average person within the UK from background radiation is 2.2 mSv. All estimated doses for dismantling are less than 1% of the through life collective dose for the [redacted] submarine.

3.6 Adaptability

64 This criterion reflects the ability to make use of future technical developments that may make the process easier or safer. It is likely that improved technology (for example robotics), may exist in the future which would reduce risk during the cutting up operation.

This includes consideration of greater separation of LLW from ILW being possible as it is likely that improved technology (for example robotics), may exist in the future which would reduce risk during the cutting up operation. Adaptability also considers possible changes to waste categorisation which could result in greater disposal of components as LLW.

65 Option 1 -- The works that would need to be done to ensure the reactor compartment is a viable storage package may reduce its future flexibility to some degree, however this remains the most adaptable option as the fore-closure options is minimised.

66 Option 2 -- retains a significant amount of flexibility, since the RPV will not be cut up until after the interim storage period and this will allow for any developments in technology to be utilised.

67 Option 3 -- involves the size reduction and grouting of waste material into their final containers and therefore the opportunity to take advantage of better cutting technology is lost, leaving little flexibility and adaptability, and little opportunity for reduced worker dose.

3.7 Interim storage area

68 Although the final packaged volume of ILW will be broadly equivalent for each of the 3 options, there are significant differences in the volume of ILW requiring interim storage, as the form of the waste differs markedly between the options.

69 It should be noted that the original estimate for the amount of ILW generated by each submarine was 19 tonnes. However, a recent Babcock report [10] recalculated this figure at 47 tonnes, largely due to a reduction in SLILW/LLILW segregation which was seen as technically difficult requiring large-scale metal-machining operations on the irradiated RPV to remove the thermal shields and RPV clad. Whilst this significant difference does not affect the interim storage for Options 1 or 2 it has significant ramifications for Option 3. This data report does not attempt to provide technical justification for one assumption or the other but purely to explore the implications for interim storage volume.

70 The Babcock report [10] contains a calculation of the likely store footprint required for interim storage for Option 1 and Option 3. The original figures, based on the storage of ILW from 23 submarines, are included below together with an extrapolation of these figures to accommodate all 27 submarines. These calculations are based on the generation of 47 tonnes of ILW equating to 8 $3m^3$ boxes per submarine (this is discussed further in Section 3.8).

	Length	Width	Height	Store footprint	Store volume
Option 1 (23 PWR 1)	56m	49m	17m	$2745m^2$	$46,650\ m^3$
Option 1 (27 vessels extrapolated)	73m	49m	17m	$3574m^2$	$60,738m^3$
Option 3 (23 PWR 1)	21.25m	39.22m	9.4m	$834m^2$	$7835\ m^3$
Option 3 (27 vessels	21.24m	51.04m	9.4m	$1084\ m^2$	$10,136\ m^3$

Option 1 Storage of RC	Option 2 Storage of RPV	Option 3 Storage of packaged ILW

extrapolated)					

71 For Option 3 the store capacity was assumed to be 198 boxes, stacked 3 high. This would accommodate the 184 boxes produced by 23 PWR 1 submarines, with an additional buffer capacity of 14 boxes. On extrapolating to take the waste from 27 submarines the store capacity would be to 231 boxes (which would be more than sufficient for the estimated 216 boxes). The 3 m^3 boxes are unshielded and hence shielding requirements have been incorporated into the store design.

72 However, based on the original estimate of 19 tonnes of ILW per submarine (at 30 years post final shutdown), calculations estimate [11] that only 3.6 $3m^3$ boxes of ILW would be generated per submarine. Taking a conservative estimate of 4 boxes per submarine then the store would be required to take 108 $3m^3$ boxes and the store footprint would be in the region of 500 – 600 m^2.

73 No comparable calculations were performed by Babcock for Option 2 RPV storage. However, approximate calculations have been performed for the purpose of this data report on the basis of the RPV dimensions and likely packaging requirements [12]. This resulted in an approximate storage area requirement of 15m by 25.5m ($382.5m^2$) without support functions. Requirements will include plant room, store room, change room, import and export facility. The footprint requirement for support functions has been estimated as 7.5x15m leading to total store dimensions of 22.5m by 25.5m and a store footprint of $574m^2$. This figure is broadly comparable with the footprint required for Option 3 assuming 19 tonnes of ILW for interim storage, but would be significantly smaller than a store for packaged ILW if 47 tonnes was assumed. However, it should be noted that these approximate calculations were performed independently from the Babcock calculations and should be taken for comparison cautiously, as they may be based on very different assumptions.

This calculation is based on the assumption that the RPV is stored within a shielded container. If this is not the case, actual storage area will be reduced but further shielding of the store may be required and a facility for unloading the RPV will also be needed. No allowance has been made for additional ILW boxes. Therefore, significant uncertainty currently exists in the volume of the store required for RPV storage.

Note from Desk Officers' meeting: the draft Babcock Marine report (Reference 10) quoted a possible mass of ILW of 47 tonnes. In the final report (Reference 16) this was reduced to 34 tonnes to reflect that the RPV head and other components are likely to be LLW at the time of early dismantling. However, the estimate of eight 3 m^3 boxes was unchanged and so this change did not affect the figures discussed at the Desk Officers' workshop. It is noted that this is likely to be a pessimistic assumption based on the uncertainties involved, and it is hoped that this number can ultimately be significantly reduced.

3.8 Volume of ILW to GDF

74 At its current level of activity, much of the RPV will not be classified as ILW in its component form, as its specific activity is lower than the ILW specific activity definition (12 GBq per tonne) [1]. The core barrel and thermal shields are all very highly activated and will exceed the ILW specific activity definition by a significant margin and hence will be classified as ILW. The RPV around the fuelled region, possibly up to the top and bottom levels of the thermal shields would be short-lived

Option 1 Storage of RC	Option 2 Storage of RPV	Option 3 Storage of packaged ILW

ILW. The remainder of the RPV, together with the Primary Shield Tank (PST) and whole sections would fall into the LLW category at the time of dismantling. Whilst not previously identified, it is noted that a percentage of the RC shielding in the tunnel, PST and RC flank may also be radioactive waste.

75 The interim storage period will allow for a significant decay of the Cobalt-60 activity, but not of the longer lived isotopes such as Nickel-63. Therefore, the interim storage period will not result in any reduction of the amount of ILW for disposal, and each option will generate broadly equivalent amounts if the same treatment of the RPV is assumed.

76 One potential difference will be changes during the interim storage period to the "ground rules" and what is presently considered ILW. It is possible that waste classification changes will mean that greater or lesser volumes of the reactor compartment and/or the reactor pressure vessel will be characterised as ILW, at the time of dismantling and size reduction. However, as this is unknown at present the MPOS should proceed on the basis of common rules and regulations. Therefore, the time dependency of the volume of ILW for disposal will not discriminate between options.

77 A wealth of information has been generated on the volumes and masses of radioactive waste associated with submarine dismantling. For the purposes of the original options study a mass of 19 tonnes of ILW and 145 tonnes of LLW was assumed. This was derived by considering the theoretical minimum amount of ILW which would be generated given the levels of activation and contamination present [1] and with dismantling taking place 30 years after final reactor shutdown.

78 In the recent Babcock report [10], new values were calculated, based on the assumption that it was impracticable to segregate all the SLILW from LLILW by large scale machining operations to remove the thermal shields and stainless steel cladding lining from the RPV. In this report the mass of radioactive waste generated from one submarine had been calculated as 47 tonnes. An estimation of the volume of this ILW indicates that it would likely fit into eight $3m^3$ NIREX boxes. This equates to a mass of 4.25 tonnes in each box.

79 An independent assessment of the use of the $3m^3$ NIREX box [11] calculated the amount of ILW that could be placed in each box. Taking account of the internal box dimensions, furniture and capping requirements, and assuming a 0.6 packing fraction (the volume of waste that can be placed in each cubic metre of internal space) it was calculated that $0.66m^3$ of waste could be placed in each $3m^3$ box. Using a density of 7.93tonnes/ m^3 (based on steel) this translated to a mass of 5.22 tonnes per box.

80 The two figures (4.25 versus 5.22), whilst not identical, are comparable, with the differences being due to the detailed technical assumptions made during the calculations. Using the same calculation methods a 19 tonne mass of ILW would require between 3.6 and 4.5 boxes to accommodate the ILW.

81 Overall, until a final decision has been made on the dismantling methodology and approach it is very difficult to quantify the volumes of ILW which will be produced. However, it can be placed in the range 3.6 to 8 boxes per submarine.

Option 1 Storage of RC	Option 2 Storage of RPV	Option 3 Storage of packaged ILW

82 However, it is important to reiterate that this value will be unchanged by the stage at which dismantling is undertaken, unless developments in the period of interim storage make segregation less dose intensive and allow for a reduction in the volume of ILW generated.

83 Although it is likely that the actual volumes of ILW for disposal in the GDF generated by each of the options will be the same there is also the issue of LLW which may be considered unsuitable for disposal in the LLWR, which would therefore need to be disposed of alongside the ILW.

3.9 Volume of LLW to the LLWR

84 Original estimates suggested that 145 tonnes of LLW would be generated from each submarine.

85 Revised figures have assumed a greater volume of ILW will be produced and this would result in an overall reduction of the LLW volume. The Babcock report indicates that approximately 55 tonnes of activated LLW and 8 tonnes of contaminated LLW will be generated during the dismantling of each submarine. A small additional amount may also be produced during the processing of 75 tonnes of recyclable material through the concentration of activity into small volumes, allowing the bulk of the material to be classified as free release.

86 Taking an assumed density of 7.93 tonnes / m^3, this would equate to 7.94m^3 of activated LLW and 1.01m^3 of contaminated LLW.

87 Small volumes of LLW will also be produced as a by product of protective clothing, tooling etc during the dismantling and size reduction process. It is anticipated that this would be suitable for direct disposal to The LLWR and volumes are difficult to estimate with any degree of accuracy until the detail of the dismantling techniques are developed.

88 It is also estimated that 75 tonnes of recyclable material will be produced from the dismantling of each submarine. Waste treatment options available include shot blasting, size reduction and smelting which will optimise the volumes of material available for recycling/re-use. Operational experience indicates that less than 10% of the process volume will be returned for disposal as LLW, i.e. less than 1m^3 of LLW).

89 From this discussion it is not clear that there are any discriminating factors between the three options in terms of LLW generation.

However, if a reduced ILW volume is assumed for the delayed dismantling options then the volume of LLW generated will need to increase accordingly. During the Desk Officers' workshop, an assumption was made that Options 1 and 2 would generate only 4 boxes of ILW, whilst Option 3 would generate 8 boxes. This results in an additional generation of 2.4 m^3 of LLW for Options 1 and 2 (based on an assumption that each 3 m^3 box of ILW would actually contain 0.6 m^3 of ILW, which has now been converted to LLW).

3.10 Accidental radiological discharges

90 This criterion measures the potential radiological discharges and emissions resulting from accidents. The potential for accidental radiological discharges arises from:

- Dismantling, size reduction and decontamination activities.

Option 1 Storage of RC	Option 2 Storage of RPV	Option 3 Storage of packaged ILW

- Accident during transportation -- this will depend on the integrity of the container in accident conditions.
- Degradation of storage container during interim storage period.

91 During the storage period the potential for accidental discharges is influenced by the passive safety of each of the packages. The requirement of passive safety is set out in the 3rd House of Lords Science and Technology Report (CND 2919) [13]. Issues relating to passive safety will include the integrity of the storage container under normal storage conditions taking account of existing and future contents, the latter resulting from degradation of the existing contents during interim storage.

92 Assumptions on how the reactor compartment and reactor pressure vessel would be sealed, contained and stored during interim storage period (for Options 1 and 2), and information/ assumptions on the storage package and store design for the ILW packages (Option 3) are contained within the option description.

93 Transport packages for all options will be required to satisfy the extant Transport Regulations issued by and are therefore designed and built to the same standard.

94 Comments are provided for each of the options relating to each of these stages:

Option 1: Storage of RC	
Dismantling, size reduction and decontamination	Some activities will be undertaken in the short term, the remainder being postponed until after the period of interim storage. This may allow for the development of alternative techniques, which could reduce the risk of accident further -- but this is uncertain at this stage.
Transportation	Approval for transportation will only be given once the regulator is satisfied that the possibility for accident has been minimised and that the radiological content can be effectively contained if that were to occur. Therefore, a minimum standard will be adopted for any option. The reactor compartment will need to be sealed prior to transportation. Option 1 would involve a sea transportation of the reactor compartment. This has been successfully achieved elsewhere, but accidents have also resulted, and there is the potential for radiological discharge if the carrying vessel were to sink during transportation. The reactor compartment will contain some mobile liquids and sludges (as it is recognised that these cannot be drained completely), and hence there remains the possibility of leakage during a transportation accident.
Interim storage	As for transportation, the possibility of accidental discharge will be influenced by the integrity of the reactor compartment during the interim storage period, and the extent to which mobile contaminants are contained within. Whilst the actual magnitude of the risk may be small, it is likely to be higher than for immobilised ILW in approved storage/disposal containers. The potential discharge of tritium would also be an issue during transportation and interim storage.

Option 2: Storage of RPV	
Dismantling, size reduction and	Some activities will be undertaken in the short term, the remainder being postponed until after the period of interim storage. This option does

decontamination	involve slightly different process steps than Option 1 and Option 3, although essentially the same tasks will be undertaken.
Transportation	Option 2 may also involve sea transportation, or at a minimum road transportation under special conditions. The transportation container for the RPV has not been developed and at this stage it is not clear what this would look like. Therefore, the potential for discharges must be at least as great as that for Option 1.
Interim storage	Option 2 requires storage of the RPV. The sealing and packaging of this vessel will be designed to minimise the possibility of degradation but the possibility must be higher than for Option 3. It should be noted that mobile liquids and sludges will have been removed, and hence the consequence of a breach to containment may be less than for Option 1.

Option 3: Storage of packaged ILW	
Dismantling, size reduction and decontamination	This option involves essentially the same process steps as Option 1, albeit on a different timescale, and so the potential for accidental discharges is the same for both options (although it is possible that developments during the interim storage period for Option 1 could lead to a reduction in the potential for accidental discharges this is by no means certain).
Transportation	Only Option 3 involves the transportation of approved NIREX containers which have already undergone rigorous testing including drop testing from height. An overpack would be required for the 3 m^3 box. This has yet to be developed, but will be a common requirement across the nuclear industry.
Interim storage	Option 3 uses an approved storage container which has been specifically designed for long-term interim storage and final disposal. Therefore, it has been designed to retain structural integrity and the possibility of accidental discharge during the storage period will be very small.

Workshop note: This criterion was originally entitled accidental radiological discharges and was intended to measure the potential radiological discharges and emissions resulting from accidents during dismantling, size reduction and decontamination activities transportation, and degradation during interim storage period. However, during the Desk Officers' workshop it was decided that this was not a discriminator and was replaced with accidental radiation exposure to cover issues surrounding the potential loss of shielding, especially during transportation. Information originally contained within this data report relating to radiological discharges has now been replaced with points relevant to radiation exposure.

Option 1 – The RC is essentially self shielding apart from on the underside, where accidental radiation exposure could potentially occur during accident conditions.

Options 2 and 3 will both involve transportation in shielded containers which will have been tested for integrity after impact due to an accident.

3.11 Radioactive discharges (routine)

95 Data on routine radioactive discharges has been taken from the proposal for dismantling HMS Renown[1]. Gaseous discharges may be generated from treatment of tritiated water and some decontamination processes using chemicals although whole plant decontamination of the primary circuit is regarded as unlikely to be applied. The discharges may include Carbon-14, and other beta emitting radionuclides.

96 Liquid waste water will be generated from the decontamination of removed components and reactor pressure vessel draining.

97 All three options involve common life cycle activities, the principal difference between the options being when particular activities are undertaken. Consequently, environmental issues associated with each stage of the life cycle apply across all of the technical options. There will be minor differences depending on the exact techniques employed. For example, Option 2 involves two separate incursions into the reactor pressure vessel which has the potential to result in higher liquid discharges depending on the exact nature of the techniques employed. In general the later the operation the smaller will be the discharged activity because of radioactive decay processes and dismantling the RPV will generate levels of higher activity waste so it may be expected that Option 3 will generate most discharges.

Note Option 3 only involves one incursion into the RPV.

98 The MoD have previously stated [1] that the decontamination processes used for nuclear submarines had been in place for years, and that the submarine dismantling programme will not drive up this discharge.

3.12 Vulnerability

99 The potential impacts of terrorist activity are considered under this criterion.

During the Desk Officers' workshop it was noted that vulnerability also includes the loss of sensitive information, and so this aspect was added into the vulnerability criterion.

100 The RC, which is stored during Option 1, is a robust package, however, it may contain liquid heels and dust and hence cannot be considered "passively safe" in a potential terrorist attack, although it should be noted that it is unlikely that liquids could actually be removed from the compartment and put to alternative use.

101 The RPV, which would be stored in Option 2, will be essentially dry during storage and hence liquid heels and dust could not be released. However, the package for storage is uncertain and so its robustness is currently unknown.

102 For Option 3, the waste is immobilised in approved disposal containers much sooner than for the other options. This renders the waste in its least vulnerable state.

For Option 1, the shape of the RC is still intact and so theoretically information could be gathered from it. For Option 2, the shape of the RPV is intact and so theoretically information could be gathered from it. For Option 3, the waste if the form that has destroyed the RC and the RPV.

Option 1 Storage of RC	Option 2 Storage of RPV	Option 3 Storage of packaged ILW

103 Some of the concepts discussed here have already been highlighted under other criteria but are discussed here under a different concept to assess whether there are any issues which have not already been adequately discussed elsewhere.

3.13 Regulatory compliance/statutory approvals

104 Meeting regulatory requirements will be a key challenge to the dismantling and waste management programme, largely due to the unique nature of the active components and the associated timeframes. There will be differences in the approvals required for each option.

105 A range of regulatory requirements will be relevant to the submarine dismantling and storage program. This will include:

- *Safety case*. Each option will require a safety case for processing, transportation, packaging and interim storage. Any major barriers to obtaining approval for the safety case should be considered.
- *Radioactive Waste Discharge authorisations.* There are no known imminent changes that are likely to influence the way the Environment Agency regulates its discharge authorisations, although this may change in the future.
- *Approvals of transportation containers*. The "package" which will be transported for each option will need to be approved by the Department of Transport. There are key requirements set out for each type of package in terms of dose, radiation level, and surface contamination. This approval will then be considered in conjunction with the transportation safety case in order for the regulatory bodies to grant permission for transportation to occur.
- *Approvals from the operators of the geological disposal facility.* Although the final product will be essentially the same for all options the GDF operators will need to be involved throughout the process to ensure their final acceptance of the waste package.
- *Planning permission*. This will be required for the construction of new facilities or the adaption of existing facilities. It is not possible to say whether this will become easier or harder in the future.

106 Issues relating to each of the options are highlighted below:,

107 Option 1 -- There is no precedent within the UK for regulatory approval of a reactor compartment as either a transport or storage package. However, this has been undertaken in other countries and no factors have been identified which would necessarily preclude the necessary approvals from being granted. Planning permission will be required, as a minimum, for a new storage facility to house the reactor compartments and for the ultimate dismantling and waste management facility. It will not be possible to apply for planning permission for the dismantling and size reduction facility which will not be required for a number of years. It is possible that gaining such permission will become harder in the interim period. However, it is also feasible that the possible expansion of nuclear activities within the UK (through the construction of new power stations) will actually make gaining planning permission for nuclear facilities a more straightforward process.

108 Option 2 -- The RPV has not, to our knowledge been used as a transport or storage package and therefore is currently unknown. This would certainly make gaining regulatory approvals a more onerous process, although not necessarily prevent it. The storage facility required will be smaller than for Option 1. The same issues will be faced in the future, when planning permission for the final dismantling and size reduction is required.

Option 1 Storage of RC	Option 2 Storage of RPV	Option 3 Storage of packaged ILW

109 Option 3 -- This option uses the 3 m³ box for the storage and transportation of ILW. This container has already been approved for this purpose, although a transportation overpack will be required which is not yet in existence. All planning permission requirements will be in the short term as both the dismantling and storage facilities will be required at the front-end. A safety case for this option will need to contain a robust justification for the dose implications of immediate dismantling.

3.14 Nuisance

110 The nuisance criterion includes consideration of both statutory and non-statutory nuisance. This includes statutory factors such as visual impact, noise, vibration, and disruption to the local area.

The definition of the criterion was changed at the Desk Officers' workshop to ensure that all potential environmental impacts were considered, including the issues described below.

111 For all the options, the level of nuisance will be dependent on the site selected for dismantling and for storage (for example a new storage facility constructed on a greenfield site will have far greater visual impact than one constructed on an existing industrial site).

112 Although dust, fumes and particulate matter would arise from the dismantling process, precautions would be taken to minimise this at source, so that overall releases would be compatible with refitting. Options 1 and 2 will involve the construction of additional facilities to cut up the RC or RPV after its period of interim storage. This may result in additional statutory nuisance compared to Option 3.

4 REFERENCES

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5 EXPLANATION OF TECHNICAL TERMS

This section provides a brief summary of some of the technical terminology used within the data report and was added subsequent to the Desk Officers' workshop.

LLW – Low Level Waste – this is defined as radioactive waste that has below 4 GBq (Giga-Bequerels) per tonne of alpha activity and below 12 GBq per tonne of beta-gamma activity. It covers a variety of materials which arise principally as lightly contaminated miscellaneous scrap and redundant equipment.

ILW – Intermediate Level Waste – this is radioactive waste with a radiological activity above 4 GBq per tonne of alpha activity or above 12 GBq per tonne of beta-gamma decay, but which does not generate sufficient levels of heat to require it to be cooled during storage.

mSv – milliSieverts – one thousandth of a Sievert, where the Sievert is the basic unit for dose equivalent in the SI system that is used to measure the amount of biological damage caused by various types of ionizing radiation, equal to the dose that produces the same amount of damage in human tissue as one gray of X-rays.

Gray – SI unit of absorbed dose which is a measure of energy deposition n in any medium by any type of ionizing radiation.

Collective dose – is a measure of the total amount of effective dose multiplied by the size of the exposed population. Collective dose is usually measured in units of man-rem or man-Sievert. Collective dose is a way of calculating the number pf potential cancers that will happen in a population exposed to a known dose of radioactivity.

ALARP – As Low As Reasonably Practicable – a term often used in the field of safety-critical and safety-involved systems. The ALARP principle is that the residual risk shall be as low as reasonable practicable. For a risk to be ALARP, it must be possible to demonstrate that the cost involved in reducing the risk further would be grossly disproportionate to the benefit gained.

APPENDIX 1
PICTORIAL REPRESENTATION OF OPTIONS

Option 1 Storage of RC	Option 2 Storage of RPV	Option 3 Storage of packaged ILW

Option 1 Storage of RC	Option 2 Storage of RPV	Option 3 Storage of packaged ILW