Geological Disposal


October 2011

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Dr Elizabeth Atherton,
Head of Stakeholder Engagement,
Nuclear Decommissioning Authority (Radioactive Waste Management Directorate),
Curie Avenue,
Harwell Oxford,
Didcot,
Oxon,
OX11 0RH, UK
EXECUTIVE SUMMARY

Introduction
The 2008 White Paper on Nuclear Power¹, together with the preceding consultation², established the process of Generic Design Assessment (GDA), whereby industry-preferred designs of new nuclear power stations would be assessed by regulators in a pre-licensing process. An important aspect of the GDA process is the consideration of the disposability of the higher activity solid radioactive wastes and spent fuel that would be generated through reactor operation and decommissioning. Consequently, the regulators indicated that the Requesting Parties (Westinghouse and EdF/Areva) should obtain, and provide to the regulators, advice on the disposability in a Geological Disposal Facility (GDF) of all higher activity wastes and spent fuel that may arise for new reactors.

The authoritative source in the UK for the provision of such advice is the Radioactive Waste Management Directorate (RWMD) of the Nuclear Decommissioning Authority (NDA). In accordance with regulatory guidance³, Westinghouse and EdF/Areva requested that RWMD provide advice on the disposability of the higher activity wastes and spent fuel expected to arise from the operation and decommissioning of AP1000 and EPR reactor designs.

Westinghouse and EdF/Areva provided information to RWMD on the higher activity wastes and spent fuel and on measures that could be taken to condition and package them. The assessments subsequently undertaken by RWMD considered disposability issues by comparison with appropriate concepts for a GDF, as published in 2003 for intermediate level wastes (ILW) and in 2005 for high level wastes and spent fuel (HLW/SF). These concepts were based on a hard rock geology and have been routinely used as the baseline for disposability assessments under the Letter of Compliance (LoC) process⁴. The safety of transport operations, handling and emplacement at a GDF, and the longer term performance of the system were considered, together with the implications for the size and design of a GDF. The assessments included comparison with legacy wastes and existing spent fuel. The GDA Disposability Assessments for the AP1000 and EPR designs were subsequently issued by RWMD to Westinghouse and EdF/Areva in November 2009⁵,⁶.

The GDA Disposability Assessments concluded that no new disposability issues would arise, as compared with the existing legacy wastes and spent fuel, although a number of detailed matters were identified that would require resolution in due course. At this early stage in reactor licensing and development of operating regimes, packaging proposals are necessarily outline in nature and therefore further examination of detailed issues would be required. It is recognised that, at a later stage in the licensing process, RWMD would expect to assess more specific and detailed proposals through the existing LoC process for endorsing waste packaging proposals.

In February 2011, RWMD published its generic Disposal System Safety Case (DSSC). The generic DSSC comprises a suite of reports providing arguments and illustrative, generic safety assessments regarding the transport, operational and environmental safety of a geological disposal system. At this early stage in the site selection process, the DSSC does not relate to any specific site or disposal facility design, hence the term ‘generic DSSC’. The published generic DSSC also forms the basis against which future LoC assessments will be undertaken.

The generic DSSC supersedes the disposal concepts and assessments used as the basis for the previously published GDA Disposability Assessments. In order to establish the continuing validity of the published conclusions of the GDA Disposability Assessments, they have been revisited to determine whether the generic DSSC materially affects the findings published in 2009.

The GDA Disposability Assessments also estimated the cooling times necessary to allow sufficient radioactive decay that the heat output of packaged spent fuel would be consistent with the temperature limit applied by RWMD. These estimates have not been revised as the temperature limit is unchanged in the generic DSSC.

**Basis of Assessment**

The information relating to reactor designs and waste and spent fuel arisings adopted in the revisited assessments remains the same as reported in 2009. Information was provided by the Requesting Parties for both reactor designs, assuming operation for 60 years with a maximum fuel assembly average irradiation (burn-up) of 65 GWd/tU. Three general categories of higher activity wastes were considered, namely ILW arising from reactor operations, ILW arising from reactor decommissioning, and spent fuel. The proposals for packaging the ILW components included the potential use of containers not previously considered to be standard. Spent fuel was assumed to be packaged into a corrosion-resistant disposal canister holding four fuel assemblies. Both copper and steel were considered as potential canister materials.

Recognising that the generic DSSC does not relate to any specific site, it instead considers examples from a range of disposal concepts that have been developed around the world for various types of wastes and for construction in suitable geological settings. The generic DSSC considers three distinct, illustrative geologies which are judged to be potentially suitable to host a disposal facility for higher activity wastes and which occur in the UK. These are described as follows:

- Higher strength rocks – these would typically comprise crystalline igneous and metamorphic rocks or geologically older sedimentary rocks where any fluid movement is predominantly through discontinuities in the rock mass.
- Lower strength sedimentary rocks – these would typically comprise geologically younger sedimentary rocks where any fluid movement is predominantly through the rock matrix.
- Evaporites – these would typically comprise anhydrite (anhydrous calcium sulphate), halite (rock salt) or other minerals that have been formed by the evaporation of surface water bodies in the geological past. Evaporites are generally found inter-layered with other, lower-strength sedimentary rocks.

The generic DSSC presents designs and associated safety cases for the Baseline Inventory set out in the Managing Radioactive Wastes Safely White Paper, and also considers an Upper Inventory intended to examine alternative waste arising scenarios.

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including a new build nuclear programme of 10GW(e) generating capacity. The wastes from new nuclear build are one contribution to the Upper Inventory considered by the generic DSSC, although this is not intended as a maximum since the eventual installed capacity of a new build programme is not known; for instance energy companies have recently committed to build up to 16GW(e) of new nuclear power stations. The revisited GDA Disposability Assessments reported here have included a more detailed and specific examination of the treatment given to these wastes.

**Disposal Facility Design Assessment**

The Disposal Facility Design Assessment considered implications of new build wastes for the projection of the disposal facility area on the land surface, known as the ‘footprint’. The estimated changes to the footprint reported in the GDA Disposability Assessments have been revisited through a comparison with the footprints associated with the Baseline Inventory and Upper Inventory. The ILW arising from a new build programme of 10GW(e) generating capacity would require an increase in the footprint area of approximately 6% over that required for the Baseline Inventory, whereas that for spent fuel would require an increase of approximately 47%. These are smaller than the changes estimated in the GDA Disposability Assessments (10% for ILW and up to 55% for spent fuel).

In both cases, the new estimates are based on the higher strength rock concept. The footprints for the illustrative example concepts developed for the other geologies are expected to be larger than those for higher strength rock, but the increase due to new build wastes would scale in proportion. As the MRWS process progresses, RWMD will revisit the design in the light of site specific information, when this becomes available.

**Transport Safety**

The transport safety assessments for the original GDA Disposability Assessments were based on comparison of doses and risks with those reported in the 2003 Generic Transport Safety Assessment (GTSA) and the later HLW/SF Transport Safety Assessment based on the GTSA\(^9\)\(^10\). In order to align more closely with international practice in transport safety, the generic DSSC Transport Safety Case was based on a substantially modified approach. In particular, the generic Transport System Safety Assessment (TSSA)\(^11\), developed as part of the generic DSSC, takes credit for the robust design and testing regime required under the IAEA Transport Regulations, resulting in transport packages that are expected to survive accidents without loss of contents.

The transport movements associated with ILW and spent fuel arising from the new build reactors have been compared with those reported in the generic TSSA. For operational and decommissioning ILW arising from a single AP1000, the increase in worker dose is negligible. For the EPR, the percentage increases in dose due to ILW transport are more pronounced. This is due mainly to the estimated dose rates from concrete casks, one of the options put forward for this waste. The transport of spent fuel from both reactor types comfortably meets all dose targets\(^12\), although there are increases of up to 30%.

**Operational Safety**

Since the publication of the GDA Disposability Assessments, the ILW and HLW/SF fault schedules underpinning the previous assessment methodologies have been reviewed and

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updated for the generic DSSC\textsuperscript{13}. In order to evaluate the effect of these changes on the operational safety assessments carried out for the GDA Disposability Assessments, the most radiologically significant waste streams were re-assessed for both the AP1000 and EPR designs.

Using the DSSC assessment basis, the modified methodology, together with revised impact and fire RFs\textsuperscript{14}, gave lower worker doses for severe impact faults. The highest doses resulted from EPR operational wastes in non-standard concrete casks.

The consequences of spent fuel handling and emplacement activities obtained with the revised DSSC methodology were very low, and were consistent with those reported in the GDA Disposability Assessment. The higher strength rocks are bounding for impact accidents due to the larger stack heights for ILW, whereas the concepts all performed similarly in fire accidents.

**Post-Closure Safety Assessment**

The GDA Disposability Assessments used a screening methodology based on the results of the groundwater assessment model described in the Generic Post-Closure Performance Assessment (GPA), published in 2003 and based on disposal of ILW in a hard-rock geology\textsuperscript{15}. For the generic DSSC Post-Closure Safety Assessment (PCSA), a revised groundwater pathway assessment was developed to quantify post-closure risks for all wastes and materials in the Baseline Inventory\textsuperscript{16}. This has been used to determine the impact of disposal of ILW and spent fuel from a new build programme.

Addition of the operational and decommissioning ILW inventories arising from a 10GW(e) fleet of AP1000s or EPRs to the ILW component of the Baseline Inventory used in the generic DSSC does not give rise to a significant increase in calculated annual individual risk from the groundwater pathway.

For spent fuel, calculations were made for two potential containment times: a long containment time (representative of a copper disposal canister), and a shorter containment time (representative of a steel disposal canister). For both sets of calculations the peak annual risk values produced by the generic PCSA model are lower than those in the original GDA Disposability Assessments. This is due to a combination of changes to the model, one of the key ones being the use of an updated set of Instant Release Fractions.

For the inventory considered, that is the baseline inventory excluding plutonium and uranium, but including the ILW and spent fuel for a 10 GW(e) fleet of new build reactors, the total calculated post-closure risk from the groundwater pathway remains below the risk guidance level. It is dominated by the ILW component, and the addition of wastes from a 10 GW(e) fleet of new build reactors makes an insignificant difference to the calculated risks.

The higher strength rocks are expected to remain bounding with respect to risk from the groundwater pathway, due to the longer groundwater return times that would be anticipated from a GDF developed for the other concepts. Overall, the post-closure conclusions of the original GDA Disposability Assessments, including the gas and intrusion pathways, are shown to remain valid for the generic DSSC.


Conclusions

The original 2009 GDA Disposability Assessments concluded that ILW and spent fuel from operation and decommissioning of an AP1000 or EPR raised no new disposability issues when compared against legacy wastes and existing spent fuel. These assessments have been reviewed in the light of recent developments to disposal concepts and generic safety assessment methodologies as applied in the generic DSSC.

Overall, the changes in concept, assessment methodology and assumptions regarding parameter values have only minor impacts on the findings of the original GDA Disposability Assessments. The review therefore confirms that there are no new issues arising from the generic DSSC that would challenge the fundamental disposability of the wastes and spent fuel expected to arise from operation of the AP1000 and EPR. This conclusion is supported by the similarity of the wastes to those expected to arise from the existing PWR at Sizewell B, which are included in the generic DSSC Baseline Inventory and have been found to be acceptable.

These conclusions are based on assessment of a GDF developed in higher strength rock, and are robust to the potential development of the GDF in alternative geological settings. This is due to the larger openings in higher strength rock (bounding for operational safety), and the dominant mechanism of advective transport in groundwater (bounding for post-closure safety). Consideration of potential variations in disposal inventory, including the recent commitment to build up to 16GW(e) of new nuclear power stations, are not expected to significantly change the conclusions of this review.

At an appropriate stage in the future, RWMD would expect to assess, and potentially endorse, more specific and detailed proposals for these waste packages through the established Letter of Compliance process for assessment of waste packaging proposals.
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1 INTRODUCTION

The 2008 White Paper on Nuclear Power [1], together with the preceding consultation [2], established the process of Generic Design Assessment (GDA), whereby industry-preferred designs of new nuclear power stations would be assessed by regulators in a pre-licensing process. Amongst the parties requesting assessment under the GDA process are the Westinghouse Electric Company LLC, which is seeking an initial endorsement of the Westinghouse Advanced Passive Pressurised Water Reactor (AP1000) design, and a collaborative venture between Electricité de France and Areva NP (EdF/Areva), which is seeking an initial endorsement of the Areva UK Pressurised Water Reactor (EPR) design.

An important aspect of the GDA process is the consideration of the disposability of the higher activity solid radioactive wastes and spent fuel that would be generated through reactor operation and decommissioning. Consequently, the regulators indicated that Requesting Parties should obtain and provide advice on the disposability in a Geological Disposal Facility (GDF) of any proposed arisings of higher activity wastes and spent fuel.

The authoritative source in the UK for the provision of such advice is the Nuclear Decommissioning Authority (NDA). In accordance with regulatory guidance [3], Westinghouse and EdF/Areva requested that the Radioactive Waste Management Directorate (RWMD) of the NDA provide advice on the disposability of the higher activity wastes and spent fuel expected to arise from the operation and decommissioning of an AP1000 and an EPR. Disposability Assessments for the UK AP1000 and EPR designs were issued by RWMD to Westinghouse and EdF/Areva in November 20091 [4,5].

The GDA Disposability Assessment process comprised three main components: a review of waste and spent fuel property data supplied by the Requesting Parties; an assessment of the compatibility of the proposed disposal packages with concepts for geological disposal, and identification of the main uncertainties and associated research and development needs relating to the future disposal of the wastes and spent fuel. The assessments considered disposability issues by comparison against appropriate geological disposal concepts which, at that time, were those published in 2003 for intermediate level wastes (ILW) and in 2005 for high level wastes and spent fuel (HLW/SF).

1.1 Publication of the Generic Disposal System Safety Case

In February 2011, RWMD launched its generic Disposal System Safety Case (DSSC). The generic DSSC [6] comprises a suite of reports describing the generic safety cases for the transport, operational and environmental safety of a geological disposal system, together with supporting design, specification and research status reports. At this early stage in the siting process for a Geological Disposal Facility (GDF), the DSSC does not relate to any specific site or disposal facility design, hence the term ‘generic DSSC’. Instead it is based on examples from a range of disposal concepts that have been developed around the world for various types of wastes and for construction in suitable geological settings. The generic DSSC considers three distinct, illustrative geologies which are judged to be potentially suitable to host a disposal facility for higher activity wastes and which occur in the UK. These are described as follows:

- Higher strength rocks – these would typically comprise crystalline igneous and metamorphic rocks or geologically older sedimentary rocks where any fluid movement is predominantly through discontinuities2.

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1 The GDA Disposability Assessments were initially issued to the Requesting Parties in November 2009. They were subsequently reviewed and reissued without protective marking in 2010.

2 The term ‘discontinuities’ applies to a range of structures of any scale that interrupt the continuity of the rock mass; the term therefore includes faults, fractures, fissures, joints, bedding planes, and shear zones.
• Lower strength sedimentary rocks – these would typically comprise geologically younger sedimentary rocks where any fluid movement is predominantly through the rock matrix.

• Evaporites – these would typically comprise anhydrite (anhydrous calcium sulphate), halite (rock salt) or other minerals that have been formed by the evaporation of surface water bodies in the geological past. Evaporites are generally found inter-layered with other, lower-strength sedimentary rocks.

During the production of the generic DSSC, the approaches and methodologies used in the safety assessments were developed and extended in line with the development of the example concepts used to illustrate the DSSC.

The generic DSSC includes quantitative assessments for the Baseline Inventory of higher activity wastes, set out in the Managing Radioactive Waste Safely (MWRS) White Paper [7]. The Baseline Inventory includes radioactive waste and legacy spent fuel that already exists, together with that anticipated to arise in the future from the operation and decommissioning of existing nuclear plant, as well as some nuclear materials that may be disposed as waste. The generic DSSC also considers an Upper Inventory, which reflects the inevitable uncertainties associated with the Baseline Inventory, including the potential for wastes and spent fuel to arise from a new build nuclear power programme. The size of such a programme is itself an uncertainty: the Upper Inventory considered a new build capacity of 10 GW(e). In the generic DSSC, the risks associated with the Upper Inventory are dealt with qualitatively. However, in this Technical Note, the detailed information available from the GDA Disposability Assessments has been used (where possible) to provide a quantitative assessment of the consequences of disposing of new build wastes, based on the DSSC assessments and methodologies.

The generic DSSC supersedes the disposal concepts and assessment basis for the previously published GDA Disposability Assessments, and will become the future baseline for assessing the disposability of waste packaging proposals through the Letter of Compliance (LoC) process. In order to establish the continuing validity of the published conclusions, the GDA Disposability Assessments therefore have been revisited to determine whether the new assessment basis reported in the generic DSSC materially affects the findings published in 2009. This Technical Note presents the results of the work undertaken to examine the effect, if any, of the safety case developments, incorporated in the generic DSSC, on the findings of the original GDA Disposability Assessments.

1.2 Scope of Current Work

The original GDA Disposal Assessments were undertaken in three stages, namely:

• Nature and Quantity Assessment;

• Disposal Facility Design Assessment
  o waste package performance evaluation
  o disposal facility design impact evaluation;

• Safety, Environmental and Security Assessments.

The Nature and Quantity Assessments involved the collation of data on operational and decommissioning ILW and spent fuel from the AP1000 and EPR, in order to establish a suitably detailed understanding of the radionuclide inventory, composition and quantity of ILW and spent fuel. The findings of the evaluation have been presented in the Disposability Assessment reports [4,5] and include descriptions of the proposed ILW packages and spent fuel disposal packages, together with details of the reference cases used in the subsequent safety assessments. The Nature and Quantity Assessments concern the potential waste arisings from the proposed reactors and are not affected by the generic DSSC.
For each reactor design, the Disposal Facility Design Assessment comprised a Waste Package Performance evaluation and a Disposal Facility Design Impact evaluation. In each case, the Waste Package Performance evaluation considered the performance of waste packages under impact and fire accidents relevant to possible accident scenarios in the transport of waste packages to a GDF and operations at a GDF. The Waste Package Performance evaluations were presented in the original Disposability Assessments and, with the exception that the release fractions (RFs) for a range of standard impact and fire scenarios were revised, they were not subject to change as a result of the generic DSSC. The Nature and Quantity Assessment and Waste Package Performance evaluation are not discussed further in this Technical Note.

The Disposal Facility Design evaluations considered the implications of each set of waste arisings and proposed waste packages on the design of a GDF, including the change in footprint area of the GDF which would result from the disposal of ILW and spent fuel packages arising from the new build reactor fleet.

Safety, Environmental and Security Assessments were undertaken for the final stage of the GDA Disposability Assessments. For each reactor design this included: a Transport Safety Assessment, an Operational Safety Assessment; a Post-Closure Safety Assessment, and; Security evaluations. The Security evaluations concerned the quantities of Nuclear Material in the proposed waste packages and the subsequent security categorisation of the packages: the results reported in the GDA Disposability Assessments are unaffected by the generic DSSC.

The review of the implications of the published DSSC for the evaluation of new build reactor wastes has taken account of the changes summarised in Table 1.

**Table 1  Summary of Changes from original Disposability Assessments**

<table>
<thead>
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<th>Assessment Stage</th>
<th>Change</th>
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<tr>
<td><strong>Nature and quantity:</strong></td>
<td></td>
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<tr>
<td>• AP1000 and EPR wastes</td>
<td>• None</td>
</tr>
<tr>
<td>• Other wastes - variant scenarios</td>
<td>• Comparison with:</td>
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<tr>
<td></td>
<td>o 2010 national inventory</td>
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<td></td>
<td>o potential for 16GW(e) installed capacity</td>
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<tr>
<td><strong>Disposal facility design:</strong></td>
<td></td>
</tr>
<tr>
<td>• Waste package performance</td>
<td>• None</td>
</tr>
<tr>
<td>• Disposal facility design impact</td>
<td>• Facility footprint re-evaluated</td>
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<tr>
<td><strong>Safety, environmental and security:</strong></td>
<td></td>
</tr>
<tr>
<td>• Transport safety case</td>
<td>• Modified in line with international practice</td>
</tr>
<tr>
<td>• Operational safety case</td>
<td>• Fault schedules reviewed and updated</td>
</tr>
<tr>
<td>• Environmental safety case</td>
<td>• Revised groundwater pathway assessment</td>
</tr>
<tr>
<td>• Security</td>
<td>• None</td>
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The GDA Disposability Assessments estimated the cooling times that might be necessary to allow sufficient radioactive decay that the heat output of packaged spent fuel would be consistent with the temperature limit of 100°C applied by RWMD. These estimates remain unchanged as the published DSSC has adopted the same temperature limit.

This Technical Note considers the implications of the changes on the ‘footprint’ calculations, the assessment of transport and operational safety, and the assessment of environmental (post-closure) safety for the AP1000 and EPR reactor designs.
2 SUMMARY OF WASTE STREAMS AND PACKAGING PROPOSALS

2.1 AP1000
For the GDA Disposability Assessment, Westinghouse provided information on the higher activity wastes and spent fuel expected to arise from an AP1000 operating for 60 years with a maximum fuel assembly average irradiation (burn-up) of 65 GWd/tU. In line with [1], the spent fuel is assumed to be managed by direct disposal after a period of interim storage. Three general categories of higher activity wastes were considered: ILW arising from reactor operation; ILW arising from reactor decommissioning and spent fuel.

There were three operational waste streams comprising filters from the reactor primary circuit, resins from the primary circuit and resins from the secondary circuit. For the GDA Disposability Assessment, it was proposed that the Primary Circuit Filters would be encapsulated in a cementitious grout in RWMD standard 3m³ boxes [8]. The Primary and Secondary Resins would be immobilised with cement in RWMD standard 3m³ drums [8]. To meet the requirements of transport regulations, the 3m³ boxes and drums would need to be transported to a GDF in a Standard Waste Transport container (SWTC). The packages would remain in the SWTC during receipt at a GDF and transfer underground.

Decommissioning ILW was assumed to comprise the more highly activated steel components that make up the reactor vessel and its internals. Westinghouse proposed to package these wastes in standard 3m³ boxes, immobilised in a cementitious grout. Again, the boxes would be transported in shielded SWTCs.

The spent fuel assemblies were assumed to be packaged in robust disposal canisters which, for the purposes of the GDA Disposability Assessment, were manufactured from a corrosion-resistant material. Both copper and steel were considered. It was further assumed that each disposal canister would contain four spent fuel assemblies and that packaging would be completed prior to delivery to a GDF.

2.2 EPR
EdF/Areva presented packaging options for a number of ILW streams arising from reactor operation and decommissioning. For operational ILW three generic packaging options were put forward for consideration.

For the EPR Reference Case, EdF/Areva proposed the use of reinforced concrete containers of a design used in France for the packaging of operational ILW. The containers would be self shielded with integral mild steel plate up to 100mm thick and outer concrete shield walls with a thickness of the order of 100-150 mm.

These concrete casks had not been considered by RWMD in previous disposability assessments and are not included in the family of standard waste packages specified by RWMD. Furthermore, such casks might not be adopted by all future operators of the EPR. Consequently EdF/Areva proposed two variant cases for the packaging of operational ILW from the EPR

Variant Case 1 assumed that operational ILW would be packaged in standard UK waste containers, namely the standard 500 litre stainless steel drum [8]. It was proposed that the waste would first be packaged in 200 litre drums, and then loaded into the 500 litre drums. The resulting annulus would be filled with a cementitious grout.

Variant Case 2 assumed the use of cast-iron casks as used in Germany for the packaging of certain light water reactor (LWR) wastes. As with the concrete casks, the cast-iron casks are presently considered to be non-standard in the UK.
For the GDA Disposability Assessment, two operational ILW streams were considered, namely: ion exchange resins and spent filter cartridges arising from clean-up of the liquid effluent and spent fuel pit treatment systems.

The proposals for the packaging of decommissioning ILW were based on the use of larger waste containers consistent with RWMD standards and specifications (the containers designated are the 3m³ box and 4 metre box), with no variants being proposed [8]. Two bounding decommissioning waste streams were considered in the original GDA Disposability Assessments. Steel from the most active part of the pressure vessel was proposed to be packaged in 4 metre boxes with 100mm concrete lining. The metal sections would be immobilised using a cement grout. Highly activated steel from internal reactor components close to the core would be packaged in 3m³ boxes, encapsulated in a cementitious grout.

The packaging concept for spent fuel was assumed to be identical to that proposed by Westinghouse and outlined in Section 2.1.
IMPACT ON DISPOSAL FACILITY DESIGN

3.1 Implications for GDF Footprint

The GDA design impact evaluation considered the fractional change in footprint area of the GDF required for the disposal of ILW and spent fuel arising from the potential operation of AP1000 or EPR reactor systems.

For the operational and decommissioning ILW arising from each AP1000, the necessary increase in the footprint area would correspond to approximately 65m of disposal vault length. This represents approximately 1% of the area required for the legacy ILW, per reactor, and less than 10% for the illustrative fleet of nine AP1000 reactors, based on the ILW GDF design presented by RWMD in [9].

For the spent fuel arising from each AP1000, on the basis of a 60 year operational life, giving rise to an estimated 640 disposal canisters, it was concluded that an area of approximately 0.11 km² would be required for the associated disposal tunnels. A fleet of nine such reactors, corresponding to a generating capacity of about 10 GW(e), would require an additional area of approximately 1 km², excluding associated service facilities. This represented approximately 6% of the area required for legacy HLW and spent fuel per AP1000 reactor, and approximately 55% for the illustrative fleet of nine AP1000 reactors, based on the generic design developed as a basis for preliminary planning for geological disposal of spent fuel [10].

For the operational and decommissioning ILW arising from each EPR, it was concluded that the necessary increase would correspond to less than approximately 60m of disposal vault length. This represents approximately 1% of the area required for the legacy ILW, per reactor, and less than 10% for the illustrative fleet of six EPR reactors, based on references [9] and [10].

For spent fuel arising from each EPR, on the basis of a 60-year operating life, giving rise to an estimated 900 disposal canisters, it was estimated that an area of approximately 0.15 km² of disposal tunnels would be required. A fleet of six such reactors, corresponding to a generating capacity of about 10 GW(e), would require an area of approximately 0.9 km², excluding associated service facilities. This represents approximately 8% of the area required for legacy HLW and spent fuel per EPR reactor, and approximately 50% for the illustrative fleet of six EPR reactors, based on references [9] and [10].

The additional footprint area to accommodate new build wastes and spent fuel has been re-evaluated on the basis of the generic GDF designs developed and presented as part of the DSSC [11]. The Generic Design Report [11] presents GDF footprints for both the Baseline Inventory and for the Upper Inventory. For the purposes of this Technical Note we have recalculated the footprint required to accommodate only the new build component of the Upper Inventory, which as noted earlier is based on a 10 GW(e) programme.

For the disposal of operational and decommissioning ILW, the DSSC example concept for higher strength rock provides a total of 24.2 disposal vaults. Disposal of corresponding wastes arising from a new build programme of 10 GW(e) generating capacity would require an extra 1.4 disposal vaults for both reactor systems. This represents an increase of approximately 6% in the GDF footprint over that required for the ILW/LLW component of the Baseline Inventory. This increase in the footprint area is less than the 10% increase reported above for the GDA Disposability Assessment.

For spent fuel disposal, the generic DSSC provides a total of 296 disposal tunnels for the Baseline Inventory for the higher strength rock. Disposal of spent fuel arising from a programme of 10GW(e) generating capacity would require an extra 138 disposal tunnels. This represents an increase of approximately 47% in the GDF footprint over that set out in the Generic Design Report for the HLW/SF component of the Baseline Inventory. This is
less that the 50% (EPR) and 55% (AP1000) increase in footprint area reported above for the GDA Disposability Assessments.

The new estimates are based on the higher strength rock concept. The absolute values of the footprints for the illustrative example concepts developed for the other geologies are expected to be larger than those for higher strength rock, due to the properties of the rock that control the size of excavated openings and the separation of heat-generating wastes. However, the proportionate increase due to new build wastes is expected to scale in proportion, resulting in an increase in footprint of about 6% for ILW and about 47% for HLW/SF in all host rocks. As the MRWS process progresses, RWMD will revisit the design in the light of site specific information, when this becomes available.

3.2 Assessment of Alternative Inventory Scenarios

The adoption of the 2010 Baseline Inventory [12] primarily affects the volumes of waste for disposal as compared to the previous baseline inventory. The ILW volume has increased by 35%, principally due to revised decommissioning forecasts at Sellafield, whereas the HLW/SF volume has decreased slightly, due to revised reprocessing assumptions. There are no new waste package types and changes to the footprint are expected to scale in proportion to the total packaged volume.

The wastes from new nuclear build are one contribution to the Upper Inventory considered by the generic DSSC, although this is not intended as a maximum since the eventual installed capacity of a new build programme is not known; for instance energy companies have recently committed to build up to 16GW(e) of new nuclear power stations. Depending on many factors, including assumptions regarding electricity generation and types of reactor, if a 16GW(e) new build programme was assumed the contribution of the SF component of the Upper Inventory would increase by a factor of less than two, with a corresponding increase in the footprint of a GDF.
4 TRANSPORT SAFETY ASSESSMENT

The GDA Disposability Assessments \[4,5\], concluded that, for either the EPR or AP1000, transport of the packages would be compatible with current RWMD plans. These assessments looked at operational and decommissioning ILW and at spent fuel, and assessed each package variant for:

- compliance with International Atomic Energy Agency (IAEA) Transport Regulations;
- effect on transport risks for a GDF.

Both aspects of the GDA Disposability Assessments have been reviewed with regard to the generic Transport Safety Case (TSC) \[13\] published as part of the generic DSSC.

4.1 Compliance with IAEA Transport Regulations

The key element in establishing the safety of transport of radioactive materials is confirmation of compliance with the requirements of the appropriate transport regulations. In the UK these are The Carriage of Dangerous Goods and Use of Transportable Pressure Equipment Regulations \[14\] which, for radioactive materials (Class 7), are effectively the IAEA Regulations for the Safe Transport of Radioactive Material, 2005 \[15\]. The generic TSC \[13\] references a more recent version of the IAEA Transport Regulations (2009), but this does not materially affect the criteria for compliance.

4.1.1 Design Approval

The fundamental principle underlying the IAEA Transport Regulations is that safety for transport through the public domain is ensured by the design of the transport packages and limits imposed on their contents, regardless of how the material is transported. Thus, safety is inherent in the package design rather than dependent on operational and procedural controls, such as restrictions on transport modes or routes. The package design and safety performance requirements are related to the potential hazard of the radioactive material being transported. The Transport Package Safety Report \[16\], as a supporting document for the TSC, sets out the process for demonstrating compliance with the requirements of the IAEA Transport Regulations through a Package Design Safety Report (PDSR) which establishes clear limits on key package safety parameters such as dose rate, containment of contents and limits on fissile contents.

The radiological criteria for compliance with the transport regulations include:

- activity content,
- external dose rates,
- criticality,
- containment under normal conditions (including gas generation),
- containment under accident conditions,
- heat output.

In addition, there are other constraints, which affect transportability, such as the presence of toxic materials and the overall mass of the transport packages.

The IAEA Transport Regulations require that the design of a transport package for higher hazard radioactive material is required to be approved by the national competent authority, which in the UK is the Department for Transport\[3\]. Approval will only be granted after a rigorous assessment of the Package Design Safety Report (PDSR) and is confirmed by the granting of a Certificate of Approval.

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\[3\] In October 2011 the Department for Transport Radioactive Materials Transport Group became part of the Office for Nuclear Regulation (ONR).
The package designs proposed for AP1000 operational and decommissioning wastes are NDA standard 3m$^3$ boxes or 3m$^3$ drums transported in an SWTC for which some progress towards competent authority approval is reported in the Transport Package Safety Report [16]. For the EPR design, the reference case transport packages are licensed for transport use in France, but would nevertheless need to gain approval for use in the UK. For decommissioning ILW, the EPR Variant Case 1 assumes the use of the NDA standard waste and transport packages, as for the AP1000, while Variant Case 2 uses containers licensed for use in Germany, which again would need approval for use in the UK.

For spent fuel from both EPR and AP1000 the GDA Disposability Assessments assumed that spent fuel assemblies would be packaged for disposal in a robust disposal canister designed to accommodate four fuel assemblies. These would be transported in a shielded Disposal Canister Transport Container (DCTC). The same assumptions are adopted in the published DSSC. Some progress towards preparing a PDSR for this option is reported in the Transport Package Safety Report [16].

For all these cases, the level of detail provided in the GDA submissions is consistent with expectations, with future work expected to lead to fully developed proposals through the Letter of Compliance process. The suite of documents that constitute the generic DSSC provide detail on the process and requirements for taking the packaging and transport proposals through to national competent authority approval and eventual operation. The DSSC documentation confirms that the basis of the GDA Disposability Assessments regarding transport safety remains appropriate.

4.1.2 Transportability Criteria

The GDA Disposability Assessments have identified a range of issues that are principally related to the assumptions regarding the maximum package inventories and management of these inventories during packaging. RWMD expects that these issues would be considered in a future Letter of Compliance interaction with the plant operator. The main issues are summarised below. It is noted that the TSC and its supporting documents do not change the criteria to be met or the approach taken to confirming compliance with the criteria so no changes in the GDA Disposability Assessments are necessary as a result of the publication of the TSC. For this reason, no additional calculations or modelling have been carried out for this review.

4.2 Effect on Transport Doses for a GDF

The transport safety assessments [17,18] reported in the GDA Disposability Assessments were based on comparison of the doses and risks with those reported in the 2003 Generic Transport Safety Assessment (GTSA) [19] and the later HLW/SF Transport Safety Assessment [20]. In order to align more closely with international practice in transport safety, the generic DSSC TSC has adopted a substantially modified approach towards demonstrating the safety of the GDF transport operation. The revised approach places greater emphasis on deterministic demonstrations of regulatory compliance rather than probabilistic assessment of accident risks. In particular, the generic Transport System Safety Assessment (TSSA), developed as part of the DSSC, concentrates on normal transport operations rather than accident consequences and provides an estimate of radiological dose to key transport workers [21].

The TSSA includes an assessment for the Upper Inventory that uses assumptions regarding waste streams that are broadly consistent with those for the GDA Disposability Assessments for both ILW and SF. However the Upper Inventory also contains inventories

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4 The GDA Disposability Assessment was undertaken by RWMD on behalf of the reactor vendor organisations (the Requesting Parties). Future interaction through the Letter of Compliance process will be with the power plant operating company.
associated with alternative scenarios regarding reprocessing, and for this reason it does not permit direct comparison between the TSSA Upper Inventory assessments and the GDA Disposability Assessments.

There is a further minor change that prevents direct comparison of the results reported in the transport safety assessments for the GDA Disposability Assessments and the results reported for the TSSA. The operational life of the GDF was assumed to be 50 years for the GDA Disposability Assessments to allow comparison with the 2003 GTSA, but has subsequently been extended to the longer operational life of 90 years for the TSSA reports. Because of this change and the inventory changes, the transport safety assessments carried out for the GDA Disposability Assessments have been repeated using a new version of the TranSAT (Transport Safety Assessment Toolkit) computer application developed for preparation of the TSSA.

The major difference in the scope of the TSSA in comparison with the GDA Disposability Assessments is the inclusion of an assessment for the transport by sea between the arising site and a port serving the GDF, in addition to the road and rail transport assessments. In the TSSA, the worker assessed to receive the highest dose is the crane operator working at the port serving the GDF. The revised assessment has therefore assessed the impact on this most exposed individual as a result of the inclusion of new build ILW and spent fuel packages.

4.2.1 Assessment methodology

The TranSAT application calculates the doses to transport workers associated with the four transport scenarios that have been developed by NDA as part of its GDF concept.

For the 'RoadRail' scenario, based on use of road transport where possible, those waste packages that comply with the weight limits for road transport are transported by road and all other waste packages are transported by rail. For the 'MaxRail' scenario, all waste is assumed to be transported via the UK rail network to as great an extent as possible (although road transport to the nearest existing railhead may be needed, using special category vehicles where necessary). For the remaining two scenarios, sea transport is added to the previous assumptions where the sea leg provides a significant reduction in the overland transport distance, and where the sea leg is sufficiently long to justify the extra handling operations needed to load and unload the ships.

In order to run TranSAT, which calculates the dose from transporting the waste to any of seven nominal zones covering England and Wales5, it is necessary to make an assumption regarding the arising site for the waste. The assessments for the GDA made the arbitrary assumption that Hinkley Point was the arising site, and this has been retained for the assessment reported here.

Three separate assessments for operational ILW, decommissioning ILW and spent fuel were made for each of the reactor designs. These assessments follow the approach of the GDA Disposability Assessments by assessing the dose implications for a single reactor using only the streams that have been identified by the Requesting Parties as limiting ILW for the operational and decommissioning phases in the reactor lifecycle, and for a single spent fuel stream.

The streams assessed are listed in Table 2, together with the waste containers assumed for each. The numbers of packages and characteristics of the streams were the same as those used for the GDA Disposability Assessments.

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5 The DSSC assumes the GDF is sited in England or Wales
Table 2  Waste Stream Outline Descriptions

<table>
<thead>
<tr>
<th>Reactor type</th>
<th>Stream description</th>
<th>Stream</th>
<th>Waste Package</th>
<th>Transport Package</th>
</tr>
</thead>
<tbody>
<tr>
<td>EPR</td>
<td>Operational ILW</td>
<td>EPR01</td>
<td>C1 (based on 2 m box)</td>
<td>-</td>
</tr>
<tr>
<td></td>
<td></td>
<td>EPR02</td>
<td>C1 (based on 2 m box)</td>
<td>-</td>
</tr>
<tr>
<td></td>
<td>Decommissioning ILW</td>
<td>EPR06</td>
<td>4 metre box</td>
<td>-</td>
</tr>
<tr>
<td></td>
<td></td>
<td>EPR08</td>
<td>3m³ box</td>
<td>SWTC*</td>
</tr>
<tr>
<td></td>
<td>Spent fuel</td>
<td>EPR09</td>
<td>Disposal canister</td>
<td>DCTC**</td>
</tr>
<tr>
<td>AP1000</td>
<td>Operational ILW</td>
<td>AP01</td>
<td>3m³ box</td>
<td>SWTC</td>
</tr>
<tr>
<td></td>
<td></td>
<td>AP02</td>
<td>3m³ drum</td>
<td>SWTC</td>
</tr>
<tr>
<td></td>
<td>Decommissioning ILW</td>
<td>AP04</td>
<td>3m³ box</td>
<td>SWTC</td>
</tr>
<tr>
<td></td>
<td>Spent fuel</td>
<td>AP06SF</td>
<td>Disposal canister</td>
<td>DCTC</td>
</tr>
</tbody>
</table>

* RWMD Standard Waste Transport Container  
** RWMD Disposal Canister Transport Container

4.2.2  Assessment Results

The results from the TranSAT runs are reported as individual worker doses. In the TSSA the crane operator working at the port serving a GDF receives the highest individual dose, estimated to be slightly less than 0.3 mSv/y. For the revised assessments, the highest individual dose is received by the same worker group but the individual doses are larger, although in no case does the dose exceed 0.5 mSv/y, which is half of the design limit annual dose to an individual worker. The increase in dose from transport of additional wastes does not raise any compliance difficulties for the transport operation as a whole.

There are small increases in dose in most cases, with very small changes to doses from decommissioning wastes. There are two notable exceptions. The first is the dose to all workers for spent fuel, which shows increases of up to 30%. This is broadly in line with the increases reported in the GDA Disposability Assessments based on the 2003 GTSA, and reflects an unavoidable increase in the dose because spent fuel is one of the major contributors to worker dose, and consideration of new build reactors represents a significant increase in the quantity of spent fuel that will require disposal.

The second increase in dose is that for operational ILW for the EPR. This is a consequence of the higher dose rates from the Reference Case C1 transport packages. As discussed in the GDA Disposability Assessment report, the assumed inventories for some of these packages would, in any case, lead to lack of compliance with IAEA Transport Regulations. This was identified in the original GDA Disposability Assessment as an area where further dialogue with the operator would be required to obtain better information of both the inventories and the packaging concept, as it is developed. This will be followed up as part of future LoC assessments.

4.3  Conclusions from Review of Transport Safety Assessment

Compliance with the regulatory requirements for the transport package is essentially unchanged in the assessment using the generic DSSC when compared with the approach used for the GDA Disposability Assessments.

The major change in the assessment methodology introduced for the generic DSSC is the change in emphasis to deterministic demonstration of regulatory compliance with less reliance on probabilistic risk assessment. In addition, an option for transport by sea has
been added. For both the AP1000 and the EPR proposals, the transport safety assessments have been repeated for limiting streams for operational and decommissioning ILW, and for spent fuel. The assessed doses to relevant worker groups fall within the design targets for the GDF in all cases.

In summary, the operational and decommissioning ILW and the spent fuel from an AP1000 is considered to be compatible with the requirements for transport as expressed by the IAEA transport regulations in all cases. For the EPR the minor issues reported in the GDA Disposability Assessment [5] remain, but these are considered to be matters for clarification, and can be managed through more realistic estimation of package inventories, which would be taken forward by interaction with operators through the LoC process.
5 OPERATIONAL SAFETY ASSESSMENT

5.1 Developments to DSSC Operational Safety Assessment

Since publication of the GDA Disposability Assessments, the ILW and HLW/SF fault schedules underpinning the previous assessment methodologies have been reviewed and updated as part of the work undertaken for the generic Operational Safety Case [22] published as part of the DSSC. The Operational Safety Assessment (ROSA) Toolkit, which is used to assess on-site and off-site doses for a range of faults in support of Design Basis Accident analysis, has also been revised to reflect the changes to the fault schedule. The toolkit has been further extended to include consequence calculations for faults involving spent fuel packages.

In addition a review was undertaken of waste package fire and impact performance, which resulted in some refinement of the generic fire and impact release fractions (RFs) for the RWMD standard packages and to the way impact faults are analysed in the assessment toolkit.

In order to evaluate the effect of these changes on the operational safety assessments carried out for the GDA Disposability Assessments, a number of cases have been re-assessed, for both the AP1000 and EPR designs.

5.1.1 Fire and Impact Release Fractions

For the GDA Disposability Assessments, package-specific RFs representing the amount of activity released from a package following fire or impact damage were derived for the different waste packages. RFs were provided for different drop heights, particle sizes and fire durations. The RFs used in the revised assessments reported in this Technical Note were chosen from the same range of package-specific RFs. However, in some cases, changes were made to reflect the revised assessment basis used in the generic DSSC – for example the OSC has updated assumptions regarding fire duration and particle size to be considered for an airborne release of activity.

5.1.2 Dose Targets

As in the original assessments, the package performance data and consequential RFs have been combined with waste stream inventories in the modified toolkit to estimate dose consequences for a range of fault sequences. The estimated doses were then compared against the results of the original assessment. The current results were also compared against the targets for design basis fault sequence mitigated doses utilised in the generic OSC. These targets are the same as those quoted in the previous Disposability Assessments.

5.2 Assessment of AP1000 Wastes and Spent Fuel

The assumptions regarding the characteristics of the AP1000 waste streams and the immobilisation and packaging of the ILW and spent fuel are unchanged from the original GDA Disposability Assessment.

In reviewing the impact of the generic OSC on the Disposability Assessment for the AP1000 design, the following cases were re-assessed:

- Operational ILW: AP01 – primary circuit filters immobilised in cementitious grout in 3m³ box;
- Decommissioning ILW: AP04 – activated metal immobilised in cementitious grout in 3m³ box;
- Spent Fuel: AP06 – four fuel assemblies in a disposal canister.
The ILW cases were chosen because they provided the highest doses over all faults in the previous assessment. The assumed containers, 3m³ boxes, would be emplaced in the Unshielded ILW (UILW) vault in a GDF, using remote-handling arrangements.

5.2.1 AP1000 Operational ILW

Impact
For the current assessment, the more conservative, bounding approach used in the generic OSC has been adopted and impact RFs representing the release of particulate up to 100 µm dimension were used. The increase in RF is partially offset by the fact that the generic OSC assessment methodology now modifies the impact RF to take account of the drop height at the fault location. The overall effect is to increase the worker and public doses by approximately a factor of 6.

The highest public doses still remain well below both the Basic Safety Level (BSL) of 1 mSv and the Basic Safety Objective (BSO) of 0.01 mSv. The worker doses are also well below the most stringent BSL for workers of 20 mSv. Only a few severe impacts are slightly above the BSO of 0.1 mSv.

Fire
For consistency with the generic OSC, the assessment has assumed exposure of the affected package(s) to a sustained fire of one hour at 1000°C, rather than the eight minute fire assumed for the original GDA Disposability Assessments. The impact on the results is marginal, with around a factor of two increase in the worker doses. Even with this increase, the highest worker doses remain well below both the lowest BSL and the BSO.

Further analysis of the public consequences revealed that the radionuclide iodine-129 dominated the dose (with a contribution >99%). Excluding the iodine-129 inventory reduced the public doses to below the BSO in all but one case. The assessment methodology conservatively assumes that the entire iodine-129 inventory is released to atmosphere on heating (RF of unity). Overall, the results are not significantly different to those in the original GDA Disposability Assessment.

Other Faults
Other fault sequences considered in the original assessment included inadequate shielding or inadvertent operator exposure to an unshielded package leading to exposure to elevated external radiation levels, together with scenarios where a failure of contamination control measures gives rise to doses to workers on site and to the general public.

The results for these fault scenarios were not affected by the assessment modifications implemented in the generic DSSC.

5.2.2 AP1000 Decommissioning ILW

Impact
Despite the increase in RF, all worker and public doses remain below the most stringent BSLs of 20 mSv and 1 mSv respectively. All public doses and the majority of the worker doses are below the BSO. A small number of severe faults involving damage to multiple packages give rise to worker doses above the BSO. In a new plant designed to modern standards such events would be expected to be highly unlikely.

Fire
The effect of the generic OSC changes is minimal with only a slight increase in worker doses. In common with the previous assessment, the public doses are dominated by the contribution from the volatile radionuclides, assigned a fire RF of unity. Further analysis of
the public consequences revealed that the doses are dominated by carbon-14 (40% dose contribution), chlorine-36 (19%), selenium-79 (39%) and tritium (1%) inventories are omitted. It is likely that a significant proportion of these radionuclides will be chemically bound to the waste and will not be released so readily on heating.

**Other Faults**

As with the operational ILW, the generic DSSC changes have no effect on external radiation or contamination faults.

### 5.2.3 AP1000 Spent Fuel

Since the original GDA Disposability Assessment was published, the Fault Schedule for spent fuel packages has been revised and analysis for those fault sequences requiring quantitative consequence assessment incorporated into the assessment methodology. The fault scenarios considered are limited to external radiation and contamination faults only, since the disposal package is anticipated to be sufficiently robust to withstand all credible fire and impact accidents. Therefore, as in the previous GDA Disposability Assessment, the fire and impact RFs for packaged spent fuel under accident conditions have been assumed to be zero for the purposes of the operational safety assessment.

**External Radiation / Loss of Shielding**

The consequences of the worst case external radiation faults obtained from the current assessment are relatively minor, with only one worker dose being just above the BSO. Apart from the additional faults, there are only small differences between the results for the two assessments, this being due to minor refinement of the assumptions regarding exposure times and distances.

**Contamination**

The assessment includes one contamination fault, namely the receipt and handling of a disposal canister with excessive surface contamination at the Waste Package Transfer Facility (WPTF). This is a minor fault resulting in dose levels around 1 μSv for workers and $10^{-5}$ μSv for members of the public.

### 5.3 Assessment of EPR Wastes and Spent Fuel

The assumptions regarding the characteristics of the EPR waste streams and the immobilisation and packaging of the ILW and spent fuel are unchanged from the original GDA Disposability Assessment.

In the original GDA Disposability Assessment, the following cases were found to give the most significant results and have accordingly been re-assessed using the generic OSC methodology:

- **Operational ILW**: EPR02 – spent cartridge filters in concrete casks, and EPR12 – spent cartridge filters in 500 litre drums;
- **Decommissioning ILW**: EPR06 – reactor vessel steel in 4 metre boxes; EPR08 – reactor internals in 3m$^3$ boxes;
- **Spent Fuel**: EPR09 – four fuel assemblies in a disposal canister.

This combination of cases is considered bounding across all faults. Packages based on the 500 litre drum and 3m$^3$ box containers are assumed to be emplaced in the UILW vaults in a GDF, using remote-handling arrangements. Packages based on the concrete casks and 4 metre box containers are assumed to be emplaced in the shielded ILW (SILW) vaults in a GDF, using contact-handling arrangements.

Quantitative assessment of the packages proposed under Variant Case 2, based on fully-sealed, cast-iron containers, was not carried out within the scope of the GDA Disposability
Assessment due to a lack of information on the performance of these packages in accident conditions. However, it was concluded that the robust nature of the containers alone potentially could provide containment of unconditioned wastes. Furthermore, such packages are currently approved for the packaging of ILW from light water reactors in Germany. The DSSC does not change this position.

5.3.1 EPR Operational ILW

The latest version of the ROSA Toolkit, modified to reflect the generic OSC methodology, has been used to carry out revised consequence assessments for spent filter cartridges, packaged in the Reference Case, C1 concrete casks, and the Variant Case, 200 litre drums in NDA standard 500 litre drums. As noted, if used, the concrete casks would comprise shielded packages and would be transferred directly underground using the SILW route and stored in the SILW disposal vaults. The 500 litre drums, as unshielded packages, would be transferred underground in shielded transport containers to the inlet cell where the packages would be removed from the transport containers and transferred to a UILW disposal vault by remote means.

Because of the different nature of the packages and the fact that they would be transferred and emplaced by different routes at a GDF, a different set of fault sequences applies to each package type.

Impact

The worst case consequences arising from impact damage to one or more packages show that there is little difference between the two sets of results. In this case, a new fault has been introduced, namely the drop of a Transport Container onto an Industrial Package, such as a Concrete Cask. Some operational wastes may not be immobilised, the impact RF was based on the release of particulate (up to 100 μm size range). Scaling the RF in line with the drop height, as introduced within the OSC, has the effect of reducing worker doses for even the most severe impact faults to well below the most stringent BSL (500 mSv). Public doses are well below the BSO. It is envisaged that, as a site-specific design is developed, it should be possible to design load paths to prevent Transport Containers being lifted over shielded packages.

Fire

The worst case fire faults for EPR operational ILW also show little difference between the two sets of results, despite the assumption of a longer fire duration in the current assessment. This is attributed to a large contribution to the dose from the most volatile radionuclides for which a fire RF of unity has been assumed in both assessments. The public doses are slightly above the BSO but well within the most stringent BSL.

Fire and Impact

The generic OSC no longer considers the potential for a fire involving UILW package(s) already affected by impact damage. The previous assessment considered a single scenario involving the catastrophic failure of the crane in the UILW disposal vault leading to both impact damage and a sustained fire. This has since been dismissed as incredible due to the low fire loading in the UILW disposal vault.

In contrast, potential fire and impact scenarios are considered for SILW packages. The results are similar to those for fire alone, with minimal increase in doses for the current assessment, despite increasing the fire duration from 8 minutes to one hour. This is again attributed to the contribution from those radionuclides potentially present and released in gaseous form in the early stages of a fire.
External Radiation
External radiation doses resulting from exposure to elevated external radiation levels from UILW packages as a result of a fault condition were identical for both the original and current GDA Disposability Assessments. The Reference Case concrete casks are of a different design whereby the waste is loaded into a steel container inside the outer concrete cask. This potentially reduces the likelihood of a layer of shielding being removed. Hence there is little value in considering these fault scenarios at present. Rather it is recommended that this be re-visited at a future stage when the current issues regarding external dose rates from these packages have been resolved.

5.3.2 EPR Decommissioning ILW
For decommissioning ILW, both the original GDA Disposability Assessments (EPR06 and EPR08) have been revisited, due to the different package types proposed (shielded and unshielded).

Impact
The worst case consequences for impact faults for the original and current GDA Disposability Assessments for reactor internal wastes in a 3m³ box, do lead to an increase in both worker and public doses. However, the results are still considered acceptable, with public doses remaining well below the BSO. The highest worker doses are above the BSO but remain below the most stringent BSL of 20 mSv.

Fire
For reactor vessel waste in 4 metre boxes, the same fire RFs were used in both original and current assessments, hence the results were unchanged. Despite the adoption of a one hour fire duration, the increase in dose is minimal. As for the operational ILW packages, this contribution to the public dose is dominated by the nuclides of the most volatile elements.

As discussed above, the treatment of potentially gaseous radionuclides in fires has been identified in the generic OSC and in the original GDA Disposability Assessments as an area requiring further development work.

Other Faults
The consequences for impact and fire faults for the shielded packages are largely unchanged from the original GDA Disposability Assessments. This is to be expected, given that the doses are dominated by the fire contribution. The consequences of the external radiation faults are also unchanged from the original GDA Disposability Assessment.

5.3.3 EPR Spent Fuel
The spent fuel assessment for EPR has also been revised, based on the Fault Schedule developed for the generic DSSC.

External Radiation
The worst case protected doses from the additional faults considered are of limited consequence with both worker and public protected doses being below the respective BSOs. The other results are slightly lower than those in the original GDA Disposability Assessment. This is due to minor changes in the assumptions regarding exposure times and distances.
Contamination
For spent fuel, the original GDA Disposability Assessment and generic OSC also consider the receipt of a disposal canister in a transport container with excessive surface contamination. This is a very minor fault with worker and public doses of the order of 1 μSv and 10^{-5} μSv respectively.

5.4 Assessment of Alternative Geological Settings
The generic OSC assessment methodology is largely based on the concept example for higher strength rock. However, this does not mean that the chosen site will exhibit this type of geology. As described in Section 1, the other geologies considered in generic DSSC are the lower strength sedimentary rock and evaporite rock.

Apart from the notable exception of the potential use of a shaft for transferring waste packages underground in the evaporite concept example, it is considered that, of the three geologies, the concept example for higher strength rock is bounding in terms of the potential consequences of impact and fire faults. This is due to the requirement to restrict opening sizes in the other geological settings which leads to smaller disposal vault dimensions and consequent reduced stack heights and associated drop heights. The frequency of dropped loads and impact events could conceivably be argued to be greater for those concepts employing stacker trucks rather than cranes for emplacement, but this cannot be established definitively at this stage.

With regard to external radiation faults, the current concept examples potentially give rise to different exposure geometries (due to differences in underground facility dimensions) and hence different worker doses. The consequences of such faults will be very dependent on the actual characteristics of the selected site, including the host rock. The use of additional shield doors at the entrances to the disposal vaults and tunnels in the concept examples for lower strength sedimentary rock and evaporites will increase the potential for external exposure faults due to failure of access controls, although these will not necessarily lead to greater consequences. In any case, the current assessment indicates that these faults tend to be relatively insignificant in terms of consequences and risks compared to fire and impact faults.

With regard to the GDA Disposability Assessments therefore, it is not considered that there is any feature of these packages which would affect their disposability in an alternative geology.

5.5 Conclusions from Review of Operational Safety Assessment
Revisions to the generic OSC for a GDF, implemented as part of the development of the generic DSSC, largely relate to the accident safety assessment and in particular, to the treatment of impact and fire faults involving mechanical or thermal challenge to a waste package.

A number of bounding cases from the original GDA Disposability Assessment were repeated, using the generic OSC fault schedules and methodologies. Overall the effect on the predicted consequences was minor. In some cases, modest increases in protected (mitigated) doses were observed, particularly for impact faults. However, these were not sufficient to cause previously acceptable doses to exceed the most stringent BSLs.

These increases were mainly due to the more conservative assumptions made in the generic OSC regarding the assessment of impact and fire faults. For impact faults, it is currently assumed in the OSC that, given an airborne release of activity, any particulate release up to 100 μm contributes to the potential dose. However, it is recognised that particles larger than 10 μm are generally not considered respirable and it is anticipated that it may well be possible to use lower RF values in the future when further work in this area
has been undertaken. In any case, the effect on the assessment results is relatively minor and does not affect the conclusions of the GDA Disposability Assessments.

The issue, identified previously, of potentially high public doses from thermal challenge to waste packages containing high levels of volatile radionuclides remains. However it is considered that, in reality, the bulk of this inventory would be chemically bound to or embedded in the waste matrix and not available for release. Hence, it is considered that the modified doses reported, which exclude these nuclides and are below the BSL, are more representative of potential consequences. This issue has also been identified in the generic OSC and, as part of the work being undertaken to support future development of the DSSC, further consideration is being given to the treatment of potentially gaseous radionuclides.

Overall, the effect of the generic OSC assumptions on the findings of the original GDA Disposability Assessments is minimal and does not change the previous conclusions.
6 POST-CLOSURE SAFETY ASSESSMENT

The GDA Disposability Assessments included quantified assessments of the post-closure risk for the groundwater pathway for both the ILW and spent fuel arisings from both AP1000 and EPR reactor designs. The assessment of the ILW component used a screening methodology based on the results of the groundwater assessment model described in the Generic Post-Closure Performance Assessment (GPA), published in 2003 [23], whereas that for the spent fuel arisings was undertaken using the groundwater assessment model developed for assessment of legacy spent fuel and HLW [24]. Both assessments were based on a higher strength rock geological setting.

The post-closure assessment focuses on the groundwater pathway for the return of radionuclides to the accessible environment. For the purposes of this review, the post-closure safety assessment was re-evaluated using the latest groundwater pathway model applied in the generic DSSC Post-Closure Safety Assessment (PCSA) [25]. Radiological exposure is assessed in terms of individual risk arising from a disposal inventory in which the new build inventory is added to the inventory considered in the PCSA. In line with the GDA Disposability Assessment the new build inventory is based on a programme of 10 GW(e) of installed capacity, assumed to comprise either six EPRs or nine AP1000s. The other radionuclide return pathways to the environment, via gas migration or human intrusion, have not been re-evaluated at this time. Inclusion of the new build wastes is not expected to alter the previous conclusions.

It is important to note that, the precise values of calculated peak risks in the generic PCSA cannot be particularly meaningful at this generic stage, because they depend on parameters that represent quantities that cannot be known until a site and concept have been identified. However, it is still possible to obtain useful information about the relative contributors to the calculated peak risk. This provides an understanding of the components of the waste that contribute most to the total risk, and also of those radionuclides in the inventory that contribute most to the total risk. This understanding ensures that the relevant issues are addressed when assessing packaging proposals by the Disposability Assessment process.

6.1 Operational and Decommissioning ILW

The GDA Disposability Assessment for the operational and decommissioning ILW utilised an assessment methodology routinely used within the Letter of Compliance assessment process [26]. Using this methodology the wastes were screened with respect to the 2003 Nirex GPA [23,27]. To demonstrate that the conclusions from the original GDA Disposability Assessment are still valid under the assessment methodology of the generic PCSA, two groundwater assessment models have been set up to incorporate the operational and decommissioning wastes arising from a 10 GW(e) fleet of AP1000s or EPRs.

In the ILW groundwater pathway model, the packaging choice is not directly a controlling factor on the calculated risk as no credit is taken for containment by the packages at present. Therefore, for the EPR wastes, Variant Case 1 (500 litre drums) was chosen as a basis for setting up the model parameters, and it was not necessary to give explicit consideration to the Reference or Variant 2 packaging cases.

The model assumptions are consistent with those used in the generic PCSA reference case. The specific assumptions used to incorporate the operational and decommissioning ILW from the AP1000 and EPR fleets of reactors are highlighted in Table 3.
Table 3   Data for New Build operational and decommissioning ILW used in the total-system model for the groundwater pathway in the generic PCSA

<table>
<thead>
<tr>
<th></th>
<th>AP1000</th>
<th>EPR</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number of additional vaults required</td>
<td>2</td>
<td>1</td>
</tr>
<tr>
<td>Volume of packaged waste</td>
<td>12,576 m$^3$</td>
<td>31,050 m$^3$</td>
</tr>
<tr>
<td>Mass of organic material (treated as cellulose degradation products)</td>
<td>640 tonnes</td>
<td>312 tonnes</td>
</tr>
<tr>
<td>Volume of vault backfill</td>
<td>82,600 m$^3$</td>
<td>43,300 m$^3$</td>
</tr>
<tr>
<td>Mass of stable carbon assumed in vaults</td>
<td>4,700 tonnes</td>
<td>2,400 tonnes</td>
</tr>
</tbody>
</table>

The calculated annual risk from the groundwater pathway for the ILW from a fleet of AP1000 and EPR models is presented in Figures 1 and 2.

Figure 1   Calculated annual individual risk from the groundwater pathway for a 10GW(e) fleet of AP1000 reactors in addition to the ILW from the PCSA reference case
As shown in Figures 1 and 2 above, the addition of the operational and decommissioning inventories to the generic PCSA makes an insignificant difference to the calculated annual individual risk from the groundwater pathway.

### 6.2 Spent Fuel

With respect to spent fuel, the GDA Disposability Assessment considered a reference case where spent fuel assemblies were packaged inside a robust disposal canister. Both copper and steel canisters were considered. The generic PCSA does not explicitly assess copper or steel canisters; instead it considers a range of potential host geological environments and disposal concepts. In particular, it considers a number of possible candidate waste container materials which have different containment times, representing the performance of different waste packages.

A comparison of the GDA Disposability Assessment for spent fuel was therefore carried out with the model used in the PCSA for those runs that are the nearest to those in the GDA Disposability Assessments in terms of the magnitude of the container containment time. These are subsequently referred to as ‘equivalent copper’ and ‘equivalent steel’ containers.

The instant release fractions (IRFs) used in the original GDA Disposability Assessments for both AP1000 and EPR were best estimate values, assuming a burn-up of 65 GWD/t, based on NAGRA data [28]. The values used in the PCSA are based on the Swedish SR-Can Interim Assessment [29], derived from data for fuel burn-up values from 15 to 60 GWD/t.

The differences between the groundwater pathway spent fuel model used in the PCSA and the original GDA Disposability Assessment in the AP1000 and EPR post closure assessments are summarised in Table 4. The results of the calculations are shown in Table 5.
Table 4  Differences between the GDA and PCSA models

<table>
<thead>
<tr>
<th>Model process</th>
<th>GDA Disposability Assessment</th>
<th>PCSA</th>
</tr>
</thead>
<tbody>
<tr>
<td>Container failure</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Copper</td>
<td>Fails with small hole with a triangular PDF in the range $3.4 \times 10^5$ to $1.1 \times 10^6$ years, the latter being most probable.</td>
<td>Fails completely with a log-triangular PDF at time $C$, with lower and upper bounds an order of magnitude either side of the peak value of $5 \times 10^5$ years.</td>
</tr>
<tr>
<td>Steel</td>
<td>Fails with small hole with a triangular PDF in the range $3.9 \times 10^4$ to $3.9 \times 10^5$ years, the latter being most probable.</td>
<td>Fails completely with a log-triangular PDF at time $C$, with lower and upper bounds an order of magnitude either side of the peak value of $10^5$ years.</td>
</tr>
<tr>
<td>Failure rate of all containers</td>
<td>All containers fail at the same time for the purposes of total risk calculation.</td>
<td>Containers are assumed to fail uniformly between $C$ and $2C$ years after the failure of the first container.</td>
</tr>
<tr>
<td>Container failure mode</td>
<td>Container initially fails with a small hole in the lid weld and is assumed to completely fail after $1.1 \times 10^6$ years (area of hole = $1 \text{ m}^2$).</td>
<td>All surface of container assumed to fail at same time.</td>
</tr>
<tr>
<td>Instant release fractions</td>
<td>Best estimate IRFs assuming a burn-up rate 65 GWD/t, based on Nagra data.</td>
<td>Lognormal distributions based on SR-Can Interim Assessment values.</td>
</tr>
<tr>
<td>Dissolution rate of fuel rod</td>
<td>Assumes a fuel rod dissolution time of $2.15 \times 10^6$ years, radionuclide dependent.</td>
<td>Uniform distribution for dissolution rate of the fuel matrix of between $5.0 \times 10^{-5}$ yr$^{-1}$ and $5.0 \times 10^{-7}$ yr$^{-1}$ (corresponds to times for dissolution of $2 \times 10^6$ and $2 \times 10^7$ years).</td>
</tr>
</tbody>
</table>

Table 5  Comparison of GDA and PCSA model risks for new build

<table>
<thead>
<tr>
<th>Scenario</th>
<th>Original GDA results</th>
<th>PCSA model from DSSC</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Time of peak risk (years)</td>
<td>Peak individual risk*</td>
</tr>
<tr>
<td>EPR ‘equivalent copper’ containers</td>
<td>$1.1 \times 10^6$</td>
<td>$4.6 \times 10^{-7}$</td>
</tr>
<tr>
<td>EPR ‘equivalent steel’ containers</td>
<td>83,000</td>
<td>$5.4 \times 10^{-7}$</td>
</tr>
<tr>
<td>AP1000 ‘equivalent copper’ containers</td>
<td>$1.1 \times 10^6$</td>
<td>$4.2 \times 10^{-7}$</td>
</tr>
<tr>
<td>AP1000 ‘equivalent steel’ containers</td>
<td>83,000</td>
<td>$4.6 \times 10^{-7}$</td>
</tr>
</tbody>
</table>

\* Risk for all containers in the model

The peak risks from spent fuel disposal are lower in the PCSA than they were in the GDA, with the difference being more pronounced for the ‘equivalent copper’ containers. This is primarily due to the lower IRFs used in the PCSA study. The peak also occurs earlier with ‘equivalent steel’ containers in the GDA than it does in the PCSA. This is primarily due to the distribution of the canister failure times (see Table 4).
6.3 Total Calculated Risk

The summed total risks from all of the waste types considered in the generic PCSA are shown in Figure 3. Note that other materials assessed in the DSSC, which are not yet declared as wastes (i.e. stocks of uranium and plutonium), are not included in these evaluations. The effect of the additional contribution from ILW and spent fuel arising from the AP1000 and EPR reactor systems, is shown in Figure 4 and 5, respectively.

It can be concluded that, even with the inclusion of the new build inventories, the total calculated post-closure risk from the groundwater pathway is dominated by the ILW component, and that the addition of wastes from a 10 GW(e) fleet of new build reactors makes an insignificant difference to the calculated risks. The fundamental GDA Disposability Assessment conclusions are therefore unchanged when using the generic PCSA methodology.

Figure 3  Calculated mean individual annual radiological risk for the generic PCSA reference case (omitting materials currently not declared as wastes)
Figure 4  Calculated mean individual annual radiological risk for the generic PCSA reference case and wastes from a 10GW AP1000 reactor fleet (omitting materials currently not declared as wastes)

Figure 5  Calculated mean individual annual radiological risk for the generic PCSA reference case and wastes from a 10GW EPR reactor fleet (omitting materials currently not declared as wastes)
6.4 Assessment of Alternative Geological Settings

The generic post-closure assessment methodology is largely based on the concept example for higher strength rock. However, this does not mean that the chosen site will exhibit this type of geology. As described in Section 1, the other geologies considered in generic DSSC are the lower strength sedimentary rock and evaporite rock.

Should a GDF be constructed in other geological environments, advective transport in groundwater may not be the dominant return pathway. In lower strength rock, diffusion may be the dominant transport mechanism, whereas in an evaporite host rock environment, transport in groundwater is not expected to be part of the base scenario. In both these cases, post-closure assessment using the higher strength host rock would be conservative.

6.5 Assessment of Alternative Inventory Scenarios

If the large inventory of depleted, natural and low enriched uranium (DNLEU) in the UK were to be declared as a waste and disposed of in a GDF, preliminary assessments indicate that it could make a significant contribution to post-closure risk in the long term. It is anticipated that the DNLEU would occupy a dedicated disposal vault (or vaults). This would enable a greater control over the chemical environment of the DNLEU as it would not be mixed with other wastes. Additional physical barriers (for example, perhaps a clay lining to the vault), could potentially be used to improve the containment of the uranium. These would be the sort of issues that would be considered during optioneering for the geological disposal of this material, if it were to be declared as a waste. The potential contribution to risk from disposal of the inventories of plutonium or high enriched uranium is much less significant.

The changes introduced by the 2010 Baseline Inventory [12] primarily affect the volumes of waste for disposal. The ILW volume has increased by 35%, principally due to revised decommissioning forecasts at Sellafield, whereas the HLW/SF volume has decreased slightly, due to revised reprocessing assumptions. The radionuclide content of the additional ILW is expected to be similar to that of existing ILW but at lower concentration, and the impact on long-term risks will be minimal. The lower volume of HLW/SF would tend to reduce risks from these components slightly.

The wastes from new nuclear build are one contribution to the Upper Inventory considered by the generic DSSC, although this is not intended as a maximum since the eventual installed capacity of a new build programme is not known; for instance energy companies have recently committed to build up to 16GW(e) of new nuclear power stations. Depending on many factors, including assumptions regarding electricity generation and types of reactor, if a 16GW(e) new build programme was assumed the contribution of the SF component of the Upper Inventory would increase by a factor of less than two. The impact on post-closure risks would not scale directly, and the anticipated small increases in long-term risk from ILW and spent fuel would not be expected to challenge the risk guidance level.

6.6 Conclusions from Review of Post-Closure Safety Assessment

The post-closure analysis for GDA Disposability Assessments of the wastes from a 10 GW(e) fleet of AP1000 or EPR nuclear reactors have been compared against the PCSA published as part of the generic DSSC.

The operational and decommissioning ILW inventories arising have been incorporated into the total-system model for the groundwater pathway as used in the generic PCSA. The output from these calculations confirms that the conclusions reported in the GDA
Disposability Assessments, that the post-closure impact of the additional ILW will be small, remain sound.

For spent fuel in both ‘equivalent steel’ and ‘equivalent copper’ disposal canisters, the peak risk values calculated using the PCSA methodology are lower than those for the GDA Disposability Assessments. This is caused by the use of lower IRF values, consistent with the dataset utilised in the Swedish SR-Can Interim Assessment. It should be noted that the DSSC recognises that work continues within the RWMD research programme to determine definitive values for IRF, appropriate for the range of fuels which may come forward for disposal in the UK.

It has been shown that the conclusions of the post-closure GDA Disposability Assessment remain valid when the new build wastes are assessed and added into the generic PCSA system-model. Even with the inclusion of the new build inventories, the total calculated post-closure risk from the groundwater pathway is dominated by the ILW. These conclusions remain valid for all alternative geological settings and inventory variations.
7 CONCLUDING REMARKS

The 2009 GDA Disposability Assessments have been reviewed in the light of the published safety cases prepared as part of the generic DSSC. The impact of the changes from the original safety assessments due to multiple concepts, assessment methodology and assumptions regarding parameter values has been evaluated.

In the generic DSSC, the GDF footprint is calculated for the Baseline Inventory and for a defined Upper Inventory. The additional footprint required to accommodate ILW and spent fuel from a 10 GW(e) new build programme has been calculated and compared against the footprint required for the Baseline Inventory. The fractional change in footprint, estimated on the basis of the generic DSSC assumptions, is slightly less than that reported in the GDA Disposability Assessments, for both the AP1000 and the EPR. The recent commitment to build up to 16GW(e) of new nuclear power stations could result in a doubling of the SF inventory, with a corresponding increase in the footprint of a GDF.

In terms of transport safety, the ILW and spent fuel from the AP1000 are considered to be compatible with the requirements of the IAEA Transport Regulations in all cases. For both the AP1000 and the EPR proposals, the transport safety assessments have been repeated for limiting streams for operational and decommissioning ILW, and for spent fuel. The assessed doses to relevant worker groups fall within the design targets for the GDF in all cases.

In terms of operational safety, the main consequence of applying the generic Operational Safety Case methodology is on the accident safety assessment. Applying the methodology and assumptions of the operational safety case to the AP1000 and EPR ILW and spent fuel packages leads to some minor increases in consequences but does not result in any calculated doses to exceed RWMD dose targets. There are still some minor issues, as reported in the GDA Disposability Assessments, relating to the potential consequences associated with the release of volatile radionuclides from waste packages subjected to high temperatures in the event of a fire. However, it is fully expected that these can be resolved by a combination of future refinements of the current preliminary inventory estimates, better understanding of the expected fire performance of the waste packages, and further development of the generic designs and safety assessments as the GDF programme moves forward.

The generic Post-Closure Safety Assessment uses an up-dated groundwater pathway model to that used in the GDA Disposability Assessments. For this review, the post-closure system-model has been run with the addition of AP1000 and EPR spent fuel inventories, using parameter values indicative of the expected maximum fuel burn-up. The output from these calculations was found to agree with the conclusions reported in the GDA Disposability Assessments. The revised calculations present a good understanding of the factors contributing to post-closure performance including the impact of different container materials. The calculations remain consistent with the position reported in the published DSSC that the overall post-closure risk is dominated by ILW and, in the DSSC, uranium. Overall the post-closure conclusions of the original GDA Disposability Assessments are shown to remain valid.

The GDA Disposability Assessments concluded that ILW and spent fuel from operation and decommissioning of an AP1000 or EPR raised no new disposability issues when compared against legacy wastes and existing spent fuels. It was noted that RWMD expect that, subsequently, these conclusions would be supported and substantiated by future refinements of the assumed radionuclide inventories of the higher activity wastes and spent fuel, complemented by the development of more detailed proposals for the packaging of the wastes and spent fuel and better understanding of the expected performance of the waste packages.
Overall, the changes in concept, assessment methodology and assumptions regarding parameter values have only minor impacts on the findings of the GDA Disposability Assessments. The review confirmed that there are no new issues arising from the generic DSSC that would challenge the fundamental disposability of the wastes and spent fuel expected to arise from operation of the AP1000 and EPR.

These conclusions are based on assessment of a GDF developed in higher strength rock, and are robust to the potential development of the GDF in alternative geological settings. This is due to the larger openings in higher strength rock (bounding for operational safety), and the dominant mechanism of advective transport in groundwater (bounding for post-closure safety). Consideration of potential variations in disposal inventory, including the recent commitment to build up to 16GW(e) of new nuclear power stations, are not expected to significantly change the conclusions of this review.

At an appropriate stage in the future, RWMD would expect to commence dialogue with new nuclear power station operators and undertake assessment of packaging proposals under the Letter of Compliance (LoC) disposability assessment process. Through this process RWMD and operators would gain confidence that the specific proposals for packaging their wastes will be compliant with GDF planning and safety cases.
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27. UK Nirex Ltd, *Assessment of Post-closure Implications of Incorporating Final Stage (Stage 3) Decommissioning Wastes Inventory and Backlog MAC Floc and TPP/Tc Total and Trial Inventory in Revised Reference Case Inventory*, Nirex Technical Note Reference 530427, 2007

