SAFETY AND RISKS IN THE TRANSPORTATION OF RADIOACTIVE MATERIALS TO AND IN AUSTRALIA

Transport safety and risks overview and assessment

15 April 2016

CLIENT: SA NUCLEAR FUEL CYCLE ROYAL COMMISSION
Safety and risks in the transportation of radioactive materials to and in Australia

Project No: IW104710
Document Title: Transport safety and risks overview and assessment
Revision: V2
Date: 15 April 2016
Client Name: SA Nuclear Fuel Cycle Royal Commission
Project Manager: Tim Johnson
Authors: Darron Cook, Quentin Flowers, Steve Manders, Neil Chapman, Charles McCombie
File Name: J:\IE\Projects\03_Southern\IW104700\Proposals\NFCRC Transportation Risk\Deliverables\150408 Transportation Safety and Risks master v2.docx

Jacobs Group (Australia) Pty Limited
ABN 37 001 024 095
Floor 11, 452 Flinders Street
Melbourne VIC 3000
PO Box 312, Flinders Lane
Melbourne VIC 8009 Australia
T +61 3 8668 3000
F +61 3 8668 3001
www.jacobs.com

© Copyright 2016 Jacobs Group (Australia) Pty Limited. The concepts and information contained in this document are the property of Jacobs. Use or copying of this document in whole or in part without the written permission of Jacobs constitutes an infringement of copyright.

Limitation: This report has been prepared on behalf of, and for the exclusive use of Jacobs’ Client, and is subject to, and issued in accordance with, the provisions of the contract between Jacobs and the Client. Jacobs accepts no liability or responsibility whatsoever for, or in respect of, any use of, or reliance upon, this report by any third party.

Document history and status

<table>
<thead>
<tr>
<th>Revision</th>
<th>Date</th>
<th>Description</th>
<th>By</th>
<th>Review</th>
<th>Approved</th>
</tr>
</thead>
<tbody>
<tr>
<td>V1</td>
<td>31 March 2016</td>
<td>Draft for client comment</td>
<td>As above</td>
<td>QF</td>
<td>TDJ</td>
</tr>
<tr>
<td>V2</td>
<td>15 April 2016</td>
<td>Final draft following internal updates and client feedback</td>
<td>As above</td>
<td>DC</td>
<td>DC</td>
</tr>
</tbody>
</table>
Contents

Executive Summary .........................................................................................................................................1
Limitation Statement........................................................................................................................................5
Definitions and abbreviations .........................................................................................................................6
1. Introduction................................................................................................................................................7
   1.1 Overview of radioactive transportation safety approaches and outcomes ........................................7
2. Baseline transportation hazards ...............................................................................................................9
   2.1 Introduction .........................................................................................................................................9
   2.2 Australia’s freight task ...................................................................................................................9
   2.3 The reliability performance of Australia’s freight task ................................................................11
      2.3.1 Road ........................................................................................................................................11
      2.3.2 Rail – shared (non-exclusive) networks ....................................................................................13
      2.3.3 Rail – exclusive networks ......................................................................................................13
      2.3.4 Sea ..........................................................................................................................................14
3. Transportation concept for radioactive materials in South Australia..................................................16
4. Radioactive waste transportation – key risk mitigations ....................................................................19
   4.1 Engineering factors - robust packages .......................................................................................19
      4.1.1 SF and HLW .........................................................................................................................19
      4.1.2 ILW ....................................................................................................................................20
      4.1.3 Packaging testing regime ....................................................................................................20
      4.1.4 Conclusions from type testing ............................................................................................21
   4.2 Engineered risk mitigation measures – separation of waste transportation from other transport and
      from the public .................................................................................................................................22
   4.3 Other mitigation measures – planning, legislative, procedural ....................................................22
5. Commonly asked questions regarding transport risk events ..............................................................24
   5.1 Radiological impacts of incident-free transport ..........................................................................24
   5.2 Risk of explosion ..........................................................................................................................24
      5.2.1 Chemical explosion ..............................................................................................................24
      5.2.2 Nuclear explosion ................................................................................................................24
   5.3 Risk of release of radioactivity ......................................................................................................25
      5.3.1 So, what are the radiological consequences if there is no leak? ...........................................25
      5.3.2 Worst case scenarios ..........................................................................................................26
6. Risk assessment approach .......................................................................................................................28
   6.1 Risk event scenarios considered ...................................................................................................28
   6.2 Assessment of the scenarios ..........................................................................................................28
7. Severe event scenarios – accidental .....................................................................................................30
   7.1 Marine transport accident in deep or shallow waters ................................................................30
      7.1.1 Ship collisions and cask damage / penetration ..................................................................31
      7.1.2 Ship fire scenarios ..............................................................................................................32
      7.1.3 Combined ship fire and collision probabilities ...................................................................32
      7.1.4 Consequences from a release of radioactive material under water ....................................32
Appendix A: International and Australian conventions and regulations
Executive Summary

This report summarises investigations undertaken by Jacobs and MCM for the South Australian Nuclear Fuel Cycle Royal Commission into risks and safety issues surrounding the transport of radioactive materials to and within Australia. Sea and land based transport movements similar to those described and assessed here would be required if a nuclear waste receipt, processing, storage and disposal industry were established in the State.

Transport of hazardous goods is generally perceived as riskier than static storage, and demands a high level of risk management and assurance. As described in this report, this high standard is achieved by multiple layers of engineering, planning, legislative, procedural and guideline-focussed risk mitigation. As background, the US Nuclear Regulatory Commission (USNRC) has demonstrated through extensive field testing and simulation that physical and procedural systems perform their intended role reliably and that radiation exposure doses to the public from routine transport of spent fuel are negligible.

Reliably high levels of safety in the transport and storage of radioactive materials are achieved through three closely related and interacting approaches:

- **Packaging** of radioactive materials is the most important safeguard, providing the highest level of protection against emission of radiation or release of radioactive materials arising from accidental or deliberate impacts, fire or attack,
- **Further design / engineering measures** to reduce the likelihood of impacts, fire or attack occurring. This is of particular relevance to South Australia as the ‘greenfield’ nature of the proposed facilities allows such design and engineering measures to be incorporated from inception, and
- **A comprehensive system of regulations and operational requirements**, enforced by effective legislative provisions.

A 2014 USNRC report presents a comprehensive list of conclusions showing the high margins of safety inherent in the transport of spent nuclear fuel, the most highly radioactive of the materials that would be transported according to the SA radioactive waste management concept. Even for the most severe incidents envisaged, spent fuel casks with an inner welded container would release no radioactivity. For casks without an inner container, there is only around a one in a billion probability that an accident could release radioactive materials, and even then a lethal dose of radiation would not be released.

Threats to radioactive materials in transport from malicious or criminal motives have also been examined extensively in field tests and via simulation by various international regulatory agencies and found the combination of engineering and other risk mitigation measures in place are both reliable and highly effective.

This report considers nine (9) transport-based risk-event scenarios, in the following categories:

- Four ‘accident’ scenarios spanning the foreseeable modes of transportation (ship / train / truck) that exist in the defined transport model for the SA radioactive waste management concept
- Four ‘attack’ scenarios which describe deliberate acts by unnamed adversaries hoping to capture or bring about the uncontrolled release of radioactive waste material
- One scenario considering an accident or attack on a low level waste movement on a public road.

It is important to note that selection of the criminal / deliberate attack scenarios in no way reflects any kind of official or unofficial assessment of their likelihood. Rather, severe but potentially possible situations have been developed in order to test the effectiveness and resilience of the overall risk mitigation system(s).

Each of these scenarios is assessed in order to allow conclusions to be drawn on the adequacy or otherwise of the existing risk mitigation framework, including policies, procedures and levels of the relevant capabilities that would be expected to be applied in the South Australian context.

A summary of these scenarios is shown below. Note that this table should not be read in isolation: context is provided throughout the report.
Table 1: Risk summary table – transportation of radioactive waste (by transport mode and event scenario)

### Incidents at sea

<table>
<thead>
<tr>
<th>Scenario</th>
<th>Risks</th>
<th>Likelihood</th>
<th>Consequences</th>
</tr>
</thead>
<tbody>
<tr>
<td>Collision</td>
<td>Cask damage / Cask leaks</td>
<td>1 in 20 million risk of collision per voyage, less than 1 in 10 collisions cause cask damage</td>
<td>As demonstrated by full scale testing and simulation, cask damage is very unlikely to lead to leaks. It is most likely the cask will fall into the sea. If there are leaks there will be so much dilution that no effects on humans are expected (see below)</td>
</tr>
<tr>
<td>Fire or collision followed by fire – at sea</td>
<td>Cask leaks</td>
<td>For engine room fires that spread to the cargo area, or fires of a serious nature arising in the cargo hold, the figure is about three per ten thousand ship-years.</td>
<td>As demonstrated by full scale field testing, fire at cask is very unlikely to lead to leaks</td>
</tr>
<tr>
<td>Fire or collision followed by fire – in harbour</td>
<td>Cask leaks</td>
<td>As above</td>
<td>As above. More opportunity for effective firefighting relative to fire at sea.</td>
</tr>
<tr>
<td>Sinking or collision followed by sinking – deep sea</td>
<td>Cask leaks</td>
<td>Requires incident (collision / fire etc to occur)</td>
<td>Cask may not be recovered. Eventual release of mobile radioactive isotopes, if assumed to enter the marine food chain and lead back to people would give rise to maximum annual radiation doses estimated at around one billionth of natural background radiation exposures.</td>
</tr>
<tr>
<td>Sinking or collision followed by sinking – shallow sea</td>
<td>Cask leaks</td>
<td>Requires incident (collision / fire etc) to occur as a precursor</td>
<td>Cask will be recovered well before leakage occurs. If this doesn’t happen then leakage may occur after many years and annual exposure of around one thousandth of natural background level</td>
</tr>
<tr>
<td>Ship hijack</td>
<td>Cask held to ransom and / or contents removed</td>
<td>Probability impossible to quantify, but should be less than for other vessels because of armed escort and physical barriers to access to fuel</td>
<td>Design makes it very difficult for terrorists to open casks. Intervention by authorities likely in short time scale</td>
</tr>
</tbody>
</table>

### Incidents during transport by rail

<table>
<thead>
<tr>
<th>Scenario</th>
<th>Risks</th>
<th>Likelihood</th>
<th>Consequences</th>
</tr>
</thead>
<tbody>
<tr>
<td>Collision / impact</td>
<td>Cask leaks /</td>
<td>Chance of a</td>
<td>No leakage from casks with welded inner</td>
</tr>
<tr>
<td>Event</td>
<td>Description</td>
<td>Probability</td>
<td>Mitigation Measures</td>
</tr>
<tr>
<td>-------</td>
<td>-------------</td>
<td>-------------</td>
<td>---------------------</td>
</tr>
<tr>
<td><strong>Fire damage</strong></td>
<td>Cask leaks / radiation barrier damaged</td>
<td>Requires proximity of fuel source and collision or similar to rupture fuel tank. So probability lower than for collision alone.</td>
<td>As demonstrated by full scale testing, fire at cask is unlikely to lead to leaks. Specialised, dedicated trains will minimise fuel storage and have suitable separation distances. Modelling shows no radioactive species released. Low level of radiation exposure to emergency responders.</td>
</tr>
<tr>
<td><strong>Structure falling on cask</strong></td>
<td>Cask damage</td>
<td>Earthquake or other event to cause structure to fail: unlikely in SA.</td>
<td>Simulation modelling shows no cask perforation.</td>
</tr>
<tr>
<td><strong>Sabotage of railway line</strong></td>
<td>Cask held by terrorist</td>
<td>Has not occurred; massive scale of casks limits actions of attackers.</td>
<td>Design makes it very difficult for terrorists to remove or open casks. Intervention by authorities likely in short time scale would further reduce consequences.</td>
</tr>
<tr>
<td><strong>Rocket (RPG) attack on train</strong></td>
<td>Cask ruptures and radiation released</td>
<td>Has not occurred (or become close to occurring). Requires specialist rockets and trained firers</td>
<td>Many operational and engineering measures to minimise risk. In worst case scenarios, assessed lifetime increase in cancer risk to exposed persons has been estimated to be 0.13%.</td>
</tr>
</tbody>
</table>

**Incidents during transport by road**

<table>
<thead>
<tr>
<th>Type</th>
<th>Description</th>
<th>Probability</th>
<th>Implications</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>HLW / ILW accident on public road</strong></td>
<td>Cask rupture</td>
<td>No travel outside secure areas in associated facilities</td>
<td>No transportation issues outside secure areas. Low speed minimises consequence of impacts and managed through secure area procedures.</td>
</tr>
<tr>
<td><strong>LLW waste accident on public road</strong></td>
<td>Container damaged</td>
<td>No incidents worldwide to date with container breached.</td>
<td>Low level waste unlikely to cause radiation exposure to emergency responders or public even to the level approaching background radiation.</td>
</tr>
<tr>
<td><strong>Hijack of a LLW truck on public road</strong></td>
<td>LLW held by terrorists</td>
<td>Has not occurred (or become close to occurring)</td>
<td>Could cause public alarm, but low level waste not a useful bargaining tool for terrorists. Intervention by authorities likely in short time scale</td>
</tr>
</tbody>
</table>

**Effectiveness of Australia’s risk management systems and protocols for transportation of radioactive waste**

International field tests and simulations of various extreme incident scenarios that have proven the resilience and effectiveness of risk controls are also found to be applicable and relevant to the South Australian context. Australia has a comprehensive system of guidelines and procedures, supported by a comprehensive legislative framework for the transportation of all hazardous goods, including radioactive waste, upheld by national and state-based freight regulators and ARPANSA guidance, which is derived from IAEA best practice protocols and technical reports. These practices are applied to more than 30,000 shipments of radioactive sources and
substances throughout Australia each year, with no significant release or loss of radioactive material recorded during transport.

The overall effectiveness of Australia’s existing security measures for the protection of radioactive material in storage or transport is also found to be sound, and compares favourably with physical and operational measures adopted in overseas jurisdictions (NTI, 2016).

This report presents the approaches and conclusions of a large body of international research in this area and explains the overall conclusion that with inherent and deliberate risk controls in place, the residual risks from the transportation of radioactive waste by sea, road and rail are consistently far lower than for many other hazards which are routinely accepted by the public.
Limitation Statement

The sole purpose of this document and the associated services performed by Jacobs is to prepare a report for the South Australian Nuclear Fuel Cycle Royal Commission (the client) in accordance with the scope of services set out in the contract between Jacobs and the Client. That scope of services, as described in this document, was developed with the Client.

In preparing this document, Jacobs has relied upon, and presumed accurate, any information (or confirmation of the absence thereof) provided by the Client and / or from other sources. Except as otherwise stated in the document, Jacobs has not attempted to verify the accuracy or completeness of any such information. If the information is subsequently determined to be false, inaccurate or incomplete then it is possible that our observations and conclusions as expressed in this document may change.

Jacobs derived the data in this document from information sourced from the Client (if any) and / or available in the public domain at the time or times outlined in this document. The passage of time, manifestation of latent conditions or impacts of future events may require further examination of the project and subsequent data analysis, and re-evaluation of the data, findings, observations and conclusions expressed in this document. Jacobs has prepared this document in accordance with the usual care and thoroughness of the consulting profession, for the sole purpose described above and by reference to applicable standards, guidelines, procedures and practices at the date of issue of this document. For the reasons outlined above, however, no other warranty or guarantee, whether expressed or implied, is made as to the data, observations and findings expressed in this document, to the extent permitted by law.

This document should be read in full and no excerpts are to be taken as representative of the findings. No responsibility is accepted by Jacobs for use of any part of this document in any other context.

This document has been prepared on behalf of, and for the exclusive use of, Jacobs’s Client, and is subject to, and issued in accordance with, the provisions of the contract between Jacobs and the Client. Jacobs accepts no liability or responsibility whatsoever for, or in respect of, any use of, or reliance upon, this document by any third party.

The document describes a set of readily foreseeable risks as of the time of writing. It is not intended to act as a detailed assessment of any particular type of threat, and should not be relied upon for any other purpose other than a general description. The risks may evolve over time, and over the course of time some aspects of the analysis may require revision to remain relevant for conceptual planning or other purposes.

In no part of this report does Jacobs, either explicitly or implicitly, make any recommendation or endorsement of the viability or otherwise of the Project.
# Definitions and abbreviations

<table>
<thead>
<tr>
<th>Abbreviation</th>
<th>Full Form</th>
</tr>
</thead>
<tbody>
<tr>
<td>ARPANSA</td>
<td>Australian Radiation Protection and Nuclear Safety Agency</td>
</tr>
<tr>
<td>IAEA</td>
<td>International Atomic Energy Agency</td>
</tr>
<tr>
<td>GDF</td>
<td>Geological disposal facility for spent fuel and high level waste</td>
</tr>
<tr>
<td>HLW</td>
<td>High level waste</td>
</tr>
<tr>
<td>IDR</td>
<td>Intermediate depth repository for intermediate level waste</td>
</tr>
<tr>
<td>ISF</td>
<td>Interim storage facility</td>
</tr>
<tr>
<td>ILW</td>
<td>Intermediate level waste, sometimes called long lived intermediate level waste (LILW)</td>
</tr>
<tr>
<td>LLW</td>
<td>Low level waste including very low level waste (VLLW)</td>
</tr>
<tr>
<td>mSv</td>
<td>milliSievert; Sievert is a measure of radiation dose</td>
</tr>
<tr>
<td>OSOM</td>
<td>Over size over mass (vehicle)</td>
</tr>
<tr>
<td>RPG</td>
<td>Rocket propelled grenade</td>
</tr>
<tr>
<td>SF</td>
<td>Spent fuel (also known as used fuel, UF)</td>
</tr>
<tr>
<td>SWTC</td>
<td>Standard waste transport containers</td>
</tr>
<tr>
<td>t</td>
<td>Tonne</td>
</tr>
<tr>
<td>tkm</td>
<td>Tonne-kilometres</td>
</tr>
<tr>
<td>USNRC</td>
<td>US Nuclear Regulatory Commission</td>
</tr>
</tbody>
</table>
1. Introduction

This report summarises investigations undertaken by Jacobs and MCM for the South Australian Nuclear Fuel Life Cycle Royal Commission into risks and safety issues surrounding the transport of radioactive materials to and within Australia. Sea and land based transport movements similar to those described and assessed here would be required if a nuclear waste receipt, processing, storage and disposal industry were established in the State.

Public and operator safety is of the highest possible importance in all aspects of the use and handling of radioactive materials. While no countries have yet established and are operating permanent disposal facilities for the most radioactive forms of waste there are still many thousands of tonnes of material shipped by road, rail and sea each year for temporary storage or reprocessing, all without a notable incident in transit.

Transport of hazardous goods is generally perceived as riskier than static storage and demands a high level of risk management and assurance. As described in this report, this high standard is achieved by multiple layers of engineering, planning, legislative, procedural and guideline-focused risk mitigation. As background, the independent US Nuclear Regulatory Commission (USNRC) has demonstrated that these systems perform their intended role reliably and that radiation doses to the public from routine transport of spent fuel are negligible.

This report describes both the approaches to risk mitigation that would apply foreseeably in the South Australian context, and how they would be expected to ‘perform’ in a hypothetical series of severe-event scenarios. This analysis, which draws on extensive, independent primary field trials of nuclear material transportation systems from a number of countries, is wide-ranging and relevant to the state of the art systems proposed to be considered for South Australia.

1.1 Overview of radioactive transportation safety approaches and outcomes

Reliably high levels of safety in the transport and storage of radioactive materials are achieved through three closely related and interacting approaches:

- **Packaging of radioactive materials** is the most important safeguard, providing the highest level of protection against emission of radiation or release of radioactive materials resulting from accidental or deliberate impacts, fire or attack
- **Further design/engineering measures** to reduce the likelihood of impacts, fire or attack occurring
- **A comprehensive system** of regulations and operational requirements, enforced by effective legislative provisions.

In Australia, implementation of the first and third approaches is based on the International Atomic Energy Agency’s international regulations for the transport of radioactive materials, first published in 1961, updated in 2012, and implemented in all Australian states and territories through legislation that enacts ARPANSA’s Code of Practice series.

As the radioactive transportation system being considered for South Australia is expected to be a new ‘green field’ system there is opportunity to incorporate a number of engineering measures to reduce both the likelihood of incidents and the consequences of low probability events.

Requirements for packaging systems are linked to the level of hazard posed by the radioactivity of the material concerned. The radioactivity levels of waste products being transported vary from levels almost undetectable against background radiation through to levels requiring the highest level of containment and protection within special, purpose-designed containers or ‘casks’. These so-called ‘Type B’ casks are used for spent fuel (SF) and high level waste transportation across the world. Type B casks have been extensively tested in severe

---

1 USNRC (2014), Spent Fuel Transportation Risk Assessment Final Report, NUREG 2125
accident and deliberate attack scenarios, and the lessons learned have resulted in steadily improved designs over decades.

The result is a long history of exemplary safety performance worldwide extending over 60 years: few incidents, no severe accidents and no documented health effects upon the public or workers directly involved in handling nuclear materials.

The World Nuclear Association, in its comprehensive review publication of January 2016 on transport of radioactive materials, opens with the following comments:

“There are around 20 million consignments of radioactive substances worldwide each year on public roads, railways and on ships. Since 1971 there have been more than 20,000 shipments of used fuel and high-level wastes (over 80,000 tonnes) over many million kilometres. Although there have been transport accidents involving radioactive materials, there has never been one in which a container with highly radioactive material has been breached, or has leaked.”

This paper describes the baseline hazards involved with transportation of generic cargo by rail, road and sea and then presents the nature of the risks involved in transport of radioactive materials, and the general and specific risk mitigation systems in place that reduce the risk during transportation to a very low level.

2. Baseline transportation hazards

2.1 Introduction

This section describes the overall freight task carried by road, rail and sea throughout Australia, and in particular, the levels of reliability achieved across the different modes for both mixed use (non-exclusive) and dedicated (exclusive use) freight systems.

As shown in the following discussion, the scale of the freight task in Australia continues to grow overall, with road and rail taking an increasing share of the total. The rate of notable incidents (which result in loss of cargo or other damage) is extremely small for mixed-use freight systems, and is even lower for dedicated or exclusive use systems, such as those envisaged for high and intermediate level waste transport in the SA radioactive waste sector.

2.2 Australia’s freight task

The Australian freight task is measured and reported in two principal ways: the number of tonne-kilometres (tkm) of freight moved, and the number of tonnes of freight uplifted, with the former a more accurate overall measure of total activity.\(^5\)

Australia’s total freight task has quadrupled over the past four decades\(^6\), with strong growth in road transport and more recently in rail, predominantly in the mining and resource sectors. Recent trends in Australia’s freight task are shown in Figure 2.1 (below).

Figure 2.1: Australia’s freight task (billion tonne-kilometres)

Source: Department of Infrastructure and Regional Development, 2014 Freightline 1, p 2

Figure 2.2 (below) provides an overview of Australia’s domestic freight task, considering transport mode, location and quantity.

---

\(^5\) For movement of freight around urban areas, tonnes lifted is a preferred summary measure, as it better represents such activity.

The geographic links and relative volumes of road and sea freight are summarised in the following figures:

**Figure 2.3 :** Australia’s road freight task

**Figure 2.4 :** Australia’s international sea freight task

---

**Note:** Line widths show relative freight volume (tonnes). Share estimates related to freight tonne kilometres.

**Source:** ABS (2013), ARA (2013), BITRE (2012b, 2013a, 2013b) and BITRE estimates.
2.3  The reliability performance of Australia’s freight task

2.3.1  Road

Transport incident rates vary by mode, with minor vehicle incidents typically not reported in national statistics. For road transport, accidents that result in one or more fatalities are collated by various government agencies and are applied here as a proxy measure for the rate of significant incidents overall for road transport.

Available data on trends in accidents involving heavy freight vehicles are summarised in Figure 2.5, which shows a slight downward trend in overall incidents over the past decade, particularly for articulated trucks, which undertake the greatest share of freight transport in Australia.

Figure 2.5: Trends in accidents involving heavy vehicles (number of fatal vehicle crashes)

Source: Department of Infrastructure and Regional Development, 2015 Fatal heavy vehicle crashes quarterly bulletin Dec 2015 p 1

Further analysis of detailed data for significant (fatal) vehicle collisions in Australia over the 12 months to October 2014 is presented in Table 2.1 (below). The scale of the freight task and its overall reliability is demonstrated in the observation that 2.131 billion tonne-kilometres of freight were moved nationally during the period (with 7.1% of total national tkm carried in SA) with 115 significant (fatal) incidents recorded (15 in SA). This equates with an overall incident of one per 18.537 billion tonne- kilometres nationally, or one per 10,105 billion tonne- kilometres in SA.
Table 2.1: Deaths from fatal accidents involving articulated freight vehicles – CY 2015

<table>
<thead>
<tr>
<th>Type (source)</th>
<th>NSW</th>
<th>Vic</th>
<th>Qld</th>
<th>SA</th>
<th>WA</th>
<th>Tas</th>
<th>NT</th>
<th>ACT</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Road user types involved (DIRD, 2014)</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Drivers</td>
<td>22</td>
<td>15</td>
<td>21</td>
<td>9</td>
<td>10</td>
<td>3</td>
<td>0</td>
<td>3</td>
<td>81</td>
</tr>
<tr>
<td>Passengers</td>
<td>4</td>
<td>2</td>
<td>6</td>
<td>4</td>
<td>1</td>
<td>1</td>
<td>0</td>
<td>0</td>
<td>18</td>
</tr>
<tr>
<td>Pedestrians</td>
<td>5</td>
<td>2</td>
<td>2</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>9</td>
</tr>
<tr>
<td>Motorcyclists</td>
<td>3</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>1</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>4</td>
</tr>
<tr>
<td>Pedal cyclists</td>
<td>0</td>
<td>10</td>
<td>0</td>
<td>2</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>3</td>
</tr>
<tr>
<td><strong>All road users</strong></td>
<td><strong>34</strong></td>
<td><strong>20</strong></td>
<td><strong>29</strong></td>
<td><strong>15</strong></td>
<td><strong>12</strong></td>
<td><strong>4</strong></td>
<td><strong>0</strong></td>
<td><strong>1</strong></td>
<td><strong>115</strong></td>
</tr>
<tr>
<td><strong>Type of accident (DIRD, 2014)</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Single vehicle</td>
<td>5</td>
<td>2</td>
<td>10</td>
<td>1</td>
<td>1</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>19</td>
</tr>
<tr>
<td>Multiple vehicle</td>
<td>24</td>
<td>16</td>
<td>17</td>
<td>14</td>
<td>11</td>
<td>4</td>
<td>0</td>
<td>1</td>
<td>87</td>
</tr>
<tr>
<td>Pedestrian</td>
<td>5</td>
<td>2</td>
<td>2</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>9</td>
</tr>
<tr>
<td>All types</td>
<td>34</td>
<td>20</td>
<td>29</td>
<td>15</td>
<td>12</td>
<td>4</td>
<td>0</td>
<td>1</td>
<td>115</td>
</tr>
</tbody>
</table>

**Accident involvement rate analyses**

<table>
<thead>
<tr>
<th>Articulated vehicles registered (ABS 9309.0)</th>
<th>20,622</th>
<th>26,160</th>
<th>21,060</th>
<th>8,429</th>
<th>15,680</th>
<th>1,652</th>
<th>1,229</th>
<th>143</th>
<th>94,975</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fatalities per articulated vehicle</td>
<td>0.00165</td>
<td>0.00076</td>
<td>0.00138</td>
<td>0.00178</td>
<td>0.00077</td>
<td>0.00242</td>
<td>0.00</td>
<td>0.00699</td>
<td>0.001211</td>
</tr>
<tr>
<td>Billion freight tkm undertaken (ABS 9223.0)</td>
<td>538,007</td>
<td>476,471</td>
<td>502,336</td>
<td>151,576</td>
<td>373,712</td>
<td>50,549</td>
<td>25,319</td>
<td>13,730</td>
<td>2,131,703</td>
</tr>
<tr>
<td>Billion freight tkm per fatality</td>
<td>15,824</td>
<td>23,824</td>
<td>17,322</td>
<td>10,105</td>
<td>31,143</td>
<td>12,637</td>
<td>--</td>
<td>13,731</td>
<td>18,537</td>
</tr>
</tbody>
</table>


ABS Cat 9223.0 Road Freight movement, Australia 12 months ended 31 October 2014
2.3.2 Rail – shared (non-exclusive) networks

Rail safety assessments and reports maintain records of various forms of incidents involving passenger and freight trains, which illustrate trends in safety and reliability for non-dedicated (shared) rail networks.

The Australian National Rail Safety Regulator’s (NRSR) 2014 Annual Rail Safety Report presented statistics for the past three years of national freight activity on shared networks. As shown below, it reports that in the three years to 2014, some 100 million train kilometres were travelled, with 96 derailments occurring, or one derailment per 1.04 million km travelled.

Table 2.2: Freight Train running line derailments - ONRSR and Great Britain

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>ONRSR (SA, NSW, NT, Tas., Vic., ACT)</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Derailments</td>
<td>34</td>
<td>39</td>
<td>23</td>
<td>96</td>
</tr>
<tr>
<td>Train km (millions)</td>
<td>31.2</td>
<td>35.3</td>
<td>33.4</td>
<td>99.9</td>
</tr>
<tr>
<td>Rail (derailments per million freight train km)</td>
<td>1.000</td>
<td>1.105</td>
<td>0.689</td>
<td>0.961</td>
</tr>
<tr>
<td><strong>Great Britain (GB)</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Derailments¹</td>
<td>6</td>
<td>8</td>
<td>14</td>
<td>28</td>
</tr>
<tr>
<td>Train km (millions)¹</td>
<td>47.8</td>
<td>48.5</td>
<td>47.2</td>
<td>143.5</td>
</tr>
<tr>
<td>Rail (derailments per million freight train km)</td>
<td>0.126</td>
<td>0.165</td>
<td>0.297</td>
<td>0.195</td>
</tr>
</tbody>
</table>


2.3.3 Rail – exclusive networks

While the above statistics refer to mixed use or non-dedicated rail networks, the rail link that is proposed to operate between the interim storage facility and the geological disposal facility / encapsulation plant will be a dedicated line, separated from other rail traffic to achieve higher levels of safety and reliability. In addition, transports will most likely carry only radioactive wastes, with no mixed cargoes.

There are already a small number of dedicated rail lines operating in Australia, notably the private operations in the Pilbara region of NW Western Australia, which offer a useful case study for comparison.

In 2012, there were three principal private networks delivering a large majority of Australia’s total 170.6 billion kilometre-tonnes of iron ore to ports on the WA coast, as follows:

Table 2.3: Australian private freight rail network statistics (2012)

<table>
<thead>
<tr>
<th>Owner</th>
<th>Network Length (km)</th>
<th>Billion tonne-kilometres (2011/12)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rio Tinto (Hamersley and Robe River)</td>
<td>1400</td>
<td>84.6</td>
</tr>
<tr>
<td>BHPB (Mt Newman and Goldsworthy Railways)</td>
<td>800</td>
<td>61.1</td>
</tr>
<tr>
<td>Fortescue Metals Group</td>
<td>250</td>
<td>15.9</td>
</tr>
</tbody>
</table>

8 The ONRSR covers all states and territories apart from Queensland, with ACT since 2014/15 and Victoria since 2013/14
9 Other private/dedicated heavy rail operations occur within port areas or as point to point tourist railways typically on legacy track in locations which are now remote from passenger or freight networks.
Throughout WA\textsuperscript{10} the number of reportable incidents has reduced from 1.66 to 0.83 per million train miles from 2013 to 2015, with 40 occurrences in 2014-15 compared to 62 in the previous year. This includes both private freight and general use lines. A reportable incident is defined as:

- an accident or incident that causes death, serious injury or significant property damage
- a running line derailment
- a running line collision between rolling stock
- a collision at a road or pedestrian level crossing between rolling stock and either a road vehicle or a person
- a fire or explosion on or in rail infrastructure or rolling stock that affects the safety of railway operations or that endangers one or more people
- a suspected terrorist attack or threat of attack
- any accident or incident involving a significant failure of a safety management system that could cause death, serious injury or significant property damage, and
- any other accident or incident that is likely to generate intense public interest or concern.

Four incidents since 2014 were deemed worthy of detailed investigation:

- collision between two road-rail vehicles with one casualty, in 2012
- over-run of train near siding in 2013
- derailment of train in 2014
- collision between track worker and passenger line in 2015.

### 2.3.4 Sea

The Australian Transport Safety Authority’ Marine Group monitors safety incidents and issues concerning shipping in Australian waters. Its most recent report, Australian Shipping Occurrence Reports 2005-2012\textsuperscript{11} summarises reported notifications, incidents and fatalities.

In the year to 2012, there were a total of 193 occurrences in Australian commercial shipping worthy of reporting, across a wide range of event types. Overall, the ATSB found that there were 1,200 unique occurrence types associated with Australian marine activity in the seven years to 2012, as summarised below.

\textsuperscript{10} Government of Western Australia, Office of Rail Safety Annual Report 2014 – 2015

Table 2.4: Occurrence type during marine occurrences, 2005 to 2012

<table>
<thead>
<tr>
<th>Occurrence type</th>
<th>2005</th>
<th>2006</th>
<th>2007</th>
<th>2008</th>
<th>2009</th>
<th>2010</th>
<th>2011</th>
<th>2012</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Damage to ship or equipment</td>
<td>31</td>
<td>30</td>
<td>28</td>
<td>21</td>
<td>42</td>
<td>31</td>
<td>17</td>
<td>26</td>
<td>226</td>
</tr>
<tr>
<td>Serious injury</td>
<td>19</td>
<td>21</td>
<td>20</td>
<td>16</td>
<td>16</td>
<td>20</td>
<td>22</td>
<td>32</td>
<td>173</td>
</tr>
<tr>
<td>Equipment failure</td>
<td>14</td>
<td>16</td>
<td>24</td>
<td>20</td>
<td>17</td>
<td>15</td>
<td>25</td>
<td>27</td>
<td>149</td>
</tr>
<tr>
<td>Fire/explosion</td>
<td>10</td>
<td>13</td>
<td>10</td>
<td>17</td>
<td>9</td>
<td>10</td>
<td>12</td>
<td>12</td>
<td>93</td>
</tr>
<tr>
<td>Machinery failure</td>
<td>7</td>
<td>22</td>
<td>7</td>
<td>2</td>
<td>7</td>
<td>8</td>
<td>9</td>
<td>24</td>
<td>86</td>
</tr>
<tr>
<td>Grounding/stranding</td>
<td>11</td>
<td>10</td>
<td>6</td>
<td>11</td>
<td>4</td>
<td>7</td>
<td>12</td>
<td>12</td>
<td>73</td>
</tr>
<tr>
<td>Contact</td>
<td>6</td>
<td>6</td>
<td>5</td>
<td>7</td>
<td>13</td>
<td>12</td>
<td>13</td>
<td>11</td>
<td>72</td>
</tr>
<tr>
<td>Fatality</td>
<td>7</td>
<td>8</td>
<td>8</td>
<td>3</td>
<td>3</td>
<td>3</td>
<td>5</td>
<td>6</td>
<td>43</td>
</tr>
<tr>
<td>Hull failure/failure of water tight openings</td>
<td>4</td>
<td>6</td>
<td>6</td>
<td>2</td>
<td>6</td>
<td>4</td>
<td>4</td>
<td>7</td>
<td>39</td>
</tr>
<tr>
<td>Collision</td>
<td>7</td>
<td>7</td>
<td>7</td>
<td>2</td>
<td>7</td>
<td>3</td>
<td>3</td>
<td>1</td>
<td>37</td>
</tr>
<tr>
<td>Pollution</td>
<td>0</td>
<td>7</td>
<td>3</td>
<td>2</td>
<td>8</td>
<td>5</td>
<td>1</td>
<td>4</td>
<td>30</td>
</tr>
<tr>
<td>Lifeboat accident</td>
<td>4</td>
<td>3</td>
<td>2</td>
<td>2</td>
<td>4</td>
<td>4</td>
<td>2</td>
<td>1</td>
<td>22</td>
</tr>
<tr>
<td>Flooding</td>
<td>1</td>
<td>2</td>
<td>4</td>
<td>2</td>
<td>3</td>
<td>0</td>
<td>2</td>
<td>8</td>
<td>22</td>
</tr>
<tr>
<td>Close quarters</td>
<td>3</td>
<td>2</td>
<td>2</td>
<td>1</td>
<td>2</td>
<td>2</td>
<td>1</td>
<td>3</td>
<td>16</td>
</tr>
<tr>
<td>Capsizing/listing</td>
<td>0</td>
<td>1</td>
<td>1</td>
<td>0</td>
<td>2</td>
<td>2</td>
<td>2</td>
<td>0</td>
<td>8</td>
</tr>
<tr>
<td>Foundered</td>
<td>1</td>
<td>0</td>
<td>1</td>
<td>0</td>
<td>1</td>
<td>1</td>
<td>0</td>
<td>1</td>
<td>5</td>
</tr>
<tr>
<td>Missing assumed lost(^5)</td>
<td>1</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>1</td>
<td>0</td>
<td>0</td>
<td>2</td>
</tr>
<tr>
<td>Other</td>
<td>6</td>
<td>11</td>
<td>11</td>
<td>7</td>
<td>23</td>
<td>17</td>
<td>10</td>
<td>19</td>
<td>104</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>132</strong></td>
<td><strong>164</strong></td>
<td><strong>145</strong></td>
<td><strong>115</strong></td>
<td><strong>174</strong></td>
<td><strong>145</strong></td>
<td><strong>132</strong></td>
<td><strong>193</strong></td>
<td><strong>1,200</strong></td>
</tr>
</tbody>
</table>


This shows that collisions and sinkings (‘foundered’) are a small proportion of the total reported incidents (4.1%) over the 2005 to 2012 period, which are themselves a small fraction of the number of ship movements. Within the collision category there is a wide range of incidents the great majority are minor with few serious impacts.

International marine insurance statistics used by IAEA demonstrate the frequency of serious collisions to be around two per thousand ship-years, or about one in 25 million nautical miles, with the frequency of total loss of vessels being around three per thousand ship-years.
3. Transportation concept for radioactive materials in South Australia

Reports prepared by and for the SA Nuclear Fuel Cycle Royal Commission\(^2\) set out a concept of what a radioactive material receipt, treatment and disposal industry in South Australia could consist of, and the associated transport requirements. The industry was postulated to provide facilities and solutions for internationally generated and stored radioactive waste, including the following categories:

- Spent fuel and high level waste (SF / HLW)
- Intermediate level waste (ILW) – also referred to as long lived intermediate level waste (LILW).

The business case investigations determined that the third waste category, low level waste (LLW), was most likely to be disposed in the originating country that created or benefitted from it, but that facilities to receive, treat and dispose of locally-generated Australian low level waste (LLW) and very low level waste (VLLW) were likely to be required.

The major components of the envisaged industry consist of:

- A purpose-built, exclusive-use port to receive radioactive waste materials from ships
- An immediate ‘laydown’ area at or very close to the port, to hold casks and other approved containers of radioactive materials received prior to despatch to longer term storage locations
- An interim storage facility (ISF) for interim dry storage of SF / HLW prior to transfer to the geological disposal facility (GDF) and for ILW waste prior to transfer to the intermediate depth repository (IDR)
- A geological disposal facility (GDF) for permanent disposal of SF / HLW in remote, geologically stable bedrock emplacement chambers located several hundred metres underground
- An encapsulation facility (EF), co-located with the GDF. This would encapsulate the SF / HLW in purpose designed capsules for permanent disposal
- An intermediate depth repository (IDR) for disposal of ILW, co-located with the GDF and sharing common infrastructure
- A low level waste repository (LLWR) for near surface disposal of LLW at a location potentially at some distance from either the ISF or the GDF.

Operation of these facilities would require the transportation movements listed in Table 3.1 (below).

<table>
<thead>
<tr>
<th>Material</th>
<th>From</th>
<th>To</th>
<th>Method</th>
<th>Requirements</th>
</tr>
</thead>
<tbody>
<tr>
<td>SF / HLW in casks</td>
<td>Ship</td>
<td>Immediate laydown area at or near port</td>
<td>Specialised over size over mass (OSOM) road transport</td>
<td>Specialised lifting and truck loading equipment</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Purpose built heavy duty roadway, used exclusively for radioactive waste industry purposes</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Specialised truck unloading and placement equipment</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Material</th>
<th>From</th>
<th>To</th>
<th>Method</th>
<th>Requirements</th>
</tr>
</thead>
<tbody>
<tr>
<td>ILW in specialist casks or ISO shipping</td>
<td>Ship</td>
<td>Immediate laydown area at or near port</td>
<td>Standard road registerable semitrailers or multi trailer combination vehicles</td>
<td>Container lifting and handling equipment at port Roadway (shared with OSOM road transport of SF / HLW) Container lifting and handling equipment at immediate laydown area</td>
</tr>
<tr>
<td>containers</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>SF / HLW in casks</td>
<td>Immediate laydown area</td>
<td>ISF</td>
<td>Specialist OSOM road transport or rail, depending on distance (assumed to be a few kilometres), with no public road movements</td>
<td>Specialised lifting and truck / train loading equipment Purpose built heavy duty roadway, or railway, used exclusively for radioactive waste industry purposes Specialised truck / train unloading and cask handling equipment</td>
</tr>
<tr>
<td>SF / HLW in casks</td>
<td>ISF</td>
<td>GDF</td>
<td>Exclusive rail</td>
<td>Specialised cask lifting and train loading equipment Purpose built heavy duty railway, used exclusively for radioactive waste industry purposes Specialised train unloading and cask handling equipment</td>
</tr>
<tr>
<td>ILW in specialist casks or shipping</td>
<td>Immediate laydown area and ISF</td>
<td>ISF and IDR, respectively</td>
<td>Rail or road registrable trucks, depending on distance and locations, no public roads movements</td>
<td>Specialised cask lifting and train / truck loading equipment Purpose built heavy duty railway or roadway, used exclusively for radioactive waste industry purposes Specialised train / truck unloading and cask handling equipment</td>
</tr>
<tr>
<td>containers</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>LLW in shipping casks</td>
<td>ISF and GDF</td>
<td>LLWR</td>
<td>Road transport, possibly on public roads</td>
<td>Waste packed appropriately and transported in standard ISO shipping containers</td>
</tr>
</tbody>
</table>

Source: Study team

The movement patterns for the high and intermediate level wastes are shown diagrammatically in Figure 3.1, below. There are also movements within the ISF and within the EF / GDF; these will have similar requirements.
Figure 3.1: Radioactive waste – transportation concept. Source: Jacobs MCM
4. Radioactive waste transportation – key risk mitigations

The key to safe transport of radioactive wastes is a combination of multiple layers of engineering, planning, legislative, procedural and guideline focussed risk mitigation. This section describes these layers of intervention and how they integrate to form a robust system that brings the residual level of risk to an acceptably low level.

4.1 Engineering factors - robust packages

In discussions on transport safety, most attention tends to focus on the casks containing spent fuel or high-level waste, since the hazard potential of this category of waste is by far the highest.

Although radioactive wastes have been transported for decades without any significant accidents, the safety of waste transports by road, rail and sea has been an issue of public concern in many countries. This has led to the IAEA issuing strict requirements on transports\(^\text{13}\) and has led also to numerous intensive studies and field experiments, the most recent of which have been documented comprehensively by the USNRC\(^\text{14}\). This recent report updates an earlier 1977 NRC report, taking into account all US and other studies completed in the interim. It concludes that improved methods and data have led to estimated risks around five orders of magnitude lower than what was published in the 1977 report. It also confirms that the essential principle ensuring safety is that the casks or containers in which the spent fuel or radioactive waste is placed are constructed to such a robust extent that they can survive virtually any conceivable incident scenario.

4.1.1 SF and HLW

Figure 4.1 (below) shows a typical transport container for spent fuel. These casks are loaded with spent fuel and sealed hermetically with bolted lids. The inset illustrates the construction of the cask walls. Using the example of the HI-STAR 100 transport container proposed in the SA NFCRC business case studies, the stainless steel cask inner shell is 6.35 cm thick, the multi-layer gamma shield surrounding this adds a total of 16 cm of carbon steel plates and this is all surrounded by an 11 cm thick polymeric neutron shield.

Figure 4.1 : HI-STAR 100 spent fuel cask (with inset showing typical wall construction) NUREG2125

---

\(^{13}\) IAEA Transport Regulations

\(^{14}\) USNRC (2014), Spent Fuel Transportation Risk Assessment Final Report, NUREG 2125
4.1.2 ILW

Figure 4.2 shows a design example from the UK for the transport of ILW. Like spent fuel casks, these are also highly robust containers. These ‘standard waste transport containers’ (SWTC) vary in fully laden weight from 30 to 65 tonnes, with the most robust containers having walls of 28.5 cm thick steel.

![Figure 4.2: ILW waste container design (Sievwright et al 2004)](image)

4.1.3 Packaging testing regime

Before they are licensed, transport casks for spent fuel have been subjected to detailed theoretical analysis, model scale tests, and full-scale tests. The full-scale tests involve:

- dropping the massive casks from a height
- subjecting them to intensive fires, and
- submerging them in water.

Figure 4.3 from a recent Sandia report illustrates these types of tests graphically.

![Figure 4.3: Standard tests for spent fuel casks (Sandia 2004)](image)

The experiments are backed up by sophisticated computer modelling of all deformations to the casks that could result from impacts of any kind. An example is shown in Figure 4.4.

---


Dramatic full-scale tests involving fast-moving trains being driven directly into spent fuel casks have validated the reliability of the computer models. Figure 4.5 (below) shows how a spent fuel cask looked after being hit by a train travelling at 130 km/h. Although it appears severely damaged because of the crumpling of the outer cooling fins, there were no releases from the cask.

4.1.4 Conclusions from type testing

The 2014 USNRC report mentioned above has a long list of conclusions indicating clearly the high margins of safety in the transport of spent fuel. Even in the most severe accidents envisaged, spent fuel casks with an inner welded container would release no radioactivity. For casks without an inner container, there is only about a one in 1 billion chance that an accident could release radioactive materials, and even then no single person would receive a lethal dose of radiation. Details of quantitative release calculations are given in Section 5 (below).

4.2 Engineered risk mitigation measures – separation of waste transportation from other transport and from the public

As the SA nuclear waste facilities will be effectively ‘greenfield’ there is opportunity at the concept and design phases to engineer in measures to eliminate some of the known risks that apply elsewhere. The simplest is to design exclusive stand-alone transport corridors on land so that all traffic is controlled by the facilities’ operator. Operational measures can then be put in place to eliminate movements of hazardous materials, such as oil wagons or LNG containers. The stand-alone facilities should be designed as far as practical not to cross other, general use, traffic pathways. This should be feasible for the short road route between the port and the ISF. Depending on the location of the GDF and associated facilities, it is probably necessary for the exclusive use rail line to cross both another railway and a major highway. Here, detailed engineering measures can be put in place to minimise the possibility of impacts. For example, crossings should not be at grade and should be designed so that traffic on the upper route cannot fall onto the lower one.

Provision has been made in the costings section of the earlier Jacobs MCM report to install two barriers / fences with associated electronic and other systems around the main facilities, including the route from the port to the ISF. Consideration should be given to doing the same along the rail route, but this may have other impacts that inhibit its adoption.

If these barriers are some distance from the line then the likelihood of an ‘accurate’ missile attack is reduced but a detailed assessment is required to quantify this.

4.3 Other mitigation measures – planning, legislative, procedural

Australia boasts a comprehensive array of international and domestic agreements, policies, standards, regulations, procedures and agencies that act to provide a robust framework for the transportation and management of a range of hazardous goods, including radioactive materials. Among these, the most relevant to this report is:


This prescriptive publication is referenced by regulations and conditions of licence, and contains practice-specific requirements that must be satisfied to ensure an acceptable level of safety in the transportation of radioactive material.

A more complete list is shown below:

**International References**
- Convention on the Physical Protection of Nuclear Material (CPPNM)
  - 2005 Amendment to the CPPNM
- International Convention for the Suppression of Acts of Nuclear Terrorism (ICSANT)
- Convention on Nuclear Safety
- UN Security Council Resolution (UNSCR) 1540 Implementation
  - UNSCR 1540 reporting
  - Extent of UNSCR 1540 implementation
- International Atomic Energy Agency Regulations for the Safe Transport of Radioactive material, 1996

**Domestic References**
- Australian Radiation Protection and Nuclear Safety Act 1998
- National Health and Medical Research Council (NHMRC) Recommendations for limiting exposure to ionizing radiation (1995) - Dose Limits
- South Australian Radiation Protection and Control Act 1982

The adequacy of these documents in the context of the future transportation of radiological waste in Australia is discussed in Section 9, below.
5. Commonly asked questions regarding transport risk events

This section addresses a number of the most commonly asked questions about the behaviour of radioactive waste transport containers and the wastes themselves under severe event scenarios. These include high speed rail and road collisions, submergence under water, extended high intensity fire and other theoretical high force/high stress situations. There is a host of common misconceptions about how radioactive waste, whether high, intermediate or low level, behaves under such situations, and the short and long term consequences of its exposure to the natural environment due to either an accident or malicious intent. The following section describes foreseeable radiation doses to members of the public in a ‘no incident’ scenario.

5.1 Radiological impacts of incident-free transport

The casks used to transport the more radioactive categories of waste are heavily shielded to reduce the radiation exposure to people working around them to very low levels. For example, the ‘external dose rate’ of a typical cask used to transport spent fuel is about 0.1 milliSievert (mSv) per hour at a distance of 2 metres from the cask. A person would have to stand next to a cask for 24 hours to receive the equivalent of their annual dose from natural background radiation. The radiation dose decreases considerably the further the person is from the cask.

For a cask being transported by road or rail, the radiation dose that would be received by someone standing by the transporter as it passed would depend on how far away they stand and how fast the truck or train is moving. The USNRC study\(^{18}\) cited extensively in the current document provides the example of someone standing 30 metres away from a cask passing by slowly, at 24 km/h. The radiation dose received depends on the type of cask, but would typically be a few billionths of a Sievert – equivalent to about one minute of natural background exposure. In practice, it is unlikely that any member of the public would spend a significant period of time this close to a transport route. This is particularly relevant to the South Australian system, which envisages a significant barrier zone that the public cannot enter.

5.2 Risk of explosion

5.2.1 Chemical explosion

The question that is often asked is whether transported radioactive wastes subject to severe impacts and intense fire could cause an explosion. The simple answer is no – the wastes themselves are stable, robust solid materials and to all intents physically and chemically inert during transport. The materials themselves could not cause a chemical explosion.

5.2.2 Nuclear explosion

Spent fuel, which contains ‘fissile’ radioactive isotopes, is packaged for transport so that an accident, incident or mismanagement cannot bring together sufficient material to allow a nuclear ‘criticality’, which would generate high levels of radiation and heat. In its 2014 study, the USNRC observed that criticality would require three conditions:

- an impact severe enough to have the potential to damage the cask seal (this requires an impact with a solid rock / concrete surface at a speed greater than about 90 km/h)
- followed by immersion in water such that cask fills with water, and
- requiring the spent fuel to be brought together inside the cask into a critical configuration.

The USNRC concludes that the probability of these three conditions occurring is so small that a ‘criticality event’ is ‘not credible’. Furthermore, a criticality event is not the same as a nuclear explosion. An explosion requires concentrated fissile material (which is not present in conventional spent fuel) to be brought together.

instantaneously under intense compression. A criticality event would only lead to a very short increase in the generation of heat and radiation, and there is absolutely no possibility that a nuclear explosion could occur.

5.3 Risk of release of radioactivity

Explosion not being an issue, the two main concerns with a transport accident are whether it:

- could damage the structure of the cask enough to reduce the level of radiation shielding it provides, thus exposing people near the cask to higher levels of radiation from the cask contents than is normally permissible, or;
- could damage the seals, or even breach a cask, allowing radioactivity to escape into the air or into water.

With these two concerns in mind, the USNRC 2014 study of spent fuel transport casks and systems looked at several types of cask used for road and rail transport and a range of severe accidents. One of the main differences in the designs is that some hold the spent fuel in a welded internal container (this design would likely be preferred for an Australian system). The study finds that for this type of cask, there would be no release and no loss of gamma shielding effectiveness even under the most severe impacts studied, which encompass all historic or even realistic accidents. Some other cask types could experience some loss of gamma shielding effectiveness during severe impacts and some release of radioactive material could occur during exceptionally severe impacts. Even then, the NRC concludes that, if there were an accident during a spent fuel shipment, there is only about a one-in-a-billion chance that the accident would result in a release of radioactive material and the consequences, as described below, would not be catastrophic.

There is often concern about the effects of fire during an accident; concerns are loss of neutron or gamma shielding and radioactive releases due to failure of seals. The NRC assumed in their calculations that the low-density neutron shielding materials melted and flowed out – but that there was no major increase in the radiation hazard. They also found that, for the types of steel casks proposed, the risk of loss of the massive gamma shielding from a cask as a result of a fire is negligible and that none of the fire accidents investigated in their study results in a release of radioactive material due to seal failures.

The studies examine the impact of fire on the spent fuel, the cask seals and the radiation shielding. In typical fires, temperatures vary in time and location from about 600 C to more than 1200 C so an evenly-applied 800 C is used in certification analyses, as it applies similar heating to an actual fire. Simulations conservatively replicate a situation where all the fuel from a rail or road tanker pools around a cask without draining away and burns until exhausted, engulfing the cask in the fire. This is considered a probable worst case scenario. The analysis found that the fuel rods would not burst and the seal would remain intact, preventing any releases of radioactivity.

5.3.1 So, what are the radiological consequences if there is no leak?

As seen above, effectively all potential accidents result in no loss of shielding and no release of radioactivity. But they would stop the movement of a shipment, they would involve conventional emergency response and they would require the situation to be recovered by removing damaged casks. Consequently, people would be working around casks for several hours, possibly over a period of one or more days, depending on how difficult it is to move casks onto replacement vehicles.

**Exposure to radiation incident response workers (cask intact)**

The NRC evaluation looked at radiation doses to emergency responders, assuming that individual responders would be working around the accident scene for 10 hours, at an average of 5 metres from a cask. In practice, it is unlikely that this would occur. The radiation doses calculated are relatively small, around 1 mSv, which is 1/50th of the maximum annual dose permitted for a worker in the nuclear industry (about a week’s exposure).

**Exposure to passing (shielded) radioactive transport**

Under normal operations, a person standing 10 metres from a passing spent fuel transport train or truck travelling by at 20 km/hr, would receive a radiation dose of about 0.025 microSv (or 0.000025 mSv), one forty-thousandth of this value. Put another way, a person would have to stand right next to ten such transports a day
for a whole year before they began to approach the recommended radiation dose limit for members of the public.

Figure 5.1: Comparative radiation doses (Image Source: Jacobs)

5.3.2 Worst case scenarios

If any release of radioactivity were to occur from a spent fuel cask, it would be through a damaged seal, as no accident scenario perforates the cask itself, so we need to consider what might actually be able to get out through damaged cask seals.

Spent nuclear fuel, the most radioactive of the wastes considered, comprises rods or pellets of uranium metal or ceramic inside long metal tubes, connected together in a grid pattern (a ‘fuel assembly’). When the fuel has been used, the tubes and the spaces between the pellets contain some inert radioactive gas (helium, krypton, xenon) and accumulations of more volatile radionuclides that have formed during the nuclear reaction. It is these radionuclides that might be released in the event of a cask seal failure, along with any fine particles of dust from the partial degradation of the fuel and the assemblies (for example, during a high impact accident). In order for there to be any release, the tubes containing the fuel would have to fracture in the accident so that their internal gas pressure forces material out through the damaged cask seal. Scientists are therefore concerned to test and evaluate how radioactive gases and very fine particulate matter might escape from a cask into the air and affect people nearby. However, only a tiny part of the spent fuel and the volatile radionuclides (a few parts in a hundred thousand) would be able to escape: the largest part of the radioactivity will remain in the spent fuel, inside the cask.

The 2014 NRC study calculated radiation doses to a ‘maximally exposed individual’ – a hypothetical person who is assumed to be located at the point of highest concentration of potentially released radioactive material (about 20 metres from the cask) for a period of 10 hours. The estimated dose from inhaling airborne radioactivity is 1.6 Sv, which, although it would not cause acute illness or death, is nevertheless a serious radiation exposure, with around a 10% risk of significant health detriment. It is highly improbable that anyone would be so close to the accident scene for so long when a leak is detected. Members of the public would not be permitted to be nearby and emergency responders would take appropriate radiation protection precautions.

‘Worst case’ contamination case study – loss of cask seals on land

A 2001 Swiss study reported ‘worst case’ effective inhalation radiation doses to people located 100 metres away from a cask with two failed seals to be about 2.4 mSv in the year after an accident (about the same as natural background radiation) and 0.3 mSv for people located 500 metres away. The same study also considered releases that could occur from a burning ship in harbour and reports average doses to local people of 0.5 mSv. As we have seen from the NRC study, the probability of such releases ever occurring is vanishingly small.

---

If a cask with a failed seal were to fall into water – a large river or the shallow continental shelf sea – releases of volatile (dispersing) radionuclides would be massively diluted and dispersed in the water. Some of these mobile radionuclides and much of any particulate matter released would be expected to interact with sediments on the riverbed or seabed. In the case of a river, this might require some type of local clean-up operation to remove contaminated sediment. Owing to the dilution and dispersion involved (particularly in the sea), the radiological impacts to people or the environment would be expected to be insignificant – many hundreds or thousands of times lower than natural background radiation.

‘Worst case’ contamination case study – loss of cask seals in water

The same 2001 Swiss study cited dose estimates for a shallow marine accident that are ten thousand time less than our average natural radiation exposures. In shallow waters, a cask would be retrieved in days or weeks. In deep ocean waters, where retrieval may be practically impossible, estimated doses to people are less than a billionth of natural background radiation.

‘Worst case’ contamination case study – rocket propelled grenade attack

An analysis conducted by the Sandia National Laboratory in New Mexico for the US Department of Energy in 1999 investigated the effects of attacks on US spent fuel trucks and rail containers using two different types of weapons. The study concluded that certain types of armour piercing weapons could penetrate US spent fuel flasks – although only the outer wall of the spent fuel cask would be penetrated. There is considerable dispute over the levels of release of radioactive material that would result from breaching a spent fuel flask. The Sandia study concluded that even in a worst case scenario, less than 1% of the spent fuel in a container would be released in the form of ‘breathable’ particles which people could inhale. Nevertheless, this is a very serious airborne release of radioactivity and would have high radiological consequences if it occurred in a populated area, with the possibility of many people receiving high radiation exposures, with severe health effects.

It is, of course, possible to construct improbable but feasible scenarios involving multiple, sustained or suicidal attacks on static transports with the most sophisticated and powerful weaponry, from which even higher impacts could be construed. Consequently, as in any type of terrorist attack, prevention of this type of incident is the most reasonable means of mitigation, as discussed further in Section 7.

These conclusions are used below in discussion of the set of extreme case scenarios.

---

20 http://researchbriefings.parliament.uk/ResearchBriefing/Summary/POST-Report-8#fullreport
6. Risk assessment approach

The safety and security of transporting radiological material has been studied and analysed extensively, and there is a wealth of risk assessment research which is publicly available. Above all, the most important fact to note is that there have been no transport accidents with HLW or SF that have led to releases of radioactive materials into the environment, so that there is no historical statistical data on this issue. Nevertheless a series of specific extreme scenarios is theorised as follows:

- for which the worst case outcomes would see radioactive material either released into the environment, or fall into the wrong hands via criminal or terrorist motives
- that, by their severity, are most likely to test the boundaries of existing policies, procedures and capabilities.

6.1 Risk event scenarios considered

This report considers nine transport-based risk-event scenarios, in the following categories:

- Four ‘accident’ scenarios spanning the modes of transport (ship/train/truck) that exist in the defined transport model for the SA radioactive waste management concept
- Four ‘attack’ scenarios involving deliberate acts by unnamed adversaries hoping to capture or bring about the uncontrolled release of radioactive material, and
- One scenario in each category considering an accident or attack on a low level waste movement on a public road.

It is important to note that selection of these scenarios in no way reflects any kind of official or unofficial assessment of their likelihood. Rather, extreme but potentially feasible situations have been prepared that intentionally test the resilience of the risk mitigation system.

Each of these scenarios is assessed in order to allow conclusions to be drawn on the adequacy or otherwise of the existing risk mitigation framework, including policies, procedures and levels of the relevant capabilities that would be expected to be applied in the South Australian context.

6.2 Assessment of the scenarios

Accident scenarios have been assessed by consideration of their probability of occurrence (based on historical data), the frequency of radioactive releases and the nature and duration of any radiation exposure. Finally, each has been considered against the protective effect of existing and potential protocols, allowing an assessment of the residual level of risk for each scenario.

The ‘attack’ scenarios have been approached differently, due to the difficulties and practical limitations of sourcing and applying actual (classified) intelligence and threat assessments in a report intended for public release, as well as public concerns over the reliability and accuracy of intelligence-based risk assessments. In the attack scenarios we have painted a picture of the potential course of action by unnamed adversaries, including their planned actions and intended outcomes, and then detailed the known and likely layers of engineering design, policies, procedures and capabilities that would be expected to come into play and help to mitigate the outcomes. This overall process is shown schematically in Figure 6.1.
Figure 6.1: Anatomy of Radiological Transport Risk Assessment

Anatomy of Transport Risks for Radiological Material

Conventional Transport Risks

- Sea Transport
- Land Transport
  - Road
  - Rail

Statistics on Investigations of Transport Accidents

- Consequences from Radiological
- Frequency of Occurrence

Non-radiological Risks of Transport Accidents

Radiological Transport Risks

- Accident Probabilities
- Accident Scenarios
  - Frequencies for Radioactivity Release
  - Radioactivity Release Rates/Source Terms
  - Meteorology

Existing and Potential Protocols

- Residual Radiological Transport Risks
  - Identified Gaps & Vulnerabilities
  - Potential Additional Mitigation Measures

Potential Outcomes
- Attack Scenarios
7. Severe event scenarios – accidental

The accidents that we are concerned with involve three types of hazard to the transport containers and their contents:

- severe impacts,
- fire, and
- immersion in water.

Regardless of the cause or nature of the accident, cask designers need to ensure that the casks would perform acceptably across a range of conditions that would encompass those of any feasible accident. As described in Section 4, the IAEA transport regulations and the associated tests that are carried out on the massive casks used to transport the most active wastes are designed precisely to address these three possible accident scenarios. One also needs to consider the possibility, however remote, that a cask might be subject to all three of these hazards during some types of accident.

The types of transport accident that have been examined typically involve the casks falling so that they land on a hard, unyielding surface or a sharp projection, the cask transporter vehicle and the cask crashing into an unyielding object at various speeds, the cask being totally engulfed by fire for some period and the cask falling into water of various depths.

How might these types of accident occur and what might they involve? The following sections look at scenarios involving the three modes of transport that would be used to move radioactive wastes to and within South Australia.

7.1 Marine transport accident in deep or shallow waters

The specialised ships that would be used to carry wastes to Australia are likely to be typical of current international radioactive waste transport ships. For example, the PNTL fleet\(^2\), operated from the UK, has cargo compartments that are protected by a double hull (see illustration below), with all essential systems having an independent back-up to provide redundancy and resilience. The ships are equipped with advanced fire detection and firefighting systems – even allowing all five holds to be flooded, with the ship remaining afloat. There are additional impact resistant structures between the hulls, secondary collision bulkheads and reinforced hatch covers. The vessels carry crews that are substantially larger than those found on chemical tanker ships of similar size. For security purposes, shipments can have armed escorts aboard that are independent of the crew, plus an armed escort vessel to accompany the transport ship from departure to arrival.

Here, it is assumed that all transport of radioactive wastes to Australia would be via dedicated, purpose designed vessels and that no packages would be transported with other cargo on general-purpose vessels.

---

\(^2\) [http://www.pntl.co.uk/our-fleet/](http://www.pntl.co.uk/our-fleet/)
The IAEA completed a detailed study of accidents at sea in 2001, drawing on data submitted by a number of countries\(^{22}\). Typical statistics for accident probabilities generated by one of the studies in the project are a probability of a severe collision on the open sea during a 1000 nautical mile voyage of less than one in twenty million per voyage. For an engine room fire propagating to the cargo hold, the probability was estimated at about five in a billion per voyage and, for a collision between a transport ship and a fuel tanker leading to a fire engulfing the transport ship for a longer period, the probability was about two in ten billion per voyage.

Because the bow velocity and rigidity are much less than those for the regulatory impact tests, no damage is expected from direct impact. In the second case, the crush force is the force restraining the package from moving ahead of the advancing bow. The tie-downs that hold the casks in place are required by regulation to fail at forces much lower than the force needed to damage the package. In such an extreme event scenario, therefore, the casks are designed to become free and move within the hold. Studies show the likelihood of the forces acting on the cask itself being high enough to cause it to fail is very low and the expected result of this scenario is the ejection of the package through the far hull of the transport ship and out into the ocean. The IAEA study reports work that estimates the probability of a cask being lost at sea (or the transport ship sinking) during a voyage through one of the world’s busiest waters, the English Channel, at about one in ten million.

Overall, the marine insurance statistics used by IAEA (1999) demonstrate the frequency of serious collisions to be around two per thousand ship-years, or about one in 25 million nautical miles, with the frequency of total loss of vessels being around three per thousand ship-years. For engine room fires that spread to the cargo area, or fires of a serious nature arising in the cargo hold, the figure is about three per ten thousand ship-years.

7.1.2 Ship fire scenarios

About half of ship fires occur in port and most originate in and affect only the machinery room or the quarters, with relatively few affecting the hold. The time to extinguish fires varies between minutes and days. If ship fires are not extinguished by firefighting, they may burn for lengthy periods of time, even though they are not likely to burn at very high temperatures or for very long periods of time in any one location.

Generally, fire duration is limited by the availability of combustible material. On a dedicated radioactive waste transport vessel, the main source of such material would be the ship's own propulsion fuel. A fire following a collision could result in damage to the fuel tank and subsequent ignition of the diesel fuel. Both events are improbable, because the fuel tanks are at the bottom of the ship and the diesel flash point is >60 °C. Even if this scenario is assumed, a fire of a duration that would threaten the cargo of casks can be excluded, because the content of the damaged fuel tank is limited and a layer of fuel on the sea surface would spread and rapidly burn off.

7.1.3 Combined ship fire and collision probabilities

The scenario of an oil or gas tanker colliding with a ship carrying radioactive wastes, followed by severe fire, is often mentioned as a potentially serious hazard. The historical event data used by the IAEA (1999) show that few serious ship fires are preceded by such impacts and the frequency of such combined events is approximately one hundred times lower than the frequency of serious fires alone, so this scenario represents a minor contributor to overall frequency of fire risk and generally permits collision to be considered separately from fire.

7.1.4 Consequences from a release of radioactive material under water

Given the above analysis, the probabilities of a collision and/or fire accident at sea causing failure of a cask are understood to be extremely low. But what are the consequences if it were to happen? Cask failure could lead to a radioactive release to the atmosphere and gas borne transport of this material from the sea to land. Deposition of gas borne radioactive material onto the ocean surface or the loss of a cask into the ocean could introduce radioactive material into marine food pathways. These impacts would be greater in coastal waters. The IAEA cites work that estimates the radiological impacts of a hypothetical, extremely severe, collision-followed-by-fire accident leading to atmospheric release of radioactivity during a voyage in USA coastal waters. The radiological consequences of this accident are estimated to be so low as to be unlikely to be capable of detection and the probability that this accident could occur while sailing near an urbanised shoreline is so small (around one in a thousand trillion) that the accident is almost not credible.

Deep waters

If a cask fell into deep waters it would be extremely difficult to recover and such an operation might not be attempted. In this respect it is worth considering that several nuclear submarines have been lost at sea and the potential radiological impacts have never been judged severe enough to even attempt retrieval. IAEA (1999) cites a study on the hypothetical loss of a spent fuel cask into both the deep ocean (2500 m) and into shallow
seas off the NE coast of Japan (200 m). In both cases it is assumed that no action was taken to recover the lost cask. The release of radionuclide-saturated water from the cask is by the buoyancy-driven flow of water through the gap in the failed O-ring seal. Radioactivity is assumed to enter the marine food chain, leading back to people. The maximum annual radiation doses to people are estimated to be around a billionth of natural background exposures for loss in the deep ocean and around a thousandth of natural background level for shallow waters. These exposures are so low (a thousandth to a billionth of natural background radiation exposures) as to be considered radiologically insignificant.

**Shallow waters**

A similar study quoted in IAEA (1999) looked at the radiation doses that might result from the loss of a spent fuel cask into the shallow waters of the Grand Banks fishing region in the NW Atlantic Ocean. Again, it was assumed that the cask was not retrieved and that all of the radioactivity escaped over various periods, from 3 to 300 years (physically and chemically, this is highly improbable). Recovery of a flask lost into the ocean a few tens of kilometres from shore would be routine and would normally be accomplished long before any significant release of radioactivity would take place.

This comprehensive study evaluated transport of radionuclides by ocean currents, deposition of radionuclides onto sediments, uptake of radionuclides by seaweed, plankton, crustaceans, molluscs and larval fish, bioaccumulation of radioactivity by predation in marine food chains and radiological exposures to people from eating sea foods, drinking desalinated sea water, inhaling sea-spray, swimming in contaminated sea water and exposure to contaminated sediments. For the shortest total release period and for a person eating seafood from the most affected waters, the annual radiation dose was about seven times average natural background, falling to about one-sixth of natural background for the longer release period. The IAEA report points out that these estimates are highly pessimistic and the actual ingestion doses that might be received by people following the loss of a cask into the ocean will always be very small – much smaller than normal background radiation exposures.

The overall conclusions of the studies that have been carried out for accidents at sea are that they are, first of all, highly unlikely, that the probability of them resulting in releases of radioactivity to the environment and radiation exposures to people is extremely low, and that the types of vessel and transport procedures already in place reduce the likelihood of accidents and releases even further.

**7.2 Marine accident in port**

Much of the previous discussion is applicable to accidents that might occur in ports or the approaches to harbours. Compared with open ocean voyages, the likelihood of shipping collisions is about ten times greater in congested sea-lanes and about one hundred time greater in ports. Because a typical voyage comprises diminishing distances travelled in each of these waters, the risk of a collision during a voyage is about the same throughout the route. The IAEA study cites the probability of a collision involving impact and crush forces associated with a severe engulfing fire in a port or the approach waters to a port to be in the order of one in a billion per ship movement.

The probability that a fire starting on a transport ship while docked in a port with the cask hold covers removed (exposing the casks to the atmosphere) will then spread to the hold and burn at sufficiently high temperatures and long enough to cause a cask to fail and radioactive material to be released, has been calculated using pessimistic assumptions. For a dedicated radioactive waste transport ship which carries no combustible cargo and is equipped with multiple (redundant) fire suppression systems, given that a fire has started, its chance of spreading to the cask hold is estimated to be less than one in ten thousand, consistent with the estimate of one in a hundred thousand for an engine room fire to spread to a cask hold.

The IAEA (1999) report concludes that if a transport ship were to be involved in a severe collision that initiates a severe fire while in port, the largest amounts of radioactive material that might be released to the atmosphere as a result of the accident would cause individual radiation exposures to local people that are well below natural background levels.
7.3 Rail accident scenarios

The nature, probability and consequences of accidents to freight trains carrying spent fuel casks has been studied extensively, with a recent report from the US Nuclear Regulatory Commission looking at the issue in detail, in the context of transporting fuel from across the USA to a national GDF.

There have been substantial improvements in rail safety in recent decades and the 2014 NRC report compiles recent accident statistics in the USA, with a baseline figure of 0.00011 accidents per thousand railcar-km. This figure was extended to look at the probabilities of specific accident scenarios during a 5000 km cross-country journey: for example, a probability of a derailment into a slope of around one in thirty million and a probability for a low speed accident on a bridge of around one in a million.

However, these probabilities are for all accidents and it is only the most severe that might cause significant damage to a cask. As discussed above, the NRC concludes that only one type of transport cask is prone to damage that could cause releases or radioactivity, a situation which thus seems completely avoidable by controlling the types of cask to be used in a project in South Australia.

Collision / impact damage

For those casks that could be significantly damaged (a design that incorporates lead shielding), NRC finds that the accident must be equivalent to an impact with hard rock or equivalent at speeds greater than 97 km/h to result in some loss of lead gamma radiation shielding or damage to the cask seals. The report notes that hard rock is not necessarily an unyielding target. However, accidents that have any radiological consequence are extremely unlikely, even for this type of cask – more than 99.999999% of potential accidents would result in neither loss of shielding nor a release of radioactive material. NRC gives an example for the probability that an accident resulting in lead shielding loss would lead to a radiation dose rate greater than 0.01 Sv/h during a rail journey across the USA from Maine in the east to Washington State in the west as about twice-in-a-trillion shipments. This very small probability indicates that severe accidents that are more traumatic to the cask than the regulatory tests are highly unlikely to happen.

Fire damage

As with all types of accident, fire is the other potential hazard to cask integrity. The conditional probability (that is, assuming first of all that there is an accident) that a gap will form in the lead shielding of this particular type of cask after a fire is exceptionally small – around one in ten billion. It is so small because a sequence of unlikely events has to occur before a fire is close enough to the cask, burning hot enough and long enough to do any damage and this series of small probabilities has to be multiplied together. The sequence could include the following conditions:

- the accident must result in a major derailment, or the location of the fire will be too far away from a cask to damage the shielding
- there must be at least one tanker wagon of flammable material involved in the accident, presumably on another train involved in the accident, because the waste transport trains will not have other cargo – and we note this is highly unlikely on an exclusive use train system with appropriately engineered crossings
- the derailment must result in a pile-up that brings the flammable material into contact with a cask (no further from a cask than a railcar length), and
- the flammable material must leak out so that it can ignite.

The probability of a pileup with a cask within a railcar length from the fire is very small and if this is removed from the estimate so that probability considers only the more likely events, the value is still very small – approximately one in ten billion.

---

The analyses of how an accident might develop and the probability that it might lead to a particular end-point are made using an ‘event tree’ approach. This essentially breaks an accident down into a string of events, each of which could develop in different ways, so that the ‘tree’ branches in different ‘directions’ after each event. There is a probability attached to each branch and the overall probability of any particular end-point situation occurring is the multiple of each branch probability that leads to it.

This approach allows the analyst to ask ‘what if’ questions. For example, if an accident happens, does it happen at slow or high speed; is it on a bridge, in a cutting, on an embankment, in a tunnel; if it is on a bridge, does a cask fall from the bridge or stay on it; if a cask falls off, does it land flat, or at an angle; does it land on a soft or a hard surface…. and so on.

Various studies have evaluated many types of potential rail accident, focusing on severe impacts and fire. Impacts studied include collisions with hard, unyielding surfaces (for example in, or at, the entry to a tunnel), with objects (such as bridge support pillars), with major structures collapsing onto a cask (for example, an overpass) and with other vehicles – in particular with a rail locomotive travelling at high speed. In the latter case, spectacular full-scale tests have been carried out, such as that carried out in the UK in 1984 between a cask and a train travelling at 160 km/h; illustrated below24.

Figure 7.3 : Stills from British Energy (1984) video of experimental train collision with radioactive waste cask

Structure falling onto a cask

The scenario where a structure collapses onto a cask passing beneath it on a transport has been evaluated using, as a model, the disaster in which an elevated portion of the Nimitz Freeway in California collapsed during a major earthquake in 1989. The analysis assumes that a cask is lying directly on the ground (with no cushioning from the transport vehicle or impact limiters) and a main beam of the elevated freeway falls and hits the middle of the cask. As in the other analyses for impacts with objects cited by the NRC study, no loss of containment would occur from this accident.

In all cases studied by NRC, the likelihood of damage outside the range of regulatory testing is extremely small, as indicated above and, for casks with welded internal containers, no accident leads to any release or radioactivity or loss of radiation shielding.

Risk reduction from dedicated rail.

As noted above, these estimated probabilities and consequences, while already low, would be considerably lower for the South Australian radioactive waste transport concept, as dedicated, exclusive use rail lines and are proposed rather than the mixed rail / mixed cargoes modelled for the USNRC and elsewhere. The design of the dedicated SA system presumes risk reduction through:

- minimal interaction with other roads or railway lines (fewer, if any at-grade crossings or complex shunting

24 Source: Central Electricity Generating Board, UK. Video is also watchable on the referenced website
See video at: https://www.youtube.com/watch?v=ZY446h4pZdc
through stations or shared stable yards)
- removal of mixed cargoes (such as fuels) which are associated with additional risk
- dedicated maintenance and renewal activities (no reliance on third party track maintenance) and corridor
- track route selection which substantially removes or reduces transportation through existing cities or towns, and
- dedicated, purpose designed trains and wagons which will convey the materials at a high degree of reliability and efficiency.

**Rail accident in a shared use tunnel**

There is a widely reported study by Radioactive Waste Management Associates\(^25\) that calculated a severe rail accident in an urban area could result in clean-up costs from US$145 billion to US$270 billion. This involved a collision followed by a fire in a mixed use tunnel. While no transport of SF / HLW or ILW in mixed use tunnels is included in the SA nuclear waste study (as no mixed use corridors or tunnels are proposed to be required) the high predicted cost of clean-up is of potential concern.

The work was reassessed by NUREG in 2006 /2009\(^26\). The results of this evaluation strongly indicate that neither spent nuclear fuel (SF) particles nor fission products would be released from a spent fuel transportation package carrying intact spent fuel involved in a severe tunnel fire such as the Baltimore (Howard Street) tunnel fire which occurred in 2001. None of the three package designs analyzed for the ‘Baltimore tunnel fire scenario’ (TN-68, HI-STAR 100, and NAC LWT) experienced internal temperatures that would result in rupture of the fuel cladding. Therefore, radioactive material (i.e., SNF particles or fission products) would be retained within the fuel rods. There would be no release from the HI-STAR 100, because the inner welded canister remains leak tight. While a release is unlikely, the potential releases calculated for the TN-68 rail package and the NAC LWT truck package indicate that any release of radiation from either package would be very small.

Therefore the predicted costs, which assume major contamination and also deaths from exposure to radiation are not a realistic outcome.

**7.4 Road accident scenarios**

Specialist road transport equipment has been used to move casks of radioactive materials in many countries for decades associated with nuclear power, medical and other industrial uses with few incidents and no major accidents. A typical example is shown in Figure 7.4.

**Figure 7.4 : Road transport of radioactive material in Japan**

\(^{25}\) 7 July 2000, [www.state.nv.us/nucwaste/news2000/nn10719.htm](http://www.state.nv.us/nucwaste/news2000/nn10719.htm)

It is postulated that an exclusive road system between the port and ISF will be implemented for the South Australian project and so only LLW is expected to be moved on public roads.

The USNRC study cited above evaluated road transport as well as rail transport, using an identical methodology. In general terms, the analyses are thus very similar and most of what is discussed above for rail transport also applies to road transport. The types of accident are similar, involving impact and fire, and the physical impacts on spent fuel casks are the same.

The exclusive road transport arrangements for casks containing SF and HLW in Australia would consist of specialist over size over mass (OSOM) heavy indivisible load carrying trailers, with one or more prime movers pulling and or pushing the trailer carrying a single cask. These vehicle types have been used without incident to transport such casks of treated Australian radioactive waste returned from reprocessing in France on public roads between Port Kembla and the ANSTO Lucas Heights reactor establishment, as shown in Figure 7.5.

Figure 7.5 : Reprocessed Australian radioactive waste being transported to Lucas Heights from Port Kembla

There are extensive regulations which govern the operation of OSOM vehicles. There are also requirements for escort and pilot vehicles depending on the size and mass of the vehicle and load.

The most active ILW would be transported in heavily shielded SWTC containers like the one shown in Figure 4.2. These casks would presumably be transported on flat-bed trucks. Other ILW is likely to be packed in, standard 20’ ISO shipping containers, most likely in some form of inner container such as 205 litre drums or some form of shielded inner containers. While public road movements of this waste are not the preferred solution in the studies to date they are common elsewhere.

7.5 Road transport of LLW

LLW will be produced during the operations at the various facilities for storing and disposing of SF / HLW and ILW, and as the site of the LLWR has not been determined, it can be assumed that the LLW will be moved some distance to the repository, dependant on its location. As it is unlikely that there will be a rail line, and consistent with the movement other low level waste in Australia, it is assumed this will mainly be moved on public roads.

Transport scenarios involving movement of low-level waste by road can be analysed with confidence because low-level wastes have been moved many millions of kilometres in many countries around the world and extensive statistics exist on actual accident frequencies and consequences. The figures show that accidents are very rare and that consequences of accidents have never been serious. In the USA alone, there are over 11,000 shipments of LLW annually and a study by the US Department of Transport\(^{31}\) showed that over a 20 year period there were only 53 accidents reported involving LLW transport and in only four of these were the containers breached. The contamination was quickly cleared up with no increase in background radiation levels at the accident site. To date there have been no LLW transport accidents with significant radiological impacts; however, several studies have aimed at quantifying the risks associated with such an accident.

In Australia, over 30,000 radioactive packages are safely transported each year. There has been intensive study on the risks of low-level waste transport because of the repeated attempts to implement a national or a state repository for LLW. In the Australian case, most LLW would be transported in standard 200 litre drums packed into shipping containers. The environmental impact statement in 2002 for a proposed national repository project\(^{32}\) included a study of the risks associated with transporting around 3,700 m\(^3\) of LLW from various locations to a centralized repository. The study noted that in 40 years of transporting LLW in Australia there had been no accidents with a significant release of radiologically harmful materials. Using Australian data, the EIS estimated the potential for accidents and concluded that there was less than a 25% chance of an accident when transporting the 2002 total inventory of 1,682 m\(^3\) over more than 9,000 km and that, even in the event of a

---


severe accident, the packaging would ensure that radioactive material would not be widely spread and that first responder teams are trained to respond quickly to any such accidents. All states and territories have in place emergency response plans in case of accidents or incidents involving radioactive (or other hazardous) materials.

Perhaps the most comprehensive study of the risks of transporting large volumes of LLW to a centralised site was done in the USA to analyse the impacts of transporting over 700,000 m³ of LLW over a distance of some 80 million km from diverse sites to a proposed repository at Yucca Mountain in the State of Nevada. Given the lack of historical data on serious accidents and on actual releases of radioactive materials, conservative assumptions were made on the probability of an accident occurring and on the fraction of the radionuclides in the shipment which could be potentially released. The consequences of releases were then estimated assuming that members of the public could be exposed by inhalation, ingestion or external exposure to the radioactive material. Different severity levels of accidents were postulated based on actual statistics of truck accidents. The accidents range from relatively high-frequency, low consequence collisions, through to low-frequency accidents in which the shipping container is exposed to severe mechanical or thermal loads. The scenarios included the containers being punctured, crushed, immersed or exposed to fire. The comprehensive results obtained indicate that the non-radiological risks to the public far exceed any radiological risks. Assuming that the transports would continue over a period of 70 years, it was estimated that one or two deaths would occur due to conventional traffic accidents. Over the same period, it was estimated that the probability of a single accident with fatal radiological consequences was less than 2 in 100,000. The radiological risk to the public due to the routine, accident-free transport was estimated to be less than a 50% chance of one death over the whole 70 year period (based on the usual assumption of no threshold even for low doses and a standard dose conversion factor).

It is apparent from the historical evidence and also from conservative risk assessments of the type described that the objective risks from transporting low-level waste are extremely small. Nevertheless, it is clear from many examples in countries including Australia that there is significant public concern about the transport of any radioactive materials through populated areas. For example, a Joint Select Committee established in NSW to consider the Commonwealth plans for a national low-level waste repository contrasted the views presented to it. Proponents of the project claim that accident risks were very small and that the probability of leakage was very small and that any leakages could be easily dealt with. This was contradicted by the Fire Brigade Union which asserted that collision with a fuel tanker, for example, could result in fires with significant releases of radioactive materials. The committee concluded that there was a clear need for the waste producers and the nuclear regulator to provide the public with better information on all aspects of radioactive waste transports.

8. Severe event scenarios – malicious, criminal and terrorist

This section builds on previous chapters that addressed a range of inherent and accidental transport-related risks, and considers four deliberate ‘attack’ scenarios that could conceivably be malicious, criminal or terrorist in nature. In examining these scenarios, we have painted a picture of the potential course of action by unnamed adversaries and then detailed the known and likely layers of measures that would be expected to come into play and help to mitigate the outcomes. We have included consideration of known and likely national and international counter-terror measures, and acknowledge that additional local measures would be expected to be devised and implemented using a risk-based, intelligence-driven, approach. This approach is well-established in Australia at both Federal and State levels, and its effective application to the security of transported radioactive materials is not expected to pose any insurmountable challenges, given the appropriate level of focus and priority.

8.1 Ship hijack in international or Australian waters

In this scenario, a ship is hijacked. While conceivably this could be in Australian waters it is more probable to be in international waters in a known high risk area. For the purpose of this assessment, the fate of the vessel and its hazardous cargo after this point is not the key focus, as the release of radioactive material has already been addressed under various accident scenarios.

This scenario is considered possible, though unlikely. Even though there have been no reported hijackings involving radioactive material, a total of 15 vessels were hijacked in 2015 (a slight reduction from the 21 in 2014) while 271 hostages were held on their ships (compared with 442 in 2014) as reported by the International Maritime Bureau (2 February 2016). No hijackings were reported in the last quarter of 2015. In recent years most such attacks have occurred in a small number of areas known as centres for piracy, including the waters off East Africa and a small number of SE Asian freight routes.

8.1.1 Engineering / design related mitigation measures

As noted above, the design of the transportation systems themselves (casks, ship design) are intentionally devised to reduce the likelihood of an accident occurring as well as the consequence of an event were it to occur.

The same principles also apply in the face of a malicious or criminal action and work to reduce both the likelihood of a successful malicious action as well as its overall consequences.

While there are several Type B cask designs in regular use, the definition of a possible nuclear waste processing and disposal industry in South Australia assumed the use of Holtec HI-STORM casks, as they are widely used internationally, and provide a flexible solution capable of containing a wide range of nuclear fuel subassemblies and canisters. The principal characteristics of these casks include:

- Cylindrical, with external diameter 2.4 m
- Length 5.12 m
- Stainless steel inner shell thickness 6.35 cm
- Carbon steel multi-layer gamma shield thickness 16 cm
- Polymeric (non-structural) neutron shield thickness 11 cm
- Mass 111.13 t

This makes them slightly smaller than 20 foot ISO shipping containers, but nearly four times heavier than typical ‘heavy’ 20 foot containers, which rarely exceed 25 tonnes. The overall weight of a loaded transport cask is typically 120 to over 125 tonnes. ILW casks are also heavy, ranging from 30 to 65 tonnes.

---

When at sea, the spent fuel and ILW casks are sealed under steel hatches which themselves weigh between 25 and 50 tonnes, and require specialised port equipment to open. Modern ships typically don’t have the on-board capability to open the 25-50 tonne hatches\(^{35}\) and certainly lack the crane capacity to move the casks themselves. Hence even under duress, removal and transfer of the casks at sea is not seen as technically feasible\(^{36}\).

### 8.1.2 Non-engineering mitigation measures

In addition to the engineered or design mitigations noted above, a wide range of non-engineering protective measures can be expected to be in place and to play some part in preventing, or at least mitigating, this scenario. These measures are considered in three categories:

- **Operational measures.** The operators of international sea freight bear the majority of responsibility for the safety of their cargo, and would be expected to take advantage of all available intelligence and data in route and contingency planning. They may, for example, consider making adjustments to their schedules to adapt to any reported incidents, or have security escorts, either in-house or by deployed naval forces or transit country security agencies (as are occasionally made available, particularly during periods of elevated threat). These measures would be reasonably expected to add to the operational and tactical advantage of freight operators and significantly mitigate the likelihood of a successful attack.

- **Australian domestic arrangements.** Australia maintains a highly developed domestic and internationally-connected network for intelligence collection and sharing, as well as potential response and recovery operations with reach well beyond Australian territory. In particular, Australian Special Forces are known to maintain an advanced ‘ship underway recovery capability’ (developed ahead of the 2000 Sydney Olympic Games) and theoretically available to recapture any vessel that might fall into the hands of belligerents. These measures would be reasonably expected to mitigate the potential consequences of a ship hijack, as long as there was sufficient political will for the timely use of force to resolve the situation.

- **International protocols.** A large number of international standards, policies, accreditation requirements and support agencies exist to provide participating nations a significant degree of assistance in the fight against attacks at sea. For example, the International Maritime Bureau manages a 24/7 Piracy Reporting Centre to field reports of attacks, to gather and share intelligence and data and to facilitate global cooperation to counter emerging trends. All of these measures would be expected to provide freight operators a considerable advantage in route selection, information-sharing and contingency planning.

### 8.2 Sabotage of a rail line

In this scenario, a rail line is sabotaged in an urban area, at a point considered most likely to result in derailment of a train carrying radioactive material and over terrain considered most likely to maximize the chances of significant damage to the cargo, local infrastructure and the environment.

This scenario is considered possible, though unlikely. Previous sections have already discussed the likelihood (low) and potential consequences of train accidents and of significant impacts involving radiological containers. Therefore, the primary focus of this discussion is on the likely effectiveness of the various preventative security measures that are likely to be in play.

#### 8.2.1 Engineering / design related mitigation measures

The design of the rail transportation systems (casks, rail design and corridor selection) are intentionally devised to reduce the likelihood of an accident occurring as well as the consequence of an event were it to occur.

The same principles also apply in the face of a malicious or criminal action and work to reduce both the likelihood of a successful malicious action as well as its overall consequences.

The comments above relating to the weight of the casks and the need for specialist equipment to release the bolts apply equally to the rail and road scenarios. The sheer weight of the casks / containers carrying HLW or

---

\(^{35}\) According to evidence provided to the Royal Commission (17^th^ November 2015) by Alastair Brown of International Nuclear Services, this was a deliberate amendment to ship design to prevent any unauthorised access to the casks whilst at sea.

\(^{36}\) Beyond the weight limitations, hatches also require specialized equipment to release the bolts as an additional security feature.
ILW, respectively, would prevent any theft or removal of radioactive materials, and as noted above, intentional derailment would be very unlikely to cause a breach of the transport containers themselves.

8.2.2 Non-engineering mitigation measures

These measures are considered in three categories:

- **Operational measures.** Under Australian regulations, transport operators of radiological freight are required to achieve accreditation under domestic legislation and regulations, including holding current and approved radioactive material transport plans and mandatory background checks on employees. These operators bear the majority of responsibility for the safety of their cargo, and would be expected to take advantage of all available intelligence and data in their transport planning, which would include a review of security risks and the appropriateness of mitigation measures. As a consequence, they might (for example) consider making adjustments to their schedules to adapt to changes in environmental and other risk factors, procure private security escorts or request police security support. Police support in this case might include patrols and advance inspections of critical rail locations, as well as dedicated escort and response arrangements. If required, police could also call upon specialist assistance from the Australian Defence Force. All such measures would be requested / decided on a risk-based, intelligence-driven basis in close collaboration with the South Australian Police and other agencies. Such measures would be reasonably expected to add to the operational and tactical advantage of rail freight operators and to somewhat mitigate any potential sabotage attack. However, it should be noted that rail transport, with its inherently inflexible routes, allows relatively little scope for deception tactics.

- **Australian domestic arrangements.** As noted in the shipping scenario above, Australia also maintains a highly developed domestic and internationally-connected network for intelligence collection and sharing, as well as potential response and recovery operations. South Australian Police are more than capable of undertaking route clearance and security escort operations, and both State and Federal Police maintain specialist and highly trained tactical response capabilities. In addition, the Australian Defence Force maintains explosive ordnance disposal capabilities and Special Forces Tactical Assault Groups for potential call-out in extreme circumstances. If called upon, this suite of measures would be reasonably expected to significantly deter, if not prevent, a potential rail attack.

- **International protocols.** Few if any international standards, policies and protections are considered likely to have a direct influence in this scenario. The most significant and relevant international standards that would play some part will largely apply to rail and radioactive container safety, and these aspects have already been addressed earlier in this report.

8.3 Hijack of a truck

In this scenario, a truck carrying radiological material is hijacked. We note that for SF / HLW and ILW road transport is only considered between the holding store at the port and the ISF and within the GDF complex: both are expected to be fenced secure zones.

This scenario is considered possible, though highly unlikely given the fenced secure zones. Although reliable data on the frequency of truck hijacks in Australia is not readily available, overseas experience and fairly regular domestic media reports suggest this is a moderately well-established (if not common) criminal tactic.

The most significant potential outcomes from this scenario would involve either the deliberate release of radioactive material into the environment, or its capture and removal by belligerents (for potential use in dirty bombs, or simply for ransom). It was noted earlier that the mass of the containers requires specialist equipment that will be difficult to source without drawing attention. Previous sections have discussed the potential consequences should radioactive material be released into the environment through an accident. It is more difficult to quantify potential releases through hijack but it is clear that exposing the waste will not be an easy task and will take time. Therefore, the primary focus of this discussion is on the likely effectiveness of the various preventative and response measures that are likely to be deployed.
8.3.1 Engineering / design related mitigation measures

The design of the road transportation system will be intentionally devised to reduce the likelihood of an accident occurring as well as the consequences of an event were it to occur.

The same principles also apply in the face of a malicious or criminal action and work to reduce both the likelihood of a successful malicious action as well as its overall consequences.

8.3.2 Non engineering / design mitigation measures

These measures are considered in three categories:

- **Operational measures.** As for the rail scenario above, Australian transport operators of radioactive freight are required to achieve accreditation under domestic legislation and regulations. These operators bear the majority of responsibility for the safety of their cargo, and would be expected to take advantage of all available security-related technology, including the routine use of vehicle tracking technology, installed and remotely recorded/monitored security cameras and reliable communications systems with 24/7 operator support. In addition, they would draw upon available intelligence and data in planning, which would include a review of security risks and the appropriateness of mitigation measures. As a consequence, they might (for example) consider making adjustments to their schedules to adapt to changes in environmental and other risk factors. They might procure private security escorts or request police security support. Police support in this case might include patrolling of key locations along the route, as well as dedicated escort and response arrangements. Such measures would be requested / decided on a risk-based, intelligence-driven basis in close collaboration with the South Australian Police and other agencies. Such measures would be reasonably expected to significantly add to their operational and tactical advantage and to significantly deter, if not prevent, any potential attack.

- **Australian domestic arrangements.** As noted in the above scenarios, Australia also maintains a highly developed domestic and internationally-connected network for intelligence collection and sharing, as well as potential response and recovery operations. If required, South Australian Police are more than capable of undertaking road clearance and security escort operations, and both State and Federal Police maintain specialist and highly trained tactical response capabilities. In addition, the Australian Defence Force maintains Special Forces Tactical Assault Groups for potential call-out in extreme circumstances. If called upon, this suite of measures would be reasonably expected to significantly deter, if not prevent, a potential truck attack.

- **International protocols.** Few if any international standards, policies and protections are considered likely to have a direct influence in this scenario.

8.4 Rocket attack on a train

In this scenario, a train carrying radioactive material is attacked with multiple armour-piercing rockets, with the intention to bring about the release of radioactive material in circumstances most likely to maximize the effects on any local population and the environment. For the purposes of this scenario, ‘rockets’ are considered in their broadest definition to include rocket propelled grenade (RPG) type weapons as well as the wide variety of anti-armour missiles in use across the globe, be they unguided (eg. Carl Gustav, AT4), wire-guided (eg Milan, TOW) or self-guided (eg. Javelin).

An analysis conducted by the Sandia National Laboratory in New Mexico for the US Department of Energy in 1999 investigated the effects of attacks on US spent fuel trucks and rail containers using two different types of weapons. The study concluded that certain types of armour piercing weapons could penetrate US spent fuel flasks – although only the outer wall of the spent fuel cask would be penetrated. There is considerable dispute over whether breaching a spent fuel flask would cause a significant release of radioactive material. The Sandia study concluded that even in a worst case scenario, less than 1% of the spent fuel in a container would be released in the form of ‘breathable’ particles which people could inhale. As noted previously, this is still a very significant release of radioactive material with potentially high local health impact consequences.

The study has been criticised by some stakeholders who believe the consequences of an attack could be far more severe than stated, given that only a single strike is considered in the scenario. For example, Abdul Mannan\textsuperscript{38} (2007) postulated a terrorist carrying out a ‘hybrid sabotage’ on a consignment of SF. This involved multiple missile fire and including an incendiary device (or accompanied by a fire from a nearby fuel source) could result in:

- a potentially larger percentage release of cask contents, possibly as great as 10 percent
- potentially higher percentage of respirable particulates and/or vaporized radionuclides, and
- potentially more widespread dispersal and deposition.

\textbf{Mannan (2007) multiple terrorist attack scenario and consequences}

Mannan considered a scenario where the cask has a breach of containment followed by an engulfing fire for several hours. The explosive attack followed by a fire leads to an increased radioactive release. The debris cloud is lifted over 500 m high which is expected to be further elevated by the fire. Within an area of 0.3 km\textsuperscript{2}, maximum total effective dose equivalent of 1 SV is predicted by his model due to release of radionuclides from the breached flask containment only, which is far below the level to cause acute radiation syndrome. However, exposure in the immediate vicinity of the blast to a high radiation field due to the remaining radioactivity still contained in the breached SF flask creates a difficult situation for the first responders.

Wind was assumed to disperse the radioactive aerosols to 36 kilometres from the blast location contaminating externally as well as internally the population to a dose contour down to 15 mSv in approximately 167 km\textsuperscript{2} area in around four and half hours.

Mannan calculated the consequences of radiation effects due to single exposure to population groups on the basis of a lifetime risk model which predicts that approximately one individual in 100 persons would be expected to develop cancer from a dose of 100 mSv while approximately 41 individuals would be expected to develop cancer or leukaemia from other causes. The increase in cancer fatality was estimated to be 0.13\% in cancer fatality due to the incident as compared to deaths due to other circumstances.

The multiple strike scenario is considered possible, though highly unlikely, while the ‘hybrid sabotage model’ is significantly less likely as it requires a number of concurrent events to occur within a conducive environment. Although sufficient media (and occasional police) reports suggest the likelihood of an unknown quantity of RPG-type weapons being in the hands of criminal groups in Australia, there have been no reported incidents involving their actual use in this country. The tactic of firing multiple unguided rockets simultaneously has been seen to increase their effectiveness against moving and hardened targets, including helicopters, though it presupposes the availability of sufficient weapons and trained firers. In the case of more sophisticated guided missile systems, there have been no public reports of thefts, losses or illegal imports in or into Australia, despite their prevalence in multiple conflict zones across the globe. Systems in the latter category are typically large, heavy and expensive, and their effective use requires considerable training.

While the most significant potential outcome from this scenario would involve the release of radioactive material into the environment, the primary focus of this discussion is on the likely effectiveness of the various preventative security measures that are likely to be deployed.

\textbf{8.4.1 Engineering / design related mitigation measures}

As noted earlier, the design principles inherent in the rail transportation systems (casks, rail design and corridor selection, rolling stock, etc) will be intentionally devised to reduce the likelihood of an accident occurring as well as the consequence of an event were it to occur.

\textsuperscript{38} Preventing nuclear terrorism in Pakistan: Sabotage of a Spent Fuel Cask or a Commercial Irradiation Source in Transport, The Henry L. Stimson Center, April 2007
The same principles also apply in the face of a malicious or criminal action and work to reduce both the likelihood of a successful malicious action as well as its overall consequences.

8.4.2 Non engineering / mitigation measures

These measures are considered in three categories:

- **Operational measures.** Operational mitigation measures are largely as detailed in the previous rail scenario. Potential differences here would be the potential to restrict rail movements to night time, to minimize or avoid stops, to make adjustments to their schedules to adapt to changes in environmental and other risk factors and to procure private security escorts or request police security support, should assessed security risks warrant such. Police support in this case might include ground and air (helicopter) patrols and advance inspections of critical rail locations, as well as dedicated escort and response arrangements. If required, police could also call upon specialist assistance from the Australian Defence Force. All such measures would be requested / decided on a risk-based, intelligence-driven basis in close collaboration with the South Australian Police and other agencies. Such measures would be reasonably expected to add to the operational and tactical advantage of rail freight operators and to somewhat mitigate any potential rocket attack. However, it should be noted that rail transport, with its inherently inflexible routes, allows relatively little scope for deception tactics, increasing the reliance on intelligence and surveillance measures.

- **Australian domestic arrangements.** Domestic security arrangements applicable in this scenario are largely as per the previous rail scenario. If called upon, this suite of measures would be reasonably expected to deter, detect and/or defeat a potential rocket attack on a train.

- **International protocols.** The main international protection considered likely to have a direct influence in this scenario is the raft of international agreements, controls, monitoring and information-sharing arrangements that seek to manage the proliferation of weapons, particularly to known terrorist and criminal groups. These measures appear to have been effective in managing the threat of sophisticated missile systems in Australia to date, however, they are considered less relevant for RPG-type weapons, given their potential to be illegally sourced within Australia (including by theft from the Australian Defence Force).

8.5 Hijack of a LLW truck on a public road

Road accidents for LLW shipments are discussed above in Section 7.5 and this section extends this to a scenario in which the transport is subject to a malicious act. This is a serious consideration for spent fuel and HLW transports, but of far less importance for LLW.

The more plausible scenarios for misuse of LLW relate to hazards from spent sealed radiation sources, used in medicine, industry or research. For the specific LLW derived from the activities at the ISF and GDF / EF / IDR there are not expected to be any spent sealed radiation sources. The wastes are not expected to contain material of sufficient radioactivity to be of interest to terrorists or those wishing to blackmail the community. Nevertheless the mitigation measures identified in Section 8.3 are still applicable.

While we are aware of an IAEA report that considers the security issues associated with misuse of sources, this is not relevant to the present scenarios.

---

9. Risk mitigation – existing and potential protocols

An overview of International and Australian regulations and procedures is presented in Appendix A. This section considers the effectiveness of Australia’s measures and considers gaps and fixes.

9.1 Assessment of Australian radiological security measures

The question of how effective are Australia’s existing security measures for the protection of radioactive material was answered in January 2016, in very large part, by an independent report the ‘NTI Nuclear Security Index – Theft/Sabotage, Third Edition’ dated January 2016. According to this independent and comprehensive study, Australia’s security arrangements are ranked first in the world amongst states with weapons-usable nuclear materials. This assessment comprised the following sub-category rankings:

- First in quantities and sites
- Sixth in security and control measures
- First in global norms
- First in domestic commitments and capacity
- Sixth in risk environment.

While this assessment was focused on the security framework for ‘weapons grade’ radioactive material, it would be reasonable to extend this level of confidence to the protection of non-weapons grade radioactive material, given that the vast majority of controls would remain applicable.

And so, if Australia’s radiological security framework of policies, procedures, commitments and general risk environment are all so positive, are there any areas of identified or potential gaps regarding the transportation of radioactive waste? This is discussed below.

9.2 Identified gaps and fixes

The security in depth for protection of the public from radioactive wastes during transport is shown schematically in Figure 9.1 below.

---

9.2.1 Shipping

The identified suite of protective measures, encompassing international, operational and Australian domestic arrangements, does not appear to present any obvious gaps that could be readily exploited by an adversary intent on capturing a ship carrying radioactive material through international waters especially if these vessels carried on-board security teams and / or had armed escort vessels. However, assuming there is a general lack of experience of the carriage of such material within the Australian maritime sector, it might be argued that additional measures and overseas experience should be called upon, at least in the early implementation stage, should the use of Australian transport operators be considered.

9.2.2 Road and rail

As for transportation by ship, the identified suite of protective measures for transport by road and rail in Australia do not appear to present any obvious gaps that could be readily exploited by an adversary intent on attacking rail or road transportation of radiological material. However, given the lack of experience of the carriage of such material within the Australian transport sector, it might be argued that additional measures and experience should be called upon, at least in the early establishment stage.
10. Risk comparisons

Some decision-makers are apt to declare that they will only proceed with something if ‘there is absolutely no risk’. By saying this, they are showing a lack of awareness of scientific reality and, maybe more importantly, of the way that we all approach hazards in our own lives.

Many activities that we involve ourselves in entail some risk to ourselves or our family, friends or neighbours. We are often unaware of what the risks are but we are also well aware that certain activities are associated with high risks, yet choose to participate in them anyway.

Scientists apply the word ‘risk’ in a formal sense: for example, for an event that might happen, risk is the multiple of the consequences of that event and the probability that the event will occur. The likelihood that an event will occur is thus a major aspect of risk estimation. In scientific use, the consequence is usually taken to be the death or serious injury of a person who is exposed to the event. For a radiation exposure event (like a leaking cask), this means that scientists need to know how much exposure a person would receive, how likely that amount of exposure is to cause death or serious genetic effects and the probability that the event will happen in the first place. The risk of exposure to a person from the event can then be calculated at, say, one in a million per year.

The same approach can be applied to any hazardous activity or potentially hazardous procedure or event. Take smoking cigarettes, for example. A person who smokes chooses to do so, so there is certainty (i.e., probability of 1) of an event occurring – since it happens, and is by choice. However, a risk can still be calculated scientifically, by multiplying the exposure to the hazard (the number of cigarettes smoked per year) by the probability that this level of exposure to the noxious content of cigarette smoke will result in death. A similar approach may be applied to calculate the risk of riding a motorbike: multiply the number of kilometres a year we travel by the probability of a fatal accident involving a motorcyclist per km travelled. The same risk may also be calculated in a different way, by looking at the number of people who die as a result of motorbike accidents each year in the whole population and arrive at a population average risk which makes no assumptions about whether individuals are motorbike riders or not. We’d expect this to be a lower risk value than one calculated for regular motorbike riders. It is thus feasible to calculate objectively the risk to individuals from various activities, in a range of different ways.

10.1 Determining ‘acceptable’ levels of risk

How the general population deals with risks tends to be far from objective. The level of risk that is acceptable or tolerable to individuals or to society in general is almost entirely a subjective issue. A significant factor is individuals’ tendency to distinguish strongly between risks that are voluntary and risks that are imposed by others – if this were not the case, there would be far fewer smokers or motorbike riders! People tend to be more prone to accept a risk not only if they can choose whether to take it, but also if they feel that they understand it and do not have a ‘dread’ of the risk.

There are large statistical databases of probabilities and consequences for a wide range of activities on which to base risk calculations and many estimates of risk values that we can compare with each other. The following Table compares values of calculated risks to a person who might be a bystander to an accident involving a radioactive waste shipment. The data in the table come from a variety of sources and are intended to be broad and illustrative rather than precise. Different sources (of which there are many) derive slightly different numbers, depending on the population they have assessed, the country they have taken data from and many other factors. The main sources used here are the US National Safety Council and the UK Health and Safety Executive.

The concept of ‘risk tolerability’ is often used by regulatory authorities in various fields of activity (not just those involved with the safety of radioactive materials). Commonly used metrics of tolerability are that risks (of death) to members of the public of more than 1 in 100,000 per year are ‘intolerable’ and would require action to mitigate them. Risks between 1 in 100,000 and 1 in a million per year are only undertaken if there is some benefit from the activity and, in any case, actions should be taken to make the risks as low as reasonably practicable, taking economic and social factors into account. Risks between 1 in a million and 1 in ten million
are often regarded as broadly acceptable and further effort to reduce risk is not likely to be required as the resources to reduce the risks are likely to be grossly disproportionate to the risk reduction achieved. Risks less than one in ten million per year are regarded as insignificant and requiring no action to reduce or mitigate them.

It can be seen that the objective risks arising from accidents involving transport of wastes are vanishingly small compared to the other activities selected for comparison and certainly well below the ‘insignificant’ level of risk tolerability outlined above. However, for the reasons also given above, this does not necessarily mean that they are any more acceptable to people. Consequently, although this type of risk comparison is instructive and allows us to put objective risks into a wider perspective, it does not necessarily allay the fears of a person who perhaps does not understand the nature of radiation, or who simply fears radioactivity.

Table 10.1: Annual risk of death for various hazards (voluntary and involuntary)

<table>
<thead>
<tr>
<th>Hazard or activity</th>
<th>Annual risk of death to a person involved or exposed</th>
<th>Assumption</th>
</tr>
</thead>
<tbody>
<tr>
<td>Smoking</td>
<td>1 in 100</td>
<td>10 cigarettes a day</td>
</tr>
<tr>
<td>Just being 40 years-old for a year</td>
<td>1 in 1000</td>
<td>Natural causes only</td>
</tr>
<tr>
<td>Long-haul aircrew: natural radiation exposure</td>
<td>1 in 4000</td>
<td>Average exposures of long-haul aircrew</td>
</tr>
<tr>
<td>Living in earth’s natural radiation background, as we all do</td>
<td>1 in 6000</td>
<td>Global average background exposure</td>
</tr>
<tr>
<td>Traffic accident</td>
<td>1 in 8000</td>
<td>Population average</td>
</tr>
<tr>
<td>Scuba diving</td>
<td>1 in 20,000</td>
<td>10 dives a year</td>
</tr>
<tr>
<td>Being shot by an assailant</td>
<td>1 in 24,000</td>
<td>USA data</td>
</tr>
<tr>
<td>Motorbike accident</td>
<td>1 in 74,000</td>
<td>Population average: USA data</td>
</tr>
<tr>
<td>Canoeing</td>
<td>1 in 75,000</td>
<td>10 outings a year</td>
</tr>
<tr>
<td>Drowning (swimming and all other causes)</td>
<td>1 in 92,000</td>
<td>Population average: USA data</td>
</tr>
<tr>
<td>Fire</td>
<td>1 in 110,000</td>
<td>Population average: USA data</td>
</tr>
<tr>
<td>Surgical anaesthesia</td>
<td>1 in 185,000</td>
<td>One operation in a year</td>
</tr>
<tr>
<td>Travel by rail</td>
<td>1 in 430,000</td>
<td>One return journey a year</td>
</tr>
<tr>
<td>Being struck by lightning</td>
<td>1 in 2 million</td>
<td>Population average</td>
</tr>
<tr>
<td>Travel by plane</td>
<td>1 in 12.5 million</td>
<td>10 journeys a year</td>
</tr>
<tr>
<td>Shark attack</td>
<td>1 in 290 million</td>
<td>Population average: USA data</td>
</tr>
<tr>
<td>Accident leading to radiation release in a 1000 km rail journey with spent fuel</td>
<td>1 in 4 billion</td>
<td></td>
</tr>
<tr>
<td>Accident leading to radiation release in a 20,000 km sea voyage with spent fuel</td>
<td>1 in 1000 trillion</td>
<td></td>
</tr>
</tbody>
</table>

Source: Various
11. Conclusion

Since 1971 there have been more than 20,000 worldwide shipments of used fuel and high-level wastes (over 80,000 tonnes) over many millions of kilometres and many hundreds of thousands of shipments of lower level radioactive materials. Although there have been a small number transport accidents involving radioactive materials, there has never been one in which a container with highly radioactive material has been breached, or has leaked. In its broad review of decades of past practice, USNRC (2014) has drawn the following conclusion.

"The risks associated with SF transportation come from the radiation that the spent fuel emits, which is attenuated—but not eliminated—by the transportation casks shielding and the possibility of the release of some quantity of radioactive material during a severe accident. This investigation shows that the risk from the radiation emitted from the casks is a small fraction of naturally occurring background radiation and the risk from accidental release of radioactive material is several orders of magnitude less."

Of the ‘worst case’ situations assessed in this report there are two scenarios where SF casks might be perforated and radiation escape:

- perforation of a cask and disruption of fuel assemblies by a rocket attack would release volatile and gaseous radionuclides, which would contribute to airborne contamination. Depending on the severity of the explosive impact, particles of fuel could also be mobilised, with fine particles being transported in the air. Measures to reduce the likelihood of a missile attack are described.

- an unrecovered cask lying on the deep ocean floor would be expected to degrade very slowly, with the seals breaking down long before the cask walls lose their integrity. Volatile and gaseous radionuclides would escape initially, as soon as the seals fail. The fuel matrix itself is highly insoluble and would dissolve extremely slowly, over thousands of years or more. All radioactivity that escapes from a degrading cask would be expected either to be deposited locally on sediments or to be diluted in thousands of cubic kilometres of seawater, so that the risks it poses to people and the environment are negligible.

There is a well-established, multi-layered process for the minimisation of likelihood and consequences for the types of accident or malicious act that could occur during the transportation of radioactive wastes to and within Australia. Given the ‘greenfield’ nature of the proposed development sector and the application of a dedicated port, railway and other inherently superior systems for the routing and conveyance of radioactive materials between arrival, storage and disposal facilities, there is ample opportunity to reduce risk even further (in terms of both probability and consequences) by methodical planning and design. This would not be as feasible if, for instance, radioactive material was required to be transported within densely populated areas, as is the case in many European and American cities.

Assessment of these processes has shown that, while there are residual risks associated with the transportation of nuclear wastes, these risks are well below levels regarded as having any significance and far lower than those associated with many activities that are generally accepted.
12. References

References are provided as footnotes throughout this report.
Appendix A. International and Australian conventions and regulations

This appendix provides an overview of relevant international and Australian conventions and regulations.

International regulations

Over the past decades a comprehensive network of conventions and regulations has been developed globally with the aim of ensuring uniform high standards of transport safety. A comprehensive overview is provided by the World Nuclear Transport Institute.41 As early as 1957, the Transport and Communications Commission of the United Nations Economic and Social Council (ECOSOC) issued UN Recommendations on the Transport of Dangerous Goods. Soon thereafter, ECOSOC decided that the IAEA should “be entrusted with the drafting of recommendations on the transport of radioactive substances”. Nevertheless, UN Recommendations on the Transport of Dangerous Goods continue to be updated regularly and issued to Member States and to international organisations concerned with implementation at national and international levels. The IAEA meanwhile works in close co-operation with the UN Committee of Experts, as well as with specialised UN agencies responsible for the various modes of transport requirements.

Since 1961, the IAEA has published and periodically reviewed and updated its Regulations for the Safe Transport of Radioactive Material. The documentation, including also advisory documents, is extensive42 and is reviewed at intervals by the Transport Safety Standards Committee of the IAEA. The Regulations are used today by a majority of countries as the basis for their national regulations. In addition, the international organisations responsible for the safe transport of dangerous goods by road, rail, sea, air and inland waterways have incorporated the relevant parts of the IAEA Regulations into their own instruments. Today, more than 60 Member States, including all major shipping and nuclear power generating countries, implement the IAEA Transport Regulations as the basis for their national regulations. A graded approach is applied in the IAEA Regulations, with three cases considered: incident-free conditions, minor mishaps and accident conditions in transport. In all cases, safety is intended to result from the design of the package, combined with simple operational control mechanisms.

In addition to the IAEA Regulations, there are several wider Conventions and Agreements that cover international transport of dangerous goods, including radioactive wastes. The organisations and guidance involved include:

- The International Maritime Organization (IMO) is recognised as the UN agency which provides the global maritime community with a forum for all matters affecting the safety of shipping and the protection of the marine environment
- The Convention for the Safety of Life at Sea (SOLAS Convention) mainly specifies minimum standards for the construction, equipment and operation of ships
- International Maritime Dangerous Goods Code (IMDG Code) is a uniform international code for the carriage of dangerous goods by sea, covering such matters as packing, containerised shipments and stowage
- The International Code for the Safe Carriage of Packaged Irradiated Nuclear Fuel, Plutonium and High-Level Radioactive Wastes On Board Ships (INF Code) sets standards above those set by the SOLAS Convention for conventional ships and lays down that some waste types may only be carried on purpose-built INF cargo ships

• The Road and Rail Transport Regulations Concerning the International Carriage of Dangerous Goods by Rail (RID) set out the minimum standards for safe packing and transport of various types of dangerous goods travelling to or through another country. These standards concern, inter alia, packaging, labelling and consignment procedures.

The above are all global agreements. At a regional level, there are further examples such as the Convention on Intergovernmental Organisation for International Carriage by Rail (OTIF) and the Agreement concerning the International Carriage of Dangerous Goods by Road (ADR), which are European based, as well as other examples related to South America and the ASEAN countries. All such agreements and regulations may be important for a potential multinational service provider accepting spent fuel or wastes from diverse nations.

**Australian regulations and requirements**

The transport of radioactive material in Australia is predominantly regulated under requirements of the Australian Radiation Protection and Nuclear Safety Agency (ARPANSA), which is based on regulations published by the International Atomic Energy Agency (IAEA). These are enacted through State and Territory Acts and Regulations. Transport of radioactive material by air or in international waters, falls respectively within the remit of the Civil Aviation Safety Authority and Australian Maritime Safety Authority.

**Framework for managing transport of radioactive material**

ARPANSA, in consultation with the Radiation Health Committee (and subject to review and endorsement by the Radiation Health and Safety Advisory Council) publishes and periodically revises publications under its ‘Radiation Protection Series’ that aligns closely with the International Atomic Energy Agency (IAEA) safety standard series. The same structure of fundamentals, codes and guides is used by ARPANSA to promote practices that protect health and the environment from harmful radiation.

**Figure 2 : IAEA’s safety standard series:**

![Image of IAEA's safety standard series]


---

43 Radioactive waste is a Class 7 substance under the Australian Code for the Transport of Dangerous Goods by Road and Rail (Australian Dangerous Goods Code ‘ADG’). Following a determination by the Standing Council on Transport and Infrastructure in 2015, Class 7 material is now only subject to the Australian Dangerous Goods code where it is transported on the same vehicle or train as dangerous goods of other classes (National Transport Commission, 2015). It is replaced instead by ARPANSA Radioactive Protection Series publications RPS 2, No. 2.1 and No. 2.2.

44 Formerly the Radiation protection Series consisted of standards, codes of practice, recommendations and safety guides.

The radiation protection series contains the following types of publications:

- Fundamentals – the basic concepts and objectives of international best practice
- Codes – that contain safety or security requirements and may be referenced by regulations or conditions of licence
- Guides – which provide recommendations on compliance with codes or application of fundamental principles

Draft publications are issued for public comment prior to finalisation and assessed for regulatory impact. ARPANSA’s remit has been extended to administering radiation health series and codes under Environmental Protection (Nuclear Codes) Act 1978, which are being progressively reviewed and republished.

The three key publications issued by ARPANSA under its radiation protection series in respect of the transport of radioactive material are:


The aim of the transport code is to create uniform requirements for transport of radioactive material by road, rail and on waterways that are under the jurisdiction of states and territories in Australia. It covers all transport of radioactive material from small medical isotopes to spent reactor fuel. The 2014 edition of the transport code is the most recent, directly adopting the latest international ‘Regulations for the Safe Transport of Radioactive Material’ (IAEA, 2012), which are embedded into the transport code. The only difference relates to radiation exposure limits which are set out in two other RPS publications46.

Requirements under the transport code, outlined briefly in the sections below, are:

- Classification of radioactive material (Section IV)
- Requirements and controls for transport (Section V)
- Form and packaging of radioactive material (Section VI)
- Test procedures to ensure compliance with packaging requirements above (Section VII)
- Approvals required for different packages (Section VIII)

**Classification of radioactive material**

Section IV of the transport code requires classification of radioactive material against UN Codes, sets out the calculations to be used as well as the properties and constituents that must be present which determine their classification47. Upper thresholds for quantities of radioactive material that may be present in a package are stipulated, including conditions under which a package may be ‘excepted’ and other types of packaging (empty or Type B(U), Type B(M) or Type C) may be transported.

**Controls on transportation**

Section V of the transport code stipulates requirements and controls for transport of radioactive material. In summary, this encompasses:

---


47 Classified as either a ‘low specific activity material’, ‘surface contaminated object’, ‘specific form radioactive material’, ‘low dispersible radioactive material’, ‘tissile material’ or ‘uranium hexafluoride’.
• Conformity of the packaging with design specifications is required before first shipment of radioactive material, and measures to ensure every subsequent shipment of waste is appropriate to the package design and fulfills the conditions of approval.

• Prohibiting carriage of other goods with radioactive material, other than as required for use of radioactive material and requires their segregation from other dangerous goods.

• Requiring properties of the package (explosiveness, flammability, corrosiveness etc.) to be taken into account in storage, labelling, marking, storage and transport and in compliance with transport regulations of countries through which materials are transported

• Establishing limits for non-fixed contamination to external surface of any package and places obligation on qualified person to assess extent of contamination and radiation level, which may be subject to additional steps as required by the competent authority

• Checking of equipment for levels of contamination, on a periodicity that is appropriate to the likelihood of contamination and extent to which radioactive material is transported

• Undertaking any decontamination as soon as possible and not reusing equipment unless specific conditions are met (including levels of radiation). The internal surfaces are exempt from this if the used exclusively for transport of radioactive materials

• Setting the quantities of LSA material and SCO that may be permitted to be transported in a single package, determined by the external radiation level and conditions under which groups of material may be transported unpackaged

• Establishing the method for determining the transport index for a package, container or unpackaged material and for determining the criticality safety index (CSI). These inform what category is appropriate.

• Requirements for marking, labelling and placarding of packages or overpacks that are durable and legible and appropriate to country of origin approval requirements if transiting through different countries with different approval types.

• Obligations on consignor regarding classification, packaging, marking and labelling of contents, information to carriers and procedure and form of notification to authorities through which consignment is transported, holding of certificates required under regulations.

• Segregation and stowage of materials, including minimum distances and maximum transit numbers

• Requirements for location of labelling for transport by road and rail, vessels, air and post

• Conditions on the holding and retention of information during and for 3 months following transport by carriers

Form and packaging of radioactive material

Section VI of the transport code stipulates the requirements for form and packaging of radioactive material. It sets out the requisite properties of ‘special form’, ‘low dispersible’ radioactive material and material excepted from fissile classification. It also stipulates the general requirements for design of all packaging, and additional requirements for packages transported by air and by package type.

Compliance and assurance

Section VII of the transport code establishes the test methods to confirm the classification of waste as LSA-III or low dispersible or special form radioactive material. It also sets out procedures for testing of different package types to ensure compliance with packaging requirements of Section VI.

Approvals for transport of radioactive material

Certification of sources of radioactive material, packages and certain transport types is a key element of the transport code - the approval process and administrative requirements is set out in Section VIII. As there are many ‘competent authorities’ in Australia who can provide certification, additional guidance around interpretation and facilitating compliance with provisions of the transport code is provided for in the Approval Processes for

The safety guide addresses the following aspects of approvals as set out in the transport code:

- Defines the key roles in the transport of radioactive material as ‘the consignor’, ‘the consignee’, ‘the carrier’ and ‘the competent authority’. Australian competent authorities are identified in the code and included in Annex A of the safety guide.
- Describes the application process and form of application required – a safety analysis, supporting documents, compliance statement, cover letter with applicant details and transport mode – and expectations around the currency and quality of supporting information provided, numeric figures, appendices and visuals.
- Radiation protection program required prior to consignment being able to be moved.
- Outlines the application process required to enable competent authority to determine compliance with the transport code. No format for application but must state whether for new, modified, renewed approval.
- Specifies the approval requirements for different forms of radioactive material (special form, low dispersible) and requirements for the different types of packages (Type B(U), Type C, Type B(M)).
- Outlines when multilateral approval is required for shipment of Type B (M) packages, fissile material, and special use vessels, and what an application for approval must include.
- Provides guidance on conditions under which loading and package accumulation requirement approval may not be required for special use vessels. These are where:
  - The radiation protection programme has been approved by relevant competent authorities,
  - Stowage requirements have been predetermined; and
  - Supervision will be undertaken by qualified personnel.

The safety guide also specifies what the radiation protection programme must demonstrate and what further details the applicant must provide with the application.

- Outlines the validation process and requirements for foreign packages through either ARPANSA or CASA (air transport).
- Sets out the additional requirements for air transport (out of scope of this report).

Responsibilities in transportation of radioactive material

The ‘Safe Transport of Radioactive Material Safety Guide’ (ARPANZA, 2008) provides guidance to transport users (consigners, carriers, consignees) and competent authorities involved in the transportation of radioactive material. It explains in greater detail the requirements of each and examples of how to prepare a transport consignment for different radioactive sources.

An overview of specific guidance for each is provided is summarised below:

Table 2: Guidance available to persons involved in transportation of radioactive materials:

<table>
<thead>
<tr>
<th>Role</th>
<th>Guidance available</th>
</tr>
</thead>
<tbody>
<tr>
<td>Consignors</td>
<td>• Packaging, labelling, certification and documentation of radioactive materials. Some examples are given to illustrate the procedure to be undertaken.</td>
</tr>
<tr>
<td>Carriers</td>
<td>• Appropriate labelling content, handling principles, emergency procedures</td>
</tr>
<tr>
<td></td>
<td>• Need to refer to code of practice for the security of radioactive sources (the security code) where a security enhanced source is being transported.</td>
</tr>
</tbody>
</table>

48 Vessel used exclusively for transport of radioactive material by virtue of its design or reason for being chartered.
49 A radioactive source, or aggregation of radioactive sources, assigned the Category 1, 2 or 3 when using the methodology set out in Schedule B of that Code.
<table>
<thead>
<tr>
<th>Role</th>
<th>Guidance available</th>
</tr>
</thead>
</table>
| Consignees       | • Verifying the integrity of the package and conformity with documentation for the consignment.  
                    • Informing the competent authority on loss or damage to a package or where there is a risk of loss of radioactive material that could pose a radiation hazard to people or the environment. |
| Competent authority | • Who the competent authorities are and what actions are required of them                                                                  
                          • Need for notification in the event of any incident or damage to a package containing radioactive material                                                                 |

Source: Study team

Guidance also covers:

- Special requirements by transport mode (air, sea, road or rail)
- Checklist for preparing or receiving radioactive materials for transport
- Emergency procedures
- Summary of requirements of the Transport Code in respect of the material, packaging, maximum radiation levels, contamination/decontamination, documentation, loading and segregation, labelling, marking and placarding, transport documents of different radioactive materials, according to the quantities to be transported
- Additional information on the competent authorities in various jurisdictions, on exemption levels and tests for package types.

**Road, rail and waterways under jurisdiction of States and Territories**

Transportation of radioactive materials by road, rail and in waters under the jurisdiction of State and Territories are subject to requirements of ARPANSA's Transport Code and brought into effect through State and Territory Acts and regulations.

In South Australia, the transport code is enacted through the *Radiation Protection and Control (Transport of Radioactive Substances) Regulations 2003*, under the *Radiation Protection and Control Act 1982*. The responsible authority is the Environment Protection Authority. The *Radiation Protection and Control Regulations* impose duties on the consignor, carrier and store-keeper of radioactive materials.

There are two areas where the transport of radioactive waste is not regulated by States and Territories:

- By air, which is covered by the *Civil Aviation Act 1988* and for which the Civil Aviation Safety Authority (CASA) is the competent authority. These provisions are not relevant to the anticipated South Australian context as the anticipated volumes of radioactive material exceed those that could feasibly be transported by air.
- On waterways that are not under the jurisdiction of Australian States or Territories. This is regulated under the *Navigation Act 2012* for which the competent authority is the Australian Maritime Safety Authority (AMSA).

**International waterways**

Chapter 3, Part 4, Subdivision B of the *Navigation Act 2012* covers the transport of dangerous goods. The Act prohibits the following activities:

- Transport of improperly labelled dangerous goods
- Failure by the consigner to provide a description in writing of the goods to the carrier, at or before the goods are placed on-board the vessel.
- Carriage or causing the carriage of dangerous goods under a false description or providing a misleading description of the sender.
The Act requires the shipper (consigner) to give notice of intention to ship dangerous goods, and provides the owner or master of the vessel with the right to refuse to carry, or inspect any package containing dangerous goods.
Specialist radioactive material ship

SF/HLW casks

ILW in special waste and ISO shipping containers

Truck on exclusive use roadway

Interim storage facility

Train on exclusive use track

Low level waste repository

Encapsulation facility, geological disposal facility and intermediate depth repository

Emplacement tunnels

Port

Immediate laydown yard

Truck on exclusive use roadway

Truck on public road

Truck on public road