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ISM

SUBMARINE DISMANTLING PROJECT

Packaged Waste Container Selection

Phases 1, 2 and 3 Combined Report

Issue 1.0 – Dec 2010

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Amendment History

Issue	Date	Details of Amendment	DCCF
0.1	October 2010	Combined report issued to MoD for discussion and comment.	
1.0	10 December 2010	Updated Combined report	

Distribution

SDP Virtual Team

EXECUTIVE SUMMARY

The Ministry of Defence is responsible for the disposal of the Royal Navy's fleet of twenty seven nuclear submarines. This responsibility involves the management of intermediate level radioactive waste produced during submarine reactor operations.

This study is directed at selecting an appropriate container for this waste. Three associated reports have been produced to date on this topic and this document combines these reports into one document. A description of the studies and the results are provided below. This combined report contains the results from three reports produced during the 3 phases of the work. None of the earlier reports have been altered to take account of the results of subsequent reports. Because of this, there may be inconsistencies when earlier reports are compared with the more recent ones. In general, the later reports should take precedence over the earlier ones.

The Phase 1 works were directed at selecting an appropriate waste package based on a range of generic waste package designs produced for the civil nuclear industry by the UK Radioactive Waste Management Directorate. The candidate packages were the 500 litre drum, 3m^3 box, 3m^3 drum, 2 metre box and the 4 metre box. A structured optioneering study was carried out, making use of propriety software packages (MicroShield and Hiview). The 3m^3 box waste package had the highest weighted and unweighted scores when assessed against a number of mainly technical criteria. The 3m^3 box waste package was declared the preferred option, subject to additional substantiation.

The Phase 2 works explored the feasibility of using a non standard waste package and a non standard overpack for containment of submarine ILW. The Windscale Advanced Gas Cooled Reactor (WAGR) box was investigated as a possible alternative to the 3m^3 box, but the results showed that it was inferior to the 3m^3 box. Information was presented on the possible uses of the Nuvia ModuCube Ministore as an overpack for the 3m^3 box waste package during long term interim storage.

The Phase 3 works were directed at exploring if the 3m^3 box waste package would be able to comply with a wide range of requirements, contained mainly in documentation produced by the UK Radioactive Waste Management Directorate. The lifecycle risks and mitigations were also identified and assessed. No significant threats to the use of the 3m^3 box waste package were identified during these studies. It was concluded that the 3m^3 box waste package was fit for purpose.

The principal recommendation from these three studies was that the stakeholders should review this combined document and if no reasons are found to the contrary, the Ministry of Defence should formally confirm that the preferred option for packaging of intermediate level radioactive waste from the dismantling of UK nuclear submarines is the 3m^3 box waste package.

It is understood that work will shortly be undertaken to update the radionuclide inventory of potential ILW. It is recognised that the results may have a significant impact on the conclusions of this work. For example, if the radionuclide activity levels (and the associated dose rates) are not as high as previously assumed, this

may allow reconsideration of IP-2 packages (i.e. the 2m and 4m boxes). In addition, if the mass of ILW is lower than previously assumed, a smaller number of ILW packages will be required.

ABBREVIATIONS

Abbreviation / Term	**Explanation**
A_2	The activity value of radioactive material, other than special form radioactive material which is listed in the IAEA transportation regulations and is used to determine the activity limits for the requirements of these regulations.
ALARP	As Low As Reasonably Practicable.
Bq	Becquerel (unit of radioactivity).
BS EN ISO	British Standard European International Standards Organisation.
CA	Competent Authority.
CCAD	Criticality Compliance Assurance Documentation.
CRUD	Radioactive deposits (origin thought to be from Chalk River Unidentified Deposits).
CRUD	Mixed impurities, especially corrosion products. (Said to originate from “Chalk River Unidentified Deposits”.
CSA	Criticality Safety Assessment
DfT	Department for Transport.
DNSR	Defence Nuclear Safety Regulator.
DSC	Disposability Safety Case
GDF	Geological Disposal Facility.
ILW	Intermediate Level Waste.
IP-2	Industrial Package Type 2 defined in the IAEA transportation regulations.
LLW	Low Level Waste.
LLWR	Low Level Waste Repository.

Abbreviation / Term	Explanation
LoC	RWMD Letter of Compliance process, formerly known as a Letter of Comfort.
LSA	Low Specific Activity.
MeV	Mega Electron Volts.
MicroShield	Proprietary software package for dose rate calculations.
MNOP	Maximum Normal Operating Pressure.
MoD	Ministry of Defence.
MoU	Memorandum of Understanding.
NAPL	Non Aqueous Phase Liquids.
NDA	Nuclear Decommissioning Authority.
Nirex	UK disposal organisation. Subsumed by NDA.
NISR	Nuclear Industries Security Regulations.
NMS	Nuvia ModuCube Ministore.
OCNS	Office for Civil Nuclear Security.
PVC	Polyvinyl Chloride.
PWR	Pressurised Water Reactor.
QMS	Quality Management System.
R&D	Research and Development.
RSTC	Reusable Waste Transport Container.
RWMD	Radioactive Waste Management Directorate of the NDA. Formerly known as Nirex.
SDP	Submarine Dismantling Project.
Sv	Sievert (unit of radiation exposure).
SWTC	Standard Waste Transport Container.

Abbreviation / Term	**Explanation**
TAF	Task Authorisation Form.
Type B Transport Package	Classification of package for transport of radioactive waste. This contains the wasteform, the waste container and the shielded overpack.
WAC	Waste Acceptance Criteria.
WAGR Box	Windscale Advance Gas Cooled Reactor waste package.
Waste container	The IAEA definition of a waste container is the vessel into which the waste form is placed for handling, transport, storage and/or eventual disposal; also the outer barrier protecting the waste from external intrusions. The waste container is a component of the waste package.
Waste package	The IAEA definition of a waste package is the product of conditioning that includes the wasteform and any container(s) and internal barriers (e.g. absorbing materials and liners), prepared in accordance with the requirements for handling, transport, storage and/or disposal.
Wasteform	The raw or grouted waste.
WPrS	Waste Product Specification.
WPS	Waste Package Specification.

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1. INTRODUCTION

The Ministry of Defence (MoD) Submarine Dismantling Project (SDP) has been tasked with the disposal of the Royal Navy's fleet of 27 nuclear submarines. This includes all submarines currently in or previously withdrawn from service, but excludes Astute and future classes. The scope of the SDP is restricted to these 27 de-fuelled submarines. The project ends with the dismantling of the 27th submarine and the disposal of the resulting intermediate level waste (ILW) to a planned national Geological Disposal Facility (GDF).

During the process of identifying appropriate submarine dismantling and disposal strategies, it was appreciated that work would need to be undertaken to identify a suitable container for packaging of the submarine ILW. This report contains the results of this work, specified in the MoD/BMT Contract #N/SUB2/70253/1 - TAF No. SDP/05, titled: "Packaged Waste Container Review". For a mixture of presentational and logistical reasons, the work was carried out in three phases, with the intention of combining the resultant reports into one document. An overview of the rationale behind each of the three phases is provided below.

The Phase 1 works [Ref. #1] were directed at selecting an appropriate waste package based on work already carried out by the UK Radioactive Waste Management Directorate (RWMD) of the Nuclear Decommissioning Authority (NDA). RWMD had already developed a range of generic waste package designs (i.e. of the 500 litre drum, 3m^3 box, 3m^3 drum, 2 metre box and 4 metre box) for the disposal of civil nuclear industry ILW in the GDF and this was the starting point for the optioneering process.

The output of Phase 1 was specified as selection of a preferred waste package from the range of generic designs produced by RWMD.

Recognising that other waste packages were being used by the civil nuclear industry, the Phase 2 works [Ref. #2] explored the feasibility of using a non NDA standard waste package and a non standard overpack for containment of submarine ILW. The non NDA standard waste package was the Windscale Advanced Gas Cooled Reactor (WAGR) box. The initial intention was to also include the so called "Yellow Box" waste package used by EnergySolutions, but the timelines associated with obtaining the necessary technical data were considered too long and the feasibility of using the Yellow Box was deleted from the scope of work. The intention was not to repeat the Phase 1 optioneering process, but instead to explore the feasibility of using the WAGR box instead of the waste package selected during the Phase 1 works. If it was concluded that the WAGR box should replace the box selected during Phase 1, the additional work would be required to substantiate the change of selection. The non NDA standard overpack was the Nuvia ModuCube Ministore (NMS). The intention was to provide an overview of the applicability of this overpack to SDP ILW, rather than compare it with existing NDA overpack designs.

The output of Phase 2 was specified as either confirmation that the (standard NDA) waste package selected during Phase 1 was sound or that another (non NDA standard) waste package should be considered. If the latter, the additional work would be required to substantiate the change of selection.

This report contains the results of Phase 3 (Detailed Evaluation of Preferred Option) of a packaged waste container study, which was specified in the MoD/BMT Contract #N/SUB2/70253/1 - TAF No. SDP/05, titled: “Packaged Waste Container Review”.

Two reports have already been provided to MoD. The results of Phase 1 (Optioneering) are contained in [Ref. #1] and the results of Phase 2 (Use of Non Standard Packages) in [Ref. #2]. This report contains the results of Phase 3.

The terminology used in this report is shown in the introductory section. It is important to appreciate that when the wasteform (i.e. the grouted or ungrouted waste) is put into the waste container (i.e. the $3m^3$ box) it is called a waste package (i.e. the $3m^3$ box waste package). When the waste package is put into a shielded transport container it is called a Type B transport package under the IAEA Transport Regulations [Ref. #3].

The Phase 3 works [Ref. #3] were directed at providing additional substantiation for use of the selected waste package. This addressed, in part, the impact of differences in the properties of the ILW produced from the dismantling of nuclear submarines compared to the ILW produced from the civil nuclear industry. If the impact of these differences was substantial, using the selected waste package for SDP ILW could be fraught. It was therefore considered that a review of the requirements contained in RWMD waste package and wasteform guidance documentation should be carried out to determine if there were any issues which could prevent or severely hinder deploying the selected package as the Ministry of Defence’s (MoD’s) preferred option for packaging of SDP ILW. In addition, the top tier risks associated with the activities performed during the various stages of the lifecycle of the $3m^3$ box waste package would be identified and evaluated. These lifecycle stages should include the concept phase, design, fabrication, manufacture/use, buffer storage, transport, interim storage and acceptance into the GDF.

The output of Phase 3 was specified as a conclusion on whether or not the preferred waste package was fit for purpose. If affirmative, those issues which need to be addressed at an early stage in the process should be identified.

This combined report contains the results from three reports produced during the 3 phases of the work. None of the earlier reports have been altered to take account of the results of subsequent reports. Because of this, there may be inconsistencies when earlier reports are compared with the more recent ones. In general, the later reports should take precedence over the earlier ones.

MoD specified that the data used during the selection process must be traceable and auditable and the arguments used for container selection must be robust and defensible.

MoD also specified that the waste containers must be capable of being used to safely package the size reduced ILW from all 27 decommissioned nuclear submarines, allowing for a ten year gap between taking each submarine out of service and the start of the dismantling process. MoD’s preference is to utilise only one type of ILW container, hence the requirement is to select a container which will accommodate the highest possible ILW Co-60 specific activity. The latter is the amount of Co-60 activity (in Becquerels) per unit mass of waste (in tonnes) and is typically expressed in units of Becquerel per tonne (Bq/t).

1.1. Structure of Report

Sections 2 provides a synopsis of the Phase 1 works, supported by Appendix #1 which contains the Phase 1 report, together with its associated Annexes. An additional annex has been added to include the resolution sheet which contains the stakeholders' comments on the Phase 1 report.

Section 3 provides a synopsis of the Phase 2 works, supported by Appendix #2 which contains the Phase 2 report, together with its associated Annexes.

Section 4 provides a synopsis of the Phase 3 works, supported by Appendix #3 which contains the Phase 3 report, together with its associated Annexes.

The reports contained in the three Appendices have been edited in places to make them more consistent with the combined report and to remove any errors or inconsistencies.

Section 5 contains the recommendations of the combined report and Section 6 the references.

1.2. Terminology

The terminology used in this report is shown in the introductory section. It is important to appreciate that when a wasteform (i.e. items of waste which can be grouted or ungrouted) is put into a waste container (e.g. a 3m3 box) it is called a waste package (i.e. a 3m3 box waste package). When the waste package is put into a shielded transport container it is called a Type B transport package under the IAEA (and UK) transport regulations.

2. PHASE 1: WASTE CONTAINER SELECTION FROM STANDARD NDA PACKAGES

The purpose of Phase 1 was to determine which of the available NDA package designs would be suitable for packaging of submarine intermediate level waste. The five candidate NDA waste packages were the 500 litre drum, the $3m^3$ box, the $3m^3$ drum, the 2 metre box and the 4 metre box [Refs #4 and #5]. As the box names imply, the volume of a $3m^3$ box is approximately 3 metres and the length of a 2 metre box is approximately 2 metres.

Recognising the importance of meeting the requirements of the transport regulations [Refs. #6, #7 and #8], the packages were grouped into transport types. Under the UK transport regulations, the first three containers (together with their overpacks) listed above, are classed as Type B containers and the last two as IP-2 containers. The amount and strength of radioactive material that can be transported is more limited when an IP-2 package rather than a Type B package is used. The use of IP-2 packages was therefore explored to establish if the dose rates emanating from packages containing SDP ILW were compliant with the transport regulations.

The RWMD Waste Package Specification [Ref. #5] states that of the two IP-2 containers, the 2 metre box may be preferred when the waste items are so dense that a filled 4 metre box would exceed mass limits. Since this was the case for SDP ILW, the initial focus was on the 2 metre box.

A study was carried out on the 2 metre box to evaluate it against the regulation that the dose rate at a distance of three metres from the unshielded surface of the waste inside a loaded IP-2 container should not exceed 10 milliSieverts per hour (mSv/h). The study showed that, based on data provided by MoD, the waste inside the 2 metre box would need to be decay stored for a period of about 30 years before it complied with this requirement. This 30 year period is well in excess of the MoD 10 year decay storage requirement. The 2 metre box was unable to meet the MoD specification and was therefore considered unsuitable for the packaging of SDP ILW. Recognising that there may be circumstances which would not require significant periods of decay storage (e.g. if the ILW inventory, particularly that of Co-60 turned out to be an overestimate), the 2 metre box was not discarded, but was taken forward into the optioneering process, to allow it to be compared with the other NDA waste packages.

A similar story unfolded for the 4 metre box, based on work performed for MoD during 2001 [Ref. #9] by Nirex (now RWMD). This study showed that, at 2001, up to 43 years decay storage would be required before the 4 metre box could be used to transport submarine ILW. For similar reasons to those given above, the 4 metre box was also carried forward into the optioneering process.

The initial scoping study discussed above was followed by an optioneering study which evaluated each of the five NDA containers (including the 2 metre and 4 metre boxes) against the following criteria: ease of size reduction; ease of grouting and lidding; packing fraction; waste disposal efficiency; flexibility; previous experience; compatibility with downstream processes; and programme issues.

Most of these criteria are self explanatory. The packing fraction is a measure of how much of the available internal volume can be filled with ILW. The higher the packing fraction, the higher the utilisation of the available internal container volume and the less unused space there will be inside a container. Waste disposal efficiency relates to the external disposable container volume. The higher the waste disposal efficiency, the more waste can be disposed of per cubic metre of the GDF.

Each container option was given a numerical ranking against each of the above criteria and assigned a weighting which reflected the perceived importance of the criterion. For example, waste disposal efficiency was given a relatively high weighting, reflecting the need to minimise the volume of waste consigned to the GDF. Because the calculated permissible waste masses and volumes were common to the derivation of both the waste disposal efficiencies and the packing fractions, it was considered prudent to minimise double accounting and give packing fraction a relatively low weighting. The scores and weights were then combined to produce an overall score for each option. The process generated both weighted and unweighted scores. The methodology made use of the Hiview software package and was similar to that used for previous SDP studies.

The results are summarised below, starting with the options which had the lowest scores.

Ranked joint last of the options, the 4 metre box scored exceedingly poorly during the optioneering process and was not the preferred option. This is logical, because it had already been established that the 4 metre box was inferior to the 2 metre box because the 2 metre box could hold more than twice the mass of waste which the 4 metre box could hold. Even if the dose rates were low enough to meet the IP-2 transport requirements discussed above, the 4 metre box would still not be the preferred option.

Ranked joint last of the options, the $3m^3$ drum scored exceedingly poorly during the optioneering process and was not the preferred option. This is also logical, since the $3m^3$ drum was not designed for high density solid wastes and has features (e.g. aperture area, waste disposal efficiency) which are inferior to those of the $3m^3$ box.

Ranked joint second of the options, the 500 litre drum performed well during the optioneering process, but did not perform well enough to be chosen as the preferred option. It has a relatively small aperture opening and a considerable amount of size reduction would be required before the waste could be loaded into the drum. This increases the amount of resources needed to perform size reduction and decreases its flexibility when compared to other packages.

Ranked joint second of the options, the 2 metre box scored reasonably well during the optioneering process but did not perform well enough to be chosen as the preferred option. Even if the dose rates were low enough to allow the 2 metre box to meet the IP-2 transport requirements discussed above, it would still not be the preferred option.

The preferred option was the $3m^3$ box. During the optioneering process, it was ranked first in both the unweighted and weighted categories. It had the joint highest high packing fraction and the highest waste disposal efficiency of all of the packages. Together with its overpack (which provides shielding and integrity) it is classified as a Type B package, which does not have the same unshielded dose rate limitations as the IP-2 package.

In summary, the results indicated that the preferred option, based on both the weighted and unweighted scores was the $3m^3$ box, followed by the 2m box/500 litre drum and then by the 4m box/$3m^3$ drum. When submitted to the Hiview software package sensitivity analysis, the preferred option was considered robust because significant changes would need to be made to the weight allocated to each attribute before another option received the highest score.

It was recommended that the $3m^3$ box be carried forward as the preferred option and that its choice be substantiated by exploring the “cradle to grave” use of the $3m^3$ box waste package. If the $3m^3$ box survived this substantiation phase and no reasons were found to change the container ranking order, it should then be declared as the MoD preferred option for packaging of submarine ILW. Recognising that identification and adoption of a single package design may not lead to overall optimisation, it was recommended that MoD should periodically review the intended package use to determine if more than one package design will be required.

The draft Phase 1 report was reviewed by MoD and then sent by MoD to SDP stakeholders for review and comment. The conclusions of the draft Phase 1 report were acceptable to MoD and to the majority of the SDP stakeholders. MoD and Nuvia discussed the stakeholder responses and produced a list of actions to address their comments. These are shown in Annex 1.4 of Appendix 1. The Phase 1 report was updated in accordance with these stakeholders’ comments and is shown in Appendix 1.

3. PHASE 2: WASTE CONTAINER SELECTION FROM NON STANDARD NDA PACKAGES

The original purpose of Phase 2 was to determine the feasibility of using the Yellow Box, the Windscale Advanced Gas Cooled reactor (WAGR) Box and the Nuvia ModuCube MiniStore (NMS) for packaging/overpacking of submarine ILW. MoD subsequently deleted the Yellow Box from the specification, therefore only the latter two were considered during Phase 2.

WAGR was a prototype of the AGR family of commercial reactors, and operated between 1962 and 1981. As the reactor was being dismantled, intermediate level waste items were loaded and cemented into specially designed reinforced concrete containers (WAGR Boxes) [Ref. #10]. Boxes containing ILW will be held in storage at Windscale until the GDF becomes available.

In a similar manner to that described in Phase 1 above, the requirements of the transportation regulations were explored to determine if there were any limitations to the use of the WAGR box.

WAGR box waste packages qualify as transport containers in their own right and are therefore capable of being transported on public roads without the requirement for an overpack which would provide additional shielding and/or containment. The WAGR box waste package, when filled with waste, is classed as an Industrial Package Type 2 (Type IP-2) under the transport regulations. The external radiation level at 3 metres from the unshielded material must not exceed 10 mSv/h. Recognising that the additional shielding afforded by grouting the annulus between the waste and the waste package and by the package construction and shielding material cannot be taken into account in meeting the 3 metre dose rate requirement, it was concluded that the dose rate limitations of the 2 metre, 4 metre and WAGR boxes were similar since they were all IP-2 packages. The WAGR box waste package was non compliant with the MoD 10 year decay storage specification. No additional MicroShield calculations were carried out to arrive at this conclusion.

However, if the current inventory of radioactive materials is shown in the future to be an overestimate and the Co-60 activity content was lower than assumed, the WAGR box waste package could still be a viable option. In order to determine where the WAGR box would have been ranked if it had been included in the Phase 1 study, the performance of the WAGR box against the Phase 1 criteria was investigated. The results indicated that the WAGR box had a similar profile to the 2 metre box. It was judged to be on a par with the 2 metre box and actually performed better against some of the criteria. This was a surprising result to the authors of this paper and was interpreted as a compliment to the originators of the WAGR box that its design appeared to have withstood the test of time. However, some concerns were expressed over the long term corrosion potential of the reinforced concrete box, mainly from carbonation and chlorination mechanisms.

It is understood that RWMD is currently reviewing these and other long term stability and containment issues to assess the future applicability of the WAGR box to other waste streams. Even if these issues are resolved, the risk to MOD of deploying a reinforced concrete box is considered higher than the risk of deploying a high integrity stainless steel container for packaging of SDP ILW.

It was concluded that the 3m^3 box remained the preferred waste package for SDP submarine ILW, as concluded in the Phase 1 report.

A review of available information on the Nuvia ModuCube Ministore (NMS) was undertaken. NMS was designed by Nuvia Limited to provide modular shielding for waste packages containing a passive inner waste form. The NMS is therefore not an alternative to the 3m^3 box (or any other) waste package, but may be used to provide shielding round the waste package. The current design of the ModuCube is intended to provide shielding during interim storage of the waste package. It is not intended as an overpack to meet transportation requirements, but this may be addressed by Nuvia Limited at a later date.

Details are provided in the Phase 2 report to indicate how the NMS could be used during buffer storage and possibly during interim storage of the submarine ILW. It was emphasised that although Nuvia Limited is in the process of taking out a patent on its design, no NMSs have yet been approved for use or manufactured.

The recommendation from the waste package study was that the 3m^3 box waste package should be carried forward into Phase 3 to explore lifecycle issues associated its use.

No recommendation was made from the NMS overpack study.

The draft Phase 2 report was reviewed by MoD, but not sent to the SDP stakeholders for review or comment.

4. PHASE 3: DETAILED EVALUATION OF PREFERRED PACKAGING OPTION

The $3m^3$ box waste package had been chosen as MoD's preferred option by an optioneering process carried out during Phase 1 and had remained the preferred option after the evaluation of the WAGR box during Phase 2. The purpose of Phase 3 was to identify any additional issues which could prevent or significantly hinder deploying the $3m^3$ box waste package as MoD's preferred option for packaging of SDP ILW.

Three approaches were adopted to identify the key technical issues associated with the packaging SDP ILW inside a $3m^3$ box waste package and to determine whether any of these issues was significant enough to prevent this waste package from being used by MoD.

The first two approaches relied heavily on the guidance documentation produced by RWMD. The third approach involved identification and consideration of the top tier risks associated with the activities performed during the various stages of the lifecycle of the $3m^3$ box waste package.

The first approach involved a detailed review of the requirements of the RWMD guidance documentation relevant to the $3m^3$ box waste package. The RWMD Waste Package Specification [Ref. #11] includes criteria, requirements, and/or limits on a range of topics relevant to the use of the $3m^3$ box waste package. These topics include activity content; dose rate; heat output; surface contamination; dimensions; lifting features; mass; gas generation; venting arrangements; integrity; criticality safety; impact and fire performance; stackability; identification; physical protection for nuclear security and quality management. The $3m^3$ box waste package containing SDP ILW was assessed against each one of these requirements to determine if compliance would be an issue.

Some of the requirements (e.g. surface contamination) related to operational issues which did not need further analyses while others (e.g. dose rate limits) involved additional work to ascertain if compliance would be an issue.

The $3m^3$ box waste package will be transported through the public domain within a reusable shielded transport container (e.g. SWTC-285) and this is designated as a Type B transport package. Under the IAEA transport regulations, a Type B transport package must meet the following dose rate limits: 2 mSv/h at the surface of the SWTC and 0.1 mSv/h at 1 metre from the SWTC. Calculations using the MicroShield software package indicated that dose rates both at the surface of the $3m^3$ box waste package and at a distance of 1 metre from the package so low that no decay storage was required. The $3m^3$ box transport package was assessed as being very robust with respect to compliance with Type B package dose rate limits. This indicated that the ILW from a nuclear submarine can be packaged and transported in conformance with the UK transport regulations, without the need for any decay storage.

The dose rates were low enough to suggest that there may be merit in reducing the thickness of the overpack shielding used in the calculations. This should not be considered until improved waste inventory data become available and MoD is satisfied that the revised inventory is representative of both the PWR 1 and PWR 2 reactors. At this stage, the opportunity should be taken to optimise the design of the packaging process, including waste loadings, use of furniture, quantity of grout and overpack shielding requirements.

The other conclusions from review of the RWMD Waste Package Specification are presented below.

- Based on current assumptions, compliance with the $3m^3$ box waste package activity content limits is not judged to be problematic. For example, the Co-60 activity content of a $3m^3$ box waste package containing SDP ILW is more than two orders of magnitude less than the limit. This obviously needs to be reviewed once better inventory data become available.

- The total heat output from a $3m^3$ box waste package was estimated at 80 Watts which is less than the RWMD 200 Watt limit at the time of transport and the 150 Watt limit at the time of vault backfilling.

- Compliance with surface contamination limits is an operational issue and should not be problematic.

- The requirements associated with the dimensions, lifting features, venting, package integrity and stackability requirements of a $3m^3$ box can be met by use of a standard RWMD $3m^3$ box, as opposed to developing a different design.

- The 12 tonne mass limit is an operational issue which should not present any major problems.

- Gases may be generated if the metallic wasteform contains entrained gases and will be generated during corrosion of the metal. Compliance with the total gas generation limits is not anticipated to be problematic.

- Criticality safety should not be an issue if no fissile materials, neutron moderators or reflectors are packaged inside the $3m^3$ box waste package.

- The impact and fire testing requirements for the $3m^3$ box waste package and transport package need to be discussed and agreed with RWMD. Compliance with the impact and fire performance requirements may be onerous but is not anticipated to be problematic.

- Recognising the importance of obtaining the necessary approvals for transport of waste packages, discussions should be held with the UK competent authority (the Department for Transport) at an early stage in the process.

- Complying with the requirement to mark each waste package with a unique, long lasting identified is not considered difficult.

- Physical protection for nuclear security should not be an issue if no fissile materials are packaged inside the $3m^3$ box waste package.

- Nuclear materials safeguard issues are not relevant to MoD ILW.
- Quality management systems need to be set up, in conjunction with RWMD, as early as possible, to ensure that their requirements will be met. No difficulties are anticipated when complying with this requirement.

It is cautioned that all of the above conclusions will need to be confirmed when new waste characterisation and other data become available and all of the above issues will need to be discussed in detail with RWMD.

The second approach involved a detailed review of the requirements of the RWMD guidance documentation relevant to the wasteform inside a $3m^3$ box waste package The purpose was to determine if any of these requirements represented significant threats to the use of the $3m^3$ box waste package as MoD's preferred option for packaging of SDP ILW.

The RWMD Wasteform Specification [Ref. #12] includes criteria, requirements, and/or limits on a number of issues. These include: physical immobilisation; immobilisation of radionuclides and particulates; response to an impact accident; response to a fire accident; free liquids; mechanical and physical properties; mechanical strength; voidage; mass-transport properties; homogeneity/uniformity; thermal conductivity; chemical containment; hazardous materials; gas generation; wasteform evolution; external dose rate and criticality safety.

The conclusions from review of the RWMD Wasteform Specification are presented below.

- The physical immobilisation requirement can be met by the use of an encapsulating matrix (e.g. cement). A wasteform encapsulation strategy may need to be produced. Particulates (e.g. layers of radioactive corrosion products, colloquially known as CRUD) and entrained gases should be avoided.

- The requirement to immobilise radionuclides and particulates can be met by grouting the waste. If the waste is not grouted before transport to the long term interim store, a justification for this will need to be supplied to RWMD as part of the Letter of Compliance process.

- The requirement to ensure that release limits will not be breached in the event of an impact accident can be met if the waste is grouted and essentially monolithic. Particulates (e.g. CRUD) should be avoided.

- The requirement to ensure that release limits will not be breached in the event of a fire accident will be met since there is no intention to put combustible items into the waste package. Combustible materials should be excluded or made safe.

- The requirement to take reasonable measures to exclude free liquids when packaging the wastes should not be onerous, since degradation of the SDP ILW will not produce significant quantities of free liquids. However, if wet processes are deployed for size reduction of the RPV, additional care must be taken to avoid the presence of free liquids.

- The requirement to design the wasteform to provide the necessary mechanical and physical properties (including mechanical strength) can be met by immobilisation of the waste.

- The requirement to minimise voidage inside a waste package is an operational issue which should be easily met. This may involve inactive trials, for example, cementation of inactive simulant wastes to produce packages which can be segmented to visually indicate the amount of internal voidage.

- The mass-transport properties of the wasteform (e.g. diffusivity, permeability and leachability) need to be established as part of the selection of an immobilisation medium. Compliance with the requirement to ensure that a wasteform is encapsulated inside a medium with acceptable mass-transport properties is not anticipated to be problematic.

- Compliance with the requirement to ensure that a wasteform is encapsulated inside a medium with acceptable homogeneity and uniformity properties is an operational issue and may involve trials. Compliance is not anticipated to be problematic.

- The requirement to ensure that a wasteform has acceptable thermal conductivity properties within an acceptable range needs further assessment, but compliance is not anticipated to be a difficult issue.

- Minimising or excluding a range of materials which could detrimentally affect the chemical containment of the wasteform is not anticipated to be problematic. CRUD, resins, plastics, paper, wood, decontamination chemicals and materials with a low pH which could reduce the alkalinity of the GDF backfill should be avoided. RWMD must be consulted if the intention is to use cement additives.

- Excluding hazardous materials such as pyrophoric materials; oxidising materials; flammable liquids and gases; explosive materials; and sealed and/or pressurised containers is an operational issue which should not be difficult to respect.

- Gas generation is addressed under both the Waste Package and Wasteform Specifications. The latter provides additional guidance on minimising gas generation by for example, use of inhibitors and other methods. The conclusion from review of the Waste Package Specification was that compliance should not be problematic. The same conclusion was reached after review of the Wasteform Specification.

- Wasteform evolution could result in corrosion to produce powders and gases, which could have an adverse impact on the performance of the waste package. Magnesium, aluminium and uranium react with grout to produce hydrogen and should therefore be excluded. Assessment will need to be carried out, but compliance is not anticipated to be problematic.

It was concluded that none of the above represented a significant threat to the use of the 3m^3 box waste package as MoD's preferred option for packaging of SDP ILW.

The third approach involved identification of the top tier risks associated with the activities performed during the various stages of the lifecycle of the 3m^3 box waste package. These stages included the preliminary/concept phases, design, fabrication, manufacture/use, buffer storage, transport, interim storage and acceptance into the GDF. The risks were associated with a number of scenarios, including: inaccurate input data and assumptions; changes to the package design; fabrication using unacceptable materials and inexperienced operators; operational issues associated with the creating the waste package (i.e. addition of waste, grouting lidding, checking); compliance with transport requirements, principally dose rate limits; integrity during long term storage; and non compliance with the GDF waste acceptance criteria.

The risks are summarised below, together with possible mitigating actions.

There is a risk is that the basis for selection of the box is based on inaccurate data and assumptions and that this produces a flawed recommendation to use the 3m^3 box waste package. Mitigation includes ensuring that whenever new information (e.g. on the waste inventory) become available, the implications of the new data are investigated to establish its impact on previous assumptions and decisions.

- There is a risk is that the information provided to RWMD as part of the Letter of Compliance process [Ref. #13] contains inaccurate data and assumptions and this results in deficiencies in the design of the waste packaging plant. Mitigation includes ensuring that whenever new data become available, the implications are investigated to establish its impact on the design of the waste packaging plant.

- There is a risk that changes are made to the package design to optimise the waste package for SDP ILW and the new design does not meet requirements. Mitigation includes not changing the package design. If changes are to be made, this should be done in consultation with RWMD.

- There is a risk that 3m^3 box is fabricated using the wrong materials and by organisations not familiar with the fabrication of such items. Mitigation includes using materials advised by RWMD and dealing only with experienced manufacturing companies.

- There many risks associated with manufacture of the waste package. Operations such as positioning of waste onto the furniture, placing the furniture in the box and grouting and lidding the box and others could go wrong and result in non conforming packages. Mitigation includes working closely with experienced personnel, including those from RWMD and the nuclear power industry.

- There is a risk that the waste package will not conform to the UK transport regulations and therefore cannot be transported off-site. It has already been established that the dose rates for packages placed at the centre of the box should be well within specified limits, but it must be ensured that this will occur in practice. Mitigation includes ensuring that the robustness of the package to changes in the geometry of the waste, grout composition and other factors is well understood by the operational teams and that these tolerances are respected. The Department for Transport should be engaged at an early stage to discuss the requirements of the approval process.

- There is a risk that the package might fail during long term storage, producing unacceptable radiation and/or contamination leaks. Mitigation includes following the RWMD guidance on package manufacture.

- There is a risk, that by the time the package is ready to be transported to the GDF, the onset of corrosion or other reasons make it unfit for transportation. Mitigation includes following the RWMD guidance, particularly that on wasteform evolution, immobilisation and package integrity and voidage.

- There is a risk that once the package is at the GDF, it might not be compliant with the relevant waste acceptance criteria. This is considered a low probability risk, but one with high consequences, since other users could also be similarly be affected. The degree of risk should diminish with time, once the site for the GDF has been selected. All waste packages, regardless of type, are susceptible to this risk. Mitigation includes following the RWMD guidance.

It was concluded that no significant threats to the use of the $3m^3$ box waste package were apparent from analysis of the risks associated with the activities performed during the lifecycle of the box.

The recommendation was made that MoD should formally confirm that the preferred option for packaging of SDP ILW is the $3m^3$ box waste package.

Application of the three approaches generated a number of key issues which will need to be addressed as part of the RWMD Letter of Compliance process. These are listed in Annex 3.4 of the Phase 3 report. Since this Annex contains a list of studies that will be required in the future, MoD may wish to be guided by it when formulating future packages of work.

The draft Phase 3 report was reviewed by MoD, but not sent to the SDP stakeholders for review or comment.

5. RECOMMENDATIONS

The following recommendations are made:

- MoD should send this draft combined report to the SDP stakeholders for their review and comment.

- If the stakeholders' comments are favourable, MoD should formally confirm that the preferred option for packaging of SDP ILW is the $3m^3$ box waste package. This recommendation is based on the conclusions of a structured optioneering process involving standard and non standard RWMD waste packages, a review of RWMD waste package and wasteform requirements and considerations relating to the lifecycle of the $3m^3$ box waste package.

- Recognising that identification and adoption of a single package design may not lead to overall optimisation, MoD should periodically review intended package use to determine if more than one package design is required.

- MoD should instigate a review of the impact of improved waste inventory data when they become available. This should include gaining an understanding of the role which IP-2 packages might play, particularly for disposal of LLW to the GDF or LLWR. It is recognised that the waste inventory results may have a significant impact on the conclusions of this work. For example, if the radionuclide activity levels (and the associated dose rates) are not as high as previously assumed, this may allow reconsideration of IP-2 packages (i.e. the 2m and 4m boxes). In addition, if the mass of ILW is lower than previously assumed, a smaller number of ILW packages will be required.

- MoD should review Annex 3.4 (Appendix 3) and the relevant RWMD specifications to gain a better understanding of the documentation requirements of the Letter of Compliance (LoC) process. MoD should ensure that the key documentation identified in Annex 3.4 is produced to a timetable which is consistent with the Loc process.

- MoD should continue to make best use of the relevant experience of RWMD and civil nuclear industry organisations.

- If possible, MoD should move forward with existing designs of boxes and overpacks. If this is not possible, MoD should work closely with RWMD to ensure that any revised designs will be fit for purpose.

- When reliable waste inventory data become available, MoD should evaluate the use of the $3m^3$ box waste package for PWR 2 reactor waste.

6. REFERENCES

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APPENDIX 1: REPORT ON WASTE CONTAINER SELECTION FROM STANDARD NDA PACKAGES

[redacted]

TAF No.SDP/05 Packaged Waste Container Review Phase 1 (Optioneering) Report.
Nuvia Ltd. Ref. No. 89330/TAF5/016. Issue: B.
March 2010.

Editorial Note: The original intention was to perform this work in two phases. Phase 1 was intended to be optioneering from a selection of standard waste packages and Phase 2 the substantiation of the option chosen during Phase 1. After completion of this Phase 1 document, an additional phase was added. The purpose of the additional phase was to address non standard waste packages. This became Phase 2. Consequently, any reference in the original report to "Phase 2" has been changed in the text below to "Phase 3" to make it consistent with the combined document.

1. INTRODUCTION

This report contains the results of a packaged waste container optioneering study, which was specified in the MoD/BMT Contract #N/SUB2/70253/1 - TAF No. SDP/05, titled: “Packaged Waste Container Review”.

This interim report addresses only the results of Phase 1 (Optioneering). The draft Phase 1 report was reviewed by MoD and then sent by MoD to SDP stakeholders for their comments. The conclusions of the draft Phase 1 report were acceptable to MoD and to most of the SDP stakeholders. MoD and Nuvia discussed the stakeholder responses and produced a list of actions to address their comments. This report is the updated Phase 1 deliverable.

MoD has agreed to proceed with Phase 3 (Detailed Evaluation of the Preferred Option) and the results from both work phases of the work will eventually be combined into one report.

1.1 Objective

The objective of the work is specified in the TAF 5 contract documentation as follows: “*To determine which of the available designs of standard NDA Intermediate Level Radioactive Waste (ILW) containers would be most suitable for the packaging of submarine ILW and to provide a robust audit trail for the recommendation”.*

1.2 Scope of Work

A meeting was held at Abbey Wood on 2nd December 2009 to discuss the scope of work, the optioneering criteria and the TAF 5 data set. The agreed scope of work is summarised below.

- The aim is to select a disposal container for packaging of ILW generated from the dismantling of UK nuclear submarines. The selection is restricted to the 5 containers specified by the NDA [Refs. #1 and #2] for packaging of ILW. The data used during the selection process must be traceable and auditable and the arguments used for container selection must be robust and defensible.

- The NDA ILW container must be capable of being used to safely package the size reduced ILW from all 27 decommissioned nuclear submarines, allowing for a ten year gap between taking each submarine out of service and the start of the dismantling process. MoD’s current preference is to utilise only one type of ILW container, hence the requirement is to select a container which will accommodate the highest possible ILW Co-60 specific activity.

The work was/will be performed in two phases, both of which are described below.

- Phase 1 (Optioneering) determined which of the available NDA package designs is suitable for packaging of submarine ILW. A scoping study was carried out to identify if any of the options are incompatible with the UK transport regulations. This was followed by an optioneering conference for selection of the preferred option. The end point of Phase 1 is selection of a preferred ILW packaging option. Issue of the Phase 1 report was effectively a hold point. MoD approval was required before moving on to Phase 3.

- Phase 3 (Detailed Evaluation of Preferred Option) will explore lifecycle issues associated with the preferred ILW container. This study will include the design, manufacture, approvals, use, transport, interim storage and acceptance of the loaded container in the planned national Geological Disposal Facility (GDF). The study will include additional technical issues which were not addressed during Phase 1 because they were common to all containers and were therefore non discriminating. The study will also address some aspects of other containers if more comparison data are required. If no reasons are found to change the container ranking order, the $3m^3$ box will then be declared as MoD's preferred container option for packaging of submarine ILW.

2. BACKGROUND

2.1 SDP Land Storage Options

The Submarine Dismantling Project (SDP) has been tasked with the disposal of the Royal Navy's fleet of 27 nuclear submarines. This includes all submarines currently in or previously withdrawn from service, but excludes Astute and future classes. The scope of the SDP is restricted to these 27 de-fuelled submarines and the project finishes with the dismantling of the 27th submarine and the disposal of the resulting ILW to a planned national Geological Disposal Facility.

Three major decisions still need to be made. These are the preferred technical dismantling solution, the choice of site to conduct initial submarine dismantling and the choice of site for interim storage of ILW. The following options are available for each of these decisions:

- **The Technical Dismantling Solution:**
  - Reactor Compartment (RC) Cut-Out.
  - Full dismantling of RC and Reactor Pressure Vessel (RPV) with associated packaging options.
  - Reactor Pressure Vessel Cut-Out and Packaged ILW.

[redacted]

[redacted]

The main driver for the TAF 5 work is that the preferred container for the interim storage of packaged ILW needs to be determined to assist in generating a shortlist of interim storage sites for ILW which is size reduced and packaged immediately after RPV cut-out. The TAF 5 information is required for consideration at the MoD Preferred Option Selection (MPOS) conference.

The SDP project team is also undertaking a Strategic Environmental Assessment (SEA), which will address selection of the dismantling and interim storage sites.

2.2 ILW Production From Submarine Reactors

A short overview is provided below of the processes which lead to the generation of ILW from nuclear powered submarines. The diagrams and some of the text are taken from Ref. #3.

Figure 2.1 below how the heat from the reactor is used to generate steam for production of propulsion and electricity.

Figure 2.1: Submarine Reactor Circuits

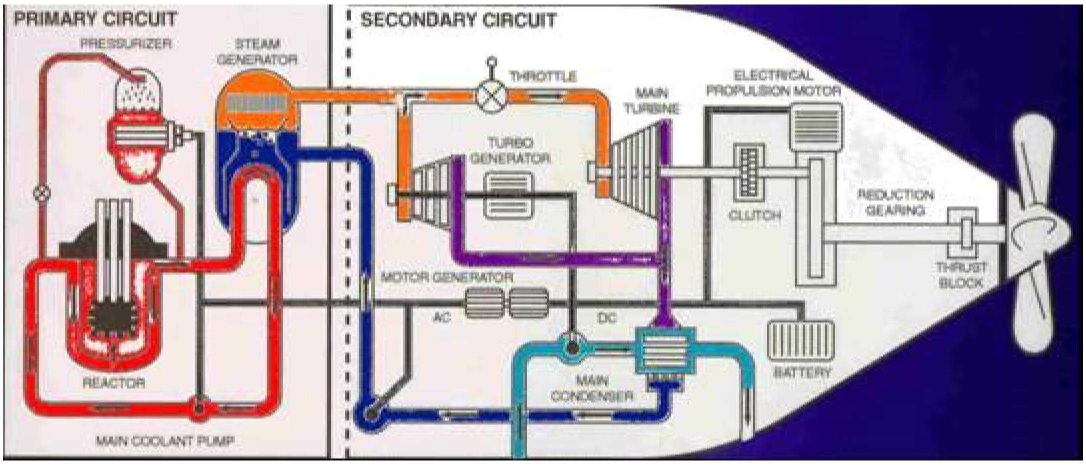
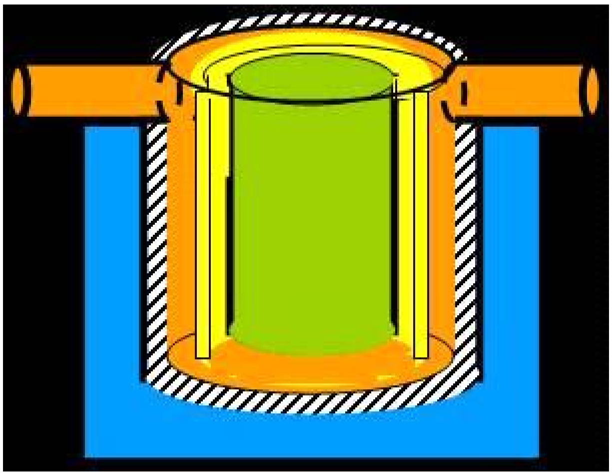


Figure 2.2 below shows a schematic of the Reactor Pressure Vessel (RPV). The fission process takes place inside the RPV. The RPV contains the nuclear fuel and control rods inside a core barrel. The RPV sits inside a separate tank, the primary shield tank (PST), which is filled with potassium chromate solution. The purpose of the potassium chromate solution is to provide a safety barrier by absorbing neutrons which penetrate the RPV during the fission process. Two of the walls of the PST are formed by the pressure hull of the submarine below the RPV and an RC bulkhead. Additionally, polythene blocks and lead are used in the RC to shield against certain types of radiation.

Figure 2.2: Reactor Pressure Vessel (RPV)



The radioactivity in the submarines arises by two routes. These are:

- Activation of materials and components by neutrons during the fission process. Activated components are typically those associated with the RPV, (e.g. the thermal shields, the core barrel, the RPV cladding and the RPV itself).
- Contamination of components by a layer of radioactive corrosion products (known as CRUD) which forms during the operation of the reactor. Examples of such components are the primary circuit and the steam generator.
- The UK definitions of low level (LLW) and intermediate level (ILW) radioactive wastes are shown below.
- LLW is defined as waste whose activity is above that of very low level waste but less than 1.2E+10 Bq per tonne (12GBq/t) for beta and gamma emitting isotopes and less than 4E+09 Bq per tonne (4 GBq/t) for alpha emitting isotopes. The current disposal route for LLW is to the national disposal facility at Drigg in Cumbria.
- ILW is defined as waste that is not sufficiently radioactive to be heat generating but has an activity concentration which exceeds that for LLW. There is currently no national disposal facility for ILW. ILW needs to be stored safely until a disposal facility becomes available. This could be between 50 and 100 years.

Cobalt-60 (Co-60) is a gamma-emitting radioactive isotope which is generated by neutron activation of Co-59. Co-60 is the dominant gamma emitter during the first few decades following reactor shut-down. This isotope has a half life of 5.27 years which means that every 5.27 years its radioactivity reduces by a factor of two. The Co-60 gamma activity decreases over decades and this is manifested by a reduction in gamma dose rates.

There are other radioactive isotopes inside the RPV which decay at far slower rates. Because the quantities of these isotopes are in excess of the limits for LLW, any waste containing substantial quantities of these long lived isotopes will remain as ILW for prolonged periods, in some cases in excess of 100,000 years. Thus although the gamma dose rates from submarine ILW will decrease with time, the categorisation of waste which contains substantial quantities of these longer lived isotopes will remain as ILW up to and after disposal in the GDF.

3. DESCRIPTION OF NDA WASTE PACKAGES

Nirex was a United Kingdom body set up in 1982 by the UK nuclear industry to examine safe, environmental and economic aspects of deep geological disposal of ILW and LLW. Originally known as the "*Nuclear Industry Radioactive Waste Executive*", it became, in 1985, the limited company "*United Kingdom Nirex Limited*". Ownership of Nirex was transferred from the nuclear industry to the UK Government departments DEFRA and DTI in April 2005, and then, in November 2006 to the UK's Nuclear Decommissioning Authority (NDA). Nirex's staff and functions were integrated into the NDA in April 2007, at which point Nirex ceased trading as a separate entity. Nirex's role continues through the activities of the Radioactive Waste Management Directorate of the NDA. Until it was subsumed into NDA, Nirex had responsilbilty for developing generic waste packages for disposal of ILW in the GDF. These are referred to below as NDA waste packages, but with reference to documentation produced by Nirex. An overview is provided below of the main features of the NDA waste packages, taken mainly from Refs. #1 and #2.

NDA has produced generic waste package specifications for the following packages:

- The 500 litre (500L) drum (one "standard" waste package and 3 variants, one for solids, one for liquids and one for supercompacted waste "pucks").
- The 3 cubic metre ($3m^3$) box (two variants).
- The 3 cubic metre ($3m^3$) drum (no variants).
- The 4 metre (4m) box (no variants).
- The 2 metre (2m) box (no variants).

It is understood that these specifications are concept designs which have been approved in principle by NDA and that the detailed waste package designs can contain modifications to suit particular circumstances, as long as these modifications are approved by NDA.

The five standard NDA packages comprise two basic types:

- **Unshielded waste packages** (i.e. 500 litre drum, 3 cubic metre box, 3 cubic metre drum) are typically manufactured from stainless steel sheet or plate. Remote handling is usually required, because of either radiation levels or requirements for containment. For similar reasons, unshielded waste packages must be transported in a reusable shielded transport container. This combination is classed as a Type B transport package under the IAEA Transport Regulations [Refs. #4 and #5].

- **Shielded waste packages** (i.e. 2 metre and 4 metre boxes) are manufactured from stainless steel and, where necessary, have built-in shielding and/or contain low activity materials, such that they do not need remote handling techniques. As well as being disposal packages, they are designed to qualify as transport packages in their own right without the need for additional outer packaging to provide radiation shielding. Classed as Industrial Package Type 2 (Type IP-2) under the IAEA Transport Regulations [Ref. #4], the allowable contents of shielded waste packages are limited to materials that qualify as Low Specific

Activity (LSA) material and/or Surface Contaminated Objects (SCO).

In addition to the standard waste packages, a limited number of non-standard waste packages have been accepted by NDA for packaging of specific waste streams, most often because the packaging concepts pre-dated the development of the standard range of containers. However, non-standard packages still have to satisfy the requirements of the NDA Specification, to levels equivalent to those required of the standard packages.

More details on the individual NDA packages (taken from Ref. #1) are provided below.

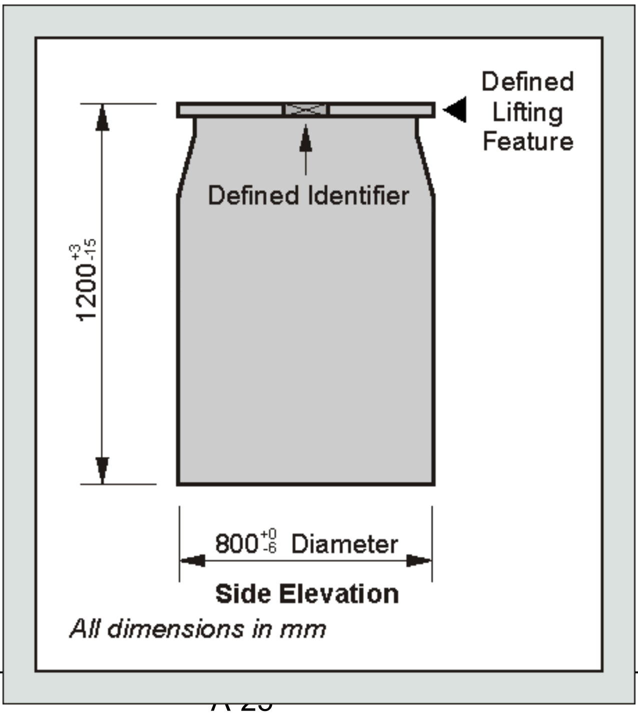
3.1 500 Litre (500L) Drum Waste Package

The principal waste package for ILW is the 500 litre drum. It is used mainly for wastes arising from the day-to-day operations of nuclear facilities. All 500 litre drums comply with the following standards:

- Dimensions within a defined envelope.
- A standardised lifting feature.
- Gross mass not exceeding 2,000 kg.
- A defined identifier format and location.
- Physical containment provided by drum body, lid and sealing system.
- Standardised stacking characteristics.
- Filtered venting where necessary.

The standard 500 litre drum is illustrated in Figure 3.1, below.

Figure 3.1: The Standard 500 Litre Drum

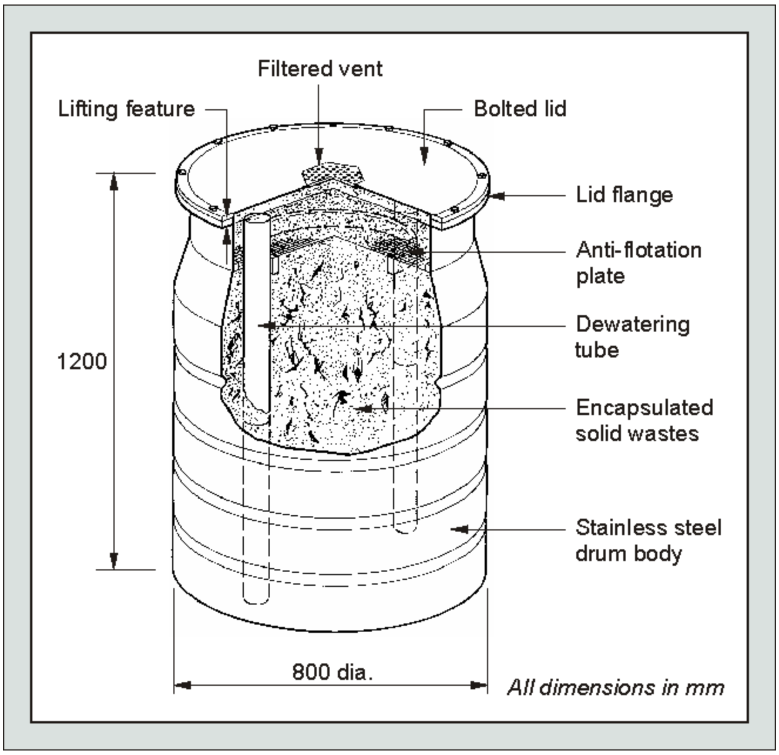


Within the standard envelope for the 500 litre drum, waste packaging organisations have developed a number of variations mainly in the lid area and in the internal drum support structures (known as “furniture”) to accommodate the process requirements for treating their diverse range of radioactive wastes.

In addition to the standard 500 litre drum, there are three major variants, one for solids, one for liquids and one for supercompacted drums (known as “pucks”). The 500 litre solids drum is the most relevant to this study and is presented below. The other two variants are not addressed further in this report.

The 500 litre solids drum is designed for immobilised solid waste forms (Figure 3.2) and may incorporate features such as grout introduction tubes, dewatering tubes and/or an anti-flotation plate (to prevent less dense items floating to the surface of the cement grout). Solid wastes are placed in the drum and then in-filled by pumping in a fluid grout. Depending on the shape and nature of the solid waste, the process may include vibration or pressure grouting to improve infiltration and assist in the elimination of voids.

Figure 3.2: The 500 Litre Solids Drum



The following summarises the principal handling and transport issues associated with the 500 litre drum.

- It is an unshielded package.
- Remote handling is necessary.
- It must be transported in a reusable shielded transport container (utilising a four drum stillage).
- The combination of the 500 litre drum and the reusable shielded transport container is known as a Type B package under the IAEA Transport Regulations.

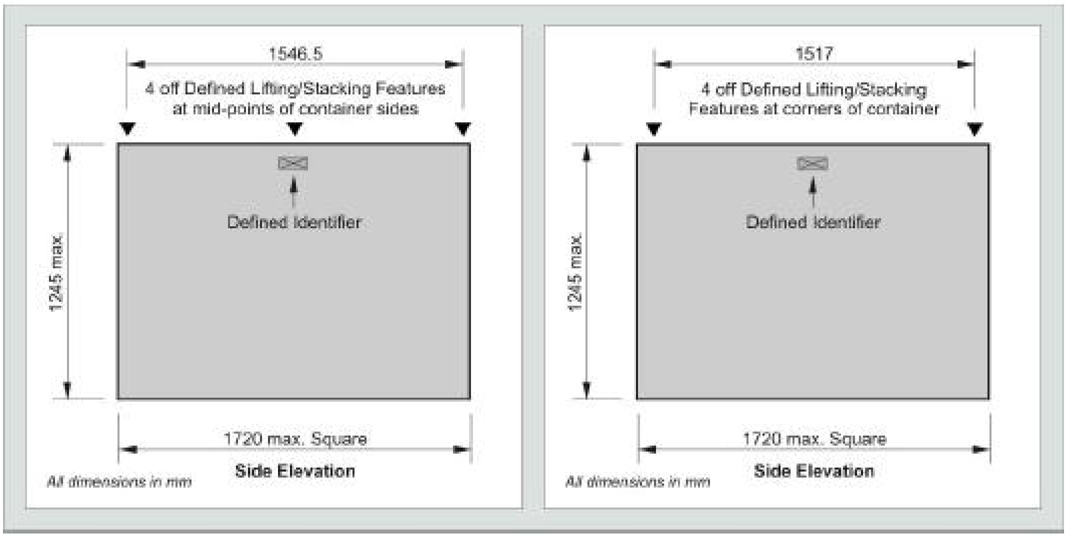
3.2 3 Cubic Metre ($3m^3$) Box Waste Package

For large, solid waste items, a box shaped container with a nominal 3 cubic metre capacity is available. All 3 cubic metre boxes comply with the following standards:

- Dimensions within a defined envelope.
- Standardised lifting features.
- Gross mass not exceeding 12,000 kg.
- A defined identifier format and location.
- Physical containment provided by box body, lid and sealing system.
- Standardised stacking characteristics.
- Filtered venting where necessary.

The two variants of the 3 cubic metre box are illustrated in Figure 3.3 below.

Figure 3.3: The Two Variants of the 3 Cubic Metre Box



The shape, dimensions and lifting/stacking arrangements of the two variants of the 3 cubic metre box have been chosen to maintain compatibility with the two principle designs of stillage used to handle 2 by 2 arrays of 500 litre drum waste packages during storage and potentially during transport.

The dimensions and lifting arrangements of the mid-side lifting variant (Figure 3.4, below) are standardised with those of the Nirex transport stillage. The illustration shows a container with rounded corners which have been specified with a radius of 430 mm historically to permit Reusable Standard Transport Container (RSTC) to be used to transport these waste through the public domain. (This part of the specification has now been removed.)

The dimensions and lifting arrangements of the corner lifting variant (Figure 3.5, below): are standardised with those of the Nirex disposal stillage and Sellafield 'compact stillage'. The plan dimension is flexible up to a maximum value of 1720 mm. Within this standard a plan dimension of 1665 mm, maintaining compatibility with the compact stillage would also be acceptable.

Both variants of the 3 cubic metre box can be transported within the Standard Waste Transport Container (SWTC). The SWTC is also designed to carry 500 litre drums, in either design of stillage, and 3 cubic metre drums.

Figure 3.4: 3 The Cubic Metre Box – Mid-side Lifting Variant

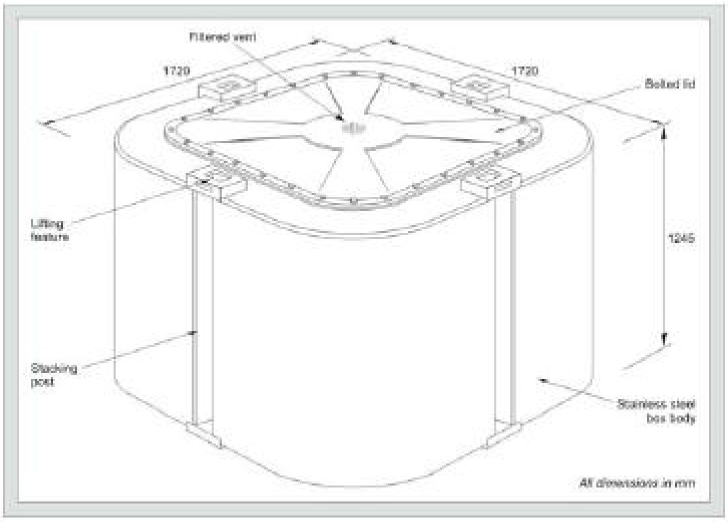
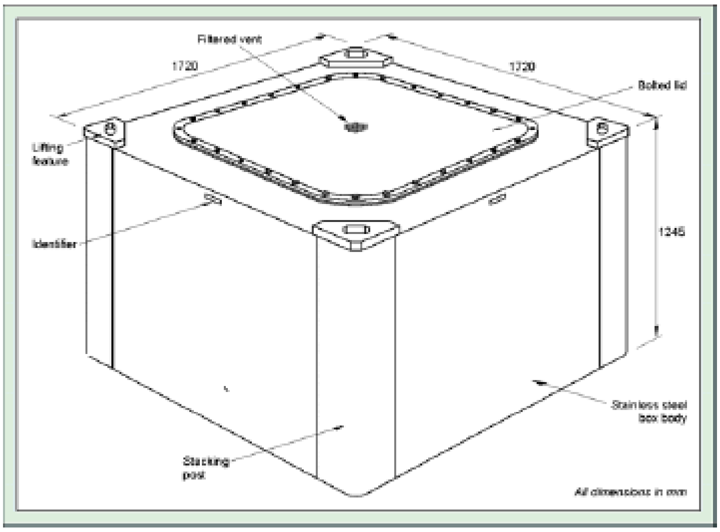


Figure 3.5: The 3 Cubic Metre Box – Corner Lifting Variant



The following summarises the principal handling and transport issues associated with the 3m^3 box waste package:

- It is an unshielded package.
- Remote handling is necessary.
- It must be transported in a reusable shielded transport container.
- The combination of the 3m^3 box waste package and the reusable shielded transport container is known as a Type B package.
- The 3m^3 box has dimensions and a shape that allows the same reusable shielded transport containers to be used for both the 3m^3 drum and up to four 500 litre drums in stillages.

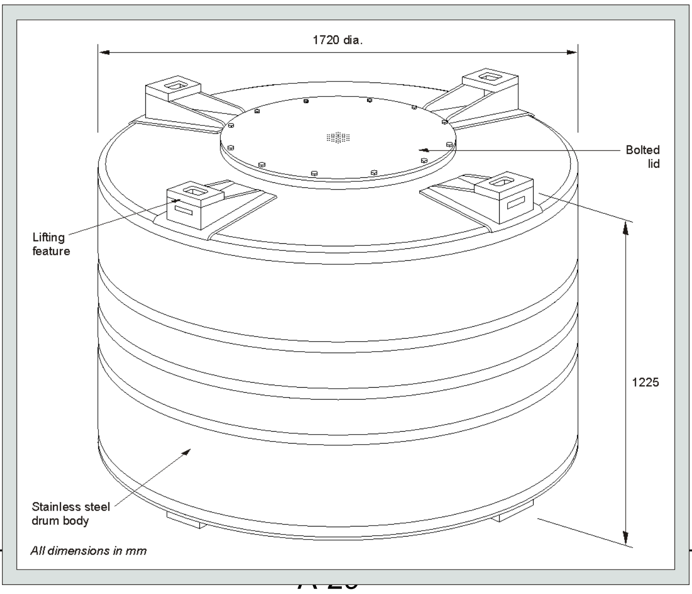
3.3 3 Cubic Metre (3m^3) Drum Waste Package

The 3 cubic metre drum is a cylindrical version of the 3 cubic metre box. All 3 cubic metre drums comply with the following standards:

- Dimensions within a defined envelope.
- Standardised lifting features.
- Gross mass not exceeding 8,000 kg.
- A defined identifier format and location.
- Physical containment provided by box body, lid and sealing system.
- Standardised stacking characteristics.
- Filtered venting where necessary.

The standard 3 cubic metre drum is illustrated in Figure 3.6 below.

Figure 3.6: The 3 Cubic Metre Drum



The following summarises the principal handling and transport issues associated with the $3m^3$ drum.

- It is an unshielded package.
- Remote handling is necessary.
- It must be transported in a reusable shielded transport container.
- The combination of the $3m^3$ drum and the reusable shielded transport container is known as a Type B package.
- The 3 cubic metre drum was developed for the conditioning of sludge and resin type wastes that arise on nuclear power plants, but can be used wherever the facility for in-drum mixing is required.
- Despite the different shape, the 3 cubic metre drum has the same outer envelope dimensions and lifting/handling features as the 3 cubic metre box. These common features also allow the same shielded transport container to be used.

3.4 The 4 Metre (4m) Box Waste Package

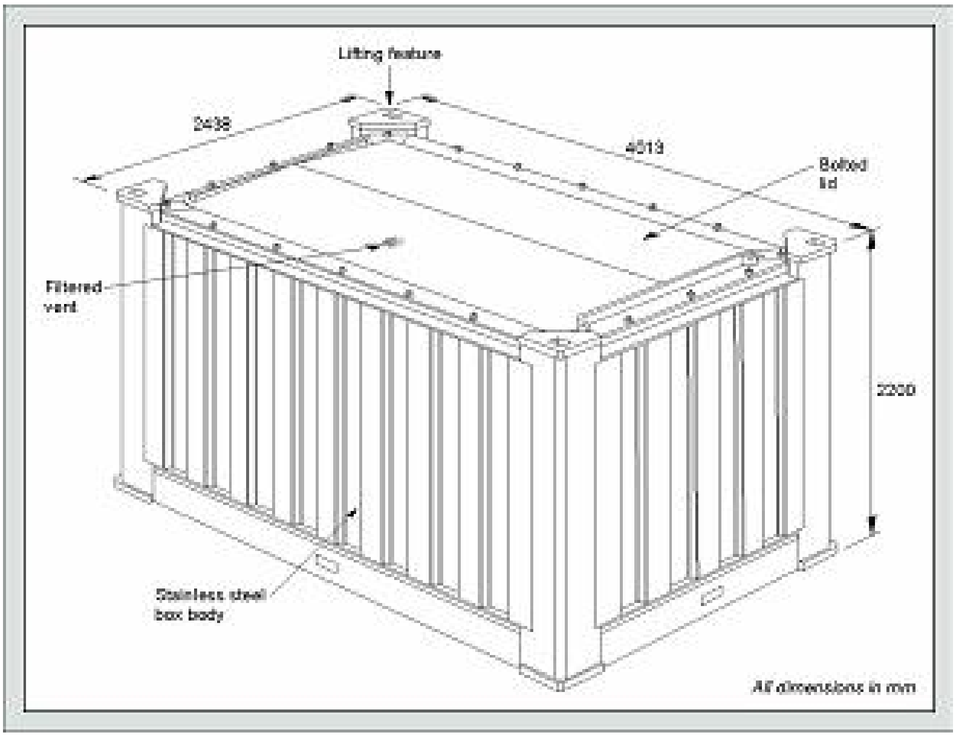
The 4 metre box is essentially a freight container that can incorporate its own shielding in the form of a concrete liner, if required. This box is intended to be used predominantly for wastes arising from the decommissioning of nuclear facilities. All 4 metre boxes comply with the following standards:

- Dimensions within a defined envelope.
- Standardised lifting features.
- Standardised tie down features.
- Gross mass not exceeding 64,000 kg.
- A defined identifier format and location.
- Physical containment provided by box body, lid and sealing system.
- Standardised stacking characteristics.
- Filtered venting where necessary.

The standard 4 metre box is illustrated in Figure 3.7 below.

[redacted]

Figure 3.7: The Standard 4 Metre Box



The following summarises the principal handling and transport issues associated with the 4 metre box.

- The waste package has its own internal shielding.
- Remote handling is not necessary.
- It does not need to be transported in a shielded transport container.
- It has dimensions that have been specified to follow the principles established for Series 1 International Organisation for Standardisation (ISO) freight containers.
- The standard ISO width of 8 feet (2.438m) has been adopted and the length has been specified as a two-thirds module of the standard 20-foot (6m) ISO container.
- The box incorporates ISO-style corner fittings to permit lifting by a twistlock frame, and tie-down to a transport vehicle.
- When filled with waste, the 4 metre box is designed to meet the requirements for an Industrial Package Type 2 (IP-2) Freight Container as specified in the IAEA Transport Regulations [Ref. #4].
- The activity content is restricted to that classified as Low Specific Activity (LSA) material or Surface Contaminated Objects (SCO) (as defined in Ref. #4) at the time of transport in the public domain.

3.5 The 2 Metre (2m) Box Waste Package

The 2 metre box is essentially a shorter version of the 4 metre box, and is intended to be used primarily for packaging wastes arising from the decommissioning of nuclear facilities. The 2 metre box may be preferred when the available space for loading is

[redacted]

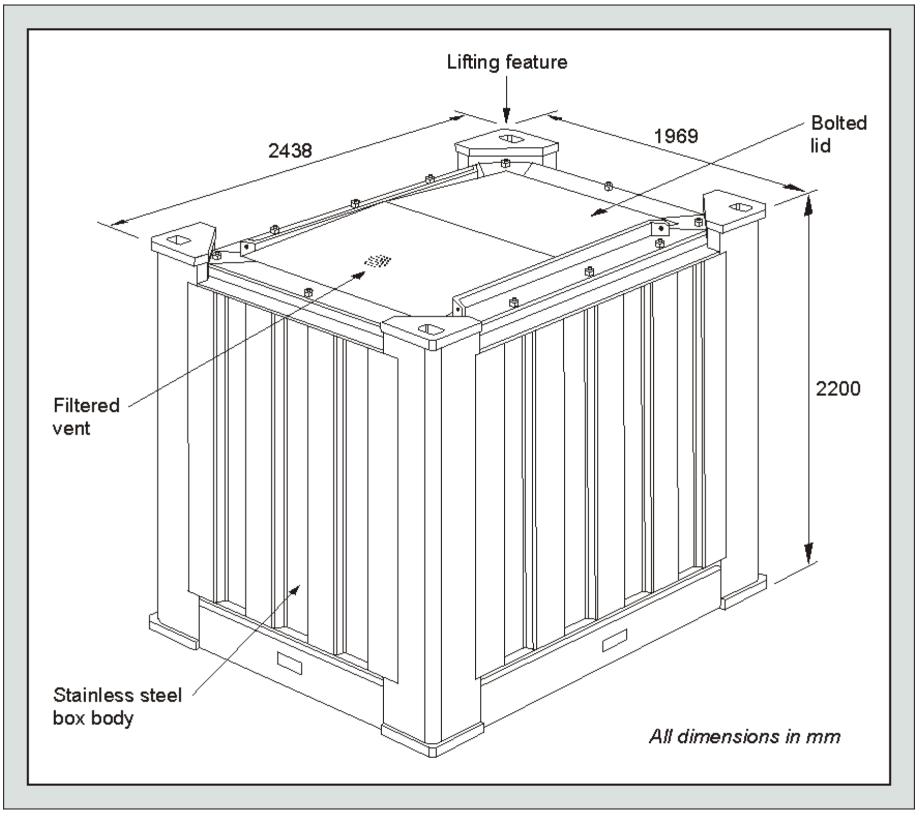
[redacted]

limited, when only a small amount of waste is involved and/or when the waste items are so dense that the mass limit of a filled 4 metre box would severely restrict the volume of waste that could be loaded.

All 2 metre boxes comply with the following standards:

- Dimensions within a defined envelope.
- Standardised lifting features.
- Standardised tie down features.
- Gross mass not exceeding 40,000 kg.
- A defined identifier format and location.
- Physical containment provided by box body, lid and sealing system.
- Standardised stacking characteristics.
- Filtered venting where necessary.
- The standard 2 metre box is illustrated in Figure 3.8 below.

Figure 3.8: The Standard 2 Metre Box



The following summarises the principal handling and transport issues associated with the 2 metre box.

- The package has its own internal shielding.
- Remote handling is not necessary.
- It does not need to be transported in a shielded transport container.

[redacted]

- The width and height dimensions of the 2 metre box are currently identical to those of the 4 metre box and the Series 1 ISO freight container, the length has been specified as 1.969m.
- The box incorporates ISO-style corner fittings to permit lifting by a twistlock frame and tie-down to a transport vehicle.
- When filled with waste, the 2 metre box is designed to meet the requirements for an Industrial Package Type 2 (IP-2) Freight Container as specified in the IAEA Transport Regulations [Ref. #4].
- The radioactivity content is restricted to that classified as Low Specific Activity (LSA) material or Surface Contaminated Objects (SCO) at the time of transport in the public domain.

3.6 Transport Regulations

The UK Radioactive Material Transport (RMT) regulations for road and rail are contained in "The Carriage of Dangerous Goods and Use of Transportable Pressure Equipment Regulations 2009" [Ref. #6]. These refer out to the "European Agreement concerning International Carriage of Dangerous Goods by Road" (ADR) and the equivalent Rail Regulations (RID).

For transport by sea, the International Maritime Dangerous Goods Code (IMDG) refer out to the IAEA Transport Regulations [Ref. #4] and are implemented in the UK by “The Merchant Shipping (Dangerous Goods and Marine Pollutant) Regulations”.

Because the UK regulations for transport of radioactive material refer out to the IAEA Transport Regulations transportation practitioners often make use of the advisory material provided by IAEA [Ref. #5] as a companion to their safety regulations.

The text below summarises the key transport requirements which are relevant to this study.

3.7 IP-2 Package Requirements

Some requirements relevant to this study are discussed below.

The content of an IP-2 package must be restricted or arranged such that the dose from the unshielded waste form does not exceed 10mSv/h at a distance of 3m. Thus, the self-shielding of the waste, grout and any required package furniture can be taken into account, but not that provided by the box.

The radiation level at the outer edges of a vehicle carrying an IP-2 package must not exceed 2 mSv/h. In practice for this type of ISO container, this is the same as the surface dose rate of the IP-2 package.

The radiation level at any point 2m from the outer edges of the vehicle must not exceed 0.1 mSv/h.

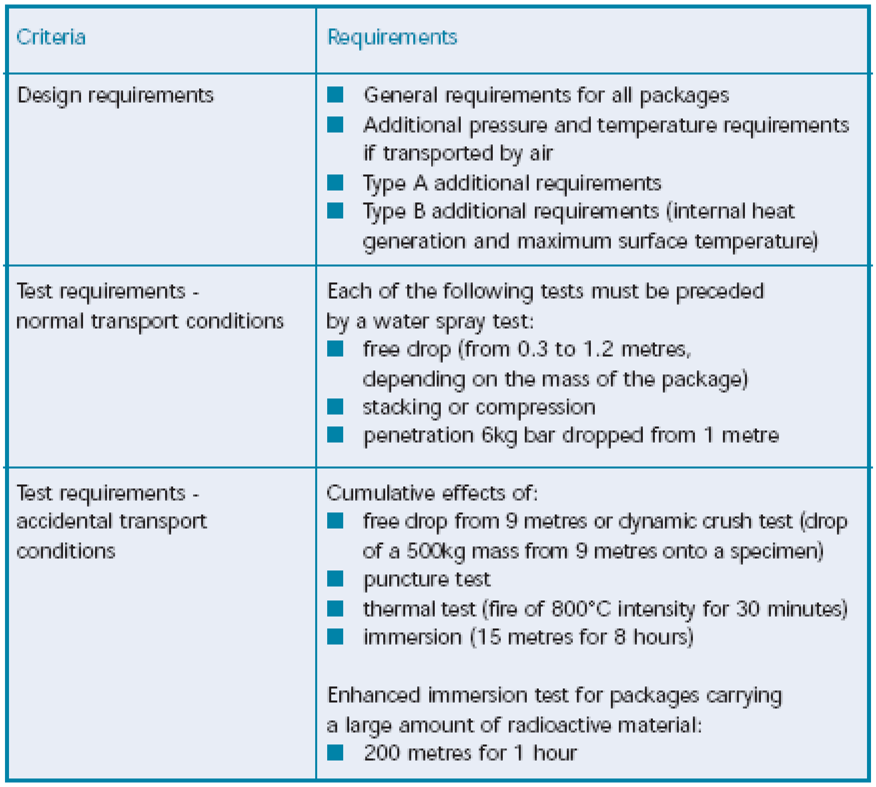
For transport in IP-2 packages, waste must meet the criteria for LSA material. For LSA-II, this means the A_2 content must not exceed $10^{-4}A_2/g$. This restriction is taken as the average over the waste form, i.e. includes the mass of grout. The boxes could be used to transport LSA-III material, which has a higher A_2 limit. However, a leach test is required, with limits on release to be met.

For transport in IP-2 packages, waste must meet the criteria for SCO material. A surface contaminated object (SCO) is a solid object which is not itself radioactive but which has radioactive material distributed on its surfaces. It has been assumed that CRUD will have been substantially removed or immobilised before transport, therefore the material will meet SCO-II limits. If CRUD were not removed or immobilised, it is likely that SCO-II limits for surface contamination would be exceeded.

3.8 Type B Package Requirements

Some general requirements relevant to this study are discussed below. Other requirements will be addressed during Phase 3 of this study.

Type B packages are required for the transport of highly radioactive material. These packages must withstand the same normal transport conditions as Type A packages, but because their contents exceed the Type A limits, it is necessary to specify additional resistance to release of radiation or radioactive material due to accidental damage. The concept is that this type of package must be capable of withstanding expected accident conditions, without breach of its containment or an increase in radiation to a level which would endanger the general public and those involved in rescue or clean-up operations. The adequacy of the package to this requirement is demonstrated by stringent accident conditions testing. The design and testing requirements are summarised below.



Criteria	Requirements
Design requirements	■ General requirements for all packages ■ Additional pressure and temperature requirements if transported by air ■ Type A additional requirements ■ Type B additional requirements (internal heat generation and maximum surface temperature)
Test requirements - normal transport conditions	Each of the following tests must be preceded by a water spray test: ■ free drop (from 0.3 to 1.2 metres, depending on the mass of the package) ■ stacking or compression ■ penetration 6kg bar dropped from 1 metre
Test requirements - accidental transport conditions	Cumulative effects of: ■ free drop from 9 metres or dynamic crush test (drop of a 500kg mass from 9 metres onto a specimen) ■ puncture test ■ thermal test (fire of 800°C intensity for 30 minutes) ■ immersion (15 metres for 8 hours) Enhanced immersion test for packages carrying a large amount of radioactive material: ■ 200 metres for 1 hour

3.9 All Transport Packages

For all transport packages, NDA has stipulated [Ref. #4] that the dose rate at 1 metre from the surface shall not exceed 0.1 mSv/h and the dose rate from the external surface shall not exceed 2 mSv/h. The implications of this are addressed in the Phase 3 report.

4. DATA ASSUMPTIONS AND EXCLUSIONS

The data which were used in the study, together with the assumptions and exclusions are shown below. Note that these were agreed with MoD prior to undertaking the study.

4.1 ILW Mass

There are three relevant waste streams from dismantling of the submarines: 7G104 (Long lived ILW), 7G103 (LLW) and 7G102 (Short lived ILW). 7G104 consists of the three thermal shields and fixture, the core barrel and the cladding which has been removed from the RPV. The mass of 7G104 per submarine is [redacted] According to Ref. #7, this will remain as ILW well beyond the decommissioned submarine afloat storage period of 30 years. Some components (i.e. the RPV cladding material) of this waste stream will decay to LLW after about 700 years and others (i.e. the core barrel) after 100,000 years. The 7G104 waste stream is addressed in this report. The other two waste streams are ignored.

[redacted]

The mass and volume of ILW per submarine will have an impact on disposal and interim storage costs. However, if there is no decay to LLW before disposal, ILW mass will not be a discriminating issue between the various ILW management options.

There is an argument which suggests that more that [redacted] of ILW will be produced during size reduction, presumably because it simplifies the size reduction process and avoids the need for segregation of LLW from ILW during size reduction in a high dose rate environment. There is a counter argument which suggests that less than [redacted] ILW will be produced, since only part of the RPV internals may have been neutron activated to ILW levels. The MoD baseline assumption is that both of these arguments are ignored and are not to be used in this study.

Use is made in this study of the calculations contained in Ref #7, which relate to a mass of [redacted] tonnes of ILW. However, the conclusions of this study are considered to be independent of the mass of ILW per submarine.

4.2 ILW Density

The ILW density is quoted in Ref. #7 as [redacted]. This is the MoD recommended density for the types of stainless steels used in submarine reactor systems.

4.3 ILW Volume

The ILW [redacted] [redacted] tonnes and a density of [redacted].

4.4 ILW Packing Fraction

Packing fraction is defined as the volume of the waste inside the container divided by the accessible internal volume of that container. Thus for example, a packing fraction ratio of 0.5 means that waste occupies 50% of the accessible internal volume of a container. A high packing fraction is desirable, since this means that a relatively high mass of ILW can be put into the package.

Because of the high gamma dose rate, loading of any ILW waste package will need to be undertaken remotely whether in a shielded cell or underwater. The size reduction methodology to be used is beyond the scope of this study. It is however assumed that sufficient size reduction will be required to satisfy the waste hierarchy by segregating LLW and optimising packing efficiency.

In order to remotely load steel waste into any of the packages it is normal industry practise to utilise purpose designed support structures that the size reduced waste is loaded into/onto before lowering the support structure with waste into the disposal package. This can be pictured as similar to a toast rack and is commonly referred to as package furniture. As well as permitting safe remote loading, the furniture fulfils the function of holding waste in the design configuration whilst the loaded package void is grouted. For example, the approved ILW package design normally requires metallic waste to be held away from the walls of a metal container.

Loading waste vertically into the top of the waste package using furniture does mean that the package lid opening dimensions can have a significant impact on the accessible internal volume of the container.

The packing fraction will depend on a number of factors such as the geometry of the container, the geometry of the waste and the design and use of internal package furniture. In addition, because the waste package will be transported to the interim store and eventually to the GDF, probably by road, the transport limit on gross package mass needs to be taken into account.

Annex 1.1 shows the derivations of the packing fractions of the five standard ILW waste packages, together with the assumptions and data used in the derivations. A considerable level of detail is provided in the calculation sheets, commensurate with the MoD requirement to provide defensible and traceable arguments.

4.5 ILW Waste Disposal Efficiency

The disposal efficiency of a package is defined as the mass of waste inside the package divided by the gross volume of the package occupied at the GDF. It is measured in tonnes/m^3. The higher the disposal efficiency, the less disposal space is required. A relatively high disposal efficiency is obviously desirable.

The waste disposal efficiency will depend on a number of factors including the disposable waste mass and on the internal and external volumes of the package.

The waste disposal efficiencies of the five standard ILW waste packages are derived in the calculation sheet shown in Annex 1.1. The assumptions and data used in the derivations are also included in the calculation sheet.

4.6 ILW Decay Period

A MoD assumption is that the NDA ILW container must be capable of being used to safely package the size reduced ILW from all 27 decommissioned nuclear submarines, allowing for a ten year gap between taking each submarine out of service and the start of the dismantling process. The 10 year gap is a rounded approximation to the time required to take the submarine out of service, remove the fuel, prepare the submarine for dismantling and dismantle it. It is recognised that the time gap for most submarines will be longer than 10 years. Nevertheless, there may be cases where accelerated dismantling is required.

Nirex was commissioned in 2000 to carry out a study [Ref. #8] which identified issues arising from the use of the 4 metre box. One of the issues identified by Nirex was the prolonged decay storage times (between 36 to 43 years) required before this box would meet relevant dose rate criteria. These prolonged decay storage times are now considered unacceptable and a 10 year decay period has been specified by MoD.

4.7 ILW Co-60 Content

According to Ref. #7, the ILW inside the RPV is made up of items with different masses and different radiological specific activities (Bq/tonne). The total mass of ILW is quoted as 18.6 tonnes. For each of the items inside the RPV, the radionuclide specific activities (Bq/tonne) have been tabulated as a function of time. The activity (Bq) per item of any radionuclide can be computed by multiplying the decay corrected value (Bq) by the mass (tonne) of the item. Adding the activities (Bq) of the items provides a total activity (Bq) for that particular radionuclide. Thus, using the information contained in Ref. #7, [redacted] of ILW has a Co-60 activity of 1.24 E14 Bq after a decay period of 10 years.

For the purposes of calculating dose rates from a 2 metre NDA box loaded with ILW which has a high Co-60 specific activity, it was calculated that, based on the above, a mass of [redacted] of ILW has a Co-60 activity of 1.16 E14 Bq after a 10 year decay period.

4.8 CRUD

During reactor operations, a layer of radioactive corrosion products (CRUD) forms which causes contamination of components, typically the primary circuit and steam generators. MoD is currently investigating how best to deal with this material and their baseline assumption is that components which are categorised as ILW are free from loose contamination. Ref. #7 contains some information on the isotopes present inside CRUD and their decay characteristics. The level of confidence in this data is not high. It is recognised that some loose contamination will be present and if so, the impact of such contamination may therefore need to be addressed.

4.9 Grouting

The assumption is made that grout will be added to the packages after they have been loaded with waste and that after this grout has cured, a capping grout will also be added.

Ref #9 states that "*In some cases, adequate immobilisation may be afforded by the waste itself. Those wastes in which the radioactivity is not present in a mobile form (i.e. bulk metals containing neutron activated radionuclides) and that will not generate mobile radionuclides by their evolution, may not require additional conditioning in order to render them passively safe and acceptable for disposal, although may require measures to reduced voidage*".

The advantages of adding grout after waste loading include:

- Reduction in container dose rates.
- Prevention of redistribution of waste and any associated variations in dose rates.
- Reduction in voidage.
- Provision of a monolithic package which can be safely handled, transported and stored in compliance with passive safety requirements.

The disadvantages of grouting after waste loading include:

- Early grouting may be viewed by some stakeholders as an unnecessary foreclosing of options.
- The grout may need to be separated from the waste at a later stage if for example, changes are made to the GDF waste acceptance criteria which preclude acceptance of the grouted wasteform.
- Grouted packages are heavier and hence may be less manageable than ungrouted packages.

It is recognised that the grout addition assumption may need to be revisited at a later date if there are compelling arguments to the contrary.

5. PHASE 1: INITIAL SCOPING STUDY

It was agreed with MoD that Phase 1 would start with a scoping study to evaluate the loaded containers against aspects of the UK radioactive waste transport regulations. The purpose of the scoping study was to determine if any of the containers were non compliant with MoD requirements.

It is understood that after loading and grouting, the containers will be transported from the size reduction facility to an off-site interim store and retained there for between 50 and 100 years. The packages will then be transported from the interim store to the GDF, which could be on another site. These transportations will be by road, rail or a combination of the two. Because three of the containers (i.e. 500 litre drum, $3m^3$ box and $3m^3$ drum) together with their overpacks are designated as Type B packages, while the other two (i.e. 4 metre box and 2 metre box) are designated as IP-2 containers, all to different designs, this was considered to be a discriminating attribute which should be investigated further as part of the initial scoping study.

5.1 The 2 Metre Box

It is a requirement of IP-2 containers (but not of Type B packages) that the dose rate at a distance of three metres from the unshielded surface of the grouted wasteform should not exceed 10 mSv/h. This is for the protection of workers and the public if the waste form is exposed during accident conditions. According to the IAEA guidance contained in Ref. #5, the additional shielding afforded by grouting the annulus between the waste and the package and by the package construction and shielding material cannot be taken into account in meeting this requirement.

In order to determine whether or not loaded IP-2 packages could meet this transportation requirement, a scoping study was carried out on the NDA 2 metre box. The MicroShield software package was used to calculate the gamma dose rate at three metres from the surface of unshielded package. The study assumed that the 2 metre box was loaded with ILW which had been decay stored for 10 years. During this period, the Co-60 activity would have decayed by two half lives, resulting in a factor of 4 reduction in activity from the start of the decay period. It was assumed that the mass of ILW inside the 2 metre box was [redacted] and that the Co-60 activity was 1.16 E14 Bq.

The waste configuration, measurement parameters and the MicroShield results are contained in Annex 1.2 and summarised below.

Annex 1.2 shows the 3 metre unshielded dose rate from a source containing 17 radioactive isotopes, including Co-60, which had been decay stored for 10 years. An identical MicroShield calculation was performed using only the Co-60 content of the source. The similarity of the two sets of results confirmed the assumption that Co-60 is the only isotope which needs to be considered in dose studies of this nature.

Annex 1.2 shows that the dose rate at more than 3 metres from the waste inside an unshielded 2 metre box was [redacted], which is significantly in excess of the 10 mSv/h limit. Because of the limitations of the MicroShield software it was necessary to assume a compact waste source term, hence the distance from the measurement point to the waste form (3.75 m) is conservatively greater than the transport regulation requirement, possibly by up to 10%. The extra distance produces a dose rate which could be slighter lower than actual. However, if the longer distance dose is greater than the relevant transportation criteria, the shorter distance (actual) dose will be even higher. This is therefore a cautious approach. A high degree of accuracy is implied by quoting the dose rate results ([redacted]) to three decimal places, but this level of accuracy is not warranted. The dose rate result is therefore quoted as [redacted]

Thus a submarine would need to be decay stored for an additional 4 half lives (ca. 20 years) before the dose rates decayed to acceptable levels for transport. Including the initial 10 year decay storage period, approximately 30 years would need to elapse before the ILW from a newly decommissioned submarine could comply with the 3 metre dose rate requirement for transportation inside a 2 metre box.

In addition to prolonged decay storage, there are other ways of reducing the gamma dose rates emanating from the 2 metre box. For example, the dose rates could be reduced by putting less waste inside the container, diluting the high gamma-emitting ILW with lower gamma-emitting ILW or LLW or using a higher density grout. The latter would decrease dose rates, but would increase the package mass. If the mass of the internal shielding, the empty box, the furniture and the low density internal grout are already very close to the mass limit for the container, use of a higher density grout could result in a lower waste mass and hence a reduced payload. Thus although the above measures are technically possible, they are not considered practical solutions which use the 2 metre box to its best potential.

Similar calculations were performed at various distances from the 2 metre box and none of the results were compliant with the transport/NDA requirements.

5.2 The 4 Metre Box

Calculations similar to those discussed above were carried out in Ref. #8 for the 4 metre box. Similar results were obtained for the 4 metre box, indicating that (at 2001) up to 43 years decay storage would be required before the 4 metre box could be used to transport submarine ILW.

5.3 Conclusions

Since MoD has specified that the ILW container must be capable of being used to safely package ILW from submarines which have been out of service for 10 years, it is concluded that neither the 2 metre not the 4 metre box is compliant with the MoD specification.

There is a strong case for not doing any further work on these boxes during this study and recommending that these boxes are not used for packaging of submarine ILW.

However, it is considered prudent to temporarily ignore the above conclusions and include both the 2 metre and 4 metre boxes in the Phase 1 optioneering study. If either of these boxes is selected as the preferred ILW container, MoD may wish to reconsider the 10 year decay period assumption. On the other hand, if neither of these boxes is chosen as the preferred option, this would provide additional justification for not recommending use of these boxes for packaging and transport of submarine ILW.

6. PHASE 1: OPTIONEERING CONFERENCE

An optioneering conference was convened by Nuvia on 10th December 2009 to discuss the various ILW packaging options. This was attended by the following Nuvia personnel:

[redacted]

The various options were assessed using a standard multi-attribute decision analysis technique, supported by the software package Hiview 3. The basic steps in the optioneering process are shown below:

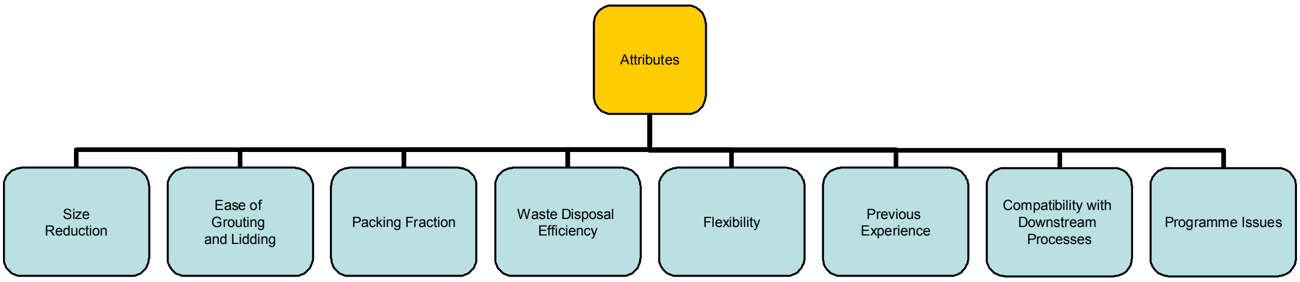
- Define the scope of the optioneering including any assumptions and constraints.
- Identify available options (screening out any that do not meet the constraints).
- Identify relevant decision attributes.
- Complete the scoring and weight allocation process.
- Analysis the results including a consideration of sensitivities and uncertainties in the scoring and weighing process.

Thus the optioneering conference methodology was consistent with that used during the SDP technical options study, as described in the Frazier Nash Technical Note [Ref. #10].

6.1 Attributes

The set of criteria (attributes) used during the optioneering process was determined prior to the conference through discussion between members of the Nuvia team. During the conference, some attributes were added or existing ones modified. The final attribute set is shown in Figure 6.1 below.

Figure 6.1: Attributes used during the Optioneering Conference



Other attributes (i.e. transport, environmental factors, regulatory approvals and costs) were also considered and but not ultimately scored, therefore they are not contained in Figure 6.1. For completeness, the discussions of these attributes are included in the text of this document.

Each of the five NDA containers was evaluated against the attributes listed above and then given a numerical ranking between 1 and 5. The convention used was that 1 was the lowest score and 5 the highest score. The lowest score meant that a container was the least favourable option for a given attribute and the highest score meant that the container was the most favourable option. In some cases, the attributes were not considered to be sufficiently discriminating or overlapped with others and were not scored. The discussion relating to these attributes was however recorded and is included within this document.

Available or derived data was used where possible during the evaluation and if no data was available, expert judgement was used.

Each attribute was assigned a weight, reflecting the perceived importance of the issue to the decision-making process. The scores and weights were then combined to produce an overall score for each option. The package with the highest overall weighted score was judged to be the most favourable option and hence designated as the preferred option.

It was recognised that allocation of a weight to each attribute is generally the most subjective part of the overall process. To test the robustness of the preferred option, the weights were subjected to a Hiview software sensitivity analysis. This indicated how much the weight allocated to each attribute had to change before another option received the highest score. If significant changes were required, the preferred option was judged to be robust. If only minor changes in weight produced another option, the selection of the preferred option was judged to be weak.

The provisional results and conclusions from the above process were incorporated into a draft report which was reviewed on 5th January 2010 by the optioneering team and subsequently updated.

6.2 Results of the Optioneering Conference

The results of the optioneering conference are presented and discussed below. Note that some of the derived data (e.g. aperture dimension, volumes, waste disposal efficiency, packing fractions) which are presented in the tables below are reproductions of the calculated values shown in Annex 1.1 and have deliberately not been rounded up or down for ease of traceability to the values in the annex. The apparent high degree of accuracy quoted for these data is artificial and should be ignored.

The output from the Hiview software package is shown in Annex 1.3. This shows the scoring tables, and the sensitivity analysis for the evaluation of the five NDA containers against each of the identified attributes.

6.2.1 Ease of Size Reduction

This attribute reflects the amount of size reduction required to produce items which will fit inside the various waste containers. A package with a large useable volume and a large aperture (opening) would require less size reduction than one with a smaller volume and opening, provided there are no other factors (e.g. gross weight) which need to be taken into account. Since ease of size reduction varies with container design and use, this is a considered to be a discriminating attribute.

The RPV will be cut out of the reactor compartment and delivered to the on-site size reduction and processing facility. The RPV will need to be size reduced inside a hot cell to allow the waste to be packaged. It is assumed that the size reduced items will be incorporated into a rack or cage support structure (furniture) which will then be inserted into the container. The dimensions of the container aperture opening will determine the optimum waste and furniture dimensions and therefore how much waste size reduction is required. The applicable cutting technologies have not yet been identified, but it is likely that saws (e.g. band, reciprocating, abrasive wire) and other cutting equipment will be used.

Because this attribute impacts strongly on the duration, cost and complexity of the size reduction process, a relatively high weighting has been applied.

The bigger the container aperture, the less size reduction required, therefore the ranking is a reflection of the magnitude of the aperture openings. The 4 metre box has the largest aperture dimensions of all of the NDA containers and therefore has the highest ranking. The 500 litre drum has the smallest aperture dimensions and has therefore the lowest ranking. The other boxes (2m box, $3m^3$ box $3m^3$ drum) are between these rankings. Both the 4 metre and 2 metre boxes are shielded with 300 mm thick high density concrete, as explained in Annex 1.1.

The table below summarises the ranking and scoring results, together with the aperture dimensions as calculated in Annex 1.1.

#	Container	Scoring	Ranking	Comments
1	500 litre drum	1	5th	Aperture diameter = 0.7 m Aperture area = 0.49 m^2
2	$3m^3$ box	3	3rd	Aperture diameter = 1.72 m Aperture area = 1.16 m^2
3	$3m^3$ drum	2	4th	Aperture diameter = 1.72 m Aperture area = 0.5 m^2
4	2m box	4	2nd	Aperture length = 1.969 m Aperture area = 4.8 m^2

#	Container	Scoring	Ranking	Comments
5	4m box	5	1st	Aperture length 4.015 m Aperture area = 9.8 m^2

6.2.2 Ease of Grouting and Lidding

This attribute reflects the ease with which grouting and lidding operations can be carried out on size reduced waste which has been placed onto its furniture and then into the container. Once the waste has been size reduced to suit the aperture of the container, it is relatively easy to load it into the container. However, for high mass, high volume containers which have large aperture openings, grouting and lidding operations can be more complex. Since ease of waste grouting and container lidding vary with package design and use, this is considered to be a discriminating attribute.

After size reduction, the waste will be put onto/into its furniture, which will then be loaded into the container. This could be carried out for example, by posting the furniture containing the stacked waste out of the hot cell, through a hole in its floor and then into its container. The container would then be moved to a location where grout can be added. Addition of grout will result in a reduction of container dose rates, prevent redistribution of waste and any associated variations in dose rates and will provide a monolithic package which can be safely handled and transported. The process may include vibration or pressure grouting to improve infiltration and assist in elimination of voids. A capping grout may be added. The lid will be put in position and bolted on to the container. The filled container will be moved to another location for quality control purposes, which could include measurements of weight, contamination and radiation.

Because many of the problematic issues addressed in this attribute can be overcome by good plant design, it is given a low weighting.

The lidding and grouting operations will be relatively easy for low mass low volume containers, but more complex for high mass, high volume containers. On this basis, the 500 litre drum is given the highest ranking and the 4 metre box the lowest ranking.

The table below summarises the ranking and scoring results, together with the container masses and external volumes as shown in Annex 1.1.

#	Container	Scoring	Ranking	Comments
1	500 litre drum	5	1st	Mass < 2 tonnes Volume = 0.556 m^3
2	3m^3 box	3	Joint 2nd	Mass < 12 tonnes Volume = 3.62 m^3
3	3m^3 drum	3	Joint 2nd	Mass < 8 tonnes Volume = 3.62 m^3
4	2m box	1	Joint 5th	Mass < 40 tonnes Volume = 10.56 m^3
5	4m box	1	Joint 5th	Mass < 64 tonnes Volume = 21.53 m^3

6.2.3 Packing Fraction

The packing fraction (no units) is defined as the volume (m^3) of ILW inside the container, divided by the available internal container volume (m^3). It is a measure of how much of the available internal volume can be filled with ILW. The higher the packing fraction, the higher the utilisation of the available internal container volume and the less unused space there will be inside a container. Conversely, the lower the packing fraction, the less the utilisation of the available internal volume of the container and the more unused space there will be inside a container. Since packing fraction is a function of package design, it is considered to be a discriminating attribute.

Waste disposal efficiency is addressed below and has been given a high weighting. Because the calculated permissible waste masses and volumes are common to the derivation of both the waste disposal efficiencies and the packing fractions, it was considered prudent to minimise double accounting and give packing fraction a low weighting.

The derivations of the container packing fractions are shown in Annex 1.1. A maximum packing fraction of 0.6 was initially assumed for all containers. If the total loaded container mass exceeded its mass limit, the packing fraction was reduced until the total mass limit was reached. If the total loaded container mass did not exceed its mass limit, a packing fraction of 0.6 was declared. The packing fraction was used to calculate the volume and mass of waste which could be put into the container. For packing fractions of 0.6, the calculations were repeated using packing fractions of 0.5 and 0.7 to provide an estimate of the possible range of waste volumes and masses. Since this was provided for information only, no conclusions were drawn from these additional calculations.

The table below summarises the ranking and scoring results, together with the container packing fractions as calculated in Annex 1.1. The highest packing fractions are those of the 3m^3 box and the 3m^3 drum and these are given the highest rankings. The volume of waste allowed in both of these boxes is not restricted by the maximum allowable container mass limitation. The lowest packing fraction is that of the 4 metre box. This is a relatively large box which needs a substantial thickness of concrete shielding. The mass of this shielding together with the masses of the empty box, the furniture and the internal grout come very close to the mass limit for the container. This means that only a relatively small mass of waste can be put into the 4 metre box. Because of the high density of the ILW, this translates into a very small volume of steel. In fact, Nirex/NDA recognised this and introduced the 2 metre box for "*waste items which are so dense that a filled 4 metre box would exceed its mass limit*" [Ref. #1].

The table below shows that the 4 metre box has a far lower package fraction than the 2 metre box. This is a consequence of the large thickness of additional shielding required (weighing approximately 40 tonnes) for the 4 metre box compared to its overall mass limit (64 tonnes), as shown in Annex 1.1. Thus about 66% of the permissible mass of the 4 metre box is taken up with concrete shielding. By comparison, the 2 metre box has the same thickness of shielding as the 4 metre box, but since it is smaller than the 4 metre box the shielding mass (ca. 21 tonnes) is less. The shielding mass for the 2 metre box is only about 50% of the overall weight limit (ca. 40 tonnes), hence a higher mass and volume of ILW can be put into the 2 metre box. The 2 metre box therefore has a higher packing efficiency than the 4 metre box.

#	Container	Scoring	Ranking	Comments
1	500 litre drum	3	4th	Packing fraction = 0.36
2	3m^3 box	5	Joint 1st	Packing fraction = 0.6
3	3m^3 drum	5	Joint 1st	Packing fraction = 0.6
4	2m box	4	3rd	Packing fraction = 0.54
5	4m box	1	5th	Packing fraction = 0.09

6.2.4 Waste Disposal Efficiency

Waste disposal efficiency (in units of tonne/m^3) is defined as the mass (tonne) of ILW within the container, divided by the external (disposable) volume (m^3) of the container. Note that waste disposal efficiency relates to the external disposable container volume, in contrast to the packing fraction (see above) which relates to utilisation of the available internal container volume. The higher the waste disposal efficiency, the more waste can be disposed of per cubic metre of the GDF. Since waste disposal efficiency varies with package design and use, this is a discriminating attribute.

The derivations of the waste disposal efficiencies are shown in Annex 1.1. These rely on the masses of waste allowed inside each package, already calculated to determine the packing efficiencies. These masses are divided by the overall volume of the disposal package to obtain a measure of the waste disposal efficiency. Thus the most efficient container relevant to this attribute is one with a high waste mass coupled with a low container volume.

Waste disposal efficiency impacts significantly on other attributes. For example, the higher the waste disposal efficiency, the higher the mass of waste which can be put into the container and the lower the volumes of waste for disposal. The lower the waste volumes, the lower the number of transports required, the lower the environmental impact and the lower the disposal costs. Waste disposal efficiency is therefore regarded as a key attribute and is given a very high weighting.

The table below summarises the ranking and scoring results, together with the container waste disposal efficiencies as calculated in Annex 1.1. The 3m^3 box has the highest waste disposal efficiency ranking because it can hold the highest mass of ILW per cubic metre of disposable volume. The 3m^3 box has the joint highest packing fraction and can hold a reasonable mass of waste inside a relatively small disposable volume. Note that the overpack is not included in the disposable volume for this container, the 3m^3 drum or the 500 litre drum.

The 4 metre box has the lowest ranking. This is because it has a low packing efficiency and can hold only a low mass of ILW in a large package volume. The 2 metre box has a higher ranking that the 4 metre box because the 2 metre box has a higher packing fraction and can hold a higher mass of waste inside a smaller package volume. It might be expected that since the internal concrete shielding is part of the disposable volume of both of the 4 metre and 2 metre boxes, both boxes would perform badly under this attribute. The 2 metre box has in fact performed well, mainly because the mass of waste (but not the mass of waste per unit volume) which it can carry is the highest of all of the containers.

#	Container	Scoring	Ranking	Comments
1	500 litre drum	4	2nd	Waste Disposal Efficiency = 1.27 tonnes/m^3
2	$3m^3$ box	5	1st	Waste Disposal Efficiency = 1.44 tonnes/m^3
3	$3m^3$ drum	2	4th	Waste Disposal Efficiency = 0.62 tonnes/m^3
4	2m box	3	3rd	Waste Disposal Efficiency = 1.18 tonnes/m^3
5	4m box	1	5th	Waste Disposal Efficiency = 0.26 tonnes/m^3

6.2.5 Flexibility

This attribute reflects the sensitivity of containers to changes in some of the base-line data, assumptions and working practices. A flexible container is one which is relatively insensitive to these types of changes. Flexibility increases with decreasing sensitivity to change. Since flexibility varies with package design and use, this is considered to be a discriminating attribute.

There is still a degree on uncertainty on some of the base line data, like for example the volume of ILW. Future changes to these data should ideally have a minimum impact on the choice of the preferred container. This may not always be possible. For example, MoD has now stipulated that submarines that have been out of commission for a minimum of 10 years should be eligible for dismantling. There was previously no time limit on this minimum period. This is a major change which would appear to have a significant impact on container choice. As discussed in Section 5, some of the packages are insufficiently flexible to meet this requirement. Recognising the importance of flexibility as an issue, a medium weighting is given to this attribute.

It is recognised that there is a myriad of data which should be tested for flexibility. This discussion is limited to issues associated with the Co-60 activity, the unshielded dose rates and the physical size of the waste.

The table below summarises the ranking and scoring results. The $3m^3$ box has the highest ranking because it is the most flexible to the Co-60 content and to the physical size of the waste. The $3m^3$ box is less dependent than the 4 metre or 2 metre boxes on the amount of time required for decay storage. Because it is a Type B package, it does not have the same unshielded dose rate limitation as the IP-2 packages, therefore it could contain higher Co-60 activities than the 4 metre or 2 metre boxes, provided these do not exceed package limits. Because it has a relatively large aperture opening, the 3m^3 box can accommodate larger waste items than the 500 litre drum or the 3m^3 drum. The 2 metre box has the lowest score because it has an unshielded dose rate constraint and because of its reduced size over the 4 metre box, it is less able than the 4 metre box to deal with large awkward pieces of metal.

#	Container	Scoring	Ranking	Comments
1	500 litre drum	3	3rd	No significant decay storage limitations. Small aperture opening.
2	3m^3 box	5	1st	No significant decay storage limitations. Large aperture opening.
3	3m^3 drum	4	2nd	No significant decay storage limitations. Small aperture opening.
4	2m box	1	5th	Significant decay storage limitations. Large aperture opening.
5	4m box	2	4th	Significant decay storage limitations. Large aperture opening.

6.2.6 Previous Experience

This attribute reflects the UK nuclear industry experience of using these containers. The experience encompasses concept design, detailed design, approvals, manufacture, testing and use. Since some containers have already been manufactured and used, while others are still at the concept design stage, this is regarded as a discriminating attribute.

NDA has approved the concept design of the five standard ILW containers. However, development of ILW containers in the UK has been slow-moving for a number of years, not because of any technical issues, but because of the politics associated with provision of a national ILW repository. Therefore lack of previous experience is not regarded as a significant technical issue and is therefore given a low weighting in this study.

The concept designs of all five standard containers have been approved in principle by NDA for waste storage and disposal, but none of them has yet been approved for transportation. The 500 litre drum is currently used throughout the UK nuclear industry (e.g. Sellafield, Dounreay, Harwell, Winfrith), mainly for on-site storage of ILW until the national repository is operational. However, it is not known if 500 litre drums have been transported in shielded stillages. There is some experience with the 3m^3 box within the nuclear industry (e.g. Hunterston, Trawsfynydd) and also with the 3m^3 drum (e.g. Hunterston).

The table below summarises the ranking and scoring results. The 500 litre drum has the highest ranking because the UK nuclear industry has most experience (relative to the other containers) of using this drum. The 3m^3 box has the second highest ranking, because the UK nuclear industry has some experience (but not as much as that for the 500 litre drum) of using this box. There is less UK experience of the other containers and these therefore have the lowest rankings.

#	Container	Scoring	Ranking	Comments
1	500 litre drum	5	1st	Used throughout the UK nuclear industry. Shielded stillages not yet approved.
2	$3m^3$ box	4	2nd	Trawsfynydd and Hunterston have experience of using this box.
3	$3m^3$ drum	1	Joint 3rd	More limited UK experience.
4	2m box	1	Joint 3rd	More limited UK experience.
5	4m box	1	Joint 3rd	More limited UK experience.

6.2.7 Compatibility with Downstream Processes and Facilities

This attribute reflects the compatibility of a filled, grouted and lidded waste package with future downstream processes (i.e. handling, transport, storage and disposal). Many of the other downstream processes (e.g. compliance with storage and disposal waste acceptance criteria) are common to all packages and are not considered further. The main issue is assumed to be the different shielding requirements for transport, storage and disposal. Because this varies with package design and use, this is considered to be a discriminating attribute.

The reduced waste disposal efficiencies of the 4 metre and 2 metre boxes are a direct consequence of the space taken up by the internal grout used for shielding. This internal shielding grout is an asset prior to disposal, since no additional shielding is required during transport or interim storage. This reduces the technical complexity of both of these types of operations. However, because it is integral to the package, the internal shielding grout is disposed of, along with the ILW, to the GDF. This increases the disposable volume and impacts on the disposal costs. Recognising that technical solutions will be found for the transport and storage shielding issues, the main impact would appear to be on costs. Because costs are addressed (in a qualitative manner) within this report, this attribute is given a low weighting.

The table below summarises the ranking and scoring results. The 2 metre and the 4 metre boxes are ranked joint first, because they have internal shielding which is compatible with an unshielded store. No additional shielding is required for the transportation of these boxes. The other three containers are ranked joint third, since they need additional shielding for both storage and transport. For the 500 litre drums, storage shielding may be provided by placing them inside below-surface tubes, (colloquially known as mortuary holes).

#	Container	Scoring	Ranking	Comments
1	500 litre drum	1	Joint 3rd	Not compatible with unshielded store
2	$3m^3$ box	1	Joint 3rd	Not compatible with unshielded store
3	$3m^3$ drum	1	Joint 3rd	Not compatible with unshielded store
4	2m box	5	Joint 1st	Compatible with unshielded store
5	4m box	5	Joint 1st	Compatible with unshielded store

6.2.8 Transport

The NDA waste package justification document [Ref. #2] specifies that the activity content of unshielded packages shall not exceed 1E5 A_2 (i.e. 1E16 Bq). Specifically, the 500 litre drum cannot exceed 2.5E4 A_2 (i.e. 1E16 Bq of Co-60) and the $3m^3$ box and drum waste packages cannot exceed 1E5 A_2 (i.e. 4E16 Bq of Co-60).

These values are at least an order of magnitude greater than the Co-60 content of the submarine ILW. It is concluded that for unshielded packages, the Co-60 content of the waste does not cause permissible activity content limits to be exceeded.

Concept designs exist to allow transportation of a 500 litre drum (4 drums in a stillage), the $3m^3$ box and the $3m^3$ drum in the same type of shielded Type B package. All three of these package designs will therefore have broadly similar technical, approval and regulatory issues to be addressed.

The NDA waste package justification document also specifies that in the case of unshielded packages, the quantity of LSA material or SCO in a single waste package shall be so restricted that the external radiation level at 3 metres from the unshielded material does not exceed 10 mSv/h.

It has already been established in this document that the loaded 2 metre and 4 metre boxes cannot be transported as IP-2 packages since the 10 year decayed material does not meet the unshielded dose rate requirement for low specific activity (LSA) wastes.

The activity content of waste packages has already been used as a discriminatory attribute in this study. Recognising the importance of transportations, additional work on waste package transportation issues will be undertaken during Phase 3 of this study.

6.2.9 Safety

This attribute reflects any significant radiological or conventional (non-radiological) safety concerns associated with the containers. All of the ILW management processes will be carried out under a safety case regime, with varying degrees of safety risk.

A measure of radiological safety can often be obtained by an assessment of operator dose. The maximum operator dose incurred throughout the ILW management process will probably be at the RPV cutting out stage, which is common to all packages. Size reduction and processing will be carried out under shielded conditions, therefore the anticipation is that these operator doses will be small. Similarly, operator doses during transport, storage and disposal will be carried out under an ALARP regime and these should also be small. Thus although safety is the principal driver for these works, radiological safety as measured by operator dose is not considered to be a discriminating attribute.

A similar argument applies to non radiological safety. A measure of conventional (non-radiological) operator safety can be obtained by an assessment of workplace slips, trips and falls. According to the US Occupational Safety and Health Administration (OSHA) , slips, trips and falls constitute the majority of workplace accidents. Good housekeeping should not be dependent on package design or use. Thus conventional industrial safety, as measured by slips, trips and falls is not a discriminating attribute.

The unshielded packages (500 litre drum, 3m^3 box and 3m^3 drum) will be classified as Type B containers and as such will need to undergo a series of tests (e.g. drop tests, fire tests) as part of the approval process. These tests relate both to normal transport and accident conditions during transport. Those packages with integral internal shielding (4m and 2 metre boxes) will be classified as IP-2 containers, and these will be tested only for normal (accident-free) conditions. It could be argued that in the event of a transport accident, the Type B packages are inherently safer than the IP-2 packages. Radiological safety, as measured by the classification of the transport package could therefore be a discriminating indicator. However, because safety is a multi-faceted discipline which merits detailed consideration at all stages in the process, it was concluded that this single argument should not be taken further.

At this stage, safety is considered to be a non discriminating attribute and was therefore not considered further in the optioneering process.

6.2.10 Environmental Impact

This attribute reflects the impact to the environment of the use of the container.

A measure of environmental impact is the quantity of ILW produced from submarine dismantling. The higher the gross volume of ILW, the more transportations will be required and the more space will be needed for storage and disposal. These issues have already been considered and will not be addressed further under this attribute.

Another measure of environment impact is the quantity of secondary waste produced. During RPV cut out, secondary solid, liquid and gaseous wastes will be produced, but this is common to all packaging options. The quantity of secondary wastes and resource use will vary with the extent of size reduction, which will differ according to package design, therefore this is a discriminating attribute. Size reduction operations generate secondary solids, liquids and gases. These include spent saw blades, cutting fines, active liquids, and active aerosols. The more size reduction, the more resource is needed and the more secondary waste is produced. Packages with large aperture openings need less size reduction and have a lesser environmental impact than those with small openings. This has already been addressed under ease of size reduction and will not be addressed further in this document.

Other measures of environmental impact are waste disposal efficiency, which is a measure of how much waste can be disposed of per cubic metre of the GDF and packing fraction, which is a measure of how much of the available internal volume of a container can be filled with waste. Since these are functions of package design and use, they are considered as discriminating attributes. However, because they have already been specifically addressed, they are not considered further in this section of the document.

At this stage, environmental impact is considered to be a non discriminating attribute and was therefore not considered further in the optioneering process.

6.2.11 Regulatory Approval

The regulatory authorities will have a wide range of concerns which need to be addressed before they will give approval for the various stages of the ILW management process. Key technical issues relating to regulatory approval will include considerations of ALARP, waste minimisation and segregation to optimise the proportion of lower activity wastes. Regulatory approval for the packages, facilities and operations will need to be obtained. This attribute has been narrowed down to reflect the confidence that regulatory (and NDA) approvals will be obtained for the packages. Since regulatory approval will vary depending on the package design and use, this is a considered to be a discriminating attribute.

It is cautioned that since this is a technical option study, the emphasis is on the technical aspects of regulatory approvals. If the optioneering was led by regulatory experts, they would probably place a different emphasis on this attribute and possibly on some of the other attributes. For this reason and because it is almost certain that regulatory approvals will eventually be obtained, it was concluded that this attribute should not be considered further in this optioneering study.

6.2.12 Programme Issues

This attribute reflects issues associated with the SDP programme. Since the content and duration of the programme will vary with the type of package used, this is considered to be a discriminating attribute.

One issue is the lead time required before the containers are available for use. The works which need to be carried out before a package can be used can include research and development activities, package and overpack design and manufacture, approvals and testing, production of the safety case, risk assessments and others. Since the lead time will vary with package and overpack design, this is a discriminating attribute.

The lead time for Department of Transport (DoT) approval for IP-2 packages is estimated at about 2 to 3 years. The estimated lead time for DoT approval of Type B packages is estimated at about 5 years. It is recognised that these estimates may be considered by some to be pessimistic. Although the 500 litre drum is available off the shelf, the overpack is not yet available. With good planning, however, most of the issues associated with this attribute can probably be overcome, therefore a low weighting is given.

The table below summarises the ranking and scoring results. The highest rankings are given to the 2 metre and 4 metre boxes because these are IP-2 packages which could be DoT approved within 2 to 3 years. The next lowest rankings are given to the 500 litre drum and the 3m^3 box, because together with their overpacks they are Type B packages and will take longer to approve. The 3m^3 drum is given the lowest ranking, reflecting the more limited UK experience of this package.

#	Container	Scoring	Ranking	Comments
1	500 litre drum	3	Joint 3rd	Longer lead time
2	3m^3 box	3	Joint 3rd	Longer lead time
3	3m^3 drum	1	5th	Longer lead time
4	2m box	5	Joint 1st	Short lead time
5	4m box	5	Joint 1st	Short lead time

6.2.13 Cost

This attribute reflects the cost of ILW management within the SDP. Because MoD has an ongoing programme to identify project costs they have advised against a detailed consideration of costs as part of this optioneering study. Some qualitative considerations are presented below.

The major costs will be related to the size reduction and waste processing facility, the interim store and waste disposal. On the assumption that the cost of the size reduction facility will not have a strong dependence on the choice of container, this attribute has been narrowed down to reflect the long term ILW storage and disposal costs. Both of these costs will be a function of package design and gross package volume, the latter being determined by the waste disposal efficiency. A high waste disposal efficiency reduces the ILW storage/disposal volumes, resulting in lower disposal costs. Because disposal costs will vary with package design and use, this should be a discriminating attribute. Because the options have already been ranked according to waste disposal efficiency, this attribute is not addressed in a quantitative manner in this study.

6.2.14 Unweighted Results

The unweighted results are summarised in Table 6.1 below.

Table 6.1: Unweighted Optioneering Results

#	Attributes	500 litre drum	$3m^3$ box	$3m^3$ drum	2m box	4m box
1.	Ease of Size Reduction	1	3	2	4	5
2.	Ease of Grouting and Lidding	5	3	3	1	1
3.	Packing Fraction	3	5	5	4	1
4.	Waste Disposal Efficiency	4	5	2	3	1
5.	Flexibility	3	5	4	1	2
6.	Previous Experience	5	4	1	1	1
7.	Compatibility with downstream processes and facilities	1	1	1	5	5
8.	Programme issues	3	3	1	5	5
	UNWEIGHTED TOTALS	**25**	**29**	**19**	**24**	**21**

The unweighted ranking order is the 3m^3 box (29 points), followed by the 500 litre drum/2m box (25/24 points) and then by the 4m box/3m^3 drum (21/19 points).

Thus the preferred option based on the unweighted scores is the 3m^3 box.

6.2.15 Weighted Results

The weighted results are shown in Table A3.4 of Annex 1.3 and summarised in Table 6.2 below.

Table 6.2: Weighted Optioneering Results

#	Attributes	Weighting	500 litre drum	3m^3 box	3m^3 drum	2m box	4m box	Cum Wt.
1.	Ease of Size Reduction	8	2.4	7.3	4.8	9.7	12.1	24.2
2.	Ease of Grouting and Lidding	2	3.0	1.8	1.8	0.6	0.6	6.1
3.	Packing Fraction	2	1.8	3.0	3.0	2.4	0.6	6.1
4.	Waste Disposal Efficiency	10	12.1	15.2	6.1	9.1	3.0	30.3
5.	Flexibility	5	4.5	7.6	6.1	1.5	3.0	15.2
6.	Previous Experience	2	3.0	2.4	0.6	0.6	0.6	6.1
7.	Compatibility with downstream processes and facilities	2	0.6	0.6	0.6	3.0	3.0	6.1
8.	Programme Issues	2	1.8	1.8	0.6	3.0	3.0	6.1
	WEIGHTED TOTALS	**33**	**29**	**40**	**24**	**30**	**26**	**100**

Note that the highest weighting is given to the waste disposal efficiency, followed by ease of size reduction, flexibility and then the other attributes.

The weighted ranking order is the 3m^3 box (40 points), followed by the 2m box/500 litre drum (30/29 points) and then by the 4m box/3m^3 drum (26/24 points).

Thus the preferred option based on the weighted scores is the 3m^3 box.

6.2.16 Sensitivity Analysis

To test the robustness of the preferred option, the weights were subjected to the Hiview software package sensitivity analysis, which determined the sensitivity of the results to changes in the weight of any of the attributes. This is shown in Annex 1.3. Significant changes to the weight allocated to each attribute would have to change before another option received the highest score. This indicated that when submitted to the Hiview software package sensitivity analysis, the preferred option is robust.

Additional sensitivity analyses (e.g. to timing assumptions) may be carried out as part of the Phase 3 works.

6.2.17 Conclusions

Similar ranking orders have been obtained for both the weighted and unweighted scores. The preferred option based on both the weighted and unweighted scores is the 3m^3 box, followed by the 2m box/500 litre drum and then by the 4m box/3m^3 drum.

When submitted to the Hiview software package sensitivity analysis, the preferred option was considered robust because significant changes would need to be made to the weight allocated to each attribute before another option attained the highest score.

It is concluded that the 3m^3 box should be carried forward into Phase 3 as the Phase 1 preferred option. If the 3m^3 box survives the substantiation phase and no reasons are found to change the container ranking order, it should then be declared as the MoD preferred option for packaging of submarine ILW.

7. SUMMARY AND CONCLUSIONS

An optioneering study was undertaken by Nuvia personnel on behalf of MoD to determine which of the available designs of standard NDA ILW containers would be most suitable for the packaging of submarine ILW and to provide a robust audit trail for the recommendation. The work was split into two phases. The purpose of Phase 1 is to determine which of the available NDA package designs is suitable for packaging of submarine ILW and select an option which will be carried forward into Phase 3. The purpose of Phase 3 is to carry out a detailed evaluation of the preferred option and examine the robustness of the Phase 1 decision. If this does not change, the Phase 1 preferred option will be declared MoD's preferred container for packing of submarine ILW.

An initial scoping study was carried out to evaluate the loaded NDA containers against aspects of the UK radioactive waste transport regulations. This was followed by an optioneering conference which used a methodology similar to that used during the SDP technical options study [Ref. #10]. The optioneering conference evaluated each of the five NDA containers against a set of attributes (criteria), which had been determined prior to the conference through discussions between members of the Nuvia team. Each container option was given a numerical ranking against each of the attributes and assigned a weight which reflected the perceived importance of the issue. The scores and weights were then combined to produce an overall score for each option. The process generated both weighted and unweighted scores. The optioneering methodology used the Hiview software package, which generated sensitivity analysis graphs to allow the robustness of the preferred option to be determined.

The results for each container are presented below and the reasons given for rejecting or promoting use of each of the containers.

7.1 The 4 Metre (4m) Box Waste Package

The 4 metre box does not meet the MoD requirement for ability to handle submarine ILW which has been decay stored for 10 years. The requirement [Ref. #4] is that for road transport, the dose rate at 3 metres from the waste inside the unshielded (but grouted) IP-2 package should not exceed 10 mSv/h. Previous work carried out during 2001 [Ref. #8] has demonstrated that the ILW would need to be stored for an additional 43 years (from 2001) before it could be transported to the interim store. On the basis that this additional decay storage requirement does not meet the MoD specification, the 4 metre box can be eliminated from the list of options.

The Nirex specification [Ref. #2] states that "*the 2 metre box is essentially a shorter version of the 4 metre box, and is intended to be used primarily for packaging wastes arising from the decommissioning of nuclear facilities. The 2 metre box may be preferred when the available space for loading is limited, when only a small amount of waste is involved and/or when the waste items are so dense that a filled 4 metre box would exceed the mass limit*". This TAF 5 analysis shows that this is indeed the case. Annex 1.1 shows that the mass of waste which can be put into a 2 metre box is about double that in a 4 metre box. The packing fraction and the waste disposal efficiencies of the 2 metre box are far better than those of the 4 metre box. Given the choice between the 4 metre box and the 2 metre box, the 2 metre box would be the preferred container. On this basis, there is a strong case for eliminating the 4 metre box (in favour of the 2 metre box) from the list of options.

During the optioneering process, the unweighted and weighted scores for the 4 metre box were lower than those for the 3 cubic metre box, the 500 litre drum and the 2 metre box. The 4 metre box scored very poorly on ease of grouting and lidding, packing fraction, waste disposal efficiency and previous experience. On the other hand, because it is a shielded package, the 4 metre box scored highly on compatibility with the interim store, since no additional shielding is required. It also scored highly on ease of size reduction, since it has a large aperture opening which requires minimal size reduction. However, the 4 metre box was not the preferred option. On the basis of the arguments presented above, the 4 metre box can be eliminated from the list of options.

In summary, the 4 metre box can be eliminated from the options because:

- It does not meet the MoD ten year decay storage requirement. The 4 metre box cannot be used for off-site transport until the dose rates have decayed to permissible levels. This can take more than 40 years [Ref. #8].
- If the choice was between a 4 metre and a 2 metre box, the 2 metre box would be preferable, since it can hold more than twice the mass of waste.
- It scored exceedingly poorly during the optioneering process (ranking joint last of the options) and was not the preferred option.

7.2 The 2 Metre (2m) Box Waste Package

The 2 metre box does not meet the MoD requirement for ability to handle submarine ILW which has been decay stored for 10 years. The requirement [Ref. #4] is that for road transport, the dose rate at 3 metres from the waste inside the unshielded (but grouted) IP-2 package should not exceed 10 mSv/h. Calculations (using the MicroShield software package) indicated that the ILW would need to be stored for an additional 20 years (i.e. a total of 30 years) before it could be transported to the interim store. On the basis that this additional decay storage requirement does not meet the MoD specification, the 2 metre box can be eliminated from the list of options.

During the optioneering process, the unweighted and weighted total scores for the 2 metre box were about the same as that for the 500 litre drum, but lower than that for the $3m^3$ box. The 2 metre box scored poorly on ease of grouting and lidding, flexibility and previous experience. On the other hand, because it is a shielded package, the 2 metre box scored highly on compatibility with the interim store, since no additional shielding is required and on programming issues. It also scored relatively highly on ease of size reduction since like the 4 metre box, it has a large aperture opening which requires minimal size reduction. When the scores were weighted, the differential between the 2 metre box and the $3m^3$ box increased. The

2 metre box was not the preferred option. On the basis of the above arguments, the 2 metre box can be eliminated from the list of options.

In summary, the 2 metre box can be eliminated from the list of options because:

- It does not meet the MoD ten year decay storage requirement. The 2 metre box cannot be used for off-site transport until the dose rates have decayed to permissible levels. This can take up to 20 years, in addition to the initial 10 years, i.e. a total of 30 years.

- It scored reasonably well during the optioneering process but not enough to be chosen as the preferred option.

7.3 The 3 Cubic Metre ($3m^3$) Drum Waste Package

The $3m^3$ drum is a cylindrical variant of the 3 m^3 box, designed to allow the conditioning of sludge and resin type wastes and can be adapted to in-drum mixing. It was not designed for high density solid wastes. For example, the aperture area is about half that of the $3m^3$ box and waste disposal efficiency is about half that of the $3m^3$ box. Given the choice between the $3m^3$ box and the $3m^3$ drum, the drum would be eliminated from the list of options.

During the optioneering process, both the unweighted and weighted total scores for the $3m^3$ drum was lower than those for all of the other boxes. Together with the 4 metre box, it was ranked the last of the five options. The $3m^3$ drum scored poorly on previous experience, compatibility with downstream processes and programme issues. None of its scores was higher than those for the $3m^3$ box. The $3m^3$ drum was not the preferred option. On the basis of the above arguments, the $3m^3$ drum can be eliminated from the list of options.

In summary, the $3m^3$ drum can be eliminated from the list of options because:

- It was not designed for high density solid wastes and has features (e.g. aperture area, waste disposal efficiency) which are inferior to those of the $3m^3$ box.
- It scored exceedingly poorly (ranking joint last of the five options) during the optioneering process and was not the preferred option.

7.4 The 500 Litre (500L) Drum Waste Package

During the optioneering process, the unweighted scores for the 500 litre drum were very close to those of the $3m^3$ box. It was ranked second of the five options. The 500 litre drum scored poorly on ease of size reduction and compatibility with downstream processes. When the scores were weighted, the differential between the 500 litre drum and the $3m^3$ box increased. This was in part a reflection of the fact that it has a relatively small aperture opening and a considerable amount of size reduction would be required before the waste could be loaded into the drum. Because of the relatively low 2 tonne mass limitation, its packing fraction was low. On the other hand, the 500 litre drum scored highly on ease of grouting and lidding and previous experience. The basis for this is the fact that there is a lot of nuclear industry experience of using this drum. This experience relates mainly to waste loading and storage but not off-site transportation. It also scored relatively highly on waste disposal efficiency. The 500 litre drum was however not the preferred option, and on this basis of the above arguments, it can be eliminated from the list of options.

In summary, the 500 litre drum can be eliminated from the list of options because:

- It has a relatively small aperture opening and a considerable amount of size reduction would be required before the waste could be loaded into the drum. This increases the amount of resources needed to perform size reduction and decreases its flexibility when compared to other packages.
- During the optioneering process, it was ranked joint second to the preferred option for the both the unweighted and weighted total scores, but was not the preferred option.

7.5 The 2 Cubic Metre ($3m^3$) Box Waste Package

During the optioneering process, the $3m^3$ box had the highest scores of all of the options for both the unweighted and weighted results. It was ranked first of the five options. The $3m^3$ box scored highly on packing fraction, waste disposal efficiency and flexibility. This was in part a reflection of the fact that it had one of the highest packing fractions and the highest waste disposal efficiency of all of the packages. Since this box and its overpack are classified as a Type B package, it does not have the same unshielded dose rate requirements as the 4 metre and 2 metre boxes, which are IP-2 packages. It scored poorly on compatibility with downstream processes. Without some form of external shielding, it is not compatible with an unshielded store.

In summary, the $3m^3$ box was selected as the preferred option because:

- It has the joint highest high packing fraction and the highest waste disposal efficiency of all of the packages.
- With its overpack it is classified as a Type B package, which does not have the same unshielded dose rate limitations as the IP-2 package.
- During the optioneering process, it was ranked first in both the unweighted and weighted categories.
- The sensitivity graphs generated from the Hiview software package showed that the choice of the $3m^3$ box was a robust decision.

8. RECOMMENDATIONS

The following recommendations are made:

1. The $3m^3$ box waste package should be carried forward into Phase 3 as the preferred option.
2. Phase 3 should explore the “cradle to grave” use of the $3m^3$ box waste package to determine the robustness of the optioneering decision. This should include additional technical issues which were not fully addressed during Phase 1 either because they were non discriminating or because sufficient data was not available.
3. If the $3m^3$ box waste package survives the Phase 3 substantiation phase and no reasons are found to change the container ranking order, it should then be declared as the MoD preferred option for packaging of submarine ILW.
4. Recognising that identification and adoption of a single package design may not lead to overall optimisation, MoD should periodically review intended package use to determine if more than one package design is required.

9. REFERENCES

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9. Waste Package Specification and Guidance Documentation. Nirex Report No. WPS/903: Guidance on the Immobilisation of Radionuclides in Wasteforms. March 2007.
10. Technical Options Study Methodology Statement. Frazer-Nash Consultancy. Ref. No. FNC 36995/61624V. September 2009.

[redacted]

Annex 1.1: NDA Package Calculation Sheets

[redacted]

Annex 1.2: MicroShield dose rate calculations

Unshielded Dose Rate at 3 metres from Waste inside the 2 metre NDA Box

Annex 1.3: Optioneering results from Hiview Software

Introduction

During the optioneering conference, various options were assessed using a standard multi-attribute decision analysis technique, supported by the software package Hiview 3. An overview is provided below of the methodology used to assess the options and the results.

Taking each of the identified attributes in turn, the options were given a numerical ranking between 1 and 5, with the least favourable option being allocated a 1 and the most favourable a 5. Other options were allocated a number on the 1 to 5 scale depending on their relative performance compared to the most and least favourable options. Available or derived data was used where possible during the evaluation and if no data was available, expert judgement was used.

The scores were then scaled to a 10 to 50 scale by Hiview (with 1 becoming a 10 and 5 becoming a 50). This enabled clearer presentation of the results and sensitivity analysis by the Hiview software.

Each attribute was then assigned a weight (see below), reflecting the perceived importance of the issue to the decision-making process. This took account of both the inherent importance of an issue and the degree of discrimination between the most and the least preferred option.

- Attributes of low importance were allocated a weight of 2.
- Attributes of medium importance were allocated a weight of 5.
- Attributes of high importance were allocated a weight of 8.
- Attributes of very high importance were allocated a weight of 10.

The combination of scores and weights was then used to calculate an overall score for each option.

It was recognised that allocation of a weight to each attribute is generally the most subjective part of the overall process. To test the robustness of the Phase 1 preferred option, the weights were subjected to a sensitivity analysis. This indicated how much the weight allocated to each attribute had to change before another option received the highest score. If significant changes were required, the preferred option was judged to be robust. If only minor changes in weight produced another preferred option, the selection was judged to be weak.

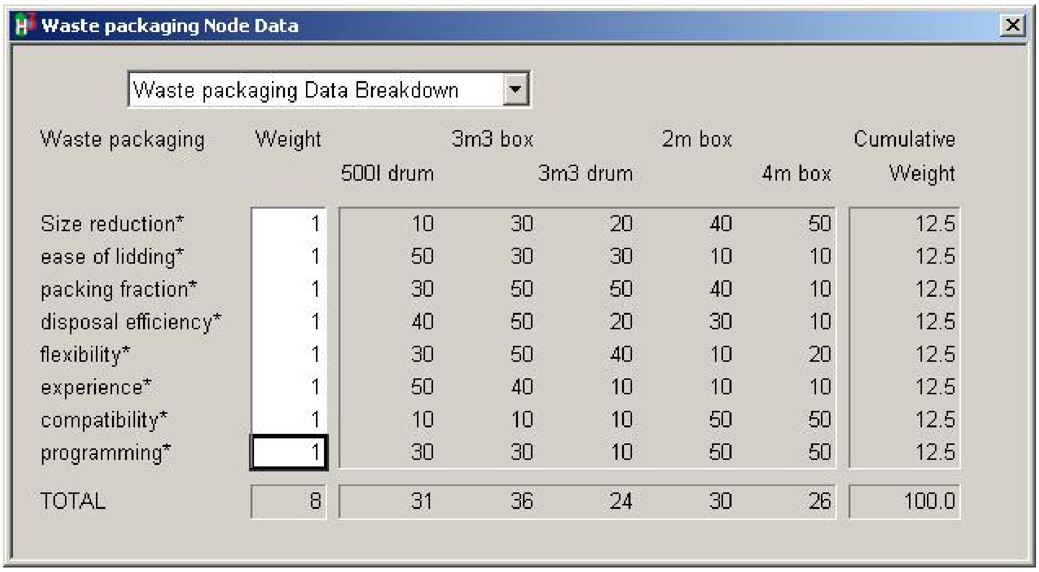
[redacted]

Results

Table A3.1 summarises the scores allocated to each of the options for each attribute (presented on a 10 to 50 scale as discussed above). The rationale behind the allocation of the scores is presented in Section 6 of the main body of the report.

Table A3.1 shows the unweighted scores, i.e. each of the attributes is considered equally important with no one attribute being given more weight than any other. As can be seen from the table, if all the attributes are considered equal, each received 12.5% of the overall weight.

Table A3.1 Summary of scores – equal weight

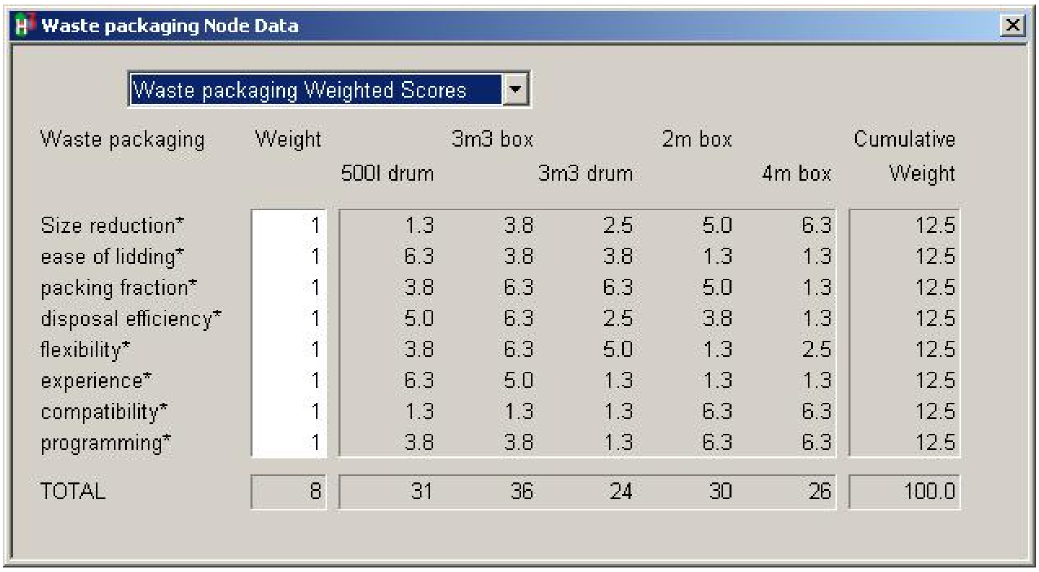


Waste packaging	Weight	500l drum	3m3 box	3m3 drum	2m box	4m box	Cumulative Weight
Size reduction*	1	10	30	20	40	50	12.5
ease of lidding*	1	50	30	30	10	10	12.5
packing fraction*	1	30	50	50	40	10	12.5
disposal efficiency*	1	40	50	20	30	10	12.5
flexibility*	1	30	50	40	10	20	12.5
experience*	1	50	40	10	10	10	12.5
compatibility*	1	10	10	10	50	50	12.5
programming*	1	30	30	10	50	50	12.5
TOTAL	8	31	36	24	30	26	100.0

Table A3.2 shows what happens when the allocated scores and the weights are combined. For example, the 2 metre box was allocated 40 for size reduction. If this score is multiplied by the 12.5% weight allocated to size reduction the resultant score is 5.0. Each score allocated is multiplied by the attribute weight in the same way and the resultant scores added up across the attributes for each option to give the overall score.

[redacted]

Table A3.2 Summary of weighted scores – equal weight



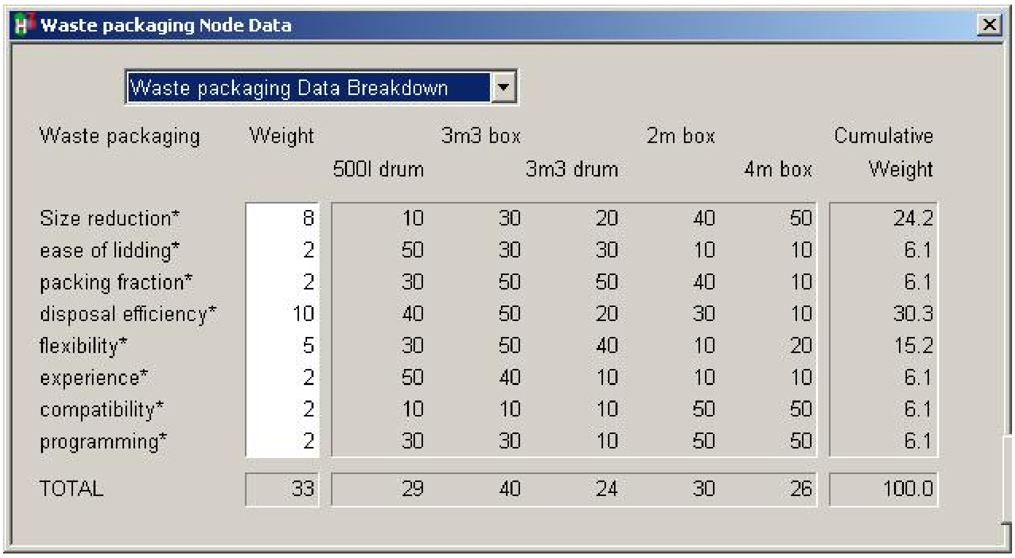
Waste packaging	Weight	500l drum	3m3 box	3m3 drum	2m box	4m box	Cumulative Weight
Size reduction*	1	1.3	3.8	2.5	5.0	6.3	12.5
ease of lidding*	1	6.3	3.8	3.8	1.3	1.3	12.5
packing fraction*	1	3.8	6.3	6.3	5.0	1.3	12.5
disposal efficiency*	1	5.0	6.3	2.5	3.8	1.3	12.5
flexibility*	1	3.8	6.3	5.0	1.3	2.5	12.5
experience*	1	6.3	5.0	1.3	1.3	1.3	12.5
compatibility*	1	1.3	1.3	1.3	6.3	6.3	12.5
programming*	1	3.8	3.8	1.3	6.3	6.3	12.5
TOTAL	8	31	36	24	30	26	100.0

Table A3.3 summarises the scores allocated to each of the options for each attribute (presented on a 10 to 50 scale as discussed above), but the table also includes the weights actually allocated to each attribute, as discussed in the introduction, and in Section 6.2 of the main body of the text.

The weight column shows the numerical weights allocated during discussion; the cumulative weight shows this translated to a percentage value.

Table A3.3 Summary of scores and weights allocated

[redacted]

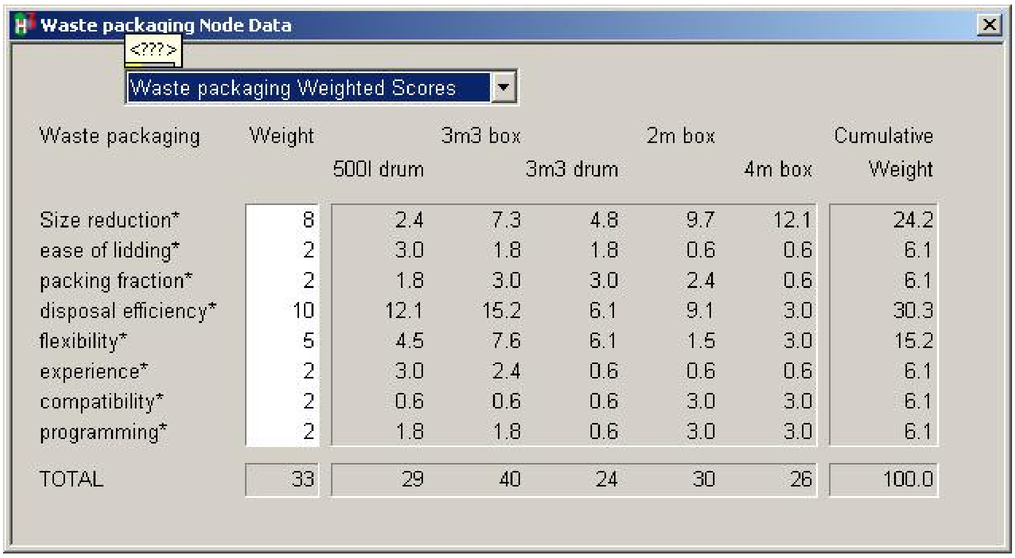


Waste packaging Data Breakdown

Waste packaging	Weight	500l drum	3m3 box	3m3 drum	2m box	4m box	Cumulative Weight
Size reduction*	8	10	30	20	40	50	24.2
ease of lidding*	2	50	30	30	10	10	6.1
packing fraction*	2	30	50	50	40	10	6.1
disposal efficiency*	10	40	50	20	30	10	30.3
flexibility*	5	30	50	40	10	20	15.2
experience*	2	50	40	10	10	10	6.1
compatibility*	2	10	10	10	50	50	6.1
programming*	2	30	30	10	50	50	6.1
TOTAL	33	29	40	24	30	26	100.0

Table A3.4 shows what happens when the scores allocated and the weights are combined. For example, the 500 litre drum was allocated 10 for size reduction. If this score is multiplied by the 24.2% weight allocated to size reduction the resultant score is 2.4 (rounded to one decimal place). Each score allocated is multiplied by the attribute weight in the same way and the resultant scores added up across the attributes for each option to give the overall score.

Table A3.4 Summary of weighted scores



Waste packaging Weighted Scores

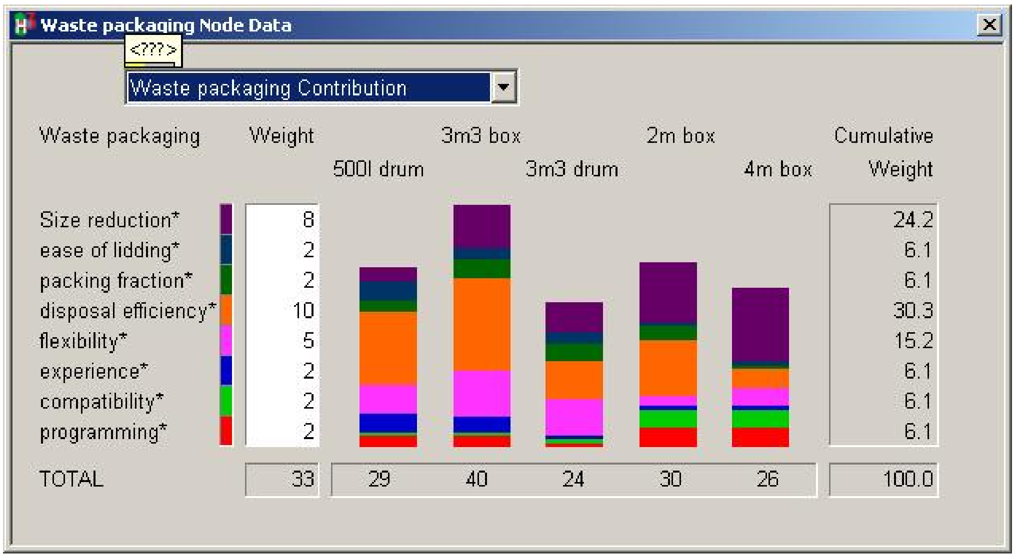
Waste packaging	Weight	500l drum	3m3 box	3m3 drum	2m box	4m box	Cumulative Weight
Size reduction*	8	2.4	7.3	4.8	9.7	12.1	24.2
ease of lidding*	2	3.0	1.8	1.8	0.6	0.6	6.1
packing fraction*	2	1.8	3.0	3.0	2.4	0.6	6.1
disposal efficiency*	10	12.1	15.2	6.1	9.1	3.0	30.3
flexibility*	5	4.5	7.6	6.1	1.5	3.0	15.2
experience*	2	3.0	2.4	0.6	0.6	0.6	6.1
compatibility*	2	0.6	0.6	0.6	3.0	3.0	6.1
programming*	2	1.8	1.8	0.6	3.0	3.0	6.1
TOTAL	33	29	40	24	30	26	100.0

This information is also presented graphically in Figure A3.1 below.

Figure A3.1 Option scores by criteria contribution

[redacted]

[redacted]



Waste packaging	Weight	Cumulative Weight
Size reduction*	8	24.2
ease of lidding*	2	6.1
packing fraction*	2	6.1
disposal efficiency*	10	30.3
flexibility*	5	15.2
experience*	2	6.1
compatibility*	2	6.1
programming*	2	6.1
TOTAL	33	100.0

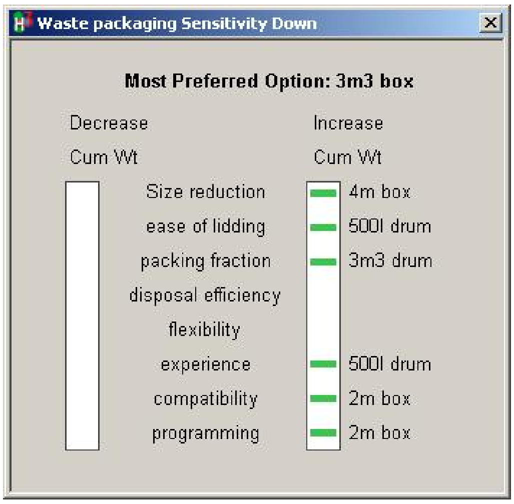
	500l drum	3m3 box	3m3 drum	2m box	4m box
TOTAL	29	40	24	30	26

Sensitivity Analysis

Sensitivity Down

The sensitivity down analysis (Figure A3.2) shows how sensitive the results are to changes in the weight of any of the attributes. The left hand column represents decreasing the weight on a given attribute and the right hand column increasing it. A red line means the weight has to be increased or decreased by less than 5% to change the highest scoring option (the new highest scoring option is listed adjacent to the line). An amber line shows the weight must change by between 5 and 15%, and a green line shows it has to change by more than 15%, and potentially significantly more.

Figure A3.2: Sensitivity Down Analysis



Most Preferred Option: 3m3 box

Decrease Cum Wt		Increase Cum Wt
	Size reduction	4m box
	ease of lidding	500l drum
	packing fraction	3m3 drum
	disposal efficiency	
	flexibility	
	experience	500l drum
	compatibility	2m box
	programming	2m box

[redacted]

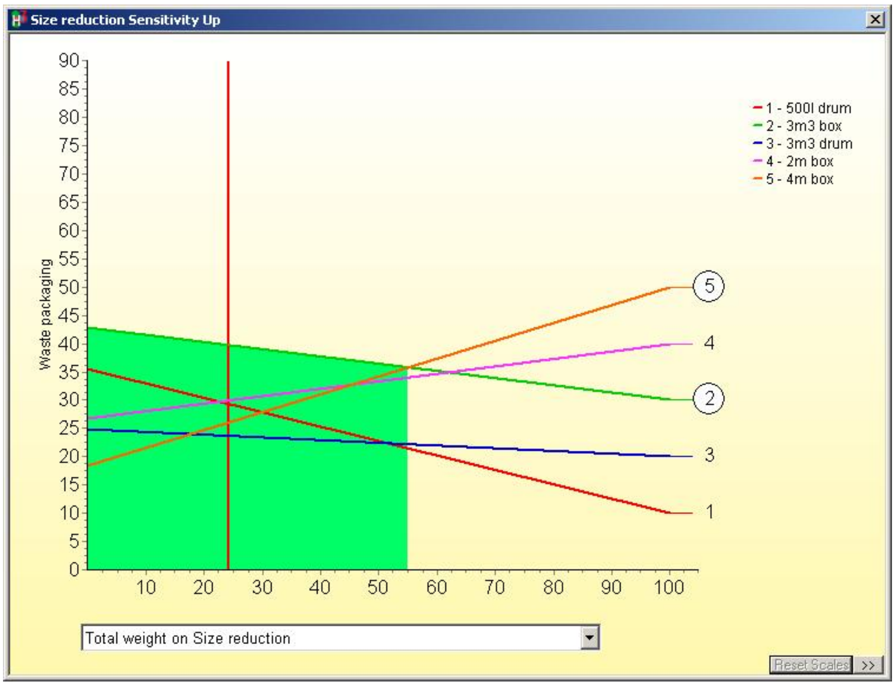
Only green lines are present and this shows that the weight allocated to any one of the attributes must be increased or decreased significantly before the highest scoring option changes. This means that the selection of the 3m^3 box is very robust. This is explored further in the sensitivity up analysis that follows.

Sensitivity Up Graphs

In Figures A3.3 to A3.10 below, each option is represented by a line on the graph which shows how that option score varies as the weight of the attribute is varied between 0 and 100%. The red vertical line shows the weight actually allocated to the attribute and the green area shows how much the weight needs to be changed before the highest scoring option is changed. Graphs are shown for all attributes.

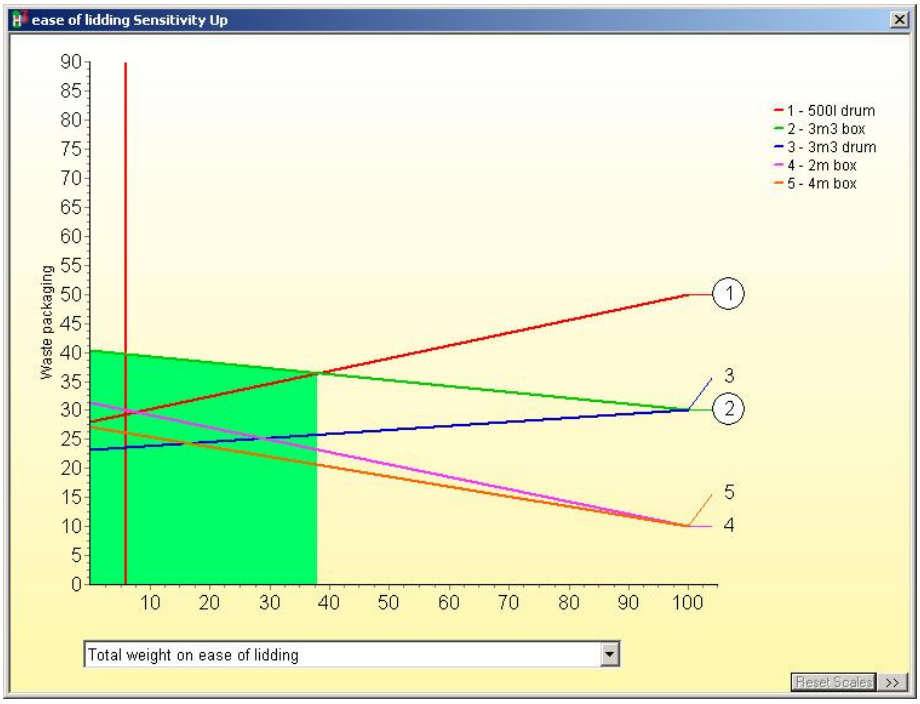
Overall, these illustrate that the weight allocated to any of the attributes needs to be changed by a significant amount before any change is seen in the highest scoring option. This shows that the selection of the 3 cubic metre box is very robust to sensitivity in weight allocated to the attributes.

Figure A3.3: Size Reduction



The weight on size reduction needs to be changed from 24% to more than 50% (i.e. more than doubled) before a change in the highest scoring option is seen (when it changes from the 3m^3 box to the 4 metre box).

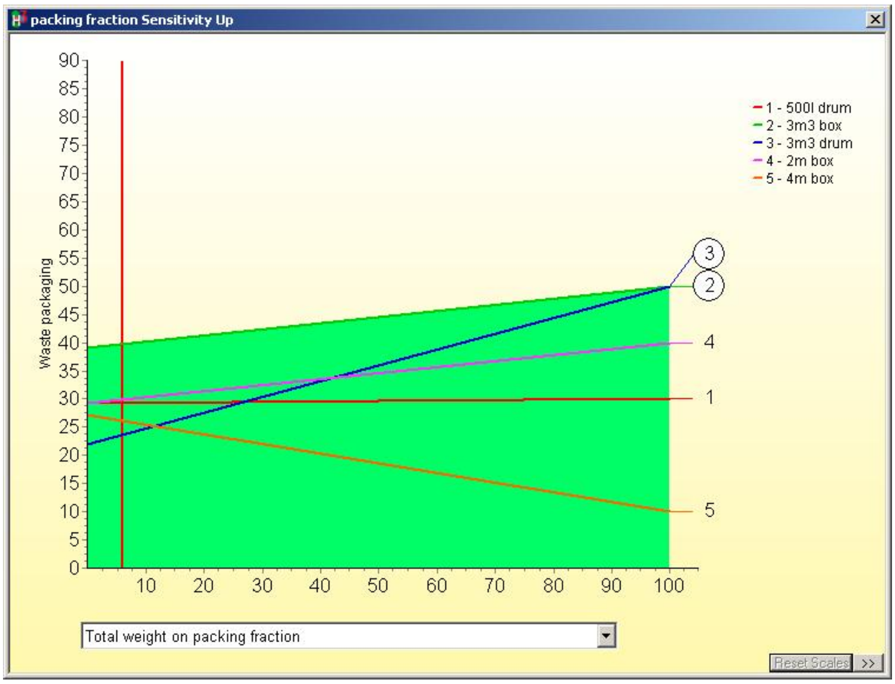
Figure A3.4: Ease of Grouting and Lidding



Total weight on ease of lidding

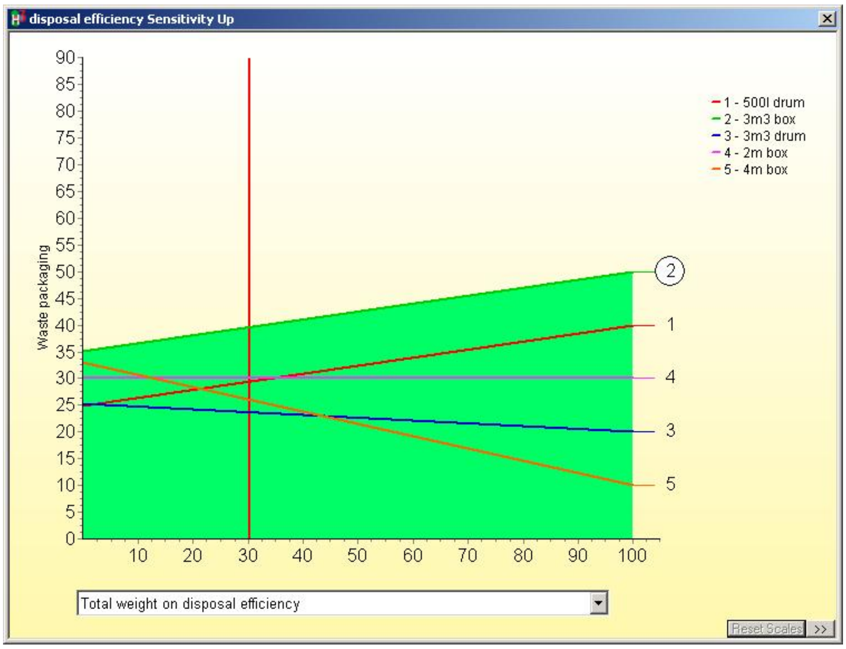
The weight on ease of lidding needs to be increased from 6% to almost 40% before a change in the highest scoring option is seen (at which point it becomes the 500 litre drum, which was assessed to be the easiest container to load).

Figure A3.5: Packing Fraction



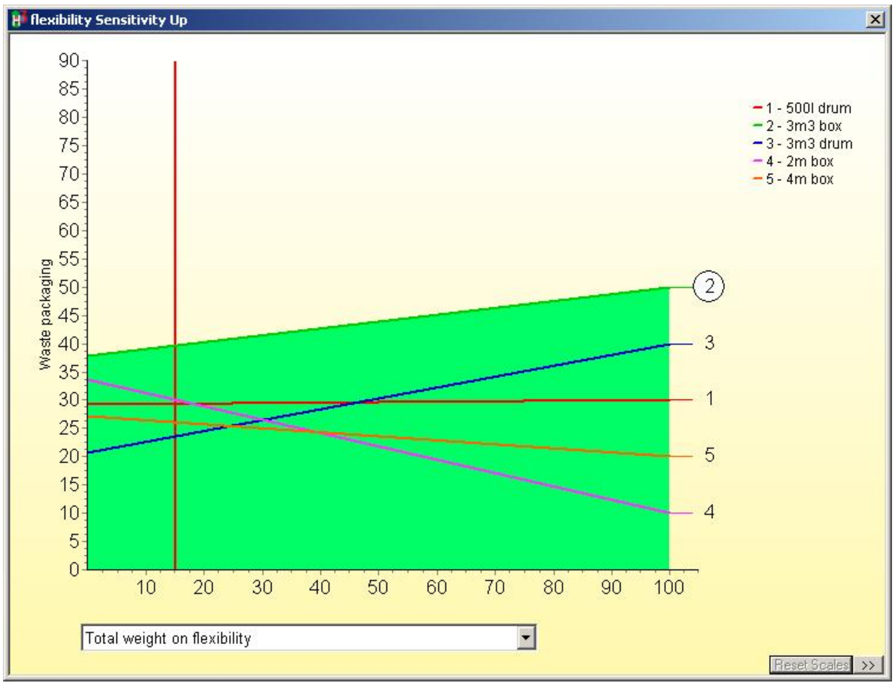
The weight allocated to packing fraction can be varied between 0 and 100% without changing the 3m^3 box as the highest scoring option (at 100% the 3m^3 cubic drum becomes equal top).

Figure A3.6: Disposal Efficiency



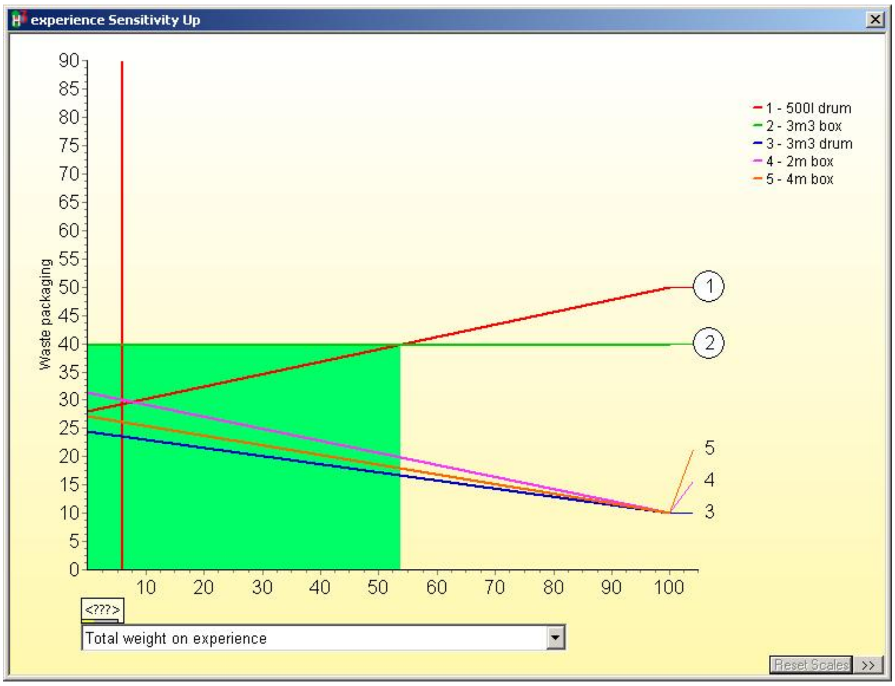
The weight allocated to disposal efficiency can be varied between 0 and 100% without changing the 3m^3 box as the highest scoring option.

Figure A3.7: Flexibility



The weight on flexibility can be varied between 0 and 100% without affecting the choice of the 3m^3 box as the highest scoring option.

Figure A3.8: Previous experience

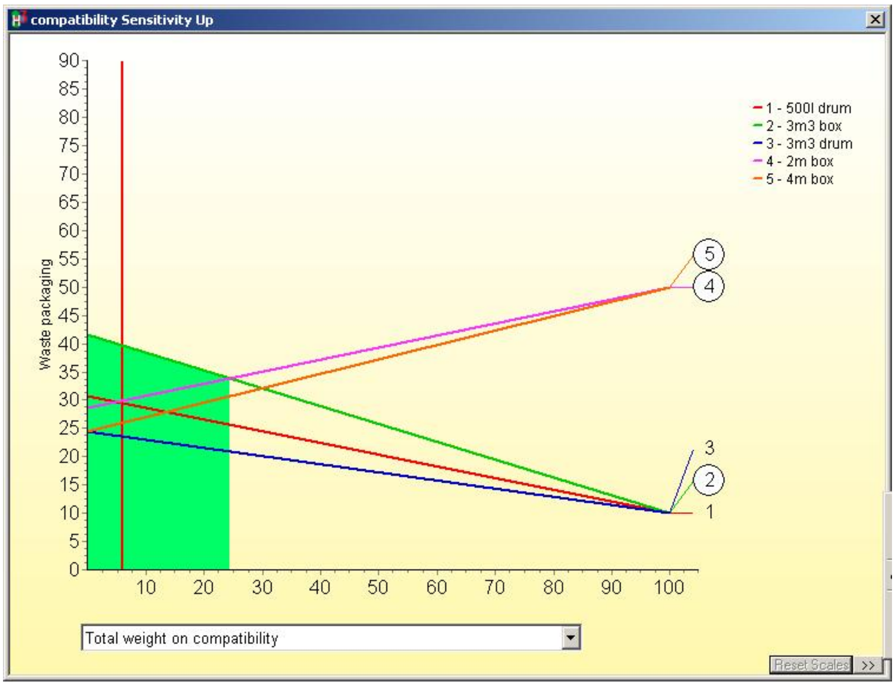


Total weight on experience

The weight on previous experience needs to be increased from 6% to over 50% before affecting the choice of the 3m^3 box as the highest scoring option. At this point the 500 litre drum becomes the preferred option, because of its extensive use in other ILW applications.

[redacted]

Figure A3.9: Compatibility with downstream processes

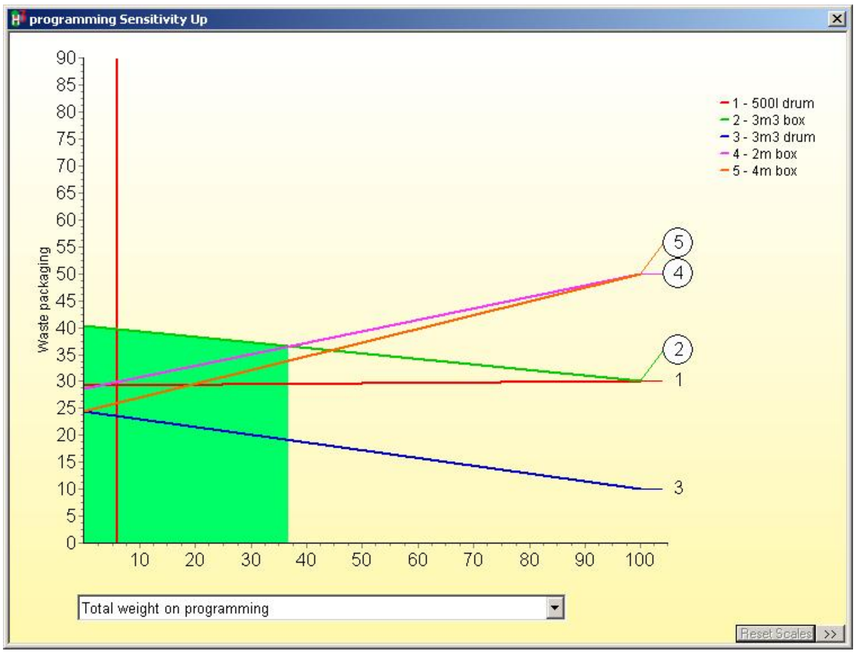


The weight on compatibility needs to be increased from 6% to about 24% before the highest scoring option changes. Although this sensitivity is not considered to be significant in the decision-making, as the weight needs to be quadrupled before changing the decision, it does highlight one of the weaknesses of the preferred option; that is the need to design, license and build a storage facility capable of accepting unshielded packages. This will be one of the technical issues which needs to be addressed as the process moves forward.

[redacted]

[redacted]

Figure A3.10: Programme



Programme issues were allocated a low weight of 6%. This would have to be increased to over 35% before another option (the 4 metre box) becomes the higher scoring option

[redacted]

ANNEX 1.4: MOD STAKEHOLDER COMMENTS ON PHASE 1 REPORT

The objective of TAF 5 is to determine which of the available designs of standard NDA ILW containers would be most suitable for the packaging of submarine ILW and to provide a robust audit trail for the recommendation. The Table below contains the agreed Nuvia actions arising from comments from MoD Stakeholder on the Phase 1 (Optioneering) report (Ref. No. 89330/TAF5/011) produced by Nuvia during January 2010. During February 2010, MoD provided Nuvia with the collated Stakeholder comments and Nuvia responded with proposed actions. These were discussed further and a way forward, which is reflected in the Nuvia agreed actions, was agreed. Abbreviations are presented below the table.

No.	Stakeholders' Comments	Nuvia Response	Nuvia Proposed Actions	MoD Comments	Nuvia Agreed Actions
NUCLEAR INSTALLATIONS INSPECTORATE (NII)					
[redacted]	Container Choice: While I have some reservations about some of the report and some of the assigned scores, the final choice of the 3m^3 box seems reasonable.		No action.	MoD agrees with Nuvia's proposed response and actions.	No action.
[redacted]	Scope of Wastes Covered: Section 2.1 is not totally clear; the story it tells is incomplete.	This was taken from the TAF Specification.	Action: Update Section 2.1 to include more background on SDP.	MoD agrees with Nuvia's proposed response and actions.	Action: Update Section 2.1 of the Phase 1 report to include more background on SDP.
[redacted]	Scope of Wastes Covered: Section 4.1 gives a value of [redacted] of ILW from each submarine; it is not totally clear how this relates to the 3		Action: Expand Section 4.1 to indicate the	MoD agrees with Nuvia's proposed response and actions.	Action: Expand Section 4.1 of the Phase 1

No.	Stakeholders' Comments	Nuvia Response	Nuvia Proposed Actions	MoD Comments	Nuvia Agreed Actions
	dismantling and storage options previously mentioned.		connection between ILW mass and the 3 dismantling and storage options.		report as proposed.
[redacted]	Timing Assumptions: The MoD has directed Nuvia to assume submarine dismantlement will commence 10 years after end of service. Section 4.7 states "After a decay period of 10 years, [redacted] of ILW has a Co-60 content of [redacted]." This is not necessarily correct, but is a base assumption for everything that follows. Derivation of this figure is in a reference that I do not have access to.	MoD to consider providing NII with the Reference 7 report.	No action.	This report is being updated by Rolls Royce to confirm that the figures are correct. The reference is classified as Restricted so will not be provided to NII.	No action.
[redacted]	Timing Assumptions: Section 5.1 discounts the 2 metre box on the basis that a 20 year decay period would be needed in order for the packaged waste to meet transport requirements. Section 5.2 similarly discounts the 4 metre box on the basis that a 43 year decay period would be needed. The above is a questionable state of affairs on the grounds that; a 10 year decay period is artificially low, particularly for the submarines that have already left service, and; if interim storage took place local to the size reduction process there would be no need to meet the transport limits until the repository was available to receive the packages - in which case even 43 years of decay would quite probably be no problem. A		Action: Perform an analysis of the sensitivity of the preferred option to timing assumptions. Discuss with MoD the scope of this analysis and whether to include it in the Phase 1 or Phase 3 report.	MoD considers that the sensitivity analysis should be included in Phase 3.	Action: Conduct a time sensitivity analysis as part of the Phase 3 works.

No.	Stakeholders' Comments	Nuvia Response	Nuvia Proposed Actions	MoD Comments	Nuvia Agreed Actions
	sensitivity study should be undertaken to review if delaying the start time of dismantling affects the final choice.				
[redacted]	Scoring Exercise: The panel appears to have been made up of 100% technical experts and did not apparently include anyone from MoD, or anyone with a strategic / safety / environmental / regulatory remit.	Section 6.2.11 of the Phase 1 report acknowledges this.	No action.	MoD agrees with Nuvia's proposed response and actions.	No action.
[redacted]	Scoring Exercise: Several of the weighting factors are heavily dependent on each other, or assess virtually the same thing (e.g. Packing Fraction, Environmental Impact and Waste Disposal Efficiency).	The EIA was not scored in the Phase 1 report. PF and WDE are different entities relying on similar input data as explained in Section 6.2.3 of the Phase 1 report.	No action.	MoD agrees with Nuvia's proposed response and actions.	No action.
[redacted]	Scoring Exercise: I feel a few of the scores for the 3m3 box are a bit optimistic and the choice is not quite as clear cut as presented.	NII agrees with the choice of the $3m^3$ box.	No action.	MoD agrees with Nuvia's proposed response and actions.	No action.
[redacted]	Scoring Exercise: The scores for the Programme Issues attribute are very questionable. I doubt there would be any material impact between the different containers, but the 500 litre drum is already in wide use so in my view should not be scored low on the basis that a Type B package generally takes longer	Good point. See PRPA-7. There is a disconnect between the	Action: Ensure that this comment is addressed and that the tables in Section 6.2.12 and Annex are self	MoD agrees with Nuvia's proposed response and actions.	Action: The programme issue scores will be reviewed and altered as required. The

No.	Stakeholders' Comments	Nuvia Response	Nuvia Proposed Actions	MoD Comments	Nuvia Agreed Actions
	to get DoT approval.	Section 6.2.12 and the Annex 1.3 tables which needs to be corrected. This will result in slightly different scoring, but will not affect the conclusions of the report.	consistent.		Phase 1 report will be altered to remove any disconnect between Section 6.2.12 and Annex 1.3.
[redacted]					
[redacted]	We believe that the report provides a good evaluation of the issues associated with package selection.		No action.	MoD agrees with Nuvia's proposed response and actions.	No action.
[redacted]	The NDA supports the conclusions that an extended decay period is required for the waste materials to be compatible for packaging as LSA and transported within an IP-2 package, such as the 2 metre or 4 metre box, as a result of previous assessment work carried out on these containers for the MoD.		No action.	MoD agrees with Nuvia's proposed response and actions.	No action.
[redacted]	Please note - IP-2 packages are subject to self-assessment and approval.		No action.	MoD agrees with Nuvia's proposed response and actions.	No action.
[redacted]	The NDA notes that the decay of Co-60 is relatively short and advantageous to waste classification, however our assessment revealed contributions from Ni-63 to become more problematic in the near term		No action.	MoD agrees with Nuvia's proposed response and actions.	No action.

No.	Stakeholders' Comments	Nuvia Response	Nuvia Proposed Actions	MoD Comments	Nuvia Agreed Actions
	and therefore support the view that waste is ILW.				
[redacted]	The selection of a $3m^3$ box for the packaging of SDP ILW would appear a logical choice.	Both NII and NDA agree with the choice of the $3m^3$ box.	No action.	MoD agrees with Nuvia's proposed response and actions.	No action.
[redacted]	The NDA supports the view that early transportation would require use of Type B packaging (such as the SWTC) and this limits the option to use of 3m3 Boxes for minimum size reduction of solid waste items.		No action.	MoD agrees with Nuvia's proposed response and actions.	No action.
[redacted]	Please note - the WPSGD has a more restrictive limit on shielding, of 0.1 mSv/hr at 1 metre from the transport package, i.e. 2 metre and 4 metre box, but this is also considered to be applicable to the SWTC.	Noted. See BADT-10	Action: Address the implications of the WPSGD within the Phase 3 report.	MoD agrees with Nuvia's proposed response and actions.	Action: Address the implications of the WPSGD restrictions within the Phase 3 report.

No.	Stakeholders' Comments	Nuvia Response	Nuvia Proposed Actions	MoD Comments	Nuvia Agreed Actions
[redacted]	6.2.6 – Previous Experience, NDA-RWMD has confidence from the development of the prototype 4 metre box and 2 metre box that transportation is possible, draft Design Safety Reports have been compiled, but no shipments have been made, likewise the SWTC has been developed to the stage where NDA-RWMD are confident of approval for use as a Type B, again through compilation of the contents specification for the Design Safety Report and underpinning analysis (FEA) and third scale drop tests and full scale detail design drawings.		No action.	MoD agrees with Nuvia's proposed response and actions.	No action.
[redacted]	The report could benefit from inclusion of 3m3 box corner lifting variant.	Agreed	Action: Update the Phase 1 report to Include the 3m^3 corner lifting variant. Discuss with MoD whether their preference is to include this in the Phase 3 report.	MoD agrees that the Phase 1 report should be updated to include the 3m^3 corner lifting variant. MoD believes that there may be differences in a "cradle to grave" analysis of the use of each variant and as such both should be included in Phase 3.	Action: Update the Phase 1 report to include the 3m^3 corner lifting variant. It was agreed with MoD that there would not be major "cradle to cradle differences, therefore there is no need to include both variants in Phase 3 report.

No.	Stakeholders' Comments	Nuvia Response	Nuvia Proposed Actions	MoD Comments	Nuvia Agreed Actions
[redacted]	Please note - The 3m3 drum has a gross mass limit of 8 tonnes	Section 3.3 of the Phase 1 report quotes a 12 tonne limit	Action: Substantiate the 8 tonnes and if correct, insert this value into Section 3.3 of the Phase 1 report.	MoD agrees with Nuvia's proposed response and actions. MoD suggests that the scores be updated as required, if this has any effect.	Action: Inert the $3m^3$ drum gross mass limit of 8 tonnes into the Phase 1 report and if required, update the scorings.
[redacted]	Nirex Specifications in References 1-4, it would be better to quote appropriate versions of WPSDG that is published as NDA-RWMD documents.	Agreed.	Action: Insert data from the latest (March 2007) NDA RWMD container report into the Phase 1 report and update the references.	MoD agrees with Nuvia's proposed response and actions.	Action: Insert data from the latest (March 2007) NDA RWMD container report into the Phase 1 report and update the references.
[redacted]					
[redacted]	Understanding whether our preferred solution holds should submarines be dismantled immediately after decontamination and defuel would be helpful.	Agreed	Covered under Action NII-5.	MoD agrees with Nuvia's proposed response and actions.	Action: See Action NII-5.
[redacted]	Looking though this I believe that a sensitivity study should be undertaken to review how the effect of changing the delay time to the start of dismantling affects the results.	Agreed	Covered under Action NII-5.	MoD agrees with Nuvia's proposed response and actions.	Action: See Action NII-5.
[redacted]					

No.	Stakeholders' Comments	Nuvia Response	Nuvia Proposed Actions	MoD Comments	Nuvia Agreed Actions
[redacted]	There are a few errors in the document (minor, but they detract from the issues and include an error in the exec summary).		No action. (See below for the detailed actions)	MoD agrees with Nuvia's proposed response and actions.	Action: Review the Phase 1 document to minimise the number of minor errors.
[redacted]	Exec summary, 2nd para, last line. Discusses 1st two containers & last two containers, what about the fifth?	Agreed. This should read "the first three containers…"	Action: Correct error in Executive Summary paragraph 2.	MoD agrees with Nuvia's proposed response and actions.	Action: Correct error in paragraph 2 of the Executive Summary.
[redacted]	[redacted]	Agreed. This text was taken from Ref. #5.	Action: Review Section 2.2 and amend in line with these comments.	MoD agrees with Nuvia's proposed response and actions.	Action: Review and amend Section 2.2 in accordance with the PRPA comments.
[redacted]	Section 2.2, last para, states Co-60 is generated inside the RPV. Loosely true, Co-60 is produced by neutron activation of Co-59 when it passes through the core.	Agreed. This text was taken from Ref. #5.	Covered under Action PRPA-3	MoD agrees with Nuvia's proposed response and actions.	Action: See PRPA-3.
[redacted]	Section 3.2, states the corner lifting variant is considered and then uses a picture of a mid side variant.	Agreed	Action: Revise Section 3.2 to include both the corner lifting and the mid side lifting variants.	MoD agrees with Nuvia's proposed response and actions.	Action: See NDA-9. Revise Section 3.2 to include both the corner lifting and the mid side lifting variants.

No.	Stakeholders' Comments	Nuvia Response	Nuvia Proposed Actions	MoD Comments	Nuvia Agreed Actions
[redacted]	Section 6.2.15, very last sentence, states the unweighted score is used.	Agreed	Action: Section 6.2.15, last sentence: Change "unweighted" to "weighted".	MoD agrees with Nuvia's proposed response and actions.	Action: In Section 6.2.15, last sentence: Change "unweighted" to "weighted".
[redacted]	Annex 1.3, table A3.1 (screen snap shot) has incorrect values under "programming" for both the 500l drum and 3m^3 box (it uses 30 instead of 10). This error is carried through all the screen snap shots. This is a very poor mistake allowed to get into the report and potentially could have undermined the whole paper if those against the MoD proposals had seen it.	Agreed. See Action NII-9.	Covered under Action See NII-9.	MoD agrees with Nuvia's proposed response and actions.	Action: See NII-9.
[redacted]	There are also several places where the document says "MoD has directed …" and as such it should reference where MoD has laid down this requirement/decision.	We could include reference to the TAF specification and/or to meetings or simply ignore the comment.	No action. (Discuss with MoD).	MoD notes that this will be difficult to reference. MoD therefore suggests that the wording be changed, e.g. "The MoD baseline assumption is…"	Action: Where relevant, change the wording in the Phase 1 report to "The MoD baseline assumption is…"
[redacted]	The description of the packages, their potential benefits and how they fit with the attributes generally makes sense and has sufficient detail to allow an understanding of how the packages meet (or otherwise) the requirements. This also applies to the ranking study.		No action.	MoD agrees with Nuvia's proposed response and actions.	No action.

No.	Stakeholders' Comments	Nuvia Response	Nuvia Proposed Actions	MoD Comments	Nuvia Agreed Actions
[redacted]	The description of the weighting study however is not clear and also has errors which do not give me confidence in how it was conducted. In table A3.1 the data has errors in the scores for the 500l drum and 3m^3 box – both given scores of 30 when it should be 10. Correcting these errors should be done before the paper is published. Whilst I have concerns over this weighting study due to the errors, the conclusion that the 3m^3 box is the best option to take forward is still robust.	NII, NDA and the MoD RPA all agree with the choice of the 3m^3 box.		MoD agrees with Nuvia's proposed response and actions, noting those related to previous comments.	No action.
[redacted]	Overall the paper puts a coherent argument on how & why the package choice was made, however I suggest the errors are corrected before this is put into the public domain.	Agreed. All of the errors will be corrected.	No specific action.	MoD agrees with Nuvia's proposed response and actions.	Action: Correct all identified errors in the Phase 1 report.
[redacted]					
[redacted]	Based on a review of the "Submarine Dismantling Project Packaged Waste Container Review" (011 - SDP-TAF5 Report Issue A 15-01-2010), I have the following comments and observations:		No action.	MoD agrees with Nuvia's proposed response and actions.	No action.
[redacted]	Overall, this seems a competent study that reaches a sensible conclusion based on the assumptions at this stage.	NII, NDA , the MoD RPA and the EA all agree with the choice of the 3m^3 box.	No action.	MoD agrees with Nuvia's proposed response and actions.	No action.
[redacted]	Splitting the study into two phases may have merit but it would have been helpful if the scope and process for Phase 3 was outlined here (e.g. which "additional technical issues" will be considered and	Nuvia proposes no immediate action. The Phase 1 and	No immediate action.	MoD agrees with Nuvia's proposed response and actions, and suggests that this	Action: Take this comment into account when combining the

No.	Stakeholders' Comments	Nuvia Response	Nuvia Proposed Actions	MoD Comments	Nuvia Agreed Actions
	how?).	2 reports will be combined into one document. Discuss with MoD.		comment is taken into account when combining the two phases.	two phases of the works.
[redacted]	Identification and adoption of a single package design (i.e. the "declared option") may not lead to optimisation overall. An optimised approach might involve use of several package designs for specific purposes, if this proves to be practicable. For example, it may prove to be the case that using a combination of package designs (e.g. 4m box for lower activity wastes) and the 3 metre cubed box for other wastes would be the best combination. Perhaps the study (Phase 3) could consider if use of a combination of packages would be practicable and might offer advantages in specific applications.	Nuvia proposes no action. Alternatively, make it clear in the revised text that the 3m^3 box is the baseline option and may evolve into either another box or use of multiple boxes. Discuss with MoD.	No action.	MoD agrees that it be made clear that the 3m^3 box is the baseline option and may evolve into either another box or use of multiple boxes. This will evolve through the concept phase of the demonstrator and be better understood once the cut-up process is more clearly defined. Close working with the demonstrator team will be required.	Action: Make it clear in the revised text of the Phase 1 report that the 3m^3 box is the baseline option and may evolve into either another box or use of multiple boxes.
[redacted]	The assumption of grout encapsulation seems sensible as a baseline concept. However, the assumptions about package volume may be impacted if a capping grout is required. The study could usefully consider the implications if a component of the available volume would be	This is a process consideration. Nuvia proposes no action. Alternatively, discuss the	No action.	MoD suggests that Nuvia discuss the requirement for a capping grout and, if necessary, what the implications are.	No action, since the capping grout is already included in the calculations in Annex 1.1 of the

No.	**Stakeholders' Comments**	**Nuvia Response**	**Nuvia Proposed Actions**	**MoD Comments**	**Nuvia Agreed Actions**
	needed to accommodate a capping grout, as this may vary in percentage volume terms from package to package.	requirement for a capping grout and what the implications are. Discuss with MoD.			Phase 1 report.
[redacted]	Safety and environmental impact attributes are not considered further as they are argued not be to discriminating. The arguments seem reasonable and similar conclusions have been drawn in other recent, optioneering studies.		No action.	MoD agrees with Nuvia's proposed response and actions.	No action.
[redacted]	It would be useful if any future optioneering conferences involved a wider range of stakeholders. For example, RWMD have technical expertise and experience in similar studies that might have usefully helped in this case.	Agreed. It is worth bearing in mind that the bigger the team, the harder it can be to come to a decision.	No immediate action.	MoD agrees with Nuvia's proposed response and actions.	No action.
[redacted]					
[redacted]	[redacted]	Good points.	Action: Incorporate some of this text into Section 2.2 of the Phase 1 report.	MoD agrees with Nuvia's proposed response and actions.	Action: Incorporate some of the suggested PLAR-1 text into Section 2.2 of the Phase 1 report.

No.	Stakeholders' Comments	Nuvia Response	Nuvia Proposed Actions	MoD Comments	Nuvia Agreed Actions
	[redacted]				
[redacted]					
[redacted]	A 1. It is noted that the report is to determine which of the available NDA package designs is suitable for packaging submarine ILW. And that it should provide a traceable and auditable argument for container selection.		No action.	MoD agrees with Nuvia's proposed response and actions.	No action.
[redacted]	B However this is only part of the complete picture. It is necessary to underpin: C a. Selection of Cut Out Vs Cut Up - MPOS	The comment is not understood. Package type is probably not a discriminator affecting MPOS option selection. Discuss with MoD.	No action (as yet).	MoD agrees that package type is probably not a discriminator affecting MPOS option selection. This report does not seek to influence which of cut-up or cut-out is the preferred option. This report may affect ILW storage site options if cut-up is the	No action.

No.	Stakeholders' Comments	Nuvia Response	Nuvia Proposed Actions	MoD Comments	Nuvia Agreed Actions
				preferred option at the MPOS conference.	
[redacted]	D b. The description to size reduce and the extent of size reduction - where has this been made?	This is an assumption.	Action: Make size reduction an explicit assumption in the Phase 1 report.	MoD agrees with Nuvia's proposed response and actions. This report does not seek to influence which of cut-up or cut-out is the preferred option.	Action: Make size reduction an explicit assumption in the Phase 1 report.
[redacted]	E c. Why just NDA boxes? There are others available - could even do a bespoke design, a non standard package?	Discuss with MoD. Once the baseline has been established, other packages may be considered on their merits.	No action.	MoD agrees with Nuvia's proposed response and actions.	No action.
[redacted]	F It is right to underpin the package selection but also need to explain how you got there - not for this report to provide the justification for these other issues but it should frame the context of just assessing NDA packages.	The comment is not understood.	No action.	MoD agrees with Nuvia's proposed response and actions.	No action.

No.	Stakeholders' Comments	Nuvia Response	Nuvia Proposed Actions	MoD Comments	Nuvia Agreed Actions
[redacted]	G 2. Section 1.2, Page 6: It is noted that a ten year decay period is assumed - that's fine, but where is the justification for this assumption. It essentially precludes the use of the two boxes. There is a fundamental requirement to identify why this is the optimum disposal period.	Discuss with MoD.	No action.	MoD suggests that the decay period required to not preclude use of the two boxes be evaluated. This should then be included in the sensitivity analysis noted in comments NII-5 and MoDPS-1 and 2. The ten year decay period remains the baseline assumption.	Action: See NII-5 and MoDPS-1.
[redacted]	H 3. Section 4.1: ILW mass - it is discussed after, but not clear to me how sensitive the results are to changes in ILW weight.	Discuss with MoD. The comment seems to be requesting an analysis of sensitivity of the optioneering results to an increase ([redacted] in the mass of ILW.	No action (as yet).	MoD agrees with Nuvia's proposed response and actions. The report from which the ILW mass is derived is being updated by Rolls Royce to confirm that the figures are correct. MoD believes that an increase in mass of ILW will not affect the	No action.

No.	Stakeholders' Comments	Nuvia Response	Nuvia Proposed Actions	MoD Comments	Nuvia Agreed Actions
				package choice, only the number of packages required.	
[redacted]	I 4. Section 4.8: I do not agree with the assumption that CRUD is not deposited on the ILW components. [redacted]. So the assumption is not valid. We can provide the reference if required.	It is up to MoD to decide how to respond to this comment.	No action.	MoD is currently investigating how best to deal with CRUD. When this is complete, the impact on the results of this report will be assessed.	Action: Make the assumption in the Phase 1 report that the waste is free from loose contamination.
[redacted]	J 5. Section 6.1: Compatibility with downstream process - this should include consideration of interface with interim storage site as discussed in the SEA - so some data could be drawn from this.	Discuss with MoD. Section 6.2.7 of the Phase 1 report addresses interim storage. The SEA has not yet been issued.	No action.	MoD agrees with Nuvia's proposed response and actions. This report may affect ILW storage site options if cut-up is the preferred option and therefore may influence the scope of the SEA.	No action.
[redacted]	K 6. Check whether GDF has its own dose rate limit as this could be a factor regarding disposal. We can provide the reference if required.	Agreed	Covered under Action NDA-7.	MoD agrees with Nuvia's proposed response and actions.	Action: See NDA-7.
[redacted]	L 7. Page 27, 6.2.2. It may not be necessary to grout the package - see RWMD guidance on non encapsulation. I think there is a possibility that grout	Not grouting would probably not alter the	Action: Include a statement on whether not	MoD agrees with Nuvia's proposed response and actions.	Action: Include a statement in the Phase 1 report

No.	Stakeholders' Comments	Nuvia Response	Nuvia Proposed Actions	MoD Comments	Nuvia Agreed Actions
	will not be required on the basis of loose contamination, as content will be low. However there may be some structural issues. Should include a statement regarding whether not grouting would alter the conclusions and perhaps identify the opportunity to pursue this.	conclusions of the report.	grouting would alter the conclusions of the report.		on whether not grouting would alter the conclusions of the report.
[redacted]	M 8. Page 30, 6.2.5. 4th paragraph: It is identified that the 3m^3 box has the greatest ranking for Co-60 content, due to the physical size of the waste. Please clarify as other packages have a larger capacity	Annex 1.1 of the Phase 1 report deals with this at length.	No action.	MoD agrees with Nuvia's proposed response and actions.	No action.

Abbreviations

EA	Environment Agency
EIA	Environmental Impact Assessment
FEA	Finite Element Analysis
ILW	Intermediate Level Waste
NDA	Nuclear Decommissioning Authority
NII	Nuclear Installations Inspectorate
PF	Packing Fraction
RPA	Radiation Protection Advisor
RWMD	Radioactive Waste Management Division
SWTC	Standard Waste Transport Container
WDE	Waste Disposal Efficiency

WPSGD	Waste Package Specification and Guidance Documents

Appendix 2: Report on Waste container selection from non standard NDA packages

[redacted].

TAF No.SDP/05 Packaged Waste Container Review Phase 2 (Use of Non Standard Packages) Report.

Ref. No. 89330/TAF5/Phase 2/017. Issue A.

August 2010.

1. INTRODUCTION

This report is the second of three reports which address the packages to be used for storage, transport and disposal of Intermediate Level Waste (ILW) arising from the UK Submarine Dismantling Programme.

The preferred container must be capable of being used to safely package the size reduced ILW from all 27 decommissioned nuclear submarines, allowing for a ten year gap between taking each submarine out of service and the start of the dismantling process. MoD's current preference is to utilise only one type of ILW container, hence the requirement is to select a container which will accommodate the highest possible ILW Co-60 specific activity.

The Phase 1 works [Ref. #1] contained the results of a packaged waste container optioneering study, which was specified in the MoD/BMT Contract #N/SUB2/70253/1 - TAF No. SDP/05, titled: "Packaged Waste Container Review". The objective of Phase 1 (Optioneering) was to determine which of the available standard NDA package designs is suitable for packaging of submarine ILW. An assessment was carried out against a number of attributes and the 3m^3 box was chosen as the preferred option. Phase 1 is now complete.

The Phase 2 works (this study) addresses the feasibility of using non standard waste packages and overpacks for the packaging and overpacking of submarine ILW and to provide a robust audit trail for the recommendation.

The Phase 3 works will provide a detailed evaluation of the preferred waste packaging option (currently the 3m^3 box) and will combine the results from all work phases into one report.

1.1 Objective

The objective of the work is specified in the TAF 5 contract Amendment #1 as follows: "*The objective of this amendment to determine the feasibility of using the ModuCube and the WAGR boxes for the packaging of submarine ILW and to provide a robust audit trail for the recommendation".* The original objective of Phase 2 was to determine the feasibility of using the Yellow Box, the Nuvia ModuCube MiniStore (NMS) and the WAGR Box for the packaging of submarine ILW and to provide a robust audit trail for the recommendation. MoD subsequently removed the Yellow Box from the specification, therefore only the latter two are considered in this document.

1.2 Scope of Work

The scope of work is presented below.

- Determine if the WAGR box is suitable for packaging of submarine ILW, as an alternative to the 3m^3 box. If it is concluded that the WAGR box is a contender for packaging of ILW, make a recommendation for additional optioneering to be carried out at a later date to select the preferred container.

- Determine if the NMS is suitable to provide shielding for the preferred ILW waste package (currently the 3m^3 box).
- Produce a draft report and submit it to MoD for review and comment.
- Attend a meeting at Abbey Wood to present the draft report to MoD.
- Incorporate the comments from MoD and submit the final report.

Provide one hard copy and one soft copy of reports and ensure that the electronic deliverables are in the appropriate Microsoft format.

2. BACKGROUND

The Submarine Dismantling Project (SDP) has been tasked with the disposal of the Royal Navy's fleet of 27 nuclear submarines. This includes all submarines currently in or previously withdrawn from service, but excludes Astute and future classes. The scope of the SDP is restricted to these 27 de-fuelled submarines and the project finishes with the dismantling of the 27th submarine and the disposal of the resulting ILW to a planned national Geological Disposal Facility (GDF).

Three major decisions still need to be made. These are the preferred technical dismantling solution, the choice of site to conduct initial submarine dismantling and the choice of site for interim storage of ILW. The SDP project team is undertaking a Strategic Environmental Assessment (SEA), which will address selection of the dismantling and interim storage sites.

The main driver for the TAF 5 work is that the preferred ILW waste package needs to be determined to assist in the selection of a suitable interim storage site for ILW which has been size reduced and packaged immediately after Reactor Pressure Vessel (RPV) cut-out.

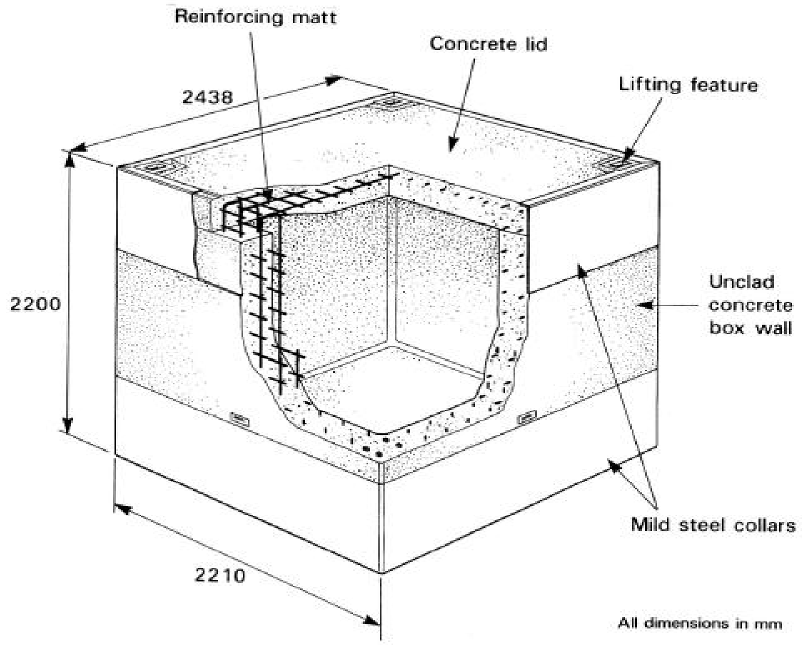
3. THE WAGR BOX WASTE PACKAGE

The Windscale Advanced Gas-cooled Reactor (WAGR) decommissioning packaging plant was designed to process solid wastes arising from the final stage of the decommissioning of WAGR. WAGR was a prototype of the AGR family of commercial reactors, and operated between 1962 and 1981. Waste package development started during the late 1970s [Ref. #2]. As the reactor was dismantled, intermediate level waste items were loaded and cemented into specially designed reinforced concrete containers (WAGR Boxes). Boxes containing wastes within LLW activity limits have already been consigned to the Low Level Waste Repository (LLWR), whereas boxes containing ILW will be held in storage until the GDF becomes available. The current situation is that around one hundred WAGR Boxes containing ILW are being held in the B64 engineered store on the Windscale site.

3.1 Construction Details

The WAGR box is essentially a pre-cast cuboidal container made from reinforced concrete with upper and lower mild steel collars as illustrated in Figure 3.1 below. Note that the WAGR box pre-dates the development of the standard range of NDA/Nirex packages and is therefore a non-standard package.

Figure 3.1: The WAGR Box Waste Package



The NDA specification [Ref. #3] states that the overall dimensions of the waste package should not exceed 2438 mm length, 2210 mm width, 2200 mm height. The nominal wall thickness is 240 mm therefore the cavity dimensions are 1958 mm internal length, 1730 mm internal width and 1720 mm internal height.

In round terms, the waste package is 2.4 metres long, 2.2 metres wide and 2.2 metres high and has an external volume of 11.85 m^3 and an internal volume is 5.83 m^3.

There are two boxes in use: one containing walls constructed from normal density concrete (ca. 2.3 tonnes/m^3) and the other from high density concrete (magnetite) (3.8 tonnes/m^3). The magnetite variant has better shielding properties and is the only one considered in this report.

According to the specification [Ref. #3], the gross mass of the waste package should not exceed 50 tonnes. This has been reduced by the operators to a working limit of 48 tonnes [Ref. #4]. Annex 2.1 provides more details on the WAGR box.

Since the WAGR box is a shielded waste package with built-in shielding, it does not need to be handled remotely when the package is disposed of at either the LLWR or in the GDF.

The WAGR box waste packages qualify as transport containers in their own right and are therefore capable of being transported on public roads without the requirement for an overpack which would provide additional shielding and/or containment. The WAGR box waste package, when filled with waste, is classed as an Industrial Package Type 2 (Type IP-2) under the UK (and IAEA) Transport Regulations [Ref. #5]. The activity contents of the waste package must be solid Low Specific Activity (LSA) material or Surface Contaminated Objects (SCO). The quantity of LSA material or SCO in the waste package must be restricted so that the external radiation level at 3 metres from the unshielded material does not exceed 10 $mSvh^{-1}$.

Corner fittings, suitable for the waste package mass, based on British and International Standards for Freight Containers enable lifting, handling and restraint of the WAGR box during transport. The corner fittings are in the form of twistlock apertures with dimensions and geometry as shown in Figure 3.2 below. The waste package is capable of being lifted using any three of the twistlock apertures.

[redacted]

Figure 3.2 Twistlock Dimensions and Geometry

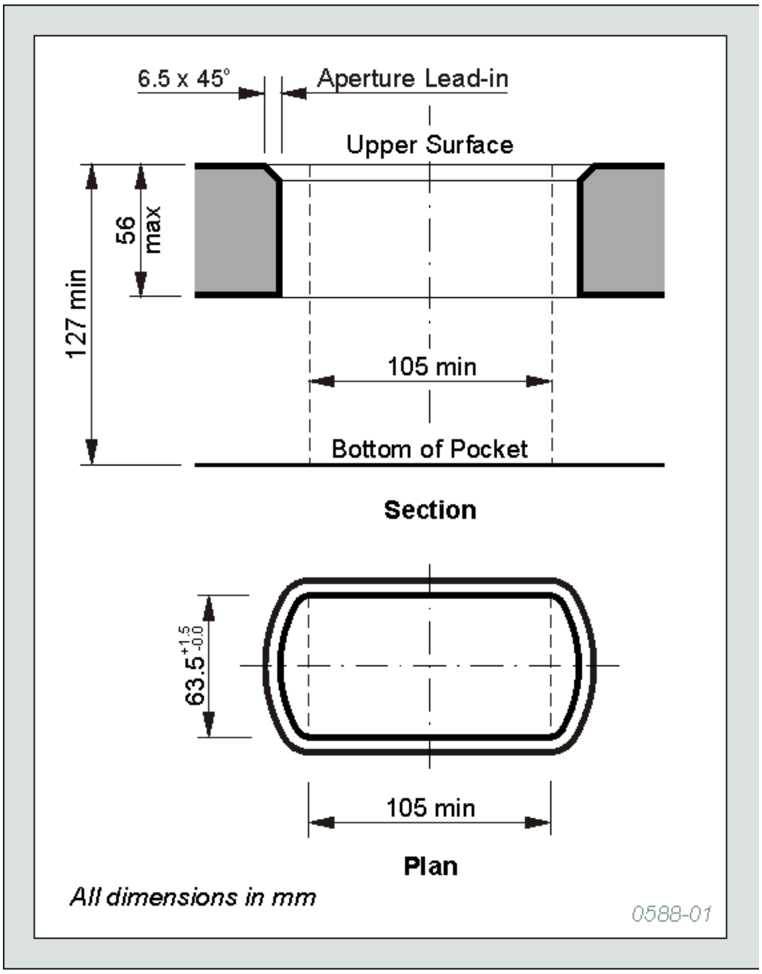


Figure 3.3 below illustrates the use of “furniture” to contain the waste inside the WAGR box and Figure 3.4 shows a number of WAGR boxes stacked inside the Windscale ILW Store.

[redacted]

[redacted]

Figure 3.3 Illustration of the Internals of a loaded WAGR Box

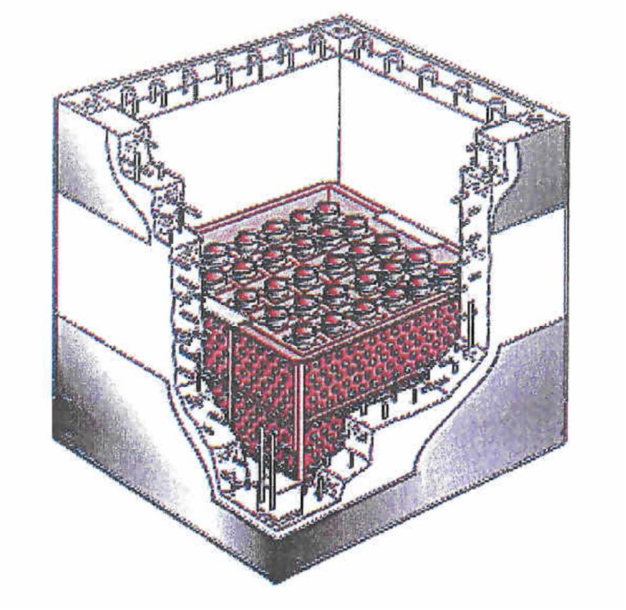


Figure 3.4 WAGR Boxes in storage at the Windscale WAGR Box Store

[redacted]

3.2 Comparison with Other NDA Waste Packages

The discussion below assesses the qualities of the WAGR box in relation to other NDA waste packages.

The results of the Phase 1 study indicated that the preferred option based on both the weighted and unweighted scores was the 3m^3 box, followed by the 2m box/500 litre drum and then by the 4m box/3m^3 drum.

The specific question addressed below whether there is any merit in deploying the WAGR box instead of (or together with) the 3m^3 box for packaging of submarine ILW. It is not the intention of this document to replicate the optioneering methodology used during Phase 1 of this study. If however this document concluded that the WAGR box was a contender for packaging of submarine ILW, provision would need to be made for additional optioneering to be carried out at a later stage.

The approach taken below is to align the WAGR box with one of the standard NDA boxes and use the Phase 1 information and arguments to compare the two boxes. Table 3.1 shows that there is a broad similarity between the WAGR box waste package and the 2m box waste package. The box dimensions are broadly similar, although there are differences in the cavity volumes and gross package weights of both boxes. In addition, both boxes are IP-2 transport containers.

Table 3.1

Box	**External dimensions (mm)**			Internal Dimensions (mm)			Cavity Volume (m^3)	Gross Package Mass (kg)
	Length	Width	Height	Length	Width	Height		
WAGR	2438	2210	2200	1958	1730	1720	5.8	48000
2m	2438	2200	1969	2278	2040	1809	8.4	40000

Note (a): 8.4 cubic metres with no shielding and 2.9 cubic metres with 300 mm shielding.

It is a requirement of IP-2 containers (but not of Type B packages) that the dose rate at a distance of three metres from the unshielded surface of the grouted wasteform should not exceed 10 mSv/h. This is for the protection of workers and the public if the waste form is exposed during accident conditions. According to the IAEA guidance contained in Ref. #6, the additional shielding afforded by grouting the annulus between the waste and the package and by the package construction and shielding material cannot be taken into account in meeting this requirement.

In order to determine whether or not loaded IP-2 packages could meet this transportation requirement, a scoping study was carried out on the NDA 2m box during Phase 1. The MicroShield software package was used to calculate the gamma dose rate at three metres from the surface of unshielded package. The study assumed that the 2m box was loaded with ILW which had been decay stored for 10 years. During this period, the Co-60 activity would have decayed by two half lives, resulting in a factor of 4 reduction in activity from the start of the decay period. It was assumed that the mass of ILW inside the 2m box was [redacted] and that the Co-60 activity was [redacted]

The Phase 1 results showed that the dose rate at more than 3 metres from the waste inside an unshielded 2m box was about [redacted], which is significantly in excess of the 10 mSv/h limit.

Thus a submarine would need to be decay stored for an additional 4 half lives (ca. 20 years) before the dose rates decayed to acceptable levels for transport. Including the initial 10 year decay storage period, approximately 30 years would need to elapse before the ILW from a newly decommissioned submarine could comply with the 3 metre dose rate requirement for transportation inside a 2m box.

Calculations similar to those discussed above were carried out in Ref. #7 for the 4m box. Similar results were obtained for the 4m box, indicating that up to 43 years decay storage would be required before the 4m box could be used to transport submarine ILW.

Since MoD has specified that the ILW container must be capable of being used to safely package ILW from submarines which have been out of service for 10 years, it was concluded during Phase 1 that both the 2m and the 4m box (both IP-2 transport containers) were non compliant with the MoD specification.

Noting that the WAGR box is also an IP-2 container, and that the additional shielding afforded by grouting the annulus between the waste and the waste package and by the package construction and shielding material cannot be taken into account in meeting the 3m dose rate requirement, it is logical to provisionally conclude that the WAGR box should also be non compliant with the MoD specification. This conclusion is based on the assumption that the MicroShield input data does not change. No additional MicroShield calculations were necessary to arrive at this conclusion.

Annex 2.1 shows WAGR box waste capacity and storage volume calculations, similar to those previously carried out for the Phase 1 report for the standard RWMD waste packages. These calculations were carried out in order to understand how much submarine ILW could be put into the WAGR box and, if significantly different, use this revised radioactivity source term to estimate in the MicroShield calculations. These results are presented in Table 3.2 below together with those for the 2m box.

Table 3.2: Summary of Results for the WAGR Box and the 2m Box (from Annex 2.1 Calculations)

A	B	C	D	E
	Volume of Waste (m3)	Weight of Waste (tonne)	Packing Fraction	Volume Disposal Efficiency (tonne/m3)
WAGR[(a)]	[redacted]	[redacted]	[redacted]	[redacted]
2m box[(b)]	[redacted]	[redacted]	[redacted]	[redacted]

Note (a): See Annex 2.1 of this report.

Note (b): See Ref. #1.

Table 3.2 Columns B and C show that the WAGR box can hold similar quantities of waste to the 2m box. There is a ca. 12% difference between the boxes, with the 2m box able to hold more waste, but when data input errors are taken into account, these differences may not be significant.

It is concluded that although there may be a slight decrease in the WAGR box payload, this will have very little (if any) effect on the dose rate at 3 metres. Thus the WAGR box would need to be decay stored for 30 years (or a couple of years less) before it could be used for off-site transportation of waste. The above results confirm that the WAGR box is not a replacement for the 3m^3 box.

3.3 Comparison with the 2 Metre Box

As discussed above, an optioneering exercise was carried out during Phase 1 of this study to evaluate the five standard NDA waste packages against a number of criteria, in order to select the preferred waste package option. In order to determine where the WAGR box would have been ranked if it had been included in the Phase 1 study, the performance of the WAGR box against the Phase 1 criteria was investigated as part of this (Phase 2) study and the results were compared to those obtained for the 2m box. The results are shown in Table 3.3 below.

[redacted]

Table 3.3: Comparison of the WAGR box against the 2m box.

Optioneering Criteria	Comparison of the WAGR box against the 2m box
Dose rate less than 10 mSv/h at 3 metres.	The WAGR box would have performed as poorly as the 2m box. The WAGR box and the 2m box are both non compliant with this requirement and would need to be stored for at least 30 years before they could be use for off-site transportations.
Ease of Size Reduction	The WAGR box would have performed as well as the 2m box, since they both have the similar aperture sizes which require minimal size reduction of the waste. The WAGR box aperture size is marginally bigger.
Ease of Grouting and Lidding	The WAGR box would have performed as poorly as the 2m box, because they are both high mass, high volume containers, which could be difficult to fill with grout.
Packing Fraction	Table 3.2 Column D indicates that the packing fraction of the 2m box is better than that of the WAGR box. The WAGR box is heavier and has more internal volume capacity than the 2m box, but cannot make best use of available space because of the limitation on its gross weight. This results in a comparatively lower packing fraction.
Waste Disposal Efficiency	Table 3.2 Column E indicates that the waste disposal efficiency of the 2m box is better than that of the WAGR box. The WAGR box has a slightly higher external volume and slightly lower payload, therefore the volume disposal efficiency (payload/external volume) of the WAGR box is inferior to that of the 2m box.
Flexibility	The WAGR box would have performed as poorly as the 2m box, since neither is flexible to the unshielded 3 metre dose rate constraint.
Previous Experience	The WAGR box would have probably performed better than the 2m box, since the WAGR box has been used extensively at Windscale for packaging of AGR decommissioning wastes. Note that neither box has yet been used for transportations on public highways.
Compatibility with downstream processes and facilities	The WAGR box would have probably performed as well as the 2m box, since neither box needs additional shielding during buffer storage or long term interim storage.
Programme issues	The WAGR box would have probably performed better than the 2m box, since at least some of the necessary approvals will presumably be already in place for use the WAGR box.

The Phase 1 report also addressed issues related to transport, safety environmental impact, regulatory approvals and cost but these were not regarded as discriminatory criteria and are therefore not discussed further.

[redacted]

Table 3.3 shows that the WAGR box has a similar profile to the 2m box when evaluated against some of the Phase 1 criteria and actually performs better in some of the criteria. The WAGR box appears to be on a par with the 2m box when evaluated against the above criteria. This was a surprising result to the authors of this paper and it is indeed a compliment to the originators of the WAGR box that its design appears to have withstood the test of time. There are however some caveats to these initial conclusions.

Issues related to the materials of construction of the candidate packages were not addressed during Phase 1, since only standard NDA stainless steel packages were considered. The (standard) 2m box is manufactured from stainless steel (with some internal grout shielding) whereas the (non standard) WAGR box is manufactured predominantly from reinforced concrete (with some mild steel metal cladding).

One issue of concern is the possibility of longer term corrosion problems associated with reinforced concrete. It is well known that reinforced concrete can fail due to a reduction in its durability. When rebar corrodes, the oxidation products (RUST) expand and tends to flake, cracking the concrete and unbonding the rebar from the concrete. Typical mechanisms leading to durability problems are carbonation and chlorination of the concrete. Carbonation, is a chemical reaction between carbon dioxide in the air with calcium hydroxide and hydrated calcium silicate in the concrete. This makes the pore water more acidic, thus lowering the pH, leading to depassivation of the rebars. Chlorides, including sodium chloride, can promote the corrosion of embedded steel rebar if present in sufficienty high concentration. Chloride anions induce both localised corrosion (pitting corrosion) and generalised corrosion of steel reinforcements. The use of epoxy-coated reinforcing bars and the application of cathodic protection can to some extent mitigate this problem.

NDA has stated [Ref. #3] that packages should be designed for a period of interim storage of up to 150 years and that a period of 500 years should be considered as a target for the integrity of the waste container. These time periods are vastly in excess of those which were extant during the 1970s and 80s when the WAGR box was being designed.

It is understood that RWMD is currently (2010) reviewing these and other long term stability and containment issues to determine the future applicability of the WAGR box to other waste streams [Ref. #8]. Even if these issues are resolved, the risk of deploying a reinforced concrete box is considered higher than the risk of deploying a high integrity stainless steel container for packaging of SDP ILW.

If the dose rate restriction at a distance of 3 metres was not an issue and the 3m^3 box option was hypothetically not viable, the authors of this report would find it difficult to choose between the WAGR box and the 2m box.

The dose rate restriction at a distance of 3 metres would cease to be an issue, if, at the time of transport, the Co-60 dose rate was less than 10 mSv per hour. This could happen, for example, if the current Co-60 activity estimates were too high or if the submarines were decay stored for extended periods. In order to quantify this, it is necessary to re-visit the MicroShield calculations which were carried out for the Phase 1 study [Ref. #1]. These indicated that a package content of [redacted] of

Co-60 resulted in a dose rate of [redacted] at 3 metres and that the dose rate was proportional to the Co-60 activity content. The dose rate would need to decrease from [redacted] to 10 mSv per hour (i.e. by a factor [redacted] before IP-2 packages could be used. This is equivalent to a [redacted] reduction in the Co-60 activity.

Thus if the Co-60 activity was reduced from [redacted] (i.e. by a factor of [redacted]), the dose rate at 3 metres would be compliant with the transportation regulations. This is rounded down to [redacted] of Co-60.

In summary, if the Co-60 activity in an ILW waste package was less than [redacted] at the time of transport, the dose rate at 3 metres would not exceed the limit stipulated in the transport regulations for transportation of IP-2 waste packages. This would remove a barrier to the use of the WAGR and 2m boxes but it is cautioned that this is not a justification for their use.

3.4 Summary and Conclusions

The WAGR box is not a viable option for packaging of SDP ILW because, as an IP-2 package, it does not meet the MoD ten year decay storage requirement. The WAGR box cannot be used for off-site transport until the dose rates have decayed to permissible levels. This can take up to 30 years. No additional waste package optioneering to assess the WAGR box against the other boxes needs to be carried out during Phase 2 of this study.

It is concluded that the $3m^3$ box remains the preferred waste package for SDP submarine ILW, as concluded in the Phase 1 report [Ref. #1].

If the WAGR box had been assessed during Phase 1, it would have ranked alongside the 2m box. If the dose rate restriction at a distance of 3 metres was not an issue and the $3m^3$ box option was hypothetically not viable, the authors of this report would find it difficult to choose between the WAGR box and the 2m box.

The dose rate restriction at a distance of 3 metres would not be an issue if the Co-60 activity was less than about 5 E12 Bq at the time of transport. This would remove a barrier to the use of the WAGR and 2m boxes but it is cautioned that this is not a justification for their use.

3.5 Recommendations

It is recommended that the $3m^3$ box be carried forward into Phase 3 (Detailed Evaluation of Preferred Option) which will explore lifecycle issues associated with the preferred ILW container.

4. THE NUVIA MODUCUBE MINISTORE (NMS)

The Nuvia ModuCube Ministore (NMS) was designed by Nuvia Limited to provide modular shielding for waste packages containing a passive inner waste form. The ModuCube is therefore not an alternative to the 3m^3 box (or any other RWMD waste package), but may be used to provide shielding round the waste package. The current design of the ModuCube is intended to provide shielding during interim storage of the waste package. It is not intended for use during transportation, but this may be addressed by Nuvia at a later date. It is emphasised that although Nuvia is in the process of taking out a patent on its design, no ModuCubes have yet been approved for use or manufactured.

The general arrangement of the ModuCube is illustrated in Figure 4.1 below.

Figure 4.1 - ModuCube™

The following summarises the principal design elements of the ModuCube.

- The ModuCube is composed of four interchangeable side panels, a base panel and a lid.
- Each of the six ModuCube panels provides 150 mm of steel shielding and is fabricated from two 75 mm thick grade S275 carbon steel plates.
- When assembled its overall dimensions are 2080 mm long x 2080 mm wide x 1675 mm high.
- It has a tare weight of approximately 22 tonnes.

- When assembled the panels provide a shielded enclosure capable of receiving RWMD approved containers, specifically four 500 litre drums, one 3m^3 box or one 3m^3 drum.
- These containers are separated from the ModuCube by stainless steel rubbing plates to prevent cross contamination from the carbon steel of the ModuCube.
- It has location and lifting features to enable it to be handled by crane or forklift truck and to facilitate stacking and lid-fitting.
- The shielded assembly is designed to remain intact under drop load conditions equivalent to a free fall onto an unyielding surface from 4 meters.

Annex 2.2 provides more detailed information on the ModuCube.

4.1 Relevance to SDP

The current design of the ModuCube could be used to provide shielding for the 3m^3 box at the following locations:

- within the buffer store on the dismantling site; and/or
- within the interim store at an off-site location, which has still to be determined.

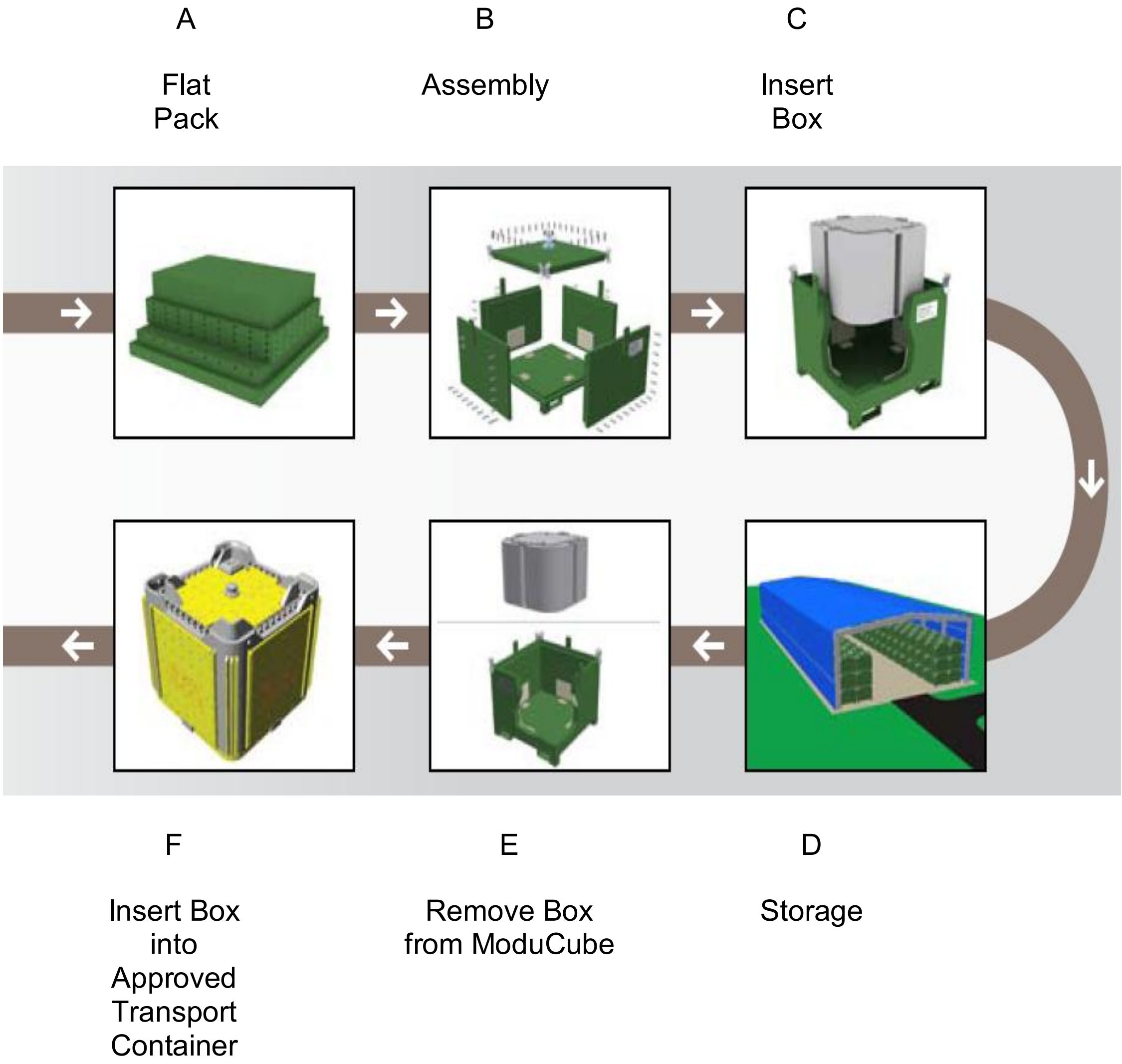
[redacted]

[redacted]

[redacted]

[redacted]

Figure 4.2 – Lifecycle of ModuCube™



4.1.2 Long Term Interim Storage

The discussion below illustrates how the ModuCube could typically be used during long term storage of waste at the interim store.

ModuCube would have no role to play if the waste was moved to a shielded interim store. If the interim store was shielded, the imported waste would be removed from its transport overpack (e.g. the reusable standard transport container (RSTC)) and the unshielded waste package stored. The transport overpack would be re-used during future imports to and exports from the interim store.

ModuCube could have a role to play if the waste was moved to an unshielded interim store. If the interim store is not shielded, additional package shielding would be required. If the ModuCube was used for this purpose, the same cycle shown in Figure 4.2 would apply. After a prolonged period (possibly > 30 years) of interim storage (Figure D), the waste package would be removed from the ModuCube (Figure E), put into an approved transport overpack (Figure F) and transported to the GDF for disposal. The transport overpack would be removed prior to disposal of the unshielded waste package at the GDF. Both the overpack and the ModuCube would then be re-used.

4.2 Summary and Conclusions

The purpose of the ModuCube is to provide modular shielding for waste packages containing a passive inner waste form. It is therefore not an alternative to the $3m^3$ box (or any other RWMD waste package), but may be used to provide shielding round the waste package.

The ModuCube is composed of four interchangeable carbon steel side panels, a base panel and a lid, providing 150 mm of steel shielding. When assembled, its overall dimensions are 2080 mm long x 2080 mm wide x 1675 mm high and it has a tare weight of approximately 22 tonnes.

When assembled, the panels provide a shielded enclosure capable of receiving the RWMD approved $3m^3$ box. It has location and lifting features to enable it to be handled by crane or forklift truck and to facilitate stacking and lid-fitting. The shielded assembly is designed to remain intact under drop load conditions equivalent to a free fall onto an unyielding surface from 4 meters. This was carried out to assess it performance when stacked 3 high.

The current design of the ModuCube is intended to provide shielding during storage of the waste package. It is not intended for use during transportation on public highways.

It is emphasised that the suggested deployment of the ModuCube during buffer and long term interim storage as described above is not a recommendation. Additional issues and interdependencies would need to be addressed to underpin its future use. These would include the following:

- Ensuring that the ModuCube design is fit for purpose and will provide adequate shielding during storage of high dos rate Co-60 submarine waste inside a $3m^3$ box. The waste will probably be conditioned in a cement grout, but further work is necessary to confirm this.
- Obtaining regulatory approvals for its intended use.

5. REFERENCES

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6. ANNEX 2.1: WAGR BOX WASTE CAPACITIES

7. ANNEX 2.2: NUVIA MODUCUBE MINISTORE (NMS): ADDITIONAL INFORMATION

Additional information is provided below on ministores, with particular reference to the Nuvia ModuCube.

7.1 Shielding

In order to develop the ministore design, Nuvia's waste management experts and Radiation Protection Advisors undertook a detailed review of UK ILW waste streams, with a focus on Magnox wastes. This review involved an analysis of each individual RWMD waste data sheet in order to undertake shielding calculations and optimise the shielding design of the ModuCube.

As a result of this waste stream assessment and shielding calculations, an optimum thickness of 150 mm was selected for the ModuCube. This optimum thickness will provide a dose rate of <1mSv at 1m for almost all waste streams. There are a very small number of waste streams which are exceptions to this. It is assumed that the above shielding thickness will need to be reviewed and an optimum value determined for shielding of high Co-60 submarine wastes.

7.2 Structural Analysis

Nuvia has developed the ModuCube design using Finite Element Analysis (FEA) to confirm the integrity of the shielding under both lid corner and lid edge impacts. The drop orientation was over the ministore centre of gravity from a height of 4m with maximum payload. The FEA was carried out to determine the suitability of the design to retain gross shielding under a postulated fall when stacked one on top of the other within the store. The impact target was an unyielding surface. The initial results of this analysis are that none of the lid bolts fail. The lid does lift up slightly, but in this case it was only in the order of 8 mm, which was considered insufficient to present a significant shielding hazard.

7.3 Corrosion Assessment

In assessing the long-term viability of the ModuCube ministore to provide a passively safe interim storage solution, Nuvia has taken a pessimistic approach and assessed the performance of the ModuCube if inspection and maintenance was not carried out and the paint system were to only last 25 years, that is, at the end of this period the paint offers no protection at all. The detailed assessment concluded that the long term integrity of the ModuCube was justified for reasons including those given below.

- Using pessimistic data, the effect of corrosion on a ModuCube is similar to the tolerance on the material it is constructed from and is therefore acceptable.
- The structural bolts are protected from anything that might initiate corrosion and are unlikely to be weakened to a significant extent.
- The wasteform is in a container that is standard across the UK and accepted for use until the GDF is available.

- Coupon ModuCubes can be provided to allow in service inspections and remedial maintenance to be carried out.
- The ModuCube design allows for the waste package to be easily removed facilitating a full overhaul of the ministore if required as part of a life extension programme.

7.4 Environmental Conditions and Inspection and Maintenance Regime

In designing the ModuCube Ministore, Nuvia has reviewed the need to retain its integrity for a minimum of 100 years and not to exhibit any dramatic deterioration for an additional 50 years after that date.

It is expected that a low-level maintenance and inspection regime would be required for the ModuCube ministores and their contents during the storage period. The inspection and maintenance tasks could include:

- A visual inspection of the paint system and local repair as necessary.
- In the event of serious deterioration of the entire paint system the decision could be made to transfer the waste to another container and refurbish the first one.
- Removing and inspecting a small proportion of the bolts from the ministores. In the event of significant loss of strength a programme of replacement could be considered.
- Visual inspection of some of the 3m³ boxes.

7.5 Overall Integrity of ModuCube System

Nuvia recognises that in designing a safe and robust interim storage system consideration needs to be given to all the components of the storage system if future issues are to be avoided. These components not only include the ministore design but also the wasteform, the container design, the store building, its atmosphere, its equipment and the monitoring, inspection and maintenance regime. Consideration also needs to be given to refurbishment plans especially where life extension may be required.

In providing an interim storage system capable of operating for 100 to 150 years, the ability to replace some components during the system's lifetime is acceptable, provided it is planned for at the design stage and there are clear criteria and procedures for determining in advance when replacement will be necessary.

The robust design of the ModuCube shielding combined with an internal immobilised waste form using RWMD approved drums and boxes will provide a passively safe storage system that will be capable of preventing radioactive release under postulated accident scenarios including terrorist attack.

The ModuCube ministore has been designed to remain intact following an impact onto a un-yielding surface from 4 m. In addition, the use of RWMD inner containers and immobilised waste has been demonstrated to limit release under 25 m impact scenarios.

The combined assembly will also provide a significant barrier to cope with thermal accident events resulting from a building fire or attack. The ability of the ModuCube to vent internal air pressure will ensure that high temperatures will not pressurise either the ModuCube or the inner waste container.

Storage of wastes fixed within a cement form within an approved range of RWMD containers ensures that risks associated with technical and regulatory issues for future transport to the GDF are significantly reduced.

7.6 Interim Storage Inspection

It should be expected that a low-level maintenance and inspection regime would be required for the ministores and their contents during the storage period. In the past, there has been a tendency to consider storage in isolation and to give inadequate consideration to refurbishment and replacement in storage system design. There are also concerns that insufficient attention has been paid to provisions for monitoring and inspection of waste packages.

Consideration should also be given to the need to handle or move ministores over the storage period. These handling features, especially lifting devices will need to be subjected to regular inspection regimes. There is little point in initiating an inspection programme if inspected items once found to be defective cannot easily be repaired or replaced. This is particularly the case where ministores are intended to provide the final transport package to the GDF. Current IAEA regulations require transport packaging to be subjected to annual maintenance inspection and replacement of containment seals together with continual maintenance to ensure that safety systems remain functional.

The ModuCube uses an internal RWMD approved stainless steel box within which the waste can be encapsulated. This feature allows the waste to be easily removed to initiate repair or replacement as required.

To support interim inspection regimes a number of “Coupon” ModuCubes can be provided and placed within the store environment. These can then be recovered periodically to allow in service inspection and prediction of life expectancy and maintenance regimes.

7.7 Storage Life Extension

Existing stores for waste packages are typically designed to provide a service life of 50 plus years. These stores will have to have their service lives extended as required, in order to provide sufficient safe and secure interim storage throughout the geological disposal facility development programme.

The replacement of these stores will need to be avoided wherever possible, and the NDA will need to ensure that its strategy for future stores (including ministores) allows for the safe and secure storage of the waste contained within them for a period of at least 100 years.

In order to mitigate the need to recover and repackage the waste to allow for life extension, any future storage solution needs to include for easy maintenance and replacement. The ModuCube can be easily decoupled from the waste and then dismantled.

This feature allows the waste to be repackaged within a new ModuCube and the existing unit removed from service, dismantled, inspected, reconditioned and placed back into service. This allows the life of the ModuCube to be extended indefinitely.

7.8 Transport to the GDF

The majority of the ILW waste destined for interim storage will eventually need to be transported to the GDF. Some waste streams will however decay over the initial 50 year period to LLW limits.

Transport of the waste within a ministore will therefore require the ministore to conform to the requirements of the IAEA regulations as either an IP-2 or Type B package.

Type B packaging will be required for more active wastes, while IP-2 packaging can transport waste of lower specific activities and waste decayed to LLW limits.

The design attributes required for a container to comply as a Type B package are extremely onerous in terms of release criteria following hypothetical thermal and accident events. The NDA through RWMD have spent many years developing a Type B transport packaging system (the SWTC) for shipment of RWMD approved stainless steel waste containers.

The development of a container capable of both interim storage and final Type B transport would be an expensive package to design, manufacture and maintain. For these reasons, Nuvia believes that a ministore should not attempt to combine both storage and transport within one design, but opt for a split of functionality between storage container and transport package.

This approach has significant design benefits in limiting the features associated with the interim storage container that would otherwise be required if it were to meet transport regulations. One such requirement is the inclusion of containment seals required to ensure that during transport, release of activity is prevented. These seals will need to be replaced and subjected to leak testing prior to transport; this is not an easy operation with a loaded container. Other issues relate to maintenance during the storage period, which would be necessary to demonstrate the ongoing performance of transport related features.

A combined ministore concept therefore requires a number of regulators to grant approval, this issue should not be trivialised or minimised in terms of progressing the ministore concept.

The ModuCube design was developed with this consideration in mind, and by utilising the existing RWMD waste containers, makes use of the many years of development undertaken by RWMD. This split between storage container and transport package additionally limits the volume being finally placed within the GDF as the ministore is removed prior to placement.

The ModuCube is not intended to provide the final transport package, relying on the SWTC to transport the grouted waste package from the interim store to the GDF.

Another significant advantage of the ModuCube relates to waste steams that have decayed to LLW over the interim storage period. These wastes can be transported within the ModuCube (as an IP-2 waste package) directly to the LLWR, where the inner box can be removed for placement within the store and the ModuCube being returned for reuse. This approach limits the volume utilised in the LLWR.

7.9 Minimising the need for Re-packing of the Wastes

The requirement for ministores to provide safe storage over extended lifetimes of up to 150 years before emplacement in the GDF is extremely challenging unless the design attributes of the ministores and the waste form are taken into account early in the design phase.

Over the interim storage period, some waste streams will eventually decay to levels that would allow the waste to be sent direct to LLWR rather than the GDF. The benefits of fixing the waste prior to interim storage allows these waste packages to be easily retrieved and transported direct to a LLW disposal facility without further repacking which would inevitably lead to increased operator dose and plant costs.

The ModuCube ministore has been designed as an IP-2 transport package and therefore can be used to transport the waste container direct to LLWR without additional handling operations.

One of the key attributes of the ministore concept should be its ability to allow future generations to deal with on-site decayed waste without additional process plant or the need to implement complex and costly repacking programmes. Ministores should also provide the ability to meet future changes in transport regulations, given uncertainties on timings for the GDF.

A successful ministore concept should therefore provide a cradle to grave solution, eliminate the need for double handling and repacking of the waste, and aid final transport to the GDF.

7.10 Storage Life Extension

The period associated with interim storage is currently unknown with initial estimates of 50 years being extended to 100 years and even 150 years. It is difficult to predict the performance of ministores over these extended time-frames, and therefore ministore designs should include the ability to implement a life extension programme.

7.11 Programme and Project Management Arrangements

A big advantage of ModuCube is that its manufacture, fabrication and application do not require highly-qualified staff. Its manufacture does not require advanced engineering methods from a single source, but is manufactured to normal engineering standards and can be carried out by many normal UK engineering suppliers.

7.12 Regulator Engagement

Encouraging discussions have been held with RWMD and NDA. Encapsulation is the present approved strategy for ILW disposal.

ModuCube provides shielding. The containment is provided by the $3m^3$ box or 500 litre drums for disposal, and these are enclosed within the ModuCube. The $3m^3$ box and 500 l drum are approved by RWMD for disposal.

7.13 Summary

The key attributes and benefits of the Nuvia ModuCube storage concept include the following:

- ModuCube provides modular shielding for waste packages and thus obviates the need for a substantial concrete shielded waste store.
- The ModuCube concept uses the current RWMD approved strategy of immobilising waste within standard RWMD approved containers, thus avoiding the need to secure RWMD approval for an alternative strategy including un-encapsulated waste.
- The ModuCube concept avoids the consignment of large volumes of non-radioactive shielding material to the GDF. This will significantly reduce the volume-related cost of ultimate disposal.
- In order to comply with transport and ultimate disposal requirements, the ModuCube concept requires that waste be immobilised in cement (or other approved immobilisation medium).
- When waste is ultimately consigned to the GDF, the shielding material is available for recycling or re-use.
- ModuCube manufacture is simple and comparatively low in cost and can be accomplished by many companies.
- ModuCube can be delivered in “flat pack” form, reducing storage space.

Appendix 3: Report on Detailed Evalution of Preferred Packaging Option

[redacted].

TAF No.SDP/05 Packaged Waste Container Review Phase 3 (Detailed Evaluation of Preferred Option) Report.

Ref. No. 89330/PDT/TAF5/TR014. Issue P1.

September 2010.

1. INTRODUCTION

This report contains the results of Phase 3 (Detailed Evaluation of Preferred Option) of a packaged waste container study, which was specified in the MoD/BMT Contract #N/SUB2/70253/1 - TAF No. SDP/05, titled: "Packaged Waste Container Review".

Two reports have already been provided to MoD. The results of Phase 1 (Optioneering) are contained in Ref. #1 and the results of Phase 2 (Use of Non Standard Packages) in Ref. #2. This report contains the results of Phase 3.

It is important to appreciate the terminology used in this report for packaging of waste. When the wasteform (i.e. the grouted or ungrouted waste) is put into the waste container (i.e. the 3m^3 box) it is called a waste package (i.e. the 3m^3 box waste package). When the waste package is put into a shielded transport container it is called a Type B transport package under the IAEA Transport Regulations [Ref. #3].

1.1 Objective

The aim of TAF 5 is to select a disposal container for packaging of ILW generated from the dismantling of UK nuclear submarines. The data used during the selection process must be traceable and auditable and the arguments used for container selection must be robust and defensible.

The objective of the work is specified in the TAF 5 contract documentation as follows: "*To determine which of the available designs of standard NDA ILW containers would be most suitable for the packaging of submarine ILW and to provide a robust audit trail for the recommendation".*

The principal objective of Phase 3 is to identify any issues which could prevent or severely hinder deploying the 3m^3 box waste package as MoD's preferred option for packaging of SDP ILW.

1.2 Scope of Work

The work was performed in three phases, all of which are described below.

- Phase 1 (Optioneering) determined which of the available NDA package designs was suitable for packaging of submarine ILW. The selection was restricted to the 5 containers specified by the NDA for packaging of ILW. A scoping study was carried out to identify if any of the options were incompatible with the UK transport regulations. This was followed by an optioneering conference for selection of the preferred option. The end point of Phase 1 was the selection of the RWMD 3m^3 box waste package as the preferred ILW packaging option.
- Phase 2 (Use of Non Standard Packages) evaluated the possible use of the WAGR box and the Nuvia ModuCube Ministore (NMS). The WAGR box

was not recommended as a replacement for the $3m^3$ box and the NMS is a shielded overpack which could be used in conjunction with but not replace the $3m^3$ box. The $3m^3$ box waste package remained the preferred option for packaging of SDP submarine ILW.

- Phase 3 (Detailed Evaluation of Preferred Option) (this document) explores the requirements and lifecycle of the $3m^3$ box waste package to determine if there are issues which could prevent it from being used.

The draft Phase 3 report will be reviewed by MoD, and their comments will be incorporated into a revised version of the report. This revised report will be sent for stakeholder review and the report will be updated in a similar manner to produce the final report. If no reasons are found, which would prevent or significantly hinder deploying the $3m^3$ box waste package, it will be declared as MoD's preferred container for the packaging of submarine ILW. If this work identifies significant barriers to the use of the $3m^3$ box waste package, another waste package would need to be considered.

2. APPROACH AND STRUCTURE OF DOCUMENT

The principal objective of this study is to identify any issues which could prevent or significantly hinder deploying the 3m^3 box waste package as MoD's preferred option for packaging of SDP ILW.

Three separate reviews/studies were carried out in order to determine the key technical issues associated with the packaging SDP ILW inside a 3m^3 box waste package and to assess whether any of these issues was significant enough to prevent this waste package from being used.

The focal point for this study is the work carried out by the Radioactive Waste Management Directorate (RWMD) of the Nuclear Decommissioning Authority (NDA). Its remit is to implement geological disposal for higher activity radioactive wastes in the UK. A major area of the work of the RWMD is the provision of advice to the packagers of radioactive waste in the UK, by way of the definition of packaging standards and the assessment of individual waste packaging proposals against these standards. This assessment process is inclusive of the design, fabrication, manufacture/use, buffer storage, transport, interim storage and acceptance of a loaded waste container into the GDF. When a waste producer is issued with a "Letter of Compliance" (LoC) [Ref. #4] during the various stages of the assessment process, this indicates that the proposed waste packages are compliant with RWMD standards and specifications and the underlying disposal concept. The LoC provides the waste packager with confidence that the risk of inappropriate treatment of waste and the potential for future repackaging, with the potential dose and cost implications, are minimised. This assessment process is recognised within the regulatory arrangements for nuclear licensed sites. The LoC process is discussed in Section 3 of this report.

The principal RWMD documents used in this study are the Waste Package Specification [Refs. #5 and #6] for the 3m^3 box and the Wasteform Specification [Refs. #7 and #8] for the corner lifting variant of the 3m^3 box. These documents define the performance requirements for the two barriers to the release of radionuclides, namely the waste container and the wasteform. The waste container and the wasteform should each be adequate in their own right and as much as possible, should also be complementary to each other.

The first (and most directly relevant) review was a detailed assessment of the requirements of the RWMD Waste Package Specification relevant to the 3m^3 box waste package. The Waste Package Specification is reviewed in Section 4 of this report.

This was augmented by a second review, which was a detailed assessment of the requirements of the RWMD Wasteform Specification relevant to the wasteform inside a 3m^3 box. The Wasteform Specification is reviewed in Section 5 of this report.

Although Sections 4 and 5 of this document contain a comprehensive review of major technical issues associated with the 3m^3 box waste package, throughout the whole of its waste management cycle, it was nevertheless considered beneficial to undertake a summary review of the various lifecycle phases. The objective was to identify any additional issues which might arise from adopting a different perspective on the issues. The lifecycle activities of the $3m^3$ box waste package are reviewed (in outline form) in Section 6 of this report.

Section 7 contains a summary and a list of conclusions from this study.

Section 8 contains the recommendations from this study.

Annexes 1 and 2 contain the outputs from the dose rate calculations performed using the MicroShield software package.

Annex 3 contains the IAEA transport package testing requirements under normal and accident transport conditions. This was added to complement the information provided by RWMD in [Ref. #6].

Annex 4 contains key issues which will need to be addressed as part of the RWMD LoC process.

3. LETTER OF COMPLIANCE ASSESSMENT PROCESS

The RWMD Letter of Compliance (LoC) assessment process for waste packaging plants is described in [Ref. #4]. The overall objective of LoC assessment process is to give confidence to all stakeholders that the future management of waste packages has been taken into account as an integral part of their development and manufacture. Application of the LoC is intended throughout the life-cycle of a waste packaging plant.

The LoC arrangements require that safety cases covering the operation of plants which are built to retrieve and condition ILW, also address the disposability of the waste packages that will be produced. This is consistent with international conventions and IAEA standards that advise that interdependences between different steps in radioactive waste management are taken into account and that we avoid imposing undue burdens on future generations.

The objective of the LoC is achieved by the site licence holders working to RWMD packaging standards and seeking input from RWMD to explicitly demonstrate that the waste packages produced by a proposed packaging process will be compliant with RWMD packaging standards and be compatible with the underlying requirements of geological disposal, as understood at the time of assessment.

This is achieved through production of a comprehensive disposability safety case which is started at an early stage and progressively developed as the packaging process is developed and the packaging plant is built. Issue of a LoC and provision of a disposability assessment allows a site licence holder to construct the conditioning proposal and provides confidence for the site licence holders and/or owner of the liability for the waste (i.e. MoD), that the risk of inappropriate treatment and the potential for future repackaging is minimised.

After a waste package has been produced, current practice is to send the waste package to an interim store. The store will have an associated safety case and the store operator will ensure that waste packages received are safety compliant, by assessment against store waste acceptance criteria (WAC).

During the long term storage period, the operator will operate the store in accord with the safety case, and will be required to maintain the waste packages under appropriate environmental and safety control. This will imply continued application of quality management systems and periodic checks by the regulator to give confidence of continued compliance.

The assessment process requires that the characteristics of the waste package (i.e. the waste container and the wasteform) are established in sufficient detail to form an effective basis for the assessments which are subsequently undertaken.

The issue of a LoC gives the site licence holder confidence that the waste package has been assessed by an independent waste management organisation in accordance with procedures that are scrutinised by the regulators, and has been found to be compliant with the concept for geological disposal as presently understood. It does not remove the need for assessment of the waste package against future WAC, but the provision of a Final stage LoC is an essential component of the package record that will be required at that time.

In the event that the waste package is deemed not to be compatible with the transport or GDF waste acceptance requirements, remediation (reworking) of the waste package might be necessary. This could involve over-packing within a larger waste container that can compensate for some known deficiencies or it might require reworking of the wasteform itself. In either case the consequences in respect of cost and dose uptake to workers could be significant and certainly undesirable. Hence the LoC process has an important role in avoiding such potential future activities.

4. WASTE PACKAGE SPECIFICATION

The Waste Package Specification contained in [Ref. #6] defines the key features and sets minimum standards of performance for the corner lifting $3m^3$ box, taking into account all of the requirements for long-term management. The corner lifting variant of the $3m^3$ box was chosen for this study because it has a bigger aperture than the side lifting variant, but both variants have virtually identical requirements.

The guidance, requirements and limits contained in the Waste Package Specification are appropriate for all stages of long-term management but are required to be applied to waste packages at the time of transport from the waste packager's site unless otherwise stated. Thus these criteria are meant to be applied when the SDP ILW package is ready to be transported from the buffer store at the dismantling site to the off-site long term interim store.

A list of criteria, which the $3m^3$ box waste package must (or in some cases, is advised to) comply with, is presented in [Ref. #5] and the same criteria, together with additional explanatory material relating to each criterion is provided in [Ref. #6]. This document is structured round [Ref. #6].

These criteria cover issues which are required to be addressed to obtain a LoC. Recognising that LoC process addresses technical issues relevant to the long term management of packaged waste, these criteria represent a good check list of technical issues relevant to the lifecycle of the $3m^3$ box waste package.

Where compliance with a particular issue is stated as "not being problematic", it is recognised that considerable effort may nevertheless be required to demonstrate the compliance.

4.1 Activity Content

The purpose of specifying activity content limits is to ensure that the $3m^3$ box waste package meets the RWMD Waste Package Specification, specifically the transportation regulation requirements.

4.1.3 RWMD Requirements

The $3m^3$ box waste package shall contain conditioned ILW or LLW and the activity content of the waste package shall be restricted, as necessary, to meet all other aspects of this specification (i.e. heat output, dose rate, criticality safety and normal operational and accident performance criteria). The activity content of the waste package shall not exceed $10^5 A_2$.

4.1.4 RWMD Explanation of Requirement

The intended use of the $3m^3$ box waste package is primarily for the conditioning, transport and long-term management of ILW. It is also suitable for use with LLW.

Transport of radioactive waste through the public domain places an absolute upper limit on the activity content of waste packages. The $3m^3$ box waste package will be transported within a Standard Waste Transport Container (SWTC), the combination of which would be classified, under the IAEA Transport Regulations as a Type B transport package. The maximum activity content of such a transport package is 10^5 A_2 and this limit is applied directly to the $3m^3$ box waste package. This limit applies to transport packages that are not designed to satisfy the requirement of an enhanced water immersion test, a standard to which the SWTC is not currently qualified. Work is currently underway which may result in qualification of the SWTC. If this happens, it may be possible to remove the $10^5 A_2$ limit.

The limit on the total activity content of an individual waste package is generic with respect to the future GDF site. However, when a specific disposal site is eventually identified, the authorised limits for certain radionuclides may be particularly sensitive to site-specific factors in the post-closure safety case. Work carried out to determine the specific impact of individual radionuclides on geological disposal has been undertaken. Guidance Quantities have been derived for each of the 112 relevant radionuclides, that could, potentially, impact on the safe long-term management of packaged waste. Waste producers intending to package significant quantities of these radionuclides before site-specific conditions for acceptance become available are advised to maintain close contact with the NDA/RWMD.

The quantity of activity that can be packaged in a $3m^3$ box waste package may also be limited by other criteria, such as external dose rate, heat output, criticality safety and the requirements of the impact and fire performance of the waste package.

4.1.5 Issues Relevant to Management of SDP Wastes

RWMD states that the $3m^3$ box waste package can also be used for LLW. There are two types of LLW relevant to this study. One is waste which may contain relatively high concentrations of short lived radionuclides (e.g. Co-60), and which could decay to LLW before the GDF is available. The other is waste which may contain relatively high concentrations of long lived radionuclides and which will not decay to LLW before the GDF is available. The inventory of these wastes needs to be established and a forward strategy, including identification of a suitable waste package, identified.

RWMD makes reference to a Standard Waste Transport Container (SWTC). It is assumed that this has evolved from work that was started in the mid 1980's on the design of a Reusable Shielded Transport Container (RSTC) and of the Sellafield Shielded Transport Container (also referred to as an SWTC). The convention is to attach the shielding thickness to the abbreviation. Thus an SWTC-285 is a Standard Waste Transport Container with 285 mm nominal shielding thickness. A variety of transport containers have been designed, including ones with 285 mm, 150 mm and 70 mm thick shielding. It is suspected that none of these has been manufactured, but this needs to be confirmed by RWMD. If this is the case, MoD could be at the forefront of the development of the SWTC. A strategy for design, manufacture, procurement and deployment of SWTCs needs to be determined, in discussion with RWMD.

The A_2 value is a measure of activity which is defined in the IAEA Transport Regulations [Ref. #3] and is used by RWMD to determine the activity limits for the requirements of these regulations. For example, the A_2 value for Co-60, (the most predominant radionuclide in submarine ILW) is 4E11 Bq. Multiplying this by 10^5, results in a Co-60 activity limit of 4E16 Bq. Current information indicates that the amount of Co-60 inside a $3m^3$ box waste package will not exceed [redacted], therefore this requirement is not anticipated, at this stage, to be a threat to the use of the $3m^3$ box waste package. As part of the LoC process, a justification will need to be produced to show that the activity content limits of all of the radionuclides are not being exceeded.

The above discussion highlights the need for good waste characterisation protocols and identification of any radionuclides which could potentially impact on the safe long term management of the waste. Details of the waste characterisation methodologies and results will be required as part of the LoC process. Lack of acceptable data on the active (and non active) content of the SDP waste would be a major threat to the success of the project.

It should also be demonstrated that the quantity of radioactivity activity inside a $3m^3$ box waste package does not affect other waste package performance criteria, such as external dose rate, heat output, criticality safety and the requirements of the impact and fire performance of the waste package. These issues are discussed in more details in later sections of this report.

4.2 Dose Rate

The purpose of specifying dose rate limits is to ensure that the $3m^3$ box waste package meets the requirements of the transportation regulations and the operational safety case at the GDF.

4.2.1 RWMD Requirements

The surface dose rate from the waste package shall not exceed a value commensurate with achieving 2 mSv/h at the surface, and 0.1 mSv/h at 1 metre from the surface, of a 280 mm steel shield (density 7700 kgm^{-3}) in direct contact with the waste package.

4.2.2 RWMD Explanation of Requirement

RWMD anticipate that $3m^3$ box waste packages will be transported through the public domain within a reusable shielded transport container as a Type B transport package.

The limits on external dose rate from transport packages in the public domain are set by the IAEA Transport Regulations [Ref. #3] but the actual limits depend on the operational procedures applied during transport. RWMD has taken a conservative approach and adopted the more stringent of the two transport regimes from the point of view of external dose rate, namely those pertaining to transport carried out under the conditions of non-exclusive use.

Exclusive use is defined by the IAEA Transport Regulations as "*the sole use, by a single consignor, of a conveyance or large freight container, in respect of which all initial, intermediate and final loading and unloading is carried out in accordance with* *the consignor or consignee*". If all of these conditions cannot be met, transport is deemed to take place under non-exclusive use.

The following conditions apply for packages transported under non-exclusive use:

- The dose rate at 1 metre from the surface of a transport package shall not exceed 0.1 mSv/h; and
- the dose rate on its external surface shall not exceed 2 mSv/h.

RWMD states that waste packages resulting in transport packages with higher radiation levels may be permitted but this would be dependent on the approval certificate for the transport container, the operational procedures applied during transport and the operational safety case for a GDF.

The ultimate upper limits for the dose rate from transport packages are those defined for exclusive use and these are shown below.

- the dose rate at 2 m from the surface of a transport package shall not exceed 0.1 mSv/h and;
- the dose rate on its external surface shall not exceed 10 mSv/h.

RWMD explains the rational for the 280 mm of steel shielding in direct contact with the waste package. The regulatory limits described above apply to the transport package of a 3m^3 box within a shielded transport container. The limit on the dose rate the waste package therefore depends on the shielding provided by the transport container, the maximum available shielding thickness being determined by the constraints on interior and exterior dimensions. The interior constraint is produced by the dimensions of the waste package, plus appropriate clearances. For a package designed to use all available transport modes, the exterior constraint is derived from the cross-sectional limits of the UK rail system loading gauge, minus an allowance for a rail wagon cover and appropriate clearances. These dimensional calculations indicate a maximum possible shielding thickness of 285 mm. To derive the package dose rate limit, a nominal shielding thickness of 280 mm of carbon steel is assumed. The reduction by 5 mm includes an allowance for manufacturing tolerances, and also reflects weight limitations and the need for thermal insulation panels on the transport container.

4.2.3 Issues Relevant to Management of SDP Wastes

From the above, it is clear that the non-exclusive use conditions are more onerous than their exclusive use equivalents. Therefore a transport package which is compliant with the dose rates of non exclusive use will automatically be compliant with the exclusive use dose rate requirements.

It is anticipated that all of the SDP packaged waste transports will be under exclusive use, therefore there may be a case for negotiating with RWMD for to allow packages with dose rates higher than non exclusive use to be transported. It is not clear if RWMD would discourage this approach because of GDF operational safety case requirements. MoD should consult RWMD well in advance if a requirement arises to transport packages with dose rates higher than those shown above for non exclusive use.

In order to understand whether a fully loaded $3m^3$ box transport package would be compliant with non exclusive use dose rate limits, MicroShield calculations were carried out to determine the dose rates both at the surface and also at a distance of 1 metre from a transport package containing a $3m^3$ box waste package.

It was demonstrated in the Phase 1 report [Ref. #1] that the gamma emissions from a waste package are dominated by the Co-60 activity content. Hence the MicroShield calculations consider only this one radionuclide in the estimation of dose rates.

Two sets of calculations were carried out. The first set postulates realistic transport package scenarios and calculates the resulting dose rates. This is the more important of the two sets. The scenarios and dose rate results are summarised in Table 4.1 and explained below. The MicroShield calculation sheets from this set of calculations are reproduced in Annex 1.

The second set of calculations postulates pessimistic (and sometimes unrealistic) scenarios in order to understand the boundaries of the shielding system. These scenarios and results are summarised in Table 4.2. The MicroShield calculation sheets for this set of calculations are reproduced in Annex 2.

Table 4.1: Results of MicroShield Calculations (1 to 4)

A	B	C	D	E	F	G
Calc.#	**Decay Time (Years)**	**Co-60 Activity (Bq)**	**Position of Source**	**Distance from SWTC**	**Limited (mSv/hour)**	**Results (mSv/hour)**
1	10	[redacted]	In middle of box	Contact	[redacted]	[redacted]
2	10	[redacted]	In middle of box	1 metre	[redacted]	[redacted]
3	None	[redacted]	In middle of box	Contact	[redacted]	[redacted]
4	None	[redacted]	In middle of box	1 metre 0.1	[redacted]	[redacted]

The rationale behind the variables contained in Columns B to E of both Tables 4.1 and 4.2 are explained below.

Column B: Two decay times were used. One period (labelled "10") assumes radionuclide decay and the other period (labelled "None") assumes no radionuclide decay.

The set labelled "10" assumes a 10 year decay period from shutting down the reactor to packaging and transporting the waste. The 10 years could be broken down into an initial 2 to 3 year period while the reactor is closed down and defuelled and an additional 7 to 8 year period while the submarine is berthed, dismantled and the waste packaged in readiness for off site transport. This is intended to provide a reasonably realistic scenario.

The second set labelled “None” does not take account of any radionuclide decay and is intended to provide an upper Co-60 activity limit. It could be argued that this is an unrealistic scenario, since there will always be a finite decay period. However, when considered in the context of current uncertainties in the submarine radionuclide waste inventories and recognising that this is a scoping study, this issue is not regarded as significant.

Column C: Two Co-60 activity values are used. One assumes a Co-60 activity of [redacted] and another assumes a higher Co-60 activity [redacted] In some calculations these are treated as point sources instead of sources whose geometries are determined by the shape of the wasteform.

Both Co-60 activity values are based on the assumption that the quantity of waste inside the 3m^3 box waste package is [redacted], as derived in the Phase 1 report [Ref. #1] and that [redacted] of ILW has a Co-60 activity of [redacted] after a decay period of 10 years. The ratio of the waste masses is [redacted]
Dividing the Co-60 activity of 1.16E14Bq by the ratio of the waste masses, (i.e. 2.2) produces a 10 year decay Co-60 activity of 5.27E13 Bq.

The Co-60 upper limit was determined by decay correcting this value. Co-60 has a half life of 5.32 years. To take account of the ca. 2 half life Co-60 10 year decay period, the revised inventory [redacted] was multiplied by 3.7 to produce an upper Co-60 activity limit of [redacted]

Column D: Three source positions are used. Two of them assume that the source is compressed into a 34 cm slab and that this slab is positioned in the middle of the box, (labelled “In middle of box”) or against the wall of the box (labelled “Against box wall”).

The middle of the box scenario has additional shielding from the 69 cm of grout around the annulus of the box. This is derived by subtracting the 34 cm (source slab) from the 172 cm (box width) and dividing the result by 2 to reflect the gap either side of the source at the centre of the box.

The “Against the box wall” scenario does not have any additional shielding by the grout annulus and is considered worse case. The use of furniture to position the waste inside the package or pre-grouting some of the intended annulus would make this very unlikely.

The other source position is that of a point source positioned against the SWTC (labelled “Against SWTC”). The source positioned against the SWTC is totally unrealistic, but was postulated to gain an understanding of the shielding offered by the SWTC.

Column E: Dose rates were measured at two distances from the SWTC. One (labelled “Contact”).was on contact with the outer surface of the SWTC and the other (labelled “1 metre”) was at a distance of 1 metre from the outer surface of the SWTC.

Column F: This column contains the regulatory dose rate limits and is presented to aid the interpretation of the MicroShield results shown in Column G.

Column G: Calculations 1 to 9 involve fixing the source term and calculating the resultant dose rates. Because the dose rate has been derived, the results in Column G for these calculations are labelled “derived”. Calculation #10 is a different type of calculation to the others. This assumes a dose rate and calculates the source strength commensurate with that dose rate. Because the dose rate has been assumed, Calculation #10 is labelled “assumed”.

Mainly for presentational reasons, the exposure rate in air is used rather than the absorbed dose rate in air. This results in an approximate. 10% to 15% overestimate of dose rates. This slight bias is not considered significant for the purposes of this scoping study.

The results from the four calculations shown in Table 8.1 are presented below.

Calculation #1 shows that the dose rate from 10 year old Co-60, placed at the centre of a $3m^3$ box waste package and measured at the surface of an SWTC is [redacted]. This is about 50,000 times less than permissible limits.

Calculation #2 shows that the dose rate from 10 year old Co-60, placed at the centre of a $3m^3$ box waste package and measured at 1 metre from an SWTC is [redacted] This is more than 3,000 times less than permissible limits.

Calculation #3 shows that the dose rate from non decay stored Co-60, placed at the centre of a $3m^3$ box waste package and measured at the surface of an SWTC is [redacted]. This is more than 13,000 times less than permissible limits.

Calculation #4 shows that the dose rate from non decay stored Co-60, placed at the centre of a $3m^3$ box waste package and measured at 1 metre from an SWTC is [redacted] [redacted]. This is more than 900 times less than permissible limits.

The results shown in Table 4.1 indicate that the ILW from a nuclear submarine can be packaged and transported in conformance with the UK transport regulations, without the need to decay store either the submarine or the waste. Expressing this in another way, if the reactor of a nuclear submarine is switched off and immediately afterwards, is defuelled, dismantled, the waste packaged into a $3m^3$ box and overpacked in a SWTC-285, the relevant RWMD dose rate limits would not be exceeded.

The results from the second set of calculations are summarised in Table 4.2 and explained below.

Table 4.2: Results of MicroShield Calculations (5 to 10)

A	B	C	D	E	F	G
Calc.#	**Decay Time (Years)**	**Co-60 Activity (Bq)**	**Position of Source**	**Distance from SWTC**	**Limited (mSv/hour)**	**Results (mSv/hour)**
5	None	[redacted]	Against box wall	Contact	[redacted]	[redacted]
6	None	[redacted]	Against box wall	1 metre	[redacted]	[redacted]
7	None	[redacted]	In middle of box (69cm of air instead of grout)	Contact	[redacted]	[redacted]
8	None	[redacted]	Against SWTC	Contact	[redacted]	[redacted]
9	None	[redacted]	Against SWTC	Contact	[redacted]	[redacted]
10	None	[redacted]	In middle of box	Contact	[redacted]	[redacted]

Calculation #5 shows that the dose rate from non decay stored Co-60, placed against the wall of the 3m^3 box waste package and measured at the surface of the SWTC is [redacted]. This is approximately one tenth of the permissible 2 mSv/h limit. This indicates that in the unlikely event that the waste mass is shifted from the middle to the wall of the 3m^3 box waste package, the dose rate at the surface of the SWTC is still within permissible limits.

This scenario is identical to that used in Calculation #3, apart from the positioning of the source. When the source is closer to the outside of the box, there is less shielding between the source and the measurement points and the dose rate should increase. Hence the higher dose rates from Calculation #5.

Calculation #6 shows that the dose rate from non decay stored Co-60, placed against the wall of the 3m^3 box waste package and measured at a distance of 1 metre from the SWTC [redacted]. This is approximately 1.7 times the permissible [redacted]. This indicates that in the unlikely event that the waste mass is shifted from the middle to the wall of the 3m^3 box waste package, the dose rate at 1 metre from the SWTC could be greater than permissible limits.

This scenario is identical to that used in Calculation #4, apart from the positioning of the source. When the source is closer to the outside of the box, there is less shielding between the source and the measurement points and the dose rate should increase. Hence the higher dose rates from Calculation #6.

Calculations #5 and #6 show that shifting the radioactive source to a position closer to the walls of the 3m^3 box waste package will not result in unacceptable dose rates measured at the surface of the SWTC, but may do so when measured at 1 metre from the SWTC.

Calculation #7 is a repeat of Calculation #5, but replacing the 69 cm of grout with 69 cm of air. This would be an extreme case which could arise if insufficient grout was added to a package and there was a direct shine path from the wasteform at the centre of the package to the inner walls of the box. The results show a contact dose rate of [redacted], which is a factor of approximately 10 less than permissible limits. This indicates that addition to the waste package of too little grout, although not desirable for a variety of other reasons, may not result in contact dose rates which exceed permissible limits. This assumes that the waste remains at the centre of the package.

Calculation #8 investigates the shielding effect of the SWTC. In the above calculations, the radiation doses from the waste are attenuated by a combination of 69 cm of grout, 0.6 cm 3m^3 box wall and 28 cm of SWTC steel. In order to confirm the role of the shielding effect of the SWTC steel, the impact of placing a point source (which contained the highest calculated Co-60 activity) against 28 cm of steel was explored. The point source was placed on one side of the SWTC and the dose rate measured on the other side. The results indicated that the measured dose rate was [redacted] which is more than 70 times the permissible limits. This indicates that the shielding effect of the SWTC is not sufficient on its own to stay within permissible dose rate limits.

Calculation #9 is a repeat of Calculation #8, this time using the decay corrected Co-60 point source. The results indicated that the measured contact dose rate was [redacted], which is about 20 times greater than the permissible limit of 2 mSv/h. This also indicates that the shielding effect of the SWTC is not sufficient on its own to stay within permissible dose rate limits.

Calculation #10 is a different type of calculation to those shown above. Its objective is to investigate what source strength is required to produce a surface dose rate equal to one of the RWMD limiting values. The assumptions were that the wasteform was positioned in the middle of the box and that the dose rate at the surface of the SWTC was 2 mSv/h. The results indicate that a source strength of [redacted] would result in a 2mSv/h dose rate at the surface of the SWTC which is the permissible limit. This indicates that a Co-60 source in excess of about [redacted] would not compromise the dose rate limits at contact with the outer surface of the SWTC.

This is an exceedingly high number. In order to provide context, it is noted that the total quantity of Co-60 in all of the UK radioactive waste, (including high, intermediate and low level wastes) was reported (in 2007) in [Ref. #9] as [redacted] which is less than the Co-60 activity level of 2E18 Bq derived above. On the assumption that the Co-60 activity content of submarine ILW will not exceed 2E18 Bq, there will be no decay storage requirement to meet the dose rate limits. However, the upper limit of [redacted] of Co-60 exceeds the Co-60 activity content limit of [redacted] (i.e. 10^5 A_2), as discussed in Section 4.1. Therefore, if the Co-60 activity content limit remained at [redacted] and the Co-60 content of the waste was above this level, the activity content, rather than the dose rate would become limiting. RWMD states in [Ref. #6] that if transport packages are designed to satisfy water immersion tests, this activity content limit may be removed.

The above discussion indicates that the 3m^3 box transport package is very robust with respect to compliance with Type B package dose rate limits and may be robust to minor operational perturbations (involving for example misalignment or redistribution of waste or addition of too little grout) from idealised conditions and geometry. Although the dose rate implications may be acceptable for some of the minor perturbations described above, any major perturbations could have serious consequences on the integrity of the waste package and must be avoided.

The very low dose rates from Calculations #1 to #4 may offer an opportunity to review the package shielding requirements and perhaps choose an existing design with a small shielding thickness or even redesign the SWTC. This should not be considered until improved waste inventory data become available. When satisfied that the inventory data is representative of the different types of submarine reactors (i.e. PWR1 and PWR 2), the opportunity should be taken to optimise the design of the packaging process, including waste loadings, use of furniture, quantity of grout and overpack shielding requirements.

It is cautioned that the above conclusions are based on scoping studies and that more detailed studies are required to substantiate these conclusions. A more detailed assessment will need to be performed as part of the LoC process to demonstrate how the 3m^3 box transport packages exported from the dismantling plant will comply with relevant dose rate and other limits.

It is concluded that compliance with the RWMD 3m^3 box transport package dose rate criteria should not be problematic. No major issues arising from this requirement are anticipated.

4.3 Heat Output

The purpose of specifying heat outputs limits is to ensure that internal heat generation will not alter the physical state of the package or its contents or adversely affect the containment or shielding offered by the transport container.

4.3.1 RWMD Requirement

The total heat output from the waste package shall not exceed 200 watts at the time of transport and 150 watts at the time of vault backfilling.

4.3.2 RWMD Explanation of Requirement

Waste packages generate heat as a result of the radioactive decay of their contents (radiogenic heat), as well as from other sources such as biodegradation, cement hydration, corrosion and other chemical reactions.

The post-backfill heat limit of 150 Watts placed on the 3 cubic metre box waste package is the most bounding for all stages of their long-term management and, whilst it would represent a robust limit, it is over conservative for the earlier stages. The 200 Watt limit is therefore applied to transport and the 150 Watt limit applied only to individual waste packages at the time of backfilling (i.e. 2090). Credit can therefore be claimed for the decay of waste package radiogenic heat output in the intervening period.

RWMD states that heat generation by non-radiogenic mechanisms can also be significant and could amount to an additional 3 Watts per cubic metre (i.e. about 9 Watts per $3m^3$ box) at times depending on the physical and chemical composition of the waste and conditioning materials.

In extreme cases this additional heat could affect thermal performance, particularly following backfilling. Non-radiogenic sources of heat should therefore be included in heat calculations if they are likely to exceed 0.1 Watts per cubic metre (i.e. about 0.3 Watts per 3 cubic metre box).

RWMD provides details of studies to investigate the effects of heat generated by waste packages during the operational period, that which have shown that an average heat output of 6 Watts per cubic metre (i.e. about 20 Watts per 3 cubic metre box) will not challenge the RWMD temperature targets. This work has also shown that the presence of limited numbers of waste packages with heat outputs at the maximum level specified for transport (i.e. 200 Watts), will not result in excessive temperatures.

4.3.3 Issues Relevant to Management of SDP Wastes

RWMD does not specifically address the exothermic reaction from grouting, presumably because the most of the heat is produced and dissipated within a couple of days.

An estimate is made below of the radiogenic heat output from the submarine ILW.

When Co-60 decays, it emits gamma radiation at various energies / wavelengths. The principal gamma emissions are those at 1.17 Mega Electron Volts (MeV) and those at 1.33 MeV. For every 100 atoms of Co-60 which decay, about 99.9 of these emit radiation at these levels. Hence the total energy released per decay of a Co-60 atom is the sum of these two values, i.e. 2.5 MeV.

The maximum Co-60 activity considered in this document is 1.95E14. The rate of release of radiogenic heat is therefore [redacted] [redacted] [redacted].

For the purposes of this discussion, this value is rounded up to 80 Watts. (A similar result is obtained by multiply the radiogenic heat output of Co-60 (0.4 Watts per TBq, (see [Ref. #8, Table 4) by the activity in TBq ([redacted])).

To help understand the effect of this heat source, it is considered helpful to imagine an 80 Watt light bulb located inside a loaded 3m^3 box. It is estimated that such a bulb could cause a temperature rise by a couple of degrees centigrade at most. The effect of the radiogenic heat output is therefore considered marginal.

Because radiogenic heat is directly proportional to activity, the radiogenic heat output from Co-60 decay will decrease with time. For example, within one Co-60 half life (5.27years) both the activity level and the heat output will be reduced by a factor of 2.

The above calculations need to be checked when improved radionuclide inventory data become available. A more detailed assessment will need to be performed as part of the LoC process to demonstrate that the radiogenic and non radiogenic heat outputs from the 3m^3 box waste packages exported from the dismantling plant will comply with relevant limits.

It is concluded that compliance with the RWMD heat output limits for a loaded 3m^3 box waste package should not be problematic and no major issues arising from this requirement are anticipated.

4.4 Surface Contamination

The purpose of specifying limits on non-fixed surface contamination is to ensure that the contamination of transport systems and the waste package handling areas in a GDF are maintained below acceptable levels. This is for the protection of the public and the workers.

4.4.1 RWMD Requirement

The non-fixed surface contamination of the waste package should be kept as low as reasonably achievable and, when averaged over an area of 300 cm^2 of any part of the surface of the waste package, shall not exceed: 4.0 Bq/cm^2 for beta, gamma and low toxicity5 alpha emitters and 0.4Bq/cm^2 for all other alpha emitters.

4.4.2 RWMD Explanation of Requirement

The above limits are intended to control surface contamination to realistic and achievable levels. They will reduce any potential requirement for the decontamination of waste package handling areas, as well as the requirement to decontaminate the internal surfaces of reusable transport containers during turn-round maintenance.

RWMD stress that work by the National Radiological Protection Board has shown that external doses, inhalation doses and ingestion doses are very low for package surface contamination at the limits quoted above.

Notwithstanding the above, the proposed radiological classification for a GDF would permit limited numbers of packages with surface contamination levels of a factor of 10 higher to be handled.

4.4.3 Issues Relevant to Management of SDP Wastes

The numerical values of the non fixed surface contamination limits shown above (i.e. 4.0 Bq/cm^2 for beta, gamma and low toxicity alpha emitters and 0.4 Bq/cm^2 for all other alpha emitters) are the same as those contained in the IAEA Transport Regulations.

RWMD does not provide guidance on fixed contamination issues. RWMD should be consulted if this becomes an issue.

A more detailed assessment will need to be performed as part of the LoC process to demonstrate that non fixed surface contamination levels on the surface of both the 3m^3 box waste package and the SWTC will not be allowed to exceed limiting values. This is an operational issue.

The international civil nuclear power industry routinely works to these limits, therefore no major issues are anticipated when complying with the above non fixed surface contamination limits on packaged submarine ILW.

It is concluded that compliance with the requirements of the RWMD limits on the non fixed surface contamination a 3m^3 box waste package and transport package should not be problematic and no major issues arising from this requirement are anticipated.

4.5 Dimensions

The principal purpose of specifying upper limits for the dimensions of the 3m^3 box is to ensure that no oversized boxes/packages are produced which would be incompatible with the arrangements for transport, handling and disposal at the GDF.

4.5.1 RWMD Requirement

The height of the waste package shall not exceed 1245 mm and the plan should not exceed 1720 mm^2

4.5.2 RWMD Explanation of Requirement

RWMD advise that it is essential that all 3 cubic metre box waste packages fit within a maximum dimensional envelope that is compatible with the systems specified for transport and the various handling systems in a GDF. Waste containers with standardised dimensions allow for the optimum utilisation of waste packaging facilities, interim surface stores and transport facilities as well as simplifying handling operations at all stages of their long-term management and making most efficient use of GDF vault volume.

The shape, dimensions and lifting/stacking arrangements of the two variants of the 3 cubic metre box have been chosen to maintain compatibility with the two principle designs of stillage that may be used to handle and stack 2 by 2 arrays of 500 litre drum waste packages during storage and, potentially, transport. The key dimensions (i.e. the plan and height) of the two variants are standardised and the only significant difference being the layout of the lifting features.

The upper limit of 1720 mm^2 on the plan dimension is set by the loading gauge of the UK rail system and the requirement to transport waste packages in transport containers with sufficient shielding to satisfy the relevant regulations on external dose rates.

The overall maximum dimensions given for the 3 cubic metre box waste package includes any vents, filters or other protrusions from the package. The base of the 3 cubic metre box waste package should be flat or, alternatively could have four feet built up by the addition of small steel plates. For either option, consideration should be given to package stability, interface corrosion, potential for wear during transport, and stresses in the package.

4.5.3 Issues Relevant to Management of SDP Wastes

Particular attention would need to be paid to this requirement if MoD specifies a non standard variant of the $3m^3$ box, which resulted in a change in the key dimensions.

Since it is not MoD’s intention to deviate from the standard RWMD waste packages, no major issues are from deviations in the dimensions of $3m^3$ box waste package are anticipated.

The LoC process does not require formal justification of package dimensions, if a standard package is used.

It is concluded that compliance with the requirements of the RWMD limits on the height and plan of a $3m^3$ box waste package should not be problematic.

4.6 Lifting Feature

The purpose of specifying uniform lifting features for all variants of the $3m^3$ box is to ensure that the boxes can be handled in the same way using the same lifting frame, in a safe manner, during all of the operational, transport and emplacement operations.

4.6.1 RWMD Requirement

The waste package shall incorporate four equally spaced lifting points in the form of twistlock apertures of dimensions and geometry as defined by RWMD. The waste package shall be capable of being lifted using any three of these twistlock apertures, without exhibiting any permanent deformation under a force equivalent to twice the gross mass limit for such packages.

4.6.2 RWMD Explanation of Requirement

During their lifetime, $3m^3$ box waste packages will be handled many times at various locations and during a variety of operations. Locations include the fabrication plant, the manufacturing plant and the buffer/long term interim stores and operations include loading and unloading of transport containers and emplacement at the GDF.

The boxes will require specific features to permit safe and efficient vertical lifting. The overall shape of the lifting feature at the top end of the package has been precisely specified to ensure that all potential variants of the $3m^3$ box can be handled in the same way using the same lifting frame. Each waste producer must obviously consider its individual requirements for its own site but must comply with the RWMD specification as a minimum.

4.6.3 Issues Relevant to the Management of SDP Wastes

Particular attention would need to be paid to this requirement if, for example, MoD specified a non standard variant of the $3m^3$ box, which resulted in a change in its lifting features.

It is not MoD's intention to deviate from the standard RWMD waste packages, therefore no major issues are anticipated from deviations in the lifting features of a $3m^3$ box waste package.

The LoC process does not require addition justification of performance of the package lifting features, if a standard package is used.

It is concluded that compliance with the requirements of the RWMD limits on the $3m^3$ box waste package lifting features should not be problematic.

4.7 Mass

The purpose of this requirement is to ensure that the $3m^3$ box waste package can be safely transported and emplaced in the GDF, in compliance with applicable weight/mass limits, as explained below.

4.7.1 RWMD Requirement

The gross mass of the $3m^3$ box waste package shall not exceed 12,000kg.

4.7.2 RWMD Explanation of Requirement

The maximum allowable mass of waste packages is set by a combination of constraints imposed by the transport system and a GDF handling systems. Waste packages can be transported by road or rail. It is noted that the possibility of transport by sea also exists, although no specific constraints would arise from that mode of transport.

The RWMD explanation for the 12 tonne mass limit is related to the requirements of the railway system. Most of the UK rail system limits axle loading to 22.5 tonne per axle, which leads to a maximum loaded rail wagon mass of 90 tonne for a four-axle wagon. As currently designed, the rail wagon anticipated for use in transporting waste packages has an unladen mass of 26t which limits the maximum transport package mass to 64 tonne. The heaviest transport container currently under consideration for such transport, the SWTC with a nominal 285 mm of shielding (SWTC- 285), has an unladen mass of 52 tonne which sets a limit of 12 tonne on the total mass of waste packages carried within it.

4.7.3 Issues Relevant to the Management of SDP Wastes

It is interesting that there is no mention in the RWMD documentation of the mass limits derived for transportation of the 3m^3 box waste packages by road. For normal road transportations, an upper weight limit restriction of 44 tonnes (which includes the vehicle weight and the load weight) is applicable, and this has no pre-notification requirements. This allows a load weight of approximately 30 tonnes assuming a typical vehicle weight of 14 tonnes. Above 44 tonnes, varying restrictions apply regarding the weight and size of the transport container which will require pre-notification. A number of issues need to be addressed, before MoD could transport by road, weights greater than the 64 tonnes limit set by rail transport. If the weight of the box increases, this will require additional drop testing. This will also require pre-notification, which considers the route to be taken, axle loadings, bridge and road loadings etc and this requires prior approval. It is also a requirement to show that the load is “Indivisible”, such that it cannot be broken down into smaller pieces to meet the normal road restrictions. This issue is currently under review by the NDA. However, since a 3m^3 box waste package containing conditioned waste cannot be further sub-divided, this latter requirement will not apply.

If the intention is to transport the waste packages only by road, and if there is some advantage to be gained, RWMD should be consulted on whether there is scope for increasing the mass limit beyond the existing 12 tonne limit.

The 12 tonne mass limit was used in the Phase 1 report as an input to the derivation of the payload and disposal efficiency of the 3m^3 box waste package. At the assumed maximum packing fraction of 0.6, the mass of the box, furniture, waste, grout etc. did not exceed the 12 tonne limit. This indicates that the box mass limit may not be exceeded by adding the maximum possible amount of metallic waste the can be physically put into the box. The 12 tonne limit should not be a difficult issue to comply with.

Instrumentation must be put in place to weigh the unladen and laden boxes and these will allow compliance with the applicable limits to be demonstrated.

It is considered good practice to aim for slightly less than the maximum mass limit. The operators of the WAGR plant have set a working mass limit (48 tonnes) at slightly less than the stipulated limit (50 tonnes).

It is not clear what specific documentation on package mass is required under the LoC process. However, it is an important parameter which can influence other package properties and it would therefore be prudent to discuss these requirements with RWMD.

It is concluded that compliance with the RWMD mass limits of 12 tonnes on the 3m^3 box waste package should not be problematic and no major issues arising from this requirement are anticipated.

4.8 Gas Generation

The purpose of establishing a limit for total gas generation is because this could lead to internal pressurisation of the waste package and consequent internal and/or external damage upon release of radioactive, toxic and/or flammable gases from packages.

4.8.1 RWMD Requirement

The total gas generation rate for the waste package should not exceed 72 litres per day. Specific limits are placed on the rates of generation of certain flammable, toxic and radioactive gases.

4.8.2 RWMD Explanation of Requirement

RWMD addresses flammable, toxic and radioactive gases and the limits for total gas generation.

The principal mechanisms which can generate gases are itemised below.

- Chemical processes such as corrosion;
- microbial degradation of organic materials;
- radiolysis of water and organic materials;
- radioactive decay producing gaseous products (e.g. Radon); and
- release of entrained radioactive gases (e.g. H-3, Argon, Krypton, Xenon).

Gases give rise to a range of potential effects that may have an influence on all stages of the long-term management of waste packages. These include:

- pressurisation and damage of the wasteform, leading to increased release of radionuclides under normal and accident conditions;
- pressurisation of un-vented waste packages, leading to distortion and/or damage to the waste container;
- pressurisation of the transport container;
- releases of radioactive/toxic/flammable gases from packages;
- alteration of the chemical characteristics of the backfill;
- pressurisation and damage to the surrounding geology;
- generation of additional groundwater flow pathways and modification of flow patterns; and
- modification to the rate of re-saturation of backfilled vaults.

RWMD states that there is a regulatory requirement to prevent the internal pressure of a transport container from exceeding a Maximum Normal Operating Pressure (MNOP) of 700 kilo Pascals.

RWMD explains the derivation of the total gas generation limit of 72 litres per day for the 3m^3 box waste package. The basis for the calculation is that the transport container remains sealed for 28 days, which is the maximum anticipated time between sealing the container in preparation for a journey and opening the container after completion of the journey. During this period, gas pressure could rise to the MNOP limits and this allows the total volume of gas to be calculated. Dividing this by 28 gives the quantity of gas per day.

4.8.3 Issues Relevant to the Management of SDP Wastes

The relevance of the above mechanisms to the submarine ILW has still to be determined.

The RWMD guidance specifies an upper gas generation limit based on a scenario involving gas build up during transport. It is assumed that these gas generation limits also apply during storage. It is worth noting that the $3m^3$ box waste package is vented, therefore gas build up should not be an issue either during transport or storage.

The SDP wasteform will contain predominantly activated metal, therefore mechanisms like generation of corrosion and entrained gases (including tritium) and radiolysis of water may be relevant. Other gas generation mechanisms may be relevant if other wastes (e.g. resins, CRUD) are disposed of in $3m^3$ box waste packages. Significant gas generation may occur when corrosion of the metallic wasteform sets in.

A more detailed assessment will probably need to be performed as part of the LoC process to establish which gas production mechanisms are relevant and to quantify their production rates to determine if the rate of gas production is a problematic issue.

It is concluded that further work is required to determine if compliance with the RWMD limits on the rate of gas generation from the $3m^3$ box waste package is problematic.

4.9 Venting

The purpose behind the requirement for venting is because pressurisation can lead to swelling, damage to the structure of the wasteform and eventual failure of the waste container. This could compromise the integrity of the barriers provided by the waste package against the release of activity.

4.9.1 RWMD Requirement

Waste packages that, by virtue of the nature of their container and/or contents, could be susceptible to pressurisation due to gas generation at any time during their long-term management, shall incorporate an engineered vent designed to retain significant particulate activity.

4.9.2 RWMD Explanation of Requirement

This requirement should be addressed in conjunction with that for “Gas Generation”, discussed in Section 4.8 above.

Pressurisation can lead to swelling, damage to the structure of the wasteform and eventual failure of the waste container. The requirement to reduce the possibility of waste package pressurisation is important at all stages of their long-term management along with the requirement to minimise the release of particulate activity. This leads to the requirement for the vent to be filtered, which could for example be achieved by the use of a proprietary high efficiency particulate in air (HEPA) or sintered filter as part of the vent, or by using a lidding arrangement that incorporates a device such as a labyrinth seal.

The requirement for venting does, however, potentially conflict with a requirement to minimise ingress of water into waste packages in the post-closure period of a GDF. This requirement should be taken into account in vent and filter design and the effective area of the vent minimised.

4.9.3 Issues Relevant to the Management of SDP Wastes

Particular attention would need to be paid to this requirement if, for example, MoD specified a non standard variant of the 3m^3 box, which resulted in a change in its venting arrangements. It is not MoD's intention to deviate from the standard RWMD waste packages, therefore no major issues are anticipated from deviations in the venting arrangements of a 3m^3 box waste package.

There is a requirement, as part of the LoC process to provide information which addresses prevention of package internal pressurisation through an engineered venting arrangement. The design of the 3m^3 box waste package already includes a filtered vent. Since it is not MoD's intention to deviate from the standard RWMD waste packages, no major issues are anticipated in meeting the venting requirements.

It is concluded that compliance with the RWMD requirements for venting the 3m^3 box waste package should not be problematic.

4.10 Integrity

The purpose behind the requirement for waste packages to maintain their integrity over long timescales is to ensure that waste packages enter the post-closure period in good condition.

4.10.1 RWMD Requirement

The integrity of the waste package shall be such that it is capable of retaining its contents and of being moved and handled safely and efficiently, as required, during all stages of long-term management.

The waste packages should be designed so that:

- *following a period of interim surface storage, currently assumed to be up to 150 years, the waste package shall meet the requirements for handling and for transport to a GDF;*

- *following emplacement in a GDF, the waste package should be capable of maintaining its integrity for the operational period, currently assumed to be 50 years;*
- *upon cessation of a GDF operational period, the waste package should retain integrity during a period of care and maintenance, during which time the waste package must be capable of being retrieved and safely handled. This period could extend to a few hundred years;*
- *following the period of care and maintenance, a GDF may be backfilled. The waste package should continue to retain its integrity for a period consistent with the containment of short-lived soluble radionuclides.*

A period of 500 years should be considered a target for the integrity of the waste container.

4.10.2 RWMD Explanation of Requirement

Integrity is defined as the ability of a waste package to maintain the containment of its contents, and to maintain the surety of its physical handling features (i.e. lifting locations).

The timescale for this requirement is set by the need for waste packages to enter the post-closure period in good condition, and it therefore needs to encompass the periods of interim surface storage, transport, GDF operations and vault backfilling.

RWMD provides guidance on ways in which the integrity of the waste container can be maintained over the required timescale. The latter include appropriate design, selection of suitable materials, appropriate manufacturing processes and provision of appropriate storage environments.

RWMD recognise corrosion as the major potential threat to long term waste container integrity. A high pH environment is beneficial in reducing corrosion. A waste conditioning matrix that does not produce high pH conditions could accelerate corrosion.

According to RWMD, the commonly adopted solution to the selection of suitable materials is to use austenitic stainless steel to grade 316L (EN 1.4404 [20]) or its equivalent. The corrosion performance and mechanical properties of this material are generally regarded as optimum for the packaging of radioactive waste, and this performance has been demonstrated by experience and research. Duplex stainless steel (notably grade EN 1.4462) has been identified as an alternative material that has the necessary corrosion performance to make it suitable for the manufacture of waste containers. RWMD caution, that whichever material is selected, the quality control of the material, the container manufacturing process and the control of surface finish of the container will also play a fundamental role in maintaining the integrity of the waste container.

RWMD provides guidance on mechanisms for corrosion of stainless steel, including general corrosion, stress corrosion cracking and pitting/crevice corrosion. For example, pitting/crevice corrosion is regarded as a greater threat to stainless steel than general corrosion and stress corrosion cracking is accelerated by the presence of chloride deposits.

RWMD has evaluated the corrosion rates of the $3m^3$ box and has concluded that the stainless steel is sufficiently thick (5 to 10 mm) so as not to threaten an integrity target of 500 years. Such a conclusion assumes that container material selection, construction techniques and storage conditions after manufacture are in line with best practice. To assist waste packagers in these areas, guidance has been produced on the general corrosion properties of stainless steel, the requirements for surface finish and on welding techniques used during the manufacture of stainless steel containers. RWMD provided appropriate references to this guidance material.

4.10.3 Issues Relevant to the Management of SDP Wastes

There is a requirement, as part of the LoC process to provide relevant information to demonstrate how a waste package will comply with long term integrity requirements.

When making decisions on long term interim storage of the submarine ILW, due note should be taken of the RWMD statement that a high pH environment is beneficial in reducing corrosion and that a waste conditioning matrix that does not produce high pH conditions could accelerate corrosion.

It is MoD’s intention to ensure that the relevant RWMD guidelines are followed throughout the whole of the LoC process, therefore there should not be any problems complying with this requirement.

It is concluded that compliance with the RWMD 500 year integrity targets for the $3m^3$ box waste package should not be problematic, provided RWMD guidelines are followed. No major issues arising from this requirement are anticipated.

4.11 Properties of the Wasteform

Recognising the mutual interdependencies involved, the Waste Package Specification [Ref. #6] also addresses the properties of the wasteform, including the requirements for immobilisation, minimisation of particulates, exclusion of free liquids and others. RWMD provides a more detailed Wasteform Specification for $3m^3$ box waste packages in [Ref. #8] and this is discussed in Section 5 of this report.

4.12 Criticality Safety

The purpose in specifying control over fissile materials is to ensure that a neutron chain reaction cannot occur at any stage in the waste management cycle, but specifically in the GDF during long term disposal. Waste packages must not represent an unacceptable criticality safety hazard, either individually or in arrays, during any stage of their long-term management.

4.12.1 RWMD Requirement

The presence of fissile materials, neutron moderators and reflectors in the waste package shall be controlled to ensure that they do not present a criticality safety *hazard during any of the active stages of their long-term management. It shall also be ensured that, following closure of a GDF, the possibility of local accumulation of fissile material such as to produce a neutron chain reaction is not a significant concern to the long-term performance of a GDF.*

4.12.2 RWMD Explanation of Requirement

Fissile materials are defined as U-233, U-235, Pu-239 and Pu-241.

Waste packages must not represent an unacceptable criticality safety hazard, either individually or in arrays, during any stage of their long-term management.

A criticality incident involving waste packages during transport or during the operational period of a GDF would result in substantially increased heat output, changes to the radionuclide inventory and elevated dose rates. Such an event would therefore present an immediate hazard to the public or workers. During the post-closure period of a GDF, the increased generation of heat could compromise the effectiveness of the barriers to radionuclide release from individual packages and from a GDF.

The RWMD approach to criticality safety is based upon the production of ‘benign packages’ containing insufficient fissile material for criticality to occur, even in worst-case conditions. This is achieved by controlling the package design, including the quantities of both fissile and moderating materials, to help eliminate the potential for criticality either in individual packages or in assemblies of packages, during routine transport and operations at a GDF. In accident conditions, the physical robustness of waste packages is such that none of the credible accidents considered would result in criticality.

RWMD has established a system of maximum allowable levels of fissile material in waste packages with respect to criticality. This has led to the derivation of a generic package screening level of 50g Pu-239 or equivalent, a value supported by conservative assumptions and calculations. This value is defined as a level below which individual and groups of standard packages, containing undefined waste, will be sub-critical under all circumstances.

4.12.3 Issues Relevant to the Management of SDP Wastes

The RWMD guidance refers to fissile materials, neutron moderators and reflectors.

RWMD state that fissile materials include U-233, U-235, Pu-239 and Pu-241. Because significant levels of fissile material are not anticipated in the submarine ILW, the initial conclusion is that this waste does not present a criticality hazard. No major issues are anticipated when complying with the fissile material limits inside a $3m^3$ box waste package.

RWMD does not provide further details on neutron moderators or reflectors. Neutron moderators include: hydrogen, deuterium, carbon, beryllium and Lithium-7, while neutron reflectors include graphite, beryllium, lead, steel and tungsten carbide. Some of these (e.g. steel and light water) will be present and others (e.g. deuterium and beryllium) will probably not be present in the SDP ILW.

There is a requirement, as part of the LoC process to provide relevant information to demonstrate how a waste package will comply with the RWMD criticality requirements. This will involve assessing the concentrations inside the 3m^3 box waste package of the materials listed above (and possibly others) and determination of their impact on the criticality requirements.

It is concluded that compliance with the RWMD fissile material limits for the 3m^3 box waste package should not be problematic, but further work is required to substantiate this.

4.13 Impact Performance

The purpose in formulating this requirement is to ensure that waste packages are capable of withstanding a number of specified impact conditions without excessive loss of contents, such that they will comply with regulatory requirements and with the assumptions which underpin the safety assessments for transport and the operational period of a GDF.

4.13.1 RWMD Requirement

The waste package should be designed such that, in the event of an impact accident:

- *releases of radionuclides and other hazardous materials are low and predictable, exhibit progressive release behaviour with increasing impact severity and do not exhibit significant cliff-edge performance characteristics within the anticipated range of impact conditions;*
- *both barriers to radionuclide release from the waste package (i.e. the waste container and the wasteform) should play an effective role in minimising those releases.*

The waste package shall be capable of being dropped, in any attitude, from a height of 0.3 metres onto a flat unyielding surface, whilst retaining its radioactive contents, and afterwards shall remain suitable for safe handling during all subsequent stages of their long-term management.

The release of radioactive contents from the waste package, as a result of credible impact accidents during transport and operational period of a GDF, shall not result in the relevant regulatory dose limits to workers and to members of the public being exceeded.

4.13.2 RWMD Explanation of Requirement

RWMD has defined three types of impact accident to which waste packages could be exposed, and these include minor impacts resulting from normal handling, impacts resulting from transport accidents and impacts resulting from accidents in a GDF. [Ref. #6] provides guidance on the issues associated with these impacts.

RWMD anticipate that waste packages may be subject to knocks, collisions and rough handling in the course of normal handling operations at any stage of their long-term management. It is expected that all waste packages should be sufficiently robust to withstand such impacts and, following external examination, should be capable of onward management without repair or rework. RWMD has adopted a drop height of 0.3 metres as being suitably representative of the types of impacts which could arise from normal handling. They acknowledge that the selection of the 0.3 metre height is somewhat arbitrary but partially justify it on the basis that impacts of a greater severity than that resulting from a drop from about 0.3 metres would not be considered 'normal'. The basis for the 0.3 metre drop test height is also partly justified with reference to the fact that Paragraph 722 of the IAEA Transport Regulations states that a free drop from 0.3 metres is required to simulate normal conditions for transport of packages with gross masses greater than 15 tonnes.

RWMD anticipate that $3m^3$ box waste packages will be transported through the public domain within a reusable shielded transport container as a Type B transport package. Under the IAEA Transport Regulations, such a transport package is required to be capable of withstanding a range of mechanical and thermal challenges. The mechanical challenges to the transport package comprise a free drop, in its most damaging orientation, from a height of 9 metres on to a flat horizontal surface, a free drop from 1 metre on to an aggressive target and a dynamic crush test. These challenges are intended for complete transport packages (i.e. with the waste package protected by the transport container). Whilst the transport container itself will be subjected to a programme of modelling and testing to demonstrate that it is sufficiently robust to withstand the regulatory requirements, an additional challenge is specified by RWMD for the unprotected waste package. This is a free drop from a height of 10 metre drop on to a flat unyielding surface as a conservative equivalent for the regulatory mechanical challenge for transport packages. As a result of such an impact, the release of activity from the unprotected waste package should not exceed that which would result in the regulatory limit of A_2 in the week following an accident being exceeded by the transport package.

Following receipt at the disposal facility, waste packages will be subject to a series of lifting and handling operations, leading to their emplacement in the vaults. During this period the possibility exists for accidents which could result in waste packages being subject to a range of mechanical impacts. These include the dropping of waste packages during handling; the dropping of equipment (including other waste packages, transport container lids etc) on to waste packages; and more extreme facility mechanical failures, such as vault roof collapses. Such accidents could result in damage to waste packages, the release of their radioactive contents and radiation dose to both workers on-site and members of the public off-site.

The impact performance of waste packages is strongly dependent on package design, and careful attention should be paid to this from an early stage in the development of a packaging proposal. In particular, the benefits provided by the waste container and the wasteform under impact conditions should both be considered, to ensure that these two components are seen as independent and complementary barriers against the release of contents.

RWMD states some basic principles that should be considered in waste, including that special consideration should be given to heterogeneous wasteforms, e.g. encapsulated hard wastes, because of the potential for waste items to penetrate the box wall under impact conditions. If the waste has sharp edges, the potential for piercing of the box skin in an impact accident should be guarded against when loading the waste into the box.

4.13.3 Issues Relevant to the Management of SDP Wastes

Since the testing regime specified by the IAEA Transport Regulations requires that the activity release rate of A_2 per week shall not be exceeded following the mechanical and thermal tests in succession, RWMD has allocated half of the allowable releases from the bare package to the mechanical challenge, and half to the thermal challenge. This results in an allowable impact release of $7.0A_2$ from the contents of the transport container and a rounded allowable waste package release of $3A_2$. This requirement should therefore be addressed in conjunction with those contained in “Fire Performance” (Section 4.14) and “IAEA Testing Requirements” (Annex 3).

Careful reading of these requirements is recommended to ensure that it is fully appreciated that any testing carried out under the transport regulations will be on the transport package (i.e. the loaded $3m^3$ box waste package inside its overpack), whereas testing performed under normal handling and GDF scenarios is on the waste package (i.e. the loaded $3m^3$ box waste package without its overpack).

Under normal handling, RWMD specifies a requirement for a 0.3 metre waste package drop test and gives the impression that this is the only waste package drop test which needs to be carried out. A 10 metre drop test is discussed in the text but it is not a specific requirement and it is not clear if this is mandatory. This needs clarification.

Under transport, RWMD refers to other transport package drop test requirements (e.g. those from 1 and 9 metres). Annex 3 contains a summary of the transport package tests required under the IAEA transport regulations.

There is a requirement, as part of the LoC process to provide relevant information to demonstrate how a waste package will comply with the RWMD radionuclide release limits under impact and fire accidents. This should be based, in part, on the results from the various drop and fire tests. If these results are already available, there may be no need to repeat the tests, but this is not assured. If, on the other hand, MoD make changes to the design and/or fabrication of the $3m^3$ box, some additional testing will be required. It is essential that the requirements for impact and fire testing of a $3m^3$ box waste package are discussed with RWMD and agreement reached on a testing programme.

Since it is currently not MoD’s intention to deviate from standard RWMD waste packages, no major issues are anticipated when complying with impact performance issues relating to the $3m^3$ box waste package. However, the specific waste package and transport package testing requirements will need to be identified in discussion with RWMD and, if required, a testing programme drawn up and implemented.

4.14 Fire Performance

The purpose in formulating this requirement is to ensure that waste packages are capable of withstanding a fire accident without excessive loss of contents, such that the relevant regulatory radiation dose limits to workers or to members of the public are not exceeded.

4.14.1 RWMD Requirement

The waste package should be designed such that in the event of a fire accident:

- *releases of radionuclides and other hazardous materials are low and predictable, exhibit progressive release behaviour with increasing fire severity and do not exhibit significant cliff-edge performance characteristics within the anticipated range of impact conditions;*
- *both of the barriers to radionuclide release from the waste package (i.e. the waste container and the wasteform) should play an effective role in minimising those releases.*

The release of radioactive contents from the waste package, as a result of credible fire accidents during transport and a GDF operational period, shall not result in the relevant regulatory radiation dose limits to workers or to members of the public being exceeded.

4.14.2 RWMD Explanation of Requirement

The effects of fire accidents can potentially affect waste packages at all stages of their long-term management, up to vault backfilling, in a similar manner to impact accidents as discussed in the previous section. Accordingly, waste packages must be capable of withstanding specified fire conditions without excessive loss of contents. For the purposes of this document, the stages at which the effects of a fire accident are considered are limited to transport and subsequent handling and emplacement in a GDF (although the latter will have many similarities to operations during storage by the waste packager prior to transport).

RWMD addresses fire accident conditions, fire resulting from transport accidents and those in a GDF and the influence of package design on thermal performance.

In developing the criteria for the required fire performance of waste packages it is necessary to define appropriate fire accident conditions (i.e. temperature and duration). The thermal test specified for Type B transport packages by the IAEA Transport Regulations requires such packages to be exposed for 30 minutes to a hydrocarbon fuel/air fire with an average temperature of 800°C, fully engulfing the package. This would result in waste packages being exposed to a thermal transient of significantly less severity. The potential for more challenging thermal transients, when unprotected waste packages could be directly exposed to fires during the operational period of a GDF and RWMD does not provide specific guidance on the types of fire tests to be carried out. Reference is made to fire testing regime contained in the IAEA Transport Regulations. For example the thermal test specified for Type B transport packages by the IAEA Transport Regulations requires such packages to be exposed for 30 minutes to a hydrocarbon fuel/air fire with an average temperature of 800°C, fully engulfing the package. RWMD provides arguments to justify increasing the temperature to 1000°C and the duration to 1 hour.

The approach to specifying allowable activity releases from waste packages following a transport fire accident is similar to that adopted in for transport impact accidents.

No particle size is specified in the criteria for fire releases as it is assumed that these releases occur in the form of vapours which are readily transmitted through a leaking transport container seal by thermally-driven air flows, and are then inhaled without restriction by exposed persons.

4.14.3 Issues Relevant to the Management of SDP Wastes

This requirement should be addressed in conjunction with those contained in “Impact Performance” (Section 4.13) and “IAEA Testing Requirements” (Annex 3).

As with the previous section, careful reading of these requirements is recommended to ensure that it is fully appreciated that any testing carried out under the transport regulations will be on the transport package (i.e. the loaded 3m^3 box waste package inside its overpack), whereas testing performed under normal handling and GDF scenarios is on the waste package (i.e. the loaded 3m^3 box waste package without its overpack).

RWMD does not provide specific guidance on the types of fire tests to be carried out. Reference is made to fire testing regime contained in the IAEA Transport Regulations (see Annex 3). RWMD provides arguments to justify increasing the temperature from the IAEA 800°C to 1000°C and the duration from the IAEA 30 minutes to 1 hour. However, they do not translate this into a set of requirements.

There is a requirement, as part of the LoC process to provide relevant information to demonstrate how a waste package will comply with the RWMD radionuclide release limits under impact and fire accidents. This should be based, in part, on the results from the various impact and fire tests. If these results are already available, there may be no need to repeat the tests, but RWMD will be the arbiter of this. If, on the other hand, MoD make changes to the design and/or fabrication of the 3m^3 box, some additional testing will be required. It is essential that the requirements for impact and fire testing of a 3m^3 box waste package are discussed with RWMD and if additional work is required, to agree and implement a testing programme.

Since it is currently not MoD’s intention to deviate from standard RWMD waste packages, no major issues are anticipated when complying with fire performance issues relating to the 3m^3 box waste package. However, the waste package and transport package testing regimes need to be discussed with RWMD.

4.15 Stackability

The purpose of this requirement is to ensure that 3m^3 box waste packages can be safely stacked during all stages of its management, but particularly in the GDF.

4.15.1 RWMD Requirement

The waste package shall be capable of withstanding a stacking load due to a seven high stack of similar waste packages, each with a gross mass of 12,000kg. This shall be the equivalent of a compressive load of 72,000kg applied along the vertical axis of the waste package. Under these load conditions, the waste package should not exhibit any permanent deformation or abnormality that would render it incompatible with any of the requirements defined in WPS/315.

4.15.2 RWMD Explanation of Requirement

RWMD states that, in a GDF vault $3m^3$ box waste packages will be stacked seven high and should be capable of being stacked in such a manner while still maintaining the ability to be handled safely.

This requires the shape of $3m^3$ box waste packages to be in conformance with the specified dimensional envelope, for the lifting capability to be in conformance with the specified lifting features and for the package to be capable of being handled safely using the standard lifting grab. In addition, waste packages should be capable of satisfying these requirements after having been stacked for the period of interim storage which is up to 150 years.

RWMD recognise that it may be necessary to position spacers between stacked waste packages to minimise interface corrosion problems, and to allow stable stacking and prevent blocking of waste package filters. Care should be taken, however, to ensure that the design of any spacer does not impose undue concentrated loads on the waste packages, which might cause damage or permanent deformation when they are stacked. For design purposes it may be assumed that only waste packages of similar design would be stacked together, or alternatively that a flat spacer is placed between them.

4.15.3 Issues Relevant to the Management of SDP Wastes

There is no explicit requirement, as part of the LoC process to provide supporting information to demonstrate how a waste package will comply with the RWMD stackability requirements. However, there is a necessity to estimate likely waste package properties and characteristics with respect to compliance with the long term integrity requirements of waste package.

Since it is not MoD’s intention to deviate from the standard RWMD waste packages, no major issues are anticipated when complying with stacking issues related to the $3m^3$ box waste package.

If the $3m^3$ box waste packages need to be stacked in the buffer store or in the long term interim store, they should not be stacked more than seven high.

It is concluded that compliance with the RWMD $3m^3$ box waste package stackability requirements should not be problematic and no major issues arising from this requirement are anticipated.

4.16 Identification

The purpose in specifying a unique identification marking on each waste package is to enable the identification and tracking of waste packages throughout all stages of their long-term management and to permit assignment of the appropriate data record.

4.16.1 RWMD Requirement

The waste package shall be marked with a unique ten character identifier as defined in Specification of Waste Package Identification System, WPS/410. The identifier shall be marked on the vertical faces of the four lifting features, 50 mm from the top edge as shown in Figure 2 of WPS/410. The characters shall be 6 – 10 mm high and should be capable of being read during all active stages of the long-term management of waste packages.

4.16.2 RWMD Explanation of Requirement

RWMD states that the identifier is required to be a permanent feature of the waste package that, as a minimum, will be readable accurately by machine and by eye upon receipt of the waste package at a GDF. The identifier needs to remain readable by some means during at least the first 50 years of the operational period of a GDF. As a design basis, a maximum period of interim surface storage of 150 years prior to transport should be assumed, leading to a minimum identifier longevity of 200 years.

For automatic reading systems to operate effectively, four identified positions are specified to provide redundancy and minimise the risk of a package becoming unidentifiable. The positions specified, on the vertical edge of the waste package lifting feature were selected partly because marking in these positions is unlikely to affect the corrosion performance and associated containment integrity of the waste package.

The recommended method of inscribing the identifier is to laser-etch the characters which, in the case of austenitic stainless steel packages, is expected to satisfy the above requirements.

In-house markings and additional labels may be applied by the waste packager if required for internal purposes, provided that they do not affect waste package performance. However, any additional identification, whether temporary or permanent, must not compromise the integrity requirements of the waste package.

4.16.3 Issues Relevant to the Management of SDP Wastes

There is no explicit requirement, as part of the LoC process to provide supporting information to demonstrate how a waste package will comply with the RWMD identification requirements.

Since it is not MoD’s intention to deviate from the standard RWMD waste packages, no major issues are anticipated when complying with the identification issues relating to the 3m^3 box waste package.

It is concluded that compliance with the RWMD $3m^3$ box waste package identification requirements should not be problematic.

4.17 Physical Protection for Nuclear Safety

The purpose in specifying a maximum Nuclear Material content of the waste packages is to allow the nuclear security physical protection arrangements to be defined.

4.17.1 RWMD Requirement

The quantity of Nuclear Material contained within the waste package shall be such that the waste package can be transported subject to standards of physical protection no higher than Category III.

4.17.2 RWMD Explanation of Requirement

The Office for Civil Nuclear Security (OCNS) define Nuclear Material as plutonium, uranium, neptunium, americium and other irradiated materials.

The Nuclear Industries Security Regulations (NISR) 2003 lay down the approvals required for the physical protection of ‘Nuclear Material’ in transit between licensed sites, against the risk of theft or sabotage. They are administered and enforced by OCNS acting on behalf of the Secretary of State for Trade and Industry.

It is the RWMD's intention that the Nuclear Material content of all waste packages destined for emplacement in a GDF will be such that they will require standards of physical protection no higher than those defined for Category III material under the NISR. This intention forms part of the Security Plan.

During the assessment of a packaging proposal, a physical protection assessment will be carried out to consider the nature and quantity of any Nuclear Material intended for transport and disposal, in particular, its attractiveness for theft and its dispersability from an act of sabotage. The assessment will conclude with a statement regarding compliance with the current GDF Security Plan. Any issues identified in the assessment that do not comply with the provisions and conditions of the Security Plan will be referred to the OCNS for information, and, if necessary, for direction.

RWMD lists the limits on the maximum permissible quantities of Nuclear Materials for waste packages transported with Category III levels of physical protection.

4.17.3 Issues Relevant to the Management of SDP Wastes

An assessment will be carried out, as part of the LoC process to demonstrate how a waste package will comply with the RWMD physical protection requirements.

It is understood that the submarine ILW will not contain Nuclear Material at the limits specified by RWMD. Complying with these requirements will therefore not be problematic for MoD.

However, there may be other issues associated with the secure storage and disposal of submarine ILW which MoD may want to discuss with RWMD.

It is concluded that compliance with the RWMD 3m^3 box waste nuclear security requirements should not be problematic and no major issues arising from this requirement are anticipated.

4.18 Nuclear Materials Safeguards

The purpose in specifying the Nuclear Material safeguards status of any fissile or source material is to minimise the potential for the diversion of civil nuclear materials to military use.

4.18.1 RWMD Requirement

The Safeguards status of any fissile or source materials (i.e. isotopes of uranium, plutonium and thorium) contained within a waste package shall be ascertained.

4.18.2 RWMD Explanation of Requirement

To prevent the potential for the diversion of civil nuclear materials to military use, packaged wastes that contain isotopes of uranium, plutonium or thorium derived from the UK civil nuclear programme may be subject to national and international controls known as 'Safeguards'. In principle, where these materials are subject to Safeguards, it is likely that they will be subject to those controls during all stages of their long-term management and a Safeguards assessment will be required. Such an assessment will review the proposed management processes for the packaged waste and consider whether they are likely to be adequate to meet the requirements of the Safeguards authorities.

In order that implications of accepting waste packages that contains safeguarded materials can be fully assessed and, in particular, the likely impact on GDF operations, the waste packager will be required to provide sufficient information on the quantity, nature and status of all Safeguarded material that will be incorporated into proposed waste packages.

4.18.3 Issues Relevant to the Management of SDP Wastes

These issues are not relevant to the management of SDP wastes.

4.19 Quality Management

4.19.1 RWMD Requirement

Quality management arrangements shall be applied to all aspects of the packaging of radioactive wastes that affect product quality. These arrangements shall be agreed with RWMD prior to the start of the activities to which they relate.

4.19.2 RWMD Explanation of Requirement

All activities relevant to licensing of a GDF will be conducted in accordance with appropriate quality management arrangements. The objective in establishing and operating a quality management system is to provide an integral framework of procedures which will ensure that the work is adequately controlled, documented and recorded. It is the responsibility of the waste packager to develop, operate and maintain appropriate quality management arrangements which meet all RWMD requirements.

These arrangements will be the subject of a separate approval by RWMD, as specified in the waste package quality management specification [Ref #10] and in [Ref. #11] which contains guidance on the quality management requirements.

[Ref. #10] addresses the requirements for waste packaging, the scope of the Quality Management System (QMS), the waste product specification (WPrS), the demonstration of effectiveness and assessment by RWMD.

Processes need to be established and implemented for the packaging of radioactive wastes, which encompass the whole lifetime of the waste packages, to ensure that packaged waste has the properties ascribed to it. These arrangements should be reviewed periodically and adequate records maintained. Persons and organisations responsible for verifying correct performance should have appropriate authority and independence.

The waste packager needs to establish, implement and maintain a formal and effective QMS with the objective of assuring the quality of both the waste package product and the associated data records. As a minimum, the QMS will comply with BS EN ISO9001. . The QMS should apply to all activities, interactions and aspects that can affect the quality of the waste package product, including the following shown below:

- waste characterisation;
- container design;
- container manufacture;
- wasteform development;
- process development;
- plant specification and design;
- LoC submissions and “Advice” actions;
- plant commissioning and operation;
- raw materials storage;
- waste package interim storage and monitoring;
- control of non-conforming packages;
- change control and continual improvement of waste package design, processing plant and interim storage; and
- package records and their long-term retention.

The waste packager shall establish and maintain a Waste Product Specification (WPrS) for the waste package. A WPrS shall fully define the waste, waste container, conditioning materials, wasteform formulation, process conditions, storage conditions and all relevant supporting R&D (including product properties and performance) for each waste package type. Guidance on the preparation of a WPrS is provided in [Ref. #12].

The waste packager shall demonstrate to RWMD, by providing objective evidence, that:

- the QMS employed applies to all stages of the process from initial design through to final packaging and interim storage;
- the waste is being packaged in compliance with the QMS and the WPrS; and
- the implementation of the QMS and compliance with the WPrS are verified by independent audit or assessment.

The waste packager shall provide, upon reasonable request, access for RWMD (or its agreed agents) to conduct assessment(s) of activities that affect the quality of waste package products.

4.19.3 Issues Relevant to the Management of SDP Wastes

Provided the RWMD guidelines on QMS are followed, no major issues are anticipated when complying with the quality assurance issues relating to the 3m^3 box waste package.

4.20 Summary and Conclusions

A review was conducted of the requirements of the Waste Package Specification, to determine if any of them represent significant threats to the use of the 3m^3 box waste package as MoD's preferred option for packaging of SDP ILW. The results are summarised below.

Compliance with waste package dose rate limits is high on the agenda of most radioactive waste packaging projects. The 3m^3 box will be transported through the public domain within a reusable shielded transport container (SWTC) and this is designated as a Type B transport package. Under the IAEA Transport Regulations, a Type B transport package must meet the following dose rate limits: 2 mSv/h at the surface of the SWTC and 0.1 mSv/h at 1 metre from the SWTC.

Calculations using the MicroShield software package indicated that dose rates both at the surface of the transport package and at a distance of 1 metre from the package were acceptably low. The results indicate that the ILW from a nuclear submarine can be packaged and transported in conformance with the UK transport regulations, without the need for any decay storage.

The results from review of other RWMD requirements contained in the Waste Package Specification are presented below.

- The total heat output from a 3m^3 box waste package is not anticipated to exceed the 200 Watt limit at the time of transport.
- The surface contamination limits is an operational issue and compliance should not be problematic.

- The requirements associated with the dimensions, lifting features, venting, package integrity and stackability requirements of a 3m^3 box can be met by use of a standard RWMD 3m^3 box, as opposed to developing a different design of box.
- The 12 tonne mass limit is an operational issue which should not present any major problems.
- Gases may be generated if the metallic wasteform contains entrained gases and will be generated during corrosion of the metal. Compliance with the total gas generation limits is not anticipated to be problematic.
- Criticality safety should not be an issue if no fissile materials, neutron moderators or reflectors are packaged inside the 3m^3 box.
- The impact and fire testing requirements for the 3m^3 box waste package and transport package need to be discussed and agreed with RWMD. Compliance with the impact and fire performance requirements may be onerous but is not anticipated to be problematic.
- Complying with the requirement to mark each waste package with a unique, long lasting identified is not considered difficult.
- Physical protection for nuclear security should not be an issue if no fissile materials are packaged inside the 3m^3 box.
- Nuclear materials safeguard issues are not relevant to MoD ILW.
- Quality management systems need to be set up, in conjunction with RWMD, as early as possible, to ensure that their requirements will be met. No difficulties are anticipated when complying with this requirement.

All of the above conclusions will need to be confirmed when new waste characterisation and other data become available and all of the above issues will need to be discussed in detail with RWMD.

None of the above represents a significant threat to the use of the 3m^3 box waste package as MoD’s preferred option for packaging of SDP ILW.

A number of key issues were identified as part of the above review and these should be addressed as part of the RWMD LoC process. These key issues are listed in Annex 4 of this document.

5. WASTEFORM SPECIFICATION

The Wasteform Specification contained in [Ref. #8] identifies the performance criteria that are required of the wasteforms for all waste packages manufactured using the $3m^3$ box.

The principal functions of the wasteform are to immobilise radionuclides and to make hazardous materials safe. During transport and handling operations the wasteform should ensure that radioactivity is not present in a gaseous, volatile, liquid or fine particulate form to such an extent that the waste package will fail to meet the requirements of the relevant Waste Package Specification. The wasteform should be compatible with the waste container to ensure that the properties of the waste package as a whole meet the requirements of the Waste Package Specification. After emplacement in a GDF the wasteform, together with the container, should provide a physical barrier to the release of radioactivity from the waste package and the wasteform, together with the backfill, should exert chemical control over the solubility of certain radionuclides in the waste.

The role of the wasteform during all stages of the long-term management of conditioned waste is to behave in a benign and predictable manner in order to prevent unpredictable waste package performance. This is particularly important during the earlier stages of the management of waste packages (i.e. during interim surface storage, transport and the operational period of a GDF) when the waste package will experience the majority of its handling operations. The most predictable waste package performance, consistent with current best practice, will be achieved by a waste package containing a wasteform that is essentially monolithic and with minimum voidage.

A list of criteria, which the wasteform inside a $3m^3$ box must (or in some cases, is advised to) comply with, is presented in [Ref. #7] and the same criteria, together with additional explanatory material relating to each criterion is provided in [Ref. #8]. This document is structured round [Ref. #8].

These criteria cover issues which are required to be addressed to obtain a LoC. Recognising that LoC process addresses technical issues relevant to the long term management of packaged waste, these criteria represent a good check list of technical issues relevant to the lifecycle of the wasteform inside a $3m^3$ box.

5.1 Physical Immobilation

The purpose of specifying physical immobilisation criteria is to ensure that releases of radionuclides from the packaged waste under normal and accident conditions are within the acceptable range of values defined by RWMD.

5.1.1 RWMD Requirements

The wasteform shall be designed to immobilise radionuclides and toxic materials so as to ensure appropriate waste package performance during all stages of long-term management. For many wastes, this immobilisation requires the use of an encapsulating matrix.

5.1.2 RWMD Explanation of Requirements

RWND defines immobilisation as a process by which mobile fractions of wastes are conditioned in such a way that the potential for migration or dispersion of the radioactivity associated with a waste by natural processes during storage, handling, transport and disposal is reduced.

Adequate immobilisation is the conditioning of waste in such a way that, as a minimum, the release of radionuclides from the packaged waste under normal and accident conditions are within the acceptable range of values defined by RWMD.

RWMD highlights the benefits to the wasteform performance of using of an inactive grout ‘cap’ on top of the active wasteform. The benefits include providing a barrier to the release of loose particulates from the upper surface of the active wasteform and improving the wasteform impact and fire accident performance.

RWMD has produced a separate guidance document [Ref. #13] which addresses wasteform immobilisation issues. This document present arguments indicating that waste packagers should aim to maximise the degree of immobilisation afforded by wasteforms.

RWMD [Ref. #13] acknowledges that, in some cases, adequate immobilisation may be afforded by the waste itself. Those wastes in which the radioactivity is not present in a mobile form (i.e. bulk metals containing neutron-activated radionuclides) and that will not generate mobile radionuclides by their evolution, may not require additional conditioning in order to render them passively safe and acceptable for disposal, although may require measures to reduce voidage.

RWMD [Ref. #13] discourages the presence of aggregates of loose particulates on the surface of the metals which could lead to inadequate penetration of the grout and hence voids within the package. It recognises that the total activity associated with potentially mobile waste fractions may so low such that the release of radioactivity under normal or any credible accident conditions cannot exceed the limits defined by RWMD. Packages which contain particulates below these “de minimus” levels may not require complete immobilisation.

RWMD [Ref. #13] scribes the immobilisation requirements in terms of impact fire performance, waste package evolution and the waste product specification [Ref. #12]

Practical guidance is provided on the immobilisation of the activity in wasteforms, including options for wasteforms which contain particulates. RWMD also addresses the release of gases (e.g. tritium and fission products) from metallic wastes and their effect on the performance of the waste package.

The demonstration of the adequacy of an approach to the immobilisation of activity in a wasteform is an important part of demonstrating the overall compliance of a waste package with the RWMD requirements. Such demonstration is likely to be underpinned by the results of R&D work involving small and/or large scale inactive and/or active wasteform trials. The demonstration of the adequacy of wasteform characteristics in this way is discussed in [Ref. #12] Such R&D work may be supported by evidence obtained during the non-active commissioning of the as-built packaging plant.

5.1.3 Issues Relevant to Management of SDP Wastes

Where radioactivity is present as activation products on large solid items (i.e. not particulates), the radioactivity may be considered to be immobile. However, degradation of such items and the formation of particulate corrosion products needs to be considered. If radionuclides are present as fixed activation products, it may be that the short term immobilisation requirements can be met without grouting. However, once degradation sets in and particulates are formed, the wasteform will gradually become non conforming and radionuclide immobilisation needs to be addressed.

RWMD discourages the presence of particulates (i.e. CRUD) on the surface of the metals which could lead to inadequate penetration of the grout and hence voids within the package. Work needs to be undertaken to understand the implications of the presence of CRUD and identify a strategy for dealing with it.

RWMD addresses the release of gases (e.g. tritium and fission products) from metallic wastes and their effect on the performance of the waste package. This raises issues related to tritium, Carbon-14 and other radiogenic gases in submarine metals. Work needs to be undertaken to understand if any diffused radioisotopes are present in significant quantities in the wasteform and if so, what the implications are. For example, metals which contain diffused tritium at levels above 12 GBq/tonne are classified in the UK as ILW and cannot be disposed of at an LLW disposal site. Also, because of its relatively high mobility, disposal limits for C-14 at a LLW site can be relatively low. These and other considerations need to be addressed in support of the strategy for segregating LLW from ILW.

RWMD state that some wastes may be suitable for packaging without the need of a conditioning matrix. In such cases (i.e. for irradiated metal wastes with little or no loose contamination), the immobilisation of radionuclides is provided by the form of the waste.

Lack of intimate encapsulation may, however, raise wasteform issues (i.e. voidage) that will need to be considered and addressed if the packaged waste is to be shown to be compliant with RWMD requirements. Fixing the waste inside the box, would help avoid redistribution of waste during transport, which could cause damage to the waste package or change the radiation dose profile of the box, making it non compliant with the relevant dose limits. One way round this would be to pre-grout the annulus round the inside of the box and place the waste (without furniture) inside the box.

The main argument against addition of a conditioning matrix is that it may foreclose future options, if the grouted wasteform is subsequently shown to be inadequate for disposal at the GDF. This is considered unlikely.

As part of the LoC process, a wasteform immobilisation strategy will need to be produced. This will include consideration of the various advantages and disadvantages of immobilisation, and if immobilisation is confirmed as the way forward, a decision on when, where and how to immobilise the wasteform [Ref. #13] is a good starting point for this study.

On the assumption that the waste is grouted before transport to the long term interim store and the issues relating to CRUD, gas release and corrosion are adequately addressed, compliance with the RWMD 3m^3 box wasteform physical immobilisation requirements should not be problematic.

If the waste is not grouted before transport to the long term interim store, a justification for this will need to be provided to RWMD as part of the LoC process.

5.2 Immobilisation of Radionuclides and Particulates

The purpose of specifying radionuclide and particulate immobilisation criteria is to ensure that the release of radionuclides from the packaged waste under normal and accident conditions are within the acceptable range of values defined by RWMD.

5.2.1 RWMD Requirements

All reasonable measures shall be taken to ensure that radionuclides and toxic materials in the waste are immobilised and that loose particulate material is minimised.

5.2.2 RWMD Explanation of Requirements

Radionuclides can be said to be immobile if the characteristics of fluidity, dispersibility and freedom of movement within the package are eliminated.

RWMD provides guidance on the use of immobilisation matrices, with emphasis on inorganic cement based immobilisation matrices.

Guidance is provided on wastes which contain free aqueous or non-aqueous liquids.

5.2.3 Issues Relevant to Management of SDP Wastes

The implications of loose particulate are addressed in Section 5.1 above.

On the assumption that the waste is grouted before transport to the long term interim store and the issues relating to loose particulates are adequately addressed, compliance with the RWMD 3m^3 box wasteform radionuclide and particulate immobilisation requirements should not be problematic.

If the waste is not grouted before transport to the long term interim store, a justification for this will need to be provided to RWMD as part of the LoC process.

5.3 Response to an Impact Accident

The purpose of specifying impact accident criteria is to ensure that the release of radionuclides from the packaged waste under impact accident conditions is within the relevant limits.

5.3.1 RWMD Requirements

All reasonable measures shall be taken to ensure that, in the event of an impact accident, the quantity of potentially mobile radionuclides present within the waste package, including those generated as a result of the impact accident, is commensurate with the waste package meeting the relevant radioactivity release limits specified in the relevant WPS/300 Series Specification.

5.3.2 RWMD Explanation of Requirements

[Ref. #6] provides guidance to assist waste packagers in ensuring that waste packages comply with the impact accident performance requirements.

RWMD guidance is that the most predictable performance will be achieved by a package containing a wasteform which is essentially monolithic.

5.3.3 Issues Relevant to Management of SDP Wastes

This guidance is complementary to that discussed in Section 4.13 of this document.

On the assumption that the waste is immobilised (and essentially monolithic) before transport to the long term interim store and the issues relating to loose particulates are adequately addressed, compliance with the RWMD 3m^3 box wasteform impact accident requirements should not be problematic.

If the waste is not grouted before transport to the long term interim store, a justification for this will need to be provided to RWMD as part of the LoC process.

5.4 Response to a Fire Accident

The purpose of specifying fire accident criteria is to ensure that the release of radionuclides from the packaged waste under fire accident conditions is within the relevant limits.

5.4.1 RWMD Requirements

All reasonable measures shall be taken to ensure that, in the event of a fire accident, the quantity of potentially mobile radionuclides present within the waste package, including those generated as a result of the fire accident, is commensurate with the waste package meeting the relevant radioactivity release limits specified in the relevant WPS/300 Series Specification. In addition, the wasteform should not readily burn or otherwise support combustion.

5.4.2 RWMD Explanation of Requirements

[Ref. #6] provides guidance to assist waste packagers in ensuring that waste packages comply with the fire accident performance requirements.

Materials which present a fire hazard should be excluded from the wasteform or made safe Intimate grouting of combustible solids with inorganic cement-based immobilising material would not be expected to result in wasteforms that would burn or otherwise support combustion.

Particular consideration should be given to the treatment of irradiated graphite prior to packaging as this material has the potential to possess significant quantities of stored Wigner energy which could be released in the event of a fire.

5.4.3 Issues Relevant to Management of SDP Wastes

This guidance is complementary to that discussed in Section 4.14 of this document.

The metallic submarine waste is not combustible, therefore no major issues arising from this requirement are anticipated. However, if combustible materials (e.g. resins) are packaged as ILW inside 3m^3 boxes, this requirement would become relevant.

As part of the LoC process, the contents of the waste will need to be specified in order to demonstrate compliance with limits on radionuclide releases during fire accidents. Supporting information will need to be provided to demonstrate the absence of problematic materials (e.g. combustible materials, irradiated graphite).

On the assumption that the waste is immobilised before transport to the long term interim store, compliance with the RWMD 3m^3 box wasteform impact accident requirements should not be problematic.

If the waste is not grouted before transport to the long term interim store, a justification for this will need to be provided to RWMD as part of the LoC process.

5.5 Free Liquids

5.5.1 RWMD Requirements

All reasonable measures shall be taken to exclude free liquids from the wasteform. This should include materials that may degrade to generate liquids. Free liquids not removed from wastes prior to waste packaging should be immobilised by a suitable waste conditioning process.

5.5.2 RWMD Explanation of Requirements

RWMD lists the types of liquids that may be present as components of wastes or may arise from the processing of wastes into wasteforms. These include:

- aqueous solutions such as bleed water, rainwater, pond waters and process liquors;
- organic liquids such as lubricating oils and solvents;
- hydraulic fluids; and

- mercury.

The evolution of wasteforms and the degradation of some waste components may also result in the creation of free liquids after waste conditioning.

Free liquids may be defined as those which may drain from the waste package subsequent to a loss of package integrity during an impact or fire accident or by container corrosion.

The presence of free liquids implies incomplete immobilisation and such liquids may give rise to a number of undesirable effects within a wasteform. These are listed by RWMD.

5.5.3 Issues Relevant to Management of SDP Wastes

The exclusion of free liquids from wasteforms will need to be demonstrated as part of the LoC process,

There is no intention to dispose of free liquids in $3m^3$ box wasteforms, therefore complying with the requirement to exclude free liquids should not be problematic. However, if wet processes are deployed for size reduction of the RPV, additional care must be taken to avoid the presence of free liquids.

5.6 Mechanical and Physical Properties

The purpose of specifying design criteria for the mechanical and physical properties of the wasteform is to ensure that the performance of the waste package is not compromised for at least the first 500 years of its long term management.

5.6.1 RWMD Requirements

The wasteform shall be designed to provide the mechanical and physical properties necessary to ensure appropriate performance of the waste package during all stages of long-term management.

5.6.2 RWMD Explanation of Requirement

RWMD states that the design and safety assessments for a GDF will be based on the requirement that the waste packages will have the mechanical strength necessary to achieve certain specified standards. Inappropriate properties might therefore compromise the basis on which a GDF is designed.

The mechanical and physical properties of the wasteform and the waste container should each be adequate in their own right and as much as possible, should also be complementary to each other.

Properties that could be affected by wasteform evolution should retain acceptable values for up to 500 years from the date of manufacture of the waste package.

5.6.3 Issues Relevant to Management of SDP Wastes

This guidance is complementary to that provided in Sections 4.10 and 4.13 of this document.

There is a requirement under the LoC process to show that the properties of the wasteform will fall within the range expected, for cement based products or to provide information on the mechanical strength of the wasteform/waste package.

On the assumption that the waste is immobilised before transport to the long term interim store, compliance with the RWMD requirement to ensure that the mechanical and physical properties $3m^3$ box wasteform are adequate, should not be problematic.

5.7 Mechanical Strength

The purpose of specifying wasteform mechanical strength criteria is to ensure that the waste package is robust enough to be safely handled, transported and stacked (during interim storage or disposal).

5.7.1 RWMD Requirement

The wasteform shall provide sufficient mechanical strength to allow the waste package to be transported and handled without affecting the ability of the waste package to meet all the requirements of the relevant WPS/300 series specification.

5.7.2 RWMD Explanation of Requirement

RWMD states that compressive strength is a useful indicator of the general robustness of the wasteform under static loadings and impact accident conditions. Although the mechanical properties of the waste container are likely to be the determining factor with respect to the ability of the waste package to meet the requirements for stacking, in some cases the wasteform may be required to provide support to the container walls to prevent buckling. Sufficient strength for transport, handling and storage is likely to be achieved using typical cementitious immobilising matrices.

5.7.3 Issues Relevant to Management of SDP Wastes

This guidance is complementary to that provided in Sections 4.10 and 4.13 of this document.

There is a requirement under the LoC process to show that the properties of the wasteform will fall within the range expected, for cement based products or to provide information on the mechanical strength of the wasteform.

On the assumption that the waste is immobilised before transport to the long term interim store, compliance with the RWMD requirement to ensure that the mechanical strength of the $3m^3$ box wasteform is adequate, should not be problematic.

5.8 Voidage

The purpose in minimising the volume of voidage is because non in-filled spaces have an adverse effect on the properties of the wasteform and package, like for example, a reduction in strength compared to predicted values.

5.8.1 RWMD Requirement

The development and production of the wasteform should ensure that the volume of voidage within the waste package (such as ullage, holes or other spaces) is minimised.

5.8.2 RWMD Explanation of Requirement

RWMD defines voidage, including macroporosity, as discrete non-infilled spaces within the wasteform.

Such voidage reduces confidence in the predictability of performance under normal and accident conditions. Furthermore, voidage may undermine steps taken to engineer particular properties of the wasteform or address specific performance criteria.

RWMD states that minimising voidage is considered best practice and generates confidence in the packaging process and the predictability of waste package performance.

RWMD provides guidance on how voidage can be reduced when filling containers. For example, voidage within wasteforms can normally be reduced by the use of conventional immobilising materials such as inorganic cements, suitably fluid grouts and efficient mixing/infilling processes.

5.8.3 Issues Relevant to Management of SDP Wastes

There is a requirement under the LoC process to show that the properties of the wasteform will fall within the range expected, for cement based products or to provide information on the macroscopic voidage of the wasteform.

On the assumption that the waste is immobilised before transport to the long term interim store, and that due care has been taken to reduce voidage, compliance with the RWMD requirement to ensure that minimal voidage inside a 3m^3 box wasteform should not be problematic.

5.9 Mass Transport Properties

The purpose in specifying wasteform mass-transport properties is to ensure the timely release of gases (which could otherwise cause damage to the integrity of the wasteform) and to control the diffusivity and permeability of the wasteform to enhance the ability of the wasteform to retain water soluble radionuclides.

5.9.1 RWMD Requirement

The wasteform shall be sufficiently permeable to allow gases generated within the wasteform to be released without compromising the ability of the waste package to meet any aspect of the relevant Ref. #300 series specification. The mass-transport properties of the wasteform (e.g. diffusivity and permeability) shall provide best practicable means for containment of water-soluble radionuclides within the waste package.

5.9.2 RWMD Explanation of Requirement

RWMD states that the mass-transport properties of the wasteform will influence the performance of the waste package, both directly through an influence on the rate of radionuclide release and indirectly through an influence on the degradation of the wasteform. Such degradation will influence both the rate of release of radionuclides under normal conditions and the response of the waste package to accident conditions.

Gases under pressure may cause degradation of the wasteform, therefore the permeability of the wasteform must be sufficiently high to allow such gases to be released. On the other hand, the diffusivity and permeability of the wasteform must be sufficiently low to allow the wasteform to retain water soluble radionuclides during the groundwater saturation phase of the GDF. The latter can be achieved by using a cementitious immobilising matrix which has a lower permeability than that of the GDF backfill.

5.9.3 Issues Relevant to the Management of SDP Wastes

There is a requirement under the LoC process to show that the properties of the wasteform will fall within the range expected, for cement based products or to provide information on the mass-transport properties (i.e. diffusivity and permeability) of the wasteform.

Properties such as diffusivity, permeability and leachability need to be established as part of the selection of the immobilisation medium. If existing immobilisation media are considered inadequate for encapsulation of SDP wastes or information on the relevant mass-transport properties does not already exist, it may be necessary to conduct immobilisation media formulation trials using simulant wastes.

Compliance with the RWMD requirement to ensure that a $3m^3$ box wasteform is encapsulated inside a medium with acceptable mass-transport properties is not anticipated to be problematic.

5.10 Homogeneity/Uniformity

The purpose in specifying wasteform homogeneity/uniformity criteria is to ensure minimisation of any localised concentrations of materials in the wasteform which could compromise the integrity of the waste package.

5.10.1 RWMD Requirement

Local concentrations of materials within the wasteform that may compromise the integrity of the waste package to meet any aspect of the relevant WPS/300 series specification should be avoided.

5.10.2 RWMD Explanation of Requirement

RWMD states that lack of homogeneity in a wasteform may undermine the steps taken to engineer particular properties of the wasteform to address other performance criteria.

Heterogeneity may also reduce confidence in the predictability of waste package performance under normal and accident conditions.

RWMD provides some examples of the effects of significant heterogeneity. These include the possibility that local concentrations of radionuclides could lead to localised increases in external dose rates and to radiolytic gas generation and high heat generation which could lead to differential stresses within the wasteform. High concentrations of reactive metals may compromise the mechanical integrity of the wasteform as a result of localised expansion caused by corrosion.

Ways to promote homogeneity and uniformity include separation of waste types; opening/puncturing of hollow or sealed items; the use of hold-down apparatus to overcome flotation; size reduction of large flat objects; placement of hard, sharp items in a controlled fashion within the container to improve impact performance; and careful wasteform design to prevent cracking.

5.10.3 Issues Relevant to the Management of SDP Wastes

There is no specific requirement under the LoC process to demonstrate that the homogeneity and uniformity of the wasteform are adequate. However, RWMD considers that best practise should be adopted to identify the potential for this type of problem and to promote homogeneity and uniformity.

If simulant waste trials are conducted, the opportunity should be taken to investigate these issues. In addition, the opportunity should be taken during inactive and/or active commissioning of the encapsulation plant to promote homogeneity and uniformity within the wasteform.

Compliance with the RWMD requirement to ensure that a 3m^3 box wasteform is encapsulated inside a medium with acceptable homogeneity and uniformity properties is more of an operational issue and is not anticipated to be problematic.

5.11 Thermal Conductivity

The purpose in specifying a thermal conductivity lower limit/threshold is to ensure that the wasteform is capable of safely dissipating any heat produced within the waste package.

5.11.1 RMWD Requirement

The thermal conductivity of the wasteform shall be sufficient to dissipate any heat generated within the waste package, when emplaced in a GDF, without unacceptable temperature rise. The minimum value of thermal conductivity should be 0.5 $Wm^{-1}K^{-1}$.

5.11.2 RMWD Explanation of Requirement

RWMD states that the effective thermal conductivity of waste packages is governed largely by that of the wasteform and this will influence the temperature which the waste packages attain during the various periods of their long-term management.

IAEA guidance [Ref. #8] recommends that wasteforms should have very low thermal conductivity for the best fire performance, whilst also acknowledging the necessity for a sufficiently high thermal conductivity to ensure acceptable thermal performance in a GDF as a whole.

RWMD suggests a minimum thermal conductivity value of 0.5 $Wm^{-1}K^{-1}$. The thermal conductivities of cements and stainless steel wastes contained in Table 1 of [Ref. #8] indicate that a wasteform which contains stainless steel fuel hulls in cements would have a thermal conductivity above this minimum guidance value and therefore be acceptable.

[redacted]

5.11.3 Issues Relevant to the Management of SDP Wastes

Since the SDP waste should not contain combustible materials, the main driver should be for a sufficiently high thermal conductivity to ensure that the thermal performance of the GDF is acceptable. RWMD suggests that a thermal conductivity above 0.5 $Wm^{-1}K^{-1}$ would be acceptable.

Typical thermal conductivities of cements and stainless steel wastes are contained in Table 1 of [Ref. #8]. A quick approximation to the thermal conductivity of the metallic SDP wastes was obtained by adding both these values. This indicates that a wasteform which contains metal in cements would have a thermal conductivity of about 2.2 $Wm^{-1}K^{-1}$ which is above the minimum guidance value and also below the possible upper limit.

A more detailed assessment will need to be performed as part of the LoC process to demonstrate that the thermal conductivity of the wastefom will fall within the specified ranges.

Compliance with the RWMD requirement to ensure that the thermal conductivity of a 3m^3 box wasteform is within an acceptable range is not anticipated to be problematic.

5.12 Chemical Containment

The purpose in specifying chemical containment criteria is to ensure that the wasteform does not contain any materials which could compromise the performance of the GDF backfill.

5.12.1 RMWD Requirement

The wasteform shall not be incompatible with the chemical containment of radionuclides and hazardous materials as embodied in the requirements of a GDF.

Where they may affect chemical containment, the following items should not be introduced through waste conditioning or packaging, and their presence in wastes should be minimised wherever practicable:

- *Oxidising agents;*
- *Acids and/or materials that degrade to generate acids;*
- *Cellulose and other organic materials;*
- *Complexants and chelating agents, and/or materials that degrade to generate such compounds;*
- *Non Aqueous Phase Liquids (NAPLs) and/or materials that degrade to generate them;*
- *Any other materials that could detrimentally affect chemical containment.*

5.12.2 RMWD Explanation of Requirement

The near-field chemical barrier in a GDF is provided by the disposal vault backfill which will be formulated to limit the migration of radionuclides over long periods of time. The backfill is designed to create and sustain an alkaline environment in which the solubility of many key radionuclides will be reduced and the corrosion rates of steels will be minimised. It is porous, presenting a large surface area to increase the sorption of many radionuclides. The backfill has also been designed to allow dispersal of any gas generated within the disposal vaults without causing over-pressurisation.

The long-term performance of a GDF relies on the backfill fulfilling its design functions. The objective in designing and engineering the wasteform is to avoid degrading the effectiveness of the backfill, and to avoid any requirement for an increased quantity of backfill material to be provided. Given the materials already present in the original waste, best practice in the wasteform is wherever practicable to use only materials and processes that contribute to achieving these objectives, and do not create additional problems of their own.

RWMD indicate that the wasteform should be designed to have a high pH which will not compromise the performance of the alkaline GDF backfill. The use of inorganic cement based matrices is the preferred method for maintaining a high pH within a wasteform. Any low pH materials which could reduce the alkalinity of the GDF backfill need to be avoided.

RWMD provides a list of materials which could interfere with the repository backfill chemistry. These include cellulosics (e.g. paper, wood and cotton), condensation polymers (e.g. some ion exchange resins, epoxy resins and nylon), addition polymers (e.g. some ion exchange resins, polythene and PVC) and grout additives. These materials should not be introduced into the waste package, but if they are, they should be minimised, where possible and RWMD advice should be sought where applicable.

5.12.3 Issues Relevant to the Management of SDP Wastes

As part of the LoC process, there is a requirement to identify the chemicals contained in the wasteform. Any materials which may affect the effectiveness of the repository chemical containment system need to be identified and justified. These include CRUD, resins, plastics, paper, wood, decontamination chemicals and others, especially those with a low pH which could reduce the alkalinity of the GDF backfill. RWMD must be consulted if the intention is to use cement additives.

Problems are not anticipated with complying with the RWMD requirement to ensure that materials which could detrimentally affect the chemical containment of a 3m^3 box wasteform are excluded or minimised where practicable.

5.13 Hazardous Material

The purpose in eliminating hazardous materials or treating them to render them less hazardous is to help assure the safety of the waste package during all waste management stages, particularly when in long term storage under a passive safety regime.

5.13.1 RMWD Requirement

The wasteform shall not contain hazardous materials, or have the potential to generate such materials, unless the treatment and packaging of such materials or items makes them safe. The means by which any of these materials is made safe shall be demonstrable for all relevant periods of long-term management.

5.13.2 RMWD Explanation of Requirement

Radioactive wastes contain a wide variety of materials, some of which, because of their chemical and/or physical nature, create additional hazards during packaging, transportation and disposal.

RWMD state that hazardous materials may exist either at the time of packaging or be produced in time by mechanisms such as interactions between materials inside a package and the degradation of the waste.

The nature and magnitude of the hazard will depend on the nature of the waste, wasteform and packaging methods. During the development of the waste package, the waste packager should demonstrate that these materials have been considered, and that they will be neutralised or removed.

Examples of hazardous materials are pyrophoric materials; oxidising materials; flammable liquids and gases; explosive materials; and sealed and/or pressurised containers.

5.13.3 Issues Relevant to the Management of SDP Wastes

As part of the LoC process, there is a requirement to identify that hazardous materials have been eliminated or made safe. Any materials which may affect the effectiveness of the repository chemical containment system need to be identified and justified. These include pyrophoric materials; oxidising materials; flammable liquids and gases; explosive materials; and sealed and/or pressurised containers.

Problems are not anticipated with complying with the RWMD requirement to ensure that hazardous materials are either excluded from a $3m^3$ box wasteform or minimised.

A more detailed assessment will need to be performed as part of the LoC process to indicate that hazardous materials have been eliminated or made safe. If hazardous materials are present, they would need to be justified and quantified. The assessment should also address the production in the wasteform of hazardous materials, like for example, gases produced from corrosion of the activated stainless steel.

Compliance with the RWMD requirement to exclude or minimise hazardous materials from a $3m^3$ box wasteform is not anticipated to be problematic.

5.14 Gas Generation

The purpose of this guidance is, in part, to understand the gas generation mechanisms which could lead to pressurisation and damage of the wasteform and to ensure that the gas limits set by the transport regulations are not exceeded.

5.14.1 RMWD Requirement

Gases generated by the wasteform shall not compromise the ability of the waste package to meet any aspect of the relevant WPS/300 Series Specification.

5.14.2 RMWD Explanation of Requirement

RWMD provides guidance on a variety of possible gas generation mechanisms, including production of gas by corrosion, microbial degradation of cellulose and organics, radiolysis of water (in the grout) and radioactive decay. Gases such as H_2O, H_2, CO_2 and CH_4 and species containing radioactive isotopes such as H-3 or C-14 may be produced, depending on the gas generation mechanism and the contents of the waste. Bulk gas releases may also entrain any smaller quantities of other radioactive species such as Rn-220, Rn-222, Ar-41 or Kr-85 which may be present in the waste.

Gases give rise to a range of potential effects that may have an influence on all periods of the long-term management of waste packages. Excessive gas generation may lead to pressurisation and damage of the wasteform.

During the waste packaging process, gas generation may also have a number of effects. Initially these will be process considerations, for example explosion/flammability safety and toxicity. However, gas generation at this initial stage of production may significantly modify the desired properties of a wasteform or compromise the packaging concept. Gas generation may be minimised during the production of a wasteform by reducing the rate of corrosion by careful selection of the wasteform cement, the use of a corrosion inhibitor or by limiting the content of gas-generating materials.

RWMD provides a list of gas production limits set by the transportation of a 3m^3 box waste package. This quotes the gas generation limit of 72 litres, discussed in Section 4.8 of this document. Gas generation may be minimised during the production of a wasteform by reducing the rate of corrosion by careful selection of the wasteform cement, the use of a corrosion inhibitor or by limiting the content of gas-generating materials.

Some metallic wastes (e.g. fuel cladding) contain tritium, either combined as metal tritides, or in the form of tritiated hydrogen which has diffused into the metal surface. These are usually ‘hard’ wastes (i.e. diffusionally thick solids) which have been tritiated at above ambient temperatures for extended periods of time. For tritium in these forms, the release rate is dependent on the corrosion rate and/or the rate of diffusion of tritium from the material.

Further guidance on tritium bearing wastes is provided in [Ref. #14]

5.14.3 Issues Relevant to the Management of SDP Wastes

The RWMD guidance should be read in conjunction with the gas generation guidance provided in Section 4.8 of the document.

An assessment will need to be performed as part of the LoC process to indicate which gas generation mechanisms are relevant to the SDP waste and the types and quantities of gases anticipated to be produced by the various gas generation mechanisms.

Compliance with the RWMD gas generation limits of a 3m^3 box wasteform is not anticipated to be problematic.

5.15 Wasteform Evolution

The purpose in specifying wasteform evolution guidance is to ensure that any chemical and physical changes that happen gradually, over a long period of time, are taken into account when designing the wasteform.

5.15.1 RMWD Requirement

Changes in the characteristics of the wasteform as it evolves shall not result in degradation that will compromise the ability of the waste package to meet any aspect of the relevant WPS/300 Series Specification.

The deleterious effects of the following processes should be considered:

- *dimensional changes, e.g. shrinkage;*
- *corrosion including, but not limited to, the production of gases and particulate material, and wasteform expansion resulting from the formation of lower density solid corrosion products;*

- *microbial activity;*
- *self-irradiation and irradiation by surrounding waste packages;*
- *heat generation by the wasteform and its surroundings including, but not limited to, localised heat sources within the wasteform, the effects on the curing of the encapsulant material and the consequential effects on longer term performance.*

5.15.2 RMWD Explanation of Requirement

Potentially, many of the aspects of wasteform and waste package performance dealt with in this document could be compromised by excessive degradation of the wasteform. Those aspects that are particularly susceptible are:

- immobilisation of radionuclides and other hazardous materials;
- container dimensions and shape;
- impact and fire accident performance;
- wasteform mechanical strength;
- wasteform voidage; and
- gas generation.

RWMD considers the threat to the dimensional stability of the wasteform. The wasteform will be subject to physical or chemical processes that may result in dimensional changes, which may ultimately lead to a reduction in the containment offered by the wasteform. The wasteform should therefore be designed to minimise the potential for dimensional changes, and to minimise the extent and rate of such changes.

RWMD considers the potential for corrosion of the wasteform. Most metals will corrode under the moist alkaline conditions inherent to the cement matrices preferred for the immobilisation of waste, although the rate and mechanism of corrosion will vary between different materials under differing conditions. Magnesium, aluminium and uranium are examples of metals present in waste whose corrosion performance under alkaline conditions may significantly affect package performance. Corrosion of wasteforms could result in the degradation of a previously solid wasteform into one that would no longer effectively immobilise the radionuclides or other hazardous materials. The products of corrosion are typically less dense than the source material, which results in a net increase in waste volume. This expansion places strain upon the encapsulating matrix, and cracking or other forms of disruption may ultimately reduce the containment offered by the waste package. Metal corrosion also often results in the generation of heat and gas. The options to reduce or minimise metal corrosion include restrictions on the reactive metals discussed above, use of low water super-plasticised cements, incorporation of corrosion inhibitors, segregation of dissimilar metals to minimise bi-metallic corrosion and minimisation of void spaces within which more corrosive conditions may develop.

RWMD considers the radiation stability of the wasteform. Radiolysis of wasteform components may give rise to new chemical species that react with the waste or immobilising material. Some of these reactions may result in a change in the performance of the wasteform, reducing its contribution to the immobilisation of radionuclides. The effects of irradiation should therefore be considered when the wasteform is being developed. Experience suggests that cementitious wasteforms are robust and not susceptible to excessive degradation under the cumulative radiation exposure that is expected during surface storage and subsequent emplacement in a GDF. In general, cements and concretes, when well formulated, are regarded as having good radiation resistance to gamma radiation doses of the order of 100MGy.

RWMD considers the thermal effects the wasteform, including heat generated by radioactive decay, corrosion, microbial degradation and other chemical and physical reactions. Guidance is provided on the radiogenic heat outputs for selected radionuclides and the heat of corrosion of selected metals.

5.15.3 Issues Relevant to the Management of SDP Wastes

The RWMD guidance should be read in conjunction with the gas generation guidance provided in Section 4.8 of this report.

The RWMD text shown above indicates that:

- magnesium, aluminium and uranium should be excluded from the SDP wasteform since they react with grout to produce hydrogen ga;
- large pieces of metal may be degraded into powdery corrosion products and this could have significant consequences for the fire and impact performance of the SDP waste package; and
- dissimilar metals in the SDP wasteform should be segregated to minimise bi-metallic corrosion.

Assessments for a variety of criteria (e.g. gas generation, corrosion, heat generation, particulates) which are required as part of the LoC process, will also need to address issues relating to the evolution of the wasteform.

Compliance with the RWMD wasteform evolution requirements for a 3m^3 box wasteform is not anticipated to be problematic.

5.16 External Dose Rate

The purpose in the provision of guidance on the nuclear properties of the wasteform is to ensure that the waste package will be compliant with the transport regulations.

5.16.1 RMWD Requirement

The radionuclide content and nature of the wasteform should ensure that waste package external dose rate limits as specified in the relevant WPS/300 Series Specification are complied with at the time of transport.

5.16.2 RMWD Explanation of Requirement

RWMD provides guidance on the meeting the external dose rate requirements. Where waste packagers encounter difficulties in meeting the shielding requirements, several options may be considered. These include:

- storage of wastes prior to transport to gain benefit from radioactive decay;
- use of an immobilising material with good shielding properties;
- increasing the shielding provided by the container by increasing wall thickness and/or the use of an annular grouted wasteform;
- reduction of package waste loadings;
- ensuring the uniform distribution of activity throughout the package;
- segregation of high activity items and placing them in the centre of the waste package.

RWMD caution that whichever method is used to meet the shielding requirements it does not affect other limits for the radionuclide contents of the containers, for example those set by heat output.

5.16.3 Issues Relevant to the Management of SDP Wastes

The RWMD wasteform guidance on external dose rates should be read in conjunction with the waste package guidance on external dose rates provided in Section 4.2 of this report.

As discussed in Section 4.2 of this report, compliance with the RWMD requirement for a 3m^3 box transport package not to exceed specified external dose rate limits is not anticipated to be problematic. Since the waste package and wasteform guidance both deal with the same issues, compliance with the RWMD requirement for a 3m^3 box wasteform not to exceed specified external dose rate limits is not anticipated to be problematic.

5.17 Criticality Safety

The purpose in specifying criticality control measures is to ensure that there will not be a criticality hazard during the various waste management stages, specifically during long term disposal in the GDF.

5.17.1 RWMD Requirement

The presence of fissile materials, neutron moderators and reflectors in the waste package shall be controlled to ensure that they do not present a criticality safety hazard during any of the active stages of their long-term management. It shall also be ensured that, following closure of a GDF, the possibility of local accumulation of fissile material such as to produce a neutron chain reaction is not a significant concern to the long-term performance of a GDF.

5.17.2 RWMD Explanation of Requirement

Waste packagers are responsible for developing operating arrangements consistent with the appropriate assessment and for providing objective evidence in the form of criticality compliance assurance documentation (CCAD). The CCAD must demonstrate how fissile material will be controlled to meet levels defined in the relevant CSA. Information on the structure and the content of CCAD is contained in [Ref. #15]

[Ref. #15] states that not all packaging proposals may require a formal CCAD of the type described in the guidance document. Many waste streams contain little or no fissile material and RWMD acknowledge that that there may be little benefit in the production of CCAD for packaging proposals for such streams. Waste packagers are therefore at liberty to present arguments as to the necessity of a fully developed CCAD for specific waste streams containing a total of less than a *de minimus* level of fissile material, and that would not be capable of producing waste packages containing more that the generic screening level. In the event of such arguments being accepted by RWMD, a statement of justification, for inclusion in the DSC, will be required in lieu of a fully developed CCAD. RWMD would require such arguments to made, and accepted, as part of the Interim Stage LoC assessment.

For guidance purposes, waste streams containing a total mass of fissile material of less than the generic screening level of 50g Pu-239 or equivalent, may not require a fully developed CCAD of the kind described in this document. However, in the case of packaging proposals involving the use of shielded waste packages, the IAEA Transport Regulations limit to allow for the exception from the requirements for packages containing fissile material (i.e. no more than 15g total fissile material) should be used.

It should be noted however that the lack of significant quantities of fissile material in a waste stream will not always obviate the need for a fully developed CCAD. Controls may have to be placed on the packaging of waste streams containing large quantities of materials that may lead to the enhanced accumulation of fissile materials in the postclosure period (e.g. ion exchange resins). The significance of such materials and their quantities and the need for any requirements for controls will be assessed by RWMD in response to the Conceptual Stage LoC submission.

5.17.3 Issues Relevant to the Management of SDP Wastes

The RWMD wasteform guidance on criticality should be read in conjunction with the waste package guidance on criticality provided in Section 4.12 of this report.

It would appear that there is no requirement a formal criticality compliance assurance document (CCAD), since the quantity is fissile material is negligible. However, discussions need to be held with RWMD to confirm that there is no requirement for a CCAD.

As discussed in Section 4.12 of this report, compliance with the RWMD criticality requirements for a 3m^3 box waste package is not anticipated to be problematic. Since the waste package and wasteform guidance both deal with the same issues, compliance with the RWMD criticality requirement for a 3m^3 box wasteform is not anticipated to be problematic.

5.18 Summary and Conclusions

A review was conducted of the requirements of the Wasteform Specification, to determine if any of them represent significant threats to the use of the $3m^3$ box waste package as MoD's preferred option for packaging of SDP ILW. The results are summarised below.

- The physical immobilisation requirement can be met by the use of an encapsulating matrix (e.g. cement). A wasteform encapsulation strategy may need to be produced. Particulates (e.g. CRUD) and entrained gases should be avoided.
- The requirement to immobilise radionuclides and particulates can be met by grouting the waste.
- The requirement to ensure that release limits will not be breached in the event of an impact accident can be met if the waste is grouted and essentially monolithic. Particulates (e.g. CRUD) should be avoided.
- The requirement to ensure that release limits will not be breached in the event of a fire accident will be met since there is no intention to put combustible items into the waste package. Combustible materials (e.g. resins) should be excluded or made safe.
- The requirement to take reasonable measures to exclude free liquids when packaging the wastes should not be onerous, since degradation of the SDP ILW will not produce significant quantities of free liquids. However, if wet processes are deployed for size reduction of the RPV, additional care must be taken to avoid the presence of free liquids.
- The requirement to design the wasteform to provide the necessary mechanical and physical properties (including mechanical strength) can be met by immobilisation of the waste.
- The requirement to minimise voidage inside a waste package is an operational issue which should be easily met.
- The mass-transport properties of the wasteform (e.g. diffusivity, permeability and leachability) need to be established as part of the selection of an immobilisation medium. Compliance with the requirement to ensure that a wasteform is encapsulated inside a medium with acceptable mass-transport properties is not anticipated to be problematic.
- Compliance with the requirement to ensure that a wasteform is encapsulated inside a medium with acceptable homogeneity and uniformity properties is an operational issue and may involve trials. Compliance is not anticipated to be problematic.
- The requirement to ensure that a wasteform has acceptable thermal conductivity properties within an acceptable range needs further assessment, but compliance is not anticipated to be a difficult issue.
- Minimising or excluding a range of materials which could detrimentally affect the chemical containment of the wasteform is not anticipated to be problematic. CRUD, resins, plastics, paper, wood, decontamination chemicals and materials with a low pH which could reduce the alkalinity of the GDF backfill should be avoided. RWMD must be consulted if the intention is to use cement additives.

- Excluding hazardous materials such as pyrophoric materials; oxidising materials; flammable liquids and gases; explosive materials; and sealed and/or pressurised containers is an operational issue which should not be difficult to respect.
- Gas generation is addressed under both the Waste Package and Wasteform Specifications. The latter provides additional guidance on minimising gas generation by for example, use of inhibitors and other methods. The conclusion from review of the Waste Package Specification was that compliance should not be problematic. The same conclusion was reached after review of the Wasteform Specification.
- Wasteform evolution could result in corrosion to produce powders and gases, which could have an adverse impact on the performance of the waste package. Magnesium, aluminium and uranium react with grout to produce hydrogen and should therefore be excluded. Assessment will need to be carried out, but compliance is not anticipated to be problematic.

None of the above represents a significant threat to the use of the 3m^3 box waste package as MoD's preferred option for packaging of SDP ILW.

The above review also identified a number of key issues which need to be addressed as part of the RWMD LoC process. These are listed in Annex 4.

6. LIFECYCLE OF 3M^3 BOX WASTE PACKAGE

The various phases of the lifecycle of the 3m^3 box are identified and discussed below, in order to identify issues and associated risks which could be a significant threat to the adoption of the 3m^3 box waste package for SDP ILW. This review is complementary to the reviews reported in Sections 4 and 5 of this report, which address the waste package and Wasteform Specifications.

This review starts at the pre-concept stage of the 3m^3 box and finishes with disposal of SDP ILW at the GDF inside a 3m^3 box waste package. The principal activities associated with the use of the 3m^3 box during each phase are defined and any associated risks of significance are identified and discussed.

This is not intended to be a comprehensive review of lifecycle waste management issues or a structured risk assessment. The focus of this section is on identification of threats to the use of the 3m^3 box waste package as MoD's preferred option for packaging of SDP ILW, particularly those threats which are significant enough to prevent the 3m^3 box waste package from being used.

6.1 Pre-Concept Phase

This phase is defined as the start of the process, during which preliminary paper studies, such as optioneering and risk assessments are carried out.

There is a risk is that the basis for selection of the 3m^3 box is based on inaccurate data and assumptions and that this produces a flawed recommendation to use the 3m^3 box waste package.

Mitigation includes ensuring that whenever new information (e.g. on the waste inventory) become available, the implications of the new data are investigated to establish its impact on previous assumptions and decisions.

Optioneering has already been carried out and the 3m^3 box waste package has been chosen as the MoD preferred option for SDP ILW. The optioneering process made use of data and assumptions which were the best available at the time, but recognised to be inaccurate. The major uncertainty was the accuracy of the waste inventory. Work is now in hand to establish a radionuclide fingerprint and derive a more accurate inventory.

If the inventory work shows that the radionuclide inventory is less than that previously assumed, this would probably not have an adverse impact on the use of the 3m^3 box waste package. Demonstration of compliance with the RWMD waste package and wasteform requirements, particularly those associated with dose rates, may well be easier. There is also the possibility that some other waste containers, (e.g. those classified as IP-2) would become more attractive, but are unlikely to negate the use of the 3m^3 box.

If the inventory work shows that the radionuclide inventory, in particular the Co-60 content, is higher than that previously assumed, this could have an impact on meeting permissible activity and dose rate limits. At Co-60 levels above 4 E16 Bq, permissible activity limits would be exceeded (see Section 4.1) and at Co-60 levels above 2E18 Bq, dose rate limits could be exceeded (see Section 4.2). Increases of such magnitude are considered highly unlikely.

Assuming that the revised inventory is not greater than the existing one by several orders of magnitude, none of the above considerations represents a significant threat to the use of the $3m^3$ box waste package as MoD's preferred option for packaging of SDP ILW.

6.2 Concept Phase

This is defined as the phase during which an RWMD concept Letter of Compliance (LoC) would be sought for the waste packaging plant.

There is a risk is that the information provided to RWMD as part of the LoC process contains inaccurate data and assumptions and this results in deficiencies in the design of the waste packaging plant.

Mitigation includes ensuring that whenever new data become available, the implications are investigated to establish its impact on the design of the waste packaging plant.

As part of the LoC process, information would be sought by RWMD on the following:

- Origin of the waste;
- Project history;
- Project plans;
- Waste characteristics;
- Waste packaging process;
- Package contents;
- Waste package properties and characteristics;
- Waste package evolution;
- Interim storage arrangements; and
- Quality assurance arrangements; and demonstration of compliance with RWMD requirements.

The quality of much of the supplied information will depend on good quality waste characterisation data.

Supporting information on some issues, such as the interim storage arrangements have yet to be gathered.

None of the above considerations represents a significant threat to the use of the $3m^3$ box waste package as MoD's preferred option for packaging of SDP ILW.

6.3 3m^3 Box Design

This is defined as the phase during which the 3m^3 box waste package is designed. This could be carried out in conjunction with the design of the wasteform and possibly also with the design of the waste packaging plant.

There is a risk that the 3m^3 box waste package design is changed to one which does not meet the requirements of the project.

The mitigator is not to change any aspect of the designs of the 3m^3 box or the overpack. If existing designs are non-optimum for packaging of SDP ILW, this could lead to a change in the design. The risk of changing the design to one which does not meet the requirements of the project will be minimised if RWMD are consulted, in a timely manner, if design changes are being contemplated.

A decision needs to be made on whether to deviate from existing package designs, or to embrace an existing design.

The transport package includes the 3m^3 box together with the SWTC transport overpack. The major advantage of not changing the package or overpack designs is that existing experience, test information, drawings etc. already exist and, if available, would reduce the amount of time and money required. Their use could also make the approvals process easier. A disadvantage is that existing designs may represent inefficient ways of packaging and transporting the SDP ILW.

For example, the assumed transport package which uses an SWTC-285 overpack, could accommodate far higher levels of Co-60 than those so far reported. An overpack with less shielding (and less weight) would not have a significant adverse effect on the performance of the transport system. On the contrary, it could result in a small increase in the waste package payload. However, changing designs would involve additional effort, money and time.

None of the above box design issues represents a significant threat to the use of the 3m^3 box waste package as MoD's preferred option for packaging of SDP ILW.

6.4 3m^3 Box Fabrication

This is defined as the period during which the 3m^3 box is fabricated and the finished product transported to a store pending use at the packaging plant.

There is a risk that the package is fabricated using the wrong materials and by organisations not familiar with the fabrication of such items.

This is mitigated by following the guidance provided by RWMD on the types of metals to be used for fabrication of the 3m^3 boxes and by using only those manufacturers who have been employed by other users for fabrication of the 3m^3 boxes.

There is a risk that handling of the fabricated packages under the wrong conditions could accelerate the onset of corrosion mechanisms.

This is mitigated by following the guidance provided by RWMD and existing users of $3m^3$ box waste packages.

A store is required for empty boxes prior to their use at the waste loading plant. The environmental conditions inside this store should be optimised in line with manufacturers and RWMD recommendations.

Advice on storage issues should be sought from RWMD and existing users of $3m^3$ box waste packages.

None of the above box fabrication issues represents a significant threat to the use of the $3m^3$ box waste package as MoD's preferred option for packaging of SDP ILW.

6.5 Manufacture of $3m^3$ Box Waste Packages

This is defined as the phase during which the $3m^3$ box is transported to the packaging plant, set in position, packaged with waste, grouted, lidded, checked and transported to a buffer store within the packaging plant. The packaging process could include the use of furniture. The grouting process will probably include addition of grout to the waste, creating an annulus round the waste and adding grout as a cap on top of the waste. The duration of buffer storage could be up to a couple of years.

There are risks associated with manufacture of the waste package. A considerable number of operations are carried out during this phase, like for example positioning of waste onto the furniture, placing the furniture in the box and grouting and lidding the box. Each of these operations carries the risk that the $3m^3$ wasteform and hence the box is deficient in some of its properties and that it could be non conforming. This might not be apparent until later on in the waste management cycle.

The risks can be mitigated to a large extent by working closely with experienced personnel, including those from RWMD and the nuclear power industry. By virtue of the LoC process, benefit will be obtained from the RWMD experience. Input from other experienced users should be sought as and when required.

Formulation trials may be required to determine the optimum grout composition for the SDP ILW.

None of the above manufacturing issues represents a significant threat to the use of the $3m^3$ box waste package as MoD's preferred option for packaging of SDP ILW.

6.6 Transport of $3m^3$ Box Waste Packages

This is defined as the phase during which the $3m^3$ box waste package is transported inside its overpack, as a transport package on the public highways, by rail and/or by road to an off-site location (to be determined) and placed inside an interim store.

There is a risk that the transport package will not conform to the UK transport regulations, (specifically those which address the package dose rate requirements) and as a consequence, the relevant authorities do not approve the transport.

Mitigation includes the studies carried out (in this document) to establish that the dose rates and the activity content should be well within specified limits. Work needs to be undertaken by the operational teams to ensure that the packages comply with the dose rate limits and other transportation requirements.

Public highway transport issues were taken account of in the formulation of the RWMD guidance documentation, therefore compliance with the RWMD guidance should satisfy the majority (if not all) of these requirements.

Recent communications indicate that if it is the intention of the SDP to deviate from the IAEA Transportation Regulations (Ref. #4 of Appendix 1), the Defence Nuclear Safety Regulator (DNSR) should be informed. MoD will need to obtain Competent Authority (CA) approval for the use of any new or modified Type B package. If the package design is the same as that used in civil applications, CA approval will be required from the Department for Transport (DfT). Because there is a Memorandum of Understanding (MoU) between DNSR and DfT, it would be logical if both organisations would conduct a joint review of package proposals. If a “Special Arrangement” is sought, for example to obtain a waiver for some aspects of the transport regulations, (e.g. if large loads are being transported), arrangements should be made for early engagement of DNSR.

The RWMD guidance on waste package testing requirements is not clear. Evidence of package testing will be required in support of obtaining approvals. RWMD need to be consulted to ensure that all of the relevant tests are carried out and that relevant documentary evidence is available.

None of the above transport issues represents a significant threat to the use of the 3m^3 box waste package as MoD’s preferred option for packaging of SDP ILW.

6.7 Long Term Interim Storage of 3m^3 Box Waste Packages

This is defined as the phase during which the 3m^3 box waste package is stored for periods of up to 150 years, awaiting transportation to the GDF. A suitable store needs to be identified for the 3m^3 box waste packages. This could have integral shielding as part of the structure of the building or provision could be made for each container to have its own shielding. During this period, the packages will need to be periodically inspected to assess package integrity.

There is a risk that the package might fail during long term storage, producing unacceptable radiation and/or contamination leaks. This could happen, for example, if the package corrosion rates were faster than predicted. Leakages could be in the form of gases.

Mitigation includes following the RWMD guidance on package manufacture and passive safety to ensure that the integrity of the waste package is maintained over long timescales.

The packages will need to be made passively safe, following the guidance provided by RWMD.

None of the above storage issues represents a significant threat to the use of the $3m^3$ box waste package as MoD's preferred option for packaging of SDP ILW.

6.8 Transport of $3m^3$ Box Waste Packages to the GDF

This is defined as the phase during which the $3m^3$ box waste package is removed from interim storage and transported to the GDF. The transport could be on the public highway or on private property, depending on the location of the GDF.

There is a risk, that by the time the package is ready to be transported to the GDF, it is not in a suitable condition to be transported because of the impact of corrosion or other detrimental mechanisms.

This risk is mitigated to a large extent by following the wasteform evolution, immobilisation, package integrity, voidage and other guidance provided by RWMD to ensure the passive safety of waste packages.

None of the above transport issues represents a significant threat to the use of the $3m^3$ box waste package as MoD's preferred option for packaging of SDP ILW.

6.9 Emplacement of $3m^3$ Box Waste Packages in the GDF

This is defined as the phase during which the $3m^3$ box waste package is accepted and emplaced in the GDF for final disposal. The process could involve checking the waste package, accepting it into the GDF by comparison with the waste acceptance criteria, removal from its transport overpack and emplacing the $3m^3$ box waste pacakge in the GDF for final disposal.

There is a risk, that once it is at the GDF, the package might not be compliant with the relevant waste acceptance criteria. This is considered a low probability risk, but one with high consequences, since other users could also be similarly be affected. The degree of risk should diminish with time, once the site for the GDF has been selected. All waste packages, regardless of type, are susceptible to this risk. Given the long timescales involved, it is difficult to comment further.

This risk is mitigated to some extent by following the guidance provided by RWMD to ensure the passive safety of waste packages.

None of the above emplacement issues represents a significant threat to the use of the $3m^3$ box waste package as MoD's preferred option for packaging of SDP ILW.

6.10 Summary and Conclusions

A review of the various phases in the lifecycle of the $3m^3$ box waste package has identified a number of technical risks, which are summarised below, together with possible mitigating actions.

- There is a risk is that the basis for selection of the box is based on inaccurate data and assumptions and that this produces a flawed recommendation to use the $3m^3$ box waste package. Mitigation includes ensuring that whenever new information (e.g. on the waste inventory) become available, the implications of the new data are investigated to establish its impact on previous assumptions and decisions.
- There is a risk is that the information provided to RWMD as part of the LoC process contains inaccurate data and assumptions and this results in deficiencies in the design of the waste packaging plant. Mitigation includes ensuring that whenever new data become available, the implications are investigated to establish its impact on the design of the waste packaging plant.
- There is a risk that changes are made to the package design to optimise the waste package for SDP ILW and the new design does not meet requirements. Mitigation includes not changing the package design. If changes are to be made, this should be done in consultation with RWMD.
- There is a risk that $3m^3$ box is fabricated using the wrong materials and by organisations not familiar with the fabrication of such items. Mitigation includes using materials advised by RWMD and dealing only with experienced manufacturing companies.
- There many risks associated with manufacture of the waste package. Operations such as positioning of waste onto the furniture, placing the furniture in the box and grouting and lidding the box and others could go wrong and result in non conforming packages. Mitigation includes working closely with experienced personnel, including those from RWMD and the nuclear power industry.
- There is a risk that the waste package will not conform to the UK transport regulations and therefore cannot be transported off-site. It has already been established that the dose rates for packages placed at the centre of the box should be well within specified limits, but it must be ensured that this will occur in practice. Mitigation includes ensuring that the robustness of the package to changes in the geometry of the waste, grout composition and other factors is well understood by the operational teams and that these tolerances are respected.
- There is a risk that the package might fail during long term storage, producing unacceptable radiation and/or contamination leaks. Mitigation includes following the RWMD guidance on package manufacture.
- There is a risk, that by the time the package is ready to be transported to the GDF, the onset of corrosion or other reasons make it unfit for transportation. Mitigation includes following the RWMD guidance, particularly that on wasteform evolution, immobilisation and package integrity and voidage.
- There is a risk that once the package is at the GDF, it might not be compliant with the relevant waste acceptance criteria. This is considered a

low probability risk, but one with high consequences, since other users could also be similarly be affected. The degree of risk should diminish with time, once the site for the GDF has been selected. All waste packages, regardless of type, are susceptible to this risk. Mitigation includes following the RWMD guidance.

None of the above risks represent a significant threat to the use of the 3m^3 box waste package as MoD's preferred option for packaging of SDP ILW.

7. SUMMARY AND CONCLUSIONS

The principal objective of this study was to identify any issues which could prevent or significantly hinder deploying the 3m^3 box waste package as MoD's preferred option for SDP ILW.

Three separate studies were carried out in order to determine the key technical issues associated with the packaging SDP ILW inside a 3m^3 box and to assess whether any of these issues was significant enough to prevent this waste package from being used.

The first study was a detailed review of the requirements of the RWMD guidance documentation relevant to the 3m^3 box waste package [Ref. #6]. These included requirements, limits and/or advice on the following topics: activity content; dose rate; heat output; surface contamination; dimensions; lifting features; mass; gas generation; venting arrangements; integrity; criticality safety; impact and fire performance; stackability; identification; physical protection for nuclear security and quality management.

No significant threats to the use of the 3m^3 box waste package were identified from any of the waste package requirements/limits. It is cautioned that many of these requirements will need to be reviewed whenever new waste characterisation and other data become available and all will need to be discussed in detail with RWMD.

Calculations using the MicroShield software package indicated that dose rates both at the surface of the 3m^3 box transport package and at a distance of 1 metre from the package were acceptably low. The results indicate that the ILW from a nuclear submarine can be packaged and transported in conformance with the UK transport regulations, without the need for decay storage.

It was recognised that work is in hand to establish a radionuclide fingerprint and derive a more accurate inventory. In the unlikely event that this shows that the Co-60 activity content is higher than expected, the dose rates from the 3m^3 box waste package would probably still be compliant with specified limits.

The second study was a detailed review of the requirements of the RWMD guidance documentation relevant to the wasteform inside a 3m^3 box waste container [Ref. #8].

The Wasteform Specification includes requirements, limits and/or advice on the following topics: physical immobilisation; immobilisation of radionuclides and particulates; response to an impact accident; response to a fire accident; free liquids; mechanical and physical properties; mechanical strength; voidage; mass-transport properties; homogeneity/uniformity; thermal conductivity; chemical containment; hazardous materials; gas generation; wasteform evolution; external dose rate and criticality safety.

The majority of the issues and limits addressed above are relevant to all wasteforms regardless of which waste container is used. The properties of the wasteform and the waste container should each be adequate in their own right and they should also be complementary to each other. If the wasteform is non compliant, the waste package will also be non compliant.

Both the waste package and wasteform specifications were formulated by RWMD to take account of the total lifecycle of the waste package, from design, through to acceptance into the GDF.

No significant threats to the use of the $3m^3$ box waste package were identified from any of the wasteform requirements/limits.

The third study addressed the risks associated with the activities performed during the various stages of the lifecycle of the $3m^3$ box. These stages included the concept phases, design, fabrication, manufacture/use, buffer storage, transport, interim storage and acceptance into the GDF.

A range of scenarios was addressed. These included: inaccurate input data and assumptions, changes to the package design, fabrication using unacceptable materials and inexperienced operators; operational issues associated with the creating the waste package (i.e. addition of waste, grouting lidding, checking); compliance with transport requirements, principally dose rate limits; integrity during long term storage; and non compliance with the GDF waste acceptance criteria.

No significant threats to the use of the $3m^3$ box waste package were identified from analysis of the lifecycle of the box, starting with its design and ending with its emplacement in the GDF.

In summary, none of the three studies described above revealed any significant threats to the use of the $3m^3$ box waste package as MoD's preferred option for packaging of SDP ILW.

The review of the RWMD specifications resulted in the identification of a number of key technical issues which need to be addressed as part of the RWMD LoC process. These are tabulated in Annex 4.

8. RECOMMENDATIONS

The principal recommendation from this study is shown below.

1. Based on comprehensive reviews of RWMD requirements/limits and on considerations relating to the lifecycle of the $3m^3$ box, during which no significant threats to its use were identified, MoD should formally confirm that the preferred option for packaging of SDP ILW is the $3m^3$ box waste package.

A number of secondary recommendations are shown below.

2. MoD should instigate a review of the impact of improved waste inventory data when they become available. This should include gaining an understanding of the role which IP-2 packages might play, particularly for disposal of LLW to the GDF or LLWR.
3. MoD should review Annex 4 and the relevant RWMD specifications to gain a better understanding of the documentation requirements of the LoC process. MoD should ensure that the key documentation identified in Annex 4 is produced to a timetable which is consistent with the Loc process.
4. MoD should continue to make best use of the relevant experience of RWMD and civil nuclear industry organisations.
5. If possible, MoD should move forward with existing designs of boxes and overpacks. If this is not possible, MoD should work closely with RWMD to ensure that any revised designs will be fit for purpose.
6. When reliable waste inventory data become available, MoD should evaluate the use of the $3m^3$ box waste package for PWR2 reactor waste.

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Annex 1: MicroShield dose rate calculations (#1 to #4)

[redacted]

[redacted]

[redacted]

[redacted]

[redacted]

[redacted]

[redacted]

Calculation 1:
Dose Rate at the Surface of an SWTC Enclosing a 3m^3 Box Waste Package Containing [redacted]

Calculation 2: Dose Rate at 1 Metre from an SWTC Enclosing a 3m^3 Box Waste Package Containing 5[redacted]

Calculation 3:
Dose Rate at the Surface of an SWTC Enclosing a 3m^3 Box Waste Package Containing [redacted]

Calculation 4:
Dose Rate at 1 Metre from an SWTC Enclosing a 3m^3 Box Waste Package Containing [redacted]

Annex 2: MicroShield dose rate calculations (#5 to #10)

Calculation #5:

[redacted]

[redacted]

[redacted]

[redacted]

[redacted]

[redacted]

[redacted]

[redacted]

[redacted]

Calculation #5
Dose rate at the surface of an SWTC enclosing a 3m^3 Box Waste Package containing 1[redacted] positioned against the box wall

Calculation #6:
Dose rate at 1 metre from an SWTC enclosing a 3m^3 Box Waste Package containing [redacted] Co-60 positioned against the box wall

Calculation #7

Dose rate at the surface of an SWTC enclosing a 3m^3 Box Waste Package containing [redacted] Co-60 positioned in the middle of the box. The 69 cm of grout has been replaced by 69 cm of air

Calculation #8

Dose rate from a point source containing 1[redacted] positioned against the SWTC

Calculation #9

Dose rate from a point source containing [redacted] Co-60 positioned against the SWTC

Calculation #10
Source strength positioned in the middle of the box required to produce a 2 mSv/h dose rate at the surface of an SWTC enclosing a 3m^3 Box Waste Package

ANNEX 3: IAEA Transport package testing Requirements

NORMAL CONDITIONS OF TRANSPORT

The IAEA Regulations for the Safe Transport of Radioactive Material 2009 [Ref. #3] specify that specimens of a waste package shall be subjected to a free drop test, a stacking test and a penetration test, preceded in each case by the water spray test. More details are provided below.

Water Spray Test

The specimen shall be subjected to a water spray test that simulates exposure to rainfall of approximately 5 cm per hour for at least one hour.

Drop Test

The target for the drop test shall be a flat, horizontal surface of such a character that any increase in its resistance to displacement or deformation upon impact by the specimen would not significantly increase damage to the specimen.

The specimen shall drop onto the target so as to suffer maximum damage in respect of the safety features to be tested:

The height of the drop measured from the lowest point of the specimen to the upper surface of the target shall not be less that the distance specified in the following Table A3.1 for the applicable mass.

Table A3.1

Package Mass (kg)	Free Drop Distance (m)
Package mass < 5000	1.2
5000 <= package mass < 10000	0.9
10 000 <= package mass < 15000	0.6
15000 < = package mass	0.3

Stacking Test

Unless the shape of the packaging effectively prevents stacking, the specimen shall be subjected, for a period of 24 hours, to a comprehensive load equal to the greater of the following:

a) A total weight equal to 5 times the maximum weight of the package; and
b) The equivalent of 13 kPa multiplied by the vertically projected area of the package.

The load shall be applied uniformly to two opposite sides of the specimen, one of which shall be the base on which the package would typically rest.

Penetration Test

The specimen shall be placed on a rigid, flat, horizontal surface which will not move significantly while the test is being carried out:

a) A bar 3.2 cm in diameter with a hemispherical end and a mass of 6 kg shall be dropped and directed to fall, with its longitudinal axis vertical, onto the centre of the weakest part of the specimen, so that, if it penetrates sufficiently far, it will hit the containment system. The bar shall not be significantly deformed by the test performance.

b) The height of drop of the bar measured from its lower end to the intended point of impact on the upper surface of the specimen shall be 1 metre.

ACCIDENT CONDITIONS OF TRANSPORT

The IAEA Regulations for the Safe Transport of Radioactive Material 2009 specify that specimens of a waste package shall be subjected to mechanical, thermal and water immersion tests. More details are provided below.

The specimen shall be subjected to the cumulative effects of the tests specified as mechanical and thermal Tests. Following these tests, either this specimen or a separate specimen shall be subjected to the effect(s) of the water immersion test(s).

The purpose of the mechanical and thermal tests is to impose on the package damage equivalent to that which would be observed if the package were to be involved in a severe transport accident. The mechanical and thermal tests are applied to the same specimen sequentially to correspond with the order expected in an accident scenario. The test requirements specified by the IAEA Transport Regulations as follows:

Mechanical Test

The mechanical tests for Type B packages consist of three different drop tests and each specimen shall be subjected to the applicable drops. The order in which the specimen is subjected to the drops shall be such that, on completion of the mechanical test, the specimen shall have suffered such damage as will lead to maximum damage in the thermal test which follows:

- Drop 1, the specimen shall drop onto the target (as defined previously) so as to suffer maximum damage, and the height of the drop measured from the lowest point of the specimen to the upper surface of the target shall be 9 metres.
- Drop 2, the specimen shall drops so as to suffer maximum damage onto a bar rigidly mounted perpendicularly on the target. The height of the drop measured from the intended point of impact of the specimen to the upper surface of the bar shall be 1m. The bar shall be of solid mild steel of circular section (15.0 ± 0.5) cm in diameter and 20 cm long unless a

longer bar would cause greater damage, in which case a bar of sufficient length to cause maximum damage shall be used. The upper end of the bar shall be flat and horizontal with its edge rounded off to a radius of not more than 6 mm.

- Drop 3, the specimen shall be subjected to a dynamic crush test by positioning the specimen on the target so as to suffer maximum damage by the drop of a 500 kg mass from 9 metres onto the specimen. The mass shall consist of a solid mild steel plate 1 metre by 1 metre and shall fall in a horizontal attitude. The height of the drop shall be measured from the underside of the plate to the highest point of the specimen.

Thermal Test

The specimen shall be in thermal equilibrium under conditions of ambient temperature of 38°C, subject to the solar insulation conditions specified in Table A3.2 and subject to the design maximum rate of internal heat generation within the package from the radioactive contents.

Table A3.2

Case	Form and location of surface	Insulation for 12 hours per day W/m^2)
1	Flat surfaces transported horizontally – downward facing	0
2	Flat surfaces transported horizontally – upward facing	800
3	Surfaces transported vertically	200
4	Other downward facing (not horizontal) surfaces	200
5	All other surfaces	400

Alternatively, any of these parameters are allowed to have different values prior to and during the test, provided due account is taken of them in the subsequent assessment of package response.

The thermal test shall then consist of exposure of a specimen for a period of 30 minutes to a thermal environment which provides a heat flux at least equivalent to that of a hydrocarbon fuel / air fire in sufficiently quiescent ambient conditions to give a minimum average flame emissivity coefficient of 0.9 and an average temperature of at least 800°C. The specimen must be fully engulfed, with a surface absorptivity coefficient of 0.8 or that value which the package may be demonstrated to possess if exposed to the fire specified. This is followed by exposure of the specimen to an ambient temperature of 38 °C, subject to the solar insulation conditions specified in Table A3.2 above. This is subject to the design maximum rate of internal heat generation within the package by the radioactive contents for a sufficient period to ensure that temperatures in the specimen are everywhere decreasing and/or are approaching initial steady state conditions.

Alternatively, any of these parameters are allowed to have different values following cessation of heating, provided due account is taken of them in the subsequent assessment of package response.

During and following the test the specimen shall not be artificially cooled and any combustion of materials of the specimen shall be permitted to proceed naturally.

Water Immersion Test

The specimen shall be immersed under a head of water of at least 15 metres for a period of not less than eight hours in the attitude which will lead to maximum damage. For demonstration purposes, an external gauge pressure of at least 150 kPa shall be considered to meet these conditions.

ANNEX 4: SUMMARY OF KEY ISSUES

Below is a summary of technical issues, which will need to be addressed to satisfy the RWMD requirements under the LoC process. These were identified in Sections 4 and 5 of this document by review of RWMD requirements. Even if some of these issues are not relevant to the disposal of SDP wastes, documentary evidence will need to be provided to demonstrate this.

Column B lists the specific requirement in the RWMD specifications which led to identification of the issue.

Column C states whether the issues were identified from review of the Waste Package or the Wasteform Specification.

Column D lists the issues which should be addressed in order to satisfy future RWMD requirements.

The issues are grouped under the RWMD requirements contained in Column B.

Table 7.1: Key Issues

A	B	C	D
#	**Criteria**	**Package/Wasteform**	**Key Issues to be Considered**
1A	Activity Content	Wasteform	• Waste Characterisation: − ILW for disposal in the GDF. − LLW for disposal in the GDF. − LLW for disposal at LLWR. − CRUD. − Resins. − Active and non active contents. • Compliance with limits.
1B	Activity Content	Waste Package	• Total package activity content. • Key radionuclides for transport and disposal. • Compliance with limits.
2A	Dose Rate	Waste Package	• Confirmation of package dose rate model. • Optimisation of package manufacture (including immobilisation, furniture, SWTC). • Compliance with limits.
2B	Dose Rate	Waste Form	• If difficulties encountered meeting requirements, seek RWMD advice on available options (e.g. reduction in payloads, segregation of high activity items and placing them at centre of waste package)
3A	Heat Output	Waste Package	• Assessment of package heat output. • Compliance with limits.
3B	Thermal	Waste Form	• Calculation of thermal conductivity of wasteform. • Demonstrate that wasteform thermal

[redacted]

A	B	C	D
#	**Criteria**	**Package/Wasteform**	**Key Issues to be Considered**
			conductivity is within acceptable range. • Compliance with limits.
4	Surface Contamination	Waste Package	• Compliance with limits.
5	Dimensions	Waste Package	• Compliance with limits.
6	Lifting Features	Waste Package	• Compliance with requirements.
7	Mass	Waste Package	• Transportation modes (road and/or rail). • Optimisation of payload. • Compliance with limits.
8A	Gas Generation	Waste Package	• Corrosion. • Entrained gases (including tritium). • Radiolysis of water. • Compliance with limits.
8B	Gas Generation	Waste Form	• Assessment of gas generation mechanisms and types and quantities of gases produced. • Address tritium issues (See [Ref. #14]. • Compliance with requirements
8C	Mass-Transport Properties	Waste Form	• Address gas permeation and containment of water soluble radionuclides. • Demonstrate that properties of wasteform are within acceptable range. • Provide information on the diffusivity, permeability and leachability of the wasteform. • Compliance with requirements.
9	Venting	Waste Package	• Compliance with requirements.
10 A	Integrity	Waste Package	• Compliance with requirements.
10 B	Voidage	Wasteform	• Demonstrate that properties of wasteform are within acceptable range. • Provide information on the macroscopic voidage within the wasteform. • Compliance with requirements.
10 C	Homogeneity / Uniformity	Wasteform	• Demonstration trials. • Compliance with requirements.
11 A	Criticality Safety	Waste Package	• Compliance with limits.
11 B	Criticality Safety	Wasteform	• Consult RWMD re requirement for a criticality compliance assurance document (CCAD). • Compliance with requirements.
12 A	Impact	Waste Package	• Consult RWMD to determine package impact performance testing requirements. • Take account of IAEA transport requirements. • Compliance with requirements.
12 B	Response to Impact Accident	Wasteform	• Demonstration of absence or immobilisation of particulates.

[redacted]

A	B	C	D
#	**Criteria**	**Package/Wasteform**	**Key Issues to be Considered**
			• Compliance with requirements.
13 A	Fire Performance	Waste Package	• Consult RWMD to determine package fire performance testing requirements. • Take account of IAEA transport requirements. • Compliance with requirements.
13 B	Response to Fire Accident	Wasteform	• Demonstration of absence of combustible and problematic materials. • Waste inventory, to allow derivation of the radionuclide release limits during fire accidents. • Compliance with requirements.
14	Stackability	Waste Package	• Compliance with requirements.
15	Identification	Waste Package	• Compliance with requirements.
16	Physical Protection for Nuclear Security	Waste Package	• Compliance with requirements.
17	Nuclear Materials Safeguards	Waste Package	• Not Applicable.
18	Quality Management System (QMS)	Waste Package	• Set up QMS system at early stage. • Waste Product Specification. • Records • Authorities • Change control. • Periodic Review. • Audits. • Compliance.
19	Physical Immobilisation	Wasteform	• Optioneering. • Strategy. • Demonstration of adequacy (R&D and/or inactive/active trials at packaging plant).
20	Immobilisation of Radionuclides and Particulates	Wasteform	• Compliance with requirements.
21	Free Liquids	Wasteform	• Demonstration of exclusion of free liquids, including materials which might degrade to produce free liquids. • Compliance with requirements.
22	Mechanical and Physical Properties	Wasteform	• Demonstrate that properties of wasteform are within acceptable range. • Provide information on mechanical and physical strength of the wasteform and waste package. • Compliance with requirements.
23	Mechanical Strength	Wasteform	• Demonstrate that properties of wasteform are within acceptable range. • Provide information on mechanical strength of

A	B	C	D
#	**Criteria**	**Package/Wasteform**	**Key Issues to be Considered**
			the wasteform. • Compliance with requirements.
24	Chemical Content	Wasteform	• Identify chemicals in wasteform. • Demonstrate absence of problematic chemicals. • Address: CRUD, resins, plastics, paper, wood, decontamination chemicals and low pH materials. • Compliance with requirements.
25	Hazardous Materials	Wasteform	• Demonstrate that hazardous materials have been excluded or made safe. • Address gases produced by corrosion of wasteform. • Identify and justify any materials which could affect the effectiveness of the GDF. • Compliance with requirements.
26	Wasteform Evolution	Wasteform	• Avoid including problematic materials (e.g. magnesium, aluminium and uranium) in the wasteform. • Consider gradual degradation of metallic wastes and bimetallic corrosion mechanisms. • Use results as input to other studies. • Compliance with requirements.
27	IAEA Package Testing Requirements	Package Normal Conditions	• Consult RWMD to determine testing requirements. • Take account of RWMD impact and fire testing requirements.
28	IAEA Package Testing Requirements	Package Accident Conditions	• Consult RWMD to determine testing requirements. • Take account of RWMD impact and fire testing requirements.
29	Transport	Transportation	• Consult the UK competent authority (the Department for Transport) to discuss transportation requirements including approvals