ENVIRONMENTAL IMPACT ASSESSMENT FOR THE PROPOSED NUCLEAR POWER STATION (‘NUCLEAR 1’) AND ASSOCIATED INFRASTRUCTURE

Management of Radioactive Waste

September 2010

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17 August 2010

DECLARATION OF INDEPENDENCE

I, JJ van Blerk as duly authorised representative of AquiSim Consulting (Pty) Ltd, hereby confirm my independence (as well as that of AquiSim Consulting (Pty) Ltd) as a specialist and declare that neither I nor AquiSim Consulting (Pty) Ltd have any interest, be it business, financial, personal or other, in any proposed activity, application or appeal in respect of which Arcus GIBB was appointed as environmental assessment practitioner in terms of the National Environmental Management Act, 1998 (Act No. 107 of 1998), other than fair remuneration for worked performed, specifically in connection with the Environmental Impact Assessment for the proposed conventional nuclear power station ('Nuclear 1'). I further declare that I am confident in the results of the studies undertaken and conclusions drawn as a result of it – as is described in my attached report.

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EXECUTIVE SUMMARY

The Environmental Impact Assessment (EIA) process for the proposed Nuclear-1 Nuclear Power Station can be separated into a Scoping Phase and an Impact Assessment Phase. During the Scoping Phase, several issues were identified for consideration in the Impact Assessment Phase.

The purpose of the this study is to address those issues identified during the Scoping Phase related to the management of the radioactive waste that will be generated during the operation and decommissioning of the Nucllear-1 Nuclear Power Station. The Terms of Reference for the study requires a description of the following:

- The sources, quantities, and level of radioactivity of all radiological waste (liquid, gaseous, and solid) estimated to be generated by the proposed Nuclear-1 Nuclear Power Station.
- The manner in which all the radiological waste is likely to be managed for the Nucllear-1 Nuclear Power Station based on the cradle to grave principle.
- How radiological waste may be processed and the potential for processing of radiological waste generated by the Nucllear-1 Nuclear Power Station.
- An estimate of the amount of low and intermediate level radioactive waste likely to be generated by the Nucllear-1 Nuclear Power Station and the source (clothing etc.) of this waste.
- The manner in which low and intermediate level radiological waste is currently transported to Vaalputs from the Koeberg Nuclear Power Station site.
- The manner in which low and intermediate level radiological waste (LILW) from the Nuclear-1 Nuclear Power Station is intended to be transported to Vaalputs.
- The available capacity for LILW disposal at Vaalputs.
- The manner in which LILW is disposed of at Vaalputs.
- International trends and policies with respect to the disposal of high-level radioactive waste (HLW);
- The South African policy and strategy on HLW and how this policy compares with international policies.
- The manner in which HLW is managed at the existing Koeberg Nuclear Power Station site. and
- The proposed manner in which HLW from the Nuclear-1 Nuclear Power Station will be managed on-site.

To realise the objectives of the study and to fulfil the Terms of Reference, the report is structured as follows:

- Section 2 presents an overview of the nuclear regulatory framework governing the management of radioactive waste in South Africa, as defined by the National Policy and Strategy for Radioactive Waste Management, as well as an overview of the applicable regulations regarding safety standards and regulatory practices.
- Section 3 presents the elements of a Radioactive Waste Management Programme, as a framework for the management of radioactive waste generated at a typical nuclear power station. The discussion is generic and largely based on IAEA guidelines presented in IAEA (2002b).
- Section 4 presents an overview of the characteristics of the radioactive waste expected to be generated by a typical third generation pressurised water nuclear power station. The discussion is divided into gaseous radioactive

waste, liquid radioactive waste, solid radioactive waste. The discussion covers the source (origin) of radioactive waste, quantity (volume) of waste, and level of radioactivity associated with the waste type, as far as possible.
- Section 5 provides an overview of the radioactive waste management practices envisaged being part of the Radioactive Waste Management Programme for the Nuclear-1 Nuclear Power Station, from generation to disposal. The discussion includes the management of gaseous waste and liquid waste at the proposed Nuclear-1 Nuclear Power Station, as well as an overview of the management practices (e.g. storage and disposal) envisaged for LILW and HLW. Where applicable, the discussion includes the processing (pre-treatment, treatment, or conditioning) of radioactive waste.
- Section 1 provides the international basis for the management of HLW. This overview serves then as basis to compare South Africa's Radioactive Waste Management Policy and Strategy, with international trends and policies. The discussion includes an overview of the applicable articles contained in the Joint Convention on the Safety of Spent Fuel Management and the Safety of Radioactive Waste Management (IAEA, 2006a), and some basic concepts for HLW management from the international literature.
- Section 7 provides an overview of the manner in which nuclear fuel is currently transported to the Koeberg Nuclear Power Station, and the manner in which nuclear fuel is likely to be transported to the proposed Nuclear-1 Nuclear Power Station.
- Section 8 presents the identification and evaluation all the significant environmental impacts that may arise as a result of the radioactive waste and spent nuclear fuel generated by the proposed Nuclear-1 Nuclear Power Station.
- Section 9 summarises the main conclusions of the report.

The main conclusions drawn from the study are:

- The Nuclear-1 Nuclear Power Station generates liquid, gaseous and solid radioactive waste as by-products of operational conditions and decommissioning activities. The solid radioactive waste is divided further into compactable waste, non-compactable waste, abnormal waste and spent fuel. Waste other than radiological waste that will be generated can be divided into conventional and hazardous waste.
- Radioactive waste management practices envisaged for the Nuclear-1 Nuclear Power Station are consistent with the IAEA guidelines for a Radioactive Waste Management Programme for nuclear power stations, from generation to disposal.
- The Nuclear-1 Nuclear Power Station strives to minimise production of all solid, liquid and gaseous radioactive waste, both in terms of volume and activity content, as required for new reactor designs. This is being done through appropriate processing, conditioning, handling and storage systems. In addition, production of radioactive waste is minimised by applying good practices for radiological zoning, provision of active drainage and ventilation, appropriate finishes and the use of current best practices for the handling of solid radioactive waste. Where possible, the Nuclear-1 Nuclear Power Station reuses or recycles materials.
- Processing of gaseous and liquid waste is aimed at reducing activity levels in the reactor building and in effluent generated as part of operational conditions. It also ensures that radiation doses to members of the public due to discharges to the environment (i.e., controlled discharges) do not exceed a fraction of the dose limit for the public (dose constraint). For this purpose,

Authorised Discharge Quantities (AADQ) is defined for these waste steams. Compliance monitoring will be done at the source and in the environment. Processing of solid waste is aimed at reducing the volume of waste (e.g., compaction), containing dispersible activity (e.g. immobilisation), or reducing the activity of abnormal waste (e.g. decontamination). The proposed processing and conditioning of solid waste are conducive to safe storage and consistent with the Vaalputs waste acceptance criteria.

- Systems are designed store processed solid radioactive waste for a period of up to three years within the facility. The storage containers are consistent with the requirements for the disposal of solid waste at the radioactive waste disposal facility at Vaalputs. The waste unsuitable for disposal at Vaalputs will be stored on site until a suitable facility is available.
- The transfer and associated transport of the waste to Vaalputs will be done in conjunction with waste shipments from the Koeberg Nuclear Power Station. This will be done according to the appropriate provisions of the IAEA Regulations for the Safe Transport of Radioactive Material, subject to a graded approach. The objective of the Regulations is to protect persons, property, and the environment from the effects of radiation during the transport of radioactive material. In terms of the Regulations, the transport process is subject to radiation protection, emergency response, quality assurance, and compliance assurance programmes.
- The concept for the disposal of solid waste at Vaalputs consists of near-surface trenches using metal containers for low-level waste and concrete containers for intermediate level waste. The long-term safety of the facility, which complies with international best practices for the disposal of low and intermediate level waste, has been demonstrated for a national inventory of radioactive waste. The inventory derived for this purpose, included waste of the proposed Nuclear-1 Nuclear Power Station. Vaalputs therefore has more than enough capacity to dispose of the solid waste estimated to be generated by the Nuclear-1 Nuclear Power Station.
- The Fuel Handling and Storage System proposed for management and storage of Nuclear-1 Nuclear Power Station spent fuel will have sufficient capacity to safely store all the spent fuel produced throughout the life of the plant and to store the spent fuel for a further 10 years after decommissioning if needed. It is thus only after 70 years that the storage facility on site (or elsewhere) will have to be upgraded to store and manage spent fuel. This should provide sufficient time to define and develop a long-term management strategy for the Nuclear-1 Nuclear Power Station spent fuel, e.g. a central geological disposal facility or an alternative.
- While reprocessing of spent fuel is not excluded as an option for spent fuel management, there is no intention to reprocess the Nuclear-1 Nuclear Power Station spent fuel at present. The main reason being the very high cost associated with spent fuel reprocessing.
- International trends and policies with respect to spent fuel and high-level waste management is based on the provisions of the Joint Convention on the Safety of Spent Fuel Management and the Safety of Radioactive Waste Management. Internationally, this waste is currently being stored (usually above ground), awaiting the development of geological repositories. While the arrangements for storage have proved to be satisfactory and have been operated without problems, it is generally agreed that these arrangements are interim and do not represent a final solution.
- The two basic challenges in perfecting a system of radioactive waste isolation is choosing an appropriate geological barrier (host medium) and designing an effective engineered barrier. Underground research laboratories made a very

positive contribution to waste isolation research, while public acceptance of radioactive waste isolation projects remains one of the major challenges.

- The National Radioactive Waste Management Policy and Strategy is consistent with international practice for the management of HLW. However, additional, more detailed regulations are needed on specific issues relevant to long-term management and geological disposal of HLW. A summary of internationally accepted requirements for geological disposal have recently been established (IAEA, 2006d). These requirements should be supplemented from the experiences of several national programs that are within a decade of operating a geological repository for HLW and spent fuel, notably Finland, Sweden, and the USA.
- The potential environmental impacts identified and assessed include all potential types of radioactive wastes expected to be generated by the proposed Nuclear-1 Nuclear Power Station. The assessment results indicate that with the implementation of appropriate mitigation measures all potential impacts are low.

CONTENTS

LIST OF ABBREVIATIONS

EIA	Environmental Impact Assessment
DEA	Department of Environmental Affairs (currently known as the Department of Water and Environmental Affairs)
IAEA	International Atomic Energy Agency
NNR	National Nuclear Regulator
SAR	Safety Analysis Report
DME	Department of Minerals and Energy (currently known as the Department of Mineral Resources)
Koeberg Nuclear Power Station	Koeberg Nuclear Power Station
NECSA	South African Nuclear Energy Corporation
BATNEEC	Best Available Technology Not Entailing Excessive Cost
NCRWM	National Commission on Radioactive Waste Management
RWMF	Radioactive Waste Management Fund
RWMP	Radioactive Waste Management Programme
SSC	Structures, Systems, Components
LILW-SL	Low and Intermediate Level Radioactive Waste – Short Lived
LILW-LL	Low and Intermediate Level Radioactive Waste – Long Lived
HVAC	Heat Ventilation and Air Conditioning
HLW	High Level Waste
RCCA	Rod Control Cluster Assemblies
WHS	Waste Handling System
NILS	Nuclear Installation License
FTP	Framework Transportation Plan
TE	Technology Envelope
ALARA	As Low As Reasonably Achievable
AADQ	Annual Authorised Discharge Quantity
LWS	Liquid Waste System
PBMR	Pebble Bed Modular Reactor
PCRSA	Post-closure Radiological Safety Assessment
ACR	Authorisation Change Request
SAPS	South African Police Service
NIA	National Intelligence Agency

1 INTRODUCTION

1.1 Background

The Eskom Conversion Act, 2001 (Act No. 13 of 2001) established Eskom Holdings Limited (Eskom) as a State Owned Enterprise, with the Government of South Africa as the only shareholder, represented by the Minister of Public Enterprises. According to the Memorandum of Association required by the Eskom Conversion Act and the Companies Act, 1973 (Act No. 61 of 1973), Eskom's main objective is to:

"provide energy and related services including the generation, transmission, distribution and supply of electricity and to hold interests in other entities."

In accordance with this mandate, Eskom proposes the Nuclear-1 project. This project involves construction, commissioning, operation and decommissioning of a conventional Nuclear Power Station, at one of three candidate sites on the South African coast. The proposed Nuclear-1 Nuclear Power Station will consist of a combination of units with a total capacity of 4,000 MW and makes provision for the potential future expansion of the power station to allow for a total capacity of approximately 10,000 MW (Arcus Gibb, 2010).

The establishment of an Nuclear Power Station includes a number of activities, which require authorisation in terms of the Environmental Impact Assessment (EIA) Regulations promulgated under the National Environmental Management Act (No. 107 of 1998), as amended. The EIA process is administrated by the Department of Environmental Affairs (DEA) and can be separated into two phases namely the Scoping Phase and the Impact Assessment Phase. In July 2008, the original Plan of Study, together with the Final Scoping Report for the Nuclear-1 EIA, was submitted to the DEA (then the Department of Environmental Affairs and Tourism) for review and approval. In a letter dated 19 November 2008, the Department approved the Final Scoping Report in accordance with EIA Regulations.

During the Scoping Phase for the Nuclear-1 project, several issues were identified for consideration in the Impact Assessment Phase. Some of those issues are related to the management of radioactive waste that will be generated during the operation and decommissioning of the Nuclear Power Station. The International Atomic Energy Agency (IAEA) fundamental safety principles (IAEA, 2006c) states that the prime responsibility for safety rests with the person or organisation responsible for facilities and activities that give rise to radiation risks (Principle 1). This responsibility includes (IAEA, 2006c):

- Ensuring the safe control of all radioactive material that is used, produced, stored or transported; and
- Ensuring the safe control of all radioactive waste that is generated.

In South Africa, activities that involve nuclear energy and radioactive waste are regulated under the Nuclear Energy Act (Act No. 46 of 1999) and the National Nuclear Regulator Act (Act No. 47 of 1999). The National Nuclear Regulator Act (1999) established the National Nuclear Regulator (NNR) as the statutory body responsible for enforcing regulatory control over nuclear facilities and the management of radioactive waste.

The NNR is the lead authority with regard to the governance of radioactive waste. Accordingly, a cooperative agreement was established between DEA and the NNR, in which it was agreed that the NNR will be the responsible authority regarding the assessment of all matters relating to impacts of ionising radiation. Reference is made to a document titled *'Notification of statement issued by the Department of Environmental Affairs and Tourism regarding the consideration of matters pertaining to nuclear safety in environmental impact assessment processes on nuclear installations'*, dated 10 February 2009. The document serves to communicate consensus reached between the DEA and the NNR in terms of management of issues relating to radiological matters. One of the main purposes of the engagement between DEA and the NNR was to *'prevent unnecessary and unavoidable duplication of effort'*.

According to Section 21(1) of the National Nuclear Regulator Act (1999), Eskom is required to request nuclear authorisation in the form of a nuclear installation license from the NNR to site, construct, operate, decontaminate, or decommission the Nuclear-1 Nuclear Power Station. Eskom should submit or make available to the NNR, in accordance with agreed timescales, all information that is specified or requested.

According to the IAEA (2004), safety related information should be presented in the form of a safety analysis report (SAR). The SAR should contain accurate and sufficiently precise information that the NNR will be able to independently evaluate the issues of nuclear and radiation safety related to the siting, design, construction, operation and decommissioning of nuclear installations. This information should include, amongst others (IAEA, 2004):

- A justification of the adequacy of the measures proposed for the safe management of radioactive waste of all types that is generated throughout the lifetime of the plant;
- Measures to control or contain the waste produced at all stages of the lifetime of the plant;
- Measures to safely handle waste of all types produced during all stages of the lifetime of the plant, including provisions for the safe handling of the generated waste while transporting it from the point of origin to the specified storage point;
- Measures to minimise the accumulation of waste produced at all stages of the lifetime of the plant, including measures taken to reduce the waste arising to a level that is as low as practicable;
- Measures to condition[1] the waste produced at all stages of the lifetime of the plant;
- Measures to store the waste produced at all stages of the lifetime of the plant, including the quantities, types and volumes of radioactive waste and the need to categorise and separate waste within the provisions for storage; and
- Measures to safely dispose of the waste produced at all stages of the lifetime of the plant, including the measures for ensuring the safe transport of waste to another specified location for longer term storage, if necessary.

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[1] Those operations that produce a waste package suitable for handling, transport, storage and/or disposal. Conditioning may include the conversion of the waste to a solid waste form, enclosure of the waste in containers and, if necessary, provision of an overpack IAEA (2007b), IAEA Safety Glossary. Terminology Used in Nuclear Safety and Radiation Protection, *2007 Edition*, International Atomic Energy Agency, Vienna..

1.2 Purpose of the Study

The purpose of this study is to address the radioactive waste management issues identified through the Nuclear Nuclear-1 EIA process in a manner that will satisfy the requirements of the NNR.

As agreed between the DEA and NNR, nuclear safety and issues relating to radioactivity are better placed within the regulatory process of the National Nuclear Regulator Act (1999). The intention is not to produce a comprehensive safety analysis report but to present an assessment of the waste management issues in an objective manner that is consistent with the requirements of the SAR process in order to facilitate regulatory approval and assure stakeholders of the adequate safety of the waste management procedures.

1.3 Location of the Proposed Nuclear-1 Project.

Three candidate sites on the South African coast have been identified for location of the proposed Nuclear-1 project. These include:

The Duynefontein site, located adjacent to the existing Koeberg Nuclear Power Station (Koeberg Nuclear Power Station) located within the Eskom Controlled Area on the farm Duynefontein. The Duynefontein site is approximately 2 km from the Duynefontein residential area, 30 km north of Cape Town and 10 km south of Atlantis, within the City of Cape Town Metropolitan Municipality jurisdiction (see **Error! Reference source not found.**)

The Bantamsklip site, located on the South Cape Coast in the area between Danger Point and Quoin Point, is approximately 30 km south east of Gansbaai. The Nuclear-1 Nuclear Power Station is proposed to be sited adjacent to the Agulhas National Park conservation area approximately 14 km from the Pearly Beach residential area (see Figure 1.2).

The Thyspunt site is located in the Eastern Cape Province of South Africa approximately 85 km south west of Port Elizabeth. The proposed site is in the vicinity of several coastal tows popular with tourists to the area. The towns include; Oyster Bay, (2 km from the site), Jeffrey's Bay (25 km from the site), St Francis Bay and Cape St Francis (both 10 km from the site). The proposed site is surrounded by agricultural land serviced by the town of Humansdorp, approximately 20 km north of the site (see Figure 1.3).

The Nuclear-1 Nuclear Power Station and associated buildings would require approximately 280 ha of land, depending on the terrain of the specific site (Arcus Gibb, 2010). In addition to the actual footprint of the power station, there will be two categories of exclusion zones around the power station complex. The purpose of these exclusion zones will be for emergency planning purposes. Guidance regarding the size of the exclusion zone required will be provided by the NNR, as per the National Nuclear Regulator Act, (1999).

Figure 1.1: Proposed location of the Nuclear-1 Duynefontein Site.

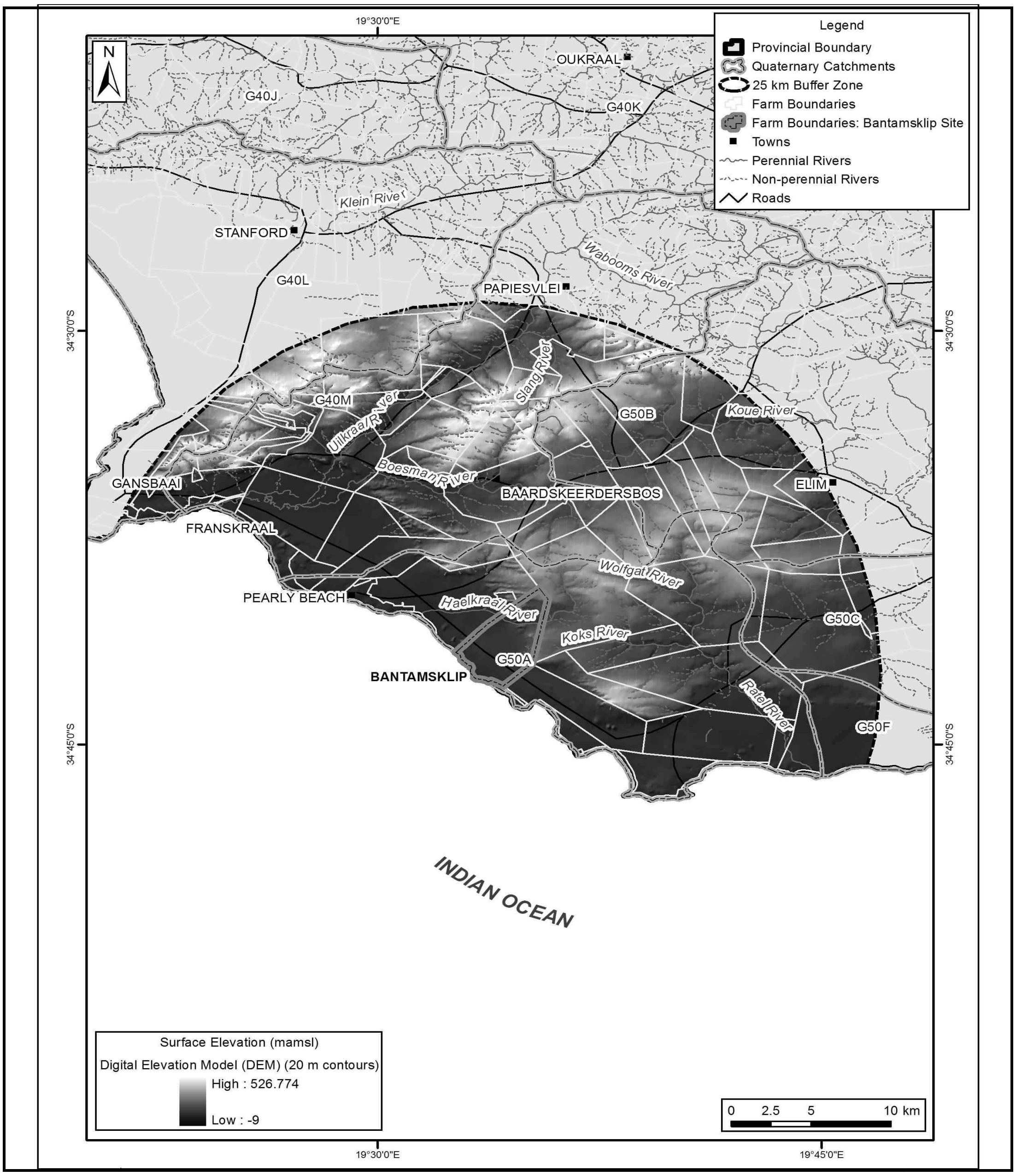

Figure 1.2: Proposed location of the Nuclear-1 Bantamsklip Site. (Obtained from, Proposed Nuclear Power Station EIA & EMP, Groundwater Assessment, Compiled by SRK Consulting, 2007).

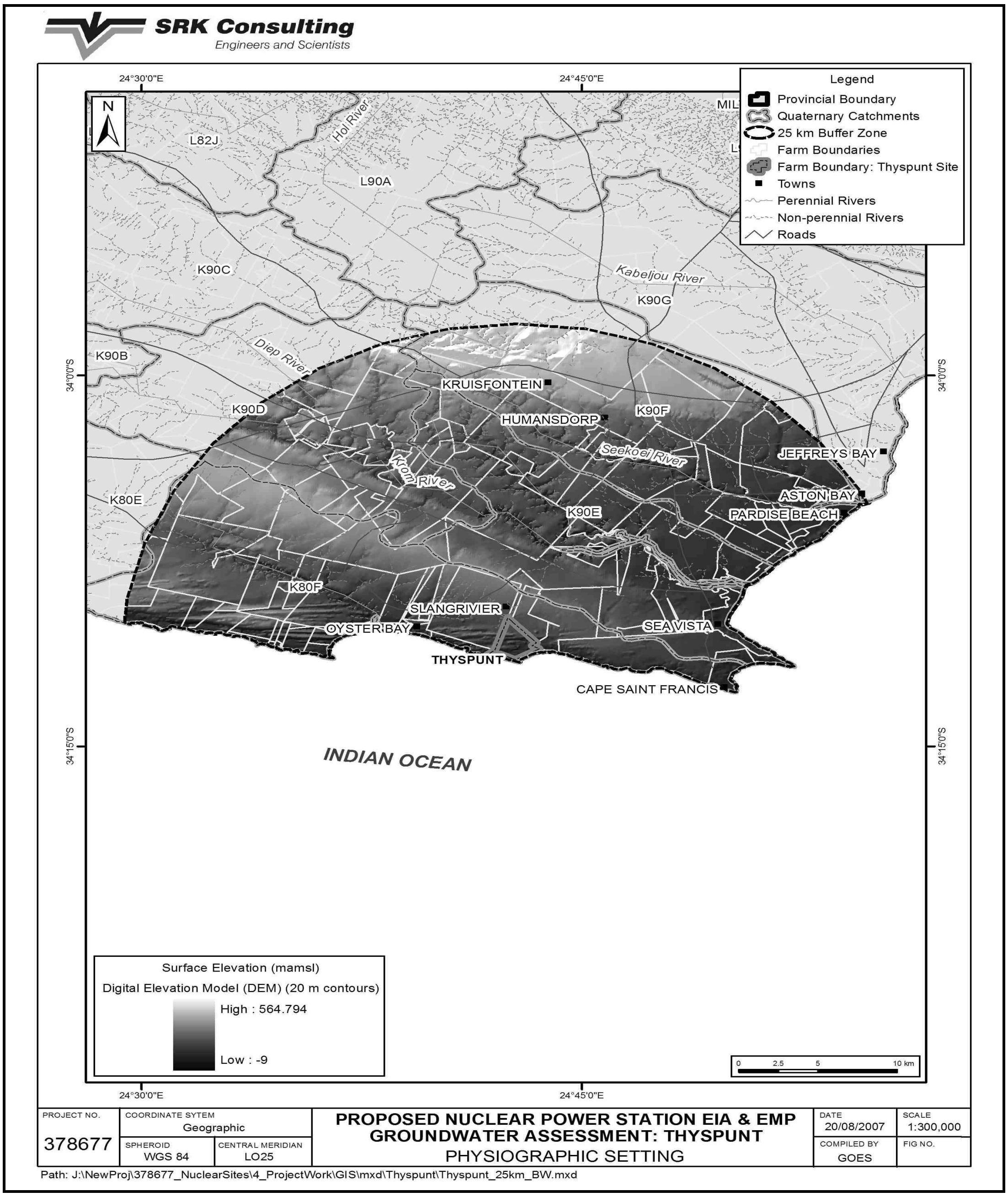

Figure 1.3: **Proposed location of the Nuclear-1 Thyspunt Site. (Obtained from, Proposed Nuclear Power Station EIA & EMP, Groundwater Assessment, Compiled by SRK Consulting, 2007).**

1.4 Terms of Reference of the Study

While some of the information presented in this report may meet the requirements for nuclear authorisation in terms of the National Nuclear Regulator Act (1999), it is not the intention of the report to meet these requirements. In addition, some of the information presented in this report may be similar to those required as part of the SAR. However, this specialist study is being conducted as part of the EIA for the

Nuclear-1 Nuclear Power Station and not to fulfil the requirements of the SAR. In accordance with the precautionary principle and in the absence of actual data, estimates of the quantities of effluent generated has been based on the emission limits as published in Regulation R.388 promulgated in terms of the National Nuclear Regulator Act (1999).

Radioactive waste management is a broad term related to all administrative and operational activities involved in the handling, pre-treatment, treatment, conditioning (processing), storage and disposal of radioactive waste (IAEA, 2007b). This report will not address all these activities for the Nuclear-1 project in detail. Instead, the scope of the report is limited to specific radioactive waste management issues identified during the Scoping Phase for the Nuclear-1 project and which are of relevance to the EIA.

The nature of the radioactive waste management practices to be employed is directly related to the characteristics of the waste to be managed. The report consequently provides a description of the sources, quantities and level of radioactivity of all radiological waste (liquid, gaseous and solid) to be generated by the Nuclear-1 Nuclear Power Station. While the focus of the report is on radioactive waste, the description includes what is termed conventional and mixed waste, where applicable.

According to the National Radioactive Waste Management Policy and Strategy (DME, 2005), the Vaalputs site, located in the Northern Cape Province of South Africa is and will continue to be used as the National Disposal Site for low and intermediate level waste (LILW). The bulk of the LILW currently disposed of at Vaalputs, originates from the Koeberg Nuclear Power Station. The report presented here for the Nuclear-1 project will include:

- An estimate of the amount and the source (clothing etc.) of low and intermediate level radioactive waste likely to be generated by the Nuclear-1 Nuclear Power Station;
- A description of the manner in which low and intermediate level radiological waste is currently transported to Vaalputs from the Koeberg Nuclear Power Station site;
- A description of the manner in which low and intermediate level radiological waste from the Nuclear-1 Nuclear Power Station is intended to be transported to Vaalputs;
- A description of the available capacity for low and intermediate level radiological waste disposal at Vaalputs; and
- A description of the manner in which low and intermediate radiological waste is disposed of at Vaalputs.

The feasibility of safely storing all radioactive waste (including high-level waste) over periods of decades has been clearly demonstrated during the operation of existing facilities (IAEA, 2003d) and are applied equally successfully in South Africa.

According to DME (2005), the disposal of radioactive waste is regarded as the ultimate step in the national radioactive waste management strategic framework, although a step-wise waste management approach is acceptable. The disposal of high-level waste, however, presents a major challenge nationally and internationally. The report consequently includes:

- a description of international trends and policies with respect to the disposal of high-level radioactive waste;

- a description of the South African policy and strategy on high-level radioactive waste and how this policy compares with international policies;
- a description of the manner in which high-level radiological waste is managed at the existing Koeberg Nuclear Power Station site; and
- a description of the proposed manner in which high-level radioactive waste from the Nuclear-1 Nuclear Power Station will be managed on-site.

In terms of national legislation, the transport of nuclear fuel is subject to the IAEA Regulations for The Safe Transport of Radioactive Material (IAEA, 2005). The report includes a description of:

- the manner in which nuclear fuel is currently transported to the Koeberg Nuclear Power Station site; and
- the manner in which nuclear fuel is likely to be transported from the fuel manufacturing plant in Europe to the proposed Nuclear-1 Nuclear Power Station site.

1.5 Structure of the Report

To realise the objectives of the study and to fulfil the terms of reference as outlined in Section 1.4, the report is structured as follows:

- Section 2 presents an overview of the nuclear regulatory framework governing the management of radioactive waste in South Africa, as defined by the National Radioactive Waste Management Policy and Strategy (DME, 2005) and the applicable regulations regarding safety standards and regulatory practices.
- Section 3 presents a theoretical overview of the content of a typical Radioactive Waste Management Programme for a nuclear power plant.
- Section 4 presents an overview of the characteristics of the gaseous, liquid, solid and other radioactive waste that will be generated by the Nuclear-1 Nuclear Power Station.
- Section 5 provides an overview of the radioactive waste management practices envisaged to be part of the radioactive waste management programme for the Nuclear-1 Nuclear Power Station, from generation to disposal.
- Section 6 provides the international basis for the management of high-level waste. This summary then serves as the basis of comparison between South Africa's Radioactive Waste Management Policy and Strategy and international trends and policies.
- Section 7 provides an overview of the manner in which nuclear fuel is currently transported to the Koeberg Nuclear Power Station and the manner in which nuclear fuel is likely to be transported to the proposed Nuclear-1 Nuclear Power Station.
- Section 8 presents the impact assessment.
- Section 9 presents the main conclusions of the study.

2 Regulatory Framework for the Management of Radioactive Waste

2.1 General

The NNR regulates all nuclear activities and the management of radioactive waste in terms of its mandate set forth in the National Nuclear Regulator Act (1999). In 2006, new regulations regarding safety standards and regulatory practices were gazetted (Government Notice No. R.388 of 2006). The main purpose of these regulations is to protect persons, property and the environment against nuclear damage.

In terms of the Nuclear Energy Act (1999) the authority over radioactive waste and irradiated fuel waste is the Minister of Energy. In 2005, the then Department of Minerals and Energy (split into the Department of Mineral Resources and the Department of Energy) published the National Radioactive Waste Management Policy and Strategy (DME, 2005). The purpose of the policy and strategy document is:

"To ensure the establishment of a comprehensive radioactive waste governance framework by formulating, additional to nuclear and other applicable legislation, a policy and implementation strategy in consultation with all stakeholders."

The principles for the management of radioactive waste in South Africa are also contained in the National Radioactive Waste Management Policy and Strategy (DME, 2005).

The purpose of this section is to provide an overview of the nuclear regulatory framework governing the management of radioactive waste in South Africa, as defined by the National Radioactive Waste Management Policy and Strategy (Section 2.2) and the regulations regarding safety standards and regulatory practices (Section 2.3).

2.2 National Radioactive Waste Management Policy and Strategy

2.2.1 General

The emphasis of the policy and strategy document is on the nuclear industry (DME, 2005), within which the management of radioactive waste is a national responsibility assigned to the Minister Energy as per the Nuclear Energy Act (1999).

Other drivers for the management of radioactive waste are the Constitution of South Africa, the National Environmental Management Act (1998) and the National Nuclear Regulator Act (1999). The scope of the policy and strategy document relates to all radioactive wastes, excluding operational radioactive liquid and gaseous effluent (waste discharges) that is permitted to be released to the environment routinely under the authority of the relevant regulators. The policy and strategy thus serves as a national commitment to address solid radioactive waste management in a coordinated and cooperative manner (DME, 2005).

2.2.2 International Radioactive Waste Management Policy Principles

The international community, through the IAEA, has developed a comprehensive set of principles for the safe management of radioactive waste (IAEA, 1995). These basic principles, summarised in Table 2.1, are applicable to all countries and can be applied to all types of radioactive waste, regardless of its physical and chemical characteristics or origin[2].

Table 2.1: Summary of the IAEA radioactive waste management principles (IAEA, 1995).

Principle	Description
Protection of Human Health	Radioactive waste shall be managed in such a way as to secure an acceptable level of protection for human health
Protection of the Environment	Radioactive waste shall be managed in such a way as to provide an acceptable level of protection of the environment
Protection Beyond National Borders	Radioactive waste shall be managed in such a way as to assure that possible effects on human health and the environment beyond national borders will be taken into account
Protection of Future Generations	Radioactive waste shall be managed in such a way that predicted impacts on the health of future generations will not be greater than relevant levels of impact that are acceptable today
Burden on Future Generations	Radioactive waste shall be managed in such a way that will not impose undue burdens on future generations
National Legal Framework	Radioactive waste shall be managed within an appropriate national legal framework, including clear allocation of responsibilities and provision for independent regulatory functions
Control of Radioactive Waste Generation	Generation of radioactive waste shall be kept to the minimum practicable
Radioactive Waste Generation and Management Interdependencies	Interdependencies among all steps in radioactive waste generation and management shall be appropriately taken into account
Safety of Facilities	The safety of facilities for radioactive waste management shall be appropriately assured during their lifetime

2.2.3 National Radioactive Waste Management Policy Principles

All radioactive waste management activities in South Africa should be managed in accordance with the set of national principles summarised in Table 2.2.

2.2.4 Responsibilities

The prime responsibility for safety, including the safety of radioactive waste management, rests with the person or organisation responsible for facilities and activities that give rise to the radiation risks.

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[2] In 2006, the IAEA Fundamentals Safety Principles were published IAEA (2006c), Fundamental Safety Principles, *Safety Fundamentals No. SF-1*, International Atomic Energy Agency, Vienna., combining three safety fundamental publications, including the publication on the safety of radioactive waste management from which these principles were drawn. A summary of the IAEA Fundamentals Safety Principles is presented in Section 6.3.

Table 2.2: Summary of the national principles for the management of radioactive waste in South Africa (DME, 2005).

Principle	Description
Polluter pays principle	The financial burden for the management of radioactive waste shall be borne by the generator of that waste
Transparency regarding all aspects of radioactive waste management	All radioactive waste management activities shall be conducted in an open and transparent manner and the public shall have access to information regarding waste management where this does not infringe on the security of radioactive material
Sound decision-making based on scientific information, risk analysis and optimisation of resources	Decision-making shall be based on proven scientific information and recommendation of competent national and international institutions dealing with radioactive waste management
Precautionary principle	Where there are threats of serious irreversible damage, lack of full scientific certainty shall not be used as a reason for postponing cost-effective measures to prevent environmental degradation
No import nor export of radioactive waste	In principle South Africa will neither import nor export radioactive waste
Co-operative governance and efficient national co-ordination	Due to their crosscutting nature all activities involving radioactive waste management shall be managed in a manner that prevents duplication of effort and maximises coordination
International cooperation	The government recognises that it shares a responsibility with other countries for global and regional radioactive waste management issues. Its actions shall follow the principles in this policy and in relevant regional and international agreements
Public participation	Radioactive waste management shall take into account the interests and concerns of all interested and affected parties, when decisions are being made
Capacity building and education	The government shall create opportunities to develop people's understanding, skills and general capacity concerning radioactive waste management

The role of government is to establish and sustain an effective legal and governmental framework for safety, including an independent regulatory body (IAEA, 2006c). Consistent with these principles, the policy and strategy defines the responsibilities of government and regulatory bodies in terms of national legislation. The responsibilities of the generators of radioactive waste, or operators of radioactive waste disposal facilities, are of particular interest and include:

- the technical, financial and administrative management of such wastes within the national regulatory framework and within any applicable co-operative governance arrangements;

- development and ongoing review of site / industry specific waste management plans which are to be based on the national radioactive waste management policy & strategy;
- execution of waste management plans by the establishment of appropriate waste management facilities and processes and the development of site / industry specific waste management systems; and
- site / industry waste management in accordance with waste management systems to reflect sustainable development and principles such as continued improvement and Best Available Technology Not Entailing Excessive Cost (BATNEEC) and other elements of the national strategy.

The responsibility of the generators of radioactive waste, or operators of radioactive waste disposal facilities, as the case may be, will be terminated upon closure of the disposal facility, at which time institutional control (where required) will commence.

2.2.5 Definition and Classification of Radioactive Waste

For the purposes of implementing the National Radioactive Waste Management Policy and Strategy, South Africa follows the IAEA guidelines regarding the definition and classification of radioactive waste (unless deviations there from can be justified). A summary of the waste classification scheme adopted for this purpose is presented in Appendix A[3].

2.2.6 Radioactive Waste Management Strategy Principles

This section of the National Radioactive Waste Management Policy and Strategy sets forward specific principles as strategic points of reference for the implementation of a radioactive waste management strategy. Some principles are general, such as the principle of reasonable consensus (for a course of action), or the principles for the development of a new course of action.

Others are more specific to waste management strategies and related to issues such as passive safety, regulatory requirements, hierarchy of waste management options, institutional control, retrievability, transfer of waste and the dilution of waste.

2.2.7 Management Structures for Radioactive Waste

In terms of the National Radioactive Waste Management Policy and Strategy, the South African Government has the responsibility to establish appropriate structures for the management of radioactive waste at a national level. For this purpose, two entities will be established:

- the National Committee on Radioactive Waste Management (NCRWM), which will oversee the implementation of the policy and strategy; and
- the National Radioactive Waste Management Agency (NRWMA)[4], which will be responsible for the national management of all radioactive waste disposal.

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[3] Note that the IAEA is in the process of revising the radioactive waste classification scheme (Draft IAEA Safety Guide 390), which includes six classes of waste. As a Member State, South Africa is in the process of reviewing the scheme.

[4] Note that in January 2009, the National Radioactive waste Disposal Institute Act (Act 53 of 2008) was promulgated, according to which the National Radioactive Waste Management Agency is replaced by the National Radioactive Waste Management Institute.

The national process for implementing the radioactive waste management strategy will be coordinated by the NCRWM. For this purpose, appropriate waste management plans will have to be developed and submitted to the NCRWM for approval.

2.2.8 Financial Provision for Radioactive Waste Management

According to the policy and strategy, government will establish a Radioactive Waste Management Fund (RWMF) by statute. The purpose of the fund shall be to ensure that there are sufficient provisions for the long-term management options of the various waste forms. These shall include:

- fees for disposal activities;
- research and development activities including investigations into waste management/disposal options;
- capacity building initiatives for radioactive waste management/disposal; and
- fees for other activities related to radioactive waste management/disposal.

In keeping with the polluter pays principle, the contributions to the fund will be from the generators of radioactive waste. Generators should enter into an agreement with the RWMF for managing long-term provisions for institutional control measures.

2.2.9 National Radioactive Waste Management Model

The national radioactive waste management model recognises all steps in the radioactive waste management process, from waste generation to the main waste management end-points and institutional control. The following steps, in particular, are addressed:

- radioactive waste generation;
- pre-disposal management of radioactive waste;
- radioactive waste management options; and
- radioactive waste management end-points.

The main radioactive waste management endpoints correspond with the waste management options and may be regarded as the outcome of a specific waste management option. Regulated disposal requires continued regulation of the disposal site for a predetermined period where after the site should be placed under institutional control[5].

2.2.10 Long-Term Radioactive Waste Management Issues

There are two long-term radioactive waste management options employed in South Africa at present:

- above ground disposal in engineered facilities for the bulk of the mining waste; and
- near surface disposal for low and intermediate level radioactive waste at Vaalputs in the Northern Cape province of South Africa.

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[5] *Control of a waste site (for example, disposal site) by an authority or institution designated under the laws of a country or state. This control may be active (monitoring, surveillance, remedial work) or passive (land use control) and may be a factor in the design of a nuclear facility (for example, near surface disposal facility).*

According to the National Radioactive Waste Management Policy and Strategy, Vaalputs will continue to be used as a National Disposal Site for the disposal of low and intermediate level radioactive waste.

Spent fuel is currently managed through two mechanisms in South Africa: dry and wet storage. Spent fuel from the Koeberg Nuclear Power Station is stored in authorised fuel pools at the Koeberg Nuclear Power Station site, as well as in casks designed and constructed for the storage of spent fuel. There is enough storage capacity at the Koeberg site for the current operational lifetime of the Koeberg Nuclear Power Station (DME, 2005). Spent fuel from the SAFARI research reactor at Pelindaba is stored at an authorised dry storage facility as well as in the reactor pool on the Pelindaba site, which is the headquarters of the South African Nuclear Energy Corporation (Necsa).

According to the National Radioactive Waste Management Policy and Strategy, the Government should initiate investigations into the best long-term option for the management of spent fuel. In the interim, spent fuel is and should continue to be, stored in authorised facilities within the generator's sites.

The National Radioactive Waste Management Policy and Strategy recognises that the storage of spent fuel on these sites is finite and not sustainable indefinitely. Government should thus ensure that investigations are conducted within set timeframes to consider the various options for safe management of spent fuel and high-level radioactive waste in South Africa. Included in the options for investigation should be the following:

- *Long-term above ground storage at an off-site facility*. This is a consideration although it may not be in line with some of the principles for radioactive waste management. The strength of this option is that if technologies that are more appropriate are developed in future, then the waste can be dealt with using those technologies. Storing above ground indefinitely may, however, result in an undue burden on future generations.
- *Reprocessing, conditioning and recycling*. An investigation commissioned by the DME has concluded that it would not be advisable to exclude the reprocessing, conditioning and recycling as an options for safe management of spent fuel (DME, 2005). Although this option is sometimes associated with proliferation concerns South Africa has concluded the IAEA Safeguards Agreements and the Additional Protocol thus should not be an issue for South Africa.
- *Geological disposal*. Internationally, geological disposal is currently the most pursued option and as such will require careful consideration. This option has been under investigation outside of South Africa for the best part of a decade and as such investigations in South Africa should commence as soon as possible. If chosen as a preferred option in South Africa, geological disposal of radioactive waste should take place with an option for retrieving the waste. (The reason for this is to not rule out the possibility of the use of future technology for better management options).
- *Transmutation*. A fourth option (Transmutation) has been - and continues to be - investigated in a number of countries. However, it has not been proven to be a workable solution and also requires major investment in technology. The Government will continue to monitor developments internationally, but this option will probably not be investigated in South Africa in the near future.

The National Radioactive Waste Management Policy and Strategy indicates that the choice of the most suitable option should take due cognisance of the policy principles and should clearly demonstrate how the option satisfies the national policy objectives.

In response to that, the National Radioactive Waste Disposal Institute Act, (Act No. 53 of 2008) was promulgated in January 2009 and came into effect in December 2009. The purpose of this Act is to ensure that the capability and capacity of the institutions to manage radiological waste is addressed. This Act provides for the establishment of a National Radioactive Waste Disposal Institute in order to manage radioactive waste on a national basis (a function historically performed by Necsa). Although the Act has come into effect, it will still be some time before the Agency is formally constituted.

At present, South Africa does not have an authorised facility for the disposal of high level waste. Thus, the only currently feasible alternative is for Eskom to store high level waste in spent fuel pools on the Nuclear-1 nuclear island, as is the case at Koeberg. The proposed Nuclear-1 facility must be designed in such a way that such long-term storage within the nuclear island building is possible.

2.3 Regulations on Safety Standards and Regulatory Practices

2.3.1 General

A nuclear regulatory guidance or requirements document aimed specifically at management of radioactive waste is currently not available in the South African context. The best information available and which the South African industry currently prescribe to, is IAEA requirements and safety guides in the safety standard series related to the pre-disposal management of radioactive waste, storage of radioactive waste, transport of radioactive material and regulatory control of discharge to the environment.

In South Africa, the Regulations on Safety Standards and Regulatory Practices (Government notice No, R.388 dated 28 April 2006) (Hendricks, 2006), however, provide the necessary standards and principles that should be met to ensure safety in any nuclear installation, including the safety of radioactive waste management.

The requirements of the Regulations on Safety Standards and Regulatory Practices (Hendricks, 2006) with respect to radioactive waste management are summarised in Section 2.3.2 to Section 2.3.5 below.

2.3.2 Principal Radiation Protection and Nuclear Safety Requirements

The principal radiation protection and nuclear safety requirements of the regulations apply to actions authorised[6] by, or seeking authorisation in terms of, a nuclear installation license, a nuclear vessel license, or certificate of registration. The application of these requirements should be commensurate with the characteristics of the action and with the magnitude and likelihood of exposure, as determined in a safety assessment. Not all the requirements are relevant to all actions. Requirements contained in the standards are related to:

- dose limits to an individual and risk limits of fatality from actions;
- optimisation of radiation protection and nuclear safety in terms of the ALARA principle;
- measures to control the risk of nuclear damage to individuals must be determined based on a prior safety assessment;
- good engineering practices;

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[6] Authorised action means an action authorised in terms of the National Nuclear Regulator Act, (Act No. 47 of 1999).

- maintaining and fostering a safety culture;
- retrospective application of the regulations;
- regulatory approval of radiation protection and nuclear safety measures;
- accident management and emergency planning, emergency preparedness and emergency response;
- a multilayer (defence in depth) system of provisions for radiation protection and nuclear safety; and
- establishing, implementing and maintaining a quality management programme.

2.3.3 Requirements Applicable to Regulated Actions

These requirements apply to actions authorised by a nuclear installation license, nuclear vessel license, or certificate of registration and include the following:

- conductance, submission and maintaining of operational safety assessments to the regulator;
- controls and limitations on operations, as established in the safety assessments (e.g. radioactive waste acceptance criteria in respect of waste disposal or storage facilities);
- establishing, implementing and maintaining a maintenance and inspection programme;
- competency and qualification of staff responsible for radiation protection and nuclear safety and for maintaining an appropriate safety culture;
- optimisation of radiation protection in terms of the ALARA principle; application of a dose constraint, annual authorised discharge quantities, radiation dose limitation, medical surveillance and health register and a dose register;
- establishing, implementing and maintaining a radioactive waste management programme, including the safe storage of radioactive waste and the removal of radioactive material, radioactively contaminated material or radioactive waste;
- establishing, implementing and maintaining an appropriate environmental monitoring and surveillance programme to verify that the storage, disposal or effluent discharge of radioactive waste complies with the conditions of the nuclear authorisation;
- transport of radioactive material off the site or on any other road accessible to the public in terms of the provisions of the IAEA Regulations for The Safe Transport of Radioactive Material;
- establishing, implementing and maintaining physical security arrangements;
- establishing, implementing and maintaining a system of records specified in the nuclear authorisation;
- monitoring of workers in the workplace; and
- occupational exposure to radon.

2.3.4 Decommissioning

These requirements apply to actions authorised by a nuclear installation license, nuclear vessel license, or certificate of registration, which involves the decommissioning of any nuclear installation, plant, or equipment having an impact on radiation protection and nuclear safety, or the release of radioactively contaminated land for other uses. These include the following:

- development and submission of a decommissioning strategy and plan to the Regulator;
- availability of sufficient resources from the time of cessation of the operation to the termination of the period of responsibility;
- conduct decommissioning operations in compliance with requirements listed in Section 2.3.3;
- release of radioactively contaminated land; and
- obligations under other statutes.

2.3.5 Accidents, Incidents and Emergencies

These requirements are applicable to emergency exposure situations requiring protective action to reduce or avoid temporary exposure and include the following:

- criteria for the definition of a nuclear accident;
- criteria for the definition of a nuclear incident;
- information to be supplied to the Regulator in case of a nuclear accident or incident; and
- emergency or remedial measures to be considered near a nuclear accident.

2.3.6 Physical Security

Physical security arrangements must be established, implemented and maintained in order to demonstrate that all necessary measures are taken to prevent, as far as reasonable, unauthorised access to sites, or diversion, theft, or removal of radioactive material.

3 Radioactive Waste Management Programme

3.1 General

IAEA (2007b) defines radioactive waste as material, whatever its physical form, remaining from practices or interventions for which no further use is foreseen:

- that contains or is contaminated with radioactive substances and has an activity or activity concentration higher than the level of clearance from regulatory requirements; and
- exposure to which is not excluded from the IAEA Basic Safety Standards published in IAEA (1996).

An application for a nuclear installation license requires, amongst others, the development of a Radioactive Waste Management Programme (RWMP). This is consistent with the NNR Guideline for Applying for a Nuclear Authorisation (NNR, 2007).

Some measures pertaining to a RWMP were listed in Section 1.1, including the need to ensure that the resultant radioactive waste meets the requirements for safe handling, transport, processing, storage and disposal, as applicable to national regulations, as well as international requirements and recommendations. More specifically, the RWMP should make provision for (IAEA, 2002b):

- keeping the generation of radioactive waste to the minimum practicable, in terms of both activity and volume, by using suitable technology;
- reusing and recycling materials to the extent possible;
- classifying and segregating waste appropriately and maintaining an accurate inventory for each radioactive waste stream, with account taken of the available options for clearance and disposal;
- collecting, characterising and storing radioactive waste so that it is acceptably safe;
- providing adequate storage capacity for anticipated radioactive waste arisings;
- ensuring that radioactive waste can be retrieved at the end of the storage period;
- treating and conditioning radioactive waste in a way that is consistent with safe storage and disposal;
- handling and transporting radioactive waste safely;
- controlling effluent discharges to the environment;
- carrying out monitoring for compliance at source and in the environment;
- maintaining facilities and equipment for waste collection, processing and storage in order to ensure safe and reliable operation;
- monitoring the status of the containment for the radioactive waste in the storage location;
- monitoring changes in the characteristics of the radioactive waste, in particular if storage is continued for extended periods, by means of inspection and regular analysis;
- initiating, as necessary, research and development to improve existing methods for processing radioactive waste or to develop new methods and to

ensure that suitable methods are available for the retrieval of stored radioactive waste.

While the national nuclear regulatory framework does not provide specific requirements for the management of radioactive waste, from generation to disposal, it does require the establishment, implementation and maintenance of a RWMP. The purpose of this section is to elaborate further on elements of a RWMP, as a framework for the management of radioactive waste generated at a nuclear power plant.

The discussion is generic and largely based on guidance presented in IAEA (2002b). The RWMP for the Nuclear-1 Nuclear Power Station is still being compiled and will form part of the SAR submitted to the NNR in support of the application for nuclear authorisation (NNR, 2007). Note however, that the NNR Licensing requirements for the Nuclear-1 Nuclear Power Station do not contain specific requirements of what should be included in the RWMP.

3.2 Generation of Radioactive Waste

3.2.1 General

Nuclear power stations generate gaseous, liquid and solid radioactive waste as by-products of their operations. The nature and the amounts of such waste will depend on the type of reactor, specific design features, operating procedures and practices, including maintenance, refuelling and operational occurrences, the operational history of the plant and the integrity of the fuel. The IAEA (2002b) requires that measures to keep the generation of gaseous, liquid and solid waste to the minimum practical should be defined within the RWMP and implemented.

3.2.2 Gaseous Radioactive Waste

Although the sources of gaseous radioactive waste differ according to the type of reactor, possible gaseous sources from nuclear reactors include leakage from the coolant, the moderator systems, or the reactor itself; degasification systems for the coolant; condenser vacuum air ejectors or pumps; the exhaust from turbine gland seal systems; and activated or contaminated ventilated air. In all cases, spent fuel in storage or in handling operations is a further potential source of gaseous radioactive waste.

3.2.3 Liquid Radioactive Waste

Although the composition of the liquid radioactive waste may vary appreciably according to reactor type, contributions to the waste stream may derive from reactor coolant let-down, evaporator concentrates, equipment drains, floor drains, laundry waste, chemicals and waste arising from the decontamination and maintenance of facilities and equipment.

3.2.4 Solid Radioactive Waste

Solid radioactive waste results from the operation and maintenance of the nuclear power plant and its associated processing systems for gaseous and liquid radioactive waste. The nature of such waste and the associated levels of activity vary from plant to plant. Solid radioactive waste consists of: spent ion exchange resins (both bead and powder); cartridge filters and pre-coat filter cake; particulate filters from ventilation systems; charcoal beds; tools; contaminated metal scrap; core components; debris from fuel assemblies or in-reactor components; contaminated rags, clothing, paper and plastic.

3.3 Classification and Segregation of Radioactive Waste

The successful management of radioactive waste depends in part on adequate classification and segregation of the waste. Gaseous radioactive waste should be classified for treatment purposes into waste arising directly from the primary coolant systems of the reactor and waste arising from the ventilation of plant areas.

Liquid radioactive waste, which is mainly water based, should be classified for processing purposes according to its specific activity and its content of chemical substances. Radioactive waste containing boric acid or organic matter, for example, may need special treatment. Non-aqueous radioactive waste such as oil should be segregated for treatment.

Solid radioactive waste should be classified according to its nature and activity; for instance, sludges, cartridge filters, contaminated equipment and components, ventilation filters and miscellaneous items (such as paper, plastic, towels) may be segregated in accordance with the type of treatment and conditioning process, such as compaction, incineration or immobilisation.

3.4 Storage and Characterisation of Radioactive Waste

The storage and characterization of radioactive waste may take place between and as part of steps in radioactive waste management.

Sufficient storage capacity should be made available for all the radioactive waste generated at the nuclear power plant during Normal Operation[7] and during Anticipated Operational Occurrences[8] if the waste cannot be disposed of, discharged, or cleared[9] from nuclear regulatory control.

In the design of storage facilities, account should be taken of the various characteristics of the waste, the possible need for its future retrieval and the potential consequences of any improper handling. Irradiated fuel assemblies contain by far the greatest quantity of radionuclides and represent potentially the greatest hazard. They are required to be stored in a manner that ensures sub-criticality[10] and the removal of residual heat in compliance with established requirements and recommendations.

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[7] Operations within specified operational limits and conditions. This includes start-up, power operation, shutting down, shutdown, maintenance, testing and refuelling IAEA (2007b), IAEA Safety Glossary. Terminology Used in Nuclear Safety and Radiation Protection, *2007 Edition*, International Atomic Energy Agency, Vienna..

[8] An operational process deviating from Normal Operation which is expected to occur at least once during the operating lifetime of a facility but which, in view of appropriate design provisions, does not cause any significant damage to items important to safety or lead to Accident Conditions ibid..

[9] Clearance refers to the removal of radioactive material or radioactive objects within authorised practices from any regulatory control applied for radiation protection purposes from the regulatory body ibid..

[10] Criticality is attained when at least one of the several neutrons that are emitted in a fission process causes a second nucleus to fission. If more neutrons are lost by escape from the system or by non-fission adsorption in impurities than are produced in fission, then the chain reaction is not self sustaining and dies out. In this case, the

Auxiliary storage capacity should always be available in anticipation of any unforeseen events, such as delays in dispatching the radioactive waste from the site or the need for repairs to the storage facility. To ensure sufficient storage capacity, the available capacity should be carefully controlled by maintaining an inventory of the radioactive waste stored and, where necessary, its location. For solid radioactive waste, in particular bulky items, full use should be made of the capacity of the store by means of appropriate arrangement or emplacement of its contents in the store.

Excessive accumulation of untreated and/or unconditioned radioactive waste may give rise to hazards and should be avoided if reasonably practicable by means of properly scheduled treatment and/or conditioning.

Containers for the storage of radioactive waste should be suitable for their contents and for the conditions likely to be encountered in storage in order that the integrity of the container can be maintained over the necessary storage period. Monitoring devices with alarms set at appropriate levels should be provided as necessary to ensure the detection, location and assessment of any leakage from the containment. Dose rates and surface contamination for waste containers should be measured in accordance with established procedures. The levels of dose rate and surface contamination as measured should comply with the requirements established by the regulatory body.

Waste should be characterised for all steps in radioactive waste management. The characterisation process should include the measurement of physical and chemical parameters, the identification of radionuclides and the measurement of activity content. Such measurements are necessary for monitoring the history of the radioactive waste or waste packages through the stages of conditioning, storage and disposal and for maintaining records for the future. The input into radioactive waste processing should be monitored in order to provide information on the performance of the plant and to help in reducing the amounts of radioactive waste generated.

3.5 Processing of Radioactive Waste

3.5.1 General

Processing (pre-treatment, treatment and conditioning) systems for radioactive waste should be operated and controlled in accordance with written procedures for Normal Operation as well as for Anticipated Operational Occurrences. The design intent and the operational limits and conditions, including authorised discharge limits, clearance levels and the criteria for maintaining doses as low as reasonably achievable, should be taken into account in these procedures.

Waste processing systems should be designed, operated and maintained in accordance with a programme in which the operational modes of the plant such as start-up, full power operation and outages are taken into consideration.

Radioactive waste should be processed as early as practicable in order to convert it into a passively safe state and to prevent its dispersal during storage and disposal.

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assembly of fissionable material is called sub-critical Cember, H. (1983), *Introduction to Health Physics*, Second Edition ed., Perganon Press, New York.

Waste packages resulting from the conditioning of radioactive waste are subject to the applicable requirements for handling, transport, storage and disposal. In order to obtain the required product, all operations should be carried out in accordance with established procedures and subject to quality assurance requirements.

3.5.2 Gaseous Radioactive Waste

In the operation of treatment systems for gaseous radioactive waste, consideration should be given to: the amount of gas to be treated; the activity; the radionuclides contained in the gas; the concentrations of particulates; the chemical composition; the humidity; the toxicity; and the possible presence of corrosive or explosive substances.

If necessary, personnel should wear appropriate protective clothing and breathing apparatus when testing, maintaining or replacing filters so as to minimise the inhalation of particulates accumulated on the filters or the structures.

3.5.3 Liquid Radioactive Waste

In the operation of processing systems for liquid radioactive waste, the amounts of liquids to be treated, the radionuclide present, the activity, the concentrations of particulates, the chemical compositions, the toxicity and the possible presence of corrosive substances should be taken into consideration.

Input streams should be characterised, in particular for new facilities, either before liquid waste streams reach the processing plant or early in the processing activities. By this means, different types of waste can be segregated appropriately and, if various options are available, the most effective methods of processing can be adopted.

For waste conditioning, a suitable matrix material, if any and a suitable container should be used. The container should be properly filled, closed and labelled in order to produce a waste package suitable for handling, transport, storage and disposal.

3.5.4 Solid Radioactive Waste

Solid radioactive waste may be inhomogeneous, with different physical, chemical and radiological properties within a batch of waste or on a smaller scale, within a single container. Special consideration should be given to representative sampling before processing to confirm compatibility with the intended process.

Input streams should be characterised either before liquid waste streams reach the processing plant or early in the processing activities. By this means, different types of waste can be segregated appropriately and, if various options are available, the most effective methods of processing can be adopted.

A number of processes based on proven technology are available for producing acceptable waste packages. Such processes should be selected based on the characteristics of the waste concerned, with consideration of radioactive decay.

3.6 Transport of Radioactive Waste

The transport of radioactive waste, both domestically and internationally, is subject to the national and international model regulations for the safe transport of radioactive materials. National and international model transport regulations are generally based on the IAEA Regulations for the Safe Transport of Radioactive Material (IAEA, 2009). The means (road, rail, or air) for the transport of radioactive waste should be considered at an early stage and its transport should comply with the appropriate regulations. The preparation of waste packages for the transport of radioactive waste should be carried out in accordance with written, approved operating procedures.

3.7 Discharge Control and Compliance Monitoring

3.7.1 General

Prior to the commencement of operations, the operating organisation should propose to the regulatory body levels for gaseous and liquid discharges. In proposing such levels, it should be demonstrated that they would result in compliance with national regulations. The purpose of setting levels for discharges is to ensure that radiation doses to members of the public due to the discharges do not exceed a fraction of the dose limit for the public (the dose constraint) when applied to the critical group and that such doses are As Low As Reasonably Achievable. The expected discharges for all operational states of the plant, and if possible also for potential future changes in operations, should be taken into account in setting the levels to be proposed for discharges.

The proposed discharge levels should be based on an assessment of their expected radiological impacts by means of predictive modelling. Expected doses to the most highly exposed individuals should be estimated. It may be necessary to establish by means of habit surveys, which members of the public are potentially the most highly exposed because of the discharges (the critical group or groups in the population). Account should be taken of their location with respect to the plant, food consumption, sources of food and drinking water and any habits or practices that might give rise to higher than average exposure to radiation.

The regulatory body, after considering the submissions of the operating organisation, should establish authorised discharge levels. Discharges may not exceed the discharge levels authorised by the regulatory body.

Compliance with authorised discharge levels should be demonstrated by means of monitoring at the source of the discharge and confirmed by measurement in the recipient environmental media (such as water or air). The monitoring may be by continuous measurement and/or by representative sampling and intermittent measurement, as appropriate. For intermittent discharges into water, the assessment should be made by means of representative sampling and measurement before and during and after each discharge, if appropriate.

Provision should be made to enable the prompt detection of any abnormal discharge of radionuclides and the identification and assay of radiological significant radionuclides should be performed for both gaseous and liquid discharges.

If an authorised discharge level has been or may have been exceeded, the operating organisation should take appropriate steps, such as terminating the discharge and taking corrective actions; estimating the amounts of radioactive substances released; recording all relevant details; report promptly to the regulatory body in accordance with prescribed procedures; and investigating and identifying the causes of any non-compliance.

3.7.2 Source Monitoring

Source monitoring refers to the measurement both of discharges and of the radiation field around the source itself. The design of the source monitoring programme should be such that it enables the verification of compliance with external exposure limits and discharge limits and criteria specified by the regulatory body. The monitoring of radioactive discharges may entail making measurements for specific radionuclides or gross activity measurements as appropriate. Measurements should normally be made before or at the point of release (for example, the stack for atmospheric discharges or the discharge pipeline for a liquid discharge).

3.7.3 Environmental Monitoring

An environmental monitoring programme should be implemented in accordance with the requirements of the regulatory body. A pre-operational programme should be implemented two to three years before the planned commissioning of the plant. This pre-operational programme should provide for the measurement of background radiation levels near the plant and their variation over and between the seasons. It should also provide the basis for the operational programme of environmental monitoring and should include the routine collection and radionuclide analyses of various samples, such as samples of vegetation, air, milk, water, sediment, fish and environmental media collected from several fixed and identified locations off the site.

The operational programme should be implemented as an extension of the preoperational programme. The samples taken during the operational programme should be similar to those taken in the preoperational programme, but they may be collected at different intervals (for example, milk may be sampled more frequently and sediment less frequently). The operational programme should be reviewed in the light of experience and it should be modified if necessary. The programme should be designed to provide information for the purposes of:

- confirming the adequacy of control over effluent discharges;
- correlating the results of environmental monitoring with data obtained from monitoring at the source of the discharges;
- checking the validity of environmental models used in establishing authorised limits;
- fostering public assurance; and
- assessing trends in the concentrations of radionuclides in the environment.

4 Nuclear-1 Nuclear Power Station Radioactive Waste Characteristics

4.1 General

From the definition of radioactive waste (see Section 3.1), it is clear that radioactive waste may differ significantly in its origin, physical, radiological and chemical properties, as well as in its effect on biological matter. Nuclear power plants generate gaseous, liquid and solid radioactive waste as by-products of their operations and decommissioning activities. These waste is generated during and after nuclear power plant operation generally can be divided into (AREVA, 2006):

- spent fuel assemblies,
- operational waste water,
- operational liquid waste,
- operational solid waste,
- operational gaseous waste,
- exhaust air,
- activated material,
- large components and parts,
- decommissioning waste.

The composition of the radioactive waste depends on the fuel used and the specific design and operation of the reactor. Consequently, each design has a unique "source term", an expression used to describe the radioactivity, in the form of radionuclides, present in a waste, expressed in units of Becquerel (Bq). For all of the radionuclides present in the waste, the discharge rate is given as the average radioactivity per radionuclide discharged on an annual basis in Bq/year.

A reactor vendor has not yet been selected for supply of the Nuclear-1 Nuclear Power Station. It is understood that, because the capacity of the available reactor designs are different, a different number of reactors may be constructed up to the maximum generation capacity of 4,000 MW, depending on the vendor that is chosen. The capacity of the largest reactor under consideration is 1,784 MW, in which case two reactors would be used to supply a total of 3,568 MW. In the case of other vendors who supply smaller reactors, a larger number of reactors could be installed (Arcus Gibb, 2010).

In the absence of final selection of a specific reactor technology, source term data from two third-generation pressurised water reactor designs, which represent the best surrogates for the types of technology that are likely to be acquired by Eskom for the - Nuclear-1 project, were obtained.

Source term data obtained from the vendors of these reactor designs have been used in this section of the report to provide an overview of the characteristics of the radioactive waste that will be generated by the Nuclear-1 Nuclear Power Station. The section describes the waste continuously generated during operation of a typical nuclear power plant irrespective of the plant operating mode (start-up operation, power operation, refuelling, maintenance and shutdown operation).

The discussion is divided into gaseous radioactive waste (Section 4.2), liquid radioactive waste (Section 4.3), solid radioactive waste (Section 4.4) and other non-radioactive process related waste (Section **Error! Reference source not found.**). The discussion will cover the source (origin) of radioactive waste, quantity (volume) of waste and level of radioactivity associated with the waste type. Where applicable, radioactivity release rates from both the surrogate reactor designs will be presented.

4.2 Gaseous Radioactive Waste

The primary sources of gaseous radioactive waste generated in the operation of nuclear power stations are (IAEA, 2003b):

- effluents from ventilation systems in buildings;
- off-gas from systems for primary coolant degasification in nuclear reactors; and
- off-gas from the venting of storage tanks.

During reactor operation, radioactive isotopes of xenon, krypton and iodine are created as fission products and released to the primary coolant as a result of small defects in fuel cladding (Westinghouse, 2007a).

In addition, hydrogen and oxygen are formed by radiolysis of the water used as the primary coolant. Hydrogen is added to the primary coolant using the chemical and volume control system to reduce corrosion of primary circuit equipment, which would otherwise result from the presence of oxygen. Dissolved hydrogen and radioactive noble gases are transported to various systems connected to the primary circuit by the normal flow of primary coolant (AREVA, 2007a). The radioactive gasses may be released under the following conditions:

- in systems that operate at a lower pressure than the primary coolant loops these gases may change from the liquid to the gaseous phase;
- during plant shut-down these gases are released in the primary circuit when the primary coolant pressure is reduced; and
- degasification of primary coolant extracted through the chemical and volume control system.

The uncontrolled release of hydrogen in the presence of oxygen could create an explosive mixture over a wide range of hydrogen and oxygen concentrations. This could endanger one or more barriers of radioactivity retention. Uncontrolled release of radioactive gases would increase the dose rate for employees and would also increase the radioactive impact of the plant on the environment. The Gaseous Radioactive Waste Processing System is used to reduce the risk of explosions due to the presence of higher gaseous concentrations of hydrogen and oxygen. It is further employed to reduce the uncontrolled releases of radioactive gaseous effluents and / or hydrogen to the environment from all components in which significant quantities of these gases may be present (AREVA, 2007a).

The activity of gaseous waste is dependent on its origin. Building ventilation air usually has lower contamination levels than process or coolant off-gas or off-gas from the venting of liquid waste storage tanks. Consideration should also be given to whether the radioactive material is present in particulate, aerosol, or gaseous form.

The gaseous radioactive emissions from a typical third generation pressurised water reactor consist of carbon fourteen (C-14), tritium (H-3) and noble gas and iodine isotopes vented from the primary coolant circuit and waste processing activities. These gases are collected by the gaseous radioactive waste system and held for decay storage in an activated carbon bed delay system. The effluent passes through a radiation monitor and discharges to the ventilation exhaust duct.

4.3 Liquid Radioactive Waste

Within a typical conventional nuclear power plant, the various Structures, Systems, Components (SSC) and operations that generate radioactive liquid waste include:

- the reactor coolant system;
- floors and equipment drainage water sumps;
- laundries, showers and decontamination;
- chemical processes;
- steam generator; and
- other operations.

The most prominent is the cooling system where water circulating through the reactor becomes contaminated by radioactive activation of the chemicals added to the cooling water, as well as metallic elements and suspended solids that originate from component wear (AREVA, 2007b). Radioactive water containing boron and hydrogen may be generated from leakage and drainage from various primary systems and components inside containment or from the chemical and volume control system when reactor coolant is replaced when boron concentration changes and coolant levels are adjusted (Westinghouse, 2007a).

Spillages, equipment leaks and floor drainage collected in sumps are generally low in volume but may contain significant amounts of radioactivity. These effluents are usually contaminated with oils greases and can contain significant amounts of suspended particulate matter. Laundry, shower and decontamination effluents usually contain soaps and detergents but are relatively low in activity. Chemical effluents are low volume and originate from equipment cleaning and degreasing. These are usually combined with drainage sump effluents for treatment (Westinghouse, 2007a).

The steam generator is a secondary system from which water is released through a blowdown system used to maintain acceptable secondary coolant level and chemistry. The secondary coolant may become contaminated through leaks in the primary coolant tubes in the steam generating unit. When the blowdown reaches significant activity levels it is diverted to the liquid radioactive waste processing system (Westinghouse, 2007a).

Other operations include cleaning of tanks, pipes and pumps, laboratory wastes and discarded samples collected for monitoring purposes.

The volume of liquid radioactive waste generated by a typical pressurised water reactor is estimated to be between 8,000 m^3 and 20,000 m^3 per annum per unit depending on the specific reactor design (Arcus Gibb, 2010; AREVA, 2006). The radioactivity in the liquid effluent originates from:

- fission products released into the primary coolant
- corrosion of reactor components
- activation of chemical compounds added to the reactor coolant

Fission products include halogens (bromium and iodine), noble gasses and tritium. Corrosion products include isotopes of chromium, manganese, iron and cobalt from the steel used to manufacture the reactor components. The most prominent activation products include carbon fourteen and tritium. The main activity in the liquid release from the Nuclear-1 Nuclear Power Station is tritium, which originate through the following processes (Westinghouse, 2007a):

- tritium formed as a fission product within the fuel assembly which diffuse through the fuel clad or leak through fuel clad defects;
- neutron reactions with soluble boron in the reactor coolant;
- neutron reactions with soluble lithium in the reactor coolant; and

Tritium in the reactor coolant replaces a hydrogen atom in a water molecule and thus cannot be readily separated from the coolant by normal processing methods.

4.4 Solid Radioactive Waste

4.4.1 General

Appendix A summarises the radioactive waste classification scheme defined in the National Radioactive Waste Policy and Strategy. The bulk of the solid waste that will be generated at the Nuclear-1 Nuclear Power Station falls under low and intermediate level waste (LILW), while high-level waste in the form of spent fuel will be the highest activity waste.

LILW can be divided further into short-lived LILW (LILW-SL) and long-lived LILW (LILW-LL). Nuclear facilities generate many different types of LILW in a wide range of radionuclide concentrations and in various physical forms and of various chemical compositions. In addition to operational waste streams, waste also arises during the decommissioning of nuclear facilities and restoration activities. Incidents or accidents may also generate waste in variable amounts and of variable composition.

LILW with low levels of activity generated in the controlled radiological areas of a nuclear power station, generally comprises of refuse that may or may not be contaminated with minute quantities of radioactive material. This waste is usually in the form of trash, clothing, masks, gloves, plastics, insulation material, paper, concrete, wood, debris, soil, or other protective clothing. LILW with intermediate level of activity, consists of sludges, spent ion exchange resins, filter cartridges, precipitation flocculants, evaporator concentrates, or irradiated scrap metal. This waste is more radioactive than the refuse but less radioactive than spent fuel.

4.4.2 Sources of Solid Radioactive Waste

During normal plant operation, solid radioactive waste is generated from the following activities:

- Plant maintenance, including decontamination, cleaning, replacement and disposal of systems, components and parts;

- Conditioning and replacement of dust filters in the Fuel Handling and Storage System;
- Operation of the liquid waste plant that generates solid waste in the form of spent resin, used filters and evaporator residue; and
- Laundry, when highly contaminated protective clothing may be discarded as unsuitable for washing.

The solid radioactive wastes differ in material, size, activity and physico-chemical conditions and consist of paper, plastic, wood, metal parts such as worn-out items, concrete, glass, electrical items such as wires, coils, motors, etc. Wet solid waste may be generated mainly during cleaning operations or after leaks. Wet solid radioactive waste is to be collected separately from other waste and stored in suitable containers until drying (AREVA, 2007c).

In some cases, large in size or bulky solid radioactive waste is generated (e.g. worn-out items, items after repair, filter housings).

According to the processing requirements, this waste is divided into compactable waste, non-compactable waste and abnormal waste. Abnormal waste such as large parts and components are collected and stored separately to facilitate further handling.

The radioactivity of the dry active waste is produced by relatively long lived radionuclides (such as Cr-51, Fe-55, Co-58, Co-60, Nb-95, Cs-134 and Cs-137) and, therefore, radioactive decay during processing and storage is minimal. These activities, which apply to the waste as generated, thus also apply to the waste as shipped (Westinghouse, 2007a).

Table 4.1 summarises the expected Nuclear-1 Nuclear Power Station low and intermediate level solid radioactive waste characteristics. The data was obtained from the Nuclear 1 NPP Consistent Dataset (ESKOM, 2010), which is based on the current situation at the Koeberg Nuclear Power Station.

Table 4.1: Summary of some of the solid LILW characteristics (ESKOM, 2010).

Solid Waste Produced	Waste Package Volume (m^3)	Mass of container + waste (kg)	Average Number of Containers per Year
Metal Containers	0.210	50-100 kg	470
Concrete Containers	2	Max. 6,300 kg	160

4.4.3 Compactable Waste

Compactable waste typically consists of items such as discarded clothing, solid cleaning materials, wrappings and HVAC filters. This waste will typically be classified as LILW, compacted in a metal container.

4.4.4 Non-Compactable Waste

Non-compactable waste includes waste such as metal parts or process components that are generally solid but can also contain voids. Typical sources of non-compactable waste include turbine and Liquid Waste System (LWS) residue from the evaporator, spent ion exchange resin vacuum cleaner waste and discarded solid objects.

This waste will typically be classified as LILW, solidified in a specially designed concrete container.

4.4.5 Abnormal Waste

Abnormal waste is generally considered as beyond the routine handling capabilities of the installed waste management system, due to characteristics such as excessive volume, high activity concentration, radionuclide composition, physical or chemical form and its non-compactability. For the Nuclear-1 Nuclear Power Station, abnormal waste may be generated after equipment failure and include waste resulting from replacement of large SSCs.

The large components may include valve motors, pipes, vessels and similar items, while high activity components include all activated or contaminated waste (excluding fuel that is normal waste) that exceeds the requirements of LILW.

4.4.6 Spent Fuel as High-level waste

In general terms, high-level waste (HLW) includes spent fuel (if it is declared as waste); radioactive liquid containing most of the fission products and actinides present in spent fuel (which forms the residue from the first solvent extraction cycle in reprocessing) and some of the associated waste streams; or any other waste with similar radiological characteristics (IAEA, 2007b).

Spent fuel refers to nuclear fuel that has been irradiated in a nuclear reactor (usually at a nuclear power plant) to the point where it is no longer useful in sustaining a nuclear reaction (IAEA, 2007b).

The Nuclear-1 Nuclear Power Station is expected to generate approximately 1,880 tons of spent fuel over its 60-year operational lifetime (ESKOM, 2010). Each spent fuel assembly contains radioactive materials that fall into three categories[11]:

- The first category contains the fission products (such as caesium, iodine, strontium and xenon) which are created when uranium or plutonium nuclei are split. They are the most radioactive components of spent fuel when it leaves the reactor vessel for the fuel pool but they decay to low levels relatively quickly and after 1,000 years only about 400 GBq of the longest-lived fission products such as I-129, remain.
- In the second category are the actinides, which are isotopes of uranium and heavier metals including plutonium. These are long-lived materials, which take 10,000 years to decay to about 800 GBq.
- The third category contains the structural materials of the fuel assemblies, which become radioactive through irradiation by neutrons. They only add a small amount of radiation to the spent fuel assembly total and decay in about 500 years to less than 200 GBq.

The bulk of the HLW that will be generated by the Nuclear-1 Nuclear Power Station consists of spent fuel removed from the reactor core, although other larger items may also be classified as HLW. The following items of equipment located within or close to

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[11] http://www.eskom.co.za/live/content.php?Item_ID=208&Revision=en/0.

the core, for example, are activated during reactor power operation and may be classified as HLW (AREVA, 2006):

- Rod Control Cluster Assemblies;
- Thimble Plug Assemblies;
- Instrumentation lances;
- Neutron sources;
- Core internals (e.g. core plate); and
- Rod drive shafts.

These parts, when removed from the reactor at the time of core replacement will be accommodated by the spent fuel handling system.

5 Management of Nuclear-1 Nuclear Power Station Waste

5.1 General

Section 2 presented an overview of the nuclear regulatory framework, within which radioactive waste must be managed in South Africa. Section 3 presented an overview of the elements of a typical radioactive waste management programme for a nuclear power plant. A similar programme will be developed for the Nuclear-1 Nuclear Power Station as part of the conditions for a nuclear authorisation application. Section 4 provided a summary of the anticipated gaseous, liquid and solid radioactive waste that the Nuclear-1 Nuclear Power Station will produce.

The purpose of this section is to provide an overview of the radioactive waste management practices that may be applicable to a typical third generation pressurised water reactor design. The processes and management systems describe should thus be regarded only as indicative of what can be expected of the radioactive waste management programme for the Nuclear-1 Nuclear Power Station. Generally, the reactor Waste Handling System (WHS) is designed to handle, store and discharge low and intermediate level liquid and solid waste generated during Normal Operation, maintenance activities and Anticipated Operational Occurrences.

As shown in **Figure 5.1**, radioactive waste management comprises all the administrative and operational activities involved in the handling, pre-treatment, treatment, conditioning, transport, storage and disposal of radioactive waste. Conditioning of waste typically includes immobilisation and packaging of waste, treatment includes volume reduction and activity removal, while pre-treatment refers to activities such as collection, segregation, chemical adjustment and decontamination (IAEA, 2007b).

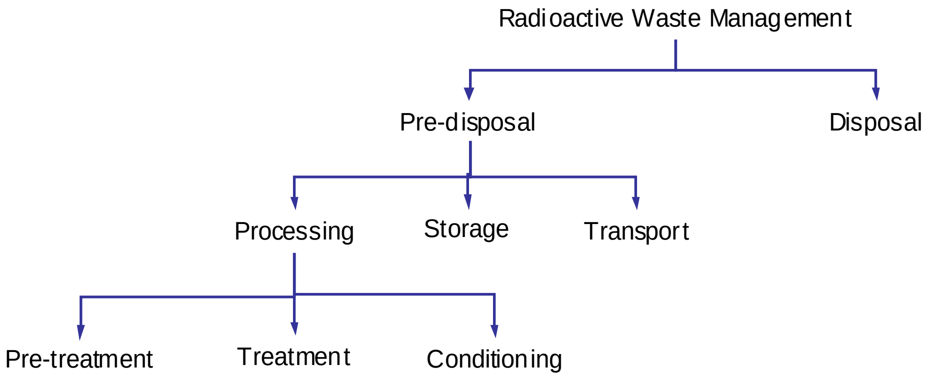

Figure 5.1: Breakdown of the various activities associated with radioactive waste management (IAEA, 2007b).

The discussion will include the management of gaseous and liquid waste in Section 5.2 and Section 5.3, respectively. This is followed by an overview of the management practices envisaged for low and intermediate level waste (LILW) in Section 5.4 and high-level waste (HLW) in Section 5.5. Where appropriate, the discussion will include the processing (pre-treatment, treatment, or conditioning) of radioactive waste.

General guidelines for the pre-disposal management of LILW and HLW is presented in IAEA (2003b) and IAEA (2003a), respectively. Guidelines for storing, as part of the predisposal management of radioactive waste, is presented in IAEA (2006b).

5.2 Management of Gaseous Radioactive Waste

5.2.1 General

The characteristics for the gaseous radioactive waste that will be generated by the Nuclear-1 Nuclear Power Station were presented in Section 4.2.

The best way to reduce discharges of gaseous radioactive waste from a nuclear power plant is to keep the source to the minimum activity practicable. The IAEA (2002b) further propose the following to reduce the generation of gaseous waste at a nuclear power plant:

- Use filters for separating aerosols or iodine from the gaseous discharges;
- Use delay systems (charcoal beds, tanks) to allow the radioactive materials in the gases to decay; and
- Use treatment for volume reduction (such as those using recombiners, absorbers and pressurised storage, which may also function as a delaying system.

5.2.2 Processing of Gaseous Waste

A typical radioactive gas processing system consists of gas cooler, a moisture separator and activated carbon-filled delay beds. The radioactive fission gases entering the system are carried by hydrogen and nitrogen gas. The primary influent source is the liquid radioactive effluent degasifier. Influents to the gaseous radioactive waste system first pass through the gas cooler where they are cooled to about 10°C by the chilled water system. Moisture formed due to gas cooling is removed in the moisture separator.

After leaving the moisture separator, the gas flows through a guard bed that protects the delay beds from abnormal moisture carryover or chemical contaminants. The gas then flows through delay beds where the fission gases undergo dynamic adsorption by the activated carbon and are thereby delayed relative to the hydrogen or nitrogen carrier gas flow. Radioactive decay of the fission gases during the delay period significantly reduces the radioactivity of the gas flow leaving the system.

The effluent from the delay bed passes through a radiation monitor and discharges to the ventilation exhaust duct (Westinghouse, 2007a).

Although not a conventional radioactive waste processing system, the most important gaseous waste processing SSC in a typical third generation Nuclear Power Station, is the Heat, Ventilation and Air Conditioning System (HVAC), which consists of a number of individual systems (AREVA, 2007a). Radioactive gases, aerosols and dust particles are removed from within the Reactor Building by purging, filtering and recirculation as part of the HVAC system. The other HVAC system significant in terms of the safety function performed, is the Service Building HVAC System.

The Reactor Building HVAC System is designed with an exhaust High Efficiency Particulate Air (HEPA) filter train that is switched on. An activated charcoal absorber filter bank is switched in line in series with the HEPA filter bank on detection of high radioactivity in the exhaust ducting. Before releases during Normal Operation are discharged to the atmosphere it is filtered by HEPA and charcoal filters. All releases to the atmosphere are above ground level. The dilution factors are specific to the design of the ventilation system and the release height.

5.2.3 Annual Authorised Discharge Quantities

Section 3.7 introduced the concept of discharge control and compliance monitoring as part of the Radioactive Waste Management Programme (RWMP) for a nuclear power plant. As stated, the purpose of setting levels of discharges is to ensure that radiation doses to members of the public due to discharges do not exceed a fraction of the dose limit for the public (dose constraint) when applied to the critical group and that such doses are as low as reasonable achievable (ALARA).

The Nuclear-1 Nuclear Power Station applications for nuclear installation licence for the siting of new nuclear installations (NILS) will present an assessment of the expected radiological impact to the most highly exposed individual for the gaseous emissions expected from the Nuclear-1 Nuclear Power Station. The assessment is expected to include best estimates activity discharges for Normal Operations, as well as best estimates of discharges from Anticipated Operational Occurrences, based on a technology envelope (TE) developed for proposed Nuclear-1 Nuclear Power Station.

Because no vendor has been selected for Nuclear-1, the NILS application will follow the approach of developing a TE for a specific site that encompasses all relevant and foreseeable radionuclide discharges, without being limited to a particular reactor design. The TE is developed for a particular site and sets an upper limit of radiological discharges for the required generation capacity.

The NNR will review these proposed discharge levels, with the view to approve Annual Authorised Discharge Quantities (AADQs) for Nuclear-1. Once operational, compliance with the Nuclear-1 AADQs for gaseous emissions must be demonstrated by means of monitoring at the source of the discharge and confirmed by measurement in the recipient environmental media.

5.3 Management of Liquid Radioactive Waste

5.3.1 General

The characteristics for the liquid radioactive waste expected to be generated by the Nuclear-1 Nuclear Power Station were presented in Section 4.3.

In a typical pressurised water Nuclear Power Station the management of liquid radioactive waste is controlled by the Liquid Waste Treatment System (LWS), which provides the capability to reduce the amounts of radioactive nuclides released in the liquid wastes through the use of demineralisation and time delay for decay of short-lived nuclides. The function of the LWS is to "*collect, segregate, treat, analyse and discharge potentially radioactive and chemically contaminated liquid radioactive waste generated during Normal Operation including maintenance activities*."

Processes that may be applied for the treatment liquid radioactive waste from a typical Nuclear Power Station include (AREVA, 2007b; Westinghouse, 2007a):

- filters of different kinds to separate un-dissolved radioactive substances from liquids;
- ion exchange resins, to separate both dissolved radioactive substances from liquids; and
- evaporators to separate both dissolved and un-dissolved substances from liquids.

The LWS is designed to perform this function during Normal Operation and Anticipated Operational Occurrences. These functions are performed with a view to ensuring compliance with regulatory dose limits and to ensure that doses to the public and workers are below limits and as low as reasonable achievable (ALARA).

5.3.2 Processing (Treatment) of Liquid Waste

In order to accommodate the various sources of liquid effluents, the LWS is divided into various sub-systems as depicted in
Figure **5.2**.

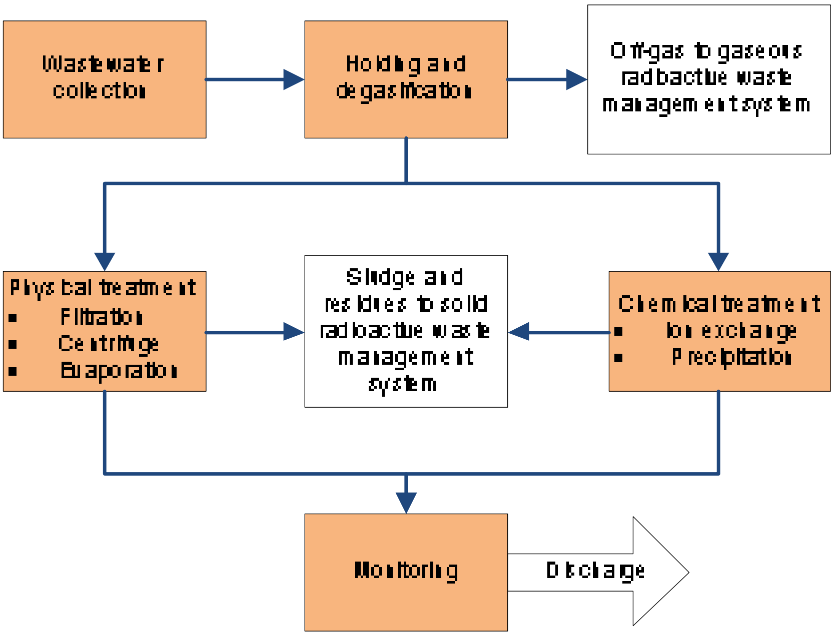

Figure 5.2: Schematic diagram showing the general subsystems for the treatment of liquid effluent radioactive waste.

The *collection subsystem* captures borated, reactor-grade, waste water from the reactor coolant system, the chemical and volume control system and the primary sampling system drains and equipment leak drains. Floor drain effluents with high suspended solids content and laundry and shower effluent are collected from various drains and sumps. Chemical waste comes from the laboratory and other relatively small volume sources. It may be mixed hazardous and radioactive wastes or other radioactive wastes with a high dissolved-solids content.

Collected effluents normally contain hydrogen, dissolved radioactive gases and short lived radioactive isotopes. The effluents thus may be routed through a *de-gasification and holding sub-system* before being treated. Dissolved hydrogen and fission gases

removed in the de-gasification system are sent via a water separator to the gaseous radioactive waste system. The de-gasified effluent discharges to an effluent holding tank. Effluent holding tanks vent to the radiologically controlled area ventilation system and may be purged with air to maintain a low hydrogen gas concentration.
A combination of chemical and physical treatment processes may be applied to reduce the volume and radioactivity of liquid effluents generated by the Nuclear-1 Nuclear Power Station.

Ion exchange processes effluent with an upstream filter followed by four ion exchange resin vessels in series. The first of the four vessels contain a top layer of activated charcoal to remove any organic contamination. The second, third and fourth contain identical ion exchange vessels are loaded with specialised ion exchange resins depending on prevailing plant conditions (Westinghouse, 2007a).

Chemical precipitation is used to process effluent that may be contaminated with soap and detergents as this type of effluent is not suited to ion exchange. The treatment steps for the precipitation subsystem are determined by the measured activity and composition of the effluent. If precipitation is necessary, the effluent should be preconditioned for precipitation. Chelating additives are added to the tank content and after mixing, the tank is isolated and the effluent is allowed to settle. The wastewater to be treated by evaporation or centrifuging is chemically adjusted to conform to the treatment processes in the liquid waste storage tanks to avoid problems during treatment and discharge (AREVA, 2007b).

Processing by evaporation can be applied to a wide variety of effluents. After analysis and following the appropriate chemical treatment, the wastewater is passed from the liquid waste storage tank to the evaporator. Water vapour leaving the column is compressed by a vapor compressor and then routed back to the evaporator where the heat of the compressed vapor is transferred to the wastewater circulating between the evaporator and evaporator column and the vapor is condensed. The condensate leaving the evaporator is cooled down in a distillate cooler to below 45°C and collected in one of the monitoring tanks. During operation, the wastewater in the evaporator bottom becomes more concentrated and is passed from the evaporator to a concentrate tank with a solids content of approximately 20 to 30 % by weight. Compared with other treatment technologies, evaporation provides the best decontamination factor ranging between 10^4 and 10^6, depending on the composition of the liquid waste (AREVA, 2007b).

Centrifuge treatment serves to decontaminate and clean radioactive wastewater which contains un-dissolved radioactive contaminates and non-radioactive particles. The collected wastewater is routed to a decanter first and then to a downstream separator. The majority of the solids are removed from the wastewater in the decanter and the remaining smaller particles are removed in the separator. The solids collected in the separator are intermittently discharged as sludge from the separator into a sludge tank while the particles removed by the decanter are continuously dewatered and dried to a specific residual moisture (AREVA, 2007b).

Precipitate sludge and spent ion exchange resins are removed to the solid waste treatment system. Treated effluent is released to the monitoring tanks.

The *release subsystem* consists of the pre-release tanks where effluent from the treatment systems intended for discharge is analysed by radionuclide-specific analysis and the activity of each radionuclide to be discharged is quantified. A check is made against the discharges authorised in the applicable period to date and then submitted to the appropriate individual for authorisation to discharge. Following authorization, the contents of the pre-release tank are discharged. The discharge is monitored by the Radiation Monitoring System. If a high signal on the discharge monitor is registered, the discharge is automatically terminated by closing the discharge valve and stopping the pump. The remaining effluent is then transferred back to the collection tank and from there, to the analysis tank for further processing. The liquid waste is discharged from the monitor tank in a batch operation and the discharge flow rate is restricted as necessary to maintain an acceptable concentration when diluted by the circulating water discharge flow to the sea. These provisions prevent the uncontrolled releases of radioactivity.

5.3.3 Reuse of Processed Liquid Waste

Where possible, processed water, rather than fresh potable water, is used to minimise the plant's water consumption. Steam generator blow-down is a large quantity of liquid and is generally returned to the steam generator following treatment. The primary cooling system is, however, sensitive to water chemistry and wastes collected from this system is usually discharged following treatment.

5.3.4 Annual Authorised Discharge Quantities

Section 3.7 introduced the concept of discharge control and compliance monitoring as part of the Radioactive Waste Management Programme (RWMP) for a nuclear power plant. As stated, the purpose of setting discharge levels is to ensure that radiation doses to members of the public due to discharges do not exceed a fraction of the dose limit for the public (dose constraint) when applied to the critical group and that such doses are as low as reasonable achievable (ALARA).

The Nuclear-1 NILS application report will present discharge levels for liquid emissions based on an assessment of their expected radiological impact to the most highly exposed individual and is expected to include best estimates activity discharges for Normal Operations and Anticipated Operational Occurrences based on a TE developed for the proposed Nuclear-1 Nuclear Power Station. The NNR will review these proposed discharge levels, with the view to approve Annual Authorised Discharge Quantities (AADQs) for the Nuclear-1 Nuclear Power Station. Once operational, compliance with the Nuclear-1 Nuclear Power Station AADQs for liquid emissions will be demonstrated by means of monitoring at the source of the discharge and confirmed by measurement in the recipient environmental media.

5.4 Management of Solid Radioactive Waste

5.4.1 General

The characteristics for the solid radioactive waste that will be generated by the Nuclear-1 Nuclear Power Station were presented in Section 4.4.2.

The Solid Waste System (SWS) typically forms part of the Waste Handling System (WHS) in a Nuclear Power Station. The function of the SWS is to segregate, handle, analyse, process, store and transport potentially radioactive and chemically contaminated solid radioactive waste generated as a result of Normal Operations and Anticipated Operational Occurrences. These functions are performed in order to maintain releases of radioactive materials within regulatory limits and as low as reasonable achievable (ALARA). Note that handling of spent fuel and other fuel-related waste is not part of the SWS, but part of the Fuel Handling and Storage

System (Westinghouse, 2007a). Section 5.5 discusses the management of high-level waste.

The solid waste management system is designed to meet the following objectives (Westinghouse, 2007a):

- Provide for the transfer and retention of spent radioactive ion exchange resins and deep bed filtration media from the various ion exchangers and filters in the liquid waste processing, chemical and volume control and spent fuel cooling systems;
- Provide for the transfer and retention of sludges and residues from settling and evaporation processes;
- Provide the means to mix, sample and transfer spent resins, filtration media and/or evaporator or settling sludges and residues to high integrity containers or liners for dewatering or solidification as required;
- Provide the means to change out, transport, sample and accumulate filter cartridges from liquid systems in a manner that minimises radiation exposure of personnel and spread of contamination;
- Provide the means to accumulate spent filters from the plant heating, ventilation and air-conditioning systems;
- Provide the means to segregate solid wastes (trash) by radioactivity level and to temporarily store the wastes;
- Provide the means to accumulate radioactive hazardous (mixed) wastes;
- Provide the means to segregate clean wastes originating in the radiologically controlled area;
- Provide the means to store packaged wastes for at least 6 months in the event of delay or disruption of offsite shipping;
- Provide the space and support services required for mobile processing systems that will reduce the volume of and package radioactive solid wastes for offsite shipment and disposal according to applicable regulations and
- Provide the means to return liquid radioactive waste to the liquid radioactive waste management system for subsequent processing and monitored discharge.

Operational solid radioactive waste generated by the Nuclear-1 Nuclear Power Station will generally be in the category LILW-SL. The Radioactive Waste Management Programme that will be developed for Nuclear-1 Nuclear Power Station will include procedures for the predisposal management (processing, storage and transport) of the solid waste. Generally, it will be handled similar to the operational waste generated at the Koeberg Nuclear Power Station, after which it will be disposed of at the national radioactive waste disposal facility at Vaalputs. The basic activities typically required for the processing of Nuclear Power Station solid waste are depicted in**Error! Reference source not found.Error! Reference source not found.**.

Guidelines for the predisposal management of LILW radioactive waste is presented in IAEA (2003b).

5.4.2 Processing of Compactable Waste

Compactable waste is generally treated by compaction to reduce the waste volume. Compactable waste such as exhaust filters, ground sheets, boot covers, hair nets, gloves etc. are compacted into steel drums. An example of this waste type is shown on the left in**Error! Reference source not found.** Figure 5.4.

A Radiation Protection Officer (RPO) should monitor the containers for surface contamination and it will be cleaned if necessary. Compacted waste is stored until it can be transferred for disposal. The standard metal container for disposal at Vaalputs is shown on the left in **Figure 5.6**.

A Radiation Protection Officer (RPO) should monitor the containers for surface contamination and it will be cleaned if necessary. Compacted waste is stored until it can be transferred for disposal. The standard metal container for disposal at Vaalputs is shown on the left in **Figure 5.6**.

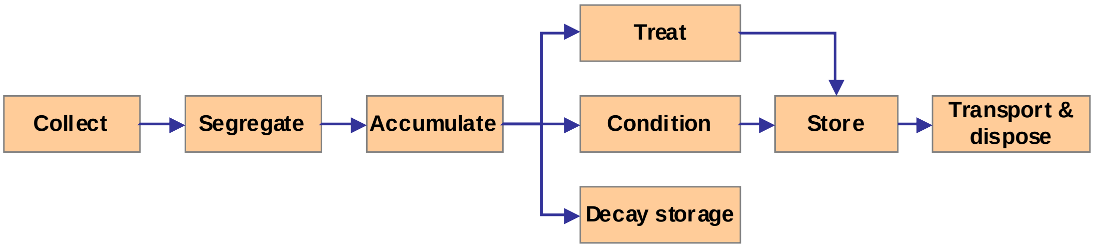

Figure 5.3: General activities for the processing of Nuclear Power Station solid radioactive waste.

5.4.3 Processing of Non-Compactable Waste

Non-compactable waste includes waste such as metal parts or process components that are generally solid but can also contain voids. Waste containing dispersible activity such as evaporator concentrates and centrifuge sludges from the treatment of liquid radioactive effluent is, immobilised in a solid matrix, in order to prevent spreading of contamination if the storage container is damaged. The radiological properties of the waste will determine if standard metal containers or concrete containers are used for storage.

An example of the immobilised waste is show on the right in **Error! Reference source not found.Error! Reference source not found.**, while the standard concrete container used for disposal of non-compactable waste at Vaalputs is shown on the right in **Figure 5.6Figure 5.6**.

5.4.4 Processing of Abnormal Waste

If the *large component* abnormal wastes (e.g. valve motors, pipes, vessels and similar items) are uncontaminated, they will be accumulated in a designated location and clearance will be requested when deemed necessary. Bulky parts may be processed in an on-site workshop.

Treatment of the contaminated waste will consist of disassembly for decontamination, disassembly to remove and segregate parts, or cutting of parts into smaller pieces. If it is decided to decontaminate the Structures, Systems and Components (SSC), they will be moved to the decontamination facility. These large items will be handled individually. The components will be marked and kept in a controlled interim storage area until release is confirmed or until further processing is undertaken.

High activity components include all activated or contaminated waste (excluding fuel that is normal waste) that exceeds the requirements of LILW. The following handling options can be considered:

- decontamination in order to remove the active layers (not applicable to activated components);
- storage on site until activity has decayed to a level when processing and disposal is feasible;
- disposal in a non-standard but approved waste container; and
- processing in a manner specific to a particular component.

When choosing the most suitable process, the dose from the whole life cycle of the component must be considered. An ALARA study will be required to optimise the choice. Remote handling will be required or the material must be packed into containers that provide adequate shielding.

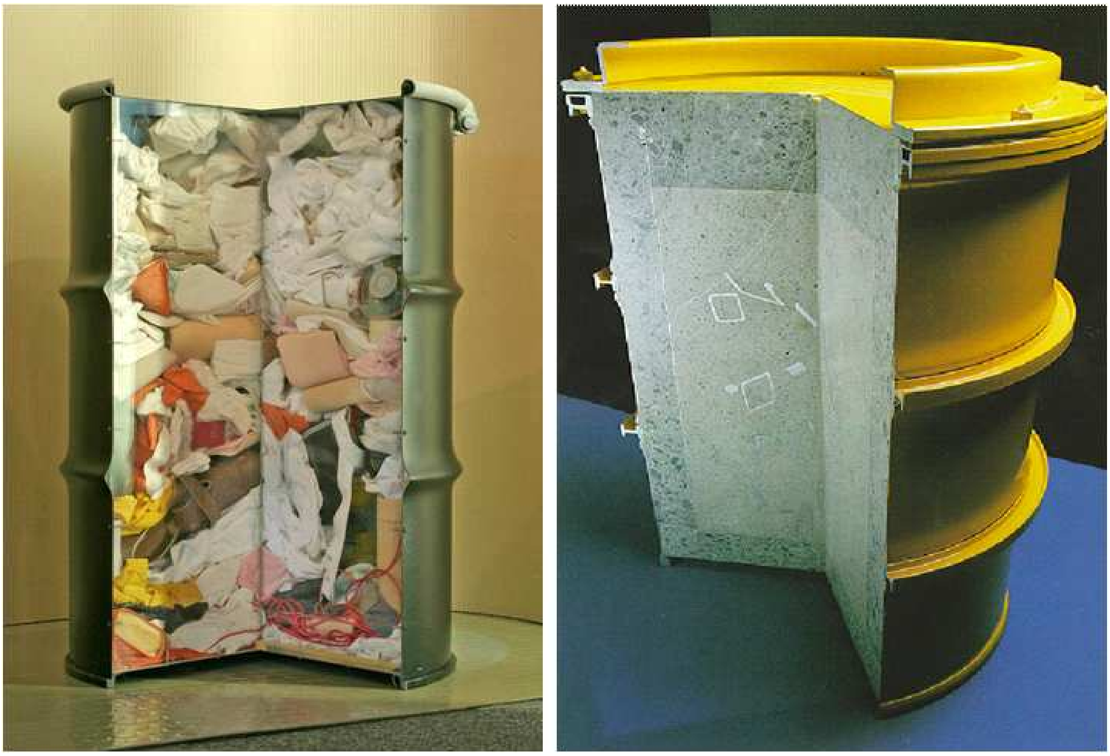

Figure 5.4 Examples of compactable LLW on the left and non-compactable ILW immobilised in cement on the right.

5.4.5 Storage of Solid Radioactive Waste

Provision is made to store compacted waste on site for up to three years. Normally, waste will be removed to Vaalputs every year. The inventory of waste to be shipped will then be compiled. An example of such a store in use at the Koeberg Nuclear Power Station is shown in **Figure 5.5Figure 5.5**. This process will include compilation of shipments, preparation of documentation, updating the inventory and final inspection of the containers for surface contamination and completeness of the data set.

Some of the abnormal waste will require storage to allow for decay of activity prior to disposal at Vaalputs as LILW-SL. Some of the waste in this group should be kept in storage on site until a facility is available where handling of abnormal waste and its decontamination can be accomplished. Abnormal waste that does not meet acceptance criteria for LILW-SL will be retained in on-site storage until a suitable repository is licensed.

Figure 5.5: **Example of a LILW store at the Koeberg Nuclear Power Station used for the storage of LILW.**

5.4.6 Disposal of Solid Radioactive Waste

In terms of the National Radioactive Waste Disposal Institute Act, (Act 53 of 2008), the National Radioactive Waste Management Institute owns and operates the Vaalputs radioactive waste disposal facility. However, the Institute is not yet operational and as an interim measure the South African Nuclear Energy Corporation (Necsa) continues to fulfil these obligations.

In terms of the National Radioactive Waste Management Policy and Strategy, Vaalputs is the designated facility for the disposal of LILW in South Africa. Disposal at the site is carried out in terms of a nuclear authorisation granted by the NNR under the National Nuclear Regulator Act (1999). The bulk of the LILW disposed of at Vaalputs at present and for which authorisation was granted, is generated by the Koeberg Nuclear Power Station.

Early in 2007, Necsa submitted an Authorisation Change Request (ACR) to the NNR for the disposal of a national inventory of LILW. The inventory derived for this purpose made provision for future Koeberg Nuclear Power Station waste, waste from the proposed Pebble Bed Modular Reactor (PBMR), as well as waste generated by a second Nuclear Power Station. The post-closure radiological safety assessment (PCRSA) prepared for this purpose is extensively documented in Van Blerk (2007) and Kozak (2007). The assessment context for the 2007 Vaalputs PCRSA assumed a total of 10 PBMR type reactors (van Blerk, 2006). The NNR still have to respond to the ACR.

Beyleveld (2006) presents a detailed description of the waste containers used for the disposal of LLW and ILW at Vaalputs. Standardised containers (in terms of dimensions and mass) are being used as far as practicable to ensure uniformity, compatibility and safe handling during all waste management processes. A 210 L metal container and the Koeberg Nuclear Power Station types C1, C2, C3 and C4 concrete containers are currently being regarded as standard containers. Examples of these are shown in **Figure 5.6**.

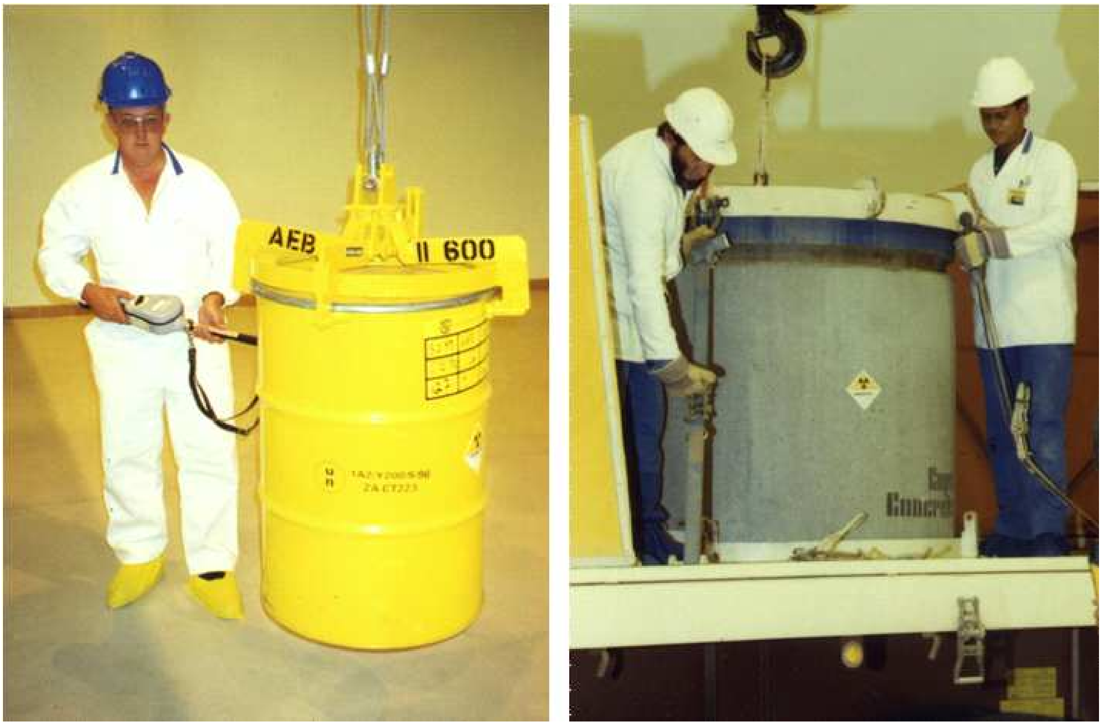

Figure 5.6: Waste packages currently being used for the disposal of LILW at Vaalputs are metal containers (left) and concrete containers (right)

Near surface trenches are currently being used as disposal concept at Vaalputs. As shown in **Figure 5.7**, two sets of trenches are presently being used for the disposal of LLW and ILW. The area set aside for LILW disposal is 500 m by 700 m. **Figure 5.8** presents the provisional trench layout until the assumed closure date of 2036, which takes into account a ratio between LLW to ILW of 3:1. The provisional trench layout may be changed in future in accordance with disposal needs. From **Figure 5.8** it is clear that a large part of the disposal area has been allocated to the waste from the 10 PBMR reactors. According to **Figure 5.8**, the following trenches are being reserved for Nuclear-1 LILW (van Blerk, 2007):

- Section A: 8 trenches for Nuclear-1 ILW that can accommodate 3,200 type C1 concrete containers; and
- Sector B: 7 trenches for Nuclear-1 LLW that can accommodate 11,550 210 L metal containers.

The number of containers assumed for a 60 year operational lifetime of the Nuclear-1 Nuclear Power Station for the national inventory of waste consist of (ESKOM, 2010):

- In total 28,200 of 210 litre capacity metal containers, with a total volume of 5,922 m^3 and a total weight of between 1,410 and 2,820 tons.
- 9,600 C4 concrete containers, with a total volume of 3,677 m^3 and a total weight of 60 480 tons.

Figure 5.7: Examples of the near surface trenches used for the disposal of LLW (top) and ILW (bottom) at Vaalputs.

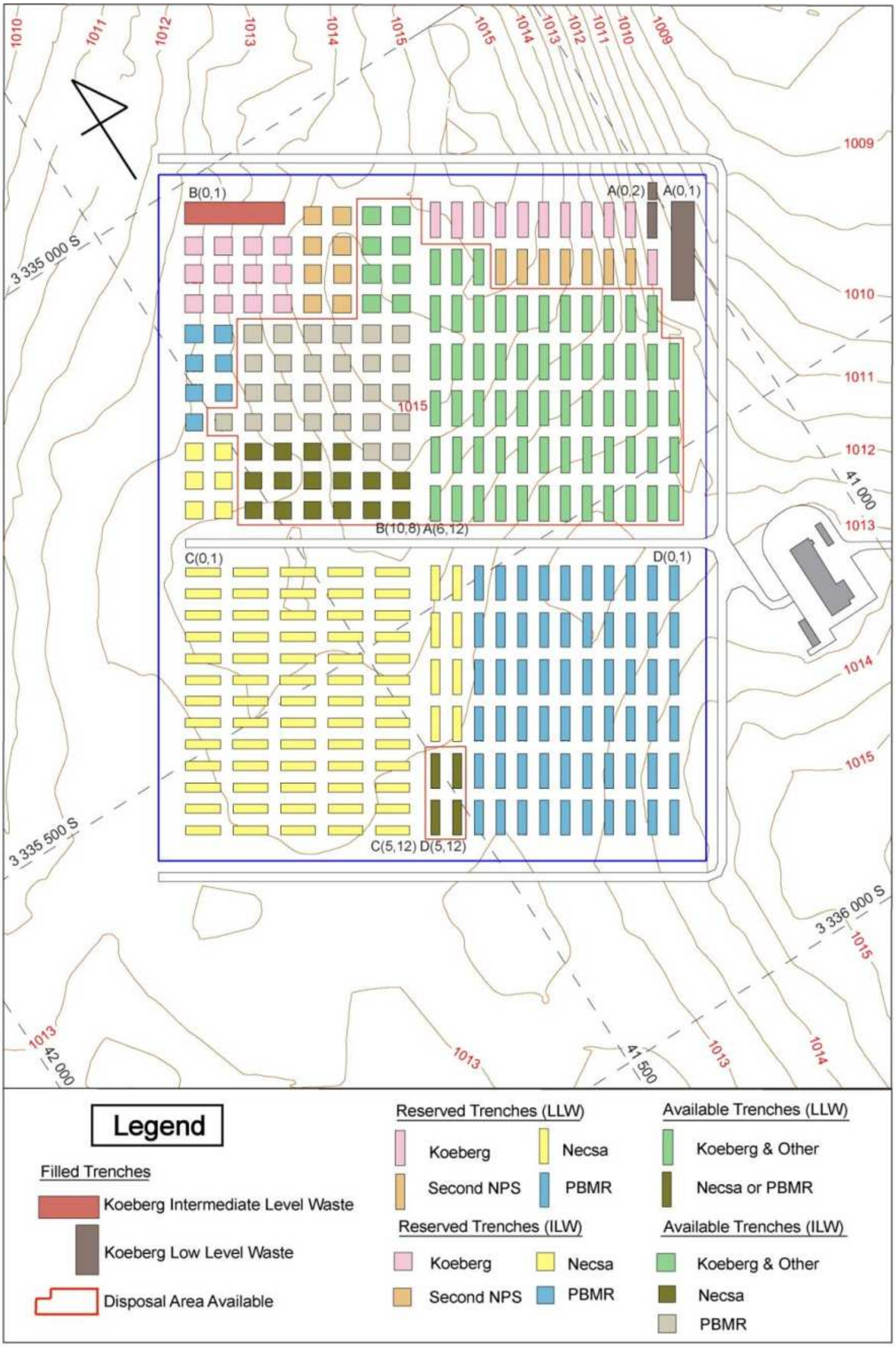

Figure 5.8: **Provisional trench layout for the disposal of LILW at Vaalputs**

This means that if the current trench dimensions are used, 17 trenches would be required to disposal of the LLW containers, while 24 trenches would be required to disposal of the ILW containers. LLW were assumed to be compacted without any concrete or cement stabilisation. ILW were assumed to be solidified in a cement matrix inside the concrete container, similar to current operational practices at the Koeberg Nuclear Power Station. A revision of the proposed trench layout may be required, considering the fact that the PBMR may not be constructed for a considerable time given the current state of that company. The PBMR waste in all likelihood would thus be less.

5.4.7 Transport of Solid Radioactive Waste to Vaalputs

At present, all radioactive waste disposed of at Vaalputs is being transported to the site by road. In terms of the safety standards and regulations, transport should be carried out according to the provisions of the IAEA Regulations for the Safe Transport of Radioactive Material (IAEA, 2009). According to these Regulations, transport of radioactive waste to Vaalputs is subject to the following general provisions to protect persons, property and the environment:

- an appropriate radiation protection programme to ensure adequate protection for workers and the public along the transport route. Compliance criteria for this purpose are published in the safety standards;
- an emergency response programme and procedures in the unlikely event of an accident or incident during the transport of radioactive waste; and
- a quality assurance programme for the design, manufacturing, testing, documentation, use maintenance and inspection of waste packages to ensure compliance with the relevant provisions of the Regulations.

The bulk of the waste currently disposed of at Vaalputs originates from the Koeberg Nuclear Power Station. Waste is being transported to Vaalputs in consignments in specially designed trucks (Eskom, 2000).

The number of metal and concrete containers shipped to Vaalputs annually, varies depending on the availability of open trenches and meeting the Vaalputs waste acceptance requirements. On average, 160 concrete containers and 720 metal containers are being shipped to Vaalputs annually. This equates to about 32 concrete containers consignments and 6 metal container consignments, given that 5 concrete containers and 120 metal containers are transported per shipment. The shipment schedule is agreed between the Koeberg Nuclear Power Station and Vaalputs management (e-mail communication 25/10/2007, Rodelo Bougard).

The preparation of a shipment of solid waste is being done according to the procedure described in Eskom (2005). The purpose of this procedure is:

- to implement the requirements of the Waste Acceptance Criteria for Vaalputs, the International IAEA transport regulations and any other applicable standards and/or procedures for all shipments of solid radioactive waste generated at the Koeberg Nuclear Power Station;
- to describe radiation protection responsibilities for processing of solid low and intermediate level radioactive waste and its accompanying documentation;
- to process and administrate solid radioactive waste containers;

- to provide guidance to radiation protection personnel for surveillance aspects and requirements of radioactive waste handling, prior to and during its shipment; and
- to set out steps to be followed in order to determine the radioactivity in radioactive waste containers.

The emergency plan for the transport of radioactive waste to Vaalputs is described in Eskom (2000) and includes:

- responsibilities;
- general and specific instructions for drivers;
- normal operation instructions for drivers;
- instructions for drivers in case of radio failure, in an event of (or involvement in) a traffic accident, or mechanical breakdown;
- instructions for the Central Alarm Station principle instructor;
- emergency instructions in the event of any abnormal occurrence during shipment of radwaste; and
- transport emergency response plan.

5.5 Management of High-level Waste

5.5.1 General

The characteristics of high-level waste (HLW) that will be generated by Nuclear-1 Nuclear Power Station were presented in Section 4.4.6.

It follows from Section 2.2 that South Africa still has to formulate a strategy for the long-term management of HLW, including spent fuel. Until such time, all spent fuel is stored temporarily either in spent fuel pools (wet storage), or in dry cask storage facilities (dry storage). This allows the shorter-lived isotopes to decay before further handling, a management strategy that is acceptable from a safety perspective. An international panel of experts on the long-term storage of radioactive waste (IAEA, 2003d) developed a position paper (IAEA, 2003d), in which they clearly state that the storage of radioactive waste has been demonstrated to be safe over some decades and can be relied upon to provide safety as long as active surveillance and maintenance is ensured.

The Radioactive Waste Management Programme to be developed for Nuclear-1 Nuclear Power Station will include procedures for the predisposal management of HLW, including storage of the spent fuel.

Further guidelines for the predisposal management of HLW is presented in IAEA (2003a).

5.5.2 Storage of Koeberg Nuclear Power Station Spent Fuel

Internationally, spent fuel is sent either for reprocessing (for re-use as nuclear fuel), or it is sent to a national repository for HLW. In South Africa neither of these options currently exists and the only feasible alternative currently available is for Eskom to store HLW in the Nuclear-1 generator building, as is the case at Koeberg. The proposed Nuclear-1 facility must be designed in such a way that such long-term storage within the generator building is possible.

Typically spent fuel is stored in the reactor building or a purpose built building situated on the aseismic nuclear island, either under water in a spent fuel pool (wet storage – see Figure 5.9Figure 5.9) or in specially constructed steel or concrete lined casks (dry storage – see Figure 5.10).). Since the Koeberg Nuclear Power Station began operating, Eskom has evaluated options such as reprocessing of spent fuel, buying special storage casks and building a facility, in which to house casks or putting high density racks into the existing spent fuel pools. In 1996, a decision was taken to implement high density racks (wet storage). It is expected that standard wet storage will be implemented at the proposed Nuclear-1 Nuclear Power Station, supplemented with dry storage as appropriate.

Wet storage of spent fuel in a spent fuel pool typically employs high density racks for storing fuel assemblies, which include integral neutron absorbing material to maintain the required degree of sub-criticality. The racks are designed to store fuel of the maximum design basis enrichment and with sufficient capacity to contain these assemblies for the life of the station (60 years) plus 10 years (Eskom e-mail, 2010). Should a HLW repository or any other long term management solution for spent fuel not be available after 70 years, the storage facility on site (or elsewhere) will have to be upgraded and refurbished to store and manage such spent fuel and other HLW for a further extended period. Each rack in the spent fuel pool consists of an array of cells interconnected to each other at several elevations and to a thick base plate at the bottom elevation. These rack modules are free-standing, neither anchored to the pool floor nor braced to the pool wall (Westinghouse, 2007b).

Figure 5.9: An example of a wet storage facility for spent nuclear fuel.

Water cools the fuel rods in the spent fuel pool and serves as an effective shield to protect workers in the fuel storage building from radiation. The spent fuel pool cooling system is designed to remove decay heat which is generated by stored fuel assemblies from the water in the spent fuel pool. This is done by pumping the high temperature water from within the fuel pool through a heat exchanger and then returning the water to the pool. A secondary function of the spent fuel pool cooling system is clarification and purification of the water in the spent fuel pool. Radioactive corrosion products, fission product ions and dust is removed from the spent fuel pool cooling system to maintain low activity levels and to maintain water clarity during all modes of plant operation. The spent fuel pool cooling system purification capability is such that the occupational radiation exposure is minimised to support as-low-as-reasonably achievable (ALARA) goals (Westinghouse, 2007b).

The rationale for onsite storage of spent fuel is to allow residual heat generated by the fuel and the radioactivity of the spent fuel to decrease. For the Koeberg Nuclear Power Station it is estimated that only 0.92% of the initial radioactivity remains in the spent fuel assembly after one year of storage in the spent fuel pool. Because the radioactive nuclides in the material decay so quickly, after 10 years which is the earliest time at which the assemblies would be taken out of the fuel pool, only 1% of the original radioactivity remains[12]. Note that the activity concentrations of long-lived isotopes will not be significantly affected by radioactive decay during this period. Depending on the half-life, it could take hundreds to thousands of years to decay to insignificant levels.

Figure 5.10: An example of a dry storage facility for spent nuclear fuel

Koeberg will start loading between 30 and 40 years worth of spent fuel, currently in the pools, into casks for storage in a dry storage facility, between 2015 and 2022. Koeberg's spent fuel pools are likely to be much larger than those of Nuclear-1, which will most likely only have 10 to 15 years of wet storage capacity. A dry storage facility will thus have to be constructed for the Nuclear-1 Nuclear Power Station to

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[12] http://www.eskom.co.za/live/content.php?Item_ID=208&Revision=en/0.

accommodate cooled, spent fuel for the operational lifetime of the facility and possibly for an additional 10 years after plant closure.

Larger items (classified as HLW) will be stored in purpose designed storage casks and sufficient space has been provided for the storage of such casks within the HLW storage area that is also located on the nuclear island. Such items will be generated during the refurbishment of the reactor and typically be reclassified after a decay period.

5.5.3 Reprocessing of Nuclear-1 Nuclear Power Station Spent Fuel

Reprocessing is a chemical process to separate any usable elements (e.g. uranium and plutonium) from fission products and other materials in spent fuels. Usually the goal is to recycle the reprocessed uranium or place these elements in new mixed oxide fuel.

While reprocessing of spent fuel is not excluded as an option for spent fuel management in the National Radioactive Waste Management Policy and Strategy (See Section 2.2.10), there is no intention to reprocess the Nuclear-1 Nuclear Power Station spent fuel at present. The main reason for this is the very high cost associated with spent fuel reprocessing.

5.5.4 Disposal of Spent Fuel

The National Radioactive Waste Management Policy and Strategy (see Section 2.2) clearly suggests that a long-term management strategy for spent fuel in South Africa has not been agreed upon. Internationally, several counties are in the process of formulating and developing long-term management solutions for their spent fuel. The preferred solution is geological disposal[13], mainly for its passive safety features, multiple safety functions in terms of natural and engineered barriers, containment of the waste and excellent ability to isolate the waste from the biosphere and humans over the long term.

Section 1 will review some of the trends and strategies followed internationally for the long-term management of HLW, including spent fuel.

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[13] *The term geological disposal refers to the disposal of solid radioactive waste in a facility located underground in a stable geological formation (usually several hundreds of meters or more below the surface) so as to provide long term isolation of the radionuclides in the waste from the biosphere IAEA (2006d), Geological Disposal of Radioactive Waste, Safety Standard Series No. WS-R-4, International Atomic Energy Agency and OECD Nuclear Energy Agency, Vienna..*

6 International Basis for Management of High-level Waste Disposal

6.1 General

The IAEA fundamental safety principles are clear that the prime responsibility for safety - including the safe control of radioactive waste management - rests with the person or organisation responsible for facilities and activities that give rise to the radiation risk (IAEA, 2006c). However, the ultimate responsibility for ensuring the safety of spent fuel and radioactive waste rests with the State, through the establishment of a legal and governmental infrastructure for nuclear, radiation, radioactive waste and transport safety (IAEA, 2000). This is confirmed in the Preamble to the Joint Convention on the Safety of Spent Fuel Management and the Safety of Radioactive Waste (IAEA, 2006a).

Witherspoon and Bodvarsson (2001) provide an extensive review of the geological challenges in radioactive waste isolation, which includes status reports on waste isolation projects from 32 countries. According to the review, there are two basic challenges in perfecting a system of radioactive waste isolation: choosing an appropriate geological barrier (host medium) and designing an effective engineered barrier. The review highlighted the positive contribution of underground research laboratories (URL) to waste isolation research and the challenges with public acceptance of the management of radioactive waste isolation projects.

Other highlights include (Witherspoon and Bodvarsson, 2001):

- approval of Decision in Principle for a final disposal facility for high-level waste (HLW) to be built at Olkiluoto in Finland in 2001;
- developments in site selection and specialised waste emplacement equipment in Sweden;
- the development of the Yucca Mountain project in the USA; and
- the developments at the Waste Isolation Pilot Plant (WIPP) located in New Mexico, which is the world’s first deep geological disposal facility.

Spent fuel is regarded differently by countries — as a resource by some and as a waste by others. The strategies for its management also vary, ranging from reprocessing to direct disposal. However, in both cases a final solution is needed and it is generally agreed that disposal deep in geological formations is the most appropriate solution (IAEA, 2007a).

In all countries, the spent fuel or the high-level waste from reprocessing are currently being stored, usually above ground, awaiting the development of geological repositories. While the arrangements for storage have proved to be satisfactory and have been operated without major problems, it is generally agreed that these arrangements are interim, that is they do not represent a final solution (IAEA, 2007a). It is becoming increasingly important to have final disposal arrangements available so as to be able to demonstrate that nuclear power is sustainable and that it does not lead to an unsolved waste problem.

A summary of the National Radioactive Waste Management Policy and Strategy (DME, 2005) is presented in Section 2.2, according to which Government should initiate investigations into the best long-term option for the management of spent fuel.

The purpose of this section is to discuss the international basis for the management of HLW disposal and to compare the National Radioactive Waste Management Policy and Strategy to that basis. The discussion begins with an overview of the applicable articles contained in the Joint Convention on Spent Fuel and Radioactive Waste Management, in Section 6.2.

In Section 6.3 to Section 6.8, basic concepts for radioactive waste management from the international literature are reviewed. These concepts are compared with current South African policy in Section 6.9.

6.2 Joint Convention on Spent Fuel and Radioactive Waste Management

The objectives of the Joint Convention on Spent Fuel and Radioactive Waste Management as stipulated in Article 1 of Chapter 1 are (IAEA, 2006a):

- to achieve and maintain a high level of safety worldwide in spent fuel and radioactive waste management, through the enhancement of national measures and international co-operation, including where appropriate, safety-related technical co-operation;
- to ensure that during all stages of spent fuel and radioactive waste management there are effective defences against potential hazards so that individuals, society and the environment are protected from harmful effects of ionising radiation, now and in the future, in such a way that the needs and aspirations of the present generation are met without compromising the ability of future generations to meet their needs and aspirations; and
- to prevent accidents with radiological consequences and to mitigate their consequences should they occur during any stage of spent fuel or radioactive
- waste management.

South Africa is a signatory to the Joint Convention, with its entry into force as of February, 2007[14]. The Joint Convention is legally binding on its contracting parties and requires that spent fuel and radioactive waste management are conducted with regard to accepted norms of safety. The safety norms are derived from the recommendations of the international safety standards, which establish best safety practices based on worldwide experience in the field (IAEA, 2007a).

The Convention applies to the safety of spent fuel management when the spent fuel results from the operation of civilian nuclear reactors. Chapter 2 (Article 4 to Article 10) deals directly with the management of spent fuel and contains the following provisions (IAEA, 2006a):

Article 4 General safety requirements

Each Contracting Party should take the appropriate steps to ensure that at all stages of spent fuel management, individuals, society and the environment are adequately protected against radiological hazards. In so doing, each Contracting Party should take the appropriate steps to:

- ensure that criticality and removal of residual heat generated during spent fuel management are adequately addressed;

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[14] See the website *http://www.iaea.org/*Publications/Documents/Conventions/jointconv_status.pdf for a status report.

- ensure that the generation of radioactive waste associated with spent fuel management is kept to the minimum practicable, consistent with the type of fuel cycle policy adopted;
- take into account interdependencies among the different steps in spent fuel management;
- provide for effective protection of individuals, society and the environment, by applying at national level suitable protective methods as approved by the regulatory body, in the framework of its national legislation which has due regard to internationally endorsed criteria and standards;
- take into account biological, chemical and other hazards that may be associated with spent fuel management;
- strive to avoid actions that impose reasonably predictable impacts on future generations greater than those permitted for the current generation; and
- aim to avoid imposing undue burdens on future generations.

Article 5 Existing facilities

Each Contracting Party shall take the appropriate steps to review the safety of any spent fuel management facility existing at the time the Convention enters into force for that Contracting Party and to ensure that, if necessary, all reasonably practicable improvements are made to upgrade the safety of such a facility.

Article 6 Siting of proposed facilities

Each Contracting Party shall take the appropriate steps to ensure that procedures are established and implemented for a proposed spent fuel management facility:

- to evaluate all relevant site-related factors likely to affect the safety of such a facility during its operating lifetime;
- to evaluate the likely safety impact of such a facility on individuals, society and the environment;
- to make information on the safety of such a facility available to members of the public; and
- to consult Contracting Parties in the vicinity of such a facility, insofar as they are likely to be affected by that facility and provide them, upon their request, with general data relating to the facility to enable them to evaluate the likely safety impact of the facility upon their territory.

In so doing, each Contracting Party shall take the appropriate steps to ensure that such facilities shall not have unacceptable effects on other Contracting Parties by being sited in accordance with the general safety requirements of Article 4.

Article 7 Design and construction of facilities

Each Contracting Party shall take the appropriate steps to ensure that:

- the design and construction of a spent fuel management facility provide for suitable measures to limit possible radiological impacts on individuals, society and the environment, including those from discharges or uncontrolled releases;
- at the design stage, conceptual plans and, as necessary, technical provisions for the decommissioning of a spent fuel management facility are taken into account; and

- the technologies incorporated in the design and construction of a spent fuel management facility are supported by experience, testing or analysis.

Article 8 Assessment of safety of facilities

Each Contracting Party shall take the appropriate steps to ensure that:

- before construction of a spent fuel management facility, a systematic safety assessment and an environmental assessment appropriate to the hazard presented by the facility and covering its operating lifetime shall be carried out; and
- before the operation of a spent fuel management facility, updated and detailed versions of the safety assessment and of the environmental assessment shall be prepared when deemed necessary to complement the assessments referred to in previous paragraph.

Article 9 Operation of facilities

Each Contracting Party shall take the appropriate steps to ensure that:

- the licence to operate a spent fuel management facility is based upon appropriate assessments as specified in Article 8 and is conditional on the completion of a commissioning programme demonstrating that the facility, as constructed, is consistent with design and safety requirements;
- operational limits and conditions derived from tests, operational experience and the assessments, as specified in Article 8, are defined and revised as necessary;
- operation, maintenance, monitoring, inspection and testing of a spent fuel management facility are conducted in accordance with established procedures;
- engineering and technical support in all safety-related fields are available throughout the operating lifetime of a spent fuel management facility;
- incidents significant to safety are reported in a timely manner by the holder of the licence to the regulatory body;
- programmes to collect and analyse relevant operating experience are established and that the results are acted upon, where appropriate; and
- decommissioning plans for a spent fuel management facility are prepared and updated, as necessary, using information obtained during the operating lifetime of that facility and are reviewed by the regulatory body.

Article 10 Disposal of spent fuel

If, pursuant to its own legislative and regulatory framework, a Contracting Party has designated spent fuel for disposal, the disposal of such spent fuel shall be in accordance with the obligations of Chapter 3 relating to the disposal of radioactive waste.

6.3 General Principles

Disposal of radioactive waste has to be planned and implemented in a way that considers long-term safety and radiation protection of the public and environment without imposing an undue burden on the future generations (IAEA, 2006d). Disposal involves the emplacement of waste in approved, licensed and specified facilities. Internationally, the strategy adopted at present to protect the public and environment without imposing an undue burden on the future generations is to concentrate and contain the waste and to isolate it from the biosphere. The degree of containment and isolation of radioactive waste depends on the performance of the disposal system as a whole and it is necessary to consider the integrated performance of any waste disposal option adopted.

The fundamental principles for radioactive waste management also reflect the basic international consensus on the overall structure of ensuring waste safety. The ICRP principles for radiation protection were extended to focus on disposal issues (ICRP, 1997; 2000a; b) and these also reflect the basic principles elaborated by IAEA (1989; 1995; 2006c). In addition, these principles are embodied in the legal framework for radioactive waste management, which is described in detail by IAEA (2000).

According to the IAEA fundamental safety principles, radioactive waste disposal facilities must meet a series of ten basic principles (IAEA, 1989; 1995; 2006c):

- Principle 1: Responsibility of safety. The prime responsibility for safety must rest with the person or organisation responsible for facilities and activities that give rise to radiation risks.
- Principle 2: Role of government. An effective legal and governmental framework for safety, including an independent regulatory body, must be established and sustained.
- Principle 3: Leadership and management for safety. Effective leadership and management for safety must be established and sustained in organisations concerned with and facilities and activities that give rise to, radiation risks.
- Principle 4: Justification of facilities and activities. Facilities and activities that give rise to radiation risks must yield an overall benefit.
- Principle 5: Optimisation of protection. Protection must be optimised to provide the highest level of safety that can reasonably be achieved.
- Principle 6: Limitation of risks to individuals. Measures for controlling radiation risks must ensure that no individual bears an unacceptable risk of harm.
- Principle 7: Protection of present and future generations. People and the environment, present and future, must be protected against radiation risks.
- Principle 8: Prevention of accidents. All practical efforts must be made to prevent and mitigate nuclear or radiation accidents.
- Principle 9: Emergency preparedness and response. Arrangements must be made for emergency preparedness and response for nuclear or radiation incidents.
- Principle 10: Protective actions to reduce existing or unregulated radiation risks. Protective actions to reduce existing or unregulated radiation risks must be justified and optimised.

The application of these principles imposes unique constraints on radioactive disposal facilities. Their safety must be assured over unprecedented timescales and must be capable of functioning in these far distant times without human intervention (Principles 6 and 7). These unique constraints must be kept in mind when considering options for waste disposal.

These principles apply to all periods of the lifetime of the disposal facility. Consequently, operational safety assessments are conducted to adhere to these principles, as well as conducting a post-closure safety assessment for a very long period after facility closure. Safety assessments for the operational period follow well-established patterns for establishing the safety of nuclear facilities. Post-closure safety assessments, however, require consideration of additional features of the repository, conducted for very long periods.

The timescales of interest for post-closure safety assessment depend on the nature of the waste disposal system and the external influences on it and the longevity of the radionuclides in the wastes. Short-lived radionuclides might only require assessments for a timescale in the order of 10^3 years, whereas longer lived radionuclides might require assessment over timescales in excess 10^5 years. Timescales can also be determined by national legislation governing the disposal of radioactive waste. Regardless, safety considerations are applied to radioactive waste requiring consideration of possible impacts on the system over many generations. These impacts are evaluated using a post-closure safety assessment of the disposal system.

A key challenge for post-closure safety assessment is the need to try to account for future changes in the disposal system, even over relatively short timescales. Indeed, IAEA (2003c) notes that challenges associated with projecting the behaviour of the system over long timescales is one of the key aspects that distinguishes post-closure assessments from operational safety assessments. Significant releases from a radioactive waste disposal facility might not occur for many hundreds or thousands of years after disposal. Over such timescales, it is clearly unrealistic to forecast human habits and behaviour.

This problem is compounded by the fact that changes to the disposal system, due to factors such as climate change, are also likely to occur over the timescales of potential interest. Changes may also arise from the natural evolution of the disposal system (for example the degradation of engineered barriers). Thus, any safety assessment of a disposal system must inevitably remain an estimate of what will actually occur in the future at a given location. It must not be seen as a prediction of future impacts (IAEA, 2003c).

6.4 Interdependencies in Waste Management

Basic steps in radioactive waste management are pre-treatment, treatment, conditioning, storage and disposal. Pre-treatment refers to all activities prior to modification of the waste in its chemical or physical form for subsequent conditioning. Conditioning refers to modifications of the waste to prepare for disposition of the waste. Storage refers to both onsite and offsite storage of the waste, in which there is no intention to permanently leave the waste at the storage facility. Disposal refers to final disposition of the waste with no intention to retrieve the waste.

There are interdependencies among and between steps in waste management. Decisions on radioactive waste management made at one step may foreclose alternatives for, or otherwise affect, a subsequent step. Furthermore, there are relationships between waste management steps and operations that generate either radioactive waste or materials that can be recycled or reused. It is desirable that those responsible for a particular waste management step or operation generating waste adequately recognise interactions and relationships so that safety and effectiveness of radioactive waste management are balanced. This includes taking into account identification of waste streams, characterisation of waste and the implications of transporting radioactive waste. Conflicting requirements that could compromise operational and long-term safety should be avoided.

Some of the key interdependencies occur between conditioning and disposal. Conditioning technologies should be undertaken with final waste form and compatibility with the disposal technology in mind. For instance, conditioning waste in a cementitious waste form should be planned with the dimensions and chemical conditions of the final repository in mind. Similarly, the repository design should account for existing conditioned waste, to ensure that the repository will be adequate to dispose of waste intended for disposal.

Since the steps of radioactive waste management occur at different times, there are, in practice, many situations where decisions must be made before all radioactive waste management activities are established. To the extent possible, the effects of future radioactive waste management activities, particularly disposal, should be taken into account when any one radioactive waste management activity is being considered (IAEA, 1995).

The interdependencies in the stages of waste management provide a linkage between predisposal and disposal phases of waste management.

6.5 Strategy for the Disposal of Radioactive Waste

6.5.1 General

Chapter 4 of the Joint Convention requires the existence of a national legal framework for radioactive waste management (Article 19). This national legal framework must take cognisance of the overall strategy for managing waste within the country. The strategy in turn must account for waste generated by the Nuclear Power Station and provide a route for disposition of all waste streams. Such a strategy requires planning the overall system of disposal within a country.

6.5.2 National Planning for Waste Disposal

Nuclear power at national level is controlled at two levels. The government provides legislation, while the regulatory body supervises and control nuclear installations and the operating organisation.

The government establishes a legislative and statutory framework for the regulation of nuclear installations. Clear separation of responsibilities and organisation is necessary between the regulatory body and the operating organisation.

A legal framework needs to be established to provide for the regulation of nuclear activities and for the clear assignment of safety responsibilities. The government of a country that uses nuclear installations is responsible for the adoption of legislation. This legislation should separate exploitation and surveillance of the nuclear installation between operating organisations and the regulatory body. The primary objectives of such legislation should be:

- to provide the statutory basis for establishing a regulatory body;
- to provide the legal basis for ensuring that nuclear installations are sited, designed, constructed, commissioned, operated and decommissioned without

undue radiological risk to the site personnel and to the public and with proper regard to protecting the environment;

- to provide adequate financial indemnification to third parties in the event of nuclear accident, in view of the potential magnitude of damage and injury which may arise from the accident; and
- to provide the regulatory body with the power to establish and enforce the necessary regulations with respect to nuclear safety.

The government of a member state embarking on or implementing a nuclear power program establishes a regulatory body for the surveillance of such a program. The planning for a regulatory body and the development of legislation should start in advance of the construction of the first nuclear installation.

The regulatory body acts independently of designers, constructors and operators to the extent necessary to ensure that safety is the only mission of the regulatory personnel. An additional important function of the regulatory body is to communicate independently its regulatory decisions and opinions and their bases to the public. The regulatory body has licensing, inspection and enforcement responsibilities and must have adequate authority, competence and resources to fulfil its assigned responsibilities.

Expertise must be available to the regulatory body in a sufficiently wide range of nuclear technologies. Depending on the activities conducted in the country, expertise should cover the following functional areas:

- specification and development of standards and regulations for safety;
- issuing of licenses to operating organisations, following appropriate safety assessments;
- inspection, monitoring and review of the safety performance of nuclear installations and operating organisations;
- requiring corrective actions of an operating organisation where necessary and taking any necessary enforcement actions, including withdrawal of a license, if acceptable safety levels are not achieved;
- advocacy of safety research; and
- dissemination of safety information.

By contrast, operating organisations are responsible for:

- specifying safety criteria;
- assuring itself that the design, construction and operation of the installation meet the relevant safety standards;
- establishing policy for adherence to safety requirements;
- establishing procedures for safe control of the installation under all conditions, including maintenance and surveillance;
- controlling fissile and radioactive materials;
- training its staff; and
- ensuring that responsibilities are well defined and documented.

The fulfilment of these responsibilities is done in accordance with applicable safety objectives and requirements established or approved by the regulatory body.

The operating organisation will usually delegate operating authority to the onsite management of the installation, which has the direct day-to-day control. Accordingly, the operating organisation has the responsibility to monitor the effectiveness of safety management at the installation and to take necessary measures to ensure that safety is maintained at the desired level.

The regulatory body issues licenses, so it has to make reviews during the lifetime of the installation. Systematic safety reassessments of the installation in accordance with the regulatory requirements should be performed throughout its operational lifetime, with account taken of operating experience and significant new safety information from all relevant sources.

6.5.3 Main Factors Used in Selecting Disposal Options

Final disposition of waste is understood to refer to final disposal. Other options, such as long-term storage do not represent final disposition. At some time in the future, all such alternative options must end in final disposal, for only disposal meets the fundamental principles of radioactive waste management (IAEA, 1995; 2006c) in the long term.

The initial stages of planning for waste disposal must address the types of waste existing and those planned to be produced. Given the types and volumes of waste to be addressed, as well as the costs and societal factors, it may be necessary to develop one or more disposal facilities.

Radioactive waste disposal facilities are faced with rigorous constraints on their performance. Their safety must be assured over unprecedented timescales and must be capable of functioning in these far distant times without human intervention. These unique constraints must be kept in mind when considering options for waste disposal.

Perhaps the most important fundamental distinction that arises in characterising disposal systems is depth to the waste. Disposal systems are characterised as either near-surface or geological disposal systems. Existing guidance puts the distinction between the two types of systems at “a few tens of meters below the ground surface” (IAEA, 1994b). More fundamentally, however, the distinction between near-surface and geological disposal facilities relates to the degree of isolation from human activities provided by the overburden soil.

Given the uncertainty about future conditions at the site, a basic concept is that near-surface disposal facilities should be, to a certain extent, intrinsically safe. This concept is based on the idea that over the long time periods for which safety must be assured, intrinsic safety is achieved by limiting the activity concentrations ($Bq.kg^{-1}$ or $Bq.m^{-3}$) acceptable in near surface disposal. Limiting the activity concentrations ensures that even if the disposal facility experiences a major disruption, resulting doses will not be excessive. In particular, experience in safety assessment has shown that doses resulting from inadvertent human intrusion are the most significant for near-surface disposal facilities and it is commonplace for activity concentrations to be established based on human intrusion analyses.

Inadvertent human intrusion is assumed to occur after some time has passed after closure of the facility. At that time, it is assumed that institutional control of the site is lost and that intrusive activities can proceed at the site without inhibition. It is important to note that these assumptions do not generally reflect an intention to release the site from institutional control, but are instead recognition that human institutions are fallible and that the facility should be safe even if memory of its existence is lost. Generally, it is assumed that institutional controls can be relied upon to prevent inadvertent human intrusion for 100 to 300 years.

Once activity concentrations acceptable for near-surface disposal have been established, remaining waste streams must be consigned to a disposal facility in which the likelihood of human intrusion is low and for which certain types of severe intrusion events are impossible. This is accomplished by consigning these wastes to a deep geological disposal facility. Consequently, a geological disposal facility may be appropriate for wastes in addition to HLW or spent fuel, if they are inappropriate for near-surface disposal.

IAEA (1994c) established a waste classification system to assist in identifying disposal options appropriate for each class of waste. This system is shown in Table 6.1. The system was derived from and is a generalisation of, the earlier classification system published by IAEA (1970). This system differs from systems of quantitative waste activity limits, in that only a limited amount of the activity-based information is included in the waste classification system and additional qualitative features of the waste are included.

Table 6.1: Waste Classification System of the IAEA (IAEA, 1994c).

Waste Class	Typical Characteristics	Disposal Options
Exempt Waste	Activity at or below clearance levels	No radiological restrictions.
Low and Intermediate Level Waste	Activity above clearance levels; heat output less than 2 kW m^{-3}.	
Short Lived Waste	Concentration of long-lived alpha radionuclides less than 4000 Bq g^{-1} in any package and 400 Bq g^{-1} averaged over all packages.	Near-surface or geological disposal facility.
Long Lived Waste	Long-lived radionuclide concentrations exceeding those for short-lived waste	Geological disposal facility.
High-level waste	Heat output greater than 2 kW m^{-3} and long-lived radionuclide concentrations exceeding the limitations for short-lived waste	Geological disposal facility.

Wastes in this system are defined as follows:

- *Exempt Waste* is of such low concentration that it can be exempted from further regulatory control in accordance with clearance levels, as the radiological hazard is negligible.
- *Low- and Intermediate-Level Waste* exceeds exemption status and also includes more highly active waste, which may include waste that requires remote handling. This category is further subdivided into *Short-lived* and *Long-lived* categories, which relate to the intended disposal technology.
- *High-Level Waste* is defined simply as that which requires a higher degree of isolation from the environment for long periods of time. These wastes will normally require both shielding and cooling.

Consequently, it can be seen that there is generally a need for two types of disposal systems, near-surface and geological disposal systems. Some countries have opted to use geological disposal for all classes of waste. The decision about the use of near-surface disposal is based on three primary factors: cost, perceived safety and land use. Near-surface disposal is less expensive to build and operate then geological disposal facilities. Consequently, from cost and operations viewpoints, there is no reason to use geological disposal facilities for LLW and certain classes of ILW. Furthermore, since many countries find near-surface disposal acceptable from a safety perspective, these costs may seem to be excessive. However, since the safety of geological disposal systems is perceived to be greater than that of near-surface disposal, some countries have gained improved public acceptance by using geological disposal for all waste. Also, not all countries have appropriate land available to develop near-surface facilities, leading them to choose the deeper option.

The waste classification system and waste acceptance criteria should be closely linked in the strategy for any specific country. One of the primary bases for developing waste acceptance criteria is the waste concentration, which in turn is a fundamental part of the waste classification system.

A variety of design alternatives have been proposed for both near surface and geological disposal facilities (IAEA, 2007a; Witherspoon and Bodvarsson, 2001). The selection of a design alternative among these options is generally made for practical considerations rather than any fundamental consideration. Numerous analyses comparing the function of a variety of near-surface designs show that all are capable of functioning to provide adequate safety.

6.6 Features of the Repository System

IAEA (2006d) describes several requirements for safety functions of a geological disposal facility: multiple safety functions, containment and isolation.

- Multiple safety functions: The natural and engineered barriers should be selected and designed to ensure long-term safety by means of multiple safety functions. That is, safety should be provided by multiple barriers whose performance is achieved by diverse physical and chemical processes.
- Containment: The engineered barriers, including the waste form and packaging, should be designed to provide a high level of containment of the waste, especially during the period when the waste produces significant quantities of heat and when radioactive decay can significantly reduce the hazard posed by the waste.
- Isolation: The disposal facility should be sited in a suitable geological formation and at sufficient depth to provide isolation of the waste from the biosphere and humans over the long term, at least for several thousands of years. Isolation, in this definition, is contrasted with containment, used in near-surface disposal descriptions.

Safety cases for geological disposal facilities and their supporting assessments must gather all the necessary information so as to elaborate convincing hypothesis on the functioning of the disposal facility. The safety case involves conduct of a safety assessment, which evaluates the functioning of the repository under all credible alternative external influences. However, additional arguments are included in the safety case, to develop a reasonable assurance of safety in all time periods of the disposal regime.

The disposal of radioactive waste is intended to isolate the waste from the accessible environment during a period sufficiently long to allow substantial decay of the shorter lived radionuclides and, in the longer term, to limit releases of the remaining radionuclides. In order to achieve these objectives, a multiple barrier concept is employed in which the waste form, the engineered barriers and the site itself all contribute to the isolation of the radionuclides. Multiple barrier concepts have been developed for both near surface and geological disposal options. It has reached a state of maturity due to the experience gained from developing and operating near surface repositories and from associated research and development. Both have provided valuable information for improvements in repository design and the technologies needed to implement them. Robust designs of engineered barrier systems should be employed in which a combination of physical barriers and chemical controls can provide a high level of isolation (IAEA, 2006d).

The major components of a disposal system generally include the waste form, the waste package, the engineered barrier system, the natural barrier system (geosphere) and the biological setting (biosphere) of the site (see **Error! Reference source not found.Error! Reference source not found.**). The waste form is the solid matrix in which the radionuclides are immobilised after treatment and/or conditioning, prior to packaging. The waste package, consisting of the waste form and container, is designed to meet the requirements for handling, transport, storage and disposal. In order to limit the release of radionuclides and other contaminants, some packages include additional features such as absorbing materials and liners.

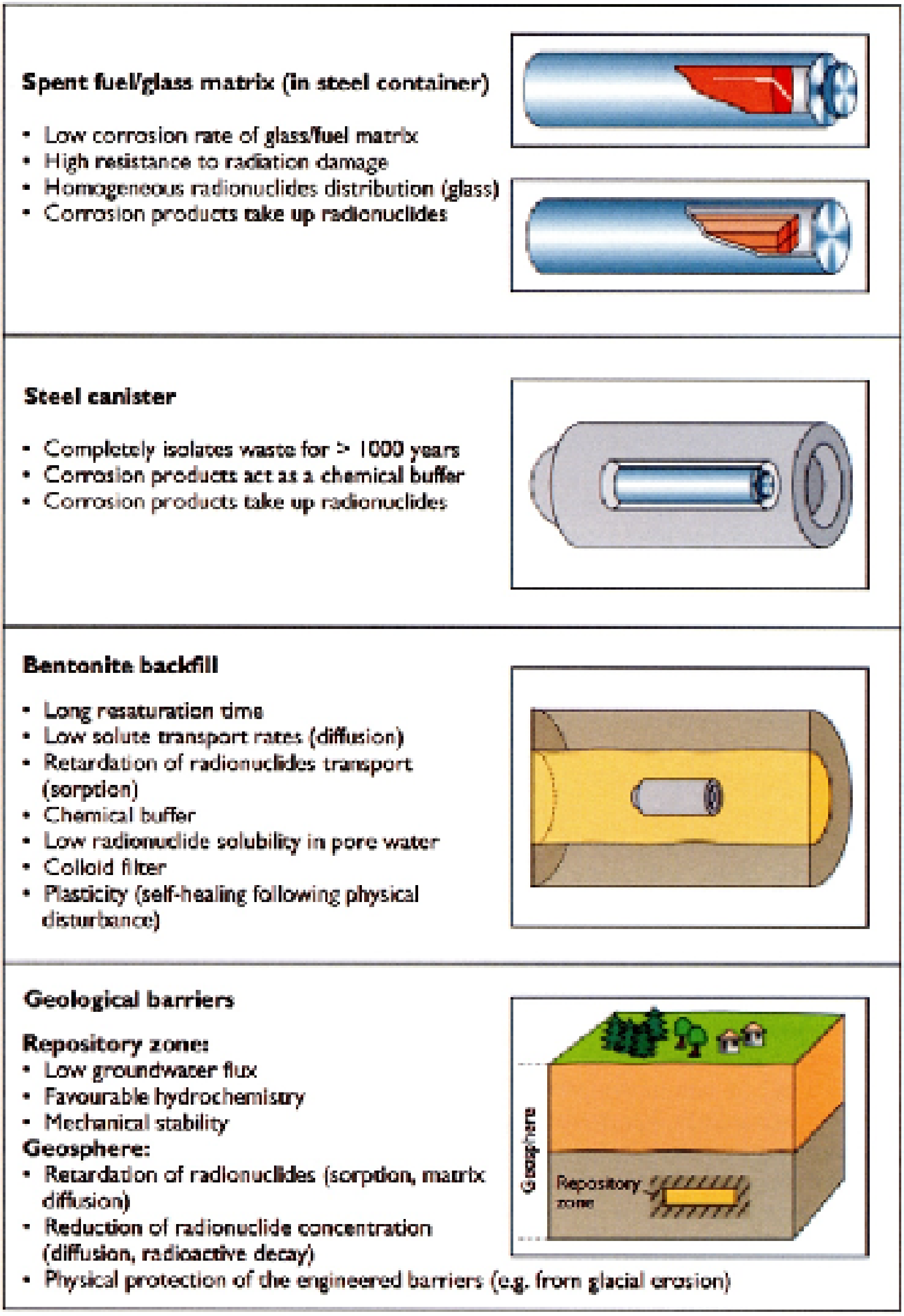
The primary components of repositories that mitigate releases are the near-field and the far-field. The near-field encompasses the engineered barriers of the waste package (composed of the waste form and a container) plus a backfill. Included in the near-field is a portion of the immediately surrounding rock that is significantly affected by the presence of the repository. The far-field consists of the undisturbed natural barriers (e.g., host rock and hydrologic setting). Taken together, these two sub-systems define a repository system of multiple, redundant and complementary barriers that act to assure the safe isolation of nuclear waste from the biosphere (see Figure 6.1 and Figure 6.2: Cutaway view of the **engineered barrier within an emplacement drift of the Yucca mountain geological repository (Dyer and Voegele, 2001)**

The biosphere is not considered a barrier to radionuclide release. IAEA (1999) suggested a stylised approach for selecting critical groups and biospheres in future situations where human behaviour or biosphere conditions cannot be known with any certainty. This approach is consistent with that adopted in areas of radiological protection where it is impracticable to establish the precise characteristics of exposed individuals. For example, a stylised ‘reference man’ is used in calculating annual limits of intakes and generic models of radionuclide behaviour are used to calculate dose coefficients.

6.7 Radioactive Waste Disposal Facilities Life Cycle

6.7.1 General

A disposal facility is developed in a staged manner. At each stage of the repository lifetime, it is necessary to demonstrate that the facility will be safe as proposed (IAEA, 2006d).



Spent fuel/glass matrix (in steel container)

- Low corrosion rate of glass/fuel matrix
- High resistance to radiation damage
- Homogeneous radionuclides distribution (glass)
- Corrosion products take up radionuclides

Steel canister

- Completely isolates waste for > 1000 years
- Corrosion products act as a chemical buffer
- Corrosion products take up radionuclides

Bentonite backfill

- Long resaturation time
- Low solute transport rates (diffusion)
- Retardation of radionuclides transport (sorption)
- Chemical buffer
- Low radionuclide solubility in pore water
- Colloid filter
- Plasticity (self-healing following physical disturbance)

Geological barriers

Repository zone:
- Low groundwater flux
- Favourable hydrochemistry
- Mechanical stability

Geosphere:
- Retardation of radionuclides (sorption, matrix diffusion)
- Reduction of radionuclide concentration (diffusion, radioactive decay)
- Physical protection of the engineered barriers (e.g. from glacial erosion)

Figure 6.1: Typical barriers in a geological repository design.

At each stage of the life cycle of the disposal facility, it is necessary to maintain the safety case, to ensure that safety will be maintained throughout. This means that the safety case needs periodic revision and updating to incorporate the most up-to-date information. As the understanding of the facility and its environs grows, the safety assessment may need to be updated as well. Such updates may be established in law, requiring a periodic review, or they may be requested by the regulatory authority to ensure that the safety case remains relevant to current practices and understanding at the site.

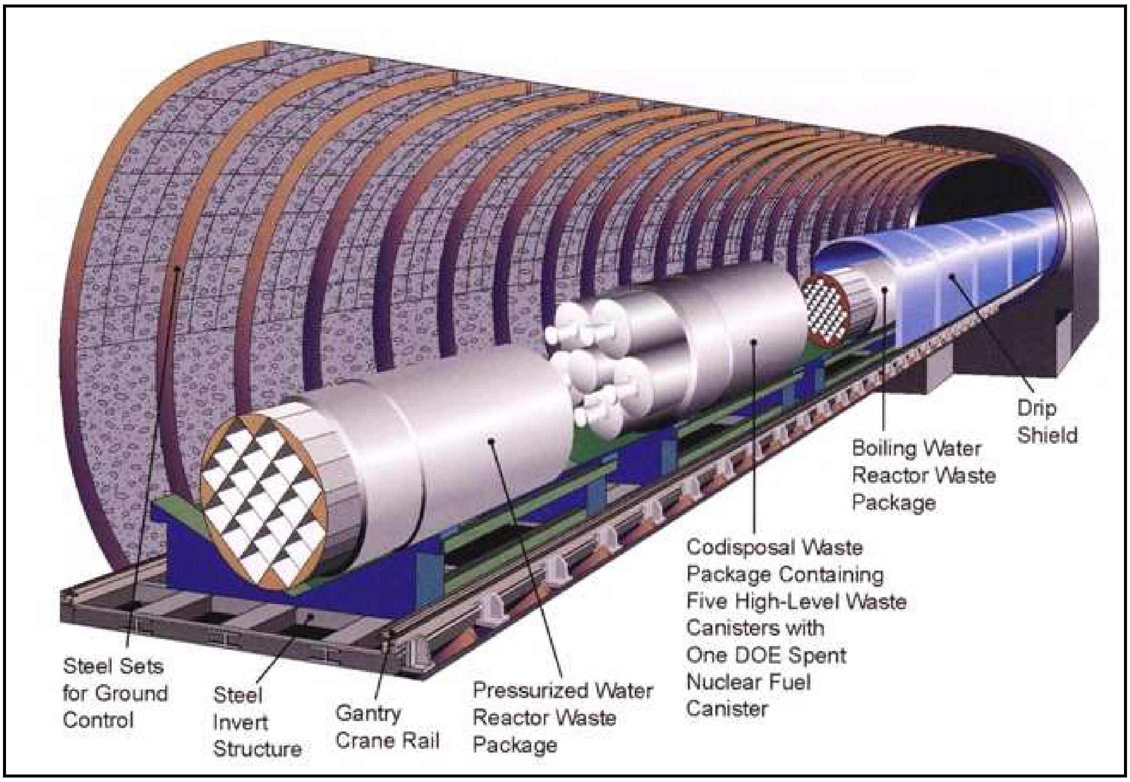


Figure 6.2: **Cutaway view of the engineered barrier within an emplacement drift of the Yucca mountain geological repository (Dyer and Voegele, 2001).**

6.7.2 Site Selection and Characterisation

IAEA (1994b) discusses features of siting near-surface disposal facilities and IAEA (1994a) discusses features of siting geological disposal facilities. The purpose of siting in either case is to identify a location that provides adequate geological stability and functionality to contribute to the long-term safety of the repository. It is particularly useful to note that the object of a siting process is not to identify the single best site possible, but rather to identify an adequate site among a number of possibilities. The goal of a siting process is to identify a suitable site in the areas of (Savage, 1995):

- long-term safety;
- safety in the operational period (short-term safety);
- technical feasibility;
- social acceptance;
- environmental considerations; and
- cost.

While technical considerations play a necessary role in site selection, political considerations have become far more important in recent years. Consequently, sites are currently often chosen based primarily on acceptance by the local population. With this additional constraint, it is necessary to ensure that site characteristics are adequate for the purpose of waste disposal.

Important technical characteristics for an acceptable site are stability and a lack of excessive complexity. Stability refers to geological stability: the site should not experience dramatic and unpredictable morphological changes over the period of concern for the safety assessment. An example of such changes for a geological disposal facility might be fault displacement or complex fracturing, leading to uncertainty in groundwater flow directions and rates. A lack of excessive complexity is intended to be a relative term, since all natural systems are complex at some level of detail. However, the intention here is to avoid locations with extreme types of behaviour, such as karstic formations, which defy attempts to understand their behaviour to the extent needed to produce a satisfactory safety case.

6.7.3 Design

The design of the repository should minimise the need for active maintenance after site closure and should complement the natural characteristics of the site to reduce any environmental impact. The design should take into account operational requirements, closure plan and other factors contributing to waste isolation and stability of the repository, such as protection of the waste from external events.

Geological disposal facilities include engineered barriers, which together with the emplacement medium and its surroundings isolate the waste from humans and the environment. The engineered barriers include the waste package and other human made features such as overpacks, mined excavations and backfills, which are intended to prevent or delay radionuclide migration from the repository to the surroundings.

Although disposal is defined as the emplacement of waste in an approved location without the intention of retrieval, some jurisdictions may nevertheless require that retrievability be designed into a repository. If the ability to retrieve waste is a design requirement, it should be considered in the design process in such a way as not to compromise long-term performance capabilities.

The design of any monitoring program should not compromise the long-term performance of the disposal system.

6.7.4 Construction

The construction stage can only start after regulatory authorisation has been issued. This usually requires that safety assessment documentation has been reviewed, the detailed repository design has been approved, the respective licensing procedures have been completed and an appropriate quality assurance program has been established. Construction of the repository may be carried out in a phased manner; in particular, it can continue and extend into the operational phase to provide additional disposal space for waste as it becomes available and is received at the facility. Depending on the size of the facility and national circumstances, the period of time from concept development to completion of construction activities may range over several decades (IAEA, 2006d).

6.7.5 Operation

The operational phase usually comprises the following activities: commissioning, waste receipt and emplacement. It is sometimes also considered to include closure (including backfilling and sealing), operational monitoring and surveillance and any emergency activities (IAEA, 2002a). However, these are usually considered to be separate from the operational phase and require a separate license.

The license to operate the repository may be subject to conditions imposed by the regulator to ensure that operations are consistent with the applicable regulations. In addition to radiological and industrial safety requirements for these activities, there may be requirements for physical security, fire protection and other safety related matters (IAEA, 2002a).

The operational period may also include variable periods of storage and pre-disposal conditioning and packaging of wastes. The license to operate the repository may be subject to conditions imposed by the regulator to ensure that operations are consistent with applicable regulations.
In addition to radiological and industrial safety requirements for these activities, there may be requirements for physical security, fire protection and other safety related matters.

Emplacement of waste comprises both physical placement in the repository and subsequent management until that part of the repository is covered or sealed. The repository may have a number of units progressively constructed and used for disposal. As soon as a particular part of the repository is filled with waste to its capacity (and under some conditions even when it is in operation), voids around the waste packages are usually filled with backfill material. It may also be necessary to protect that part of the repository with a temporary cover or seal to limit infiltration of water and to provide radiation shielding.

During operation of the repository, the operator must be able to demonstrate that the repository is performing as designed with respect to its impact on workers, members of the public and the environment and is in compliance with the license conditions. This may require, for example, inspections of waste emplacement activities, monitoring required under the terms of the license, assessment of worker exposures and operation of a monitoring system to detect any abnormal releases from the repository. The repository operational period may last between 30 and 40 years for near-surface facilities and a hundred years or more for geological disposal facilities.

6.7.6 Closure

Closure refers to technical and administrative actions taken at the end of its operational period to put the repository in its final state ensuring long-term safety. Closure of the repository takes place after the receipt of waste ceases and waste emplacement operations have been completed. Engineered barriers, in particular the final cover, are emplaced to ensure integrity of the repository, to minimise the ingress of infiltrating water to the waste, thereby limiting radionuclide releases and to reduce the likelihood of disturbance by human activities. Closure should be conducted in a manner that ensures proper post-closure performance of the repository, accounting for design changes that have been updated through the operational period (IAEA, 2006d).

6.7.7 Post-Closure

The post-closure period of the repository life-cycle refers to the time in which the repository is developed to its final state and is performing its function of isolating waste from humans and the environment. The post-closure period is often considered to be further subdivided into periods of active institutional control and passive institutional control. Some form of institutional control may be assumed to remain in place for a period of around 100 to 300 years after the repository is sealed (IAEA, 1999).

Institutional control will preclude any inadvertent human intrusion into the repository and disruptive natural events are not expected to occur over this period. Therefore, the International Commission on Radiological Protection (ICRP) system of protection for practices in normal situations applies, including dose limitation, etc. This system of protection is further elaborated upon in the International Basic Safety Standards (IAEA, 1996).

Institutions designated for post-closure control of repositories can be instrumental in providing scientific and technical support for safety in the following ways (IAEA, 2002a):

- Consequence reduction. Once a situation giving rise to excessive radiation exposure is identified, the institution can evaluate a range of options intended to reduce exposure. This is usually referred to as remediation or intervention. It is necessary to consider whether any action is justified; for example, remedial actions should result in more good than harm.
- Reduction of the likelihood of the consequence arising. Institutional control measures, such as the construction and maintenance of fences and other physical security measures, markers, land use controls and archives can all be seen as means to reduce the likelihood of the waste being disturbed. It is important not only to reduce the likelihood of radiation exposures being received, but also to reduce the likelihood of engineered barriers being impaired.
- Monitoring of sites. Post-closure monitoring can serve several functions. It can provide an early warning of system malfunctions that might lead to unacceptable impacts on individuals and the environment. It can also help in verifying the intended overall performance of the disposal system.

6.8 Societal and Other Aspects

6.8.1 Public Acceptance

One of the most challenging tasks facing radioactive waste management is to explain safety assessment to stakeholders in a way that enables all concerned to play a meaningful role in the risk management and decision-making process. The US National Research Council has stressed,

> "No matter how well analysts perform risk assessments, the impact and information content may be lost if the results are not communicated effectively to the people who need to use the information (NRC, 1996)"

In today's political situation, the public plays a large role in making decisions about environmentally sensitive projects and any project associated with radioactivity comes under particular scrutiny. It is a fact of today's world that nuclear projects are held to higher standards than other activities. Consequently, there is a need for particular attention to be paid to public communication, safety assessment and quality assurance parts of the project, which tend to be the focus of public attention.

6.8.2 Natural and Archeological Analogues

Natural systems where processes occur that are assumed to be similar to those in a repository environment are generally termed natural analogues. Closely linked to the studies of natural analogues are studies of ancient human made materials, provided the processes and conditions to which they have been subjected are natural. Studies of archaeological and historical artefacts, ancient buildings and anthropogenic sources of radionuclides such as nuclear weapons fallout can all be included in the field of analogue studies.

The relationship between natural or archaeological systems and a radioactive waste repository are inevitably imperfect and consequently it is difficult to apply the results of analogue studies directly in a quantitative way, for example to perform quantitative validation of models or to provide values for parameters used in these models (IAEA, 2002a). Consequently, natural and archaeological analogues are generally considered to be of greater use in communication with the public in a qualitative sense, than of direct technical use in safety assessments.

An additional use of natural analogues is to establish the role of natural indicators and fluxes, against which the behaviour of the disposal system can be compared. This is considered to represent a use of multiple lines of reasoning to bolster the safety case (IAEA, 2006d).

6.9 Comparison of South African Policy with the International Basis

DME (2005) provides the overall policy on and strategic framework for the management of radioactive waste for South Africa, including high-level. Section 2.2 presents a summary of the policy and strategy.

DME (2005) establishes a set of national radioactive waste management principles, which are explicitly linked to the basic IAEA principles. DME (2005) cites a version of the IAEA principles that are no longer current, but the differences between the older IAEA principles and the current ones are not dramatic and represent the same underlying ideas. The IAEA basic principles are used to derive the following nine national principles (see Table 2.2):

- polluter pays principle;
- transparency in all aspects of radioactive waste management;
- sound decision-making;
- precautionary principle;
- no import or export of radioactive waste;
- cooperative governance and efficient national coordination;
- international cooperation;
- public participation; and
- capacity building and education.

These national principles are not directly derived from the international principles, but rather include extensions of the IAEA principles for the management of radioactive waste (IAEA, 1995) to the South African national context. In particular, the principles: No import or export of radioactive waste, International cooperation and Capacity Building and Education are not found in the international principles, whereas the remaining principles can been considered to be implicitly considered in the IAEA principles.

DME (2005) next establishes roles and responsibilities for various organisations, in keeping with international practice (e.g. IAEA, 2000; 2006c). In addition, DME (2005) establishes policies on the interpretation of South African basic principles for radioactive waste management and establishes a specific timetable for the implementation of these policies. The policies established in DME (2005) are clearly in agreement with international concepts and approaches for HLW management.

The South African waste classification system appears to be derived directly from the IAEA system of classification (IAEA, 1994c).

DME (2005) discusses several options for disposition of HLW and spent fuel. The only option that results in final disposition of the waste is in a geological disposal facility; other options are only modifications of waste (e.g. reprocessing), or delay of the final decision (e.g. long-term storage). Consistent with international thinking, the policy and strategy recognise that the storage of spent fuel is finite and not sustainable indefinitely and that investigations need to be conducted to consider various options for safe management of spent fuel and HLW in South Africa. Given the long lead times necessary to site, license and construct a geological disposal facility, it is therefore considered necessary for South Africa to begin initiating a repository program.

While DME (2005) provides the overarching principles and policies for regulatory practices, it does not address more specific elements necessary for siting, design, licensing and construction and operating of a high-level waste repository as required in Article 4 to Article 10 of the Joint Convention. Other elements of the regulatory regime that remain to be developed in South Africa include:

- guidelines for operational and post-closure radiological safety assessments;
- specific safety criteria for high-level waste disposal and time frames over which they need to be applied;
- financial elements of the regulatory regime;
- criteria for public involvement and transparency; and
- considerations of institutional control, irretrievability and recordkeeping.

Therefore, it is concluded that current South African policies on HLW management are consistent with international practice, but that additional detailed regulation is needed on specific issues relevant to long-term management and disposal of HLW.

A summary of internationally accepted requirements for geological disposal have recently been established (IAEA, 2006d). However, these requirements should be supplemented from the experiences of several national programs that are within a decade of operating a geological repository for HLW and spent fuel, notably Finland, Sweden and the USA.

7 Transport of Nuclear Fuel

7.1 General

The safety standards for regulatory practices (Government Notice No. R.388 of 2006), requires that radioactive material or any other equipment or objects contaminated with radioactive material, when being transported off the site or on any other road accessible to the public, must be transported in terms of the provisions of the IAEA Regulations for The Safe Transport of Radioactive Material (IAEA, 2009). The purpose of these regulations is to protect people, property, and the environment during the transport of radioactive material. This protection is achieved by (i) requiring containment of the radioactive material, (ii) control of external radiation levels, (iii) prevention of criticality, and (iv) prevention of damage caused by heat. The requirements should be applied in a graded approach to contents, limits for packages and conveyance. This means that the level of application will vary between the transport of solid waste to Vaalputs and the transport of fresh nuclear fuel.

It is anticipated that for the first five years of operation, Eskom may obtain the unirradiated nuclear fuel for Nuclear-1 Nuclear Power Station from the chosen vendor to allow for immediate utilisation of the reactor. Thereafter, Eskom may source the uranium from other sources, including local commercial sources, should these become available in South Africa (Arcus Gibb, 2010). Unirradiated nuclear fuel for the Nuclear-1 Nuclear Power Station will thus, at least for the first five years of operation, be imported by ship to a South African harbour and transported by road from the harbour to the Nuclear-1 Nuclear Power Station site. A process similar to what is being followed for the transport of nuclear fuel to the Koeberg Nuclear Power Station can be used for this purpose (see Section 7.2). For the transport of nuclear fuel from a local supplier to the Nuclear-1 Nuclear Power Station site, a different process would have to be followed.

The purpose of this section is to present an overview of these transport processes, starting with an outline of the manner in which nuclear fuel is currently transported to the Koeberg Nuclear Power Station site, in Section 7.2, and followed by a description of the manner in which nuclear fuel is likely to be transported to the proposed Nuclear-1 Nuclear Power Station, in Section 7.3.

7.2 Transport of Nuclear Fuel to the Koeberg Nuclear Power Station

Transport of nuclear fuel to the Koeberg Nuclear Power Station is carried out in terms of the provisions of the IAEA Regulations for The Safe Transport of Radioactive Material (IAEA, 2009) and the US Code of Federal Regulations Part 73.

Imported nuclear fuel elements are delivered at Cape Town harbour. At this point, the Koeberg Nuclear Power Station security group is responsible for the overall safety and protection of the fuel, in conjunction with the South African Police Service (SAPS), Crime Intelligence and the National Intelligence Agency (NIA). Fresh nuclear fuel is delivered every 16 to 18 months. The fuel is loaded onto a 40 ft open container when delivered and loaded onto a normal truck. The loaded vehicles travel by road in a convoy to the Koeberg Nuclear Power Station, protected by the SAPS. Protection of nuclear fuel in transit is of utmost importance. For this purpose, internal and external threats were identified, which forms the basis for a security plan. The security plan includes a road traffic plan.

7.3 Transport of Nuclear Fuel to the Nuclear-1 Nuclear Power Station Site

7.3.1 General

Transport of nuclear fuel to the Nuclear-1 Nuclear Power Station site is a licensed procedure, the license being issued by the NNR. The licensing process considers two aspects of the transportation procedure: the packages, in which the material is loaded for transport and the transport action itself (e.g. route, method, procedures, etc.).

The licensing strategy is based on national and international guidelines and regulations to ensure the safe transport of radioactive material. The most important of these are the IAEA Regulations for, The Safe Transport of Radioactive Material (IAEA, 2009). The provisions of these regulations are not based on quantitative risk assessment, and they do not require such assessment to be undertaken. However, certain parts of the total transport action will be subject to quantitative assessments.

An EIA for the transport of nuclear fuel from the nearest harbour to any of the candidate sites will have to be performed once a decision as to the site that will be used for the Nuclear-1 project has been made. Done as part of the EIA, a Framework Transportation Plan (FTP) will have to be developed to deal with the transport of nuclear fuel from the point of entry into South Africa to the Nuclear-1 Nuclear Power Station site. The FTP should cover pre-transport planning, pre-transport readiness/verification, and loading-transport-uploading.

7.3.2 Pre-Transport Planning and readiness/Fitness Verification

Pre-transport planning includes the selection of appropriate packages, containers, and vehicles, emergency planning for the transport process (including preparedness and contingencies, and security), route planning, loading and off loading facilities, and insurance and securities.

Pre-transport readiness/fitness verification includes verifying operator and driver fitness, vehicle fitness, proto team/escort fitness, and route fitness, as well as maintenance and inspection of vehicles.

7.3.3 Transport Procedures

The transport of nuclear fuel will be managed and controlled in accordance with transport procedures, which may include amongst others:

- Travel restrictions (e.g. speed, weather, time of day);
- Selection of alternative routes by providing information on the relative hazards associated with each route;
- Driver certification, training and experience;
- “Fitness for purpose” test on vehicle, which comprises prescribed vehicle inspections and inspection procedures;
- Shipment and unit sizes;
- Convoy (size and composition);

- Vehicle security;
- Composition of human escorts (Radiation Protection Officers and Security Officers);
- Operating technical specifications;
- Work procedures, which include package preparation, as well as handling and labelling requirements;
- Administrative requirements;
- Radiation protection;
- Fire protection;
- Quality assurance;
- Packaging and packaging inspection requirements;
- Emergency response plans, which includes risk categorisation; and
- Responsibility matrix for all activities.

7.3.4 Transport Alternatives

Road transport is the preferred alternative due to more limited handling, low volumes, and low frequency of movement of material. Other alternatives that can be considered include rail and air transport.

7.3.5 Nuclear Safety

Basic package design for uranium oxide powder has to provide containment of the uranium up to high temperatures. Each package of restricted volume is built with a double walled cavity filled with a neutron absorbent material. This ensures that a criticality accident[15] cannot take place. The principle of mass control and geometric subcritical (see footnote 10) are applied to the containers used for the transportation of enriched uranium and fresh fuel. Loading of the individual packages in a freight container will also be controlled.

7.3.6 Effect on the Environment

The radiological hazard of fresh uranium fuel is considerably less than that of spent nuclear fuel. Due to the former's encapsulated and contained nature, it is in turn much less hazardous than the transport of uranium concentrate yellow coke (Ammonium Diuranate) from mines, which is a routine activity.

Transport containers will be designed according to IAEA standards for the transport of radioactive material. Radiation exposure through the walls of the container is below the limit of 2 mSv and decreases rapidly with distance, e.g. at 1 m from the container to 10 m from the container, exposure is decreased by a factor of 100. During transport, the only potential effects on the environment would arise from accidents and the release of Uranium from the fuel.

In the event of an accident, the fuel packages are designed to remain intact and will not release any fuel. In the unlikely event of fuel being released, the effect on the public or the environment should be negligible. Issues that should be considered include hijacking and theft, vehicle breakdowns, route hazards, community conditions, national and provincial policies, public acceptance, and selecting a suitable contractor.

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[15] A criticality accident sometimes referred to as an excursion, or a power excursion occurs when a nuclear chain reaction accidentally occurs in fissile material, such as enriched uranium or plutonium. This releases neutron radiation, which is highly dangerous to surrounding personnel and causes induced radioactivity in the surroundings (http://en.wikipedia.org).

8 Impact Assessment

8.1 Introduction

The objective of this impact assessment is to identify and evaluate all the significant impacts that may arise as a result of the radioactive waste and spent nuclear fuel generated by the proposed Nuclear-1 Nuclear Power Station. The impacts identified are evaluated according to an objective set of criteria in accordance with Government Notice R.385, promulgated in terms of Section 24 of the National Environmental Management Act, (Act 107 of 1998) and the criteria drawn from the IEM Guidelines Series, Guideline 5: *Assessment of Alternatives and Impacts*, published by the Department of Environmental Affairs and Tourism (April 1998) as well as the Guideline Document on Impact Significance (DEAT 2002).

8.2 Impact identification and assessment

Sources of radioactive waste that will be generated at the proposed Nuclear-1 Nuclear Power Station, irrespective of the location of the plant and its associated infrastructure, are gaseous, liquid and solid radioactive waste. The latter can be divided further into HLW, ILW and LLW. ILW and LLW and collectively referred to as LILW.

The potential impacts on human health and the environment associated with radioactive waste relate principally to health effects associated with the irradiation of living tissue in humans and non-human biota. For this impact to occur, humans and non-human biota have to be exposed to the radionuclides associated with the waste either through direct ingestion or inhalation of the radionuclides or through external exposure (gamma radiation).

It is clear from the discussions presented in the foregoing sections that all forms of radioactive wastes are strictly controlled and that numerous specialised systems and management practices are in place to prevent uncontrolled contact with these substances. These controls and practices differ for the different forms of radioactive waste.

Gaseous and liquid wastes are almost exclusively associated with the operation of the proposed Nuclear-1 Nuclear Power Station. Specific systems are included in the design and operation of the Nuclear Power Station to control releases under Normal Operation and Anticipated Operational Occurrences. AADQs are defined so that discharges do not exceed a fraction of the dose limit for the public (dose constraint) when applied to the critical group and that such doses are ALARA.

LILW solid waste will be managed according to predefined systems and management practices. These include procedures for the predisposal management (processing, storage and transport) of the waste. Generally, it will be handled similar to the operational waste generated at the Nuclear-1 Nuclear Power Station, after which it will be disposed of at the national radioactive waste disposal facility at Vaalputs. The transport of LILW to Vaalputs is done by road according to the provisions of the IAEA Regulations for the Safe Transport of Radioactive Material (IAEA, 2009).

South Africa still has to formulate a strategy for the long-term management of HLW, including spent fuel. Until such time, all spent fuel is stored temporarily either in spent fuel pools (wet storage), or in dry cask storage facilities (dry storage). This allows the shorter-lived isotopes to decay before further handling, a management strategy that is acceptable from a safety perspective.

Disposal of radioactive waste at an authorised facility is being done according to an approved disposal concept, defined and developed with due consideration of the nature of the waste to be disposed of and the natural environmental system, collectively referred to as the disposal system. The disposal system developed for this purpose makes provision for the containment of radionuclides until such time that any releases from the waste do not pose a radiological risk to human health and the environment. The safety assessment process used as basis for this purpose, considers both intentional (as part of the design criteria) and unintentional (natural or human induced conditions) releases of radionuclides. Unintentional releases include consideration of unintentional human or animal intrusion conditions, which might lead to direct access and external exposure to radiation.

Once released into the environment, radionuclides might migrate through the environmental system along three principle pathways: atmospheric, groundwater and surface water. Due to the physical nature of LILW and HLW disposal concepts, migration along the atmospheric pathway is unlikely. The principle environmental pathway of concern is thus the groundwater pathway, with the surface water pathway of secondary concern as an extension of the groundwater pathway. Disposal systems are designed that the impact is on a small scale and localised.

The potential impacts on the environment associated with gaseous, liquid and solid radioactive waste identified for the Nuclear 1 project are:

- Contamination of water resources due to the release of radioactivity contained in liquid waste (Commissioning, Operational and Decommissioning Phase).
- Contamination of the atmosphere due to the release of radioactivity contained in gaseous waste (Commissioning, Operational and Decommissioning Phase).
- Contamination of water resources due to the release of radioactivity contained in LILW or HLW stored at the Nuclear-1 Nuclear Power Station (Commissioning, Operational and Decommissioning Phase).
- Contamination of water resources by radioactivity due to disposal of LILW at Vaalputs (Operational and Post-closure Phase).
- Contamination of water resources by radioactivity due to accidental spillage of radioactive waste during transport of LILW to Vaalputs (Operational Phase).

8.3 Impact rating criteria

8.3.1 Introduction

The potential impacts listed above were evaluated according to the following impact rating criteria:

- **Nature**: The nature of the impact refers to the type of effect the potential impact will have on the affected environment.
- **Intensity**: This is a relative evaluation of the extent to which the receiving environment is affected as a result of the identified impacts.
- **Extent**: Extent refers to the spatial scale of the potential impact.
- **Duration**: The impact criteria provided describe the 'duration' assessment norm as *the expected lifespan of the potential impact*.
- **Impact on irreplaceable resources**: The resources potentially affected by the identified impacts are expected to recover over time.
- **Consequence**: The consequence and significance of impacts are derived values based on the values selected for the foregoing criteria.
- **Probability of occurrence**: Probability of occurrence is a description of the probability of the impact actually occurring.

Legal requirements applicable to the impacts have been described in Section 2.

8.3.2 Mitigation

The potential impacts are evaluated with and without mitigation. The mitigation measures accounted for are as follows and must be adhered to:

- The design of proposed Nuclear 1 Nuclear Power Station must take into account releases of gaseous and liquid effluent under all possible operating conditions and must ensure the releases are managed to stay ALARA.
- The high level waste management system must be designed to safely manage and hold all HLW and spent fuel for the duration of the life span of the Nuclear Power Station.
- The decommissioning EMP must contain measures to prevent poor waste disposal practices and to mitigate against the irresponsible handling and disposal practices.
- Disposal sites at which waste from Nuclear-1 is disposed must be audited on a periodic basis to ensure that they comply with legal requirements.
- An emergency response plan for road transport of LILW must be in place to swiftly deal with any accidental spillages of these wastes during transport to Vaalputs.

8.4 Results of the impact assessment

The results of the impact assessment of radioactive waste management associated with the Nuclear 1 Nuclear Power Station are presented in Table 8.1.

Table 8.1: The results of the impact assessment of radioactive waste management associated with the Nuclear 1 Nuclear Power Station.

Impact	Nature	Intensity	Extent	Duration	Irreplaceable resources	Probability	Significance
Contamination of water resources due to the release of radioactivity contained in liquid waste (Commissioning, Operational and Decommissioning Phase).							
Without mitigation	Negative	Low	Low	Medium	Low	High	**Low-Medium**
With mitigation	Negative	Low	Low	Medium	Low	Medium	**Low**
Contamination of the atmosphere due to the release of radioactivity contained in gaseous waste (Commissioning, Operational and Decommissioning Phase).							
Without mitigation	Negative	Low	Low	Medium	Low	High	**Low-Medium**
With mitigation	Negative	Low	Low	Medium	Low	Medium	**Low**
Contamination of water resources due to the release of radioactivity contained in LILW or HLW stored at the Nuclear Power Station (Commissioning, Operational and Decommissioning Phase)							
Without mitigation	Negative	Medium	Low	Low	Low	Low	**Low**
With mitigation	Negative	Low	Low	Low	Low	Low	**Low**
Contamination of water resources by radioactivity due to disposal of LILW at Vaalputs (Operational Phase)							
Without mitigation	Negative	Low	Low	High	Low	Low	**Low**
With mitigation	Negative	Low	Low	High	Low	Low	**Low**
Contamination of water resources by radioactivity due to accidental spillage of radioactive waste during transport (Operational Phase)							
Without mitigation	Negative	Medium	Low	Low	Low	Low	**Low**
With mitigation	Negative	Low	Low	Low	Low	Low	**Low**

9 Conclusions

The Nuclear-1 Nuclear Power Station generates liquid, gaseous and solid radioactive waste as by-products of operational conditions and decommissioning activities. The solid radioactive waste is divided further into compactable waste, non-compactable waste, abnormal waste and spent fuel. Waste other than radiological waste that will be generated can be divided into conventional and hazardous waste.

Radioactive waste management practices envisaged for the Nuclear-1 Nuclear Power Station are consistent with the IAEA guidelines for a Radioactive Waste Management Programme for nuclear power stations, from generation to disposal.

The Nuclear-1 Nuclear Power Station strives to minimise production of all solid, liquid and gaseous radioactive waste, both in terms of volume and activity content, as required for new reactor designs. This is being done through appropriate processing, conditioning, handling and storage systems. In addition, production of radioactive waste is minimised by applying good practices for radiological zoning, provision of active drainage and ventilation, appropriate finishes and the use of current best practices for the handling of solid radioactive waste. Where possible, the Nuclear-1 Nuclear Power Station reuses or recycles materials.

Processing of gaseous and liquid waste is aimed at reducing activity levels in the reactor building and in effluent generated as part of operational conditions. It also ensures that radiation doses to members of the public due to discharges to the environment (i.e., controlled discharges) do not exceed a fraction of the dose limit for the public (dose constraint). For this purpose, Authorised Discharge Quantities (AADQ) is defined for these waste streams. Compliance monitoring will be done at the source and in the environment. Processing of solid waste is aimed at reducing the volume of waste (e.g., compaction), containing dispersible activity (e.g. immobilisation), or reducing the activity of abnormal waste (e.g. decontamination). The processing and conditioning of solid waste are conducive to safe storage and consistent with the Vaalputs waste acceptance criteria.

Systems are designed store processed solid radioactive waste for a period of up to three years within the facility. The storage containers are consistent with the requirements for the disposal of solid waste at the radioactive waste disposal facility at Vaalputs. The waste unsuitable for disposal at Vaalputs will be stored on site until a suitable facility is available.

The transfer and associated transport of the waste to Vaalputs will be done according to the appropriate provisions of the IAEA Regulations for the Safe Transport of Radioactive Material, subject to a graded approach. The objective of the Regulations is to protect persons, property and the environment from the effects of radiation during the transport of radioactive material. In terms of the Regulations, the transport process is subject to radiation protection, emergency response, quality assurance and compliance assurance programmes.

The concept for the disposal of solid waste at Vaalputs consists of near-surface trenches using metal containers for low-level waste and concrete containers for intermediate level waste. The long-term safety of the facility, which complies with international best practices for the disposal of low and intermediate level waste, has been demonstrated for a national inventory of radioactive waste. The inventory derived for this purpose, included waste of the proposed Nuclear-1 Nuclear Power

Station. Vaalputs therefore has more than enough capacity to dispose of the solid waste estimated to be generated by the Nuclear-1 Nuclear Power Station.

The Fuel Handling and Storage System proposed for management and storage of Nuclear-1 Nuclear Power Station spent fuel will have sufficient capacity to safely store all the spent fuel produced throughout the life of the plant and to store the spent fuel for a further 10 years after decommissioning if needed. It is thus only after 70 years that the storage facility on site (or elsewhere) will have to be upgraded to store and manage spent fuel. This should provide sufficient time to define and develop a long-term management strategy for the Nuclear-1 Nuclear Power Station spent fuel, e.g. a central geological disposal facility or an alternative.

While reprocessing of spent fuel is not excluded as an option for spent fuel management, there is no intention to reprocess the Nuclear-1 Nuclear Power Station spent fuel at present. The main reason being the very high cost associated with spent fuel reprocessing.

International trends and policies with respect to spent fuel and high-level waste management is based on the provisions of the Joint Convention on the Safety of Spent Fuel Management and the Safety of Radioactive Waste Management. Internationally, this waste is currently being stored (usually above ground), awaiting the development of geological repositories. While the arrangements for storage have proved to be satisfactory and have been operated without problems, it is generally agreed that these arrangements are interim and do not represent a final solution.

The two basic challenges in perfecting a system of radioactive waste isolation is choosing an appropriate geological barrier (host medium) and designing an effective engineered barrier. Underground research laboratories made a very positive contribution to waste isolation research, while public acceptance of radioactive waste isolation projects remains one of the major challenges.

The National Radioactive Waste Management Policy and Strategy is consistent with international practice for the management of high-level waste. However, additional, more detailed regulations are needed on specific issues relevant to long-term management and geological disposal of high-level waste. A summary of internationally accepted requirements for geological disposal have recently been established (IAEA, 2006d). These requirements should be supplemented from the experiences of several national programs that are within a decade of operating a geological repository for high-level waste and spent fuel, notably Finland, Sweden and the USA.

The transport of fresh nuclear fuel from the point of entry into the Republic of South Africa to the Nuclear-1 Nuclear Power Station site is subject to the provisions of the IAEA Regulations for the Safe Transport of Radioactive Material, subject to a graded approach. Transport of nuclear fuel is an action, which require authorisation in terms of the Environmental Impact Assessment (EIA) Regulations promulgated under the National Environmental Management Act (No. 107 of 1998), as amended. An assessment of the transport will therefore have to be completed when a site for the proposed Nuclear-1 Nuclear Power Station has been selected as the specific route and associated risks will have to be considered.

The potential environmental impacts identified and assessed include all potential radioactive wastes expected to be generated by the proposed Nuclear-1 Nuclear Power Station. The assessment results indicate that with the implementation of appropriate mitigation measures all potential impacts are low.

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Appendix A
National Radioactive Waste Classification Scheme

Waste Class	Waste Description	Waste type / Origin	Waste Criteria
HLW	Heat generating radioactive waste with high, long and short lived radionuclide concentrations.	Used fuel declared as waste or used fuel recycling products. Sealed sources.	Thermal power > 2 kW m^{-3}. **or** Long-lived alpha, beta and gamma emitting radionuclides at activity concentration levels > levels specified for LILW-LL. **or** Long-lived alpha, beta and gamma emitting radionuclides at activity concentration levels that could result in inherent intrusion dose (the intrusion dose assuming the radioactive waste is spread on the surface) above 100 mSv per annum.
LILW-LL	Radioactive waste with low or intermediate short-lived radionuclide and intermediate long-lived radionuclide concentrations.	Irradiated uranium (isotope production). Un-irradiated uranium (nuclear fuel production). Fission and activation products (nuclear power generation and isotope production). Sealed sources.	Thermal power (mainly due to short lived radio nuclides (T ½ < 31 y) < 2 kW m^{-3}). **and** Long-lived radio nuclides (T ½ > 31 y) concentrations. Alpha: < 4000 Bq g^{-1} Beta and gamma: < 40000 Bq g^{-1} (Maximum per waste package up to 10x the concentration levels specified above). **or** Long-lived alpha, beta and gamma emitting radionuclides at activity concentration levels that could result in inherent intrusion dose (the intrusion dose assuming the radioactive waste is spread on the surface) between 10 and 100 mSv per annum.
LILW-SL	Radioactive waste with low or intermediate short-lived radionuclide and / or low long-lived radionuclide concentrations.	Un-irradiated uranium (nuclear fuel production). Fission and activation products (nuclear power generation and isotope production. Sealed sources.	Thermal power (mainly due to short lived radio nuclides). (T ½ < 31 y) < 2 kW m^{-3}. **and** Long-lived radio nuclide (T ½ > 31 y) concentrations. Alpha: < 400 Bq kg^{-1} Beta and gamma: < 4000 Bq g^{-1} (Maximum per waste package up to 10x the concentration levels specified above). **or** Long-lived alpha, beta and gamma emitting radionuclides at activity concentration levels that could result in inherent intrusion dose (the intrusion dose assuming the radioactive waste is spread on the surface) below 10 mSv per annum.
VLLW	Radioactive waste containing very low concentration of radioactivity.	Contaminated or slightly radioactive material originating from operation and decommissioning activities.	Clearance or authorised discharge or reuse criteria and levels approved by the relevant regulator.
NORM-L (low activity)	Potential radioactive waste containing low concentrations of NORM.	Mining and Minerals processing. Fossil fuel electricity generation. Bulk waste – un-irradiated uranium (nuclear fuel production).	Long-lived radionuclide concentration: < 100 Bq g^{-1}.
NORM-E (enhanced activity)	Radioactive waste containing enhanced concentrations of NORM.	Scales Soils contaminated with scales	Long-lived radionuclide concentration: > 100 Bq g^{-1}.