Radioactive Waste Management

NDA Report no. DSSC/301/01

Geological Disposal

Generic Transport Safety Assessment

December 2016

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Preface

Radioactive Waste Management Limited (RWM) has been established as the delivery organisation responsible for the implementation of a safe, sustainable and publicly acceptable programme for the geological disposal of the higher activity radioactive wastes in the UK. As a pioneer of nuclear technology, the UK has accumulated a legacy of higher activity wastes and material from electricity generation, defence activities and other industrial, medical and research activities. Most of this radioactive waste has already arisen and is being stored on an interim basis at nuclear sites across the UK. More will arise in the future from the continued operation and decommissioning of existing facilities and the operation and subsequent decommissioning of future nuclear power stations.

Geological disposal is the UK Government's policy for higher activity radioactive wastes. The principle of geological disposal is to isolate these wastes deep underground inside a suitable rock formation, to ensure that no harmful quantities of radioactivity will reach the surface environment. To achieve this, the wastes will be placed in an engineered underground facility – a geological disposal facility (GDF). The facility design will be based on a multi-barrier concept where natural and man-made barriers work together to isolate and contain the radioactive wastes.

To identify potentially suitable sites where a GDF could be located, the Government has developed a consent-based approach based on working with interested communities that are willing to participate in the siting process. The siting process is on-going and no site has yet been identified for a GDF.

Prior to site identification, RWM is undertaking preparatory studies which consider a number of generic geological host environments and a range of illustrative disposal concepts. As part of this work, RWM maintains a generic Disposal System Safety Case (DSSC). The generic DSSC is an integrated suite of documents which together give confidence that geological disposal can be implemented safely in the UK.

Executive Summary

Background and Objectives

RWM has been established as the delivery organisation responsible for the implementation of a safe, sustainable and publicly acceptable programme for the geological disposal of the UK's higher activity waste.

The generic Disposal System Safety Case (DSSC) plays a key role in the iterative development of a geological disposal system and is a demonstration that a geological disposal facility (GDF) can be implemented safely. The generic DSSC also forms a benchmark against which RWM provides advice to waste producers on the packaging of wastes for disposal.

The generic DSSC comprises safety cases for the transport of waste to a GDF, for operation of a GDF, and for post-closure environmental safety. The generic Transport Safety Case consists of three documents that together aim to:

- provide confidence in the radiological safety of the transport, without being specific to any potential GDF location
- provide a baseline against which waste packaging proposals can be assessed, in order to determine whether they are likely to be transportable in the future
- provide a means for engagement with stakeholders, such as waste producers and communities interested in hosting a GDF, on topics related to transport safety
- informs RWM's generic science and technology plan as part of the iterative approach to implementing geological disposal

This document, the generic TSA, reports on an assessment of doses to operators from routine transport operations. It is accompanied by the Transport Package Safety (TPS) report, which describes the procedures, assessments and approvals that are, or will be, in place to ensure the radiological safety of each package. The generic TSC Main Report draws together the safety arguments and main conclusions from the generic TSA and TPS reports.

The more specific objectives of the generic TSA are to:

- provide an illustrative evaluation of radiological doses to transport operators from routine operations, and to compare these doses with RWM's safety criteria
- support the advice given to waste producers, as part of the Disposability Assessment process, on the likely impact of their packaging proposals on doses to transport operators
- provide a baseline for future optimisation studies

Assessment Basis

The basis for this assessment is the transport system as defined in RWM's generic illustrative designs. The radioactive waste inventory for disposal is as defined in the Government White Paper, Implementing Geological Disposal.

Assessment Approach

There are two parts to the approach: a bounding and a best estimate assessment. The same calculation method is used for performing the bounding and best estimate assessments, although the two assessments are based on different assumptions and use different data.

The **bounding assessment** provides information on whether individual doses could, in bounding circumstances, exceed the legal dose limit. Bounding circumstances include, for example, operations involving packages with the maximum dose rate and maximum annual exposure times. The bounding case assessment considers maximal use of each transport mode (rail, road or sea) separately, in order to cover cases that are bounding for groups of operators involved in any of the possible modes.

The **best estimate assessment** provides an understanding of how predicted operator doses compare to RWM's Basic Safety Objective (as opposed to the legal limit). Like the bounding assessment, it forms part of the iterative safety integrated design process. In particular, it informs future optimisation of the transport system by providing a baseline against which to estimate the effectiveness of optimisation measures. To enable this optimisation, both individual and collective doses are presented. The assessment is based on representative or typical data and takes account of the scheduling of specific packages in each year and of the radioactive decay that will have occurred by the time the package is transported. In accordance with the RWM Transport Safety Strategy, the transport mode is assumed to be rail where possible, with a transfer by road to a nearby rail transhipment centre if a waste storage site does not have an on-site railhead.

There are some waste packages for which RWM does not know the activity of the contents. In the best estimate assessment, no doses have been calculated for tasks involving these packages. This affects less than 5% of transport units. This assumption does not affect the bounding dose assessment, which is based on all transport packages being at the maximum dose rate allowed by the IAEA Transport Regulations.

Assessment Results

Bounding annual individual doses to transport operators, and a comparison with RWM's limit, are given below. These results show that, even under bounding conditions, no operator group could receive an annual individual dose in excess of the legal limit of 20 mSv/yr for employees working with ionising radiation.

Operator Group	Annual individual dose (mSv/yr)	Percentage of legal limit (20 mSv/yr)
STGO1[1] and STGO 3 drivers	9.0	45%
Train crew	7.9	40%
Ship crew	2.7	14%
Rail transhipment handlers	2.8	14%
Rail transhipment crane operators	2.8	14%
On-board ship banksmen	10.9	55%
On-board ship crane operators	7.5	38%

Best estimate individual annual doses to transport operators are shown in the table below. Maximum, minimum and mean values refer to the range of doses calculated for each year of the transport operation and for each notional GDF location considered in this generic TSA (in the absence of an identified GDF site, notional locations are defined at the

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[1] Transport by road is by vehicles with Special Type (General Order 2003) (STGO) authorisation; higher categories are for packages with higher per-axle mass [Road Traffic Act 1988, Part 2]

approximate central point of each of a number of zones covering England and Wales, such that a representative range of travel distances can be determined).

Operator Group	Individual Dose (mSv/yr) max/mean/ min across all years and zones			Percentage of Basic Safety Objective (1 mSv/yr)	
	Maximum	Mean	Minimum	Maximum	Mean
STGO1 drivers	2.2E-01	1.2E-02	1.2E-08	22%	1.2%
STGO3 drivers	4.1E-01	5.0E-02	0.0E+00	41%	5.0%
Train crew	7.9E-01	5.7E-02	9.0E-06	79%	5.7%
Rail transhipment handlers	5.0E-02	3.2E-03	1.6E-07	5.0%	0.3%
Rail transhipment crane operators	2.3E-01	1.3E-02	7.4E-07	23.0%	1.3%

The main findings of the best-estimate assessment are as follows.

- individual annual doses to all transport operators can be kept within the Basic Safety Objective of 1 mSv/yr
- the operator group receiving the highest individual annual dose is the train crew
- location of GDF makes negligible difference to the doses received
- doses to operators vary widely over time, being correlated to the scheduled disposal windows for each waste category
- spent fuel from new build reactors contributes 38% of the total collective dose
- the task that gives rise to the highest collective dose is the pre-despatch checks carried out by the train crew

Consideration of the above significant contributors suggests that areas where future optimisation studies could initially be focused include:

- doses received during pre-despatch checks, for example by reducing exposure time and increasing distance
- doses received in engaging/ releasing tie-down for Disposal Container Transport Containers (DCTCs) (it is assumed in this generic TSA that engaging / releasing tie-downs will be a remote operation for all package types except DCTCs)
- doses received from certain waste streams, notably spent fuel from new build reactors, for example by additional shielding or optimised scheduling

Such studies would show what measures, if any, were reasonably practicable in each area. However, it is not necessarily in such higher dose aspects of the system that reasonably practicable, or even the most effective, risk reduction measures can be found: they are simply a sensible place to start within a system-wide process of optimisation.

Conclusions

The dose assessments presented in this report give confidence that doses to operators from routine operations will be within the legal limit even under bounding conditions, and can also be kept below the Basic Safety Objective. However, this does not remove the requirement for optimisation of the transport system, which will include ensuring that transport packages at least meet the standards of relevant good practice in transport.

The assessment will need to be updated and refined as better information becomes available – for example regarding those packages for which the dose rate is not yet known and for which no best estimate doses have yet been calculated. Additionally, the assessment of any proposed new transport packages will need to consider the impact of any changed handling requirements on doses to workers.

This safety case will provide the transport safety basis for future disposability assessments and iterative design development.

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1 Introduction

1.1 Introduction to the generic Disposal System Safety Case

RWM has been established as the delivery organisation responsible for the implementation of a safe, sustainable and publicly acceptable programme for geological disposal of the UK's higher activity radioactive waste. Information on the approach of the UK Government and devolved administrations of Wales and Northern Ireland[2] to implementing geological disposal, and RWM's role in the process, is included in an overview of the generic Disposal System Safety Case (the Overview) [1].

A geological disposal facility (GDF) will be a highly-engineered facility, located deep underground, where the waste will be isolated within a multi-barrier system of engineered and natural barriers designed to prevent the release of harmful quantities of radioactivity and non-radioactive contaminants to the surface environment. To identify potentially suitable sites where a GDF could be located, the Government is developing a consent-based approach based on working with interested communities that are willing to participate in the siting process [2]. Development of the siting process is ongoing and no site has yet been identified for a GDF.

In order to progress the programme for geological disposal while potential disposal sites are being sought, RWM has developed illustrative disposal concepts for three types of host rock. These host rocks are typical of those being considered in other countries, and have been chosen because they represent the range that may need to be addressed when developing a GDF in the UK. The host rocks considered are:

- higher strength rock, for example, granite
- lower strength sedimentary rock, for example, clay
- evaporite rock, for example, halite

The inventory for disposal in the GDF is defined in the Government White Paper on implementing geological disposal [2]. The inventory includes the higher activity radioactive wastes and nuclear materials that could, potentially, be declared as wastes in the future. For the purposes of developing disposal concepts, these wastes have been grouped as follows:

- High heat generating wastes (HHGW): that is, spent fuel from existing and future power stations and High Level Waste (HLW) from spent fuel reprocessing. High fissile activity wastes, that is, plutonium (Pu) and highly enriched uranium (HEU), are also included in this group. These have similar disposal requirements, even though they don't generate significant amounts of heat.
- Low heat generating wastes (LHGW): that is, Intermediate Level Waste (ILW) arising from the operation and decommissioning of reactors and other nuclear facilities, together with a small amount of Low Level Waste (LLW) unsuitable for near surface disposal, and stocks of depleted, natural and low-enriched uranium (DNLEU).

RWM has developed six illustrative disposal concepts, comprising separate concepts for HHGW and LHGW for each of the three host rock types. Designs and safety assessments for the GDF are based on these illustrative disposal concepts.

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[2] Hereafter, references to Government mean the UK Government including the devolved administrations of Wales and Northern Ireland. Scottish Government policy is that the long term management of higher activity radioactive waste should be in near-surface facilities and that these should be located as near as possible to the site where the waste is produced.

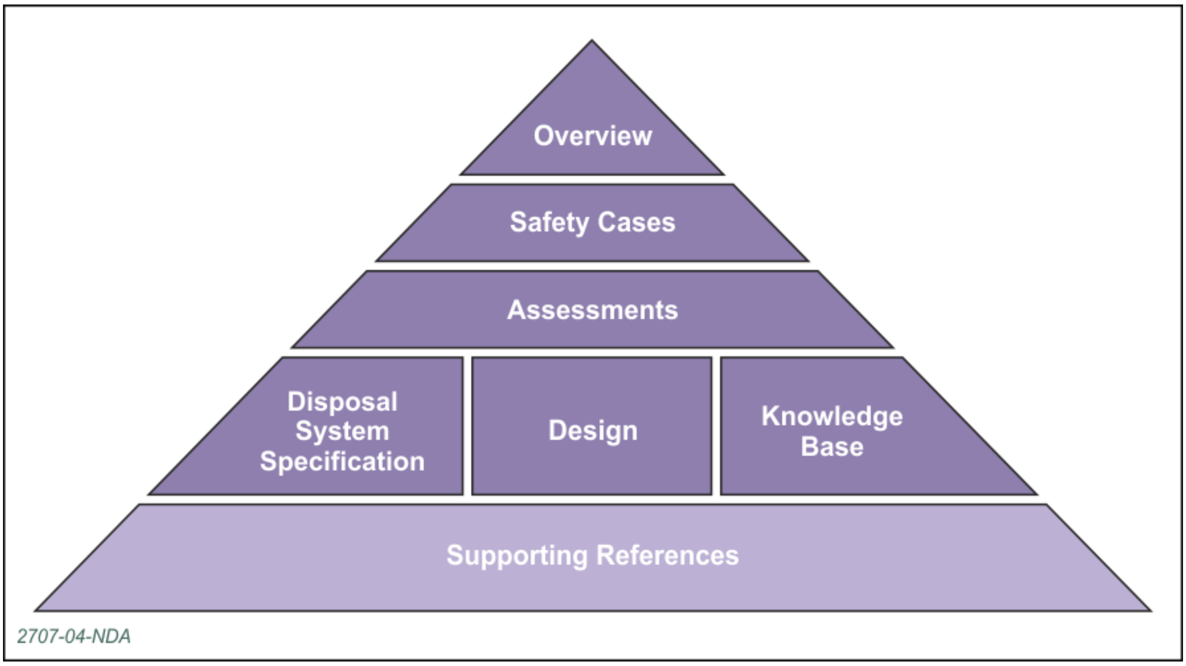
High level information on the inventory for disposal, the illustrative disposal concepts and other aspects of the disposal system is collated in a technical background document (the Technical Background) [3] that supports this generic Disposal System Safety Case.

The generic Disposal System Safety Case (DSSC) plays a key role in the iterative development of a geological disposal system. This iterative development process starts with the identification of the requirements for the disposal system, from which a disposal system specification is developed. Designs, based on the illustrative disposal concepts, are developed to meet these requirements, which are then assessed for safety and environmental impacts. An ongoing programme of research and development informs these activities. Conclusions from the safety and environmental assessments identify where further research is needed, and these advances in understanding feed back into the disposal system specification and facility designs.

The generic DSSC provides a demonstration that geological disposal can be implemented safely. The generic DSSC also forms a benchmark against which RWM provides advice to waste producers on the packaging of wastes for disposal.

Document types that make up the generic DSSC are shown in Figure 1. The Overview provides a point of entry to the suite of DSSC documents and presents an overview of the safety arguments that support geological disposal. The safety cases present the safety arguments for the transportation of radioactive wastes to the GDF, for the operation of the facility, and for long-term safety following facility closure. The assessments support the safety cases and also address non-radiological, health and socio-economic considerations. The disposal system specification, design and knowledge base provide the basis for these assessments. Underpinning these documents is an extensive set of supporting references. A full list of the documents that make up the generic DSSC, together with details of the flow of information between them, is given in the Overview.

Figure 1 Structure of the generic DSSC

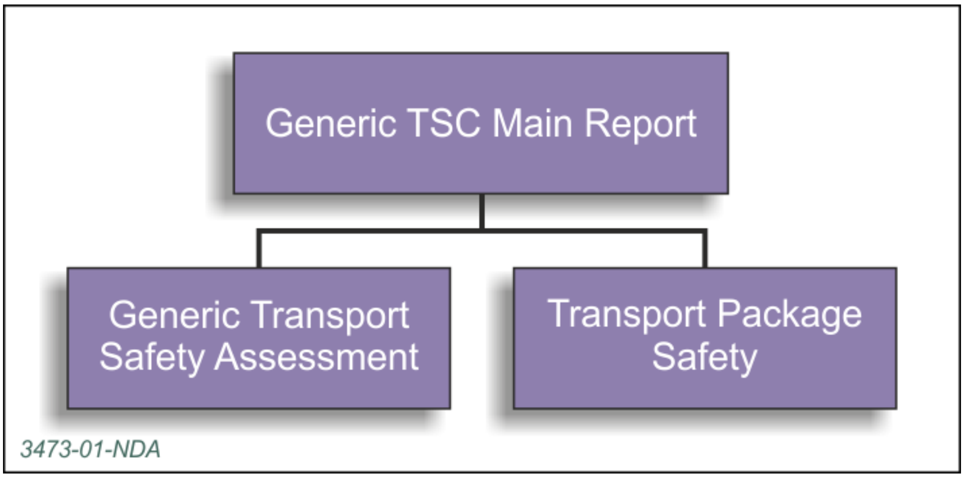


1.2 Introduction to the generic TSA

This document is the generic Transport Safety Assessment (generic TSA) and is one of 3 documents that make up the generic Transport Safety Case (generic TSC).

The structure of the generic TSC is shown in Figure 2. The safety arguments made in this document and the Transport Package Safety report [4] are drawn together and summarised in the generic TSC Main Report [5].

Figure 2 Structure of the generic Transport Safety Case



The generic DSSC was previously published in 2010. There are now a number of drivers for updating the safety case as an entire suite of documents, most notably the availability of an updated inventory for disposal [6].

This document updates and replaces the 2010 generic Transport System Safety Assessment (TSSA) [7], which was published as part of the 2010 generic DSSC suite.

This issue includes the following improvements:

- The basis of assessment has been refined:
  - **Changes to the inventory:** This assessment is based on the 2013 Derived Inventory. The main changes to the inventory since publication of the 2010 generic TSSA and their implications for the 2010 generic DSSC are discussed in [8]. The most significant changes are: the inclusion of wastes and spent fuel associated with a 16 GW(e) nuclear new build programme; reuse of 95% of existing plutonium stocks as mixed oxide spent fuel; the exclusion of waste managed under the Scottish Government's policy for higher activity wastes and the inclusion of material associated with UK defence activities. These changes in the inventory have led to an increased GDF footprint and extended operating time.
  - **New or revised waste packages:** Such waste packages include Disposal Containers for spent fuel and vitrified HHGW; 500 litre robust shielded drums, 3 cubic metre robust shielded boxes and 500 litre and 1 cubic metre concrete drums, for ILW.
  - **Updated transport schedule:** The updated schedule is now aligned with the 2013 Derived Inventory and the extended GDF operating time required for its disposal.
- Improvements in the assessment method:
  - **Treatment of uncertainty in the inventory:** The approach of the 2010 generic TSSA of a single upper bound inventory to reflect inventory uncertainty has been replaced with a consideration of a single inventory together with a range of alternative inventory scenarios with altered quantities and properties of wastes, for example, to reflect different operational scenarios for the evolution of the

    industry, such as an increased new nuclear build programme and increased disposal of LLW at the Low Level Waste Repository near Drigg, Cumbria.
  - **Assessment of bounding and best estimate assessments:** The bounding assessment gives confidence that a dose received by an operator under bounding conditions will be within the legal limit, while the best estimate assessment allows for future optimisation of the transport system.
  - **Improved dose model:** The ‘point source model’ previously used for determining the external package dose rate at a given distance from the package surface has been replaced by a ‘disc source model’ which gives a more realistic dose-distance relationship.
  - **Transport mode assumptions:** The current best estimate transport mode is rail supported by road where necessary, as this is in most cases the most practical mode and is in keeping with the RWM Transport Safety Strategy [9] which is to use rail transport in preference to road. Hence the best estimate dose assessment assumes a maximum use of rail transport. The bounding assessment however considers maximal use of each transport mode - rail, road and sea - separately, in order to cover cases that are bounding for groups of workers involved in any of the possible modes.
- Other improvements:
  - **Removal of duplicate information:** Technical background information that was duplicated across the 2010 generic DSSC documents so that they would stand alone has been removed and placed in the Technical Background to avoid repetition. The main implication of this for the generic TSA is that the assessment basis is described only at a high level, with greater detail in the Technical Background.
  - **Updated dose rate limits:** Maximum external package dose rates allowed by RWM in disposability assessments have been amended. The 2010 assessment assumed that the more restrictive limit, as defined in the IAEA Transport Regulations [10] for non-exclusive use would apply. In this 2016 assessment, it is assumed that the less restrictive limit, for exclusive use, will apply. (Exclusive use means that a single consignor has use of the conveyance or of a large freight container, in respect of which all loading, unloading and shipment are carried out in accordance with the directions of the consignor or consignee).

1.3 Objectives

1.3.1 Objectives of the generic TSC

The generic Transport Safety Case aims to:

- provide confidence in the radiological safety of the transport system, without being specific to any potential GDF location, this forms part of RWM’s demonstration to regulators and stakeholders that safe geological disposal is feasible
- provide a baseline against waste packaging proposals can be assessed, under the Disposability Assessment process, in order to determine whether they are likely to be transportable in the future
- provides a means for engagement with stakeholders, such as waste producers and communities interested in hosting the GDF on topics related to transport safety
- informs RWM’s generic science and technology plan [11] as part of the iterative approach to implementing geological disposal

These objectives are met by the following documents that make up the generic TSC:

- **Transport Safety Case Main Report**, which draws together the safety arguments and main conclusions of its underpinning reports, namely:
    - **Transport Package Safety report**, which describes the procedures, assessments and approvals that are, or will be, in place to ensure the radiological safety of each package
    - **Generic TSA**, ie this document, which reports on an assessment of doses to operators from routine transport of radioactive wastes to the GDF

1.3.2 Objectives of the generic TSA

The objectives of the generic TSA are to provide an illustrative evaluation of radiological doses to operators from routine operations of the transport system, and to compare these doses with RWM's radiological protection criteria. In the longer term, as the generic TSA evolves, it will provide an informed basis for continued planning and design of the whole transport system, and for development of assessment approaches.

More specifically, the findings of this and any future generic TSAs can be used:

- to provide preliminary guidance on the levels of dose associated with the illustrative transport operation, that is, a preliminary prior risk assessment (or prior radiological evaluation) as required for the eventual development of Radiation Protection Programmes (RPPs) as required under the Ionising Radiations Regulations
- provide a baseline for future optimisation of the transport system
- to provide a basis for advice to waste producers (for example by setting out the assumptions on which the assessment is based) so that they can optimise their packaging plans with respect to transport, as part of the Disposability Assessment process (noting however that it does not provide advice specific to any particular packaging solution)
- to identify any limitations in the safety assessment capability in sufficient time to allow development of improved approaches before a full assessment is required
- in addition, the assessment reported here has provided the opportunity to build on experience and feedback [12,13] on earlier assessments, thus improving the state of readiness before development of site-specific transport system design begins

The audience of this report is expected to be:

- the radioactive material transport regulator, the transport function within the Office for Nuclear Regulation (ONR)
- RWM's internal functions, notably those responsible for future optimisation studies, transport system design and disposability assessments
- waste producers
- other stakeholders, especially communities interested in hosting the GDF or who may reside along a potential transport route to the GDF

1.4 Scope

1.4.1 Scope of assessment

The scope of this assessment is the radiological safety of the transport of the radioactive waste inventory for disposal to a GDF, for an illustrative transport system design.

No location has yet been identified for the GDF and so there are uncertainties on certain aspects of transport system design, such as routes, transport modes and infrastructure. This document therefore provides a preliminary assessment of an illustrative, generic transport system. A systematic optimisation approach will be undertaken to aid decision making on the transport system in future and the process for this is described in RWM's Quality Management System [14]. The evolution of the TSA, as knowledge on possible location information develops, is described in the Transport Safety Strategy [9].

This report provides an indication of the radiological doses that transport operators would receive from routine[3] transport operations, based on current knowledge.

In the bounding assessment, annual individual operator dose is calculated, for comparison against the legal limit. In the best estimate assessment, individual doses are again calculated, for comparison with the Basic Safety Objective. In addition, collective doses are calculated, as these can also be used in future optimisation studies.

Exclusions

The following are not included in this assessment.

- **Calculation of doses to the public:** This will only be considered at a site-specific stage when sufficient information on the transport system is known to enable areas of potential public exposure to be identified; for example, in the vicinity of transhipment points.
- **Risks due to accidents:** Such risks will be controlled through compliance, as appropriate to the package, with the accident performance requirements of the IAEA Transport Regulations. In the case of packages for which there are no accident performance requirements, RWM considers that safety is assured through compliance with the low specific activity and wasteform requirements.
- **Risks from minor mishaps:** Such risks include those leading to changes in shielding or small releases of activity.
- **Risks due to non-compliance with the IAEA Transport Regulations and other design and operational requirements:** This includes, for example, risks due to manufacturing defects or human error.
- **Risks associated with non-radioactive hazardous materials within the waste:** RWM is currently developing its approach to the assessment of such materials in all areas of safety.
- **Transport security and safeguards requirements:** Security is covered by the Nuclear Industries Security Regulations [15] and safeguards by the EURATOM treaty [16,17]. RWM's work on security and safeguards is described in the Generic Transport System Design (GTSD) [18, Section 8) and in [19].
- **Emergency arrangements:** Emergency arrangements are required by the IAEA Transport Regulations, and as such there is a requirement in the Carriage of Dangerous Goods and Use of Transportable Pressure Equipment Regulations [20, 21] for a written emergency plan to be in place prior to the shipment of any package containing radioactive material. More information on emergency arrangements can be found in the GTSD.

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[3] For the purposes of the generic TSC, routine transport means incident-free transport. ('Normal' transport includes minor mishaps).

1.4.2 Scope of transport operation

All aspects of the transport system including routes, conveyances, transport packages, operational procedures and logistics have been considered for this assessment.

For the purpose of the generic TSA, it is assumed that the transport operation:

- starts at the point where the transport package is loaded and secured to a transport conveyance within the nuclear licensed site at which it is stored
- covers the journey through the public domain, including any en-route transhipment facilities, where the transport packages are transferred from one conveyance to another
- continues into the GDF (nuclear licensed site) up to the point where the responsibility for the transport packages is handed over to the GDF operator[4]

Hence the assessment considers operators associated with transport, including drivers and crew of conveyances and handlers at transhipment points.

It excludes, however, assessment of doses to handlers and health physicists working within waste producing sites, as their safety will be assured by the safety case process for that nuclear licensed site.

1.5 Document structure

The remainder of this document is structured as follows:

- Section 2 provides contextual information, including the regulatory requirements and RWM's strategic principles
- Section 3 sets out the basis of the assessment
- Section 4 describes the acceptance criteria, assessment methodology and data references
- Section 5 presents the results of the assessment
- Section 6 discusses the assessment results
- Section 7 presents the conclusions from the assessment

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[4] This will be before the point when the package is released from the conveyance. In practical terms this means either that the driver uncouples their rail wagon or vehicle trailer (minimal dose being incurred by this task) and drives off, or that - if the package is released from the wagon or trailer with the loco / tractor unit still coupled - the driver is not involved in this task.

2 Context

The regulatory regime that applies to transport of radioactive material is described in the Transport Package Safety report and summarised here, together with an explanation of the role of the generic TSA within that regime.

The key legal requirements that relate specifically to the radiological safety of transport are:

- The transportation of radioactive wastes and materials has to meet the requirements of the IAEA Transport Regulations, which are implemented in UK law by the Carriage of Dangerous Goods Regulations 2009 [20], as amended by the Carriage of Dangerous Goods Regulations 2011 [21]. Key requirements include the need for:
    - Type B and fissile radioactive waste transport package designs (that is those containing the most hazardous waste) to be approved by a competent authority
    - Type IP-2 radioactive waste transport package designs (those containing less hazardous waste) to be approved by a competent body subject to regular audit by the competent authority
    - the implementation of RPPs, documenting the controls in place by the consignor, transport operator and consignees to limit doses to operators and the public
- The Ionising Radiations Regulations 1999 [22] (IRR99) place limits and other requirements on radiation exposures, requiring, amongst other things, that the radiation exposures of all persons are restricted 'so far as is reasonably practicable' (SFAIRP).

There are also broader duties under general health and safety legislation, with key requirements as follows:

- Under the Health and Safety at Work (etc) Act 1974 [23] (HSWA), there are general duties on employers to ensure, SFAIRP (commonly equated with the term 'as low as reasonably practicable' (ALARP)), the health, safety and welfare of their employees, and that persons not in their employment, are not exposed to risks to their health or safety. These duties apply to both radiological and non-radiological risks.
- The Management of Health and Safety at Work Regulations 1999 [24] place a general requirement on employers to carry out 'suitable and sufficient risk assessment'. This applies to both radiological and non-radiological risks.

The generic TSA provides preliminary guidance on the levels of dose associated with the illustrative transport operation, and hence forms the basis of a preliminary prior radiological evaluation – a necessary step in developing an RPP.

The generic TSA also provides a starting point for future optimisation studies, supporting a demonstration that, as required under the HSWA and IRR99, risks or doses have been SFAIRP.

Responsibility for demonstrating and providing a safe transport operation will be shared between a number of organisations, for example consignors, carriers and the consignee (the GDF operator). One of RWM's strategic principles is that until such time as these responsibilities are assigned, RWM will represent the role of waste consignor, carrier and the consignee and take responsibility for developing and implementing its Transport Safety Strategy.

Hence the generic TSA provides information to regulators to give confidence that a transport operation to the GDF can be achieved safely and in accordance with regulatory requirements in place.

3 Assessment Basis

This section provides a high level summary of the illustrative transport system that forms the basis of the generic TSA. Further detail is given in other generic DSSC reports, primarily the Technical Background and the GTSD [18]. The data on which the assessment is based are provided in the generic DSSC Data Report [25].

3.1 Inventory

The assessment is based on the 2013 Derived Inventory [26]. This is derived from the 2013 UK Radioactive Waste Inventory [27] (UKRWI) and the Inventory for Disposal as defined in the 2014 White Paper [2]. More information on the inventory is given in the Technical Background. The derivation and content of the 2013 Derived Inventory are described fully in the Derived Inventory report.

In producing the Derived Inventory, waste packaging assumptions made by waste producers have been reviewed and, where necessary, revised to ensure that assumed packaging allows for waste to be packaged in a form suitable for its safe management, storage, transport, underground emplacement and disposal. Additional information has been derived, such as heat generation and external dose rates required for this and other generic DSSC assessments.

The 2013 Derived Inventory presents the Inventory for Disposal in broad groups defined for the purposes of developing disposal concepts, and also in a more detailed breakdown of waste groups. The wastes are broadly grouped as:

- high heat generating waste (HHGW): that is, spent fuel from existing and future power stations, and High Level Waste (HLW) from spent fuel reprocessing
- high fissile activity waste: that is, plutonium (Pu) and highly enriched uranium (HEU)
- low heat generating waste (LHGW): that is, Intermediate Level Waste (ILW) arising from operating and decommissioning of reactors and other nuclear facilities, together with a small amount of Low Level Waste (LLW) unsuitable for near surface disposal, and stocks of depleted, natural and low-enriched uranium (DNLEU)

3.2 Waste categories, packaging and transport units

The waste containers and transport containers assigned to wastestreams in the 2013 Derived Inventory are listed and described in the GTSD. A summary of the waste packages and transport arrangements, as assumed in the generic TSA, is given in Table 1.

In some cases, waste packages may be conveyed in a transport overpack either singly or in multiples. To allow for this complexity, the term ‘transport unit’ is used. A transport unit is a package or collection of packages that are handled and transported as a single unit. For example, a transport unit could be either a transport package, if handled as a discrete unit during transport, or a collection of transport packages in an overpack.

For the purpose of the generic TSA some simplifying assumptions have been made. For example, in the GTSD, 500 litre robust shielded drums could be carried in an ISO overpack or a SWTC-150. The last of these has been assumed in the generic TSA.

Table 1 Summary of illustrative waste and transport packages

	Waste category or group	Waste package	Transport unit
LHGW	LLW & ILW	500 litre drum	SWTC[5]-70, SWTC-285
		3 cubic metre box	
		3 cubic metre drum	
		6 cubic metre concrete box	6 cubic metre concrete box
		2 metre box	2 metre box
		4 metre box	4 metre box
		Miscellaneous Beta Gamma Waste Store MBGWS) box	SWTC-150
		500 litre robust shielded drum	SWTC-150
		3 cubic metre robust shielded box	ISO overpack
		1 cubic metre concrete drum	ISO overpack
		500 litre concrete drum	ISO overpack
	DNLEU[6]	3 cubic metre box	SWTC-70, SWTC-285
		500 litre drum	
		DV-70	Transport and disposal container (TDC)
HHGW	HLW	Disposal container	Disposal Container Transport Container (DCTC)
	Spent fuel[7]		
	Pu		
	HEU		
	MOX		

There are some waste packages for which RWM does not know the activity of the contents. In this best estimate assessment, no doses have been calculated for tasks involving these packages. This affects less than 5% of transport units. This assumption does not affect the bounding dose assessment; however, as in the bounding case, all transport packages are assumed to have the maximum dose rate allowed by the IAEA Transport Regulations

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[5] Standard Waste Transport Container.

[6] The current dose assessment assumes the 500 litre drum for all DNLEU. However, a formal change to the disposal system to use TDCs for Depleted Uranium (DU) has since been implemented. The implications for the dose assessment are discussed in Section 6.5.

[7] This includes both legacy spent fuel from Magnox, advanced gas-cooled reactor (AGR) and pressurised water reactor (PWR) plant, and spent fuel arising from a programme of new nuclear power stations.

The sensitivity of the best estimate assessment to this assumption is discussed in Section 6.3.2.

3.3 Transport modes and infrastructure

The bounding assessment considers doses to operators from transport by road, rail, sea or a combination of these, in order to cover cases that are bounding for groups of operators involved in any of the possible modes. However, since the RWM Transport Safety Strategy is to use rail transport rather than road where practical [9], the best estimate assessment considers transport to the GDF by rail, with road transport from the waste storage site to a nearby railhead where necessary.

Where there is a need to move transport units from one mode to another, this will be carried out at a transhipment point such as a railhead. The current UK transport infrastructure system is considered to be suitable for the predicted requirements of the transport operation.

Transport by road is by vehicles with Special Types (General Order 2003) (STGO) authorisation. In this assessment, lighter packages, giving a per-axle weight of less than 11.5 tonnes (usually packages up to 30 tonnes), will be transported by HGV under STGO Category 1 (STGO1). Heavier packages such as SWTC-285s will be carried by STGO Category 3 (STGO3) vehicles.

Transport by inland waterway is not assessed as there are currently very few significant movements by this mode and few, if any, possible GDF locations might use this mode. However should a specific site have this as a potential transport route, then this mode would be considered at that time. Air transport has also been discounted as a possibility at this stage due to the weight of the transport packages and the limited availability of suitably located and equipped airports.

A more detailed description of each transport mode and relevant assumptions is given in the GTSD.

3.4 Routes

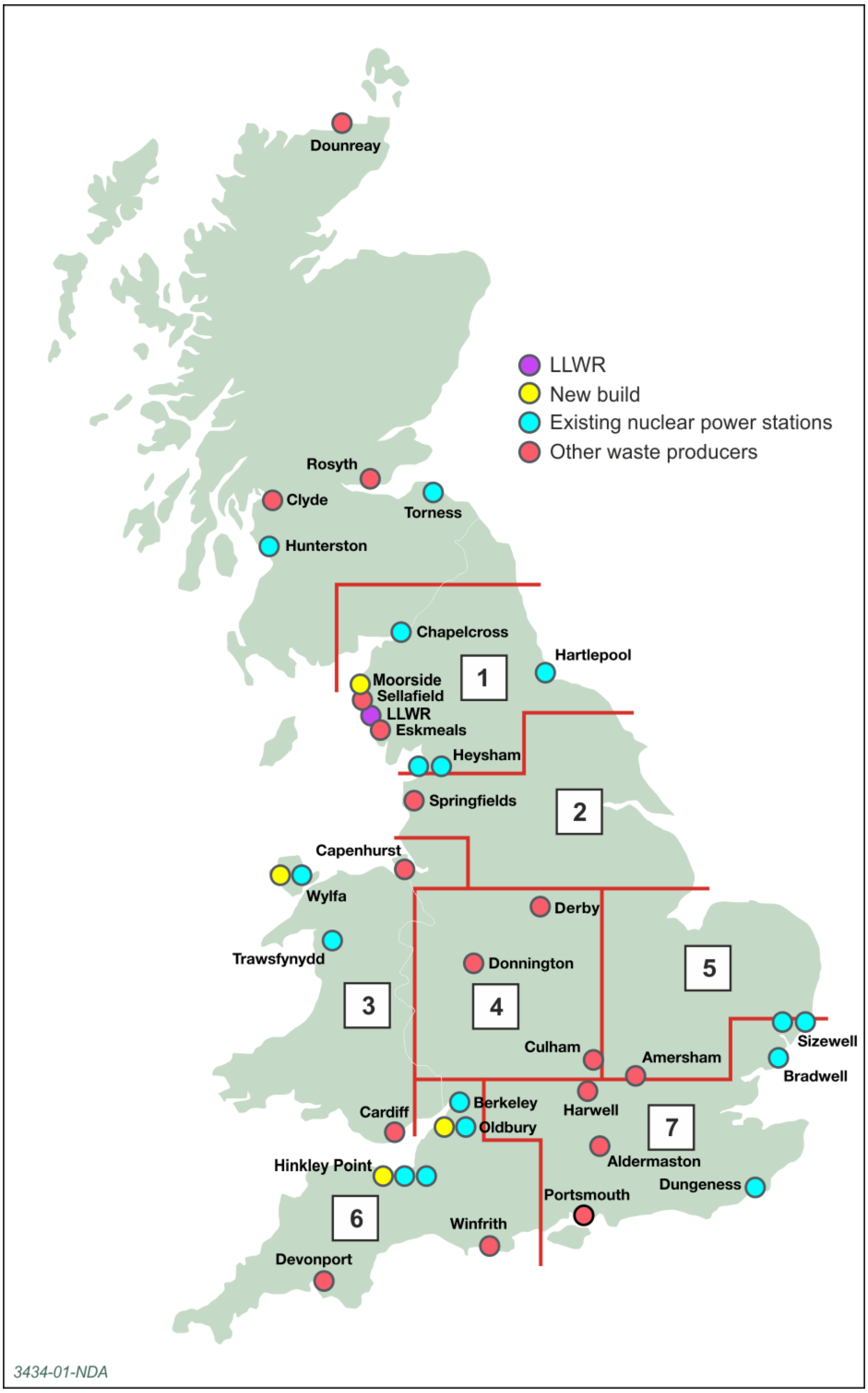
Waste is currently stored at arising sites around the UK, as shown in Figure 3.

Transport routes from those sites will depend on the location of the GDF. To address this uncertainty in this generic assessment, a number of notional GDF locations are defined. This is achieved by dividing England and Wales into zones of approximately equal area, with one zone covering Wales and the remaining six covering England, as also shown in Figure 3.

Scottish Government policy is that higher activity waste should be in near-surface facilities near to the sites where the waste is produced. Hence for this generic transport assessment, only zones covering England and Wales are considered.

The approximate geographical central point of each zone is defined as a notional location for the GDF, and conceptual rail routes from each waste producing site to each of these notional GDF locations are defined so that the distance covered by each package on its journey to these notional zones can be determined. An assessment has been performed for each of the seven zones, creating ranges of results.

Figure 3 **Sites where radioactive waste and materials are currently stored, with zones for notional GDF location**



3.5 Operators

Operators who would potentially be exposed to doses from routine transport operations include drivers and crew of the various conveyances, as well as handlers at transhipment points. The operator groups defined in this assessment, in line with the scope defined in Section 1.4.2, are listed in Table 2.

Table 2 Transport operator groups

Operator group	Description
STGO1 drivers	Drivers qualified to operate STGO1 vehicles carrying transport units (either filled or empty) from the waste arising sites to an off-site railhead, despatch port or GDF.
STGO3 drivers	Drivers qualified to operate STGO3 vehicles carrying transport units (either filled or empty) from the waste arising sites to an off-site railhead, despatch port or GDF.
Train drivers / crew	Operators who drive or guard the train between any combination of railheads, sea ports and GDF.
Ship crew	Ship crew who continuously man the sea vessel, work routine ship's watches and remain with the ship during loading and unloading operations.
Rail transhipment handlers	Handlers involved in the transhipment from a road vehicle to a rail wagon at an off-site railhead, responsible for engagement and release of tie-downs and checking transport units as they are being crane-loaded onto rail wagons.
Rail transhipment crane operators	Crane operators who will remove transport units from an STGO vehicle and load them directly onto rail wagons.
On-board ship banksmen	Members of the ship's crew who are responsible for checking transport units as they are being crane-loaded into the ship hold.
On-board ship crane operators	Members of the ship's crew who are responsible for manning the on-board ship crane during a land-vehicle to sea transhipment.
The following operators are bounded by the above and so are not assessed:	
Despatch port banksmen	Workers at a despatch port who are responsible for guiding and checking transport units as they are being crane-loaded onto the ship. While both despatch port and GDF port banksmen are dockside and responsible for guiding and checking packages as they are crane-lifted on/off a ship, the GDF port banksmen are also responsible for engaging tie-down of transport units to rail wagons at the GDF port. Despatch port banksmen do not incur dose from releasing the tie-down on arrival at the despatch port, as it is assumed that this task is carried out remotely. This operator group is therefore bounded by the GDF port banksmen, and hence – for the reasons given below – by rail transhipment handlers.
GDF port banksmen	Workers at the GDF port who are responsible for guiding, checking and engaging tie-down of transport units as they are being crane-loaded onto rail wagons. This operator group is bounded by rail transhipment centre handlers, who carry out both engagement and release of tie-down.

3.6 Tasks

The operator groups in Table 2 undertake the tasks shown in Table 3.

Table 3 Tasks carried out by each operator group

Name	Task sequence
STGO1 drivers	Carry out pre-despatch checks Drive STGO vehicle
STGO3 drivers	
Train crew	Carry out pre-despatch checks Drive train
Ship crew	Crew ship
Rail transhipment handlers	Release tie-downs of transport unit from road vehicle Engage tie-downs of transport unit on train
Rail transhipment crane operators	Lift transport unit from STGO vehicle and place onto rail wagon
On-board ship banksmen	Tie-down transport unit onto ship Crew ship Release transport unit (assumed to be a manual task only for DCTCs)
On-board crane operators	Lift transport unit off vehicle and into ship hold using crane Crew ship Lift transport unit off vessel and onto train using crane

Guiding of packages during crane lifting has not been assessed as this activity is expected to be designed out of the crane lifting operation. This is considered reasonable because transhipment operations elsewhere do not require nearby banksmen and it should be possible to design the transhipment facility with suitable line of sight for the crane operator.

4 Assessment Overview

This section describes the types of dose calculations undertaken, the criteria against which they are assessed and the approaches, tools and data used to predict those doses.

Section 4.1 outlines the dose metrics for individual and collective dose to workers in routine operations, together with the corresponding radiological protection criteria. The method for predicting these doses is described in Section 4.2. Section 4.3 outlines the software tools and data used.

The effects of some of the key uncertainties in the inventory are explored in the sensitivity studies discussed in Section 6.3.1.

4.1 Dose metrics and acceptance criteria

In general, operators will receive radiation doses through multiple exposure pathways during routine (incident-free) transport. The dominant pathway is the exposure to external radiation emitted from transport units and it is this pathway that is considered under this assessment. Other exposure pathways include airborne releases and those via non-fixed surface contamination. However, these are excluded from the assessment because doses incurred via these pathways are limited by compliance with the IAEA Transport Regulations, in which the limits on such exposure are very stringent and would not plausibly amount to a significant dose.

4.1.1 Bounding and best estimate assessments

As described previously, there are two parts to this assessment:

- a bounding assessment
- a best estimate assessment

The bounding assessment provides information on whether routine doses could, in bounding circumstances, exceed the dose limit. Bounding circumstances include, for example, operations involving packages with the maximum dose rate and maximum annual exposure times. It forms part of the iterative safety integrated design process [28] as applied to the generic illustrative design [29].

The best estimate assessment provides an understanding of how predicted doses compare to the Basic Safety Objective (as opposed to the legal limit). It informs the optimisation of the transport system by providing a baseline against which to estimate the effectiveness of optimisation measures. Like the bounding assessment, the best estimate assessment forms part of the iterative safety integrated design process.

RWM requires that in the event that bounding or best estimate doses are predicted to be above the legal limit or Basic Safety Objective respectively, the assessor must first determine whether this is a result of undue pessimism in the assessment. If predicted doses remain above the legal limit or Basic Safety Objective once undue pessimisms are removed, this is fed back into the safety integrated design process so that any reasonably practicable measures to reduce dose can be identified.

4.1.2 Collective and individual dose

In order to calculate the individual dose to an operator, the collective dose (man-mSv/yr) is first calculated. These calculations take into account the number of operators exposed as well as the dose to each individual operator. They are an important complement to individual operator dose calculations, especially for comparison of options. In particular, in future optimisation assessments, collective dose assessments are necessary to ensure that the proposed measures achieve safety benefits overall and do not simply result in dose sharing or dose redistribution. For example, increasing the size of an operator group and reducing individual shift hours as a method of dose control would decrease the individual dose due to sharing of workload; however, the collective dose would remain constant, indicating that the proposed measure did not achieve physical safety benefits overall.

Individual dose is calculated by dividing the collective dose by the total number of operators in each group, regardless of individual shift patterns. This means, for example, that changes of shift during a journey have no effect on collective dose.

Inputs to the bounding assessment are defined in order to estimate the maximum individual dose to an operator. Both individual and collective dose are useful indicators for the best estimate assessment, as this may be used as a baseline for optimisation studies. Annual doses are therefore presented in terms of individual dose for the bounding assessment; and individual dose and collective dose for the best estimate assessment. For the best estimate assessment, doses are calculated for each year of the transport operation, whereas the bounding dose assessment is calculated for a notional year corresponding to bounding parameters.

4.1.3 Acceptance criteria

RWM's radiological protection criteria for routine doses to operators are based on the statutory dose limits in the IRR99 and the guidance in the ONR Safety Assessment Principles (SAPs). The relationships between RWM's criteria and these statutory / regulatory criteria are shown in Table 4. Although the SAP criteria were developed for licensed sites, RWM also applies them to transport.

The Basic Safety Level (BSL), as defined in the SAPs [30], corresponds to the legal limit in the IRRs, and represents that above which the dose from the activities is intolerable, while the Basic Safety Objective forms a benchmark that reflects modern nuclear safety standards and expectations. The Basic Safety Objective is primarily of interest to regulators, as it is the dose below which they will not generally spend regulatory effort on detailed assessment of a duty holder's safety case. However, the requirement on duty holders to reduce dose to SFAIRP / ALARP remains, even when doses are below the Basic Safety Objective.

Table 4 Dose[8] criteria for routine operations

Effective Doses from Ionising Radiation (mSv/yr)					
Exposed Person Group	**Ionising Radiations Regulations (IRR99)**	**ONR Safety Assessment Principles (SAPs)**		**RWM Criteria**	
		Basic Safety Level	**Basic Safety Objective**	**Legal Limit**	**Basic Safety Objective**
Employees working with ionising radiation (>18 years of age)[9]	20	20	1	20	1
Average for defined groups of employees	Not defined	10	0.5	Not defined	Not defined
Public (not used in this assessment)	1	1	0.02	1	0.01

It is also necessary for individual packages to comply with dose rates and other criteria defined in RWM's waste package specifications (see the Technical Background). These specifications are derived from regulatory requirements, most notably the SAPs and the IAEA Transport Regulations, as well as RWM's own criteria for disposability.

In the 2010 assessment, RWM's waste package specifications set out a requirement for all individual packages to comply with dose rate criteria defined in the IAEA Transport Regulations for non-exclusive use shipments, which are more restrictive than those for exclusive-use shipments (regardless of whether the package is intended to be shipped under exclusive or non-exclusive use). This requirement has since been revised and packages now need to comply with the criteria applicable to the intended use. The impact of this change on the dose assessment is that individual packages may be shipped with higher external package dose rates than those assumed for previous assessments. The derivation of dose rate and other criteria set out in the waste package specifications is described in more detail in the Transport Package Safety Report.

4.2 Assessment methodology

This section gives an overview of the methods used to calculate bounding and best estimate collective and individual operator doses. Further details are provided in Appendix A.

The same calculation method is used for performing the bounding and best estimate assessments, although the two assessments are based on different assumptions and use different data. The bounding assessment is based on bounding data, for example, maximum dose rates, exposure durations and package throughput rates. The best estimate assessment is based on best estimate data, and also takes account of the scheduling of specific packages in a given year and the radioactive decay that will have occurred by the time the package is transported.

For both assessments, the collective dose received by a defined group of operators from a transport unit when performing a given task is a function of the exposure distance, the dose

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[8] The quantity to which the criteria relate is the 'annual effective dose' from sources of ionising radiations. In this report it is simply referred to as 'dose'.

[9] The assessment reported here considers only employees working with ionising radiation who are over 18 years of age.

rate from the package at that distance, the exposure duration and the number of operators involved in the task. Factors are applied to account for shielding and for cases when multiple packages are placed close together. The total annual dose to an operator group from a given task is calculated by multiplying the dose from that task by the number of tasks carried out per year. The methods used for determining these parameters are described in the following sub-sections.

The bounding assessment is a simplification of the best estimate assessment; hence, the methodology for the best estimate assessment is presented first, followed by an explanation of how it is simplified to perform the bounding assessment.

4.2.1 Best estimate assessment

The best estimate assessment assumes that all transport is by rail where possible. For despatch sites without a railhead, a journey by road to a nearby rail transhipment centre will be necessary.

Operator groups and tasks

The first step in the assessment was to identify all relevant operator groups through a review of the transport system requirements. Relevant operator groups are defined as those where an individual operator could conceivably receive a dose greater than the Basic Safety Objective. The relevant operator groups identified are those listed in Table 2, with the exception of those that apply to sea transport.

In order to identify groups in a robust and thorough manner, a process flow diagram was used to set out broad activities (or nodes) in the disposal process, such as ‘waste transport’. Each node is made up of a number of processes, for example, ‘transport by road’ or ‘transport by rail’. At the lowest level, each process is further divided into tasks.

The following assumptions were made in identifying relevant operator groups:

1. Operators that carry out one or more tasks that could be allocated to the same person (taking into account the practical constraints of the sequencing and physical locations of the tasks, and the competences required) are assigned to the same operator group. For example, one of the two train crew will not only operate the train; they will also perform pre-despatch checks before departure. In this case, a single operator group is defined that carries out both crewing and checking operations. If a single worker can plausibly undertake all the tasks in a process, it is assumed they do so in order to give a conservative dose prediction.
2. All road-to-rail transhipment handlers across the transport system belong to a single operator group, and so the same group operates all railheads, and the group’s tasks are independent of the transhipment point at which they are carried out. This is unrealistic in practice, as the number of operators required will vary significantly at each railhead for each year of operation. To a lesser extent (except in the case of DCTCs) the type of transport unit handled can affect the doses received. However, accounting for such variations would add unnecessary complexity to this illustrative assessment, and so this conservative approach is considered appropriate at this stage.

Exposure durations

For tasks involving the driving or crewing of a vehicle, the exposure duration is calculated by dividing the route distance by the average transit speed of the vehicle along that route. No distinction is made at this stage between different road types and population densities; instead an average is taken to be the speed limit applicable to the road vehicle on dual carriage ways.

For handling tasks such as engagement and release of tie-down and pre-despatch checks, the exposure duration is taken from occupancy assessments.

With regard to release of tie-down, the transport system design assumes that Disposal Container Transport Containers (DCTCs), used for transporting HLW and spent fuel, are released manually (requiring work in relatively close proximity) while all other transport units are released remotely. The dose assessment software tool (described in Section 4.3) is unable to draw this distinction by defining package-specific tasks, and so the dose assessment assumes that all transport units, including DCTCs, are released remotely, with no operator exposure. This gives rise to some optimism, but as the number of DCTCs is only a small percentage (7.4%) of the total, to assume instead that all packages are manually released would result in high degree of conservatism.

In this assessment, it is assumed that handlers who are not fully occupied are not exposed to dose in any waiting time or while performing other tasks away from the package, such as administrative duties.

Exposure Distance

For some tasks the exposure distance is calculated from the constraints imposed by the transport system design. For example, the exposure distance for crew transporting a package is dependent on the size of the vehicle. For handling tasks such as release / engagement of tie-down and pre-transport checks, the exposure distance is taken from occupancy assessments.

Dose rate at the exposure distance

The dose rate in mSv/hr from a given package at a given distance, also referred to as the source term, is extrapolated from the dose rate at a reference distance using the ‘disc source approximation’ method. Essentially, a dose-distance relationship is determined by modelling the face of a transport unit as a circular disc source with a characteristic radius that best reproduces the dose-distance relationship of the transport unit. This approximation provides an accurate representation of the variation of dose rate with distance from the package surface, particularly at distances close to the transport unit. This is an improvement in the ‘point source approximation’ used in the 2010 generic TSSA, because it avoids being overly pessimistic at short distances while remaining conservative at longer distances.

The disc source approximation method requires a characteristic radius for each transport unit type. This can be found by regression provided that there are modelled dose rates at multiple reference distances. Each of the transport unit types has been modelled and dose rates per unit activity concentration have been calculated for a range of gamma ray energies and a number of reference distances. These have been used to determine the characteristic radii as described in the generic DSSC data report [25].

The source term is also dependent on the length of time spent in storage due to the radioactive decay that will have occurred during that time. Doses to operators are calculated for each year of the transport operation, based on an illustrative schedule that sets out which packages are transported in which year, and the corresponding package dose rates at the time of transport. Although doses are calculated for each year of the transport operation the dose rate data are only available in five-year steps. The transport schedule is derived using best-estimate, yet conservative assumptions: stores are emptied in turn, the Sellafield site is closed after other sites and wastestream transports have been ordered so that the transport units with the highest dose rates are prioritised as soon as they become available for transport. Thus reliance on scheduling as a means of dose control is avoided.

There are some waste packages for which RWM does not yet know the activity of the contents. In this assessment, zero doses were calculated for tasks involving these packages. This affects less than 5% of transport units. The sensitivity of the assessment to this assumption is discussed in Section 6.3.2.

Annual number of tasks performed

The number of times a task is performed in a single year is normally equal to the number of transport units processed that year, as defined in the transport schedule. For example the number of handling tasks is equal to the number of transport units transported. However, for tasks involving the use of a conveyance, the number of tasks will vary according to the number of transport units that can be loaded onto that conveyance. For example, the number of rail transit tasks undertaken in a given year (from a site without a railhead) will be fewer than the number of STGO transit tasks as multiple transport units are moved in a single train journey, whereas only a single transport unit is transported on an STGO vehicle.

Shielding and multiple unit correction factors

Shielding factors are applied to account for any structures that may provide shielding between the operator and the transport unit, such as vehicle cab shielding. These do not allow for internal shielding built into a transport unit as this is implicit in the source term.

Where a task involves exposure to multiple source terms, for example, exposure of a ship's crew to a number of transport units in the hold during transit, a correction factor is applied to the source term to account for the cumulative dose. The correction factor takes account of the design geometry, for example, where packages shield one another or are at differing distances from the operator.

4.2.2 Bounding assessment

The approach to the bounding assessment was to assign feasible bounding values to parameters that would maximise the dose received by individual operators. A maximum annual individual dose is calculated for every operator group identified in Table 2, including those involved in sea transport.

Although DCTC packages are a relatively small component of the inventory (7.4%), tasks involving DCTCs are bounding because it is assumed that they require manual engagement/ release of tie-down, in close proximity. Consequently, the bounding scenario is defined on an operator-by-operator basis: the assessment being based on the handling and transport arrangements for either ILW packages (which are considered representative of all other package types), DCTCs or a combination of both ILW packages and DCTCs in a single year, whichever leads to the highest overall dose to each operator group.

The optimism introduced in the best-estimate assessment, whereby all transport units were assumed to be released remotely, therefore does not affect the bounding assessment. Similarly, the assumed zero dose assumed for those waste packages for which RWM does not know the activity of the contents does not affect the bounding assessment, as all transport packages were assumed to have the maximum dose rate allowed by the IAEA Transport Regulations.

Operator groups and tasks

Operator groups and task parameters are as those considered in the best estimate assessment (Table 2) plus for sea transport operators. Note that the GDF port banksmen and despatch port banksmen are not assessed as these operators are both bounded by rail transhipment handlers.

Exposure duration and distance

In general, the bounding exposure duration for tasks involving ILW packages are the same as used in the best estimate assessment, for example, pre-despatch checks. However, as the bounding calculations were carried out by hand, they are not limited by the functionality of the software package used (see Section 4.3), and it was possible to reflect differences in exposure duration and distance between packages. The exposure duration and distance for tasks involving release or engagement of tie-down of a DCTC were therefore set according to the current assumed design intent, which is that:

- engagement and release of tie down of DCTCs on the conveyance requires a manual operation at close proximity

Additionally, the exposure duration and distance for tasks involving engagement or release of tie-down of an ILW package have been set according to the design intent for ILW packages:

- release from the tie-down uses an automated twistlock mechanism and hence does not require a manual operation
- engaging the tie-down of an ILW package requires a manual handling operation involving the pulling of a lever at the end of the conveyance, taking less time than required for DCTCs

Handling tasks generally lead to a higher dose than transit tasks over the same exposure duration; therefore, the annual exposure duration for transit tasks is set to be the time remaining from the maximum permitted hours of exposure per annum (see Appendix A.2.1) after the time spent on handling tasks per annum has been deducted.

Dose rate at the exposure distance

The dose rate from transport units is defined to be the legal maximum considered suitable for exclusive-use transport as specified in the IAEA Transport Regulations. This differs from the best estimate assessment which uses dose rates derived specifically for each transport unit (where available).

Number of tasks performed

The bounding assessment does not allow for any specific scheduling of the waste inventory in determining the number of packages handled (and hence the number of tasks undertaken). Instead, the transport unit throughput is taken as the maximum throughput as specified by the GDF illustrative design for each category of waste.

There are certain task definitions where it is important to avoid dose-sharing between operators in cases where the number of operators required for each task varies. For example, transporting a package by rail includes a task to carry out pre-despatch checks as well as the transit task itself. Two crew members are required for the transit task but only one is required for the checking task. Rather than assume that the two drivers share the checking work, it is assumed that a single driver is utilised as much as possible within the constraints of working time regulations and package throughput, and hence performs all checking duties.

Shielding and multiple unit correction factors

Correction factors are the same for the bounding assessment and best estimate assessment.

4.3 Tools and data

The Transport and Operational Dose Assessment (TODA) toolkit [31] was used to perform the best estimate assessment. An audit [32] of the software toolkit used in the 2010 generic TSSA - the Transport Safety Assessment Toolkit (TranSAT) - had found TranSAT to be hampered by retention of legacy functionality over years of changing requirements, and that yet further changes would be required to implement RWM's methodology. Hence the most efficient approach was to retire TranSAT and build TODA to meet current and predicted future requirements.

The bounding assessment, which is much simpler as it does not take into account differences between wastestreams and the year of the transport operation, was carried out using a purpose-built spreadsheet. Both TODA and the spreadsheet are outlined below.

TODA is able to calculate doses received from external radiation by operators during routine transport of waste packages to the GDF and as a result of normal operations at the GDF. This version of the generic DSSC is the first time a single toolkit has been used to carry out assessments for both the transport and operational safety cases. It represents an improvement in efficiency and gives increased confidence in consistency between the two assessments.

With regard to transport, TODA is able to consider transport to a number of notional locations for a generic GDF and also to a single location as a site-specific stage. It is able to address transport strategies that combine different modes of transport.

Data are stored in and loaded from import sheets, which link directly to the RWM data catalogue of Data Definition Forms. RWM's data management procedure, and the data used in this assessment and across the generic DSSC are described in the generic DSSC Overview

Outputs can then be filtered, sorted and exported to an Excel spreadsheet for further manipulation and charting.

The following import sheets are used by TODA:

- **Route data model** – contains infrastructure distances for each mode of transport for every combination of waste storage site to notional GDF location
- **Inventory** – contains the storage location, dose profile and package type for all wastestreams
- **Schedule** – contains the number of transport units exported per wastestream per year
- **Transport mode compatibility** – contains a Boolean flag for every wastestream specifying whether its transport units have a sufficiently low mass to be transported by STGO1 vehicle (all wastestreams are assumed to be compatible with STGO3, rail and ship transport)
- **Workforce** – contains all operator groups identified in Table 2 along with any pre-defined operator group sizes and maximum hours of exposure per annum
- **Tasks** – contains a work breakdown structure with accompanying task and occupancy parameters for all processes identified in the best estimate assessment
- **Transport batching policy** – contains the number of transport units per movement and the associated multi-unit correction factors for each combination of transport mode and package type
- **Calculation** – contains definitions for calculation type (ie transport, integrated or operational), dose rate extrapolation methodology (ie disc or point source

approximation), GDF location to be assessed, average transit velocities and relevant import sheets

One important feature of TODA is its flexibility in assessing alternative import sheets. By allowing the user to swap import sheets and re-run the assessment with other parameters unchanged, alternative scenarios can be assessed and sensitivity to certain data can be investigated. For example, the effects of changing the disposal inventory can be readily assessed by swapping one inventory import sheet for another.

As mentioned above, the bounding assessment was performed using a stand-alone spreadsheet. This was partly due to limitations in the functionality of TODA, since it is not possible to define package-specific tasks. This is important because the manual handling arrangements for DCTCs are considered to be the most complex, involving the operator being in close proximity to the package for a long duration of time. Therefore the spreadsheet includes separate tasks for both DCTCs and ILW packages.

5 Assessment Results and Comparison with Criteria

This chapter summarises the results of the dose assessments, and compares them with given criteria where available. A discussion of these results is given in Section 6.

5.1 Best estimate assessment

The results of the best estimate assessment have many dimensions, including year, zone for notional GDF location, waste category, wastestream, operator group and task. Only some of the many permutations of results that would be possible for such a multi-dimensional system are useful. Those presented here have been selected on the basis that they allow for one or more of the following:

1. to allow comparison with the Basic Safety Objective
2. to show variability across zones or years
3. to show dominant contributors in order to identify where optimisation should be prioritised

A comparison of individual doses with the Basic Safety Objective is shown in Table 5. Table 6 shows the collective dose calculated for each operator group. Collective and individual doses are shown as maxima, mean and minima across all zones and years of transport.

Table 5 Best estimate individual doses, shown as maxima, minima and mean of all zones and all years, with Basic Safety Objective

Operator Group	Individual Dose (mSv/yr) spanning all years and zones			Maximum Annual Individual Dose as % of Basic Safety Objective (1 mSv/yr)
	Maximum	Mean	Minimum	
STGO1 drivers	2.2E-01	1.2E-02	1.2E-08	22%
STGO3 drivers	4.1E-01	5.0E-02	0.0E+00	41%
Train crew	7.9E-01	5.7E-02	9.0E-06	79%
Rail transhipment handlers	5.0E-02	3.2E-03	1.6E-07	5%
Rail tranship. crane operators	2.3E-01	1.3E-02	7.4E-07	23%

Table 6 **Best estimate collective doses, shown as maxima, minima and mean of all zones and all years**

Operator Group	Collective Dose (man-mSv/yr) spanning all years and zones		
	Maximum	Mean	Minimum
STGO1 drivers	4.3E-01	2.3E-02	2.4E-08
STGO3 drivers	8.1E-01	1.0E-01	0.0E+00
Train crew	1.6E+00	1.2E-01	3.3E-05
Rail transhipment handlers	2.0E-01	1.3E-02	6.5E-07
Rail tranship. crane operators	4.6E-01	2.6E-02	1.5E-06

These results are discussed in Section 6.1.

5.2 Bounding assessment

Bounding annual individual doses to transport system operators, and a comparison with the legal limit, are given in Table 7.

Table 7 **Bounding individual doses to operators**

Operator Group	Annual Individual Dose (mSv/yr)	Percentage of legal limit (20 mSv/yr)
STGO1 and STGO3 drivers	9.0	45%
Train crew	7.9	40%
Ship crew	2.7	14%
Rail transhipment handlers	2.8	14%
Rail transhipment crane operators	2.8	14%
On-board ship banksmen	10.9	55%
On-board ship crane operators	7.5	38%

The results in Table 7 show that even under the bounding conditions, no operator group receives an annual individual dose in excess of the legal limit of 20 mSv/yr for employees working with radiation. These results are discussed in Section 6.2.

6 Discussion

The results of the best estimate and bounding assessments are discussed in Sections 6.1 and 6.2 respectively. Section 6.3 describes the sensitivity of the results to the major identified uncertainties, and Section 6.4 presents a comparison with the results of the 2010 assessment. Section 6.5 discusses the effect of recent changes to the disposal concept for DNLEU.

6.1 Best estimate assessment

The results presented in Section 5.1 are shown in such a way as to:

- allow comparison with the Basic Safety Objective
- show variability across zones or years
- show the greatest dose exposures or dominant contributors, in order to identify where optimisation should be prioritised

Findings relating to each of the above are presented in Sections 6.1.1 to 6.1.5 following. Potential areas for optimisation are considered in Section 6.1.6

6.1.1 Comparison with the Basic Safety Objective

Best estimate individual annual doses to all operators (Table 5) are below the Basic Safety Objective for all years of transport and for all notional GDF locations.

6.1.2 Variation of dose with GDF zone

Table B1 shows that doses to operators have very little dependence on GDF location. This is exactly as expected for operators such as transhipment handlers and crane operators who only undertake tasks that are independent of GDF location. However negligible variation is also seen for groups that drive vehicles or trains, for which in-transit doses will depend on journey time. The reason for the negligible variation is that doses to these groups are dominated by those from pre-despatch tasks, rather than doses in transit.

6.1.3 Variation of dose with year of transport

Figures B2 and B3 show the wide variability of collective and individual dose, respectively, over time. The noticeable 5-year steps are due to the resolution of the input data.

Doses are correlated to the scheduled disposal windows for each waste category. Peaks in early years are due to transport of specific ILW streams. Doses then remain low until a notable increase occurs in 2075, coinciding with the scheduled disposal window for HLW. Following this, the trend in high doses continues due to the scheduled transport of legacy spent fuel in 2090. Both HLW and legacy spent fuel packages have relatively high external package dose rates compared to other waste categories, so this is expected. There is an overall decrease in operator doses in the years 2105 to 2130, roughly corresponding to a break in the transport of ILW, HLW and spent fuel and increase in lower external dose rate DNLEU transport movements. From approximately 2130 onwards, the dose to operators quickly increases with the recommenced transport of MOX and NNB spent fuel wastestreams. This steadily tails off as the activity of the spent fuel waste decays in storage.

6.1.4 Highest exposures / contributors – operator groups

Table B1 shows that the operator group receiving the highest individual annual dose is the train crew.

The pre-despatch checks performed by the train crew are the greatest contributor to collective dose. Pre-despatch checks incur higher doses than crewing a vehicle in transit due to the absence of shielding and the close proximity to the package. The dose is relatively high for train crew compared to vehicle drivers as every package must travel via rail at some point on its journey, whereas only packages from sites without railheads travel via STGO.

Other tasks that contribute significantly, in order of highest contribution to dose, are the pre-despatch checks carried out by the STGO3 drivers, and the lifting operation carried out by rail transhipment crane operators where the transport unit arrives on an STGO3.

The dose to STGO3 drivers is substantially higher than the dose for STGO1 drivers, even though the number of STGO3 journeys is only 15% of that for STGO1 journeys. This is predominantly due to the transport of spent fuel in DCTCs which cannot travel to a rail transhipment centre via STGO1 vehicle because of their high mass. Although spent fuel only accounts for 17% of the packages transported by STGO3 drivers, spent fuel generally has a significantly higher dose rate in comparison to LLW, ILW and DNLEU, leading to a larger dose.

It is notable that train crew doses are greater than those for handlers. This is because handlers are only exposed to packages for a very short amount of time, for only some of the inventory. Train crew are exposed to every package in the schedule. Additionally, their exposure duration to a single package can be of the order of ~10 hours which, even accounting for shielding and dose attenuation, outweighs the unshielded short exposure duration of handlers.

6.1.5 Highest contributors – waste categories and streams

Spent fuel from new build reactors (MAP100 and MEP100) is notable, as it contributes 38% of the total collective dose. This is because of relatively high dose rates for these packages and a relatively large inventory. The average dose rates for these packages across the years of transportation are 3.2×10^{-2} mSv/hr at 1metre for EPR waste and 2.4×10^{-2} mSv/hr at 1metre for AP1000 waste.

All operator groups with the exception of STGO3 drivers received the highest proportion of their collective dose from ILW shipments, simply because of the large numbers of ILW shipments compared to the other waste categories. STGO3 drivers receive most of their collective dose from spent fuel shipments, as these dominate their transport movements in terms of the number of shipments. Collective doses from shipments of spent fuel are higher than those from other waste categories because of a combination of relatively high dose rates and frequent package transhipments; even though the number of packages is lower than for ILW.

6.1.6 Potential areas for optimisation

These results suggest that higher dose-contributing areas where optimisation studies could initially be focused are:

- pre-despatch checks: there is no additional shielding present in this task, the exposure distance is small, the exposure duration is relatively long and the task must be done for every single transport unit at both the consignor site and, if applicable, rail transhipment centre
- DCTC tie-down (it is assumed that the engagement or release of tie-down will be a remote operation for every package type except DCTCs)
- doses received from certain waste streams, notably spent fuel from new build reactors, for example by additional shielding or optimised scheduling

In principle, the higher dose aspects of the system have greater potential for dose reduction so they are a sensible place for optimisation studies to start. However, it is important to note that there may be more reasonably practicable or more effective risk reduction measures available for other aspects of the system. Optimisation eventually needs to be demonstrated for the system as a whole.

6.2 Bounding assessment

The results in Table 7 show that even under bounding conditions there is no operator group that receives an annual individual dose in excess of the legal limit of 20 mSv/yr for employees working with radiation.

Bounding conditions are extreme and unlikely, and in practice, annual doses are likely to be significantly lower than these maxima. At the package level, it is assumed in this bounding assessment that each package has an external package dose rate equal to the maximum dose rate permitted by the IAEA Transport Regulations, and that operators work all their maximum allowable operating hours in the year. At a higher level, some broad bounding assumptions have been made, as listed in Table 8. Whilst these conditions are unlikely, they are not unfeasible, and hence there is no justification for adopting any less bounding conditions.

Table 8 Assumptions in the bounding assessment

Operator	Bounding assumption
All	The number of packages transported in one year is equal to the maximum assumed throughput of the GDF
STGO1 and STGO3 drivers	All packages in a year travel from the consignor site to a rail transhipment centre, with the journey distance maximised in order to fully utilise the driver in a single year
Train crew	All packages in a year travel via rail to the GDF, where the journey distance is maximised in order to fully utilise the rail crew
Ship crew	All packages in a year travel by sea from a despatch port to the GDF port, where the journey distance is maximised in order to fully utilise the ship crew
Rail transhipment handler	All packages in a year pass through a single transhipment centre (that is, all packages start their journey on a road vehicle, and require transhipment to rail)
	The packages handled include a combination of DCTCs and ILW packages. DCTCs have bounding handling exposure parameters as they are manually released.
On-board ship banksmen	All packages in a year travel by sea from a despatch port to the GDF port, where the journey distance is maximised in order to fully utilise the ship banksmen
On-board ship crane operator	All packages in a year travel by sea from a despatch port to the GDF port, where the journey distance is maximised in order to fully utilise the ship crane operators

Thus any packaging proposal made by the waste producers can (provided the ALARP requirement is also satisfied) be considered as being radiologically safe for transport if it complies with the relevant waste package specification, can be transported by the transport system design as described in Section 3 and that exposure durations and distances are bounded as described in 4.2.2 and the assumed values given in the Data Report.

6.3 Sensitivity studies

6.3.1 Inventory

The White Paper [2] states that it is not anticipated that the categories of waste and material included in the inventory for disposal in the GDF will change significantly. They provide the most complete picture of the possible inventory for disposal and are presented as such in order to give communities considering hosting the GDF the full picture of the wastes and materials to be considered. Hence a single inventory, the 2013 Derived Inventory, has been assessed. The approach adopted across the generic DSSC is to explore a wider range of inventory uncertainties through assessment of a number of inventory scenarios to estimate the impacts of uncertainties on designs and safety assessments.

The inventory scenarios in Table 9 have been identified in the Inventory Scenario report [33] for consideration in the generic DSSC. These are organised into groups that would lead to a similar effect.

Table 9 Inventory scenarios grouped by effect

Scenario No. [33]	Scenario	Effect [33]
Scenarios that increase the number of packages of legacy or new build spent fuel		
2	Less reprocessing of Magnox fuel	Number of packages of legacy spent fuel would increase from 3,610 to 7,000, and small decreases in the other waste categories would be observed.
3	Increased lifetime of operating legacy reactors	Number of packages of legacy spent fuel would increase from 3,610 to 4,770, and small decreases in the other waste categories would be observed.
8	Increase in number of new build reactors	Proportionate increase in numbers of packages of spent fuel and other wastes
Scenarios that increase or decrease the number of packages of ILW		
11	Graphite not disposed of in GDF	The number of ILW packages is reduced from 204,000 to 176,000
6	Short-lived ILW streams decay stored and disposed of as LLW	The number of ILW packages is reduced from 204,000 to 201,000
7	Depleted uranium is increased	The number of ILW packages would increase, depending on how much the volume of depleted uranium is increased (0.6 waste packages per tonne of DNLEU)
10	Alternative packaging assumptions for ILW	The number of ILW packages is increased or decreased, depending on the alternative assumption.
Scenarios that increase or decrease the number of packages across all waste types		
4	Recognise UKRWI uncertainty estimates	Applying lower uncertainty factors to all packages decreases the number of packages by 18% and applying upper uncertainty factors increases the number of packages by 64%.
Scenarios that change the waste package properties (for example package dose rate)		
5	Separated stocks of plutonium not managed as mixed oxide spent fuel	Alternative arrangement would change the waste package properties, for example package dose rates, depending on the nature of the alternative arrangement.
4	Recognise UKRWI uncertainty estimates	Applying lower uncertainty factors to all packages decreases the activity by 24% and applying upper uncertainty factors to all packages increases the activity by 85%.

The following additional scenarios are recognised in the inventory scenarios report but not discussed here as they are either bounded by other scenarios or their implications on safety arguments discussed elsewhere [33]:

- more reprocessing of oxide fuel (scenario 1)
- LLW diverted from LLWR to the GDF (scenario 6)
- foreign waste (scenario 9)

The remainder of this section presents a qualitative discussion on the groups of scenarios presented in Table 9.

The bounding assessment is independent of inventory since bounding inventories and package numbers are used in the calculation. However, should the basis of assessment change as a result of an inventory scenario, for example if a second inlet cell were to be added to accommodate increased package numbers, the bounding assumptions would need to be modified and a consequence of this could be that the legal limit is exceeded.

The best estimate assessment however is dependent on inventory, and hence the doses to operators will be higher or lower than those presented in this report, for each scenario. The scenario groups in Table 9 fall into two broad categories: those that increase or decrease the number of packages and those that increase or decrease the waste package properties.

Scenarios that increase or decrease the number of packages

Scenarios that could lead to more or fewer packages of the same type and contents would have a broadly proportional effect on the annual dose to operators, although this effect will in most respects not be realised, as it is expected that the GDF will operate at maximum throughput. If the number of packages increases to a level that cannot be accommodated within the planned operating period, that period would have to be increased. However, if the GDF throughput was increased (for example by adding a second inlet cell), the annual dose to operators would continue to increase proportionally with the number of packages and the Basic Safety Objective could potentially be exceeded.

Scenarios that change the waste package properties

Scenarios that could change the characteristics of the waste package would only have an effect if they changed package dose rates. For example, thermal treatment, if it gives greater waste concentration, could lead to higher package dose rates and hence increased doses to operators. Nevertheless, any effect would be limited due to the upper limits on permissible dose rates

Although doses received by operators depend on the package dose rate, there is not always a clear link between waste group and higher or lower package dose rates, as variations are to an extent compensated for by selecting waste containers and transport containers with an appropriate level of shielding for each wastestream. Therefore, the dose to operators is often relatively insensitive to the waste group. A notable exception to this is DNLEU, which mostly has low dose rates, yet represents a large number of packages. This means that low annual doses are expected in years when most of the packages transported are DNLEU. Conversely, as noted earlier, spent fuel – especially new build spent fuel – has higher package dose rates and contributes significantly to collective dose. Operator doses would therefore be expected to be sensitive to spent fuel shipments, increasing with the number of spent fuel packages.

6.3.2 Packages for which dose rates are not yet known

In the best estimate assessment, no doses have been calculated for tasks involving packages for which the dose rate at the time of transport is not yet known. While this assumption affects less than 5% of transport units, it is optimistic. An alternative, pessimistic, approach would be to assume that all such packages have the maximum dose rate, as in the bounding dose assessment.

If this alternative assumption is made, the highest individual dose to workers rises from 0.79 mSv/yr (for train crew in 2044) to 2.34 mSv/yr (for train crew in 2046). This dose is dominated by the streams with no (known) dose rate in the years when they represent a significant proportion of the annual throughput. As would be expected, this makes the best estimate assessment for such years more similar to the bounding case. Using the limiting dose rate therefore distorts the best estimate assessment, causing it to be dominated by the bounding assumptions rather than known information, and hence potentially obscuring the effects of wastestreams for which dose rates are already known to be high. The assessment will need to be revisited when actual dose rate data become available for these packages.

6.4 Comparison with results of the 2010 assessment

It is not possible to make a straightforward, like-for-like comparison of the predicted doses from the present assessment and those from the 2010 generic TSSA [7]. This is because there have been significant changes to the assumptions, data and methods of assessment, as listed in Section 1.2. These include, for example, changes in the inventory, schedule and assumed transport modes, different operator group definitions, and differences in the approach to modelling uncertainty (the present assessment being based on bounding and best estimate cases rather than a baseline case with variants).

Nevertheless, by comparing doses for those operator groups that are similarly defined in both assessments, it can be seen from Table 10 that dose ranges overlap and are of similar orders of magnitude. This, together with a degree of independence between the assessments in terms of their data sources and software models used, provides some confidence in both assessments.

Table 10 Comparisons of individual doses: 2010 and 2016 assessments

2010 Assessment		**2016 Assessment**	
Operator Group	**Dose range (mSv/yr) (across transport mode scenarios and zones)**	**Operator Group**	**Dose range (mSv/yr) (best estimates, across years and zones)**
HGV crew	0.05 to 0.29	HGV (STGO 1 and STGO 3) drivers	0.0 to 0.41
Rail crew	0.07 to 0.12	Train crew	9E-6 to 0.79

6.5 Changes to disposal concept for DNLEU

Since carrying out the dose assessment, RWM has implemented a change to the DNLEU packaging concept as assumed in the DSS and 2013 Derived Inventory (see Section 3.2 and Table 1). The proposed change is to dispose of most depleted uranium in the form of oxide powders, using current / planned storage containers which are then cement-grouted into a strengthened stainless steel transport and disposal containers (TDCs), while retaining the use of 500 litre drums for the remaining DNLEU.

This would have safety benefits in terms of meeting retrievability requirements, in the evaluation of accident performance and in reducing the need for upstream chemical and physical processing. From the transport safety point of view, the benefit is in significantly reducing the number of transport movements and handling operations, due to the higher payload of the proposed solution.

The quantitative dose assessment has not been updated at this stage, as there is insufficient information on dose rates from the TDC to do so. However, it is not expected that this will cause a major change in the best estimate dose, as DU is not a major contributor to the total dose.

7 Conclusions

Bounding and best estimate assessments of doses to transport operators from routine operations of a generic, illustrative transport have been carried out.

The bounding assessment showed that, even under bounding conditions, no operator group receives an annual individual dose in excess of the legal limit of 20 mSv/yr.

The main conclusions of the best-estimate assessment were as follows:

1. Best estimate individual annual doses to all transport operators can be kept within the Basic Safety Objective of 1 mSv/yr.
2. The operator group receiving the highest individual annual dose is the train crew.
3. Location of GDF makes negligible difference to the doses received.
4. Doses to operators vary widely over time, being correlated to the scheduled disposal windows for each waste category.
5. Spent fuel from new build reactors contributes 38% of the total collective dose.
6. The task that gives rise to the highest collective dose is the pre-despatch checks carried out by the train crew.
7. Based on the breakdowns of dose, areas where optimisation to reduce doses to operators could initially be focused include:
    a. Pre-despatch checks: there is no additional shielding present in this task, the exposure distance is small, the exposure duration is relatively long and the task must be done for every transport unit.
    b. DCTC engagement and release of tie-down (it is assumed that every package type except DCTCs, this will be a remote operation).
    c. Doses received from certain waste streams, notably spent fuel from new build reactors, for example by additional shielding or better optimised scheduling.
8. These areas are a sensible place to start identifying reasonably practicable dose reduction measures because the initial doses are higher. However, it is important to note that there may be more reasonably practicable or more effective risk reduction measures available for other aspects of the system. Optimisation to reduce doses will be a system-wide process.

In summary, therefore, the dose assessments presented in this report give confidence that doses to operators from routine operations will be within the RWM limit, even under bounding conditions, and can also be kept below the RWM Basic Safety Objective. However, this does not remove the requirement for optimisation of the transport system, which will include ensuring that transport packages at least meet the standards of relevant good practice in transport.

The assessment will need to be updated and refined as better information becomes available – for example regarding those packages for which the dose rate at the time of transport is not yet known and for which no best estimate doses have yet been calculated. Additionally, the assessment of any proposed new transport packages will need to consider the impact of any changed handling requirements on doses to workers. This safety case will provide the transport safety basis for future disposability assessments and iterative design development.

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Glossary

A glossary of terms specific to the generic DSSC can be found in the Technical Background.

Appendix A – Details of the Methods Used in the Dose Calculations

This appendix presents additional detail on the assessment methodology and assumptions used for calculating operator doses. Section A1 lists the assumptions made in the assessment. Section A2 details the dose assessment methodology used in both individual and collective operator dose assessments.

A1 Assumptions

This section describes the approach and assumptions used in the dose assessment. It covers operator manning parameters; transport conveyances, speeds and movements, and transport distances, scheduling and modes.

A1.1 Task, occupancy and operator parameters

Ten relevant operator groups have been identified, although only eight have been assessed (see Table 2). These groups may not cover all the operators involved in the transport operations, nor do they distinguish between variations across a group, however they give an illustrative representation of the typical operator groups that could potentially receive a dose above the Basic Safety Objective.

Exposure distances and durations

Exposure distances are measured from either the surface or centre of the transport package. This is specified for every sub-task. With the exception of ship-transport of packages, the exposure distances for tasks pertaining to the physical transport of packages (that is, driving a STGO1, STGO3 or train) have been measured from the centre of the package using the transport vehicle's dimensions. Additionally, the exposure distance for crane-operating sub-tasks have been defined as being measured from the centre of the transport package.

For sea transport, the exposure distance between the crew quarters and the nearest transport packages is set by the International Maritime Dangerous Goods IMDG Code [1], taking into account the transport index of the packages and the assumed steel double-bulkhead between the hold and living quarters.

Most task exposure distances and durations have been taken from task and occupancy studies. All others have been calculated using the transport system design and infrastructure data. These values represent averages over the task duration.

Maximum exposure hours per annum

For both the bounding and best estimate assessments, the annual exposure durations per operator group are simply the maximum permitted annual hours of employment as defined in the working time regulations specific to that operator type. This approach simplifies the assessment by avoiding the need to define tasks which do not lead to direct exposures, such as any waiting time, administrative responsibilities or bounded tasks.

The maximum exposure hours per annum for each operator has been calculated by assuming an operator works the maximum permitted number of hours in a week summed over an entire year (accounting for standard entitled annual leave and public holidays). The calculation used to determine the maximum working hours for handlers is as follows:

$$\begin{aligned} &Maximum\ hours\ of\ exposure \\ &= Max\ hours\ per\ week \times (52 - Number\ of\ weeks\ annual\ leave \\ &- Number\ of\ weeks\ public\ holiday) \end{aligned}$$

For all drivers, it is assumed that only half of their annual employment hours will lead to an exposure from a transport package, because a round trip will consist of an outward journey and a return journey of equal length and duration, only one of which conveys waste. Therefore, the maximum hours of exposure per annum for drivers were approximated by halving the maximum permitted annual hours of employment. The calculation used to determine the maximum hours of exposure for drivers is as follows:

$$\begin{aligned}&Maximum\ hours\ of\ exposure\\&= \frac{1}{2} \times Max\ hours\ per\ week \times (52 - Number\ of\ weeks\ annual\ leave\\&- Number\ of\ weeks\ public\ holiday)\end{aligned}$$

Note that 'week' refers to a working week, equivalent to 5 working days.

Number of operators

The number of operators in a group is needed in order to calculate the average individual dose from collective dose[10] and is determined by one of two methods:

- **Effort-limiting:** This involves dividing the cumulative annual duration of all tasks undertaken by a group by the maximum permitted annual hours for that group and rounding up to the nearest integer. This will vary from year to year in the best estimate assessment.
- **Pre-defining the group size:** The group size is taken to be a pool whose number is dependent on the nature of the task; for example, a ship’s crew must be large enough to operate the ship, irrespective of the duration of each task to be carried out. This will not vary from year to year.

The method selected in each case is the one which produces the greatest required group size. This gives the minimum number of people required to perform the operation, thus ensuring that there is no ‘dose sharing’.

In the bounding assessment, there are certain task definitions where it is important to avoid dose-sharing between operators in cases where the number of operators required for each task varies. For example, transporting a package by rail includes a task to carry out pre-despatch checks as well as the transit task itself. Two crew members are required for the transit task but only one is required for the checking task. Rather than assume that the two drivers share the checking work, it is assumed that a single driver is utilised as much as possible within working time regulations and package throughput, and hence performs all checking duties.

Transport conveyances, speeds and movements

Transport conveyances are the vehicles or vessels used to transfer transport units between waste-producing sites, transhipment points and the GDF. The transport vehicles assessed in this report include:

- STGO1 abnormal load vehicles
- STGO3 abnormal load vehicles
- rail wagons
- ships

More information about the specifications of these vehicles can be found in the GTSD.

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[10] At the generic stage, the total number of packages to transport is known, but the distribution of work between individuals is not. Therefore the individual dose is calculated from the collective dose as described in section A2.1.

For the illustrative generic transport system, it is judged that route-specific modelling of the varying speeds for different road types will add complexity without improving the accuracy of the assessment. Therefore, a conservative average transit speed has been defined for each transport mode. For example, it is assumed that the dual carriage way speed restrictions on STGO1 and STGO3 vehicles are an appropriate approximation of the mean speed across all road types over the duration of a transport movement.

The number of transport movements (where, for example, a transport movement could be a single train of multiple wagons) required for a particular wastestream depends on the transport mode, the number of transport units per conveyance and number of conveyances per movement, as follows:

Transport mode	Number of transport units per conveyance	Number of conveyances per movement
STGO1	1	1
STGO3	1	1
Rail wagon	1	12 wagons per train
Ship	18	1

These parameters are referred to as batching parameters, and those used in this assessment are consistent with the GTSD.

Transport distances

In order to assess the best estimate dose to drivers or crew, mode-dependent route distances are required. Distances have been calculated for the following journey legs:

- rail distances from on/off-site arising site railheads to notional GDF locations
- road distances from waste arising sites to nearest off-site railheads

Note that sea workers are not included in the best estimate calculation, nevertheless they are considered in the bounding assessment. Transport distances are not required for the bounding assessment, however.

Transport schedule

Doses received by operators will vary in each year of the transport operation. This is because the waste, types of packages and number shipped will also differ from year to year. Furthermore, radioactive decay will cause the external transport unit dose rate to evolve over time.

Assumed years in which each package is shipped are given in the transport schedule. This has been derived by assuming certain waste types are shipped over time periods aligned with their times of arising and at a rate in keeping with the maximum throughput of the GDF inlet cell. The schedule spans the assumed operating lifetime of 2040 to 2190.

Rules are defined in producing the transport schedule as follows:

- waste is transported as soon as it becomes available for disposal
- prioritise wastestreams from non-Sellafield sites
- order all wastestreams by descending dose rate

- adhere to annual GDF throughput rates for each waste category as defined in the GTSD

This approach is consistent with the philosophy of early closure of non-Sellafield sites while minimising reliance on scheduling as a means of dose control. Additionally, prioritising wastestreams with the highest dose rates as soon as they become available for transport will lead to a conservative best estimate dose.

Some wastestreams have dose rates greater than permitted for exclusive use as defined in the IAEA Transport Regulations. It is assumed that these wastestreams are kept in storage until their dose rates have decayed to permitted levels. For wastestreams that never drop below exclusive-use limits, the exclusive-use dose rate limit is assigned for all scheduled years and the wastestream is given consigning priority from when it is available for transport. If waste is available for transport in a given year but no dose rate information is yet available, the waste is stored until the years where dose rate data become available. If no wastestreams with dose rate information are available in a given year, the schedule will assume one of the remaining wastestreams and assign a zero dose rate.

Exclusive-use dose rate limit

Consignments under exclusive use are defined in the IAEA Transport Regulations as having a sole consignor, with external dose rates not exceeding 0.1 mSv/hr at 2 metres from the vehicle. It is assumed that a transport package will take approximately the full width of a vehicle, therefore it is considered appropriate to adopt the same dose rate at 2 metres from the transport package surface for use in the dose assessment where no suitable dose rate is available.

Transport modes

The transport scenario used in the best estimate assessment is aligned with the current NDA Transport Safety Strategy, preferring rail over road where possible. In more detail, the following assumptions are used to determine the mode of transport used for each wastestream:

- if the waste producing site has an on-site railhead, all transport packages are transported by rail directly to the GDF
- if no on-site railhead is available and the transport package mass is greater than 30 tonnes, the package is taken by STGO3 to the nearest off-site railhead and transhipped onto rail wagons, which are then transported directly to the GDF
- if no on-site railhead is available and the transport package mass is less than 30 tonnes, the package is taken by STGO1 to the nearest off-site railhead and transhipped onto rail wagons, which are then transported directly to the GDF

For the bounding assessment, no preferred transport mode has been assumed. An illustrative calculation has been made for every operator type, including road, rail and sea transport workers.

A2 Dose Assessment Methodology

Section A2.1 describes the method used to calculate collective and individual annual doses to transport operators. An important factor in that calculation is the external transport unit dose rate at a given distance from the package surface, which is calculated using the disc source approximation, and this is described in Section A2.2).

The nomenclature used in this section is presented in Table A1.

Table A1 Nomenclature

Symbol	Description
$D_{task\ collective}$	The collective dose to an operator group arising from performing a specific task 'j' with a particular wastestream 'i' (mSv).
$D_{annual\ collective}$	The collective dose to an operator group in a specific year arising from performing all relevant tasks involving wastestreams specified by the transport schedule (mSv).
$D_{annual\ individual}$	The mean individual dose to an operator in a specific year arising from performing all relevant tasks involving wastestreams specified by the transport schedule (mSv).
f_σ	The dimensionless dose rate correction factor for a task where multiple transport units are present.
f_α	The dimensionless dose rate attenuation factor for any shielding present in a particular task.
t_{exp}	The exposure duration to an operator for a particular task (hr).
$\dot{D}(\ d_{exp})$	The dose rate from a package as a function of the exposure distance (d_{exp}) and wastestream-specific dose rate (mSv hr^{-1}).
d_{ref}	The distance at which the reference dose rate of a package is taken (m).
d_{exp}	The fixed exposure distance for a specific task (m).
R	The characteristic radius of a circular disc that best reproduces an equivalent dose-distance relationship as a physical transport unit, as used in the disc source approximation.
s	The length of a journey dependant on the waste-arising site and transport mode (km).
v	The average transit speed of a vehicle in a particular task (km hr^{-1}).
$N_{operators\ per\ task}$	The number of operators involved in a specific task.
$N_{tasks\ per\ year}$	The annual number of tasks performed by an operator group involving a specific wastestream.
$N_{operators\ per\ year}$	The annual number of operators employed in a group.

A2.1 Collective and individual annual dose to transport operators

The collective dose received by an operator group for task 'j' and package 'i' is given by the following:

$$D_{task\ collective_{i,j}} = N_{operators\ per\ task_j} \cdot f_{\sigma_j} \cdot f_{\alpha_j} \cdot t_{exp_j} \cdot \dot{D}_{i,j}\left(d_{exp_j}\right)$$

In this assessment, it is assumed that operators only receive doses from the closest transport packages in a transport movement or transhipment operation because the closest packages provide shielding from the other packages. Therefore, for tasks involving multiple transport packages, it is necessary to multiply the dose received from all packages by a dimensionless correction factor f_σ so that the operator only receives a dose equivalent to the dose received from the closest transport packages.

For tasks that involve either moving or escorting a package along a predefined route, the exposure duration is given by dividing the route length s by the average transit speed v of the vehicle:

$$t_{exp_j} = \frac{s_{i,j}}{v_j}$$

Exposure durations for other tasks are based on occupancy studies.

The collective annual dose received by an operator group is calculated by summing the dose received from every task performed and package processed by that operator group within a particular year:

$$D_{annual\ collective} = \sum_{package\ i;\ task\ j} D_{task\ collective_{i,j}} \cdot N_{task\ iterations\ per\ year_{i,j}}$$

The legal dose limit and Basic Safety Objective are specified in units of dose per year to an individual operator. It is therefore necessary to determine the dose to an individual in a year. For the bounding dose assessment, it is necessary to assume that one individual is exposed in every task of the year. Therefore the individual dose is calculated by dividing the collective dose by the number of operators per task:

$$D_{bounding\ annual\ individual} = \sum_{package\ i;\ task\ j} \frac{D_{task\ collective_{i,j}} \cdot N_{task\ iterations\ per\ year_{i,j}}}{N_{operators\ per\ task_j}}$$

For the best estimate assessment, the individual dose can be approximated by dividing the annual collective dose to a group of operators by the number of operators in the group:

$$D_{average\ annual\ individual} = \frac{D_{annual\ collective}}{N_{operators\ per\ year}}$$

The same calculation methodology is used for every task and operator group in order to provide illustrative assessment of operator doses during routine transport operations.

A2.2 Dose rate calculations and the disc source approximation

The dose rate from a transport unit at a given exposure distance, required for the annual operator dose calculation, is calculated using 'disc source approximation'.

Essentially, the face of a transport unit is modelled as a circular disc source with a characteristic radius R that best reproduces an equivalent dose-distance relationship as the physical transport unit. This approximation is an accurate representation of how dose rate extrapolates with respect to distance from the transport unit, particularly at small distances. The calculation avoids being overly pessimistic at short distances while remaining conservative at longer distances. A characteristic radius has been determined for every type of transport unit.

The dose rate at an exposure distance d_{exp} is given by:

$$\dot{D}\left(d_{exp}\right) = \dot{D}\left(d_{ref}\right) \cdot \frac{\left(1 - \dfrac{d_{exp}}{\sqrt{\left({d_{exp}}^2 + R^2\right)}}\right)}{\left(1 - \dfrac{d_{ref}}{\sqrt{\left({d_{ref}}^2 + R^2\right)}}\right)}$$

where $\dot{D}\left(d_{ref}\right)$ is the external transport unit dose rate at a reference distance d_{ref} from the transport unit.

The above equation can be used to determine a characteristic radius for a package if reference dose rates are provided at multiple distances from the package. The dose gradient can be used to infer a characteristic radius that would otherwise produce the same dose rate extrapolation to some distance if only one other reference dose rate is available.

In order to avoid being optimistic or overly pessimistic, careful judgement was given to the selection of the reference distances and energy bands when calculating the characteristic radii for each transport unit type since the profile of the gradient changes according to which energy band data is selected. Modelled dose rates were available at 0m, 1m and 3m for energy bands ranging from 0.3 to 4 MeV for various transport unit configurations.

It was found that there was a less than expected drop in dose rate at short distances due to the addition of oblique radiation paths through thick shielding. This is a result of modelling of the radiation pathways: the source is considered to be 'smeared' over the surface of a package and is assumed to emit radiation isotropically at every point on the surface. Close to the package, a secondary component of radiation from non-facing surfaces becomes significant as it passes through the package. Those effects are stronger in the near-field and therefore have a larger effect at 0m and on low energy gamma rays, which have a short range. Therefore, the 1m and 3m dose rates were used to determine characteristic radii for each transport unit type.

Dose rates from low energy gamma rays corresponding to an energy band of 0.8 MeV were used in this assessment. This value was selected because Cs-137 and Co-60 are significant gamma-emitter radionuclides for transport: the Cs-137 (Ba-137m) to Ba-137 energy band is 0.66 MeV, and from Co-60 (Ni-60m) to Ni-60 is 1.17 MeV and 1.33 MeV. At distances greater than 1m, this choice is slightly optimistic when compared to lower energy bands but conservative in comparison to high energy bands. Contrary to this, however, lower energy bands contribute less to absorbed dose than higher energy bands. Therefore, 0.8 MeV is believed to be the most appropriate selection when considering both factors.

The 2010 iterations of the generic TSA [2] used a combination of the ‘point source approximation’ and linear extrapolation to model the dose rate–distance relationship. The point source model produces pessimistic dose rates at short distances and optimistic dose rates at long distances.

Appendix B – Detailed Results

Results from the best estimate assessment that show variability across zones and the dominant contributors are presented here.

Variation across zones and the duration of the transport operation

In order to show how doses vary across zones, individual annual doses to operators are shown for each zone and averaged across each year of the transport operation, in Table B1. These doses are also shown graphically in Figure B1 to show how doses to the different operator groups compare.

Variation across years for collective dose is shown in Figure B2. Here, doses are plotted for each year and for each operator group, averaged over the zones. Variation with year for individual dose is shown in Figure B3.

Dominant contributors

Wastestreams that contribute most to the collective dose to operators are shown in Table B2.

Figure B1 **Individual dose to each operator group, averaged across all zones and all years**

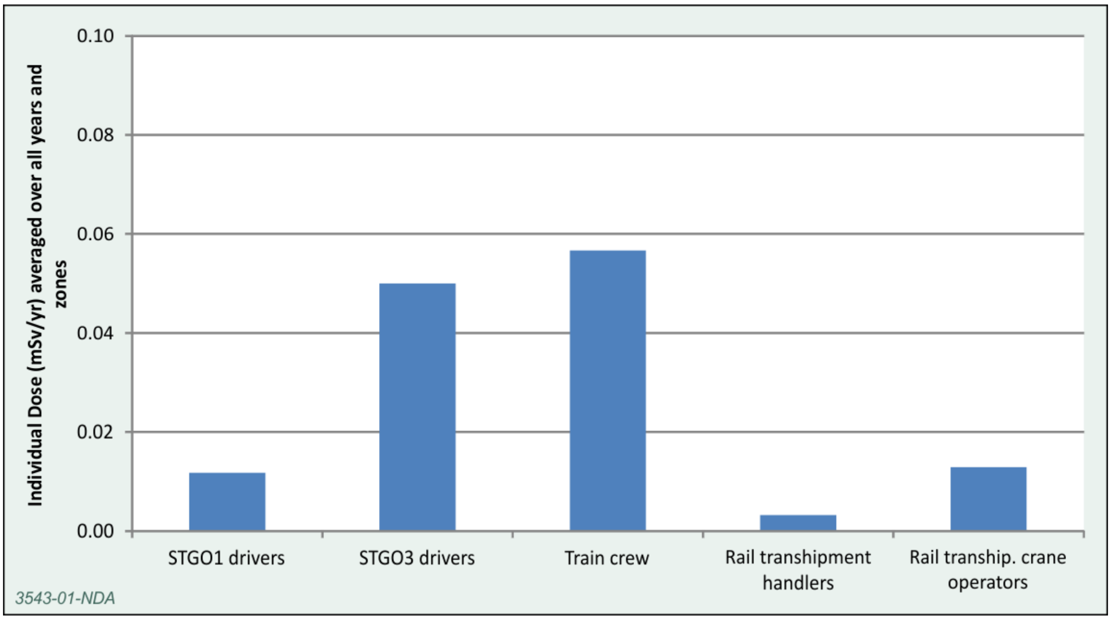

Figure B2 Zone-averaged annual collective doses to each operator group over the entire schedule

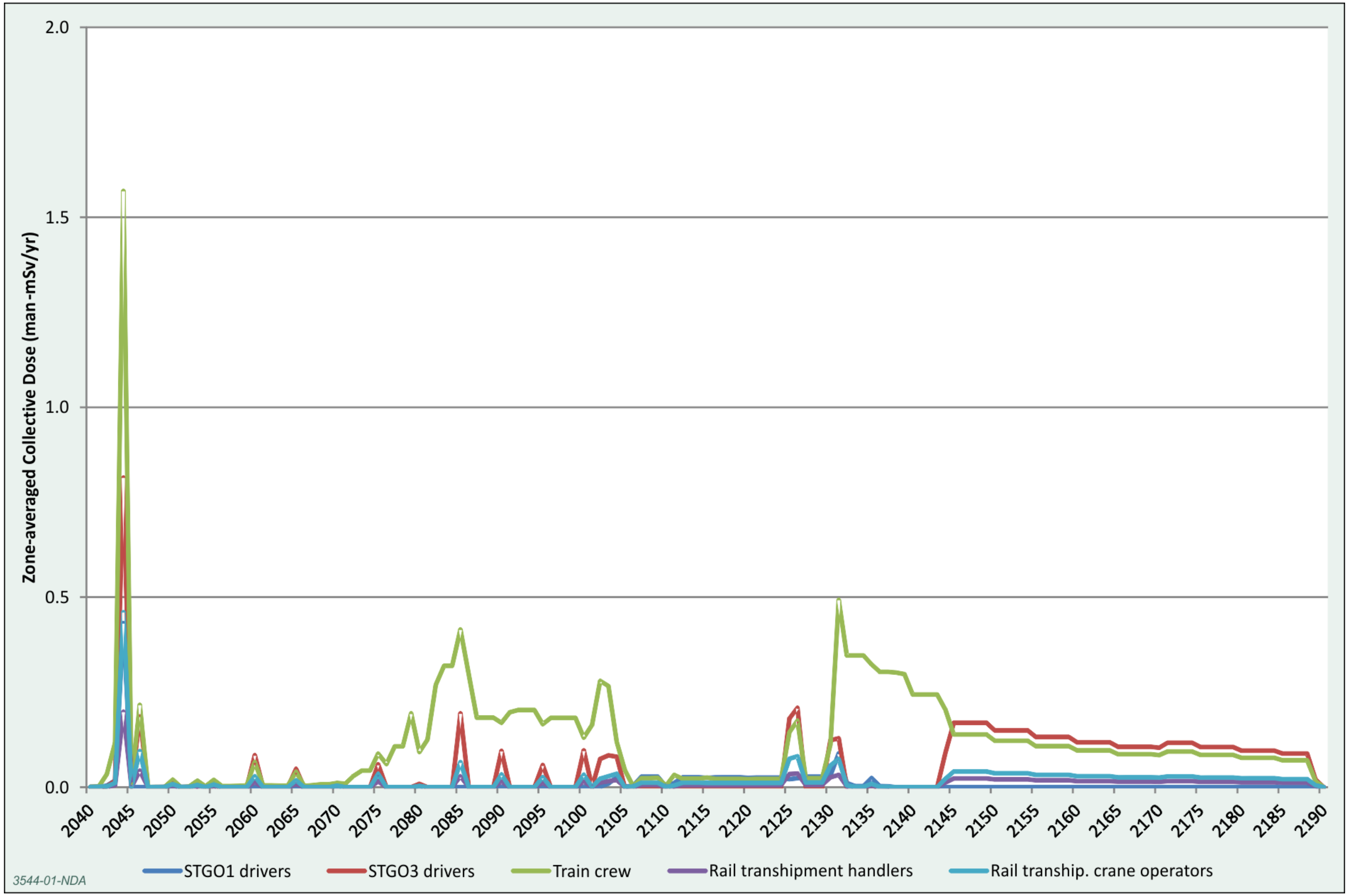

Figure B3 Zone-averaged annual individual doses to each operator group over the entire schedule

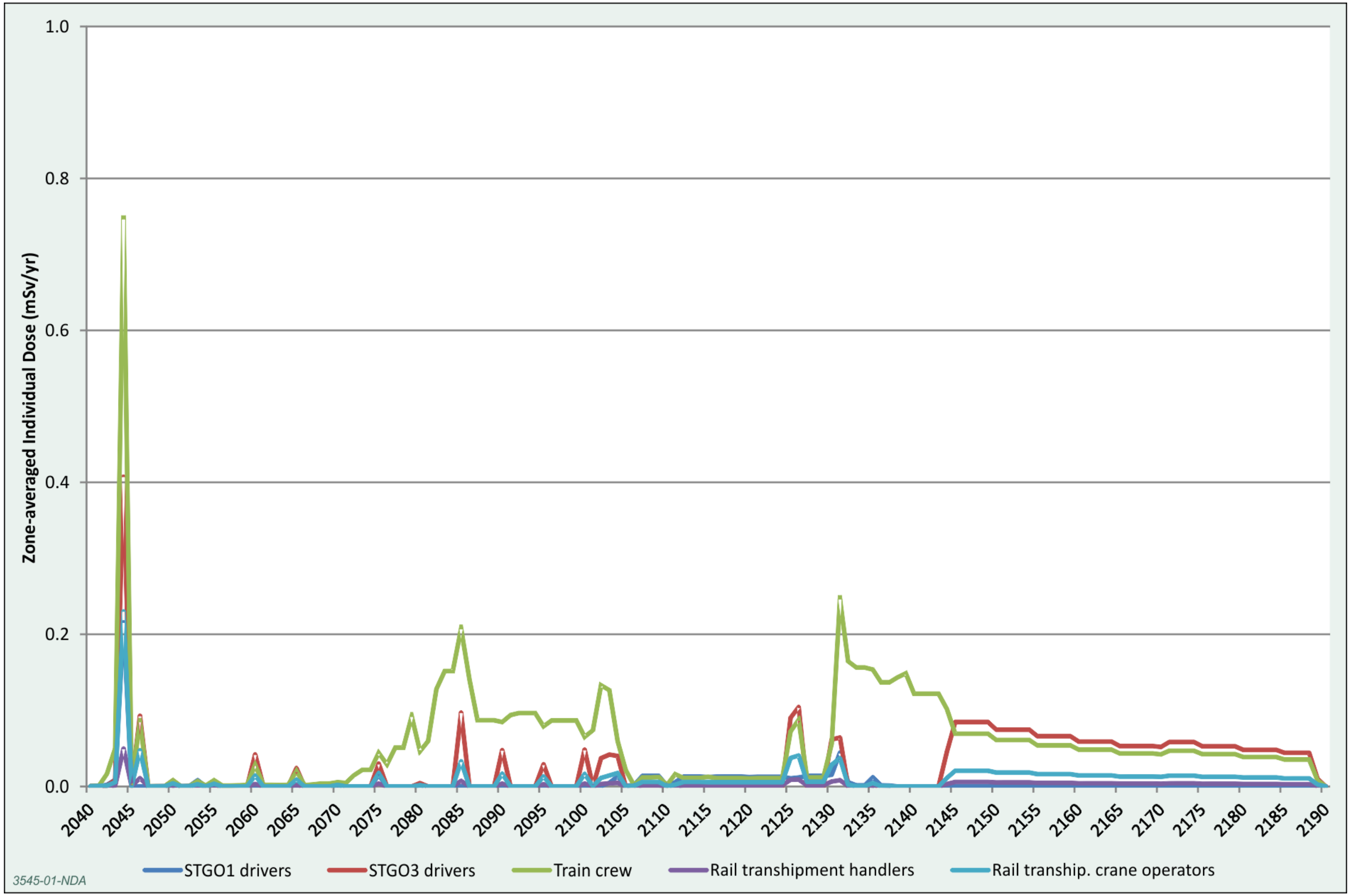

Figure B4 Transport schedule for each waste category overlaid with total annual collective dose to all operator groups

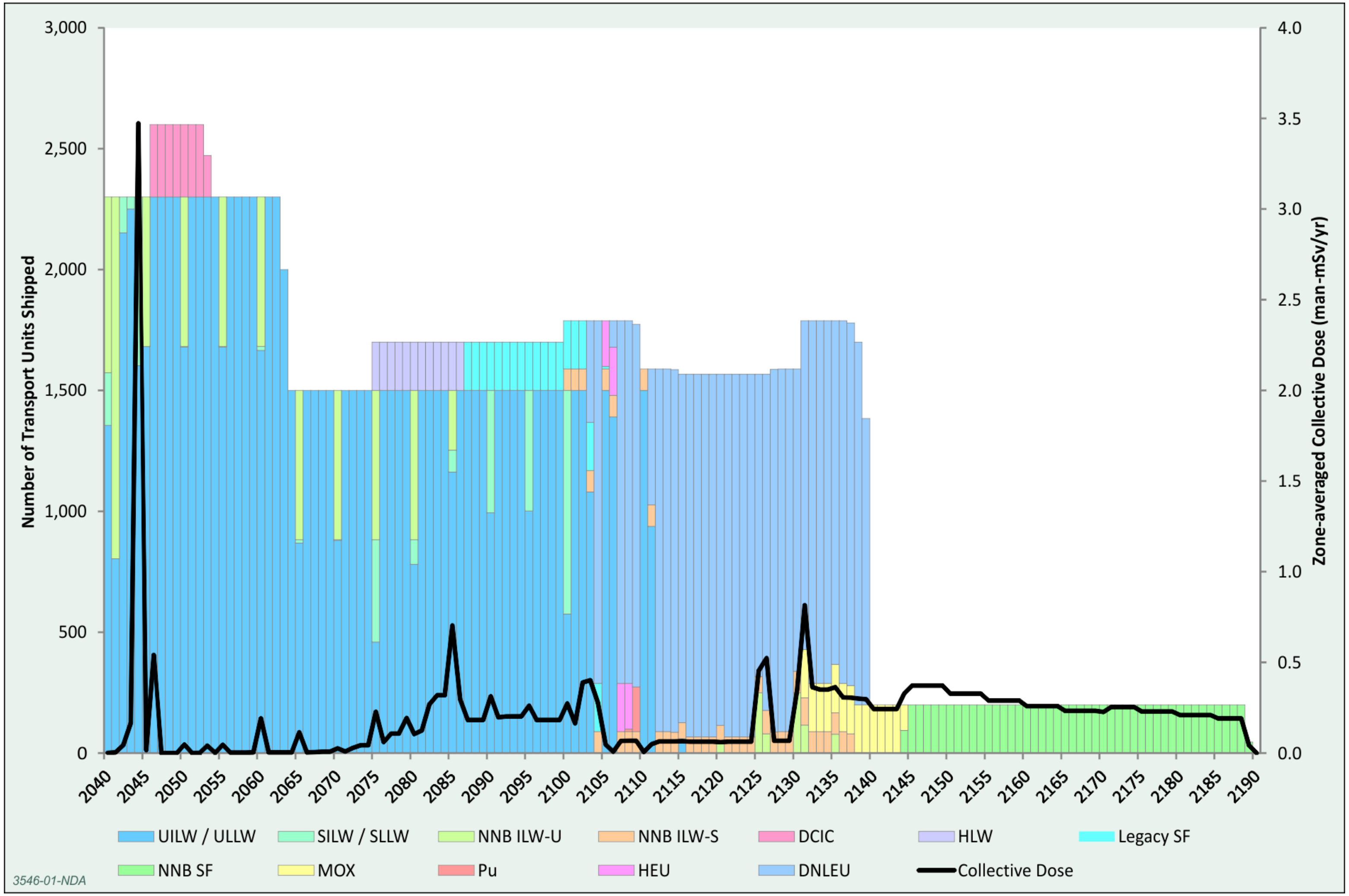

Table B1 Annual individual dose to each operator group for each zone, averaged across all years of the schedule

Exposed Persons Group	Average Individual Dose (mSv/yr) spanning all schedule years									
	Zone 1	Zone 2	Zone 3	Zone 4	Zone 5	Zone 6	Zone 7	Max Zone	Min Zone	Average
Rail transhipment handlers	3.21E-03	3.21E-03	3.21E-03	3.21E-03	3.21E-03	3.21E-03	3.21E-03	No zone dependency		3.21E-03
Rail tranship. crane operators	1.29E-02	1.29E-02	1.29E-02	1.29E-02	1.29E-02	1.29E-02	1.29E-02			1.29E-02
STGO1 drivers	1.17E-02	1.17E-02	1.17E-02	1.17E-02	1.17E-02	1.17E-02	1.17E-02			1.17E-02
STGO3 drivers	5.00E-02	5.00E-02	5.00E-02	5.00E-02	5.00E-02	5.00E-02	5.00E-02			5.00E-02
Train crew	5.65E-02	5.83E-02	5.82E-02	5.81E-02	5.84E-02	5.02E-02	5.68E-02	5.84E-02 (Zone 5)	5.02E-02 (Zone 6)	5.67E-02

Table B2 **Collective dose to each operator group for highest-contributing wastestreams, totalled over all years of the schedule and averaged across each zone**

Wastestream	Description	Waste Category	Zone-averaged Collective Dose (man-mSv) totalled over all schedule years					
			% to all operators	STGO1 drivers	STGO3 drivers	Train crew	Rail tranship. crane operators	Rail transhipment handlers
MEP100	Spent EPR Fuel	NNB SF	25.0%	-	3.5E+00	2.9E+00	8.6E-01	4.8E-01
MAP100	Spent AP1000 Fuel	NNB SF	13.3%	-	1.9E+00	1.5E+00	4.5E-01	2.5E-01
MOX100	Spent MOX Fuel	MOX	12.2%	-	-	3.8E+00	-	-
2D116	Miscellaneous Plants Initial/Interim Decommissioning: Processing Plants, Tanks, Silos etc	UILW / ULLW	9.9%	-	-	3.1E+00	-	-
9G18/C	Ion Exchange Material - Conditioned Waste	SILW / SLLW	4.1%	-	5.4E-01	4.4E-01	2.0E-01	8.6E-02
MU010	DU tails (unirradiated)	DNLEU	3.7%	4.5E-01	-	3.9E-01	2.0E-01	9.3E-02
EP301	Decommissioning: Reactor Vessel	NNB ILW-S	2.4%	-	3.4E-01	2.5E-01	1.1E-01	5.0E-02

Wastestream	Description	Waste Category	Zone-averaged Collective Dose (man-mSv) totalled over all schedule years					
			% to all operators	STGO1 drivers	STGO3 drivers	Train crew	Rail tranship. crane operators	Rail transhipment handlers
EP303	Decommissioning: Lower Reactor Internals Including Heavy Shield	NNB ILW-U	1.9%	-	2.6E-01	1.9E-01	9.6E-02	4.4E-02
M3S100	Spent PWR Fuel	Legacy SF	1.9%	-	2.4E-01	2.4E-01	7.0E-02	3.9E-02
3S306	Decommissioning: Stainless Steel ILW	UILW / ULLW	1.8%	-	2.0E-01	2.0E-01	1.0E-01	4.7E-02
2F01/C	Vitrified High Level Waste	HLW	1.6%	-	-	5.1E-01	-	-
5C08	ILW Concrete Lined Drums	UILW / ULLW	1.3%	1.7E-01	-	1.6E-01	5.7E-02	2.3E-02
2D02/C	Vitrified High Level Waste - Magnox	HLW	1.2%	-	-	3.9E-01	-	-
M2D100	Spent AGR Fuel	Legacy SF	1.0%	-	-	3.2E-01	-	-
2D137	Miscellaneous Plants Final Decommissioning: Processing Plants, Tanks, Silos, etc.	UILW / ULLW	1.0%	-	-	3.0E-01	-	-

Table B3 Collective dose to each operator group for highest-contributing waste categories, totalled over all years of the schedule and averaged across each zone

Waste Category	Zone-averaged Collective Dose (man-mSv) totalled over all schedule years					
	% to all operators	STGO1 drivers	STGO3 drivers	Train crew	Rail tranship. crane operators	Rail transhipment handlers
NNB SF	38.3%	-	5.4E+00	4.4E+00	1.3E+00	7.3E-01
UILW / ULLW	20.7%	4.2E-01	4.4E-01	5.1E+00	3.4E-01	1.5E-01
MOX	12.2%	-	-	3.8E+00	-	-
SILW / SLLW	11.5%	8.1E-02	1.3E+00	1.5E+00	4.9E-01	2.1E-01
DNLEU	5.3%	5.9E-01	-	6.7E-01	2.7E-01	1.2E-01
Legacy SF	3.1%	-	2.4E-01	6.0E-01	7.0E-02	3.9E-02
NNB ILW-S	2.9%	6.8E-02	3.4E-01	3.1E-01	1.4E-01	5.9E-02
NNB ILW-U	2.9%	9.3E-02	3.1E-01	3.0E-01	1.4E-01	6.3E-02
HLW	2.9%	-	-	9.0E-01	-	-
DCIC	0.1%	1.7E-02	1.2E-04	1.7E-02	6.1E-03	2.5E-03
Pu	0.0%	-	-	1.2E-03	-	-
HEU	0.0%	-	-	5.2E-07	-	-
Total		1.3E+00	8.0E+00	1.8E+01	2.8E+00	1.4E+00

Table B4 Collective dose to each task for highest-contributing waste categories, totalled over all years of the schedule and averaged across each zone

Waste Category	Zone-averaged Collective Dose (man-mSv) totalled over all schedule years									
	% to all tasks	STGO1 drivers		STGO3 drivers		Train crew		Rail tranship. crane operators		Rail transhipment handlers
		Carry out pre-despatch checks	Drive STGO1 vehicle	Carry out pre-despatch checks	Drive STGO3 vehicle	Carry out pre-despatch checks	Crew train	Lift transport unit from STGO1 vehicle and place onto rail wagon	Lift transport unit from STGO3 vehicle and place onto rail wagon	Tie down transport unit onto rail wagon
NNB SF	38.3%	-	-	4.3E+00	1.2E+00	4.3E+00	1.4E-01	-	1.3E+00	7.3E-01
UILW / ULLW	20.7%	3.8E-01	3.8E-02	3.7E-01	7.0E-02	4.9E+00	2.1E-01	1.4E-01	2.0E-01	1.5E-01
MOX	12.2%	-	-	-	-	3.6E+00	1.5E-01	-	-	-
SILW / SLLW	11.5%	7.2E-02	8.8E-03	9.5E-01	3.1E-01	1.4E+00	7.7E-02	3.1E-02	4.6E-01	2.1E-01
DNLEU	5.3%	4.8E-01	1.1E-01	-	-	6.4E-01	3.8E-02	2.7E-01	-	1.2E-01
Legacy SF	3.1%	-	-	2.3E-01	9.2E-03	5.8E-01	2.4E-02	-	7.0E-02	3.9E-02
NNB ILW-S	2.9%	5.7E-02	1.1E-02	2.4E-01	9.8E-02	3.0E-01	1.4E-02	2.2E-02	1.1E-01	5.9E-02
NNB ILW-U	2.9%	7.7E-02	1.6E-02	2.0E-01	1.1E-01	2.8E-01	1.6E-02	2.8E-02	1.1E-01	6.3E-02
HLW	2.9%	-	-	-	-	8.6E-01	3.6E-02	-	-	-
DCIC	0.1%	1.6E-02	1.1E-03	9.6E-05	2.0E-05	1.6E-02	4.7E-04	6.0E-03	4.5E-05	2.5E-03

Waste Category	Zone-averaged Collective Dose (man-mSv) totalled over all schedule years									
	% to all tasks	STGO1 drivers		STGO3 drivers		Train crew		Rail tranship. crane operators		Rail transhipment handlers
		Carry out pre-despatch checks	Drive STGO1 vehicle	Carry out pre-despatch checks	Drive STGO3 vehicle	Carry out pre-despatch checks	Crew train	Lift transport unit from STGO1 vehicle and place onto rail wagon	Lift transport unit from STGO3 vehicle and place onto rail wagon	Tie down transport unit onto rail wagon
Pu	0.0%	-	-	-	-	1.1E-03	4.8E-05	-	-	-
HEU	0.0%	-	-	-	-	5.0E-07	2.1E-08	-	-	-
Total		1.1E+00	1.9E-01	6.2E+00	1.8E+00	1.7E+01	7.1E-01	4.9E-01	2.3E+00	1.4E+00

References for Appendices

1 International Maritime Organisation*, International Maritime Dangerous Goods Code 2014 Edition*, ISBN: 9789280115970, 2014.

2 NDA, *Geological Disposal: Generic Transport System Safety Assessment*, NDA/RWMD/022, December 2010.

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