Eskom	PLAN	Steam Generator Replacement Project

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……………………………………	……………………………………	pp ……………………………………(Mandlakayise Bassie)
Justice Nzimande	**Luchen Reddy**	**Justice Gumede**
Senior Advisor Projects	**Middle Manager (SGR Project)**	**Senior Manager (SGR Project)**
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CONTENT

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1. INTRODUCTION

Necsa prepared this document for the Steam Generator Replacement (SGR) project at Koeberg Nuclear Power Station (KNPS), to present the detailed Radioactive Waste Management Plan (RWMP) for the Original Steam Generators (OSGs).

Koeberg Operating Unit (KOU) is planning to replace the Original Steam Generators (OSG) for both reactor units as part of the plant life extension program. The SGR project will require the disposal of the six (6) OSGs. These OSGs will be contaminated with radioactive material and must be managed as radioactive waste. A suitable waste management method for the management and disposal of the OSGs must be evaluated and selected to comply with the Radioactive Waste Management Policy and Strategy for the Republic of South Africa, 2005 and National Radioactive Waste Disposal Institute Act.

Revision 4 of the RWMP was submitted to the National Committee on Radioactive Waste Management (NCRWM). The responses to the comments from the NCRWM were included in revision 5 of the RWMP. The Replacement Steam Generators (RSG) which will have to be disposed of in the future are included in this revision.

2. SUPPORTING CLAUSES

2.1 SCOPE

2.1.1 Purpose

The purpose of this document is to present the detailed radioactive waste management plan for the KNPS OSGs and RSGs.

2.1.2 Applicability

This document shall apply to the SGR project and future disposal of RSGs.

2.1.3 Effective date

The document will be effective when authorised.

2.2 NORMATIVE/INFORMATIVE REFERENCES

2.2.1 Normative

Refer to Appendix 1- PEL-2019-REP-0004

2.2.2 Informative

Refer to Appendix 1- PEL-2019-REP-0004

2.3 DEFINITIONS

Refer to Appendix 1- PEL-2019-REP-0004

2.4 ABBREVIATIONS

Refer to Appendix 1- PEL-2019-REP-0004

2.5 ROLES AND RESPONSIBILITIES

Not Applicable

2.6 PROCESS FOR MONITORING

Not Applicable

2.7 RELATED/SUPPORTING DOCUMENTS

Not Applicable

3. DOCUMENT CONTENT

Refer to Appendix 1.

4. ACCEPTANCE

This document has been seen and accepted by:

Name	Designation
Phina Thauge	Engineer: Nuclear Back-End Management
Luchen Reddy	Middle Manager (SGR Project)

5. REVISIONS

Date	Rev.	Compiler	Remarks
March 2020	1	L. Hordijk	None
December 2021	2	L. Hordijk	Address relevant NCRWM comments - Refer to NWRDI acceptance in executive summary and include letter as Annexure 1 - Through-out the document changed OSG to SG (both original and replacement steam generators) - Updated Section 6.1 to include info on RSG. - Moved SG dose rate from 6.2 to separate paragraph: 6.3 - Updated Section 7.2 on waste classification justification - Updated Section 7.4 and refer to chemical characterisation study of SGs - Included Section 15.2 on Vaalputs compliance

6. DEVELOPMENT TEAM

Not Applicable

7. ACKNOWLEDGEMENTS

Not Applicable

APPENDIX A – RADIOACTIVE WASTE MANAGEMENT PLAN – KNPS STEAM GENERATOR DISPOSAL

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RADIOACTIVE WASTE MANAGEMENT PLAN – KNPS STEAM GENERATOR DISPOSAL		

REPORT PREPARED FOR ESKOM KOEBERG NUCLEAR POWER STATION

TITLE	**RADIOACTIVE WASTE MANAGEMENT PLAN – KNPS STEAM GENERATOR DISPOSAL.**

	Name	Designation/Capacity	Signature	Date
Prepared	L Hordijk	Waste Specialist, NLM	[signature]	14/12/2021
Reviewed	B vdL Nel	Chief Engineer: NLM	[signature]	14/12/2021
Reviewed	JH Lubbinge	Engineer: NLM	[signature]	14/12/2021
Reviewed	R Swart	Snr Technologist: NLM	[signature]	2021/12/14
Reviewed	PB Dyasi	Technologist: NLM	[signature]	2021/12/14
Approved	T Ndlovu	Acting Senior Manager: NLM	[signature]	2021/12/15
Accepted	Luchen Reddy Eskom (KOU)	Middle Manager Projects	[signature]	15/12/2021

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REVISION HISTORY

This document has been revised in accordance with the following schedule:

Rev. No.	Date approved	Nature of Revision	Prepared
1.0	15-08-2019	1st Issue	L Hordijk
2.0	30-10-2019	Address Eskom Comments as per 4600064286 E/C 0039 and SGR/4887/19	L Hordijk
3.0	28-01-2020	Address further Eskom Comments as per 4600064286 E/C 0049	L Hordijk
4.0	03-03-2020	Address further Eskom Comments as per 4600064286 E/C 0050	L Hordijk
5.0	See title page	Address relevant NCRWM comments • Refer to NWRDI acceptance in executive summary and include letter as Annexure 1 • Through-out the document changed to Stem Generator (SG) when referring to both OSG and Replacement Steam Generators (RSG) • Updated Section 6.1 to include info on RSG. • Moved SG dose rate from 6.2 to separate paragraph: 6.3 • Updated Section 7.2 on waste classification justification • Updated Section 7.4 and refer to chemical characterisation study of SGs • Included Section 15.2 on Vaalputs compliance	L Hordijk

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1. EXECUTIVE SUMMARY

Koeberg Operating Unit (KOU) is planning to replace the Original Steam Generators (OSG) for both reactor units as part of the plant life extension program. The Steam Generator Replacement (SGR) project will require the disposal of the six (6) Original Steam Generators (OSG). The six Replacement Stream Generators (RSG) will ultimately also have to be disposed. These Steam Generators (SGs) (OSGs and RSGs) will be contaminated with radioactive material and must be managed as radioactive waste. A suitable waste management method for the management and disposal of the SGs must be evaluated and selected to comply with the Radioactive Waste Management Policy and Strategy for the Republic of South Africa, 2005 [3] and National Radioactive Waste Disposal Institute Act [2].

This document was prepared to present the detailed radioactive waste management plan for the Koeberg Nuclear Power Station (KNPS) SGs.

A waste classification evaluation was done and the SGs were classified as Low Intermediate Level Waste - Short Lived (LILW-SL).

A total of eleven waste management options were identified and evaluated. Each of the waste management options were considered in two rounds of evaluations. The implication/impacts, including the advantages and disadvantages of each were considered. The purpose of the two rounds was to first do a high level evaluation in order to eliminate options that are clearly not practical. The second round evaluation considered in detail the practical viable options. A total of four options were evaluated during the second round.

Based on the consideration criteria listed in Radioactive Waste Management Policy and Strategy for the Republic of South Africa [3], specific evaluation criteria were defined within ten major criterion groups. Each criterion is described in the form of a 'goal' that the developer of the waste management option would wish to achieve and the 'optimum objective' for each goal that a developer might strive to achieve is also defined. A total of 27 specific criteria (grouped into 10 major criteria) were used to compare the four waste management options. The result of the evaluation is reflected in Table 1 below.

Table 1: Overall scoring of final SG waste management options

Option no	Waste management option	Overall score
(h)	Sectioning of the SGs at KNPS inside the Interim storage facility after which the sections are packaged and disposed at Vaalputs (possible clearance of some of the material)	2.80
(i)	Recycling of SGs at Studsvik (Cyclife), Sweden. The complete SGs are shipped to Sweden for recycling, and the secondary waste returned to South Africa for disposal at Vaalputs	2.13
(j)	Direct transport of SGs to Vaalputs as a complete unit and disposed at Vaalputs	4.26
(k)	SG stored in Interim storage facility on KNPS site for decay until the KNPS end-of-life. Disposal as a complete unit at Vaalputs.	4.07

Based on this assessment the option to directly dispose of the complete SG at Vaalputs (Option j) is the most suitable option.

Extensive consultation took place between NRWDI and Eskom during the preparation of this RWMP regarding the waste classification, disposal approach, and possible operational and design impacts. To this end, NRWDI has compiled a letter (NRWDI-LET-0607), which refers to these consultations, expresses the NWRDI support, confirms that NRWDI has reviewed and assessed the RWMP. This letter is included as Attachment 1 of this document. The outcome of NRWDI's assessment concluded that the RWMP was found to be comprehensive, compelling and plausible. Against this background, NRWDI has endorsed and accepted the RWMP.

2. PURPOSE AND SCOPE

The purpose of this document is to present the detailed radioactive waste management plan for the Koeberg Nuclear Power Station Steam Generators. The Original Steam Generators will be replaced in the next few years, whereas the Replacement Steam Generators will also be removed during the final decommissioning of KNPS.

As per the *Radioactive Waste Management Policy and Strategy for the Republic of South Africa* [3] the waste generator is required to evaluate, determine and present the waste management options applicable to a waste stream. This plan needs to be reviewed and accepted by the National Committee on Radioactive Waste Management (NCRWM), who then on acceptance will recommend ministerial approval as per [1].

This document has been prepared considering the requirements for a Radioactive Waste Management Plan as specified in the *Radioactive Waste Management Policy and Strategy for the Republic of South Africa* [3] Section 9 and in the *Solid Radioactive Waste Management Plan for Koeberg Nuclear Power Station* [7] Section 7.3.

A total of six original steam generators will be removed and replaced for the two operating units at KNPS for the life extension program of KNPS. The Replacement Steam Generators (total six) will be removed during KNPS decommissioning. Thus a total of twelfth Steam Generators will need to be managed.

This plan therefore considers the following:

(a) Background
(b) Detailed description of the SGs
(c) Waste classification
(d) International practice and operating experience
(e) Regulatory framework
(f) Detailed possible waste management options
(g) Evaluation criteria
(h) Options evaluation
(i) Detailed description of the selected option
(j) Conclusion

3. REFERENCES

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4. DEFINITIONS AND ABBREVIATIONS

4.1 Definitions

Term	Description
Controlled disclosure	Controlled disclosure to external parties (either enforced by law, or discretionary)
Interim Storage Facility	Interim Storage Facility: New concrete enclosed storage building used for the interim storage of the SGs on the KNPS site
Secondary waste	Waste which is generated during the processing or conditioning of the SG
Self-Propelled Modular Transporter	A platform vehicle with a large array of wheels. SPMTs are used for transporting massive objects such as large bridge sections, oil refining equipment, motors and other objects that are too large or heavy for trucks (used for on-site transfer)
Ton	Metric ton (1000kg)
Vaalputs	Vaalputs Radioactive Waste Disposal Facility. South Africa's national LLW disposal site. Currently operated by Necsa on behalf of NRWDI
Waste Form	Waste in its physical and chemical form after treatment and/or conditioning (resulting in a solid product) prior to packaging. The waste form is a component of the waste package [8]

4.2 Abbreviations

Abbreviation	Description
ALARA	As Low As Reasonable Achievable
Andra	Agence national pour la gestion des déchets radioactifs (French National Radioactive waste management agency)
AREVA	French multinational group specialising in nuclear power, currently ORANO
ASME	American Society of Mechanical Engineers
BATNEEC	Best Available Technology Not Entailing Excessive Cost
Bq/g	Becquerel per gram
BWR	Boiling Water Reactor
CANDU	Canada Deuterium Uranium (Canadian pressurised heavy-water nuclear reactor)
CIRES	Le Centre industriel de regroupement d'entreposage et de stockage (Andra –France Industrial centre for disposal of VLLW)
CNSC	Canadian Nuclear Safety Commission
CPI	Consumer Price Index
CRUD	Colloquial term for corrosion and wear products that become radioactive when exposed to neutron field.
CSA	L'Andre Centre de Stockage de l'Aube (Andra –France disposal site for LILW-SL)
CWF	Compact Waste Facility (USA)
DoE	Department of Energy (now Department of Mineral resources and Energy)
D&D	Decontamination and Decommissioning
EDF	Électricité de France
EIA	Environmental Impact Assessment
Enresa	Empresa Nacional de Residuos Radiactivos SA (Spanish Radioactive Waste Management Agency)
FWF	Federal Waste disposal Facility (USA)
GWe	Gigawatts (Power output)
HDPE	High Density Polyethylene
ILW	Intermediate Level Waste
ISF	Interim Storage Facility
KNPS	Koeberg Nuclear Power Station
KOU	Koeberg Operating Unit
LILW	Low and Intermediate Level Waste
LILW-SL	Low and Intermediate Level Waste – Short Lived
LLW	Low Level Waste
MCNP	Monte Carlo N-Particle Transport Code (software)
MWe	Megawatts (Power output)
NCRWM	National Committee on Radioactive Waste Management
Necsa	South African Nuclear Energy Corporation
NNR	National Nuclear Regulator
NRWDI	National Radioactive Waste Disposal Institute
NPP	Nuclear Power Plant
OPG	Ontario Power Generation
OSG	Original Steam Generator (steam generators which will be replaced)
PCRSA	Post Closure Radiological Safety Assessment
PWR	Pressure Water Reactor
RSG	Replacement Steam Generator
RWMPS-SA	Radioactive Waste Management Policy and Strategy for the Republic of South Africa
SCO	Surface Contaminated Object
SFR	Swedish Final Repository
SG	Steam Generator (both OSG and RSG)
SGR	Steam Generator Replacement project
SKB	Svensk Kärnbränslehantering AB (Swedish Nuclear Fuel and Waste Management Company)

Abbreviation	Description
SPMT	Self-Propelled Modular Transporter
USA	United States of America
VLLW	Very Low Level Waste
WAC	Waste Acceptance Criteria
WIPP	Waste Isolation Pilot Plant (USA)

5. BACKGROUND

Koeberg Operating Unit is planning to replace the OSGs for both reactor units as part of the plant life extension program. The Steam Generator Replacement (SGR) project will require the disposal of the six (6) OSGs. The six Replacement Stream Generators (RSG) will ultimately also have to be disposed. These OSGs and RSGs will be contaminated with radioactive material and must be managed as radioactive waste. A suitable waste management method for the management and disposal of these SGs must be evaluated and selected to comply with the *Radioactive Waste Management Policy and Strategy for the Republic of South Africa, 2005* [3] and *National Radioactive Waste Disposal Institute Act* [2].

A high level solid radioactive waste management plan for the Koeberg Nuclear Power Station [7] was drafted and submitted to DOE and the NCRWM for acceptance. This plan also included the radioactive waste management plan development process (Section 7.3) which is applicable for each waste stream, e.g. SGs. Eskom received comments on this document, including a request that a waste stream specific waste management plan for the SGs needs to be submitted; therefore this document was developed.

The methodology approach for developing this waste management plan in [7] is outlined below:

(a) Identification, collection and segregation of waste streams;
(b) Classification and categorisation of waste streams;
(c) Identification of waste management options;
(d) Evaluation of the different waste management options in terms of cost-effectiveness, technological benefits, safety, as well as social and environmental sustainability;
(e) Selection of the waste management option;
(f) Development of waste management plan via consultation;
(g) Submission of waste management plan to institutional organisation;
(h) Approval of waste management plan; and
(i) Implementation of plan via the regulatory processes

The *Solid Radioactive Waste Management Plan for KNPS* [7] also specifies:

(a) That the options for the management and disposal of the specific waste stream shall be evaluated in a systematic way as a multi-attribute analysis.
(b) The criteria set out in Table 2 below should be considered in evaluating the options. (Note that these criteria are also listed in the RWMPS-SA [3]).
(c) The outcome of this multi-attribute analysis will be regarded as (Best Available Technology Not Entailing Excessive Cost) BATNEEC.

This document has been prepared according to the above requirements.

During the OSG replacement project planning, a number of international facilities with similar projects were visited and information gathered, these are reflected in [9], [10] and [11]. Information from these reports are utilised in this report.

Table 2: Evaluation criteria for radioactive waste management options, as per [3] and [7]

Element		Sub-element	
A	Cost effectiveness	A1	Life cycle cost of waste
B	Technological status / benefit	B1	Existing or new technology
		B2	International practice
		B3	Waste prevention potential
		B4	Waste minimisation potential
		B5	Waste quality
		B6	Regulatory implications
C	Safety	C1	Worker safety impact
		C2	Public safety impact (operational)
		C3	Transport minimisation / prevention
		C4	Accident risk
		C5	ALARA
D	Social and environmental sustainability	D1	Public safety impact (long term)
		D2	Perceived risk and social acceptability
		D3	Benefit to the community in relation to the "no action" option
		D4	Environmental impact
		D5	Continual improvement potential

6. SG DESCRIPTION

6.1 Detail Description

The function of SGs is to transfer reactor core heat from the primary to the secondary circuit while providing a physical barrier between the primary and secondary side. The SGs thus perform a safety function of preventing the possible transfer of radioactive material from the primary circuit to the secondary circuit and into the atmosphere. The SGs are referred to as OSGs upon removal from the primary circuit.

The KNPS OSGs are of a model 51 B design, which is a further development of the Tricastin model 51 M steam generator design.

The SG consists of two separate vessels i.e. the primary or tube side and the secondary or shell side.

The primary or tube side consists of the following components:

(a) The channel head at the bottom of the SG which is provided with two nozzles, one for inlet and one for outlet of the primary coolant. It is also provided with two manholes. The channel head or water box, which is divided into two compartments by the partition plate, also accommodates the SG support feet,
(b) The tube sheet, in which 2 x 3 330 holes for the OSG and 2 x 4 996 holes for the RSG, are drilled to receive the heat exchanger tubes. This sheet is forged in a single piece with a diameter of 3 454 mm and a thickness of 534 mm for the OSG and 582 mm for the RSG, and;
(c) The OSG has 3 330 bent U-shaped heat exchanger tubes with an outside diameter of 22.20 mm and a wall thickness of 1.27 mm. The tube material is mill annealed Inconel alloy 600. The RSG has 4 996 bent U-shaped heat exchanger tubes with an outside diameter of 19.05 mm and a wall thickness of 1.09 mm. The tube material is thermally treated Inconel alloy 690.

The OSG secondary or shell side comprises of:

(a) the lower shell which consists of three shell sections, and a two piece transition cone; the lower portion of the first section is provided with two hand holes and four inspection ports,
(b) the upper shell, which consists of two shell sections of larger diameter; the upper shell houses the

water steam separation equipment and includes the feed water nozzle and manholes, and

(c) the upper head, fitted with a steam outlet nozzle into which flow restrictors are installed. It consists of a plate with seven round holes; it is forged integrally with the outlet nozzle body; individual convergent-divergent nozzles are fitted into each of the seven holes. The seven nozzles have an equivalent diameter of 406 mm.

The RSG secondary or shell side comprises of:

(a) The boiling section (lower part) consists of a low alloy steel vessel composed of (from bottom to top):
   - A forged cylindrical shell (lower shell) welded to the tubesheet with openings for inspection and maintenance, and a wide range lower level tap,
   - A forged intermediate shell welded to the lower shell and the conical shell, with inspection ports at various Tube Support Plate (TSP) levels,
   - A forged conical shell with cylindrical ends welded onto the intermediate shell.

(b) The steam drum (upper part) consists of:
   - Two forged cylindrical shells including a feedwater nozzle and two manways give access to the steam drum. Davits (swing arms) are provided to handle the covers of the secondary manways. Required measurement nozzles (water level and pressure taps) are also provided and taps located in the steam phase are equipped with stabilizers for measurement accuracy.
   - A forged elliptical head (upper dome) with an integral steam outlet nozzle and an integral stub for the connection (welding) of the support skirt of the dryer block. The steam outlet nozzle is equipped with a 7-hole steam flow restrictor with a safe end of SA-105M welded to the nozzle.

The empty mass of the OSG and RSG are 298.5 ton [12] and 325 ton respectively; this excludes the hot leg elbow which will remain attached to the SG when being removed from the KNPS system. This hot leg consists of a straight and elbow section with internal diameter of 0.76 m and total length of 1.61 m [13]. The total empty weight hot leg is 3 ton. The length of the OSG is 20.65 m and the maximum diameter is 4.47 m. The length of the RSG is 20.61 m and the maximum diameter is 4.465 m. Refer to Figure 3, Figure 4 and Figure 5, included in Attachment 2.

6.2 SG Removal

Before the Koeberg SGs are disconnected from the system and removed out of the containment area, routine internal flushing (crud burst) will be done. Crud burst includes the circulation of the primary water until the criteria for stopping the primary pumps is reached (this is typically when the activity in the primary water reaches a specified level defined by Eskom). This is done as per standing procedures during each outage. No separate additional internal flushing or decontamination is planned.

When the SGs are removed they will not be externally decontaminated. The external surface will be painted. It should be noted that the majority of the SG external surface is enclosed in thermal insulation material, which would most probably have prevented the external surface of the SG to be contaminated during the operational period. This insulation material is removed before the SG is removed from the containment area.

6.3 Radiation Dose Rates

During outage 223 and 124 detail radiological surveys were performed on the OSGs. The surveys were done when the primary side of the OSG was empty/drained and the secondary side was still filled with water, in addition the applicable areas on the OSGs were covered with insulation material (low density material which does not have significant shielding capacities). The maximum contact dose rate was below 0.5mSv/h for unit 1 OSGs during outage 124, whereas the maximum contact dose rate on unit 2 OSGs were below 0.2mSv/h.

Considering these results and the shielding effect of the water in the secondary side, the expected maximum contact dose rates on the fully empty OSG will in all likelihood be below 1 mSv/h, which is the typical dose rates indicated in literature. Therefore the contact dose rates are not expected to exceed the IAEA transport regulation [25] or the Vaalputs WAC [19] maximum contact dose rate of 2mSv/h.

7. SG WASTE CLASSIFICATION

7.1 Radiological

The Radioactive Waste Management Policy and Strategy for the Republic of South Africa, 2005 (RWMPS-SA) [3] section 10, specifies the national radioactive waste classification scheme. It also specifies the applicable waste class criteria.

The purpose of this section is to identify and justify the applicable waste class of the KNPS SGs.

Based on the SG waste type and origin this waste could be regarded as LILW-SL. The definition and criteria applicable for LILW-SL as per [3] is reflected in Figure 1.

Due to the operational use and origin of the SGs they will generate little or almost no heat.

In the following section the SG nuclide inventory is evaluated and compared to the LILW-SL criteria.

Waste class description

Radioactive waste with low or intermediate short-lived radionuclide and / or low long-lived radionuclide concentrations.

Waste type/Origin

- Un-irradiated uranium (nuclear fuel production)
- Fission and activation products (nuclear power generation and isotope production) and
- Sealed sources.

Waste Criteria:

- Thermal power (mainly due to short-lived radio nuclides ($T_{½}$ < 31 y)) < 2 kW/m^3.

AND

Long-lived alpha emitting nuclide ($T_{½}$ > 31 y) concentrations:

- < 400 Bq/g average per consignment
- < 4 000 Bq/g average per waste package

AND

Long-lived beta/gamma emitting nuclide ($T_{½}$ > 31 y) concentrations:

- < 4 000 Bq/g average per consignment
- < 40 000 Bq/g average per waste package

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.

Figure 1: Waste description and criteria for LILW-SL [3]

7.2 Nuclide Inventory

The radio nuclide inventory of the OSGs in KNPS Units 1 and 2, were measured and analysed by AREVA, [14] and [15]. These results are summarised in Table 3. These results are based on measurements done during outages in 2016 and 2017. The conclusion of the AREVA report was that the nuclide inventory was comparable to other SG projects done by AREVA. Necsa performed Monte Carlo N-Particle (MCNP) modelling of the KNPS SGs using the AREVA inventory and obtained comparable outer surface dose rates as measured by AREVA [16].

Table 3 provides the nuclide inventory of the SGs in Units 1 and 2. This includes all the nuclides as reported by AREVA. During the above mentioned modelling and assessment [16] the following nuclides were also added. Reasons are provided.

- Sr-90 and Sr-89 (with their progeny nuclides Y-89 and Y-90): Survey of published literature on SG source-terms show that these are also present [17].
- Ag-110 and U-234: These were added as a direct decay product since they are produced by Ag-110m and Pu-238 respectively which are both included in the AREVA inventory.
- U-235m and U-237: These were added, since these short-lived progeny nuclides will be generated almost instantaneously by precursor nuclides that are present in the AREVA inventory.
- Nb-94 was added since this was detected in the CRUD smear analysis which was performed on KNPS OSG. The total activity was about 400 times lower then Co-60 [18].

Table 3: OSG Unit 1 and 2 source term

Nuclide	OSG Activity at T=0 as per [12] and [13]		T = 25y		T = 300y		Half Life	Emission	ACTIVITY CONCENTRATION (Bq/g) T = 0: Empty SG, ONLY all SG internals	Empty SG, ONLY internals at heat exchanger tubes	Empty SG, Internals & outer shell (no grout backfill)	Complete SG & grout backfilled #	All SG internals & completely grout backfill #	Internals at heat exchanger tubes & this volume grout backfilled #
							t ½ > 31y		A	B	C	D	E	F
	Max	Frac-tion	Max	Frac-tion	Max	Frac-tion	t ½		Total Weight (ton)					
	(Bq)		(Bq)		(Bq)		(y)		112,5	96,8	301,5	648,6	466,9	263,6
Ag-110	6,45E+08	0,0%	0,00E+00	0,0%	0,00E+00	0,0%	0,00	βγ	5,73	6,66	2,14	0,99	1,38	2,45
Ag-110m	4,61E+10	0,1%	4,64E-01	0,0%	0,00E+00	0,0%	0,68	βγ	409,78	476,24	152,90	71,08	98,73	174,90
Am-241	1,63E+07	0,0%	1,57E+07	0,0%	1,01E+07	0,0%	432,20	αγ	0,14	0,17	0,05	0,03	0,03	0,06
C-14	7,14E+10	0,1%	7,12E+10	4,1%	6,89E+10	23,2%	5 730,00	β	634,67	737,60	236,82	110,08	152,91	270,89
Cm-242	1,69E+08	0,0%	0,00E+00	0,0%	0,00E+00	0,0%	0,45	αγ	1,50	1,75	0,56	0,26	0,36	0,64
Cm-243	2,27E+07	0,0%	1,25E+07	0,0%	1,79E+04	0,0%	29,10	αγ	0,20	0,23	0,08	0,03	0,05	0,09
Cm-244	2,27E+07	0,0%	8,71E+06	0,0%	2,33E+02	0,0%	18,10	αγ	0,20	0,23	0,08	0,03	0,05	0,09
Co-57	9,58E+10	0,2%	7,49E+00	0,0%	0,00E+00	0,0%	0,74	βγ	851,56	989,67	317,74	147,70	205,17	363,46
Co-58	2,03E+13	32,3%	0,00E+00	0,0%	0,00E+00	0,0%	0,19	βγ	180 444,44	209 710,74	67 330,02	31 298,18	43 474,59	77 017,47
Co-60	3,70E+12	5,9%	1,38E+11	8,0%	0,00E+00	0,0%	5,27	βγ	32 888,89	38 223,14	12 271,97	5 704,59	7 923,94	14 037,67
Cr-51	3,37E+12	5,4%	0,00E+00	0,0%	0,00E+00	0,0%	0,08	βγ	29 955,56	34 814,05	11 177,45	5 195,81	7 217,21	12 785,66
Fe-55	2,66E+13	42,3%	4,66E+10	2,7%	0,00E+00	0,0%	2,73	βγ	236 444,44	274 793,39	88 225,54	41 011,41	56 966,71	100 919,44
Fe-59	7,79E+11	1,2%	0,00E+00	0,0%	0,00E+00	0,0%	0,12	βγ	6 924,44	8 047,52	2 583,75	1 201,05	1 668,31	2 955,50
H-3	3,78E+08	0,0%	9,27E+07	0,0%	1,79E+01	0,0%	12,33	β	3,36	3,90	1,25	0,58	0,81	1,43
Mn-54	4,96E+11	0,8%	7,94E+02	0,0%	0,00E+00	0,0%	0,86	βγ	4 408,89	5 123,97	1 645,11	764,72	1 062,24	1 881,81
Nb-94	9,25E+09	0,0%	9,24E+09	0,5%	9,16E+09	3,1%	20 300,00	βγ	82,22	95,56	30,68	14,26	19,81	35,09
Nb-95	3,66E+12	5,8%	0,00E+00	0,0%	0,00E+00	0,0%	0,10	βγ	32 533,33	37 809,92	12 139,30	5 642,92	7 838,28	13 885,91
Ni-63	1,75E+12	2,8%	1,47E+12	84,7%	2,19E+11	73,7%	100,10	β	15 555,56	18 078,51	5 804,31	2 698,12	3 747,81	6 639,44
Pu-238	1,58E+07	0,0%	1,30E+07	0,0%	1,48E+06	0,0%	87,70	αγ	0,14	0,16	0,05	0,02	0,03	0,06
Pu-239	1,07E+07	0,0%	1,07E+07	0,0%	1,06E+07	0,0%	24 110,00	αγ	0,10	0,11	0,04	0,02	0,02	0,04
Pu-240	1,07E+07	0,0%	1,07E+07	0,0%	1,04E+07	0,0%	6 563,00	αγ	0,10	0,11	0,04	0,02	0,02	0,04
Pu-241	1,23E+09	0,0%	3,68E+08	0,0%	6,26E+02	0,0%	14,35	αγ	10,93	12,71	4,08	1,90	2,63	4,67
Sb-124	1,95E+11	0,3%	0,00E+00	0,0%	0,00E+00	0,0%	0,16	βγ	1 733,33	2 014,46	646,77	300,65	417,61	739,82
Sr-89	6,20E+08	0,0%	0,00E+00	0,0%	0,00E+00	0,0%	0,14	β	5,51	6,40	2,06	0,96	1,33	2,35
Sr-90	6,20E+07	0,0%	3,40E+07	0,0%	4,52E+04	0,0%	28,79	β	0,55	0,64	0,21	0,10	0,13	0,24
U-234	2,40E+01	0,0%	2,40E+01	0,0%	2,40E+01	0,0%	245 500,00	αγ	0,00	0,00	0,00	0,00	0,00	0,00
U-235m	1,07E+07	0,0%	0,00E+00	0,0%	0,00E+00	0,0%	0,00	γ	0,10	0,11	0,04	0,02	0,02	0,04
U-237	3,99E+02	0,0%	0,00E+00	0,0%	0,00E+00	0,0%	0,02	βγ	0,00	0,00	0,00	0,00	0,00	0,00
Y-90	6,20E+07	0,0%	0,00E+00	0,0%	0,00E+00	0,0%	0,18	βγ	0,55	0,64	0,21	0,10	0,13	0,24
Zn-65	1,62E+11	0,3%	9,20E-01	0,0%	0,00E+00	0,0%	0,67	βγ	1 440,00	1 673,55	537,31	249,77	346,94	614,62
Zr-95	1,63E+12	2,6%	0,00E+00	0,0%	0,00E+00	0,0%	0,18	βγ	14 488,89	16 838,84	5 406,30	2 513,11	3 490,82	6 184,16
Total:	6,29E+13		1,74E+12		2,97E+11									
			Total Long-lived Beta Gamma (Bq/g):						16 272,44	18 911,67	6 071,81	2 822,46	3 920,53	6 945,42
			Total Long-lived Alpha (Bq/g):						0,48	0,55	0,18	0,08	0,11	0,20
								#	Grout density:				1,80	ton/m^3

The nuclide inventory, refer to Table 3, is compared to the applicable LILW-SL criteria as shown in Figure 1 above. Different scenarios are considered to determine the applicable activity concentrations:

A: Empty SG, only all the SG internals (not including outer shell). No grout backfilling.

B: Empty SG, only internals at heat exchanger tubes. No grout backfilling.

C: Empty SG internals and outer shell. No grout backfilling.

D: Complete SG and grout backfilled

E: All SG internals and grout backfilled. Excludes outer shell.

F: Only internals at heat exchanger tubes and only this area grout backfilled.

Considering that the SG will be disposed as a complete unit, the outer shell is regarded as package/container, which is also in line with IAEA SSR-6 [25] requirements. When the SG are disposed, they will be backfilled with grout to fill the voids. Therefore the total internal fill volume is the waste form.

LILW-SL waste class have activity limits for individual packages and a consignment. Where the limit on individual packages are 10 times higher than for a consignment. Even though the term "consignment" is used in the context of transport, albeit possibly erroneously in the case of disposal requirements, practically this should mean that individual packages in a trench could have activities 10x higher than the average over the whole trench. Therefore even if one would conservatively consider that the activity in the SG is only concentrated in the heat exchanger tubes backfilled with grout, the activity concentration for this area complies with the individual package limits. This scenario is column F in Table 3.

The calculated activity concentration assumes that the activity is homogeneously distributed in the total applicable weight. The activity however is primarily distributed on the internal surfaces of the SG primary side, e.g. the inside surface of the heat exchanger tubes and the channel head or water box.

The alternative criteria for LILW-SL, as shown in Figure 1 above, makes provision for considering the intrusion scenario when the specific waste stream is disposed.

The RWMPS-SA also specifies in Section 10 that regulated near surface disposal (<10 m) is the disposal option for LILW-SL. In addition RWMPS-SA also specifies in Section 13 that "Vaalputs shall continue to be used as a National Disposal Site for Low and Intermediate Level Waste". Thus if the SGs are classified as LILW-SL they could be disposed at Vaalputs. Therefore the applicable Vaalputs requirements and assessments are considered below in considering the intrusion scenario.

The inherent intrusion scenarios are considered in the Post Closure Safety Assessment of Vaalputs [20]. This scenario is applicable after the institutional control period of Vaalputs, thus 300 years after the last waste was received and disposed at Vaalputs. During this institutional period no intrusion would be possible, since the facility will still be protected and guarded, thus no public or uncontrolled access would be allowed.

Table 3 also provides the projected maximum nuclide inventory after 25 years and 300 years. After 300 years mainly only three nuclides are present: Ni-63, C-14 and Nb-94.

The Vaalputs Post Closure Safety Assessment considered the intrusion scenario for various NPP and Necsa origin waste and nuclides, however not the disposal of SGs and the related nuclides. The applicable material and nuclides (and those nuclides contributing to the intrusion scenario dose) considered in the current Vaalputs Post Closure Radiological Safety Assessment, are typically (due to their major total activity contribution, dose equivalent factor, and/or nuclide half-life) Cs-137, Sr-90 and Uranium nuclides.

The OSG activity at T=300 years is dominated by Ni-63, with 74% of the nuclide inventory, refer to Table 3. Ni-63 has a half-life of approximately 100 years and appreciable decay is therefore expected over the post closure period. A comparison with the worst case driller intrusion scenario in VLP-SAC-011 [21] (refer to Section 6.3) shows that the biggest contributors in the driller intrusion scenario are U-238, U-234 and its progeny Ra-226. The half-lives of U-238 and U-234 are 4.47E9 and 2.45E5 years respectively, which indicates insignificant decay over the post closure period. The nuclide inventory for the uranium nuclides combined at T=300 years is considerably higher than for the Ni-63 contribution of all the SGs (refer to Table A 16 in Appendix A of VLP-SAC-011 [21]). In addition, the dose conversion factors for inhalation, ingestion and external dose are all orders of magnitude higher than for Ni-63 which would further lead to a lower total effective dose contribution (refer to Table A 23 in Appendix A of VLP-SAC-011 [21]).

In addition to the current Vaalputs Post Closure Safety Assessment, an assessment (VLP-SAC-017 [22]) was done to determine what would be the dose based limiting concentrations for LILW waste disposal at Vaalputs (refer to Table 4.2 in VLP-SAC-017 [22]). The dose based limiting concentration per nuclide derived in VLP-SAC-017 is far higher than calculated for any SG disposal scenario. Apart from this, the lowest activity dose based limiting concentration derived for any beta/gamma nuclide in VLP-SAC-017 [22] is also still orders of magnitude higher than the LILW-SL activity concentration limits.

It therefore shows that the SGs fall within the ambit of the derived dose based limiting concentrations in the current VLP PCRSA in addition to meeting the LILW-SL criteria.

The required backfilling of the internal volume (fill voids) would also provide an additional barrier as it would aid in retarding nuclide migration to the geosphere. Therefore the grouting/backfilling of the SGs when they would be disposed at Vaalputs should be considered.

Therefore it can be assumed that even though the inherent intrusion scenario of the SGs still have to be assessed, the possibility that it will increase the estimated dose is insignificant.

Based on the above it can therefore be assumed that the complete SG can be regarded as LILW-SL as specified in the RWMPS-SA, however before the SGs can be considered for disposal at Vaalputs the SGs needs to be considered in the intrusion scenario of the PCRSA of Vaalputs.

In addition if one considers the total projected nuclide inventory at the KNPS end-of-life (e.g. 25 years), thus reflecting the typical nuclide inventory after 25 years of storage on the KNPS site, the majority of the nuclides decayed to very low levels (almost clearance levels) but the complete SG would not be able to be cleared as non-radioactive waste. This would imply that even if the SGs are kept in storage for decay, it still has to be managed as radioactive waste.

7.3 SCO-III compliance

The IAEA transport regulation, IAEA SSR-6 [25], makes provision for the transport of a large solid object which cannot due to its size be transported in a transport package as referred to in this regulation. The primary requirements for SCO-III are reflected below:

> SCO-III: A large solid object which, because of its size, cannot be transported in a type of package described in these Regulations and for which:
>
> (i) All openings are sealed to prevent release of radioactive material during conditions defined in para. 520(e);
> (ii) The inside of the object is as dry as practicable;
> (iii) The non-fixed contamination on the external surfaces does not exceed the limits specified in para. 508;
> (iv) The non-fixed contamination plus the fixed contamination on the inaccessible surface averaged over 300 cm^2 does not exceed 8×10^5 Bq/cm^2 for beta and gamma emitters and low toxicity alpha emitters, or 8×10^4 Bq/cm^2 for all other alpha emitters.

As indicated in Section 6.2, the SG openings will be sealed when removed from the containment area. The external surfaces painted and the external surfaces should comply with the external contamination levels specified above in (iii). A preliminary calculation was performed to determine whether the SGs will comply with the SCO-III internal fixed and non-fixed contamination limits specified in (iv) above, refer to Table 4.

Conservatively it is assumed that the total SG nuclide activity inventory is evenly distributed over the total internal surface area of all the heat exchanger tubes. The results indicate that the SG non-fixed contamination plus the fixed contamination on the inaccessible surface will exceed the SCO-III limit when the SG considered for immediate transportation after removal. However, for a decay period of one (1) year, the SCO-III limit will not be exceeded.

Table 4: SCO-III activity compliance

Nuclide	OSG Activity at T = 0y as per [12] and [13]				Half Life	Emission	Internal Surface Contamination (Bq/cm²)	
					t ½ > 31y		T = 0 y	T = 1 y
	Unit 1 (Bq)	Unit 2 (Bq)	Max (Bq)	Frac-tion	t ½ (y)		Tube surface area (cm²) # 4.70E+07	4.70E+07
Ag-110	6.45E+08	5.53E+08	6.45E+08	0%	0.00	βγ	1.37E+01	0.00E+00
Ag-110m	4.61E+10	3.95E+10	4.61E+10	0%	0.68	βγ	9.81E+02	3.56E+02
Am-241	1.56E+07	1.63E+07	1.63E+07	0%	432.20	αγ	3.47E-01	3.46E-01
C-14	7.14E+10	6.77E+10	7.14E+10	0%	5 730.00	β	1.52E+03	1.52E+03
Cm-242	3.31E+07	1.69E+08	1.69E+08	0%	0.45	αγ	3.60E+00	7.61E-01
Cm-243	2.27E+07	2.20E+07	2.27E+07	0%	29.10	αγ	4.83E-01	4.72E-01
Cm-244	2.27E+07	2.20E+07	2.27E+07	0%	18.10	αγ	4.83E-01	4.65E-01
Co-57	5.71E+10	9.58E+10	9.58E+10	0%	0.74	βγ	2.04E+03	8.04E+02
Co-58	1.17E+13	2.03E+13	2.03E+13	32%	0.19	βγ	4.32E+05	1.22E+04
Co-60	3.70E+12	2.93E+12	3.70E+12	6%	5.27	βγ	7.87E+04	6.90E+04
Cr-51	3.37E+12	2.76E+12	3.37E+12	5%	0.08	βγ	7.17E+04	7.77E+00
Fe-55	2.66E+13	1.52E+13	2.66E+13	42%	2.73	βγ	5.66E+05	4.39E+05
Fe-59	7.79E+11	3.89E+11	7.79E+11	1%	0.12	βγ	1.66E+04	5.64E+01
H-3	2.34E+08	3.78E+08	3.78E+08	0%	12.33	β	8.04E+00	7.60E+00
Mn-54	3.89E+11	4.96E+11	4.96E+11	1%	0.86	βγ	1.06E+04	4.70E+03
Nb-94	9.25E+09	7.33E+09	9.25E+09	0%	20 300.00	βγ	1.97E+02	1.97E+02
Nb-95	4.67E+11	3.66E+12	3.66E+12	6%	0.10	βγ	7.79E+04	5.63E+01
Ni-63	1.75E+12	1.75E+12	1.75E+12	3%	100.10	β	3.72E+04	3.70E+04
Pu-238	1.43E+07	1.58E+07	1.58E+07	0%	87.70	αγ	3.36E-01	3.34E-01
Pu-239	9.09E+06	1.07E+07	1.07E+07	0%	24 110.00	αγ	2.28E-01	2.28E-01
Pu-240	9.09E+06	1.07E+07	1.07E+07	0%	6 563.00	αγ	2.28E-01	2.28E-01
Pu-241	1.23E+09	1.01E+09	1.23E+09	0%	14.35	αγ	2.62E+01	2.49E+01
Sb-124	1.95E+11	1.75E+11	1.95E+11	0%	0.16	βγ	4.15E+03	6.21E+01
Sr-89	7.79E+07	6.20E+08	6.20E+08	0%	0.14	β	1.32E+01	8.84E-02
Sr-90	7.79E+06	6.20E+07	6.20E+07	0%	28.79	β	1.32E+00	1.29E+00
U-234	2.10E+01	2.40E+01	2.40E+01	0%	245 500.00	αγ	5.11E-07	5.11E-07
U-235m	9.08E+06	1.07E+07	1.07E+07	0%	0.00	γ	2.28E-01	0.00E+00
U-237	3.01E+02	3.99E+02	3.99E+02	0%	0.02	βγ	8.49E-06	4.51E-22
Y-90	7.79E+06	6.20E+07	6.20E+07	0%	0.18	βγ	1.32E+00	2.53E-02
Zn-65	1.62E+11	1.24E+11	1.62E+11	0%	0.67	βγ	3.45E+03	1.22E+03
Zr-95	2.14E+11	1.63E+12	1.63E+12	3%	0.18	βγ	3.47E+04	6.67E+02
Total:	**4.95E+13**	**4.96E+13**	**6.29E+13**					
				Total Beta Gamma			**1.34E+06**	**5.67E+05**
#: From document KBA1217RCPM09 [27]				**Total Alpha**			**3.19E+01**	**2.78E+01**

7.4 Physical and Chemical characteristics

As per a study on the chemical composition of the SGs [23], the SGs are manufactured from the following ASME materials:

(a) Pressure retaining parts:
- ASME SA-508 cl. 3
- ASME SA-533 gr. B cl. 1
- ASME SA-216 gr WCC
- ASME SB-163 Alloy N06600 (Inconel 600)
- ASME SA-193 gr. B7 and B16 (Bolting)

(b) The non-pressure retaining parts:
- ASME SA-285 gr. C

- ASME SB-168 Alloy N06600
- Austenitic Stainless Steel: SFA 5.14 – ER Ni Cr 3 (Cladding)

(c) The chemical composition of these materials is as specified in the applicable ASME codes and includes typically the following elements: Iron, Manganese, Nickel, Chrome, Copper, Silicon, Carbon, Cobalt, Sulphur Titanium, Niobium, Phosphor, Aluminium and Vanadium.

In addition, the only other material inside the SG is the corrosion film built-up inside the tubes (CRUD). CRUD is a colloquial term for corrosion and wear products (rust particles, etc.) that become radioactive (i.e., activated) when exposed to neutron field. The CRUD typically consists of Chrome (30%), Nickel (25%), Iron (18%), Cobalt (0.24%) and Oxygen (27%).

The above mentioned study [23] concludes as follows:

Based on the fact that the Koeberg SG crud is similar to the crud as found in the studied SGs (which includes AREVA units) and the fact that the Koeberg SG construction materials are standard steel and alloy, no toxic elements are present in amounts which will be in conflict with the Vaalputs WAC [19]. From a chemical element perspective, the Koeberg SGs can therefore be safely disposed at Vaalputs.

8. INTERNATIONAL PRACTICES

A review was done to establish the international practices of similar projects in progress and projects successfully completed elsewhere in the world. The intent was to ascertain the methodologies, procedures, techniques and processes followed by these facilities. An overview of a few countries is given below, including conclusions drawn from these. The following countries are considered: Spain, France, USA, Canada and Sweden. The information was obtained as follows:

(a) International visits by Necsa (Enresa in Spain and ANDRA in France) [11]
(b) Conferences attended by Necsa (USA)
(c) International visits by Eskom (EDF and ANDRA in France, and Studsvik in Sweden) [9]
(d) Literature studies

8.1 Spain

8.1.1 Spain Nuclear Program

Spain has a small fleet of NPP (7) currently in operation. The NPPs are operated by different operators. One has already been decommissioned (Vandellos 1, a gas graphite reactor), one is currently being decommissioned (Jose Cabrera, a single loop PWR) of which 80% of the decommissioning has been completed and one has stopped operation and is due for decommissioning (Santa Maria de Garona, a BWR). The Spanish government decided that the fleet will not be expanded and the remaining 7 NPPs will be taken out of operation between 2027 and 2032.

8.1.2 Waste management

The Spanish Parliament created Enresa as a public, non-profit organisation responsible for the management of radioactive waste in 1984. Enresa was created to perform the public service of collecting, treating, conditioning, storing and disposing of the radioactive waste produced throughout Spain. Enresa is also responsible for the decommissioning of the NPPs and the disposal of the resultant waste. The decision for the waste management approach lies with Enresa.

8.1.3 ***Waste disposal facilities***

Enresa currently operates two disposal facilities, both on the El Cabril site (~100 km from Cordoba, Southern Spain). The first cask with LILW waste was disposed in a vault in 1993, and the VLLW disposal cells received waste from 2008. The two facilities:

(a) LILW engineered disposal vaults, and
(b) VLLW disposal cells

<u>Design of LILW engineered disposal vaults</u>

The LILW engineered disposal vaults are concrete structures built above ground. These vaults are about 10 m high, 20 m wide x 24 m long with a wall thickness of 0.5 m (3520 m^3). Only the concrete containers containing LILW (Total volume of each 11 m^3, with internal volume of 5.8 m^3) are disposed of in these vaults. The concrete container forms part of the barrier system of the vault. There are 28 vaults in total. When the vault is full, the voids between the containers are filled with sand. The top layer of the containers is covered with an HDPE liner, after which a reinforced concrete cover/roof is installed. The whole concrete vault is then waterproofed with a sealant. At a later stage the vaults are covered with a long-term cover, which consists of waterproofing and water diversion layers, and finally with layer topsoil and grass. Currently, about 76% of the existing disposal volume has been used. Enresa is busy with planning on creating additional disposal capacity.

The typical activity limits for LILW:

Level 1: Maximum activity per unit mass of final waste for different radio-nuclides:

- $< 1.85 \times 10^2$ Bq/g alpha
- $< 1.85 \times 10^4$ Bq/g per individual radio-nuclide for beta/gamma, half-life > 5 years (except tritium)
- $< 7.40 \times 10^3$ Bq/g tritium
- $< 7.40 \times 10^4$ Bq/g total beta/gamma activity, half-life > 5 years Co-60 and Cs-137 below 30×10^6 Bq/kg,

This waste form uses a relatively simple solidification recipe with reduced cement loading.

Level 2: More detailed activity limits and limits per package for those nuclides in the Reference Inventory

- $\leq 3.7 \times 10^3$ Bq/g alpha per "disposal unit" after 300 years.
- Co-60 and Cs-137 above 30×10^6 Bq/kg of final waste.

This waste form requires more stringent conditions, more cement and less waste per drum.

Both Level 1 and Level 2 waste is disposed in the LILW vaults.

<u>Design of VLLW disposal cells</u>

The disposal cells are constructed inside valleys on the El Cabril site. A 'dam' wall is built in the valley and a big area up-stream levelled out. This area is covered with various layers comprising HDPE, clay, bentonite, and geotextile. Each cell is divided into so-called "lines of operation", which are protected by a light roof structure. Waste is off-loaded and placed into the cell inside this covered area. Waste is disposed of in various forms, from bulk bags, drums, baskets, containers and whole individual items. Voids between the packages are filled with sand. When the cell is full to about ground/embankment level, the whole cell is covered with a cap consisting of clay, waterproof geomembrane, earth, soil and vegetation. Waste is typically slightly contaminated material from nuclear facilities and includes decommissioning waste. The total activity is less than 100 Bq/g. Currently about 10% of the existing disposal volume has been used.

8.1.4 *SG waste management*

With the current decommissioning of Jose Cabrera NPP, the SG was sectioned on-site. The SG was cut in-situ after it was decontaminated. The decision to cut the SG in-situ was taken since removing it from its location in the NPP was not feasible. Enresa decision on the waste management of the SG and other large components was primarily based on the following factors:

(a) They have a LILW-SL disposal facility at El Cabril and they wanted to follow a standard disposal solution, by remaining within the current approved and standing operational approach at the disposal site (i.e.: waste packaged into the square concrete containers and no need to for review/update of the operational and post closure safety assessment). For this reason, it was decided that SGs and other large components will be segmented and optimally placed inside their standard concrete disposal containers.
(b) Transport to the disposal site of the whole SGs would be challenging due to the El Cabril and surrounding area topography.
(c) The disposal facility has limited disposal space and therefore a key driver was to optimally section the SGs and package as dense as possible inside the standard concrete containers.
(d) Another factor was that they wanted to standardise the NPP decommissioning approach. Thus lessons learned on the Jose Cabrera could be applied on further NPPs.

8.2 France

8.2.1 *French nuclear program*

France has a big fleet of NPPs (58) currently in operations. These NPPs are operated by EDF (Électricité de France). In 2014 a government policy was approved which specified that the nuclear contribution to the total energy generation has to be reduced to 50% by 2035. The plan also states that 14 of the country's NPPs would be shut down by 2035. However, the plan also states that the option to build new NPPs remains.

In July 2010 EDF stated that it was assessing the prospect of a 60-year lifetime for all its existing reactors. This would involve the replacement of all steam generators (3 in each 900 MWe reactor, 4 in each 1300 MWe unit) and another refurbishment to take them beyond 40 years. EDF has replaced the OSGs at 22 of its 900 MWe units and is currently replacing those at about two units per year.

8.2.2 *Waste management*

The French government created ANDRA which is a publicly owned body, independently from the waste producers, responsible to find, implement and ensure safe management solutions for all radioactive waste in France. They report to the ministry of Energy and Environment as state owned company. ANDRA provides waste acceptance criteria to the waste generators and is delegated by the French regulator to approve any new or non-previously approved waste packages.

8.2.3 *Waste disposal facilities*

ANDRA currently operates two disposal facilities, both in the Aube district (~200km from Paris):

(a) CSA waste disposal facility for LILW-SL waste
(b) CIRES waste disposal facility for VLLW waste

CSA waste disposal facility for LILW-SL waste

The CSA waste disposal facility for LILW-SL (Both short lived LLW and ILW) consists of concrete disposal structures/vaults built above ground. These vaults are about 8 m high, 25 m wide and 200 m long and have intermediate sections into which waste drums and packages are placed using a remotely operated overhead crane. The walls of each vault are 0.4 m (top) to 0.7 m (bottom) thick. The variable thickness allows the walls to withstand the pressure from grout when the vault is filled with grout. For vaults that are only filled with sand, the vault walls have a uniform 0,4 m thickness. When a vault is full, the cavities between the waste packages are filled with cement grout or sand respectively, depending on whether the vault contains metal drums or concrete containers. The roof is installed and thereafter the whole concrete vault is then waterproofed with a sealant. When a few adjacent vaults are filled and sealed, these vaults are covered with clay soil, sand, fertile soil and grass. Underneath the whole site is a clay layer of about 20 m thick (natural barrier).

The disposal concept consists of:

(a) 1st barrier is the waste package (grouted metal and concrete packages)
(b) 2nd barrier is the disposal structure (concrete vault with drainage and monitoring galleries)
(c) 3rd barrier is geological (clay layer underneath and over the vault, installed after the vaults are filled and closed).

The typical activity limits:

LLW: >100 to ≤ 20 000 Bq/g

ILW: >20 000 to 1 000 000 Bq/g

Both limits consider the total nuclide inventory of the waste. In addition a 2mSv/h is used as boundary between LLW and ILW.

CIRES waste disposal facility for VLLW waste

The disposal trenches are dug about 8.5 m deep below the surface into the natural clay layer. The trenches are about 25 m wide at surface level and 176 m long, the slopes of the trenches are 53° and disposal is done up to 6 m above ground, the total capacity of a trench is 34000 m^3. A drainage pipe system with an inspection well is installed in the bottom of the trench. The trenches are designed with a ramp to transport standard waste packages into the trench with a forklift or small trucks. The trench is lined with a geomembrane and a protective liner before waste is placed inside. Waste is disposed in various forms, from bulk bags, drums, baskets, containers and whole individual items. Voids between the packages are filled with sand.

When the trench is full, it is covered with sand and clay, and then sealed with a waterproof geomembrane. The trench are then covered with clay soil, sand, fertile soil and grass. The monitoring well extends through the top of the top clay layer and allows for periodic inspection of the trench.

Waste is typically slightly contaminated material from nuclear facilities and includes decommissioning waste. The total activity limit is 100 Bq/g. Due to the activity limits applied, this facility is not regarded and licensed as a nuclear facility. It is broadly regarded the same as any other conventional waste disposal site and regulated accordingly.

8.2.4 ***SG waste management***

EDF (the waste generator), and not ANDRA, is responsible to make decisions on the best suitable and cost-effective option for the management of their radioactive waste. Thus disposal of the complete SGs at ANDRA is one of their options. EDF did send 2 SGs from Chooz A NPP to ANDRA for disposal and are busy with the planning to dispose of a few further SGs from the same NPP. For this reason, ANDRA developed a dedicated trench at CIRES for these items.

In 2016 EDF bought the Studsvik Low-Level Radioactive Waste operations in Sweden and the UK and are now trading under Cyclife Holding. This includes the metal recycling facility in Sweden which is used for the sectioning and melting of SGs. It is not known if any France SG was sent to Cyclife for recycling. This means that the above-mentioned number of replaced SGs is stored at the applicable NPP on-site.

ANDRA chose the disposal of the SGs from Chooz A at CIRES, above CSA, due to the CSA disposal cell design which:

(a) Limits the placement of big items,
(b) Disposal concept relies on the waste package for the first barrier of containment (relies on the integrity of the container to contain the activity), and
(c) Has a very high disposal rate compared to CIRES (about 10 times more than CIRES).

This means that SGs had to be decontaminated to levels which can be accepted for disposal at CIRES i.e. VLLW.

With the SGs disposed at CIRES, sectioning of the SGs on site was not considered. This was mainly due to the following reasons:

(a) The complexity of cutting, which requires elaborate mechanical design and planning,
(b) The radiological risks and possible spread of contamination (ALARA) at the NPP site,
(c) Required infrastructure inside the facility where these radiological tasks can be performed,
(d) Additional site licensing of this additional facility and radiological process,
(e) Detail planning required ensuring that the segmented items are optimally (utilising minimum disposal volume) packaged in the final disposal package. Optimise the disposal volume due to disposal capacity restrictions.

8.3 United States of America

8.3.1 USA nuclear program

USA has about 99 NPPs in operation. These are operated by 30 different companies. By 2025 a total of 18 NPP will be taken out of operation. The majority of the NPPs are busy or planning operational lifespan extension. By 2017 a total of 56 NPP had replaced their original steam generators.

8.3.2 Waste management

USA does not have a government institute for the central management of low level radioactive waste. Any waste management is the responsibility of the waste generator (applicable NPP). The NPP has to decide what would be the most appropriate waste management option for their waste, including the management of SGs. The waste disposal facilities are privately managed and operated, totally independent from the NPPs.

8.3.3 Waste disposal facilities

The disposal facilities for LLW in the USA are listed below. As per 10 Code of Federal Regulation (CFR) 61, LLW is divided into three subclasses: Class A (lowest activity concentrations), Class B, and Class C. These classes are defined in 10CFR61.55 [26] by the concentration of specific long-lived (10CFR61.55 Table 1) and short-lived radionuclides (10CFR61.55 Table 2). Limits for various nuclides are specified. If any of the nuclide activity complies with a higher class, the whole waste package shall be regarded as the higher class. Typical for Alpha emitting nuclides with half-life longer than 5 years: Class A 370 Bq/g, Class B N/A and Class C: 3700 Bg/g.

(a) Compact Waste Facility (CWF) and Federal Waste disposal Facility (FWF) in Andrews, Texas which are both operated by Waste Control Systems. These are shallow land disposal facilities. Waste is disposed at a depth between 12 m and 30 m below surface. The facility WAC of both facilities allows for the disposal of large components, e.g. SGs, and specifies that the item needs to be backfilled with grout. Large items, including complete SGs were disposed at these facilities. FWF is solely used for disposing waste that is the responsibility of the USA Federal Government. It can accept Classes A, B and C LLW.

(b) Clive disposal facility close to Salt Lake City, Utah which is operated by Energy Solutions. This is a shallow land disposal site (about 3 m below ground level to about 12 m above ground level). The facility is licensed to dispose large metallic items including SGs. It can only accept Class A LLW.

(c) Barnwell Disposal Facility in South Carolina is operated by Energy Solutions. This is a shallow land disposal site. The facility WAC allows for the disposal of large components, e.g. SGs. It can accept Classes A, B and C LLW.

(d) The Richland facility, located in southeast Washington State on the federal Hanford Nuclear Reservation 40 km West of Richland is operated by US Ecology. This is a shallow land disposal site. It can accept Classes A, B and C LLW.

(e) Waste Isolation Pilot Plant (WIPP), is a deep geological repository licensed to dispose transuranic radioactive waste. It is located close to Carlsbad, New Mexico. WIPP permanently disposes of transuranic waste that is the by-product of the nation’s nuclear defence program. Waste from NPPs or large metal items from NPPs cannot be disposed here.

*8.3.4 **SG waste management***

As indicated the waste management remains a decision of each individual NPP operator. SGs are either stored on the NPP site, or disposed as complete units at one of the above listed disposal sites. It should be noted that in some cases the low activity (or clearable) sections were removed from the SG, before it was disposed.

Storage on-site occurs in case where the state is not part of any Agreements State in a compact (do not have access to a disposal facility) or where the activity is too high to either perform the transport or meet the acceptance criteria of the disposal site. The latter is an interim arrangement to allow for either further decay or future decontamination efforts.

Disposal as complete units are by far the preferred option. In a paper at PATRAM (2014) it was reported by the USA Department of Transport that 27 steam generators were transported for disposal throughout the USA.

The transportation of large components which are contaminated is supported by regulatory relief provided by the USA Nuclear Regulatory Commission. This relief provides guidance and directions on meeting the regulatory requirements as well as compensatory measures.

8.4 Canada

*8.4.1 **Canada nuclear program***

About 15% of Canada's electricity comes from nuclear power, with 19 reactors mostly in Ontario providing 13.5 GWe of power capacity [8]. The decisions to build any new large-scale facilities have been put on hold or cancelled amongst others due to rising costs and lower than expected electricity demand growth. Instead, refurbishments will be used to extend the life of Canada’s existing nuclear generation facilities. Refurbishing CANDU units consists of such steps as replacing fuel channels and steam generators and upgrading ancillary systems to current standards.

Four NPPs have been shut down and are being decommissioned. They were shut down in 1977, 1984 and 1987 respectively and are expected to be demolished in about 30 years.

8.4.2 Waste management

The NPPs are responsible for LILW , which are currently stored above ground. No activity limits between the different waste categories have been established in Canada's radioactive waste regulations. Historically, waste generators segregated waste based on dose rate.

Ontario Power Generation (OPG) in 2005 proceeded with plans to construct a deep geologic repository for 200 000 m^3 of its LILW from three plants, Bruce, Pickering and Darlington (total 18 reactors). The repository will be located 680 m beneath OPG's Western Waste Management Facility on the Bruce site, which it has operated since 1974. An environmental assessment was prepared and reviewed, but final ministerial decision is still outstanding. Financing for the repository project is provided from the decommissioning fund established under the Ontario Nuclear Funds Agreement.

The Western Waste Management Facility in Ontario stores all the LILW from the Bruce, Pickering and Darlington nuclear power stations.

8.4.3 Disposal facilities

Canada does not have a currently operating disposal facility for LILW.

8.4.4 SG waste management

To manage the SGs from the Bruce Power NPP started a project in 2010 to recycle the decommissioned steam generators from Bruce A Units 1 and 2 instead of placing them into storage.

The Canadian Nuclear Safety Commission (CNSC) issued a transport licence and certificate to Bruce Power for the transportation of the SGs to Studsvik for recycling. In making its decision, the CNSC confirmed there was a negligible risk to the health and safety of the public and the environment.

The project to recycle SGs from Bruce Power Station in Canada at Studsvik was put on hold due to political reasons preventing the SGs from being transported. The concern was related to the transport of the SGs over the Great Lakes and the St. Lawrence Seaway. The primary driver for the public resistance stemmed from the term 'Special Arrangement' which was interpreted as 'a very special arrangement between the regulator and the operator'. The CNSC had approved the shipment of the SGs but the approval has subsequently expired.

The SGs are stored at the Western Waste Management Facility, Ontario.

8.5 Sweden

8.5.1 Sweden nuclear program

Sweden currently has eight operational nuclear power reactors which provide about 40% of its electricity. In 1980, the government decided to phase out nuclear power, but in June 2010 Parliament voted to repeal this policy. The country's 1997 energy policy allowed 10 reactors to operate longer than envisaged by the 1980 phase-out policy, but also resulted in the premature closure of a two-unit plant (1200 MWe). Some 1600 MWe was subsequently added in uprates to the remaining ten reactors. In 2015 decisions were made to close four older reactors by 2020, removing 2.7 GWe net.

8.5.2 *Waste management*

Nuclear waste generators are responsible for the costs of managing and disposing of spent fuel and waste. The Swedish Nuclear Fuel and Waste Management Company (SKB) was set up by the NNP owners to manage and dispose of radioactive wastes following the Swedish Waste Legislation (Stipulation Act) in 1977.

In addition the Sweden government established the Swedish National Council for Nuclear Waste (Kärnavfallsrådet). The Council is responsible to investigate and clarify matters relating to nuclear waste and decommissioning and dismantling of nuclear facilities and to advise the Government in these matters. The Council also serves as a knowledge base for other stakeholders such as concerned public authorities, the nuclear power industry, municipalities, non-government organisations, interested members of the public and the mass media.

Studsvik built and operated a metal treatment and recycling facility in Nyköping. This metal treatment facility is currently owned and operated by Cyclife (part of the EDF group) and provides a series of services: Segmentation, decontamination, melting (up to 5,000 tons per year), clearance and recycling of produced metal ingots and characterisation and conditioning of secondary waste for return to customer. Large components weighing up to maximum 400 tons and with lengths up to 30 meters can be accepted for treatment. Their experience includes the recycling of:

- 4 x 165 t SGs from Stade NPP, Germany
- 9 x 310 t SGs from Ringhals NPP, Sweden

Cyclife has signed an eight-year contract with Uniper (Power plant owner) in October 2019 for the treatment and recycling of contaminated metal generated through the decommissioning of Oskarshamn 1 and 2 (NPPs) and Barsebäck 1 and 2 (Gas Power Plants). Uniper has a common strategy for dismantling and demolishing the units, which were shut down between 1999 and 2017.

8.5.3 *Disposal facility*

Sweden has a disposal facility for LILW-SL. This repository (Sweden Final Repository - SFR) is located at Forsmark and in bedrock about 50 meters below sea level and operates since 1988.

This is where operational waste from nuclear power plants, which includes used protective clothing, replaced components and filtering materials that have been used to decontaminate reactor water, is deposited. Radioactive waste from hospitals, industry and research is also kept here.

In 2014 SKB submitted an application to the authorities for a permit to extend the SFR primarily to make provision for decommissioning waste. This includes the disposal of reactor pressure vessels.

The waste classification system at SFR is based on the degree of containment and isolation required for the waste material in order to ensure the safety of workers and the public in the short and long terms.

No activity limits between the various waste sub-classes have been established. Instead, the industry has set some basic parameters and surface dose rates to differentiate between intermediate activity wastes and low activity wastes; also taken into consideration is the presence of short- and long-lived radionuclides.

8.5.4 *SG waste management*

To date all the Sweden NPP SGs were or are to be processed at Studsvik for recycling. The secondary radioactive waste is disposed at SFR.

8.6 Summary and conclusions on international practices

The various international practices as outlined above with regards to the management and disposal of SGs were discussed in terms of the following:

(a) Size of NPP fleet in various countries
(b) Waste management disposal institutes
(c) Disposal facilities
(d) SG waste management approach

From the information provided above the following broad-line summaries can be drawn:

(a) NPPs in France have to either clean the SGs to VLLW activity levels to allow disposal at the national disposal site (CIRES), or send them for recycling (Studsvik, Cyclife in Sweden), or store on-site for delayed management. The last option is followed by the majority of NPPs. In addition, the SGs which were and are planned to be disposed at Andra are smaller size SGs.
(b) All the NPPs in Spain will ultimately be decommissioned and no life extension is planned as per government decision. Enresa, the national body responsible for decommissioning and disposal, is responsible for the decommissioning of these NPPs. They decided to standardise on the decommissioning and disposal approach for the big metallic items by sectioning it and dispose in their standard concrete containers inside the LILW bunkers at El Cabril.
(c) The NPPs in the USA must decide how and when the possible SGs are managed. There are several disposal sites nationally which accepts and allows the disposal of the complete SG in disposal facilities. No facility in the US exists for the recycling of SGs.
(d) The NPPs in Canada are responsible for the further management of the SGs. Canada does not have a disposal site or recycling facility for SGs, therefore there were plans to send units to Studsvik, but for public resistance reasons on transport the project was terminated, and the units are stored on the NPP site.
(e) Sweden established a facility for the recycling of SGs, and other metallic waste. In addition the NPPs are jointly responsible and did establish a disposal site (50m below the sea bed). This facility cannot practically receive and dispose complete SGs, but do however provide for elevated radiation waste, typically the secondary waste generated by the recycling facility. To date SGs were and are now also planned (contractually) to be recycled at Studsvik.

From the above the following can be concluded:

- SGs are stored on-site when it is either difficult/costly to send internationally for recycling, and when no or limited disposal (approach) option exist
- The management of SGs is primarily determined by the local waste management options available to the applicable NPP owner.
- Where the disposal site allows for the disposal of complete SGs, the disposal concept is typical shallow land disposal, comparable to the Vaalputs disposal site.

This programme developed by Necsa therefore considers international approaches and compares the disposal options which would be best suited to South Africa taking into account for e.g. local technical expertise, disposal facilities etc.

9. SOUTH AFRICAN REGULATORY FRAMEWORK

The following sections detail the applicable acts and regulations. Section 0 lists the other acts which were also considered.

9.1 Nuclear Energy Act

The *Nuclear Energy Act* [1], as per section 34(1), specifies that no person may, without the written permission of the Minister, discard nuclear related equipment and material 34(1)(r), radioactive waste 34(1)(s), and the transport thereof 34(1)(t).

9.2 National Radioactive Waste Disposal Institute Act

Vaalputs is owned by the NRWDI and the relevant WAC needs to be complied with. Further the *National Radioactive Waste Disposal Institute Act* [2] section 23(1) requires that any person who has to dispose of radioactive waste must apply to the chief executive officer for a radioactive waste disposal certificate in the prescribed format and must furnish such information as the board may require.

Further Section 25(1) specifies that the generators of radioactive waste are responsible for technical, financial and administrative management of such waste within the national regulatory framework at their premises and when such waste is transported to an authorised waste disposal facility.

Section 25(2): The generators of radioactive waste must -

(a) develop and implement site-specific waste management plans based on national policy;

(b) provide all relevant information on radioactive waste as required by the chief executive officer;

Section 25(3): The generators of radioactive waste remain responsible for all liabilities in connection with such radioactive waste under their control until such time as the radioactive waste has been received and accepted in writing by the Institute, following an inspection, at which time liability shall pass to the Institute.

9.3 Radioactive Waste Management Policy and Strategy for the Republic of South Africa

As per the *Radioactive Waste Management Policy and Strategy for the Republic of South Africa* [3] the waste generator is required to evaluate, determine and present the waste management options applicable to a waste stream. This plan needs to be reviewed and accepted by the NCRWM, who then on acceptance will recommend ministerial approval as per [1].

9.4 National Nuclear Regulator Act

The *National Nuclear Regulator act* [4] requires as per section 5:

(a) provide for the protection of persons, property and the environment against nuclear damage through the establishment of safety standards and regulatory practices:

(b) exercise regulatory control related to safety over-

i. the siting, design, construction, operation, manufacture of component parts, and decontamination, decommissioning and closure of nuclear installations; through the granting of nuclear authorisations;

(c) exercise regulatory control over other actions, to which this Act applies through the granting of nuclear authorisations.

9.5 Road Traffic Act

The *National Road Traffic Act* [5] prescribes requirements related to:

(a) Dangerous goods transport,
(b) Abnormal load transport,
(c) Applicable approvals required.

This includes the requirements of SANS 10233:2011 [27] (and SANS 10299:2011 [28]) related to transport of dangerous goods which were incorporated in the National Road Traffic Act as per government notice R 191 in Government Gazette No. 35106 dated 5 March 2012.

9.6 Other acts and regulations

(a) Hazardous Substances Act, 1973 (Act No. 15 of 1973);
(b) Mine Health and Safety Act, 1996 (Act No. 29 of 1996);
(c) Mineral and Petroleum Resources Development Act, 2002 (Act No. 28 of 2002);
(d) The National Environmental Management Act , 1998 (Act No. 107 of 1998);
(e) National Water Act, 1998 (Act No. 36 of 1998);
(f) Dumping at Sea Control Act, 1980 (Act No. 73 of 1980);

10. WASTE MANAGEMENT OPTIONS

The RWMPS-SA lists six possible radioactive waste management options:

(a) Regulated disposal;
(b) Authorized disposal / discharge;
(c) Authorized re-use / recycling;
(d) Regulated reprocessing (used nuclear fuel);
(e) Regulated storage and
(f) Clearance

Various waste management options were considered for the SGs and are listed below.

These include the three primary international practices: Sectioning for disposal, recycling at Studsvik and complete unit disposal in a shallow land disposal site.

All these options listed below are in the above listed context “Regulated disposal”, except Option (g) which is “Clearance”. Option (i) below includes that some of the waste can be cleared, however the total nuclide and activity inventory (in about 20% of the total metal volume of the SGs) will still require “Regulated disposal”. In addition, due to the presence of longer lived nuclides, as shown in Section 7.2, the SGs will not be able to be cleared even after being stored for an extended period beyond the KNPS end-of-life.

Therefore, the waste management options are:

Option (a): Storage of the complete SGs in the existing on-site cask storage and LLW building on the KNPS site until the KNPS end-of-life in 2045, thereafter disposal at Vaalputs;

Option (b): Storage of the complete SGs on a KNPS on-site open concrete base until the KNPS end-of-life in 2045, thereafter disposal at Vaalputs;

Option (c): Storage of the complete SGs in a new concrete enclosed ISF at Vaalputs until the KNPS end-of-life in 2045, thereafter disposal at Vaalputs;

Option (d): Storage of complete SGs in a new concrete enclosed ISF at a non-Vaalputs or non-KNPS site until KNPS end-of-life in 2045, thereafter disposal at Vaalputs;

Option (e): Storage of the complete SGs at an off-site non-Vaalputs or non-KNPS site on an open concrete base until KNPS end of life in 2045, thereafter disposal at Vaalputs;

Option (f): Complete SG is transported to Necsa, where it will be sectioned and melted in the existing smelter. Secondary radiological waste is transported to and disposed at Vaalputs;

Option (g): Long term storage of the complete SGs inside the KNPS on-site concrete enclosed ISF until the units can be regarded for clearance;

Option (h): Sectioning of the SG on the KNPS site inside the concrete enclosed ISF, after which the sections are placed into waste packages and disposed at Vaalputs. Possible sections that could be cleared as non-radioactive waste will be cleared from the KNPS site;

Option (i): Recycling of the complete SGs at Studsvik (Cyclife), Sweden. The complete SGs are shipped to Sweden for recycling, and the secondary waste returned to South Africa for disposal at Vaalputs;

Option (j): The complete SGs are, as a complete unit, transported to and disposed in a trench at Vaalputs;

Option (k): On-site storage of the SG inside the concrete enclosed ISF until KNPS end-of-life, after which the SG is taken to Vaalputs as a complete unit for disposal.

Each of the above listed options was considered in two rounds of evaluations. The implication/impacts, including the advantages and disadvantages of each were considered. The purpose of the two rounds was to first do a high level evaluation in order to eliminate options that are clearly not practical. The second round evaluation considered in detail the practical viable options.

Options (a) to (g) were eliminated during the first round of evaluation. A brief summary on the reasons why they were eliminated is reflected in
Table 5. Further detail on these options are included in Attachment 3.

Options (h) to (k) were considered in more detail, refer to Table 6. Each of these options were broken down in the detail foreseen processing steps. The processing step's justification and possible impacts or risks are listed as applicable. All these management options would require the same initial processing steps of internal in-situ flushing (e.g. crud burst), removal from the KOU, transfer to the ISF and initial storage in the ISF. These generic steps are considered separately in Table 6 under 'Gen', before each of the waste management options are considered in Sections (h), (i), (j) and (k).

Table 5: Eliminated waste management options

Option No.	Option description	1st round conclusion
(a)	Storage of the SGs in the existing on-site cask storage and LLW building until KNPS end-of-life in 2045	Not sufficient storage space available in these facilities
(b)	Storage of the SGs on an on-site open	Not best practice, and would require very large exclusion zone

Option No.	Option description	1st round conclusion
	concrete base until KNPS end-of-life in 2045	due to radiation.
(c)	Storage in new concrete enclosed storage building (ISF) at Vaalputs until KNPS end-of-life in 2045	Too many duplicated activities, duplicated large expenses and extra exposure activity impacts. In addition possible large expenses impacts are delayed for later.
(d)	Storage of SGs in a new concrete enclosed storage building at a non-Vaalputs or non-KNPS site until KNPS end-of-life in 2045	New nuclear site (elaborate licensing process which include siting, design, etc.), including support infrastructure and resources to operate and secure facility. Many duplicated activities (e.g. 2 x off-site transport, 2 x ISF), duplicated large expenses and extra exposure activity impacts. In addition possible large expense impacts are delayed for later.
(e)	Storage of SGs at an off-site non-Vaalputs or non-KNPS site on an open concrete base until KNPS end of life in 2045	Not best practice, and would require very large exclusion zone due to radiation. New nuclear site, including support infrastructure and resources to operate and secure facility. Many duplicated activities (e.g. 2 x off-site transport, 2 x ISF), duplicated large expenses and extra exposure activity impacts. In addition possible large expense impacts are delayed for later.
(f)	Complete SG transported to Necsa, where it will be sectioned and melted in the existing smelter. Secondary radiological waste to Vaalputs	Necsa smelter not authorised for other waste material, will require total relicensing. No experience with the separation of non-uranium contaminated metal. Sectioning facility and process to be developed. Depending on the smelter effectiveness the waste volume reduction could be low. Total nuclide inventory will still have to be disposed at Vaalputs.
(g)	Long term storage of the SGs in the ISF on the KNPS site (beyond KNPS end-of-life)	ISF operation to extend very long beyond KNPS end-of-life.

Table 6: Final considered waste management options

Option		Brief scope:	Details/Justification	Impacts / Risks
	Generic process steps		***SG is inside the Reactor building internal in-situ flushed (e.g. crud burst). These are all generic, and required, processing steps to each of the waste management options detailed in Sections (g), (h), (i) and (j) below.***	
Gen	1	In-situ internal flushing	1. Reduce internal contamination (nuclide inventory), and external radiation (dose rate) 2. Lowering of collective dose 3. SG opening are closed 4. No external decontamination will be done before the external surface is painted 5. Ensure that SG can be easily handled, manipulated, transported and stored 6. Possibility to utilize own staff for majority of work scope	1. If the internal CRUD burst does not reduce the internal activity enough, it could have the implication that the SGs have to be stored on the KNPS site for an extended period for further decay until the applicable further processing steps can be implemented, e.g. activity low enough to comply to Studsvik WAC (Option (i)); elevated personnel exposure during sectioning of the SG (Option (h)). 2. Risk that if SG was externally contaminated before it was painted, thus the paint fixed and covered the contamination, and the unit is destined to Vaalputs for disposal as a complete unit, it will require regulatory approval to deviate from Vaalputs WAC [19] section 9.3 (d). 3. Depending on the physical cleanliness of the SG external surface (e.g. covered with isolation material remnants, moist) it could be difficult to paint and seal the SG. This could cause flaking of paint during or after removal. Thus surface preparation could be required before painting is done.
Gen	2	Removal of lagging material		
Gen	3	Radiological survey		
Gen	4	Paint external surface and removal from containment area		
Gen	5	Loading and securing on SPMT	1. Loading and securing equipment need to be identified and designed 2. The saddles required are to be utilised, and designed accordingly, for the handling, transfer, storage and transport of the SGs 3. Local equipment and expertise available in South Africa 4. Localisation - Government focus area	1. SG support saddles need to be designed and manufactured
Gen	6	Transfer to ISF	1. Short distance on-site transfer of unshielded SG 2. Local equipment and expertise available in South Africa 3. Localisation - Government focus area	
Gen	7	Off-loading from SPMT	1. SG off-loaded on supports 2. Local equipment and expertise available in South Africa 3. Localisation - Government focus area	1. SG supports need to be designed and manufactured

Option		**Brief scope:**	**Details/Justification**	**Impacts / Risks**
Gen	8	Store SG in ISF at KNPS	1. This facility will be constructed by KNPS. General purpose to have the units safely and securely stored in a shielded store, where the units can await the final waste management option to be implemented 2. Allow for the final radiological survey to be done for full characterisation and nuclide inventory determination 3. Each of the waste management options considered will require interim storage before the next required processing steps can be performed or carried out.	1. Capital cost to establish the facility 2. New facility, including licensing, design, siting etc.
(h)	**Overall description:**		***SG is, after internal in-situ flushing (crud burst) and removed from the KOU, stored in a KNPS ISF, the concrete enclosed ISF also used to section the SG, sections are packaged into a newly to-be-developed waste packages suitable for these heavy items, and then shipped to Vaalputs for disposal. Clearable material shall be released from the KNPS site.***	
(h)	9	Store SG in ISF at KNPS (waste management specific requirements)	1. Allow decay or internal decontamination to ensure dose rates are low enough to section unit. 2. ISF need to be changed and sectioning process to be installed to allow for the sectioning of the SGs inside the ISF. 3. Methodology and process needs to be developed for systematically sectioning the SG. This is foreseen to be done by international experts. 4. New waste package needs to be developed for the heavy steel sections (current waste packages cannot be used, these are too small and waste form is too heavy). 5. Regulatory approval required for new waste package. 6. Regulatory approval for store and activities: decay storage, decontamination & sectioning 7. Regulatory approval required for the clearance methodology 8. Pre-shipment storage area required for secondary waste packages 9. Actual work and sectioning can be done by local labour under possible supervision of international expert. 10. Certain sections of the SG could possibly be cleared as non-radioactive waste and recycled back into the steel industry	1. ISF design to allow for the dismantling of the SG. In addition a safe sectioning protocol and process needs to be developed 2. Capital cost for equipping ISF and high initial cost of learning and methodology development 3. Time delay due to obtaining necessary regulatory approval 4. Workers to perform the sectioning will receive higher radiological exposure due to sectioning which has to be done in close proximity of the SG. 5. All sections needs to be characterised in detail to enable sorting. Extensive measuring program needs to be initiated to enable free release of certain SG parts / sections. 6. New waste package needs to be developed and regulator approved to allow the packaging of the heavy metal items 7. Sectioned items should be small enough to fit into new waste packages, this could mean that extensive cutting (and personnel radiological exposure) needs to be done 8. Large volumes of secondary waste needs to be interim stored before they are allowed/approved to be shipped to Vaalputs (would require extra storage space)

Option		Brief scope:	Details/Justification	Impacts / Risks
			11. No large items need to be transported as 'abnormal load' to Vaalputs. Routine shipment and experience to date could be applied in shipment. 12. Same facility, equipment and process can be utilised for the sectioning of the replacement SGs and other equipment at the KNPS end-of-life 13. Local labour and expertise could be utilised to perform the actual work/sectioning, probably under supervision of the utility providing the equipment.	9. Vaalputs operational SAR to be updated and regulator approved for the handling of these new packages. 10. Possible international expert would be required for the SG sectioning process methodology and design – This could however have a large cost impact to the project
(h)	10	Secondary waste package loading on truck	Depending on the waste package design and size, special loading and truck securing would have to be designed and approved	1. Large number of waste packages that needs to be loaded
(h)	11	Transport to Vaalputs	1. Regulatory approval for waste package 2. Normal transport means (standard trucks) of waste package will be required (normal waste to Vaalputs truck), thus these packages will also be covered in the existing transport plan and no new revised transport plan is required. 3. Transport impact on the public domain could be much less (normal truck on the road, no abnormal load.)	1. Large number of waste packages that needs to be transported to Vaalputs 2. Due to total weight of packages, large number of shipments would be required
(h)	12	Off-loading and disposal at Vaalputs	1. Require revision of Vaalputs operational SAR to include handling and disposal of new large and heavy waste packages 2. No special and complex off-loading required 3. No special design/adapted trench design required	1. The new bigger and heavier waste package for containing the sectioned metal would require the review and approval of the current approved Vaalputs operational SAR

Option		Brief scope:	Details/Justification	Impacts / Risks
(h)	13	**General justifications or possible impacts or risks not covered in the detail steps**	1. Depending on the equipment to be used to section the SG, almost only localised expertise, processes and facilities will be utilised - Government focus area 2. Most of the project cost will remain in South Africa, including the future cost relating to the decommissioning of KNPS at end-of-life. 3. There is adequate disposal capacity at Vaalputs, even though big volumes are disposed 4. The same facility and new waste package can also be used for the waste management of other large metal components, including the replacement SGs at the KNPS end-of-life. 5. Eliminates future unknown additional costs since project will be completed when items have been disposed	1. Since only sectioning is done, the possibility that a significant portion of the SG is clearable will be little. 2. The total volume to be disposed will most probably be more than when the SG is disposed as one unit. Based on ENRESA experience in sectioning a reactor pressure vessel and packaging it in their waste packages, the total volume actually disposed was almost 3 times more than the complete vessel volume. Final volume depends on the waste container volume and geometry, and waste packing density. The waste packing density is dependent on the sectioning approach, and weight allowance of the waste container. Due to the SG design, it will be difficult and timeous to ensure optimal cutting and packing of the waste containers. 3. The total nuclide inventory is still disposed at Vaalputs, thus same safety impact as when the SGs are disposed as complete units at Vaalputs.
(i)		Overall description:	***SG is, after internal in-situ flushing (crud burst) and removed from the KOU, stored in the concrete enclosed ISF, shipped to Studsvik for processing, and receiving and disposal of the secondary waste generated at Studsvik***	
(i)	9	Store SG in ISF at KNPS (waste management specific requirements) for decay (estimated: 15 years)	1. Allow decay to ensure compliance to Studsvik WAC criteria. 2. Bridge possible delay between SG removal and actual shipment to Studsvik. 3. Regulatory approval for store and activities: decay storage, decontamination. 4. Conventional and radiological exposure risks managed in a purpose built facility	1. Based on current AREVA calculated nuclide inventory is the total Co-60 activity 3.7 TBq. To ensure SG complies with Studsvik WAC of 0.5TBq, the unit needs to be stored 15 years to decay. This means that SG might have to be stored for extended period. Additional risk is that by then the Studsvik WAC and other requirements are applicable, or even risk that facility does not exist anymore.
(i)	10	Loading on truck		1. Specialized crane and lifting equipment is required for loading of the SG when compared to sectioning option.
(i)	11	Transport to Saldana harbour	1. Regulatory approval for waste package. 2. Regulatory approval for transport plan. 3. Abnormal load transport. 4. Same route justification, route and transport plan can be used as for the new SGs.	1. Radiological and conventional risks to be assessed and included in transport plan for regulatory approval 2. Specialized truck is needed for transport to Saldanha (same as the one used to transport the new SG from Saldana to KNPS). 3. Regulatory approval needs to be obtained for the SG as waste/transport package, IAEA SSR-6 [22] requirements related Surface Contaminated Object-III (SCO-III) and NNR letter K21426N which specify SG to comply

Option		Brief scope:	Details/Justification	Impacts / Risks
				with IP-2 package requirements needs to be evaluated and considered. Finite Element Analysis would be required to either demonstrate compliance to SCO-III or IP-2 criteria.
(i)	12	Loading on Ship	1. Special lifting crane required 2. Same equipment can be used which was used to unload the new SG when it will be delivered to KNPS	
(i)	13	Transport from Saldana to Studsvik	1. Regulatory approval for waste package. 2. Regulatory approval for transport plan. 3. Regulatory approval for nuclear vessel 4. Dedicated ship is routinely used for these shipments, thus it was already approved for use by several international regulators.	1. Actual shipment of SGs is dependent on the availability of the ship 2. May cause significant delay in whole KNPS SG waste management project schedule which will have a knock-on effect on costs (e.g. delay in actual shipment from KNPS to Saldana, processing at Studsvik, return of secondary waste to SA, and disposal of this waste at Vaalputs.)
(i)	14	Packaging of secondary waste in containers (At Studsvik)	1. About 30% of weight is regarded as secondary waste, thus total about 96 tons. 2. New waste package required for secondary waste, thus development, testing and regulatory approval needs to be done 3. Import approval required of secondary waste back into SA	1. Expected contact dose rates on waste packages containing the secondary waste (as per information from Studsvik) exceeds the Vaalputs WAC of 2mSv/h (most of the SG nuclide inventory is concentrated in this waste). 2. Either waste has to be distributed between more drums to ensure WAC compliance, or special regulatory approval needs to be obtained to allow elevated dose rate drums to be transported, received, handled and disposed.
(i)	15	Transport from Studsvik to Saldana	1. Regulatory approval for nuclear vessel 2. Dedicated ship routinely used for this shipments is used, thus it was already approved for use by several international regulators.	1. Actual shipment of waste drums is dependent on availability of ship and if shipment will be combined with other shipment/s of waste. 2. Secondary waste needs to be returned back to SA within 3 years. Due to regulatory approval of the waste package, processing at Studsvik and transport delays this duration could be exceeded
(i)	16	Unload from ship to truck		
(i)	17	Transport from Saldana to Vaalputs	1. Regulatory approval of transport plan (new route) 2. Alternatively transport to KNPS and utilise routine authorised transport from KNPS to Vaalputs 3. If approved containers are utilised, then no special arrangement requirements and approvals are required.	1. Vaalputs operational safety assessment will need revision to address these packages 2. Transport from Saldana to Vaalputs not currently regulatory approved

Option		Brief scope:	Details/Justification	Impacts / Risks
(i)	18	Disposal at Vaalputs	1. New waste package is required for the secondary waste. These will be heavy and could have elevated contact dose rates, thus the off-loading and handling will require special handling/ The Vaalputs operational SAR would need to be reviewed 2. Reduced waste volume disposed at Vaalputs. 3. Standard off-loading approach and equipment would be utilised	1. Almost the complete SG nuclide inventory still needs to be disposed at Vaalputs (all the activity is concentrated in the secondary waste). Other waste that remains in Sweden need to comply to clearance levels, thus will represent only a small fraction of the total activity, thus from a Vaalputs disposal safety perspective there is no reduction in possible long term exposure risk (PCSA). 2. Depending on the packaging and total activity some packages could be non-LLW, thus not be possible to dispose at Vaalputs and would require long term on-KNPS- site storage for ultimate disposal at a (to-be-developed) ILW disposal site.
(i)	19	**General justifications or possible impacts or risks not covered in the detail steps**	1. Eliminates future unknown additional costs since project will be completed when items have been disposed at Vaalputs 2. Reduction of waste volume and weight 3. Applies the most desirable waste management option w.r.t. WM hierarchy as per RWMPS-SA, e.g. clearance	1. Many processing steps and each of these have their own complex design and authorisation processes 2. Due to the many steps (loading, off-loading, on-site and off-site road transports, shipment by sea, interim storage) and Studsvik cost, the overall project cost is high 3. Studsvik has limited operational experience, which can further delay the completion of the project 4. Multilateral and international regulatory approvals would be required for transport 5. Potential negative public reaction, considering Bruce Power, Canada experience 6. Studsvik has a small production line. EDF bought recently Studsvik and trade as Cyclife Holding. Priority could therefore be that EDF SGs will be regarded as priority. At this stage most of the EDF SGs are stored on the applicable NPP sites, thus these could be regarded as a national priority.

Option		**Brief scope:**	**Details/Justification**	**Impacts / Risks**
(j)	**Overall description:**		***SG is, after internal in-situ flushing (crud burst) and removed from the KOU, stored in the concrete enclosed ISF, shipped as a complete unit to Vaalputs for direct disposal into a trench***	
(j)	9	Store SG in ISF at KNPS for about 2-5 years (waste management specific requirements)	1. Allow decay of short-lived nuclides and ensure reduced contact dose rate during transport to Vaalputs. 2. Bridge possible delay between SG removal and actual shipment to Vaalputs due to project implementation and regulatory approvals. 3. Regulatory approval for store and activities: decay storage	1. Large capital cost for construction 2. Long term facility operation and costs
(j)	10	Loading on truck		1. Specialized crane is required for loading of the SG when compared to segmentation option 2. Design of SG cradles/saddles for the safe handling and placement will be required. 3. Design of SG securing mechanisms required
(j)	11	Transport to Vaalputs	1. Regulatory approval for waste package (special arrangement) 2. Regulatory approval of transport plan 3. Alternative route to avoid bridges. Road improvements/changes and overhead cable repositioning 4. Involvement of local emergency services and local authorities regarding transport plan and emergency response 5. Abnormal load transport 6. Transport plan used for the transport of the new SGs from Saldana harbour can be used as basis for developing the new transport plan for the SGs to Vaalputs 7. Local expertise available for the transport of abnormal loads	1. Abnormal load transport required 2. Road improvement/changes required 3. Due to very slow transport, narrow road and bridges, public traffic on the road will be restricted. 4. Involvement of local traffic police and emergency services required. 5. Regulatory approval needs to be obtained for the SG as waste package, IAEA SSR-6 [25] requirements related Surface Contaminated Object-III (SCO-III) and NNR letter K21426N which specify SG to comply with IP-2 package requirements needs to be evaluated and considered. Finite Element Analysis would be required to either demonstrate compliance to SCO-III or IP-2 criteria.
(j)	12	Off-loading, disposal and backfilling at Vaalputs	1. Alternative trench design required, e.g. include ramp for truck to enter trench base 2. Vaalputs operational SAR to be updated to include the placement and backfilling of the SGs 3. Enough disposal space available at Vaalputs, even if trenches need to include a ramp on both side for the entrance and exit of the transport vehicles.	1. Very specialised off-loading required 2. Possible revised trench design to allow for large SG outer diameter and the transport vehicle to drive into the trench for hydraulic jack off-loading approach and to carry the total SG weight of ~330 tons 3. Vaalputs safety case will need to be revised to address the package off-loading and in-situ backfilling. 4. Backfilling would be required to address the voids requirement in the Vaalputs WAC [19] and to retard the nuclide migration to the geosphere (intrusion scenario).

Option		Brief scope:	Details/Justification	Impacts / Risks
				5. Process needs to be developed, designed and licensed for the safe backfilling of the SG inside the trenches 6. Possible increased exposure to Vaalputs personnel
(j)	13	**General justifications or possible impacts or risks not covered in the detail steps**	1. Only localised expertise processes and facilities are utilised - Government focus area 2. All project cost will remain in South Africa 3. Adequate disposal capacity at Vaalputs, even though large volumes are disposed 4. Various other NPP internationally have experience in direct disposal 5. Eliminates future unknown additional costs since project will be completed when items have been disposed	1. Significant volume of waste disposed (12 SGs: total about 2000m^3), but compared to SG sectioning (see above) direct disposal might yield less waste volume. 2. Backfilling/grouting required of the SG. This would require separate design, licensing and approvals.
(k)	**Overall description:**		**SG is, after internal in-situ flushing (crud burst) and removed from the KOU, stored in the concrete enclosed ISF on the KNPS site until the KNPS end-of-life (2045). It is assumed for comparison purposes that the complete SGs will then be disposed at Vaalputs.**	
(k)	9	Store SG in ISF at KNPS (waste management specific requirements)	1. Allow decay of short-lived nuclides and ensure reduced contact dose rate during transport to Vaalputs. 2. Regulatory approval for store and activities: decay storage, and possible external and internal decontamination	1. Long term storage (care and maintenance required) until KNPS end-of-life (2045)
(k)	10	Transport to and dispose SG at Vaalputs as a complete unit	1. SG has decayed, and will have lower contact dose rates 2. Processing steps and action impacts are as described above for "Complete SG disposed at Vaalputs". **See Option (j) above**.	1. Cost related to transport and final disposal delayed 2. Applicable regulations could be changed.
(k)	11	**General justifications or possible impacts or risks not covered in the detail steps**	1. SG can decay over the storage period and ease/reduce exposure during further processing at KNPS end-of life 2. No off-site transport required in the short term.	1. Delayed management will still be KNPS responsibility 2. Final solution is disposal at Vaalputs – only delayed (thus it will remain a liability) and will require recycling or disposal at a later stage 3. Final disposal is just deferred 4. Delayed and possible escalated cost when actual waste management and disposal is ultimately done

11. COST ANALYSIS OF OPTIONS

Cost estimates are reflected in the following subsections for the waste management options as detailed in Table 6. Cost of the closures for the SG, support and rigging saddles and the ISF are the same and common to each waste management option. It should be noted that these costs are just rough estimates for comparison purposes. Most of the costs are taken from [10], which is dated from 2014, thus the total cost has been escalated with CPI [29] (09-2015: 4.6%; 09-2016: 6.1%; 09-2017: 5.1%; 09-2018: 4.9%; 09-2019: 4.1%). The disposal related costs at Vaalputs are based on current costs, thus these were exclude from the escalation.

11.1 Sectioning at KNPS and secondary waste disposal at Vaalputs - Option (h)

The expected cost for sectioning the SGs inside the ISF at KNPS, packaging the sectioned items, transport and disposal at Vaalputs is about R 444 million. The breakdown is given below:

Cost of the SG closures, support and rigging saddles and the ISF #1	R 84 m
Cost of design, purchase and install the required equipment and facility #2	R 80 m
Cost of processing #3	R 27 m
Secondary waste containers #4	R 24 m
Secondary waste transport from KNPS to Vaalputs #5	R 50 m
Secondary waste disposal at Vaalputs #6	R 110 m
Licensing and other authorisations related costs #7:	R 15 m
TOTAL (2014 value): **TOTAL (2019 CPI adjusted, excl ISF & secondary waste disposal)**	**R 390 m** **R 444 m**

Notes #:

1. SGR project estimate for ISF R80 m; R4 m for saddles and closures design and manufacture
2. This is estimate of design, purchase/manufacture and install of:
   - **a.** ISF containment improvement (to control and operate as contamination area)
   - **b.** Extraction ventilation and filtration systems and stack
   - **c.** Cutting technique and equipment
   - **d.** SG handling during sectioning
   - **e.** Packaging processes (various waste streams)
3. To process 6 SGs at least 3 years, 15 team members
4. Design, approval and supply. If 0.5 m^3 container, waste volume increase factor: 2, total 6000 containers~ R4000/container
5. Based on current KNPS-Vaalputs transport costs and Studsvik secondary waste cost in 11.2 below. Studsvik secondary waste is 20% of total volume: R5m. Thus with total waste volume being 2 x SG volume: 5x10=R50m
6. Double of complete SG disposal, see note 3 in Section 11.3
7. Increased due to sectioning process development to be licensed

11.2 Recycling at Studsvik (Cyclife) and secondary waste disposal at Vaalputs – Option (i)

The expected cost for recycling at Studsvik in Sweden and disposal of the secondary waste at Vaalputs is about R561 million. The breakdown is given below:

Cost of the SG closures, support and rigging saddles and the ISF #1	R 84 m
SG Transport from Koeberg to Saldanha (including loading at Saldanha) #2	R 28 m
Sea Transport from Saldanha to Studsvik #3	R 38 m
Offloading, transport and waste treatment at Studsvik #3	R 238 m
Secondary waste transport from Studsvik to Saldanha (incl waste containers) #3	R 48 m
Secondary waste transport from Saldanha to Vaalputs #4	R 5 m
Secondary waste disposal at Vaalputs #5	R 11 m
Licensing and other authorisations related costs #6	R 9 m

TOTAL (2014 value): **TOTAL (2019 CPI adjusted, excl ISF & secondary waste disposal)**	**R 461 m** **R 561 m**

Notes #:

1. SGR project estimate for ISF R80 m; R4 m for saddles and closures design and manufacture
2. Based on quote
3. Based on Studsvik budget quote
4. Based on current KNPS-Vaalputs transport costs
5. See note 3 in Section 11.3 below. 20% x 1950m3 x R28 200/m3
6. Obtain applicable approvals and licenses. This includes Finite Element Analysis required to demonstrate SCO-III or IP-2 criteria compliance for off-site transport of complete SG (R4m)

11.3 Direct complete SG disposed at Vaalputs – Option (j)

The expected cost for transporting the complete SGs to Vaalputs and dispose them there is about R 237 million. The breakdown is given below:

Cost of the SG closures, support and rigging saddles and the ISF #1	R 84 m
Cost for SG transport to Vaalputs #2	R 44 m
Cost for trenches #3:	R 7 m
Cost for SG Disposal #4:	R 55 m
Cost for rigging at Vaalputs #5	R 13 m
Licensing and other authorisations related costs #6:	R 13 m
TOTAL (2014 value): **TOTAL (2019 CPI adjusted, excl cost of trenches and SG disposal)**	**R 216 m** **R 237 m**

Notes #:

1. SGR project estimate for ISF R80 m; R4 m for saddles and closures design and manufacture
2. Based on budget quote transport from Saldanha to KNPS, R39 m. Cost has been added related to the probable required road improvements/changes (R5 m).
3. Based on current typical trench cost of R1m. These trenches will however have very long ramps on both sides, thus bigger, however 2 or 3 SGs could be disposed in one trench. Thus assume R7m for 6 SGs.
4. 6 x 325m^3 (total volume of SG) = 1950 x R 28 200 / m3. Disposal rate is based on current (2019/20) annual Eskom cost to Vaalputs (R18 555 000) and Eskom- Vaalputs contract rate approach for additional volume above 654m^3, which is based on the total annual cost divided by 654m^3.
5. Based on Koeberg re-racking disposal project
6. Obtain applicable approvals and licenses. Also includes R1m for Vaalputs related approvals (safety case). This includes Finite Element Analysis required to demonstrate SCO-III or IP-2 criteria compliance for off-site transport of complete SG (R4m)

11.4 Interim storage on KNPS site until KNPS end-of-life. Disposal as a complete unit at Vaalputs – Option (k)

The expected cost for the long-term storage on-site in the ISF and final disposal during KNPS decommissioning is about R263 million. The breakdown is given below:

Cost of the SG closures, support and rigging saddles and the ISF #1	R 84 m
Cost for ISF maintenance #2	R 20 m
Cost for SG transport to Vaalputs #3	R 44 m
Cost for trenches #3:	R 7 m
Cost for SG Disposal #3:	R 55 m

Cost for rigging at Vaalputs #3	R 13 m
Licensing and other authorisations related costs #4	R 13 m
TOTAL (2014 value): **TOTAL (2019 CPI adjusted)**	**R 236 m** **R 263 m**

Notes #:

1. SGR project estimate for ISF R80 m; R4 m for saddles and closures design and manufacture
2. 20 year ISF operation and maintenance
3. Same as cost for direct disposal, section 11.3. However total cost is assuming financial provision is made now for the 20 year later actions to be done. Also assumes no change in regulation or approach. Risk however is high that regulations could change and project cost could increase accordingly.
4. Obtain applicable approvals and licenses. This includes Finite Element Analysis required to demonstrate SCO-III or IP-2 criteria compliance for off-site transport of complete SG (R4m)

11.5 Cost comparison

The above cost estimates are summarised in Table 7 below:

Table 7: Cost comparison summary

Option no	Option description	Total estimated cost
(h)	Sectioning at KNPS and secondary waste disposal at Vaalputs	R 444 m
(i)	Recycling at Studsvik (Cyclife) and secondary waste disposal at Vaalputs	R 561 m
(j)	Direct complete SG disposed at Vaalputs	R 237 m
(k)	Interim storage on KNPS site until KNPS end-of-life. Disposal as a complete unit at Vaalputs	R 263 m

The total costs of options (j) and (k) are about half the total estimated cost of options (h) and (i). Thus even if there are significant errors in the cost estimates, the probability is therefore high that these two options could be more favourable from a cost perspective.

There is no significant cost difference between option (j) and (k), however even if there would be under or over estimates, option (k) will always have a higher cost then option (j). Option (k) includes the same cost items as option (j), except the additional cost related to the operation of the ISF. The significant risk to option (k), and which is not applicable to option (j), is that the current applicable regulatory requirement and regime could change and increase the cost accordingly.

Thus by only considering the total cost, the preferred option would be the direct disposal of the SG at Vaalputs.

12. EVALUATION CRITERIA

12.1 General considerations for assessing a management option

The fundamental safety requirements on an SG waste management option are:

- the radioactive materials are fully contained within the system, and
- Unnecessary radiation exposures to workers and the public are avoided, both under normal operating conditions and in case of accidents or malevolent acts.

From these, one can derive specific safety relevant criteria that can be used in the selection of a preferred management option.

In addition, the selection will be influenced by practical aspects related to

- the handling operations of the SG itself and any containers needed to transport or store the SG, and
- siting issues including space requirements, geotechnical or environmental restrictions and public acceptability.

Finally, economic considerations will play an important role. To be considered are the following aspects:

- Capital costs.
- Transport costs.
- Decontamination and decommissioning costs.
- Disposal cost.
- Financing requirements and their timing.

12.2 Specific Criteria for Selecting Waste Management Options

Based on the above general considerations, 27 specific criteria were formulated (refer to Table 9) for use in comparing the different waste management options in a systematic manner. These criteria were formulated so that they can be used to score each option.

Table 8 below list the evaluation criteria as defined in the *Solid Radioactive Waste Management Plan for KNPS* [7] and the *RWMPS-SA* [3], and shows all the applicable above mentioned specific criteria number and goal per RWMPS-SA sub-criteria. All the RWMPS-SA evaluation criteria are extensively covered. Sub-criteria "B5: Waste Quality" is not included, since this criteria is equal important for each considered waste management option. The final end point of each option is disposal, thus the waste destined to the disposal site has to comply with the WAC of Vaalputs.

Security is not listed in the RWMPS-SA, but is included as one of the 27 specific criteria (SS1).

Table 8: Evaluation criteria goals per RWMPS-SA evaluation criteria

RWMPS-SA & Eskom evaluation criteria				Applicable SG WMP Criteria (Table 9)	
Element		Sub-element			
No	Criteria	No	Sub-criteria	No	Goal
A	Cost effectiveness	A1	Life cycle cost of waste	C1	Minimise direct capital costs
				C2	Minimise operational costs
				C3	Minimise decommissioning and decontamination costs
				C4	Use RSA suppliers (local currency)
				C5	Minimise financial risk (uncertainties)
B	Technological status / benefit	B1	Existing or new technology	E1	Availability of proven technology and commercially available components
		B2	International practice	E1	Adequate capacity for all conceivable future SG management option

RWMPS-SA & Eskom evaluation criteria				Applicable SG WMP Criteria (Table 9)	
Element		Sub-element			
No	Criteria	No	Sub-criteria	No	Goal
		B3	Waste prevention potential	WD1	Minimal production of radioactive wastes during the implementation of the management option
				WD2	Minimal decontamination and decommissioning required for secondary infrastructure and equipment required to implement the management option
		B4	Waste minimisation potential	WD1	Minimal production of radioactive wastes during the implementation of the management option
				WD2	Minimal decontamination and decommissioning required for secondary infrastructure and equipment required to implement the management option
		B5	Waste quality	N/A	This criteria is applicable to the same degree for each waste management option, thus not considered and included
		B6	Regulatory implications	R1	Speed and simplicity of authorisations
				R2	Minimal required authorisations
C	Safety	C1	Worker safety impact	OS1	Minimise external dose exposure during whole operation
				OS2	Minimise internal dose during whole operation
				OS3	Robustness to all conceivable accidents
				CS1	Prevent handling incidents/accidents
		C2	Public safety impact (operational)	RS1	Minimisation of off-site radionuclide (contamination) releases during handling, transport, dismantling and conditioning (any site)
				RS2	Ensure long-term structural integrity of the containment facility/structure
				RS3	Minimisation of off-site radiation/exposure during handling, transport, dismantling and conditioning (any site)
				RS4	Robustness to all conceivable accidents during all activities
		C3	Transport minimisation / prevention	RS3	Minimisation of off-site radiation/exposure during handling, transport, dismantling and conditioning (any site)
				S1	Use of local skills and workforce
				ENV 3	Low carbon footprint
				CS2	Prevent transport incident accidents
		C4	Accident risk	OS3	Robustness to all conceivable accidents
				E3	Avoidance of SG dropping accidents
				CS1	Prevent handling incidents/accidents
				CS2	Prevent transport incident accidents
		C5	ALARA	OS1	Minimise external dose exposure during whole operation
				OS2	Minimise internal dose during whole operation
D	Social and environmental sustainability	D1	Public safety impact (long term)	RS2	Ensure long-term structural integrity of the containment facility/structure
		D2	Perceived risk and social acceptability	S2	Minimise impact on society
		D3	Benefit to the community in relation	S1	Use of local skills and workforce

RWMPS-SA & Eskom evaluation criteria				Applicable SG WMP Criteria (Table 9)	
Element		Sub-element			
No	Criteria	No	Sub-criteria	No	Goal
			to the "no action" option		
		D4	Environmental impact	ENV 1	Limited land use requirements
				ENV 2	Low energy use
				ENV 3	Low carbon footprint
		D5	Continual improvement potential	E2	Adequate capacity for all conceivable future SG management option

The criteria defined in Table 9 are within ten major criterion groups. Each criterion is described in the form of a 'goal' that the developer of the waste management option would wish to achieve and the 'optimum objective' for each goal that a developer might strive to achieve is also defined. However, optimum objectives cannot always be met and some options cannot achieve certain optimum objectives at all. Consequently, selecting an option will always involve balancing criteria against each other in an optioneering approach. In addition, some criteria will be of more importance to the developer than others, which is why the criteria are weighted in the comparison exercise described in the Section 13.1.

Table 9: WMP Evaluation criteria and the applicable optimal objective

WMP CRITERIA			
Major Criterion	**No.**	**Goal**	**Optimum objective**
Radio-logical Safety of the Public	RS1	Minimisation of off-site radionuclide (contamination) releases during handling, transport, dismantling and conditioning (any site)	Zero off-site contamination releases at any time
	RS2	Ensure long-term structural integrity of the containment facility/structure	Design to provide assured structural and physical integrity over whole operational period
	RS3	Minimisation of off-site radiation/exposure during handling, transport, dismantling and conditioning (any site)	Zero public dose
	RS4	Robustness to all conceivable accidents during all activities	Off-site releases under all conceivable accident scenarios to meet recognised risk standards for members of the public
Radio-logical Safety of the Work-force	OS1	Minimise external dose exposure during whole operation	Zero dose exposure
	OS2	Minimise internal dose during whole operation	Zero internal dose
	OS3	Robustness to all conceivable accidents	Releases under all conceivable accident scenarios to meet recognised risk standards
Security	SS1	Robustness to theft or to malevolent actions by insiders or outsiders	High-level of physical protection and isolation in structures that are difficult to penetrate and ensure difficulty to access
Engineer-ing	E1	Availability of proven technology and commercially available components	All aspects of the management option is available from recognised suppliers

WMP CRITERIA			
Major Criterion	**No.**	**Goal**	**Optimum objective**
simplicity, flexibility and availa-bility	E2	Adequate capacity for all conceivable future SG management option	An approved methodology that can easily be applied or implemented with KNPS end-of-life
	E3	Avoidance of SG dropping accidents	Designs that minimise handling frequencies and limit high lifting of the SG
Waste generated during implemen-tation of option	WD1	Minimal production of radioactive wastes during the implementation of the management option	Designs with zero/minimum generation of radioactive wastes
	WD2	Minimal decontamination and decommissioning required for secondary infrastructure and equipment required to implement the management option	Minimise D&D activities
Regulation	R1	Speed and simplicity of authorisations	Systems that have already been licensed in SA or in several other countries
	R2	Minimal required authorisations	Minimise authorisations
Societal	S1	Use of local skills and workforce	Designs that can be built in RSA and on-the-spot, rather than relying on significant use of international experts
	S2	Minimise impact on society	Minimum disruption to public
Environ-mental	ENV1	Limited land use requirements	Small footprint
	ENV2	Low energy use	Option that use minimum energy
	ENV3	Low carbon footprint	Option with fewer transport movement requirements
Economic	C1	Minimise direct capital costs	No direct capital cost
	C2	Minimise operational costs	No operational cost
	C3	Minimise decommissioning and decontamination costs	No decommissioning or decontamination cost
	C4	Use RSA suppliers (local currency)	Option that can be implemented in RSA
	C5	Minimise financial risk (uncertainties)	No uncertainty on total waste management option cost
Conven-tional safety	CS1	Prevent handling incidents/accidents	Zero handling incidents
	CS2	Prevent transport incident accidents	Zero transport incidents

13. WASTE MANAGEMENT OPTION EVALUATION

13.1 Evaluation Approach

The criteria presented in Table 9 were used as the basis for comparing the waste management options reflected in Table 6 during a series of workshops carried out at Necsa. The intention of this comparison exercise was to inform the recommendation by allowing the team to explore all aspects of a waste management option in some detail and at the same level.

The approach which was adopted looked at each individual option and applied a simple score to the extent to which each option met each specific criterion. This was based upon the judgement of the workshop participants. The processing steps and the applicable detail/justifications and impacts/risks as detailed in Table 6, were considered by all the workshop participants in the evaluating a specific criteria. Consensus scores were allocated and the merits and disadvantages listed as notes for each criteria. Where applicable the option scoring is done and applied by comparing the extend or number of activities applicable for each option. In these cases a description/listing of these are given in the notes. Scores for each criterion were then weighted – first, within the major criterion category and then between these categories, using the following rules:

(a) **Scoring**: Scores out of 6 were given for each criterion, for how well an option matched the goal described for that criterion, taking account of the optimum objective described in the list of criteria. Descriptions of the scores are reflected in Table 10 below.
(b) **Criterion weights**: After scoring, each criterion was weighted for its significance within the set of criteria making up its major criterion (e.g. there are five criteria, C1 to C5, within the major criterion, 'Economic'). Percentage weights were then allocated for the perceived importance of a criterion within its major criterion group, adding up to 100%.
(c) **Major criterion weights**: After scoring and weighting each of the criteria, the ten major criteria were themselves allocated a percentage weight, again adding up to 100%, based on their perceived importance in reaching a decision.
(d) **Total, weighted scores**: These were calculated by determining the sum total of each option's weighed major criterion total.

Table 10: Scoring description

1	Non-compliance or not achieving objective
2	Low
3	Intermediate
4	Good
5	Excellent
6	Total achievement to optimum objective

Before evaluating each of the waste management options by the evaluation team, two steps were performed:

(a) Ensuring that all team members were totally familiar with the full scope and extend of the appropriate waste management options, thus considering the information of the various options as reflected in Table 6;
(b) Review and possible removal of any criteria from the list that were either not appropriate or would be non-discriminating for assessment of the specific option and the group of selected options.

<u>The important caveat is made that the results are dependent on the weightings applied, which are to some extent subjective to the experts involved, and they are quite sensitive to these</u>.

13.2 Evaluation

The outcome of the evaluation is reflected in Table 12. The abbreviations for the waste management options used in Table 12 are detailed in Table 11 below.

Table 11: Waste management option abbreviations

Option No. #	Abbreviation	Description
(h)	S & D	Sectioning of the SGs at KNPS inside the Interim storage facility after which the sections are packaged and disposed at Vaalputs (possible clearance of some of the material)
(i)	R at S	Recycling of SGs at Studsvik (Cyclife), Sweden. The complete SGs are shipped to Sweden for recycling, and the secondary waste returned to South Africa for disposal at Vaalputs
(j)	D at V	Direct transport of SGs to Vaalputs as a complete unit and disposed at Vaalputs
(k)	S L D	SG stored in Interim storage facility on KNPS site for decay until the KNPS end-of-life. Disposal as a complete unit at Vaalputs.

#: Option number as listed and fully described in Section 10.

It should be noted that final scoring should be interpreted in context of the merits and disadvantages listed in the notes on each option for the specific criteria, and the detail operational steps described, the impact and risks detailed in Table 6.

Table 12: Waste management Option Evaluation

CRITERIA				OPTIONS				Goal Weight (%)	WEIGHTED SCORE				Major Criterion Weight (%)	NOTES ON OPTION MERITS (M) AND DISADVANTAGES (D)			
Major	No.	Goal	Optimum objective	S & D (h)	R at S (i)	D at V (j)	S L D (k)		S & D (h)	R at S (i)	D at V (j)	S L D (k)		S & D (h)	R at S (i)	D at V (j)	S L D (k)
Radiological Safety of the Public	RS 1	Minimisation of off-site radionuclide (contamination) releases during handling, transport, dismantling and conditioning (any site)	Zero off-site contamination releases at any time	3	2	4	4	40	1.2	0.8	1.6	1.6	*15*	(D): High volume of cutting needs to be done during which gaseous releases are formed. (D): This activity fully relies on good filtration systems and containment to prevent activity releases. A big number of secondary waste packages will be generated and needs to be transported to Vaalputs. (M): Activity concentration in each package will be lower than those from Studsvik. (D): Various off-site transport required (KNPS to Vaalputs) during which accidents and releases could happen. Thus Intermediate probability to achieve goal.	(D): Studsvik will section and melt material during which gaseous releases are formed. These activities fully relies on good filtration systems and containment to prevent activity releases. (D): Secondary waste (which contains almost the total SG activity inventory) are shipped and transported back to SA and Vaalputs. (D): This option involves many on and off-site transport (road and sea) during which items (complete SG and waste packages are loaded and unloaded multiple times. (D): Multiple activities during which accidents and releases could happen. Thus Low probability to achieve goal.	(M): The open sections of the SGs are sealed with welded steel flanges when it is removed from the KNPS containment area. Further it is handled and disposed as a complete and sealed unit. (M): Activity is contained in the thick steel SG outer shell. Thereafter only once loaded at KNPS and unloaded at Vaalputs. (M): Slow speed transport. Thus probability of activity release during a possible transport or handling accident in relatively low. (M): Only one transport per SG operation, KNPS to Vaalputs. Thus good probability to achieve goal.	(M): The open sections of the SGs are sealed with welded steel flanges when it is removed from the KNPS containment area. (M): During storage in the ISF very low probability of activity release. Further it is handled and ultimately disposed as a complete and sealed unit. (M): Activity is contained in the thick steel SG outer shell. Thereafter only once loaded at KNPS and unloaded at Vaalputs. Slow speed transport. Thus probability of activity release during a possible transport or handling accident in relatively low. (M): Only one transport per SG operation, KNPS to Vaalputs. Thus good probability to achieve goal.

CRITERIA				OPTIONS				Goal Weight (%)	WEIGHTED SCORE				Major Criterion Weight (%)	NOTES ON OPTION MERITS (M) AND DISADVANTAGES (D)			
Major	No.	Goal	Optimum objective	S & D (h)	R at S (i)	D at V (j)	S L D (k)		S & D (h)	R at S (i)	D at V (j)	S L D (k)		S & D (h)	R at S (i)	D at V (j)	S L D (k)
Radiological Safety of the Public	RS 2	Ensure long-term structural integrity of the containment facility/structure	Design to provide assured structural and physical integrity over whole operational period	3	3	4	2	10	0.3	0.3	0.4	0.2		(M) The integrity of the ISF, which will be used for the sectioning, has a small impact. (M) It is foreseen that the duration of the SG sectioning operation would be completed over a relative short period in which the facility would hardly degrade. Thus intermediate probability to achieve goal.	(D) Studsvik is already operating various years, thus integrity is dependent on their maintenance programme. (M) The processing of the KNPS SGs would however not be a long duration in this facility. (M) The temporary storage in the ISF and handling of the SG at KNPS is relatively short. Thus intermediate probability to achieve goal.	(M) Only short period of storage on KNPS site in the ISF, until it is directly transported to and disposal at Vaalputs. (M) Thus no long duration in which the SG is exposed to weather conditions and subject to possible degradation. (M) At Vaalputs the complete SG is enclosed (covered with soil) inside the trench shortly after disposal. Thus good probability to achieve goal.	(D) Interim storage facility will be located on the KNPS site, thus ISF and SGs are exposed for the period of storage (~25 years) to sea climate conditions which could affect the integrity. (M) When finally the SG is disposed at Vaalputs, the complete (decayed) SG is enclosed (covered with soil) inside the trench shortly after disposal. Thus low probability to achieve goal.

CRITERIA				OPTIONS				Goal Weight (%)	WEIGHTED SCORE				Major Criterion Weight (%)	NOTES ON OPTION MERITS (M) AND DISADVANTAGES (D)			
Major	No.	Goal	Optimum objective	S & D (h)	R at S (i)	D at V (j)	S L D (k)		S & D (h)	R at S (i)	D at V (j)	S L D (k)		S & D (h)	R at S (i)	D at V (j)	S L D (k)
Radiological Safety of the Public	RS 3	Minimisation of off-site radiation /exposure during handling, transport, dismantling and conditioning (any site)	Zero public dose	3	2	3	4	30	0.9	0.6	0.9	1.2		(D) Since it is foreseen that a big number of waste packages are required to package the sectioned SG, numerous off-site shipments from KNPS to Vaalputs are required. (D) The total nuclide inventory/ activity would be the same as when the complete SG is transported to Vaalputs, however distributed between the numerous waste packages. Thus possible public exposure could be similar as when the complete unit is transported. Thus intermediate probability to achieve goal	Possible public exposure during numerous off-site transport: (D) - Whole SG to Saldana harbour (D) - Whole SG sea transport from Saldana to Studsvik. (D) - Secondary waste packages (which include almost total nuclide inventory/ activity) sea transport to RSA (D) - Secondary waste transport to Vaalputs. Thus low probability to achieve goal. Thus low probability to achieve goal	(D) Single but slow transport of complete unit to Vaalputs (D) Relatively high contact dose, since it is shipped 'shortly' after removal from the KNPS Thus intermediate probability to achieve goal	(M) SG have decayed for 25 years before being shipped to Vaalputs, thus low contact dose rates are expected when they will be transported to Vaalputs. Thus good probability to achieve goal
	RS 4	Robustness to all conceivable accidents during all activities	Off-site releases under all conceivable accident scenarios to meet recognised risk	3	2	4	5	20	0.6	0.4	0.8	1		(D) Off-site release risk if ISF containment or filtration system fails while the SGs are sectioned. (D) Additional risk while the numerous	(D) Relative high probability of accidents due to various (repeated and long distance) off-site road and sea transport of items containing total	(M) Off-site releases only foreseen to be possible during the once-off slow transport to Vaalputs. (M) Activity contained	(M) Very low probability of off-site releases when being stored in the ISF for ~25 years. (M) Off-site releases only foreseen to be possible during the

CRITERIA				OPTIONS				Goal Weight (%)	WEIGHTED SCORE				Major Criterion Weight (%)	NOTES ON OPTION MERITS (M) AND DISADVANTAGES (D)			
Major	No.	Goal	Optimum objective	S & D (h)	R at S (i)	D at V (j)	S L D (k)		S & D (h)	R at S (i)	D at V (j)	S L D (k)		S & D (h)	R at S (i)	D at V (j)	S L D (k)
			standards for members of the public											shipments of secondary waste is shipped to Vaalputs. Thus intermediate probability to achieve goal	SG nuclide inventory (whole SG and secondary waste packages from Studsvik). (D) In addition SGs are sectioned and melted at Studsvik (thus contents of SG is exposed inside the facility) Thus low probability to achieve goal	inside thick walled SG. Thus good probability to achieve goal	once-off slow transport to Vaalputs. (M) Activity contained inside thick walled SG will however be significantly lower due to 25 years decay. Thus excellent probability to achieve goal
	Total:							***100***	***3***	***2.1***	***3.7***	***4***					
	Weighted Major Criteria								***0.45***	***0.32***	***0.56***	***0.60***					
Radiological Safety of the Workforce	OS 1	Minimise external dose exposure during whole operation	Zero dose exposure	2	1	4	5	40	0.8	0.4	1.6	2	*15*	(D) During sectioning the internal heat exchanger tubes would also be exposed to workforce. These contain the most activity, and are normally shielded by the thick outer shell of the SG. (D) Therefore significant exposure to workforce is foreseen. In addition workforce will be exposed during the secondary waste package packaging,	Large number of activities where workforce exposure is expected: (D) - SG handling; - Loading and unloading of whole SG; (D) - on-site and off-site road transport, sea transport of whole SG; (D) - Sectioning and melting of SG at Studsvik; (D) - Packaging, sea transport to RSA and off-site transport to Vaalputs of secondary	(M) Workforce will be exposed during the single special arrangement transport from KNPS to Vaalputs. (M) This transport will be slow, thus possible exposure time could be long, however workforce would not be required close to the SG during transport. (D) In addition possible exposure during the possible backfilling of the SG inside the	(M) SG will be allowed to decay for ~25 years before shipment to Vaalputs, thus Workforce will be exposed during the single special arrangement transport from KNPS to Vaalputs on SG with significant lower external contact dose rates. (M) This transport will be slow, thus possible exposure time could be long, but exposure rates very low.

CRITERIA				OPTIONS				Goal Weight (%)	WEIGHTED SCORE				Major Criterion Weight (%)	NOTES ON OPTION MERITS (M) AND DISADVANTAGES (D)			
Major	No.	Goal	Optimum objective	S & D (h)	R at S (i)	D at V (j)	S L D (k)		S & D (h)	R at S (i)	D at V (j)	S L D (k)		S & D (h)	R at S (i)	D at V (j)	S L D (k)
														loading, transport and off-loading at Vaalputs. Thus low probability to achieve goal.	waste (high activity); (D) - Disposal of secondary waste at Vaalputs. Thus not achieving goal.	trench at Vaalputs and disposal at Vaalputs. Thus good probability to achieve goal.	(M) In addition workforce would not be required close to the SG during transport. (M) In addition possible low exposure during the possible backfilling of the SG inside the trench at Vaalputs and disposal at Vaalputs. Thus excellent probability to achieve goal.
Radiological Safety of the Workforce	OS 2	Minimise internal dose during whole operation	Zero internal dose	2	1	5	5	30	0.6	0.3	1.5	1.5		(D) During sectioning of the SG, the heat exchanger tubes (which contain the activity) need to be cut and crud will be exposed. (D) Exposure to workforce rely on effectiveness of extraction ventilation and personnel protection. (D) Due to complexity and duration, workforce would have elevated risk of exposure. Thus low probability to achieve goal.	Large number of activities during which accidents could happen and workforce exposed: (D) - SG handling; (D) - Loading and unloading of whole SG; (D) - on-site and off-site road transport, sea transport of whole SG; (D) - off-site transport of secondary waste to Vaalputs. (D) In addition: During sectioning and melting of the SGs, and the packaging of the secondary waste (containing almost all the activity) at Studsvik	(M) SG is sealed with steel flanges before being removed from the containment building. (M) Outer surfaces are cleaned and finally painted. (M) Workforce could only be internally exposed during accident where SG contents is exposed/released. (M) Transport is very slow and SG made of very thick steel, thus probability of exposure during possible accident very low. (M) In addition possible	(M) SG is sealed with steel flanges before being removed from the containment building. (M) Outer surfaces are cleaned and finally painted. (M) SG is stored in the ISF for ~25 years, during which activity will decay. (M) Workforce could only be internally exposed during accident where SG contents is exposed/released (decayed content). (M) Transport is very slow and SG made of

CRITERIA				OPTIONS				Goal Weight (%)	WEIGHTED SCORE				Major Criterion Weight (%)	NOTES ON OPTION MERITS (M) AND DISADVANTAGES (D)			
Major	No.	Goal	Optimum objective	S & D (h)	R at S (i)	D at V (j)	S L D (k)		S & D (h)	R at S (i)	D at V (j)	S L D (k)		S & D (h)	R at S (i)	D at V (j)	S L D (k)
															exposure to workforce rely on effectiveness of extraction ventilation and personnel protection. Thus not achieving goal.	exposure during the possible backfilling of the SG inside the trench at Vaalputs and disposal at Vaalputs. Thus excellent probability to achieve goal.	very thick steel, thus probability of exposure during possible accident very low. (M) In addition possible low exposure during the possible backfilling of the SG inside the trench at Vaalputs and disposal at Vaalputs. Thus excellent probability to achieve goal.
	OS 3	Robustness to all conceivable accidents	Releases under all conceivable accident scenarios to meet recognised risk standards	2	1	5	5	30	0.6	0.3	1.5	1.5		(D) Relative high risk during sectioning. (D) In addition numerous off-site shipments have made to ship the secondary waste packages to Vaalputs; (D) All these secondary drums have to be loaded and off-loaded. Thus low probability to achieve goal	Various activities during which accidents could happen: (D) - handling, (D) - loading and unloading (D) - on and off-site road transport (D) - sea transport, (D) - handling, sectioning and melting at Studsvik. Thus not achieving goal	(M) Very limited handling of the SG. SG will also, due to heavy weight, be transported very slowly, thus probability of accidents low. Thus excellent probability to achieve goal	(M) Very limited handling of the SG. SG will also, due to heavy weight, be transported very slowly, thus probability of accidents low. (M) Activity content of SG will have decayed thus lower dose rates. Thus excellent probability to achieve goal
	Total:							***100***	***2***	***1***	***4.6***	***5***					
	Weighted Major Criteria								***0.30***	***0.15***	***0.69***	***0.75***					

CRITERIA				OPTIONS				Goal Weight (%)	WEIGHTED SCORE				Major Criterion Weight (%)	NOTES ON OPTION MERITS (M) AND DISADVANTAGES (D)			
Major	No.	Goal	Optimum objective	S & D (h)	R at S (i)	D at V (j)	S L D (k)		S & D (h)	R at S (i)	D at V (j)	S L D (k)		S & D (h)	R at S (i)	D at V (j)	S L D (k)
Security	SS 1	Robustness to theft or to malevolent actions by insiders or outsiders	High-level of physical protection and isolation in structures that are difficult to penetrate and ensure difficulty to access	2	1	5	4	100	2	1	5	4	*5*	(D) Sectioned items are more susceptible to theft, but operation is done on the KNPS site (within security area). (D) Various off-site transport activities needs to be done to take waste packages for disposal at Vaalputs Thus low probability to achieve goal	(D) Numerous and long duration activities outside the KNPS security fence, involving off-site transport which are relatively easy accessible (open to public), thus open to public interference. Thus not achieving goal	(M) Single off-site shipment of a very large item, Thus excellent probability to achieve goal	(D) ~25 years storage on the KNPS site in the ISF, and then single off-site shipment of a very large item. Thus duration of exposure to possible malevolent actions is higher than for direct disposal of SG Therefore good probability to achieve goal.
	Total:							***100***	***2***	***1***	***5***	***4***					
	Weighted Major Criteria								***0.10***	***0.05***	***0.25***	***0.20***					
Engineering simplicity, flexibility and	E1	Availability of proven technology and commercially available components	All aspects of the management option is available from recognised suppliers	4	5	5	5	30	1.2	1.5	1.5	1.5	*5*	(M) New to SA, Internationally the technology and experience is available. (D) Not readily local experience available. Thus good probability to achieve goal	(M) Proven technology available at Studsvik. KNPS size SG already processed at Studsvik. Studsvik has their own ship and experience in the sea transport of SGs. Thus excellent probability to achieve goal	(M) Not local experience on transport of very large radiological item, however many non-radioactive shipments of very large items done by various companies in South Africa. Internationally experience available in the shipment of SGs. Thus excellent probability to achieve goal	(M) Not local experience on transport of very large radiological item, however many non-radioactive shipments of very large items done by various companies in South Africa. Internationally experience available in the shipment of SGs. Thus excellent probability to achieve goal

CRITERIA				OPTIONS				Goal Weight (%)	WEIGHTED SCORE				Major Criterion Weight (%)	NOTES ON OPTION MERITS (M) AND DISADVANTAGES (D)			
Major	**No.**	**Goal**	**Optimum objective**	**S & D (h)**	**R at S (i)**	**D at V (j)**	**S L D (k)**		**S & D (h)**	**R at S (i)**	**D at V (j)**	**S L D (k)**		**S & D (h)**	**R at S (i)**	**D at V (j)**	**S L D (k)**
Engineering simplicity, flexibility and availability	E2	Adequate capacity for all conceivable future SG management option	An approved methodology that can easily be applied or implemented with KNPS end-of-life	3	2	5	4	40	1.2	0.8	2	1.6		(M) Facility and process for sectioning the SGs could probably be used again at KNPS end-of-life to section the SGs (thus the facility and established expertise could then be available). (D) This however depends whether the cutting process is temporary installed, or permanent implemented system. (D) In addition one has the risk of the possible effect of non-use and old technology by the time of reuse. Thus intermediate probability to achieve goal.	(D) Studsvik methodology availability depends on if this service provider will still be available in 25 years' time, and if their technology will by then still be acceptable and utilised. (D) In addition the regulations and practice of international shipment of SGs could have changed, or even become more stringent. Thus low probability to achieve goal.	(M) Methodology for the shipment of a complete SG is developed and approved, thus could be applied again. Require re-approval of the transport (possible new regulations, but both shipments will have the same typical radiation levels and activity). (D) Regulations could however have changed by 2045. Thus excellent probability to achieve goal if compared to other options	(M) After KNPS end-of-life, facility not operational and C&M license required, with different requirements applicable. However methodology that will need to be developed for the shipment of the SGs to Vaalputs, can again be applied when the other SGs also needs to be shipped to Vaalputs at a later stage. (D) Regulations could have changed by 2045 (D) and again when 2nd batch of SGs needs to be shipped. Both shipments will be with the same typical radiation levels and activity. Thus good probability to achieve goal.
	E3	Avoidance of SG dropping accidents	Designs that minimise handling frequencies and limit high lifting of the SG	5	2	4	4	30	1.5	0.6	1.2	1.2		(M) Only one on-site transfer of the SG to the ISF. Thus excellent probability to achieve goal.	Various activities with the complete SG: (D) - loading at KNPS (D) - transport from KNPS to Saldana (D) - unloading and loading from truck onto	(M) Single off-site transport to Vaalputs on lowbed truck/trailer. Loading at KNPS and off-loading at Vaalputs Thus good probability	(M) Single off-site transport to Vaalputs on lowbed truck/trailer. Loading at KNPS and off-loading at Vaalputs Same number and types of handling of SG

CRITERIA				OPTIONS				Goal Weight (%)	WEIGHTED SCORE				Major Criterion Weight (%)	NOTES ON OPTION MERITS (M) AND DISADVANTAGES (D)			
Major	No.	Goal	Optimum objective	S & D (h)	R at S (i)	D at V (j)	S L D (k)		S & D (h)	R at S (i)	D at V (j)	S L D (k)		S & D (h)	R at S (i)	D at V (j)	S L D (k)
															sea vessel (D) - sea transport to Studsvik (D) - off-loading and loading at Studsvik facility. Thus low probability to achieve goal.	to achieve goal.	then direct disposal at Vaalputs. Thus good probability to achieve goal.
	Total:							***100***	***3.9***	***2.9***	***4.7***	***4.3***					
	Weighted Major Criteria								***0.20***	***0.15***	***0.24***	***0.22***					
Waste generated during implementation of option	WD 1	Minimal production of radioactive wastes during the implementation of the management option	Designs with zero/minimum generation of radioactive wastes	3	2	5	5	50	1.5	1	2.5	2.5	*5*	This excludes the secondary (SG sectioned) waste which will be generated during the sectioning activity. (D) However large quantities of waste are foreseen to be generated during sectioning of the SGs. (D) This includes facility regular cleaning / decontamination material and waste, personnel protective equipment, extraction system filters, etc. Thus intermediate probability to achieve goal.	This excludes the secondary waste being returned from Studsvik to South Africa. (D) However large quantities of waste are foreseen to be generated during sectioning of the SGs. (D) This includes facility regular cleaning / decontamination material and waste, personnel protective equipment, extraction system filters, etc. (D) In addition waste could also be generated during the various SG and secondary waste handling, loading, unloading and	(M) The contents of the SG will not be exposed during the handling and off-site transport to Vaalputs. Thus minimal waste could be generated during handling and transport. (M) No processing of the SG is required for this option. Thus excellent probability to achieve goal.	(M) Possible waste generated during routine ~ 25 year operation of the ISF, however very low probability to be radioactive waste. (M) The contents of the SG will not be exposed during the storage, handling and off-site transport to Vaalputs. Thus minimal waste could be generated during handling and transport. (M) No processing of the SG is required for this option. Thus excellent probability to achieve goal.

CRITERIA				OPTIONS				Goal Weight (%)	WEIGHTED SCORE				Major Criterion Weight (%)	NOTES ON OPTION MERITS (M) AND DISADVANTAGES (D)			
Major	No.	Goal	Optimum objective	S & D (h)	R at S (i)	D at V (j)	S L D (k)		S & D (h)	R at S (i)	D at V (j)	S L D (k)		S & D (h)	R at S (i)	D at V (j)	S L D (k)
															shipments. Thus low probability to achieve goal.		
	WD 2	Minimal decontamination and decommissioning required for secondary infrastructure and equipment required to implement the management option	Minimise D&D activities	2	3	5	4	50 %	1	1.5	2.5	2		Each option would require the ultimate D&D of the ISF. (D) However since the ISF is foreseen to be used for the sectioning of the SGs, the facility will highly probable become contaminated, and would require more complex D&D. (D) In addition the cutting equipment and extraction system will require D&D Thus low probability to achieve goal.	Each option would require the ultimate D&D of the ISF. (D) However since the ISF is foreseen for this option to be utilised for ~15 years to allow for decay to levels acceptable for the Studsvik WAC, the ultimate D&D could be more involved. (D) In addition the Studsvik sectioning and melting facility also require D&D, which is a supplier responsibility, but clients would be required to contribute (as part of the services cost) towards the ultimate D&D of this facility D&D. Therefore intermediate probability to achieve goal.	Each option would require the ultimate D&D of the ISF. (M) Since SG will only be stored until the required approvals were obtained and arrangement made for transport, no impact on ISF is foreseen Thus excellent probability to achieve goal	Each option would require the ultimate D&D of the ISF. (D) However since the ISF will be utilised for ~25 years, the ultimate D&D could be more involved. Thus good probability to achieve goal.
	Total:							***100***	***2.5***	***2.5***	***5***	***4.5***					
	Weighted Major Criteria								***0.13***	***0.13***	***0.25***	***0.23***					

CRITERIA				OPTIONS				Goal Weight (%)	WEIGHTED SCORE				Major Criterion Weight (%)	NOTES ON OPTION MERITS (M) AND DISADVANTAGES (D)			
Major	No.	Goal	Optimum objective	S & D (h)	R at S (i)	D at V (j)	S L D (k)		S & D (h)	R at S (i)	D at V (j)	S L D (k)		S & D (h)	R at S (i)	D at V (j)	S L D (k)
Regulation	R1	Speed and simplicity of authorisations	Systems that have already been licensed in SA or in several other countries	3	3	5	5	30	0.9	0.9	1.5	1.5	*15*	(D) Sectioning of SGs not licensed in SA with NNR, but was licensed in Spain: Enresa and Sweden: Studsvik. (M) SA has experience in waste package development and authorisation, including transport and disposal of radioactive waste to and at Vaalputs. Thus intermediate probability to achieve goal.	(D) Local authorisations would be required for: - SG abnormal load shipment from KNPS to Saldana. (internationally done but not in SA) - Ship loading and shipment from SA to Studsvik (new to SA) - Shipment of secondary waste to SA (receiving) - Secondary waste shipment and disposal at Vaalputs Thus intermediate probability to achieve goal.	(M) Possibly limited experience on special arrangement and abnormal load road transport of radioactive item in RSA. (M) International experience in the transport and disposal of whole SGs available. (M) SA has experience in waste package development and authorisation, including transport and disposal of radioactive waste to and at Vaalputs. Thus excellent probability to achieve goal.	ISF experience available. (M) Possibly limited experience on special arrangement and abnormal load road transport of radioactive item in RSA. (M) International experience in the transport and disposal of whole SGs available. (M) SA has experience in waste package development and authorisation, including transport and disposal of radioactive waste to and at Vaalputs. Thus excellent probability to achieve goal.

CRITERIA				OPTIONS				Goal Weight (%)	WEIGHTED SCORE				Major Criterion Weight (%)	NOTES ON OPTION MERITS (M) AND DISADVANTAGES (D)			
Major	No.	Goal	Optimum objective	S & D (h)	R at S (i)	D at V (j)	S L D (k)		S & D (h)	R at S (i)	D at V (j)	S L D (k)		S & D (h)	R at S (i)	D at V (j)	S L D (k)
	R2	Minimal required authorisations	Minimise authorisations	3	2	5	4	70 %	2.1	1.4	3.5	2.8		**Scoring for this criteria is done by comparing the number and extend on authorisations required. Thus no specific disadvantages or merits**			
														Authorisations required for (incl indication of complexity): - Sectioning process and facility (new and emphasis on proof of compliance to containment and personnel exposure minimisation required) - Secondary waste package (local experience) - transport of secondary waste Vaalputs - Disposal of these at Vaalputs Thus intermediate probability to achieve goal.	Authorisations required for: - special arrangement transport of whole SG to Saldana, - sea transport to Studsvik (multinational approval vessel approval), - Secondary waste package (could be complex due to high activity content and to be used for sea transport) - return sea shipment of secondary waste to SA - off-site transport to Vaalputs (new route if from Saldana, alternatively, separate approval from Saldana to KNPS, and KNPS to Vaalputs), - Disposal at Vaalputs Thus low probability to achieve goal.	Authorisations required for: - Post Closure Safety Assessment review - special arrangement transport and waste package of whole SG to Vaalputs - Off loading and disposal at Vaalputs. Thus excellent probability to achieve goal.	Authorisations required for: - ISF ~25 year operational licence - Post Closure Safety Assessment review - special arrangement transport and waste package of whole SG to Vaalputs - Off loading and disposal at Vaalputs, Thus good probability to achieve goal.
	Total:							***100***	***3***	***2.3***	***5***	***4.3***					
	Weighted Major Criteria								***0.45***	***0.35***	***0.75***	***0.65***					

CRITERIA				OPTIONS				Goal Weight (%)	WEIGHTED SCORE				Major Criterion Weight (%)	NOTES ON OPTION MERITS (M) AND DISADVANTAGES (D)			
Major	No.	Goal	Optimum objective	S & D (h)	R at S (i)	D at V (j)	S L D (k)		S & D (h)	R at S (i)	D at V (j)	S L D (k)		S & D (h)	R at S (i)	D at V (j)	S L D (k)
Societal	S1	Use of local skills and workforce	Designs that can be built in RSA and on-the-spot, rather than relying on significant use of international experts	5	2	3	4	50	2.5	1	1.5	2	5	(M) Local labour could be utilised over a relative long duration for performing the SG sectioning and packaging secondary waste. (M) Local (existing) contractors can be utilised for transporting secondary waste to Vaalputs. Thus excellent probability to achieve goal.	(D) Local skills would only be utilised during the transport of the SG to Saldana, and the secondary waste from Saldana to Vaalputs, all the other activities would be carried out by international expertise. Thus low probability to achieve goal.	(M) Local service providers are foreseen to be utilised for the transport of SGs to Vaalputs (this would however be only for a relative short duration) Thus intermediate probability to achieve goal.	Local skill would be utilised to operate the ISF for the ~25 years. Local service providers are foreseen to be utilised for the transport of SGs to Vaalputs (this would however be only for a relative short duration) Thus good probability to achieve goal.
	S2	Minimise impact on society	Minimum disruption to public	5	3	2	2	50	2.5	1.5	1	1		(M) Only the secondary waste packages are transported off-site from KNPS to Vaalputs. Numerous shipments will be required, but utilising standard trucks. Very low to no impact to the public foreseen. Thus excellent probability to achieve goal.	(D) Abnormal transport of the whole SG from KNPS to Saldana (relative short distance) will have an impact on the public, since the complete width of these roads will be used, thus impacting routine traffic. (M) Low impact during secondary waste shipment to Vaalputs since standard trucks will be utilised Thus intermediate probability to achieve goal.	(D) Abnormal transport of the whole SG from KNPS to Vaalputs (long distance on main national roads) will have an impact on the public, since the complete width of these roads will be used, thus impacting routine traffic. Thus low probability to achieve goal.	(D) Abnormal transport of the whole SG from KNPS to Vaalputs (long distance on main national roads) will have an impact on the public, since the complete width of these roads will be used, thus impacting routine traffic. Similar as for direct disposal of SG at Vaalputs, transport will only be later. Thus low probability to achieve goal.

CRITERIA				OPTIONS				Goal Weight (%)	WEIGHTED SCORE				Major Criterion Weight (%)	NOTES ON OPTION MERITS (M) AND DISADVANTAGES (D)			
Major	No.	Goal	Optimum objective	S & D (h)	R at S (i)	D at V (j)	S L D (k)		S & D (h)	R at S (i)	D at V (j)	S L D (k)		S & D (h)	R at S (i)	D at V (j)	S L D (k)
	Total:							***100***	***5***	***2.5***	***2.5***	***3***					
	Weighted Major Criteria								***0.25***	***0.13***	***0.13***	***0.15***					
Environmental	EN V1	Limited land use requirements	Small footprint	2	5	4	4	20	0.4	1	0.8	0.8	*5*	(D) Use ISF for sectioning. (D) Packaged secondary waste volume will be more than the total volume of the complete SG (non-sectioned). (D) Thus bigger disposal volume at Vaalputs would be required. (D) In addition significant volume of waste will also be generated during the sectioning operation and the D&D of the sectioning process and facility. Thus low probability to achieve goal.	(M) Waste volume will be reduces by melting at Studsvik. Significant volume is recycled. (M) Secondary waste (about 30% of total SG volume) needs to be disposed at Vaalputs. Final volume of this waste will depend on the waste packaging approach and design Thus excellent probability to achieve goal.	(M) Total volume of the complete SG is disposed at Vaalputs Thus good probability to achieve goal.	(M) Total volume of the complete SG is disposed at Vaalputs Thus good probability to achieve goal.
	EN V2	Low energy use	Option that use minimum energy	3	2	5	4	30	0.9	0.6	1.5	1.2		(D) Significant energy use would be required to section the SGs, including operation of the filtration system. (D) In addition numerous shipments of the secondary waste	(D) Significant energy use to section and melt the SGs at Studsvik. (D) Significant energy use during the numerous and long distance transports from KNPS to Sweden,	(M) relative low energy use for the slow and medium distance transport from KNPS to Vaalputs Thus excellent probability to achieve	(D) Energy use for the operation of the ISF for ~25 years. (M) relative low energy use for the slow and medium distance transport from KNPS to Vaalputs

CRITERIA				OPTIONS				Goal Weight (%)	WEIGHTED SCORE				Major Criterion Weight (%)	NOTES ON OPTION MERITS (M) AND DISADVANTAGES (D)			
Major	No.	Goal	Optimum objective	S & D (h)	R at S (i)	D at V (j)	S L D (k)		S & D (h)	R at S (i)	D at V (j)	S L D (k)		S & D (h)	R at S (i)	D at V (j)	S L D (k)
														packages from KNPS to Vaalputs. Thus intermediate probability to achieve goal.	and back, and the shipment of secondary waste to Vaalputs. Thus low probability to achieve goal.	goal.	Thus good probability to achieve goal.
	EN V3	Low carbon footprint	Option with fewer transport movement requirements	4	1	3	3	50	2	0.5	1.5	1.5		**Scoring for this criteria is done by comparing the number and distances of transport activities. Thus no specific disadvantages or merits**			
														Numerous medium distance shipments on standard trucks from KNPS to Vaalputs of secondary waste in waste drums Thus good probability to achieve goal.	- Abnormal load transport from KNPS to Saldana; - Long distance sea transport to Studsvik; - Long distance sea transport from Studsvik; - Several medium distance road transport from Saldana to Vaalputs on standard trucks - Changes/upgrades roads and powerlines to Saldana for abnormal load. Thus not achieving goal	- Abnormal load slow transport from KNPS to Vaalputs - Changes/upgrades to roads and powerlines Thus intermediate probability to achieve goal.	- Abnormal load slow transport from KNPS to Vaalputs - Changes/upgrades to roads and powerlines Thus intermediate probability to achieve goal.
	Total:							***100***	***3.3***	***2.1***	***3.8***	***3.5***					
	Weighted Major Criteria								***0.17***	***0.11***	***0.19***	***0.18***					

CRITERIA				OPTIONS				Goal Weight (%)	WEIGHTED SCORE				Major Criterion Weight (%)	NOTES ON OPTION MERITS (M) AND DISADVANTAGES (D)			
Major	No.	Goal	Optimum objective	S & D (h)	R at S (i)	D at V (j)	S L D (k)		S & D (h)	R at S (i)	D at V (j)	S L D (k)		S & D (h)	R at S (i)	D at V (j)	S L D (k)
Economic	C1	Minimise direct capital costs	No direct capital cost	2	5	5	5	30	0.6	1.5	1.5	1.5	*15*	ISF capital cost applicable to each option, thus not considered			
														(D) Capital expenditure related to the sectioning and extraction and filtration systems. Thus low probability to achieve goal.	(M) No additional capital cost. Thus excellent probability to achieve goal.	(M) No additional capital cost. Thus excellent probability to achieve goal.	(M) No additional capital cost. Thus excellent probability to achieve goal.
Economic	C2	Minimise operational costs	No operational cost	3	1	4	3	30	0.9	0.3	1.2	0.9		**Scoring for this criteria is done by comparing the scope and number costing activities in each option. Thus no specific disadvantages or merits**			
														Costs related to: - Cutting operation, including operation of ventilation/extraction system - Waste package costs - Transport of secondary waste to Vaalputs Thus intermediate probability to achieve goal.	Costs related to: - Abnormal load transport from KNPS to Saldana - Loading and off-loading SG at KNPS and Saldana - Studsvik cost (sea transport of SG and secondary waste, sectioning and melting of SGs - Secondary waste package cost - Secondary waste transport from Saldana to Vaalputs. Thus not achieving goal.	Costs related to: - Abnormal load transport from KNPS to Vaalputs - Off-loading cost. - Changes and improvements to road infrastructure to allow transport (e.g. road, power lines, etc.). - Back filling of SG Thus good probability to achieve goal.	Costs related to: - ISF operation cost. - Abnormal load transport from KNPS to Vaalputs - Off-loading cost. - Changes and improvements to road infrastructure to allow transport (e.g. road, power lines, etc.). - Back filling of SG. Thus intermediate probability to achieve goal.

CRITERIA				OPTIONS				Goal Weight (%)	WEIGHTED SCORE				Major Criterion Weight (%)	NOTES ON OPTION MERITS (M) AND DISADVANTAGES (D)			
Major	No.	Goal	Optimum objective	S & D (h)	R at S (i)	D at V (j)	S L D (k)		S & D (h)	R at S (i)	D at V (j)	S L D (k)		S & D (h)	R at S (i)	D at V (j)	S L D (k)
	C3	Minimise decommissioning and decontamination costs	No decommissioning or decontamination cost	2	5	5	4	20	0.4	1	1	0.8		(D) D&D of sectioning process and equipment, extraction and filtration system, and ISF would be required. Thus low probability to achieve goal.	(M) No D&D required. Thus excellent probability to achieve goal.	(M) No D&D required. Thus excellent probability to achieve goal.	(D) Possible D&D of ISF due to the ~25 year SG storage. Thus good probability to achieve goal.
Economic	C4	Use RSA suppliers (local currency)	Option that can be implemented in RSA	4	2	4	4	10	0.4	0.2	0.4	0.4		(M) Local labour suppliers can be used for the sectioning operation in the ISF. (M) Local transport suppliers can also be used for the transport of the secondary waste to Vaalputs. Thus good probability to achieve goal.	(D) Only local transport can be done by RSA suppliers. All others (significant part of project scope) are international supplied services Thus low probability to achieve goal.	(M) Local abnormal load transport company and expertise can be used for the transport of the SG to Vaalputs. Thus good probability to achieve goal.	(M) ISF can be operated by local labour. (M) Local abnormal load transport company and expertise can be used for the transport of the SG to Vaalputs. Thus good probability to achieve goal.
	C5	Minimise financial risk (uncertainties)	No uncertainty on total waste management option cost	3	1	5	3	10	0.3	0.1	0.5	0.3		(D) No details available on sectioning process, thus cost related to the development and obtaining the final equipment and technique has uncertainties. Thus intermediate probability to achieve goal	(D) Studsvik cost (which is the majority cost component of the total project cost) if fully dependent on the foreign exchange rate. Rand exchange rate very volatile. Thus not achieving goal.	(M) Local contractors and vehicles used for the abnormal load transport to Vaalputs. (M) Route assessment (KNPS to Vaalputs) done, detail assessment still to done, which could include improvement/ changes on road, bridges and fences.	(D) Uncertainty of future (25 years later) cost of transport to and disposal at Vaalputs (M) Local contractors and vehicles used for the abnormal load transport to Vaalputs. (M) Route assessment KNPS to Vaalputs) done, detail assessment still to done, which could

CRITERIA				OPTIONS				Goal Weight (%)	WEIGHTED SCORE				Major Criterion Weight (%)	NOTES ON OPTION MERITS (M) AND DISADVANTAGES (D)			
Major	No.	Goal	Optimum objective	S & D (h)	R at S (i)	D at V (j)	S L D (k)		S & D (h)	R at S (i)	D at V (j)	S L D (k)		S & D (h)	R at S (i)	D at V (j)	S L D (k)
																Thus excellent probability to achieve goal	include improvement/ changes on road, bridges and fences. Thus intermediate probability to achieve goal
	Total:							***100***	***2.6***	***3.1***	***4.6***	***3.9***					
	Weighted Major Criteria								***0.39***	***0.47***	***0.69***	***0.59***					
Conventional safety	CS 1	Prevent handling incidents/ accidents	Zero handling incidents	2	2	3	3	50	1	1	1.5	1.5	*15*	(D) Activities and personnel involvement is high during sectioning and secondary waste packaging and shipment of these to Vaalputs. Thus low probability to achieve goal	(D) Various loading and off-loading for transport and shipment. SG processing at Studsvik Thus low probability to achieve goal	(D) Handling of whole SG during loading at KNPS and off-loading at Vaalputs Thus intermediate probability to achieve goal	(D) Handling of whole SG during loading at KNPS and off-loading at Vaalputs Thus intermediate probability to achieve goal
	CS 2	Prevent transport incident accidents	Zero transport incidents	3	2	4	4	50	1.5	1	2	2		(D) Numerous shipments of secondary waste packages from KNPS to Vaalputs on standard road trucks Thus intermediate probability to achieve goal	Various transport activities: (D)- Short distance abnormal load from KNPS to Saldana (D)- Long distance sea shipment to Studsvik (D)- Long distance sea shipment back to SA with secondary waste (D)- Medium distance road transport with standard trucks and	(M) Single shipment per SG: Abnormal load slow medium distance transport from KNPS to Vaalputs Thus good probability to achieve goal	(M) Single shipment per SG: Abnormal load slow medium distance transport from KNPS to Vaalputs Thus good probability to achieve goal

CRITERIA				OPTIONS				Goal Weight (%)	WEIGHTED SCORE				Major Criterion Weight (%)	NOTES ON OPTION MERITS (M) AND DISADVANTAGES (D)			
Major	No.	Goal	Optimum objective	S & D (h)	R at S (i)	D at V (j)	S L D (k)		S & D (h)	R at S (i)	D at V (j)	S L D (k)		S & D (h)	R at S (i)	D at V (j)	S L D (k)
															from Saldana to Vaalputs Thus low probability to achieve goal		
	Total:							***100***	***2.5***	***2***	***3.5***	***3.5***					
	Weighted Major Criteria								***0.38***	***0.30***	***0.53***	***0.53***					
	Grand Total								***2.80***	***2.13***	***4.26***	***4.07***	***100***				

13.3 Evaluation Summary

A summary of the evaluation reflected in Table 12 is presented in Table 13 below.

Table 13: Evaluation summary

		Weighted Score for each Option				Major Criterion Weight
Major criterion	**Criteria Code**	**S & D (h)**	**R at S (i)**	**D at V (j)**	**S L D (k)**	
Radiological Safety of the Public	RS1-RS4	**0.45**	**0.32**	**0.56**	**0.60**	15.0%
Radiological Safety of the Workforce	OS1-OS3	**0.30**	**0.15**	**0.69**	**0.75**	15.0%
Security	SS1	**0.10**	**0.05**	**0.25**	**0.20**	5.0%
Engineering simplicity, flexibility and availability	E1-E3	**0.20**	**0.15**	**0.24**	**0.22**	5.0%
Waste generated during implementation of option	WD1-WD2	**0.125**	**0.125**	**0.25**	**0.225**	5.0%
Regulation	R1-R2	**0.45**	**0.35**	**0.75**	**0.65**	15.0%
Societal	S1-S2	**0.25**	**0.13**	**0.13**	**0.15**	5.0%
Environmental	ENV1-ENV3	**0.17**	**0.11**	**0.19**	**0.18**	5.0%
Economic	C1-C5	**0.39**	**0.47**	**0.69**	**0.59**	15.0%
Conventional safety	CS1-CS2	**0.38**	**0.30**	**0.53**	**0.53**	15.0%
TOTAL (Overall score)		***2.80***	***2.13***	***4.26***	***4.07***	***100.0%***

The evaluation determined that the direct disposal of the complete SG at Vaalputs (Option j) is the most suitable option in terms of the overall score calculated. It should be noted that the feasibility study performed by Eskom [10], totally independently done from Necsa, came to the same conclusion.

14. OVERALL EVALUATION COMPARISON

The purpose of this section is to compare the cost analysis outcome, as per section 11.5, and the option evaluation outcome as reflected in section 13.3.

Both evaluations show that the most suitable and cost effective option is Option (j): Direct disposal of the complete SG at Vaalputs.

15. DETAIL DESCRIPTION OF MOST SUITABLE OPTION

This paragraph provides more detail on the most suitable waste management option as identified in Section 13 above. The broad line processing/action steps of the direct disposal of the complete SG at Vaalputs are already reflected in Table 6 section Option (j).

15.1 General

In order to dispose of the complete SG, the body/shell of the SG is regarded and handled as the waste package, thus the following two key requirements are applicable:

(a) Waste form and nuclide activity should be contained inside the SG body
(b) The outer surface of the SG should comply to Vaalputs WAC [19] limit of non-fixed surface contamination
(c) Radiation levels on the outer surface of the SG should comply to the Vaalputs WAC [19] limits

15.2 Vaalputs compliance

The compliance with the key Vaalputs criteria are indicated below. The other detail aspects of the Vaalputs WAC will be addressed during the project implementation phase. The further details for the typical implementation of the trench design, placement and void filling will be considered and addressed also during the implementation phase.

*15.2.1 **Dose rates***

As indicated in Section 6.3, the external surface dose rate is expected to comply with the Vaalputs WAC [19] limit of 2mSv/h.

*15.2.2 **Activity limit compliance***

As indicated in Section 7.2, the SGs do comply with the LILW-SL criteria, as specified in the Vaalputs WAC [19].

*15.2.3 **Disposal***

The size of the SG (maximum diameter less than 5 m) would not require Vaalputs to deviate from the standard and licensed trench depth of 8 m and minimum cap thickness of 3 m. The maximum diameter of the SG is 4.47m. The horizontal adjustment of the trench design to allow for the placement of the SGs in the trench would be part of the further project implementation.

*15.2.4 **Trench placement***

Due to the total weight of the SG (about 330 tons) the offloading from the transport vehicle into the trench would not be possible with a crane standing adjacent to the trench. Therefore the offloading will need to be done inside the trench. This will however mean that the transport vehicles need to drive into the trench. The trench design will need to be adapted to include a ramp into the trench. Offloading the SG from the transport vehicle into the trench may be accomplished by hydraulic jacks or gantry cranes that are installed in the trench.

*15.2.5 **Voids***

The SGs need to be backfilled to fill all the voids inside the SGs and assist in retarding the migration of the nuclide activity in the geosphere. This could be done with a pump, which feeds the filling material through a pipe into the SG. A vent opening would also be required. The vented air will be directed through a typical filtration system. After the SG has been backfilled, the trench will be backfilled as per standard procedure.

15.3 SG preparation

Various preparational activities will need to be performed inside the KNPS containment area before the SGs are removed. This includes the internal flushing (CRUD burst) of the systems, removing the isolation material, sealing of the SG pipe and nozzle connections which need to be cut to disconnect the unit from the KNPS system and painting the external surface.

In order to ensure that the SG would comply with the key criteria listed above and in applying the ALARA principle, it is essential that:

(a) Crud burst cleaning technique is applied while the SGs are still connected to the KNPS system which includes the circulation of the primary water until the criteria for stopping the primary pumps is reached.
(b) After disconnecting the SG from the KNPS system, all the openings (e.g. pipes and nozzles) are sealed to ensure that no activity could seep or leak out during further handling, transport and disposal. The design of the applicable flanges or plugs should make provision for the grout backfilling at Vaalputs, thus typically a few flanges should allow for connecting the grouting pipes and pumps to the SG.
(c) Further the external surface of the SGs will be painted.

When the SGs are removed they will not be externally decontaminated. The external surface will be painted. It should be noted that the majority of the SG external surface is enclosed in thermal insulation material, which would most probably have prevented the external surface of the SG to be contaminated during the operational period. This insulation material is removed before the SG is removed from the containment area.

An important Vaalputs WAC [19] requirement in this context is Section 9.3 (d), which requires NNR approval where waste container external surfaces have been coated/painted (excluding standard coating applied by manufacturers). The risk that needs to be mitigated and justified would be that the contamination would not spread or be released when the paint is damaged during handling or degraded inside the disposal trench, thus having the probability of quick release of activity inside the trench. Normally the activity would be contained inside the waste package, and release would be dependent on the degradation of the container (in this case the SG external wall). This risk however could be minimised if a radiological survey could be performed to confirm that the external surface of the SG is clean, and if required the contaminated areas cleaned, before the unit was painted.

15.4 SG transfer to and storage in ISF

The SG will be lifted out of the containment area by overhead cranes. Positioning and securing frames will be fastened or welded onto the SGs. These frames would allow the stable horizontal positioning and transport of the units. The SGs are then transported on a SPMT to the ISF. The ISF will be located on the KNPS site. During the transfer of the complete, and unshielded, SG applicable temporary radiological controls will be applied. The SGs will be offloaded inside the ISF in such a way that the units can again reasonably easy be lifted and loaded on the truck required to transport the unit to Vaalputs. Thus typically the units will be off-loaded on supports.

The operational license of the ISF would require the inclusion final radiological characterisation. If however the final external dose rates are exceeding the Vaalputs WAC, the SGs needs to be stored for an extended period to decay.

The units will be stored inside the ISF until the applicable authorisations obtained and planning is done for the transport to and disposal at Vaalputs.

The design of the ISF should consider that the SGs need to be off-loaded when being removed from the containment area, but also when the units are to be loaded on the specialised trailer and trucks for the transport to Vaalputs.

It is foreseen that the following authorisations would be required:

(a) Construction of the ISF approval at the NNR
(b) Operational safety case for the ISF approval at the NNR
(c) On-site transfer of the SGs to the ISF approval at the NNR

15.5 Transport to Vaalputs

The SG is loaded on a specialised trailer which are pushed and pulled by large trucks. The trailer is a multi-axle design which ensures that that maximum allowable ground bearing pressure of 2.3 Ton/m^2 on public roads is not exceeded. An assessment [24] was done on the route that this specialised, wide and very heavy truck needs to follow to Vaalputs.

A large part of this route is routinely used for the conveyance of radioactive waste materials from KNPS to Vaalputs. The proposed route (total about 640km) is shown in Figure 2. One bypass route via Klawer, Vredendal, Lutzville to Nuwerus using the R363 was proposed to avoid the fixed overhead rail bridge at Sout River on the N7 between Vanrhynsdorp and Nuwerus.

Some civil works may be required between Klawer and Vredendal on the R363 since the 2-lane road of about 22 km is just as wide as the trailer combination. Further inspection is required by a civil/structural engineer of the whole route to determine which modifications, if any, are required (e.g. road widening and additional lay-by areas).

About a total of 111 overhead telephone lines and 27 overhead power lines would need to be lifted/height increased to allow the truck to pass. The complete route need to be inspected by a registered civil/structural engineer before any final conclusions can be made, and only after the approval from the Department of Transport and Public Works, Western and Northern Cape regions, Telkom and Eskom have been obtained.

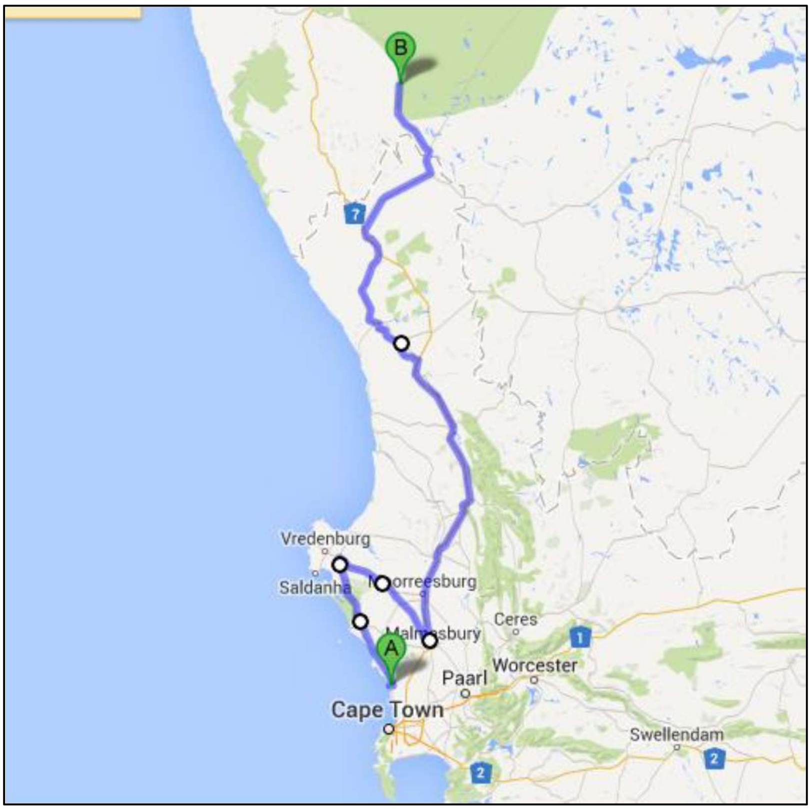

Figure 2: Proposed route from KNPS to Vaalputs

It is foreseen that the transport of each SG from KNPS to Vaalputs will extend over a total period of at least 8 days to maximum 21 days. The maximum speed that the vehicles travel is about 30 km/h. However the speed is not the limiting factor with regards to the transport. The full duration is dependent on various factors, which include:

(a) The transport is only done during the day and not over weekends.
(b) The vehicles regularly are required to stop along the route to allow the normal traffic to pass (the vehicle will utilise the full width of a normal 2-lane road).
(c) The overhead Telkom and power lines are lifted as the transport vehicles progress, thus progress is also dependent on the Eskom and Telkom personnel availability.
(d) Road and weather conditions.

It is foreseen that the following authorisations and involvements would be required:

(a) SG/waste package and special arrangement transport approval at the NNR
(b) Transport plan approval at the NNR, and possible local emergency services and authorities awareness sessions in the transport plan and emergency response.
(c) Department of Transport approval for abnormal load transport and possible road improvements, including provincial government approval (provincial roads)
(d) Telkom on overhead telephone line changes
(e) Eskom on overhead power line changes

15.6 Offloading and disposal at Vaalputs

The complete SG is disposed inside a possible dedicated trench for the SGs at Vaalputs.

Due to the total weight of the SG (about 330 tons) the offloading from the transport vehicle into the trench would not be possible with a crane standing adjacent to the trench (as what is routinely done for offloading normal waste packages). Therefore the offloading will need to be done inside the trench. This will however mean that the transport vehicles need to drive into the trench. The trench design will need to be adapted to include a ramp into the trench.

Offloading the SG from the transport vehicle into the trench may be accomplished by hydraulic jacks or gantry cranes that are installed in the trench. CIRES (France) followed the approach of offloading SGs in the trench using hydraulic gantry cranes and slings.

The SGs needs to be backfilled to fill all the voids inside the SG and assist in retarding the migration of the nuclide activity in the geosphere. This could be done with a pump, which feeds the filling material through a pipe into the SG. A vent opening would also be required. The vented air will be directed through a typical filtration system. The filling of the voids is not only required as per Vaalputs WAC, but also will provide an additional barrier as it would aid in retarding nuclide migration to the geosphere.

After the SG has been backfilled, the trench will be backfilled as per standard procedure.

It is foreseen that the following documents/authorisations would be required:

(a) Revision of the Vaalputs Post Closure Safety Assessment to consider the SGs, possible other KNPS life extension program and decommissioning waste, and inherent intrusion dose scenario.
(b) Revised Vaalputs Operational Safety Assessment Report approval at the NNR. This to consider the PCRSA, the SG handling, off-loading, and grout backfilling (conditioning).
(c) Revision of the Vaalputs WAC to include all the criteria applicable LILW-SL and possible other requirements resulting from the revised Vaalputs Post Closure Safety Assessment and Operational Safety Assessment Report.
(d) Trench design change approval.

15.7 Projected time lines for implementation

Table 14 below gives a projection of the foreseen activities and time lines required for the implementation of the complete SG disposal at Vaalputs.

Table 14: High level action plan

No	Activity description	Duration in months	
		Target date (best-case scenario) #1	Target date (worst-case scenario) #2
A	Acceptance of Waste Management Plan		
B	Establish ISF (Eskom) - Design - Licensing (NNR approval) - Construction	**A +18**	**A + 24**
C	Licensing strategy for the SG transport and disposal at Vaalputs to NNR (Obtain consensus with NNR on licensing and approval requirements) - Review of all applicable requirements and approvals - Drafting - Review - NNR review and approval	**A + 6**	**A + 15**
D	Final Characterisation of SG - procedures - Measurements - Final source term model and determination, - Report	**B + 8**	**B + 12**

No	Activity description	Duration in months	
		Target date (best-case scenario) #1	**Target date (worst-case scenario) #2**
E	Post Closure Radioactive Safety Assessment of Vaalputs - Preparation - Review	**12 (#3)**	**30 (#3)**
F	Waste Package Safety Case/report - Package design for transport and disposal - FEM modeling - Draft report - Review - NNR review and approval	**A +18 & D + 4**	**A + 27 & D + 4**
G	Transport Plan - Transportation study - Transport safety assessment - Document drafting and review - NNR review and approval	**A + 18**	**A + 27**
H	Operation Safety Assessment report of Vaalputs - Off-loading studies - Void filling detail design - Trench backfilling approach - Drafting report - Internal review - NNR review and approval	**E + 6**	**E + 15**
I	Preparation for transport and disposal - Road improvements design and implementation - Void filling installation and commissioning - Trench preparation and establishment - Draft work procedures on transport and disposal - Training	**C + 18**	**C + 24**
J	Transport and disposal - Actual transport - Placement in trench - Void filling - Trench backfilling	**I + 3**	**I + 6**

Assumptions for best-case scenario (#1):

- Use Areva supports, and they are suitable for ISF placement and transport to Vaalputs
- Submissions to NNR only one cycle of comments, and 3 months turnaround time
- Required expertise personnel available 50% of their time to perform work on this project

Assumptions for worst-case scenario (#2):

- Design and manufacture of new supports required
- Submissions to NNR three cycles of comments, and 4 months turnaround time for each cycle
- Required expertise personnel available 40% of their time to perform work on this project

Note #3: PCRSA is an input to Vaalputs Operational Safety Assessment. The operational safety assessment was previously approved by the NNR without the PCRSA being approved by them. Best scenario assumes that the PCRSA does not require NNR approval, however worst case scenario assumes NNR approval would be required.

16. CONCLUSION

This waste management plan considered and evaluated various waste management options related to the disposal of the KNPS SGs.

A total of eleven waste management options were considered, of which seven were eliminated during the first round of assessment, and four were assessed in detail.

Applying 27 specific criteria, which were grouped into 10 major criteria, the four waste management options were compared.

Based on this assessment the option to directly dispose of the complete SG at Vaalputs is the most suitable option.

This waste management option however assumes that the ISF will be erected by KNPS and will be utilised to store the SGs until the required authorisations have been obtained to transport to and dispose the SGs at Vaalputs.

17. ATTACHMENT 1: NRWDI LETTER

Private Bag X1, Pretoria, 0001
Gauteng Province
Republic of South Africa
T: +27 (0)12 305 3222
F: +27 (0)12 305 3200
E: info@nrwdi.org.za

NRWDI
NATIONAL RADIOACTIVE WASTE DISPOSAL INSTITUTE

Mr. Luchen Reddy
Project Manager
Steam Generator Replacement Project
Private Bag X10
KERNKRAG
7440

Our reference:	
Your reference:	
Document no.:	*NRWDI-LET-0607*
Enquiries:	*Alan Carolissen*
E-mail:	*Alan.Carolissen@nrwdi.org.za*
Telephone:	*+27 (0) 82 809 7750*
Date:	*31 May 2021*

Dear Luchen

KOEBERG NUCLEAR POWER STATION ORIGINAL STEAM GENERATOR (OSG) RADIOACTIVE WASTE MANAGEMENT PLAN (RWMP)

Our previous letter NRWDI-LET-0501 dated 8th April 2020 and the NCRWM's comments pertaining to the Koeberg Nuclear Power Station's RWMP for the OSG's has reference.

It is herewith confirmed that extensive consultation took place between NWRDI and the OSG project team regarding the radiological, operational and disposal aspects relating to the preparation of the RWMP for the OSG's as well as the subsequent compliance with the Vaalputs waste acceptance criteria. The outcome of NRWDI's assessment concluded that the Koeberg Nuclear Power Station's RWMP for the OSG's is comprehensive, compelling and credible.

Based on the project deliberations and the RWMP provided, NRWDI confirms that the OSG's can in principle be accepted for disposal at Vaalputs, based on the following process, as applicable:

- The Post-closure radiological Safety Assessment (PCRSA) is reviewed and updated to include this waste stream;
- The Vaalputs operational safety case (SAR) is updated accordingly;
- NNR approval of the transport safety case;
- NNR approval of the OSG waste stream / waste package for disposal at Vaalputs;
- Koeberg applies for disposal of OSG's at Vaalputs;
- Verification of compliance with the Vaalputs waste acceptance criteria;
- Excavation of trenches; and
- Disposal of OSG's at Vaalputs.

Against this background, NRWDI has endorsed and accepted the KNPS Original Steam Generator Radioactive Waste Management Plan.

NRWDI-FRM-0001, Rev. 12

Classification	Open

2.

I want to take this opportunity to personally thank you for the continued good cooperation between the NRWDI and Eskom officials.

Yours sincerely,

Mr. Alan Carolissen
Acting CEO: NRWDI

18. ATTACHMENT 2: DRAWINGS

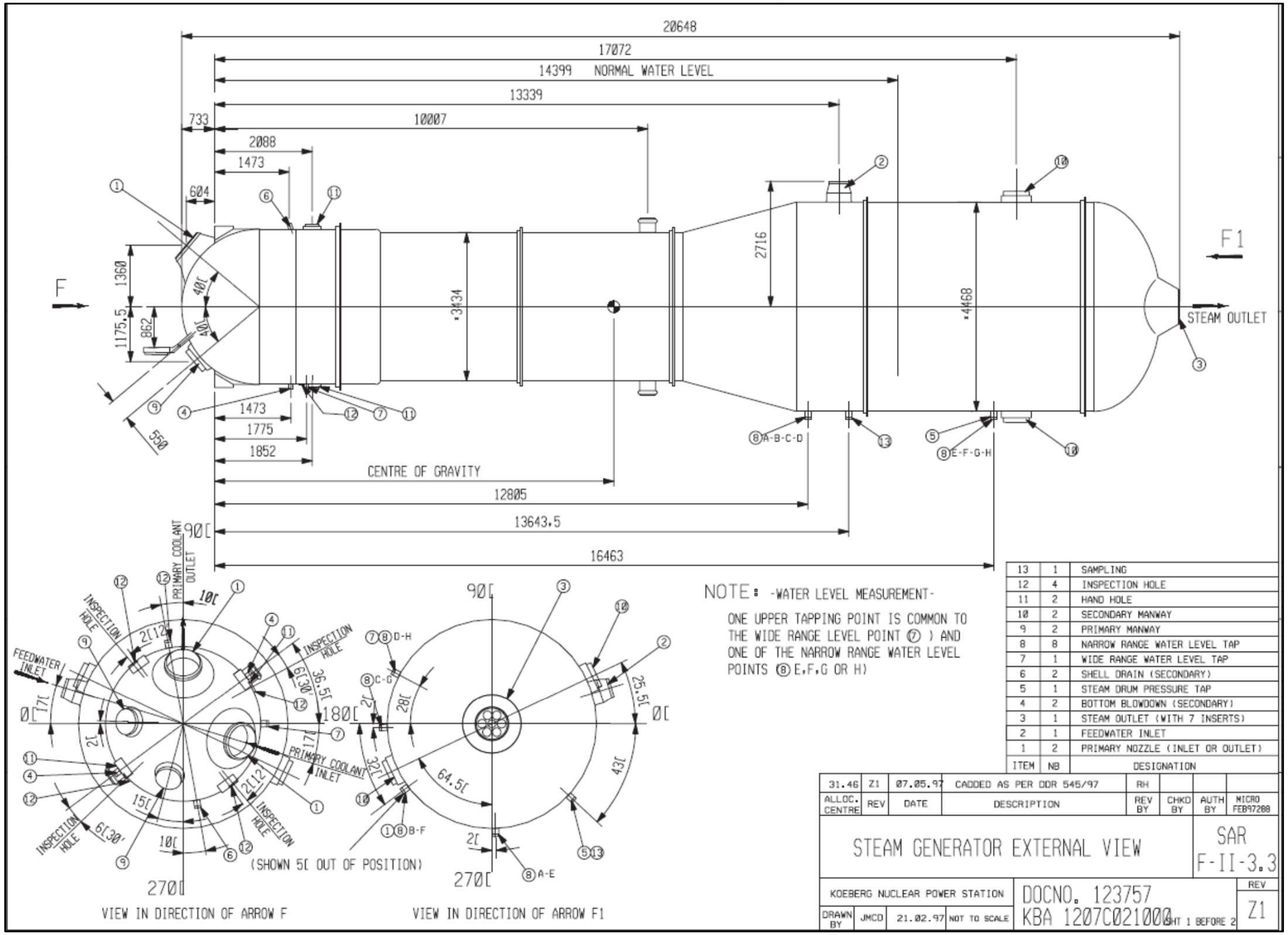

Figure 3: Original Steam Generator Dimensions and layout

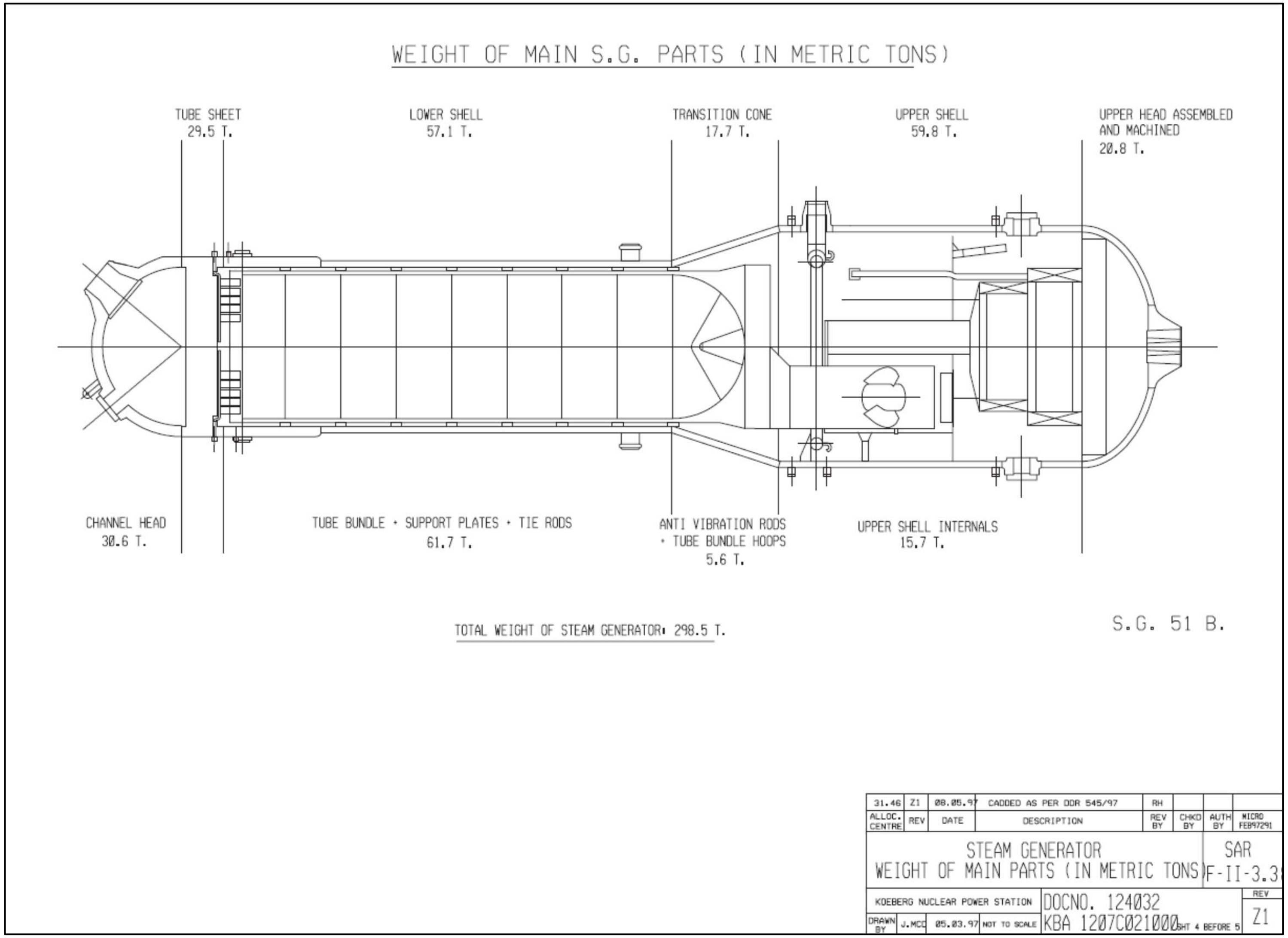

Figure 4: Original Steam Generator main parts and weights

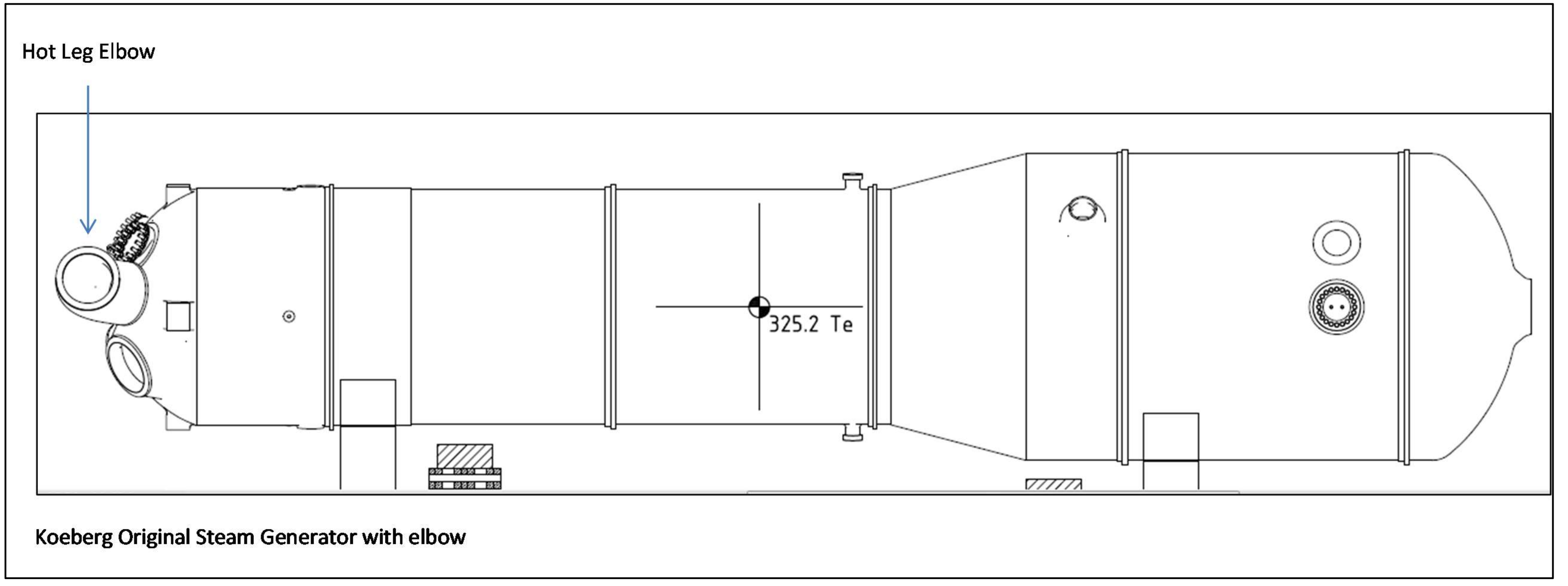

Figure 5: OSG including the hot leg elbow as it will be removed at KNPS

19. ATTACHMENT 3: ELIMINATED WASTE MANAGEMENT OPTIONS (1ST ROUND) - DETAILS

Option No.	Option description	Details / Justification	Impacts / Risks	1st round conclusion
(a)	Storage of the SGs in the existing on-site cask storage and LLW building until KNPS end-of-life in 2045	1. Utilising existing authorised infrastructure (LLW store on the KNPS site) 2. Requires only relicensing of the two facilities to allow for the storage of these SGs 3. SGs would be allowed to decay for ease of further processing 4. Only requires SG on-site transfer	1. Storage areas already fully utilised. 2. Store not large enough to store both the 6 SGs, and the current waste 3. Replaced SGs will, by the KNPS end-of-life also need to be disposed (these will then still be highly active compared to the current SGs, thus 2 different waste management processes would be required.	**Eliminated.** Not sufficient storage space available in these facilities
(b)	Storage of the SGs on an on-site open concrete base until KNPS end-of-life in 2045	1. Concrete slab and access road to be constructed in the middle of a large exclusion/safety zone. This large area not to allow free access to personnel or public. 2. Ease of construction 3. Ease of SG placement 4. Waste management of the SGs and KNPS end-of-life waste can be managed concurrently	1. SGs exposed over long term to weather conditions. 2. An extended controlled zone radius of 125m around the SGs would be required initially to ensure dose rate are below limits for non-controlled zone (supervised zone would require 35m) [16]. 3. If SGs are not externally decontaminated during or after removal, they need to be painted with a durable paint to ensure no longer term spread of contamination when the paint degrades. (SGs were stored at Salem, USA in the open, not decontaminated but painted, they were however not stored for an extended period). 4. Replaced SGs will, by the KNPS end-of-life also need to be disposed (these will then still be highly active compared to the SGs), thus two different waste management processes would be required. 5. Regulatory approval will have to be obtained for the storage area.	**Eliminated.** Not best practice, and would require very large exclusion zone.

Option No.	Option description	Details / Justification	Impacts / Risks	1st round conclusion
(c)	Storage in new concrete enclosed storage building (ISF) at Vaalputs until KNPS end-of-life in 2045	1. SGs needs to be transported from KNPS to the ISF at Vaalputs, either be conditioned/sectioned at the ISF at Vaalputs and then transfer the final waste packages into trench for disposal, or the complete SG needs to be transferred from the ISF at Vaalputs into the trench for disposal. Even if ownership and liabilities are transferred from KNPS to Vaalputs when the SGs are delivered to the ISF at Vaalputs, KNPS will be fully responsible for all the related cost and liabilities until fully disposed (polluter pay principle) 2. SGs not stored on the KNPS site 3 Only one off-site transfer required (KNPS to Vaalputs) 4. Waste management of the SGs and KNPS end-of-life waste can be managed concurrently. 5. Ownership and liability could be transferred from KNPS to Vaalputs	1. New nuclear installation licence required (incl. EIA) for ISF at Vaalputs 2. Regulatory approval would be required for the ISF. 3. All the same pre activities (interim storage, on-site and off-site transport, waste package approval) needs to be done as when SG would be taken to Vaalputs for direct disposal 4. Liability expenses related to delayed waste management (further transport, sectioning and/or disposal) 5. Delayed management will still be KNPS responsibility 6. Comparing to direct disposal, this option would have the additional expenses related to the ISF construction, ISF operation and the later on-site transport and placement in the trench 7. KNPS is the waste generator, thus polluter pay principle, therefore KNPS will be fully liable to all further management, disposal and liability costs.	**Eliminated.** Too many duplicated activities, duplicated large expenses and extra exposure activity impacts. In addition possible large expenses impacts are delayed for later.

Option No.	Option description	Details / Justification	Impacts / Risks	1st round conclusion
(d)	Storage of SGs in a new concrete enclosed storage building at a non-Vaalputs or non-KNPS site until KNPS end-of-life in 2045	1. SGs needs either be transported twice: from KNPS to the ISF, and again from the ISF to Vaalputs for complete SG disposal, or transported from KNPS to the ISF, condition/section the SG at the ISF, and transport the applicable waste packages to Vaalputs for disposal 2. SGs not stored on the KNPS site 3. Waste management of the SGs and KNPS end-of-life waste can be managed concurrently	1. New nuclear site 2. New nuclear installation licence required (incl. EIA) for the ISF site and facility. This includes extensive licensing, siting, design, etc. 3. Regulatory approval would be required for the ISF. 4. Future radiological decommissioning of the site. 5. SGs exposed over long term to weather conditions. 6. An extended controlled zone radius of 125m around the SGs would be required initially to ensure dose rate are below limits for non-controlled zone (supervised zone would require 35m) [16] 7. All the same pre activities (interim storage, on-site and off-site transport, waste package approval) needs to be done as when SG would be taken to Vaalputs for direct disposal 8. Liability expenses related to delayed waste management (further transport, sectioning and/or disposal) 9. Delayed management will still be KNPS responsibility 10. Comparing to direct disposal, this option would have the additional expenses related to the ISF construction, ISF operation, the later off-site transport to Vaalputs and the placement in the trench 11. Two off-site transfers required (KNPS to ISF, and ISF to Vaalputs)	**Eliminated.** New nuclear site (elaborate licensing process which include siting, design, etc.), including support infrastructure and resources to operate and secure facility. Many duplicated activities (e.g. 2 x off-site transport, 2 x ISF), duplicated large expenses and extra exposure activity impacts. In addition possible large expense impacts are delayed for later.
(e)	Storage of SGs at an off-site non-Vaalputs or non-KNPS site on an open concrete base until KNPS end of life in 2045	1. SGs needs either be transported twice: from KNPS to the open ISF, and again from this ISF to Vaalputs for complete SG disposal, or transported from KNPS to the open ISF, condition/section the SG at the open ISF, and transport the applicable waste packages to Vaalputs for disposal 2. SGs not stored on the KNPS site 3. Waste management of the SGs and KNPS end-of-life waste can be managed concurrently	1. New nuclear site 2. New nuclear installation licence required (incl. EIA) for the ISF site and facility. This includes extensive licensing, siting, design, etc. 3. Regulatory approval would be required for the ISF. 4. Future radiological decommissioning of the site. 5. All the same pre activities (interim storage, on-site and off-site transport, waste package approval) needs to be done as when SG would be taken to Vaalputs for direct disposal 6. Liability expenses related to delayed waste management (further transport, sectioning and/or disposal) 7. Delayed management will still be KNPS responsibility	**Eliminated.** Not best practice, and would require very large exclusion zone. New nuclear site, including support infrastructure and resources to operate and secure facility. Many duplicated activities (e.g. 2 x off-site transport, 2 x ISF), duplicated large expenses and extra exposure activity impacts. In addition possible large expense impacts are delayed for later.

Option No.	Option description	Details / Justification	Impacts / Risks	1st round conclusion
			8. Comparing to direct disposal, this option would have the additional expenses related to the ISF construction, ISF operation, the later off-site transport to Vaalputs and the placement in the trench 9. Two off-site transfers required (KNPS to ISF, and ISF to Vaalputs)	
(f)	Complete SG transported to Necsa, where it will be sectioned and melted in the existing smelter. Secondary radiological waste to Vaalputs	1. Necsa has various radiological facilities where SG sectioning could be done 2. Radiological smelter is being commissioned 3. Localised radiological facilities are used 4. Local knowledge gained in the further development of the smelting technique for non-uranium bearing metal	1. Necsa smelter EIA only allows for fixed (limited) quantity of uranium bearing metal to be melted, thus new EIA would be required 2. Facility would require new regulatory approval 3. Due to Smelter size, SGs will require to be sectioned in small sections for melting 4. Sectioning facility to be developed and regulatory approval obtained 5. Total SG nuclide inventory (activity) will still need to be disposed at Vaalputs (e.g. slag) 6. Secondary waste package to be developed and regulatory approval obtained 7. Abnormal and special arrangement transport of SGs from KNPS to Necsa (~1600km) 8. Secondary waste to be transported (various shipments) to Vaalputs for disposal.	**Eliminated**. Necsa smelter not authorised for other waste material, will require total relicensing. No experience with the separation of non-uranium contaminated metal. Sectioning facility and process to be developed. Depending on the smelter effectiveness the waste volume reduction could be low. Total nuclide inventory will still have to be disposed at Vaalputs.
(g)	Long term storage of the SGs in the ISF on the KNPS site (beyond KNPS end-of-life)	1. Utilising the ISF for long term to store the SGs until it would be possible for clearance of these items 2. Only requires SG on-site transfer 3. No off-site movement of radioactive material required.	1. Long term management of the ISF, even beyond the end-of-life of KNPS 2. SGs cannot be considered for clearance after 25 years, refer to Section 7.2. Even if consider 50 years Ni-63 and Co-60 are significantly above clearance levels.	**Eliminated.** ISF operation to extend very long beyond KNPS end-of-life.