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TITLE	**SAFETY ASSESSMENT FOR THE THABANA PIPESTORE EXTENSION**

1.0 AUTHORIZATION

	NAME	SIGNED	DATE
PREPARED	A Kaisavelu Nuclear Safety Engineer L&SA		
CHECKED	BL Cawood Nuclear Safety Analyst L&SA		
CHECKED	JH Lubbinge Engineer NLM		
CHECKED	O Siko Engineer ENS: PE		
ACCEPTED	ES Tshabalala Acting manager: PDO		
ACCEPTED	L Hordijk Waste Specialist NLM		
APPROVED	H Monkoe Licensing Services Management		

1.1 Distribution list

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1.2 Revisions

This document has been revised according to the following schedule:

Revision	Date	Nature of Revision	Prepared by
Final draft	Aug-2019	First issue	MI Modukanele
1.0	27 May 2021	Final review after basic design finalised	A Kaisavelu
2.0	30 May 2022	NNR comments as per NIL04B0147 were addressed	A Kaisavelu
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4.0	See title page	NNR comments as per NIL04B0196 were addressed	A Kaisavelu

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Appendix 1: Radiological safety assessment for extending the Pipestore, i.e. for drilling the 78 (48 SAFARI-1 and 36 NTP) additional holes, installing the pipes, fitting the plugs, extending the building.

Appendix 2: HotSpot results

2.0 PURPOSE

The purpose of this document is to present and report the result of safety assessment performed for the following activities in Thabana Pipestore as part of Thabana Pipestore Extension project:

- Extending (constructing and installing) the SAFARI-1's section of the existing Pipestore (that presently has 60 pipes) by additional 48 pipes of the original design and configuration as for the existing pipes;
- The construction and installation of 36 pipes to store NTP Long Term Storage (LTS) containers (containing the uranium residue) having the same original design and configuration as for the existing SAFARI-1 pipes, however having a different diameter for the storage vessel ;
- The operation of the Pipestore extension with its 144 pipes totally filled with spent fuel elements from SAFARI-1, and NTP LTS containers;

The above-mentioned aspects are assessed with a view to obtain approval from the NNR to extend and operate the facility.

3.0 SCOPE

Only the SAFARI-1 and NTP sections of the Pipestore extension is addressed, since the Hot Cell Complex Section in its present status will not be used. The safety implications of the extension operations in the SAFARI-1 and NTP sections, as well as the total safety of the completely filled SAFARI-1 and NTP sections of the Pipestore, have been assessed and are presented.

References in this report to 300 g HEU fuel elements include and envelope the control rod fuel assemblies of 202 g of HEU. Likewise, references to 340 g LEU fuel elements include and envelope the corresponding 230 g LEU control rod fuel assemblies.

4.0 REFERENCES

[1]	MES MEC-REP-0132:	Report: Thabana Pipestore Consolidated Basic Design.
[2]	NL27/NW-PSA-0012:	Thabana Pipestore (LCR A59; Rev. 0, Nov. 1997).
[3]	GSR Part 3:	Radiation Protection and Safety of Radiation Sources: International Basic Safety Standards.

[4]	SHEQ-INS-8080:	Radiation dose limitation.
[5]	ICRP 23:	Standard Reference Man.
[6]	RD 0024:	Requirements on Risk Assessment and Compliance with Principal Safety Criteria for Nuclear Installations.
[7]	NLM-PRG-021	ALARA review for PDO Facilities
[8]	LCR 535:	Modification to LCR A59 (AA 4582), appended as Annexure 4.
[9]	ICI Report MD 19128/1:	Reliability Data.
[10]	NW-PSA-0002:	Safety assessment for the extended Pipestore on Thabana
[11]	RRT-CRIT-REP-18004:	Nuclear Criticality Safety Calculations For Safari-1 Spent Fuel Assemblies In The Thabana Pipe-Store
[12]	RRT-SHLD-REP-19002:	Dose-rate assessment for the Thabana Pipestore holding LTS-containers with Solid-Residue from irradiated target-plates
[13]	NLM-REP-15/153:	Re-assessment of the presence of fission gas in the pipes at the Thabana Pipestore
[14]	NLM-PD-00029:	Facility And Process Description Of The Extended Thabana Pipestore (2018).
[15]	LSA-HAZ2018-REP-0003:	Thabana Pipestore Extension Project: Hazop 1 And Hazop 2 Report
[16]	NTP-SPE-4105:	User Requirement Statement: Long Term Storage of Uranium Residue
[17]	RR-SPE-0041:	Thabana Pipestore User Requirement for SAFARI-1 Spent Fuel and Control Rod Assemblies
[18]	RRT-SHLD-04-04:	Shielding calculations for the extended Pipestore
[19]	LSA-HZA2012-REP-0002:	External events applicable to nuclear facilities at the Pelindaba site
[20]	083975 Pelindaba PFP Site:	Probabilistic Seismic Hazard Analysis and design basis seismic ground motion
[21]	LSA-GEN2017-REP-0001	Report: Meteorological Data for Dispersion Analysis
[22]	DOE Handbook 3010	Airborne release fractions/rates and respirable fractions for non-reactor nuclear facilities, Volume I - Analysis of experimental data, DOE Handbook DOE-HDBK-3010-94, 1994
[23]	LSA-NLM2017-STR-0001	Licensing Strategy for the Extension of the Thabana Pipestore

[24]	RR-REP-16/23	Safety Assessment of the SAFARI-1 Spent Fuel Transfer Cask
[25]	-	https://www.unitconverters.net/radiation-activity/curie-to-becquerel.htm
[26]	NLM-REP-22/167	Thabana Pipestore Storage Vessel Inert gas pressure change justification – Revision of NLMREP-19/174

5.0 DEFINITIONS AND ABBREVIATIONS

5.1 Definitions

Pipestore extension : The existing store with 60 SAFARI-1 pipes plus the planned extension that will have 48 SAFARI-1 and 36 NTP additional pipes, giving a total of 108 SAFARI-1 and 36 NTP pipes.

5.2 Abbreviations

HEU: High Enriched Uranium.
HCC: Hot Cell Complex.
HSE: Health, Safety and Environment.
IAEA: International Atomic Energy Agency.
IBR: Inverted Box Rib
LEU: Low Enriched Uranium.
MEU: Medium Enriched Uranium (a term often used at Necsa to refer to HEU_{45})
NLM: Nuclear Liability Management.
QMS: Quality Management System.

6.0 OVERVIEW OF THE ASSESSMENT FOR THE PIPESTORE EXTENSION

The lay-out of the Pipestore extension is shown in Appendix 1, Figure 1. The process description for the Pipestore extension is given in [14]. Since the pipes in the planned Pipestore extension will be of the same design and construction as for the existing Pipestore, the safety assessment of the existing licence [2] is regarded as directly applicable. Therefore certain sections of document [2] have been repeated here unchanged, while others have been adapted to provide for the hazards of the Extended Pipestore. A hazard analysis in dose a form of a HAZOP study for the Pipestore extension with its 48 pipes in the SAFARI-1 and 36 pipes for the NTP sections was done in [15].

7.0 SOURCE TERM OF THE PIPESTORE EXTENSION

The planned Pipestore extension will store a maximum of 960 SAFARI elements and 969 NTP LTS containers [1]. One SAFARI pipe can store up to 20 elements, and that of NTP can store up to 32 LTS containers. The planned extended Pipestore will be projected to full capacity by year 2035 which is the year when SAFARI will be taken out of operation as per ([16], [17]).

7.1 Source term for a SAFARI-1 fuel element

The source term for a SAFARI-1 fuel element is given in Table 1 below, as taken from [18]. Two fuel types were analysed in [18], i.e. for an element containing 300 g of U-235 and HEU of U(90) for 80% burn-up (60 g of U-235 remaining) and another element containing 340 g of U-235 and LEU of U(19.75) for 63% depletion of U-235 (125.8 g of U-235 remaining). The values given in Table 1 are for 3.6 years (calculated heat output is then 15 W or less per element, as per the OTS limit) after the elements were discharged from the SAFARI-1 reactor.

Table 1: Source term for a spent fuel element 3.6 years after discharge

Nuclides	**Activity of mass U-235 per element**			
	300 g of HEU [U(90)]		340 g of LEU [U(19.75)]	
	Ci	Bq #	Ci	Bq #
Light elements	8.53E-09	3.16E+02	2.29E-08	8.47E+02
Actinides	1.75E+01	6.48E+11	2.24E+02	8.29E+12
Fission products	4.27E+03	1.58E+14	4.59E+03	1.70E+14
TOTALS		**1.59E+14**		**1.78E+14**

#: The Ci-values were multiplied by 3.7E+10 Bq/Ci [25].

7.2 Source term for the NTP LTS container

The MEU target-plates were previously used for isotope production in NTP. The present NTP policy (2019) is to restrict target-plates for isotope production, to LEU target plates. The acceptance criteria for the storage of the NTP LTS containers in the Pipestore extension is based on the cooling time of minimum 2 years. As a result, practically all solid-residue from irradiated MEU will be older than 3 years. The calculation models in this document will therefore be restricted to solid-residue from LEU target plates - such residue is typically “younger” and therefore more radio-active [12]. The source term for one LTS container containing the solid residue from the LEU target plates is 3.83E13 Bq after storage in NTP for 2 years [12].

8.0 SHIELDING CALCULATIONS FOR THE THABANA PIPESTORE EXTENSION

8.1 Assumptions

For SAFARI-1 fuel elements

The shielding calculations done for SAFARI-1 fuel elements by the Radiation and Reactor Theory Group are presented in [18]. Three scenarios were analysed as follows:

- 300 g of U-235 HEU as U(90) per element.
- After 80% burn-up (60 g of U-235 remaining).
- After 3.6 years since being removed from the reactor.

Results for the 340 g of U-235 LEU are slightly lower by a factor of 0.85.

The dose-rates to an Operator for various situations and actions considered in this section are based on the calculations in [18], where the burn-up of all the fuel elements was assumed to be 80%. In reality however, the average burn-up of fuel elements transferred to the Pipestore will be about 60 to 66%, with a spread ranging from as low as 50%, and up to the maximum of 80%. Consideration to such a range of burn-ups shows that as long as the criterion for selecting fuel elements for transfer to the Pipestore remains at a heat load of 15 W or less per element, the dose-rate at the top of a closed pipe will remain within the values given in Section 8.2.1.

It follows that dose-rates associated with all the other situations and actions considered in the rest of Section 8 below will also be similar. This means that the results of Section 8 represent the worst-case scenarios. It will therefore be possible to transfer any fuel element of any burn-up to the Extended Pipestore as soon as its calculated heat power falls below 15 W and consequently the length of the decay period in the reactor pool will be shorter than given in [18] in most cases.

For NTP LTS containers

The dose-rate calculations for the planned Thabana Pipestore extension, for the long-term storage of NTP LTS-containers that each contains two 2-litre canisters filled with solid-residue from irradiated target-plates are presented in [12]. This uranium solid-residue contains highly radio-active fission products and is classified as high-level fissile-material radio-active waste (HLW). Important design-basis assumptions are that:

a. Each LTS-container holds the solid-residue from 2 X 70 = 140 individual LEU target-plates,
b. The in-core irradiation time per target plate assembly was 200 hours.
c. The reactor-power was 20 MW,
d. Each target-plate assembly operated at a constant fission-power of 175 kW during irradiation,
e. The solid-residue subsequently underwent 2 years of cooling prior to placement into pipe-storage.

These assumptions are conservative, because typical maximum target plate assembly (containing 7 plates) power levels tend to be below 140 kW. The value of 175 kW per target plate assembly (containing 7 plates), is taken from the operating license of SAFARI-1. The reactor is licensed for a maximum target plate power of 25 kW per individual target plate, i.e. 7 x 25 kW = 175 kW per target plate assembly. LTS-containers typically contain the solid-residue from 70 to 98 LEU target plates, with a 99-percentile maximum of circa 126 target plates; the modelling assumption of 140 target plates per LTS-container is therefore a conservative value that will safely "envelope" all LTS-containers filled with solid-residue from irradiated LEU target-plates.

The present NTP policy (2019) is to restrict target-plates for isotope production, to LEU target plates. As a result, practically all solid-residue from irradiated MEU target plates, will be older than 3 years. The calculation models will therefore be restricted to solid residue from LEU target plates — such residue is typically “younger” and therefore more radio-active [12]. The dose-rates to an Operator for various situations and actions considered in this section for the LTS containers are based on the calculations in [12].

8.2 Dose rate calculations

8.2.1 Dose-rates from a Sealed (plugged) filled Storage Pipe

The dose rate from a storage pipe which is filled and sealed is based on the following;

SAFARI-1: It is assumed that the pipe is packed with 20 elements and properly sealed with the lead plug. The highest dose-rate (due to gamma streaming and penetration) obtained on floor level is 26.9 µSv/h at 30 cm from the pipe axis [18]. See calculated dose to an Operator in Section 9.1.

NTP: It is assumed that the pipe is packed with 32 LTS containers. The peak dose-rates for a single, closed pipe were calculated in the zone of human occupancy, directly overhead the central filled pipe in the midst of a very large array of filled pipes, is 6.5 µSv/h and is observed at 40 cm from the pipe axis [12]. The peak dose rate for a number of radii, measured from the centre line of the pipe is presented in [12].

8.2.2 Dose-rates from an Open (unplugged) filled pipe

SAFARI-1: A pipe filled with 20 elements is assumed. When the pipe is opened, the Operator stands at least 3 m away. The mean dose-rate obtained is 4.2 µSv/h at 3 m from the pipe axis and 2 m above floor level [18]. See calculated dose to an Operator in Section 9.1.

NTP: It is assumed that a pipe is filled with 32 LTS containers, and the mean dose-rate obtained is 9.37 µSv/h at 3 m from the pipe axis [12].

8.2.3 Dose-rates while an element is being loaded or removed

SAFARI-1: During loading or removal of a fuel element, the large shielding ring is in position between the top of the pipe and the cask. During this action the small shielding ring is around the bottom part of the cask. Two Operators stand in contact with the cask to couple or uncouple hoist rods (1.2 m long) for lowering or lifting a fuel package. A maximum of 10 rods can be used depending on the depth a package should be lowered or be lifted. The time to perform this activity is 2 to 3 minutes per rod. A typical dose rate of 100 µSv/h was measured on contact of the cask when it contains an element.

After a package has been lowered by the first hoist rod, it is stationary in the pipe opening at about 0.5 m below the cask to allow for the coupling of the second hoist rod. This is virtually the exact position of maximum shine to the Operator of 990.3 µSv/h at 1 m above floor level and 75 cm from the pipe axis.

For persons standing at 3 m from the pipe axis on floor level, the dose-rate could (from the inverse square law) be (1945.1 µSv/h)$(0.6/3)^2$ = 78 µSv/h [18].

NTP: The calculated contact dose-rate of 380 µSv/h is obtained on the transfer cask when it contains the LTS container [12]. When the LTS container is being lowered, it is assumed that the pipe already contains 31 LTS containers. The peak net dose-rate that will be experienced by an operator standing adjacent to a docked transfer-cask, during package lowering, with the additional shielding rings in position at the bottom of the cask, will be approximately 60 µSv/h at a distance of 40 cm from the pipe axis, contributed by the large array of filled, closed pipes [12].

9.0 NORMAL OPERATION

The most important design property of the facility is that it is a no-release facility. This implies that no releases of radioactivity should occur during normal operation. However, Occurrence 1072 was registered in November 2003 for a pipe that leaked Kr-85 together with the Ar/He mixture normally in the pipes, after the August 2003 loading campaign. Kr-85 was also found to be present in a number of other SAFARI-1 storage pipes, but it did not leak out as those pipes were not leaking.

Since the fuel elements are not leak-tight, fission gas could leak from them into the inert atmosphere of the pipe where it is contained. If a pipe has to be opened, and the test shows that fission gas is present, the gas is blown off via a pipe that reaches atmosphere outside the store. The analysis in Section 10.1 shows that if a pipe that contains fission gas would be opened without having been tested for fission gas, the operators would still be exposed to an acceptable low dose. See the insignificant impact from the analysis in Section 10.2.

Another radiological hazard is from the external radiation emitted by waste packages, but which are adequately shielded according to accepted standards, as analysed below.

9.1 External radiation dose from working in the Extended Pipestore

The dose that an Operator may accrue is from external radiation during loading and retrieval of the spent fuel elements and LTS containers. Two scenarios will be analysed, namely when a filled pipe is being emptied, and when an empty pipe is being filled with the spent fuel elements and LTS containers, assuming that 20 elements and 32 LTS containers will be handled in each case.

9.1.1 Doses to an Operator from retrieving spent fuel elements from a filled pipe

A breakdown of these tasks is given in Table 2. It is assumed that all pipes are filled with 20 fuel packages after 80% burn-up and for 3.6 years after discharge from the reactor, as discussed in Section 8. Table 2 displays dose to worker(s).

Table 2: Operator dose to retrieve the first package from a filled pipe.

Task element	**Dose-rate (μSv/h)**	**Exposure time (minutes)**	**Dose (μSv)**
Remove cover plate, fit large shielding ring, couple plug to crane, unbolt blank flange #1	26.9	10	4.5
Remove plug #2	3400	0.083 (5 s)	4.7
Couple empty cask to hoist sling #3	4.2	2	0.1
Lift cask to above pipe, position on ring #3	4.2	5	0.4
Fit small shielding ring, uncouple sling, open bottom valve of cask, lower first hoist rod through cask, fit hoist rod and scale to top package in pipe #4	990.3	3	49.5
Lift package into cask #4	990.3	0.083 (5 s)	1.4
Close bottom valve, remove hoist rod and scale, remove small ring, couple sling to cask #5	370	2	12.3
Lift cask from pipe onto trailer #6	4.2	3	0.2
Lower plug onto pipe #7	3230	0.083 (5 s)	4.5
Total dose per removal of first fuel package (D1)			**77.6**

#1: Assumed dose-rate for working at a sealed and filled storage pipe (Section 8.2.1).

#2: Operator is now at 3 m from the plug when it is lifted; assume scattered dose-rate from plug is half of 717.7 mSv/h as in centre of pipe at floor level [18]; then if plug radius is 0.292 m the dose-rate at 3 m away would be (0.5)(717.7 mSv/h)$(0.292/3)^2$ = 3.4 mSv/h for 5 seconds.

#3: Operator stands at 3 m from open pipe (Section 8.2.2).

#4: Operator is at cask, 1 m above floor level and 75 cm (0.75 m) from cask axis (Section 8.2.3).

#5: Operator is at cask with package inside cask; assume shine is now 19/20 of 990.3 μSv/h, but from about 0.65 m further down (one package removed; height of package is 13.3 m/20 packages = 0.66 m, Section 5.5 of [1]), giving (19/20)(990.3 μSv/h)$[0.75/(0.75 + 0.65)]^2$= 270 μSv/h. Add a typical 100 μSv/h on contact of the cask when it contains an element, giving 370 μSv/h to an Operator for 2 minutes.

#6: Operator is at 3 m from pipe and cask, but 19/20 of 4.2 μSv/h since 19 packages left, giving 4.0 μSv/h (from #3).

#7: Scattering again from plug (as in #2), but now giving 19/20 of 3400 μSv/h, i.e. 3230 μSv/h, since only 19 packages left.

Dose for removal of the second package

The various doses for the removal of the second package have to be calculated from the values applicable to the full pipe. This is done by assuming that the dose-rates for tasks #1 to #4 in Table 2 have decreased by a factor (19/20)$(0,75/1.4)^2$ = 0.27 of the original dose-rates, since 19 packages are left, and the top package is about 0,65 m further away from the Operator (from #5 in Table 2). The doses for tasks #5 to #7 are lower with a factor (18/20)$(0.75/2.05)^2$ = 0.12 since 18 packages are left, and the top package is now 2.05 m away from the Operator.

However, when the second package is lifted, it has to stay stagnant in the pipe opening for about 2 minutes to allow for the second hoist rod to be uncoupled before the package could be lifted into the cask. The dose to the Operator for this situation is assumed to be similar to that of task #4, which is 990.3 μSv/h for 2 minutes, giving Ds = 33 μSv. This value will hence be added to the dose incurred for every package that is removed.
The total dose-rate (D2) for the removal of the second package would then be

D2 = (Sum of doses #1 to #4)(0.27) + (Sum of doses #5 to #7)(0.12) + Ds
= (60.6 μSv)(0.27) + (17.0 μSv)(0.12) + 33 μSv
= 51.4 μSv.

Dose for removal of the third package

For the removal of the third package the doses for tasks #1 to #4 decrease with a factor 0.12 as 18 packages are left at 2.05 m from the Operator. Doses for tasks

#5 to #7 are now lower with a factor $(17/20)(0.75/2.7)^2 = 0.065$, since 17 packages are left at 2.7 m from the Operator.

It is now necessary to uncouple two hoist rods before the package could be lifted into the cask. So, when that second rod is uncoupled the package is one rod-length (1.2 m) away from the pipe opening (0.5 m below the cask) for which the dose was taken as Ds = 33 μSv. The dose to the Operator at that stage is then Dr = $(33\ \mu Sv)(0.5/1.7)^2 = 2.9\ \mu Sv$.

The total dose-rate (D3) for the removal of the third package would then be

$$
\begin{aligned}
D3 &= (60.6\ \mu Sv)(0.12) + (15.1\ \mu Sv)(0.065) + 33\ \mu Sv + 2.9\ \mu Sv \\
&= 44.2\ \mu Sv.
\end{aligned}
$$

The dose (Ds + Dr) = 35.9 μSv will hence be added to the doses applicable to the removal of the other packages.

Dose for removal of the fourth package

The doses for tasks #1 to #4 are for 17 packages at 2,7 m from the Operator, and those for tasks #5 to #7 for 16 packages at (2.7 + 0.65) m = 3.35 m down. This gives the total dose to the Operator as

$$
\begin{aligned}
D4 &= (60.6\ \mu Sv)(0.065) + (15.5\ \mu Sv)(0.75/3.35)^2 + (Ds + Dr) \\
&= (3.9 + 0.8 + 35.9)\ \mu Sv \\
&= 40.6\ \mu Sv.
\end{aligned}
$$

For the removal of further packages it is assumed that the dose-rates for the tasks #1 to #7 will decrease such that only (Ds + Dr) = 35.9 μSv remains dominant.

When the hoist rods are coupled and lowered to retrieve packages, there is no package connected, and the applicable dose is assumed to be only that calculated for fetching the first 4 packages, i.e. (D1 + D2 + D3 + D4), plus the dose applicable to the other 16 packages of (Ds + Dr) each.

Therefore, the total dose to an Operator for the removal of all the 20 packages in a pipe is then

$$
\begin{aligned}
D20 &= (D1 + D2 + D3 + D4) + 16\,(Ds + Dr) \\
&= (77.6 + 51.4 + 44.2 + 40.6) + 16(35.9)\ \mu Sv \\
&= (213.8 + 574.4)\ \mu Sv \\
&= 0.79\ mSv.
\end{aligned}
$$

9.1.2 Doses to an Operator from retrieving LTS containers from a filled pipe

The assumptions in Section 8 are used in this regard for the dose calculations i.e. the uranium residue inside the LTS container underwent 2 years of cooling time, and 140 individual LEU target plates are contained in one LTS container. Table 3 presents a breakdown of the tasks to empty such a filled pipe and the respective dose values.

Table 3: Operator dose to retrieve the first LTS container from a filled pipe [12]

Task element	**Dose-rate (µSv/h)**	**Exposure time (minutes)**	**Dose (µSv)**
Remove cover plate, fit large shielding ring, couple plug to crane, unbolt blank flange #1	6.5	10	1.1
Remove plug #2	10	0.083 (5 s)	0.01
Couple empty cask to hoist sling #3	9.37	2	0.31
Lift cask to above pipe, position on ring #3	9.37	5	0.78
Fit small shielding ring, uncouple sling, open bottom valve of cask, lower first hoist rod through cask, fit hoist rod and scale to top package in pipe	60	3	3
Lift package into cask	60	0.083 (5 s)	0.08
Close bottom valve, remove hoist rod and scale, remove small ring, couple sling to cask #5	380	2	12.7
Lift cask from pipe onto trailer #6	9.08	3	0.45
Lower plug onto pipe #7	9.6875	0.083 (5 s)	0.01
Total dose per removal of first fuel package (D1)			**18.44**

#1: Assumed dose-rate for working at a sealed and filled storage pipe (Section 8.2.1).
#2: Operator is now at 3 m from the plug when it is lifted
#3: Operator stands at 3 m from open pipe (Section 8.2.2).
#4: Operator is at cask, 1 m above floor level and 75 cm (0.75 m) from cask axis (Section 8.2.3).
#5: Operator is at cask with package inside cask
#6: Operator is at 3 m from pipe and cask
#7: Scattering again from plug (as in #2).

Dose for removal of the second LTS container

The various doses for the removal of the second LTS container have to be calculated from the values applicable to the full pipe. The height of the LTS container is 410 mm (0.410 m). The distance from the bottom of the cask to the top of the second LTS container is: (0.75 + 0.410 = 1.16 m). The dose calculation for removing the second LTS container is done by assuming that the dose-rates for tasks #1 to #4 in Table 3 have decreased by a factor $(31/32)(0.75/1.16)^2 = 0.40$ of the original dose-rates, since 31 LTS containers are left, and the top LTS container is 0.41 m further away from the Operator (from #5 in Table 3). The doses for tasks #5 to #7 are lower with a factor $(30/32)(0.75/1.57)^2 = 0.21$ since 30 LTS containers are left, and the top package is now 1.57 m (1.16 + 0.410 = 1.57 m) away from the Operator.

However, when the second package is lifted, it has to stay stationery in the pipe opening for about 2 minutes to allow for the second hoist rod to be uncoupled before the package could be lifted into the cask. The dose to the Operator for this situation is assumed to be similar to that of task #4, which is 60 μSv/h for 2 minutes, giving Ds = 2 μSv. This value will hence be added to the dose incurred for every LTS container that is removed.

The total dose-rate (D2) for the removal of the second package would then be

D2 = (Sum of doses #1 to #4)(0.40) + (Sum of doses #5 to #7)(0.21) + Ds
= (5.28 μSv)(0.40) + (13.16 μSv)(0.21) + 2 μSv
= 6.88 μSv.

Dose for removal of the third package

For the removal of the third package the doses for tasks #1 to #4 decrease with a factor 0.21 as 30 LTS containers are left at 1.57 m from the Operator. Doses for tasks #5 to #7 are now lower with a factor $(29/32)(0.75/1.98)^2 = 0.13$, since 29 LTS containers are left at 1.98 m (1.57 + 0.410 = 1.98 m) from the Operator.

It is now necessary to uncouple two hoist rods before the package could be lifted into the cask. So, when that second rod is uncoupled the LTS container is one rod-length (1.2 m) away from the pipe opening (0.5 m below the cask) for which the dose was taken as Ds = 2 μSv. The dose to the Operator at that stage is then Dr = $(2\ \mu Sv)(0.5/1.7)^2 = 0.17\ \mu Sv$.

The total dose-rate (D3) for the removal of the third package would then be

D3 = (5.28 μSv)(0.21) + (13.16 μSv)(0.13) + 2 μSv + 0.17 μSv
= 4.99 μSv.

The dose (Ds + Dr) = 2.17 µSv will hence be added to the doses applicable to the removal of the other packages.

<u>Dose for removal of the fourth package</u>

The doses for tasks #1 to #4 are for 29 LTS containers at 1.98 m from the Operator, and those for tasks #5 to #7 for 28 LTS containers at (1.98 + 0.410) m = 2.39 m down. This gives the total dose to the Operator as

$$
\begin{aligned}
D4 &= (5.28\ \mu Sv)(0.13) + (13.16\ \mu Sv)(0.75/2.39)^2 + (Ds + Dr)\\
&= (0.69 + 1.30 + 2.17)\ \mu Sv\\
&= 4.16\ \mu Sv.
\end{aligned}
$$

For the removal of further LTS containers it is assumed that the dose-rates for the tasks #1 to #7 will decrease such that only (Ds + Dr) = 2.17 µSv remains dominant.

When the hoist rods are coupled and lowered to retrieve the LTS containers, there is no LTS container connected, and the applicable dose is assumed to be only that calculated for fetching the first 4 LTS containers, i.e. (D1 + D2 + D3 + D4), plus the dose applicable to the other 28 LTS containers of (Ds + Dr) each.

Therefore, the total dose to an Operator for the removal of all the 32 LTS containers in a pipe is then

$$
\begin{aligned}
D32 &= (D1 + D2 + D3 + D4) + 28\,(Ds + Dr)\\
&= (18.44 + 6.88 + 4.99 + 4.16) + 28(2.17)\ \mu Sv\\
&= (34.47 + 60.76)\ \mu Sv\\
&= 0.10\ mSv.
\end{aligned}
$$

9.1.3 Doses from loading spent fuel elements, and the LTS containers into a pipe

It is regarded that the dose to an Operator for loading the same 20 packages, and 32 LTS containers in a pipe would at most be the same as for retrieving them.

9.1.4 Total annual dose to an Operator working in the Extended Pipestore

For SAFARI-1, if the packages are stored at 60/a i.e. filling 3 pipes, and the contents of one pipe is retrieved in a year, the annual dose to an Operator (who performs all these tasks) would be 4 times the dose from emptying one pipe, so that:

$$Dta = 4(D20) \qquad = 4(0.79)$$

= 3.2 mSv/a

For NTP, if the LTS containers are stored at 96/a i.e. filling 3 pipes, and the contents of one pipe is retrieved in a year, the annual dose to an Operator (who performs all these tasks) would be 4 times the dose from emptying one pipe, so that

Dta = 4(D20) = 4(0.10)
= 0.4 mSv/a

Operators are normally rotated for performing these tasks, resulting in the dose of less than 3.2 mSv/a and 0.4 mSv/a for SAFARI-1 and NTP respectively [7]. Furthermore these doses are based on conservative assumptions. During operation the actual doses to the operators will be closely monitored, and can be expected to be substantially less than indicated above.

9.2 Radiological hazards due to the extension activities

Extending the Existing Pipestore requires that an additional (48 pipes for SAFARI-1 spent fuel elements, and 36 pipes for NTP LTS containers) 84 holes will be drilled and pipes installed. Concrete slab will be installed between the pipes. The building will also be extended. During the extension activities, the overhead crane will also be extended. The potential radiological hazards of doing these extensions and installations nearby the filled pipes are addressed and analysed in Appendix 1. It is indicated that operators and members of the public would be exposed to insignificant doses.

9.3 Loading and Transferring of Casks [2]

The loading and transfer of casks are not part of this SAR.

SAFARI-1: The transport casks is being licensed under NIL02-NAR-0054. All actions involving the transport of casks will be conducted as described in this NAR.

NTP: The licensing of the transfer casks is not yet finalised, and will be handled separately from the current scope of the planned Thabana Pipestore extension as indicated in [23]. Thus, prior to commissioning of the planned Thabana Pipestore extension, the said licensing process will be completed. As a result, the NTP transfer cask will be licensed prior to commissioning activities.

9.4 Placing Packages in Pipes [2]

Shielding calculations for SAFARI-1 spent fuel elements given in [18], have shown that routine movements on the floor above pipes are allowed under the same conditions as in a Blue area, with the highest dose rates occurring only in the small area directly on top of a pipe plug (17.5 µSv/h). In-between pipes the dose rate decreases to that acceptable in an uncontrolled/unclassified area.

The need for additional shielding during loading was indicated and this is provided in the form of a large portable steel ring that will screen radiation while the fuel element is passing the gap between the cask and the pipe [2] as well as a small portable steel ring that fits around the bottom part of the cask. The supervising RPO will ensure that the required distance of at least 0.5 m from any sources of radiation be maintained during all operations, but the exact minimum distance required will be determined by him or her through measurement.

Shielding calculations for NTP LTS containers [12] shows that routine movements on the floor above pipes are allowed under the same conditions as in a Blue radiation area, with the peak dose-rates calculated in the zone of human occupancy, directly overhead the central filled pipe in the midst of a very large array of filled pipes, is 6.5 µSv/h and is observed at 40 cm from the pipe axis [12]. In-between pipes the dose rate decreases to that acceptable in an uncontrolled/unclassified area.

9.5 Lifting Equipment [2]

A pendant controller is fitted to the overhead crane. This enables the crane operator to work at a safe distance from the load area under the crane and hence from the casks and open pipes. Personnel will thus not be exposed to hazards from the crane operation. The risk from a cask drop is low (Section 10.3.2). No other hazards are foreseen from normal handling of the packages and cask.

The risk to a Member of the Public is regarded insignificant, since there is no general access to the site for the public. Moreover, since the store will hold nuclear material which is under safeguards, the whole facility is surrounded by a security fence and security alarms fitted to the fence and building. The IAEA surveillance equipment is able to operate without inspection for three months.

10.0 HAZARDS DUE TO ACCIDENT CONDITIONS

Based on historical data and/or operational experience, the SAFARI-1 spent fuel elements tend to get damaged during the cropping process (removal of the control rods). In one of the occurrences the cladding of the SAFARI-1 spent fuel elements got damaged and led to a minor fission gases leaking from the fuel elements during storage in the SAFARI-1 spent fuel pool. Some of these occurrences are as follows: occurrence number 870 (2002-01-08), NC 10/03 (2010-01-13), NC 10/24 (2010-06-04), and NC 08/96 (2008-10-01).

For NTP LTS containers, there was never a case whereby the LTS container leaked i.e. no breach of containment occurred during storage/handling in the NTP facility (P-1701). For the accident analysis, the SAFARI-1 spent fuel elements are used as the bounding case as there have been occurrences where breach of containment occurred (damage/leakage through the cladding as a primary containment).

10.1 Opening a Pipe before testing of the gas content [2]

For the radiological hazard associated with the exposure to gas products when a pipe would be opened before any routine sampling of the atmosphere inside has been done, Origen calculations for a single SAFARI-1 fuel element were done with the following values taken from [10]:

The ^{235}U charge is 300 g of HEU as U(90); discharge 60 g after 80% burn-up [18].

Assumptions:

- The inhalation dose from H-3 and I-129 is calculated at a breathing rate for light work of Br = 1.2 m^3/h from Standard Reference Man [5];
- The inhalation and exposure time is taken as t = 10 minutes during which the concentration stays constant;
- The dose due to Kr-81 and Kr-85 exposure is calculated for an exposure time of 10 minutes, i.e. t = 10 min/(24 hours/day x 60 min/hour) = 0.007 d;
- The volume of the Extended Pipestore is (29 x 11.8 x 7.5) m^3 = 2566.5 m^3;
- The gas released from the pipe instantly fills the volume of the Extended Pipestore, giving C = (8.07E+10 Bq/2566.5 m^3) = 3.1E+07 Bq/m^3 for H-3, and similar for the other nuclides in Table 4.

Table 4: Gas products from a SAFARI-1 fuel element for 3,6 years cooling after discharge.

Nuclide	**Half-life [3]**	**Activity released (Ci)**	**Activity released (Bq)**	**Dose Coefficients (Dc) #**
H-3	12.3 a	2.18E+00	8.07E+10	1.8E-11 Sv/Bq
Kr-81	2.1E+05 a	2.75E-09	1.02E+02	2.1E-11 Sv/d per Bq/m^3
Kr-85	10.7 a	6.12E+01	2.26E+12	2.2E-11 Sv/d per Bq/m^3
I-129	1.57E+07 a	1.30E-04	4.81E+06	5.1E-08 Sv/Bq
Rn-220	55.6 s	5.17E-07	1.91E+04	-
Rn-222	3.82 d	1.76E-12	6.51E-02	-

#: The dose coefficients for Tritium (as tritiated water vapour) and I-129 were taken from SHEQ-INS-8080 [4], Appendix A. The values for Kr-81 and Kr-85 were taken from SS 115 Table III.2H (p. 370) of GSR Part 3. Rn-220 and Rn-222 are not analysed because of the relatively low activities released and their short half-lives.

The doses for H-3 and I-129 are calculated from
Dh = (C)(Br)(t)(Dc), so that

D(H-3) = 0.11 mSv;
D(I-129) = 0.02 mSv.

The doses from Kr-81 and Kr-85 are calculated from

Dk = (C)(t)(Dc), so that

D(Kr-81) = 5.8E-09 µSv,
D(Kr-85) = 136 µSv = 0.14 mSv.

Total dose to an Operator from one fuel element = 0.27 mSv.

But, each element is made up of nineteen individual plates. The dose due to the release of the inventory of one plate is therefore 1/19 of the total dose calculated above, giving 0.27 mSv/19 = 0.014 mSv = 14 µSv.

If we assume that this ‘accident’ of one plate leaking, happens once a year, it is regarded as being normal operation according to [6].

Dose to an operator from one leaking fuel plate = 14 µSv/a.

The external radiation dose to a Member of the Public is insignificant, since the public will not be allowed in the Store.

10.2 Fission gas leaking from pipes [13]

The dose to an operator from the inhalation of fission gas leaking from a pipe is calculated by assuming that, the full contents of fission gas of 31.6 kBq/L (worst case of highest value) of Kr-85 leaks into the atmosphere of the Pipestore. The pipe length is about 16 m and the internal diameter of the pipe is 0.125 m. The total volume of the Pipestore facility is 2566.5 m^3. Furthermore the maximum pipe pressure of 45 kPa is used, this results in a bigger volume of gas (299 L) and therefore elevated level of activity which could be released into the TPS. If 10 kPa (the OTS minimum) would have been used the resultant possible exposure would be minimum and would not take the worst case scenario into account. Hence using 45 kPa in the calculation results in the most conservative exposure.

The volume of the pipe is $(\pi)\ (0.125/2)^2(16) = 0.196\ m^3$ = 196 litre.

If the pressure is at 45 kPa above atmospheric pressure of 86 kPa at Pelindaba, the volume of gas under this pressure in a pipe is (V2 = P1*V1/P2),
Where:
P1 = absolute pressure in pipe (86 kPa + 45 kPa); the vacuum is drawn in a pipe before being filled with Argon/Helium mixture,
P2 = atmospheric pressure (86 kPa),
V1 = pipe volume, and
V2 = gas volume at 45 kPa above atmospheric pressure,

Thus:
V2 = ((86 kPa + 45 kPa) (0.196 m^3)) / (86 kPa) = 0.299 m^3 = 299 litre.

The total maximum activity K-85 released is A = Total gas volume x maximum activity concentration.
= (299 litre) (3.16E + 04 Bq/litre)
= 9.45E+06 Bq.

Concentration of Kr-85 in the Pipestore facility is C = Total activity / total volume of Pipestore
= (9.45E+06 Bq)/2566 m^3
= 3.68E+03 Bq/m^3.

If this concentration would be contained in the store for a year, and an Operator works there for 120 hours/a, the annual dose to him would be:
Dp = (C)(t)(Dc) = 1.62 μSv/a

Where:
C = 3.68E+03 Bq/m^3
t = (120 h/a)/6 h/d = 20 d/a
Dc = 2.2E-11 Sv/d per Bq/m^3 [3]

If all the 108 pipes would leak simultaneously as pipe F3, the dose to an operator would be (108 X 1.62 μSv/a) = 175 μSv/a.

Members of the Public are not allowed in the facility therefore, dose to the Member of the Public is calculated at 1 km from the Pipestore assuming a release rate in one month (30 days).

HotSpot release of Kr-85 of 9.45E+06 Bq for 30 days gives a dose of 2.9E-12 Sv/a. The calculation was done for the stability class F and wind speed of 3.1 m/s (measured at 50 meters) [21]. Hotspot results are included in Appendix 2.
The above dose is insignificant, even if the contents of all 108 pipes would be leaking simultaneously, giving a total dose of Dp = 108 x 2.9E-12 Sv/a = 3.13E-04 μSv/a.

10.3 Operation of the storage pipes without an inert atmosphere

The main purpose of the inert atmosphere is to prevent the corrosion of the storage pipes, or the stored items (spent fuel and LTS containers), refer to NLM-REP-22/167 [26] and Section 13.2 (g). Corrosion of the pipes or the stored items can only start when the storage pipes are operated over a very long period without being under an inert atmosphere.

The operational approach to ensure and verify that the storage pipes remain under an inert atmosphere is detailed and justified in [26]. The gas pressure (which as per OTS limit always needs to be a readable positive pressure above atmosphere) is monitored and recorded from the pressure gauges installed on each storage pipe on a monthly basis. The procedure requires the backfilling the pipe with inert gas as soon as a predefined pressure drop is detected, this also include the inspection of the sealing flanges and seals. The seals showed to be to date always the reason for a possible pressure drop, e.g. aging/brittleness. When these are replaced the required inert gas pressure is retained. If the fuel would also start leaking giving the operator the impression that the pressure in the pipes are from inert gas but is in reality from fission products, the operator and members of the public could possibly be exposed to fission products, Scenario 10.1 calculates the consequences of such an accident.

The pressure of the inert atmosphere in the storage pipes are however monitored closely and corrective actions implemented if a pressure drop is detected. Thus the possibility of not having a pipe under an inert atmosphere for a very long period and the possible resultant loss of containment to the environment/soil is negligible/impossible.

10.4 Accidents during Transport and Handling of Items

10.4.1 TRAFFIC ACCIDENT [2]

The safety assessment regarding the traffic accident for the transfer of the SAFARI-1 spent fuel elements is performed as part of NIL02-NAR-0054.

10.4.2 DROPPING A CASK ([2], and [24])

The finite element analysis was performed on a SAFARI-1 transfer cask dropping from a maximum height of 15 m. The outcome from the impact analyses clearly shows that the cask will not break open and expose the fuel assembly. In addition to this, there will be no significant reduction in the amount of the shielding material between the fuel assembly contained in the cask and the outside. The cask will therefore maintain both its containment and shielding functions [24].

In the event of an over-wound crane cable, in this accident scenario the cask is lifted so high that the crane hook slams into the framework, the cable breaks and the cask drops to the floor. This may be caused by a stuck hand switch and a failed limit switch that is mounted on the main frame below the winding drum.

With about 60 packages to be placed in storage per year, and about 20 packages probably to be removed in a year, the crane will be in operation about 120 hours out of a year of 8 760 hours. This leads to a probability of 0.014 in use (Section 10.4.1) and a crane failure frequency for the crane in this store of 0.02/a. Since the casks will conform to basic transport standards, a drop from the crane height of ca 4 m should not breach the integrity of the cask.
The fall of a cask onto a pipe plug will not cause damage to an extent that would lead to any release of the pipe contents [2]. The risk of this scenario to the operator is low.

10.4.3 DROPPING SPENT FUEL CONTAINERS ([2] and [24])

The containers holding the SAFARI-1 spent fuel elements will be lowered into the storage pipes using mechanical tools. The basket being lowered will be locked in position on the tool until its weight is supported by the spring at the bottom of the pipe, or by the top container of the stack in the pipe.

If a basket were to be dropped there would not necessarily be a release of activity. Any gaseous products present in the spent fuel are contained within the fuel. Thus in the event of a basket being dropped, the mechanical handling tool would be raised, the cask removed and the sealing plug replaced in the pipe. This would render the situation safe until remedial action to retrieve the basket could be taken.

10.5 Accidents Involving the Stored Elements

10.5.1 A FAULT BREAK THROUGH THE PIPE ASSEMBLY [2]

The only way that a stored element can be physically damaged, is for a fault break to rip right through the surrounding soil, the concrete and the storage pipe itself. It can be accepted that the seismic movement on a fault takes place deep underground, at least a few kilometres below the surface, and virtually never breaks through to the surface in the case of intra-plate earthquakes. Bending and folding in the sedimentary cover accommodates the deformation and these effects tend to disappear closer to the surface.

The frequency of a seismic event that would cause major damage to the pipes themselves and the fuel elements could probably be in the order of 1.0E-04/a according to [20]. Further, considering the probability of (4 h/day)(30 days/a[#]) / (8760 h/a) = 0.014 that an operator will be present in the Store, gives a frequency of (1.0E-04/a)(0.014) = 1.4E-06/a that an operator could probably be seriously exposed to fission products, uranium and actinides from damaged fuel elements due to this seismic event. This value is below the allowed radiological mortality rate of 5.0E-05/a for an operator, as given in [5], and therefore acceptable.

[#: The maximum period spent by any individual in the Pipestore is 4 hours during a busy day. The maximum number of days involved in the storing of elements is taken as 30 per year, giving an exposure time of 120 hours/a [8]. The rest of the about 3 hours per day is spent on transporting the elements by cask from SAFARI-1 to the Pipestore.

10.5.2 LOOSE GROUND SETTLING AND STEEP SLOPES SLIDING [2]

This will not be a problem since the slopes close to the facility are fairly flat and stable and there is no lose ground on the site.

10.5.3 THE STORAGE PIPES SHAKE AND THEIR CONTENTS "SHAKE" [2]

The relatively tight placement of the pipes in the boreholes precludes large amplitude vibrations of the pipes. Their natural response of low frequency vibrations with large amplitudes because of their relative flexibility will therefore be shifted to a band of higher frequencies and higher accelerations. Even in the acceleration-amplified range, however, the value is not expected to exceed 1 "g". The items can be expected to survive the impacts.

10.5.4 DAMAGE TO THE PIPESTORE FROM AN AIRCRAFT CRASH

The air craft crash frequency can be determined in relation to the area over which the facility extends, by following the method from [19]. The proposed store has a floor area of 55.82 m x 11 m as seen in Figure 1

The probable crash frequency per annum, P, is then

$$P = P_a \times N_c \times F(x) \times A_{eff}$$

Where:

P_a = The accident rate per distance flown,

N_c = The number of flights per year,

A_{eff} = The effective crash area presented by the specific facility and,

F(x) = The crash site distribution function associated with a straight flight path.

Table 5: General Aviation movements past Pelindaba

Airport	N_c Number of flights/year past Pelindaba	Fly by distance from prohibited zone (km)	Flight path distance from Building to the west (km)	Flight path distance from Building to the east (km)
Lanseria	837	7518	3.158	-
	5022	10296	3.158	-
	2511	13074	3.158	-
Grand Central	4368	9.840	-	9248

Determine $F(x) = \frac{g}{2} e^{-g|x|}$

Where:

F(x) The crash site distribution function associated with a straight flight path g Decay constant for various aerial applications (0,625 km^{-1} general aviation aerial application).

Determine $A_{eff} = A_f + A_s$

$$A_f = (WS + R) \cdot H \cot \phi + \frac{2 \cdot L \cdot W \cdot WS}{R} + L \cdot W$$

$$A_s = (WS + R) \cdot S$$

where:

A_{eff} = Annual aircraft crash probability rate per km²

A_f = effective fly-in area;
A_s = effective skid area;
WS = aircraft wingspan, 0.0222 km;
R = length of the diagonal of the facility,
= $(L^2 + W^2)^{0.5}$
H = facility height = 0.0072 km;
Cot Φ = mean of the cotangent of the aircraft impact angle = 8.2;
L = length of facility = 0.05582 km;
W = width of facility = 0.011 km;
S = aircraft skid distance (mean value) = 0.0183

P = 4.07E-7/a for the Thabana Extension facility (sum of all the general aircraft probabilities). According to [19], the event is screened out if the event frequency is less than 10^{-6} per year. As a result, for the Thabana Pipestore extension the air craft crash is thus not considered for the accident analysis.

10.5.5 DAMAGE TO THE PIPESTORE FROM A LARGE FIRE

The probability of a conventional fire in the storage facility is considered small, since there will be no flammable materials kept in the store. The store has IBR sheeting walls and roof. This makes the probability of a fire caused by lightning negligible. Fire extinguishers are installed, and the store is under constant video camera surveillance at the Necsa Emergency Control Centre, since the stored elements are under Safeguards. Further, the fuel packages are stored underground and are therefore out of the reach of any fire above.

However, there is always the probability of a fire caused by sabotage or conventional causes. The impact of a large fire is analysed below.

<u>The following assumptions are made:</u>

The risk is calculated by assuming that all 108 pipes are filled with HEU fuel packages, and the fire melts the pipe plug and 1% of the uranium, actinide and fission product contents of the fuel elements in the top packages of a pipe is released, i.e. from 108 elements. The doses incurred from the inhalation of the most abundant nuclides for initial 300 g HEU elements are determined, as given in Table 6. The time that the fire lasts is taken as 2 hours, which is for a very large fire from the burning of aviation turbine fuel of the capacity of a fully fuel-loaded Boeing 747 (Personal information: Fire Fighting Dept., Johannesburg International Airport). Note that this is not an accidental aircraft crash but an act of sabotage.

Table 6: Doses from the inhalation of fission products and uranium from one element, due to a large fire in the Extended Pipe Store.

Nuclide	**Activity released after 20 years accumulation [10] Bq**	**1% of the inventory Bq**	**Airborne Release Fraction [22]**	**Damage ratio Respirable Fraction Leak path fraction**
H-3	3.22E+10	3.22E+08	1	1
Kr-85	7.77E+11	7.77E+09	1	1
Sr-90	1.41E+13	1.41E+11	1E-3	1
I-129	4.81E+06	4.81E+04	1	1
Cs-137	1.48E+13	1.48E+11	1E-3	1
U-234	1.63E+07	1.63E+05	1E-3	1
U-235	4.81E+06	4.81E+04	1E-3	1
U-236	8.51E+07	8.51E+05	1E-3	1
U-238	4.07E+05	4.07E+03	1E-3	1
Pu-238	2.44E+11	2.44E+09	1E-3	1
Pu-239	1.26E+09	1.26E+07	1E-3	1
Pu-240	1.22E+09	1.22E+07	1E-3	1
Pu-241	1.67E+11	1.67E+09	1E-3	1
Pu-242	9.99E+06	9.99E+04	1E-3	1
Am-241	8.88E+09	8.88E+07	1E-3	1
Am-242m	8.51E+06	8.51E+04	1E-3	1
Am-243	3.40E+07	3.40E+05	1E-3	1

The dose calculated from the release of this mixture of fission products and Uranium was calculated by Hotspot. The dose to a worker on the Pelindaba Site 200 m is 1.1E-10 Sv and the dose to a member of the public 1 km away is 5.7E-07 Sv. The calculation was done for the stability class F and wind speed of 3.1 m/s (measured at 50 meters [21].

Where,

Material at Risk (MAR) = 1% of the Activity Bq

Airborne release fraction (ARF) = 1E-3 for metal under thermal stress, or 1 for volatile isotopes [22];

Damage Ratio (DR) = Assumed to be 1 due to fire;

Respiratory fraction (RF) = Assumed to be 1 due to fire;

= Taken as 1 due to explosion.

The dose to a worker from 108 elements are 1.1E-10 Sv x 108 = 1.2E-08 Sv and to a member of the public the dose form 108 elements are 5.7E-07 Sv x 108 = 6.16E-05 Sv.

<u>Risk to the Worker</u>

Hence the mortality risk to a Necsa worker on site (at 200 m away) is given by

Mn = (Frequency)(Dose)(Pn)(Mortality Coefficient)
= (F)(D)(Pn)(Mor)
= 1.24E-04/a x 1.20E-08 Sv x 0.22 x 4E-02 Sv^{-1}
= 1.3E-14 mortalities/a,

where:

Pn = 0.22 (probability of worker on site: 8 h/d x 5 d/w x 48 w/a out of 8760 h/a)

F = 1.24E-04/a (frequency of fire in a low pressure storage area with fixed roof; [10], p. 36. This figure is for all fires. Only large fires, including those from additional fuels, could cause the above consequences. Thus the figure is conservative).

Mor = The ICRP [5] coefficient is 4E-2 mortalities per Sv for accidents.

The above mortality rate to a Necsa worker on site is within the NNR limit of 5.0E-05 mortalities/a as given in [6], and therefore acceptable.

<u>Risk to Member of the Public 1 km down-wind</u>

Mn = (Frequency)(Dose)(Mortality Coefficient)
= (F)(D)(Mor)
= 1.24E-04/a x 6.2E-5 Sv x 5E-02 Sv^{-1}
= 3.8E-10 mortalities/a,

where:

F = 1.24E-04/a (frequency of fire in a low pressure storage area with fixed roof; [9], p. 36. This figure is for all fires. Only large fires, including those from additional fuels, could cause the above consequences. Thus the figure is conservative).

Mor = The ICRP [5] coefficient is 5E-2 mortalities per Sv for accidents

Which is also within the limit of 5.0E-06 mortalities/a [6].

The only other possible way in which the store may have a radiological impact on the public, is addressed in [2]. The critical pathway for this impact is via the ground-water. Since it can only happen in the worst possible scenario where everything underground is sheared off, it represents an accident condition with very low probability. It was argued that the geological and hydrological conditions are such that this pathway will have a negligible impact even if it goes undetected for as long as sixteen years.

10.5.6 CRITICALITY SAFETY

The criticality calculations in [11] show that the planned Extension of the Pipestore will be subcritical when the pipes have been filled with SAFARI-1 spent fuel elements. A highest k-eff value of about 0.43 was obtained for elements containing both the HEU and LEU, which is well below the accepted value of 0.95 for sub-criticality.

10.5.7 TORNADO AND STRONG WIND

The SAFARI-1 spent fuel elements are stored underground inside the pipes, and in a case of a tornado and strong wind the damage will be to the building not the pipes underground.

11.0 PRELIMINARY DECOMMISSIONING STRATEGY

The phased approach below will be followed when performing the decommissioning activities in the Thabana Pipestore facility.

Phase 1
Decommissioning of the Thabana Pipestore facility will be done by removing the SAFARI-1 spent fuel and the NTP LTS container inventory. The destiny of this material still needs to be established at a later stage (e.g. reprocessing).

Phase 2
The decommissioning activities of this phase will be to firstly determine if the storage vessels are contaminated or not. The internal surface of the storage vessels is the only part that is likely to get contaminated in the Thabana Pipestore

facility. Thereafter the cleared items (items not contaminated) could be sold as scrap material. The items that are contaminated, will be subjected to decontamination, after which it will also be handled as cleared scrap material.

Phase 3

The objective of this phase will be to aim to reach clearance levels for the whole facility. If the storage vessels are still intact and no leakage occurred during storage i.e. no contamination to the environment. Thus clearance of the facility is most probable in this regard.

12.0 CONCLUSION AND RECOMMENDATION

The maximum dose to an Operator would be 3.2 mSv/a and 0.4 mSv/a for SAFARI-1 and NTP activities respectively, including the very low doses from the accidents regarded as normal operation, and the dose to a Member of the Public would be insignificant.

With regard to the OTS requirements in Section 13 it is concluded that if conformed to, the risk associated with the proposed facility will be acceptable and that it will provide adequate protection to personnel and members of the public from harmful exposure to radiation.

The proposed operating procedures and emergency measures provide for safe operation and control over the use of the facility while provision is also made for the control and accounting of radioactive material.

Adequate provision is made for the protection of the environment from radiation and hazardous contamination, while the physical impact on the environment is acceptable.

It is thus recommended that the proposed facility be licensed for extension to 144 pipes, to use as storage for spent fuel from SAFARI-1 and the LTS containers from NTP as stated, and that the facility may be inspected as required according to approved procedures and radiological control measures. No need for further restrictions on the use of the proposed facility is foreseen.

It is also recommended that the selection of fuel elements for transfer from SAFARI-1 to the planned Pipestore extension be based on the calculated heat power of less than 15 W, rather than on a fixed cooling/decay period in the SAFARI-1 pool, as was previously the case.

For NTP it is recommended that the selection of the LTS containers for transfer from NTP to the planned Pipestore extension be based on the cooling time of minimum 2 years.

13.0 REQUIREMENTS TO BE ADDRESSED IN THE OTS

The requirements to which the facility will have to conform during extension and when in operation, to ensure its safety, are summarised as follows:

13.1 During Extension

(a) The additional boreholes shall be drilled by rotary air-flush so as not to disturb the strata or introduce a drilling fluid into the system.
(b) Surface water shall be diverted to prevent the ingress of water into the weathered top layers of the strata.
(c) Confirmation shall be given that the SAFARI-1 and NTP storage pipes have been satisfactorily leak-tested after manufacture.

13.2 During Operation

(a) Portable shielding rings of appropriate dimensions shall be placed on the floor between the pipe and the SAFARI-1 cask, and around the bottom of the cask when depositing or removing fuel elements.
(b) All operations shall be carried out by experienced and competent operators.
(c) Measurement of the presence of fission gas shall be done before a pipe containing fuel packages is being opened.
(d) Fuel assemblies shall not be stored in the pipes before their decay heat power has fallen below 15 W, calculated individually for each assembly. The solid residue stored in the LTS containers must have subsequently underwent 2 years of cooling prior to placement in the pipe-storage.
(e) Limitation on the enrichment levels and U-235 mass of each SFE for storage. Only the following SFEs are accepted for storage: HEU Fuel elements containing 305 g U-235 as U (< 93%), HEU control rod fuel assemblies containing < 207 g U-235 as U (< 93%), LEU Fuel elements containing < 345 g U-235 as U (< 20%) and LEU control rod fuel assemblies containing < 235 g U-235 as U (<20%).
(f) Limitations on radiation and contamination levels at the Thabana Pipestore facility. The following acceptance criteria shall be adhered to: Outside the Thabana Pipestore facility and inside the security fence - Blue radiation and White contamination, Inside the Thabana Pipestore facility - Blue radiation and

White contamination, Around the storage pipe during the transfer of spent fuel - Red radiation and White contamination.

(g) The pipes remain filled with an inert gas to a minimum of 10 kPa gauge pressure above atmosphere. When the pressure drops below 10 kPa all operations shall be stopped, the pipe shall not be opened and an event shall be registered, initiating further investigation.
(h) Licensed transport containers with shielding characteristics that have been demonstrated to be adequate shall be used. Only Safari-1 Spent Fuel Transfer Cask (or Flask) shall be used for the transfer of SFE.
(i) The Hot Cell Complex section at Thabana Pipestore shall not be used.

14.0 List of Occurrences at Thabana Pipestore

(a) NIL04-OCC-0001: Contractor not wearing EPD on site at TPS.
(b) NIL04-OCC-0003: Smears on the transfer cask exceed white levels.
(c) NIL04-OCC-0010: Unsafe condition of vehicles used to transfer spent fuel elements.
(d) NIL04-OCC-0013: Pressure in pipes below the specified limit.

15.0 APPENDIX 1:

RADIOLOGICAL SAFETY ASSESSMENT FOR EXTENDING THE PIPESTORE, i.e. FOR DRILLING THE 84 (48 SAFARI-1 AND 36 NTP) ADDITIONAL HOLES, INSTALLING THE PIPES, FITTING THE PLUGS, EXTENDING THE BUILDING

The following scenarios are addressed in assessing the safety of the Pipestore extension operations:

- Radiological hazard to the workers from the radioactive packages in the Existing Pipestore;
- Radiation hazard to the workers from changes in the radiological conditions of the Existing Pipestore.

15.1 During drilling of the additional holes and installation of the pipes

Workers not involved with the extension operations will be allowed in the existing Pipestore, as supervised by an RPO.

In Figure 1 is shown that the additional holes will be drilled at 3.93 m and 11.55 m from the existing holes and pipes for SAFARI-1 and NTP respectively. The SAFARI-1 holes will be used as bounding case since they will be drilled closest (3.93 m) to the filled pipes in comparison to the NTP holes (11.55 m). At present all the existing pipes are nearly filled and six are empty. It may however be assumed that all the 60 pipes may be filled before drilling commences.

The highest dose-rate (due to gamma streaming and penetration) obtained on floor level is 26.9 µSv/h at 30 cm from the pipe axis [18], however at 3 m away the dose-rate cannot be distinguished from background level, which does not exceed 0.1 µSv/h. At 3.93 m away the dose-rate would expectedly not exceed background level. The iron-sheeting wall will not be removed during the drilling and installation processes, to prevent workers from entering the existing store and exposure to radiation from the tops of the filled pipes. The workers will thus be working in an unclassified area.

It can be concluded that there is insignificant radiological hazard to all workers concerned with the drilling of new holes and the installation of new pipes, no matter the duration of the tasks, and if the existing radiological conditions do not change.

Members of the public will not be allowed at the Pipestore, so that the radiation hazard to them would also be insignificant.

15.2 During extension of the building

Extension of the building to include the new pipes will be done after completion of the tasks in Section 14.1. Then iron-sheeting wall will be removed and the walls and roof extended to include the new storage pipes. The nearest that a worker could get to a filled pipe is about 1 m during this activity. The dose-rate at this distance cannot be distinguished from background level, which does not exceed 0.1 µSv/h. The workers will still be working in an uncontrolled area.

The area including the existing pipes will be under constant supervision by an RPO. During the extension activities, the overhead crane will also be extended. The workers during this extension activity will be working above the pipes. Shielding calculations for SAFARI-1 spent fuel elements given in [18], have shown that movements on the floor above pipes are allowed under the same conditions as in a Blue area, with the highest dose rates occurring only in the small area directly on top of a pipe plug (26.9 µSv/h). In-between pipes the dose rate decreases to that acceptable in an uncontrolled/unclassified area.

There is insignificant radiological hazard to all workers concerned with the extension of the building; also insignificant radiation hazard to members of the public since they will not be allowed at the works.

15.3 During fitting of pipe plugs and associated gas/leak testing equipment

The fitting of plugs and gas equipment on top of the pipes will be done after extension of the building to keep out as much dirt and dust as possible.

Although the iron-sheeting wall would have been removed, the area including the filled pipes will stay cordoned off as mentioned in Section 14.2. The dose-rate condition is the same as for Section 14.2, and the workers will still be working in an uncontrolled area.

Radiation hazard is insignificant to workers fitting plugs and gas equipment, no matter the duration of the tasks, and if the existing radiological conditions do not change. The radiation hazard to a member of the public is regarded insignificant since such a person will not be allowed at the Store during the installations.

15.4 Using the existing store during extension operations

Simultaneous operations of the existing Pipestore and of the Extensions will be avoided. It may however become necessary if the extension work takes an inordinate amount of time, e.g. > 2 years. If it becomes necessary that further spent fuel packages from SAFARI-1 be stored in the existing store while the extensions are in progress, the extension work will be stopped and the workers removed from the Store site.

After storage has been completed, radiation measurements will be performed by the RPO. If the same radiological conditions as in Section 14.1 is found, permission will be given by the RPO to proceed with the extension of the Store. If dose-rates above background are measured, the cause of this radiation will be investigated and removed. Only if the radiation level has been restored to background level will the RPO give permission to proceed with the extensions.

15.5 Change in radiological conditions

Any change in the existing radiological conditions at the Store for whatever reasons, e.g. higher dose-rates than background level, as detected by the RPO performing daily measurements, will result in the immediate stopping of the extension work and the subsequent removal of the workers from the Store site. The cause of the change will be investigated and removed. Only if the radiation level has been restored to background level will the RPO give permission to proceed with the extensions.

15.6 Damage to existing holes and filled pipes due to drilling of new holes

The holes of the existing store are 1.5 m apart (Figure 1). Those of the new store will also be 1.5 m apart. But the new holes of the Pipestore extension will be drilled 3.93 m from nearest the existing holes (Section 14.1). Rotary air-flush drilling will be done and not percussion drilling. The holes of the Existing Pipestore were done by using rotary air-flush drilling and no evidence of damage to or collapsing of already drilled holes (1.5 m apart) was found while new holes had been drilled.

It is thus regarded that the risk of damage to the existing holes and filled pipes will be insignificant when new holes are being drilled. However, in any event of detected damage to the existing pipes, or changes in radiological conditions, the procedures described in Section 14.5 will be followed.

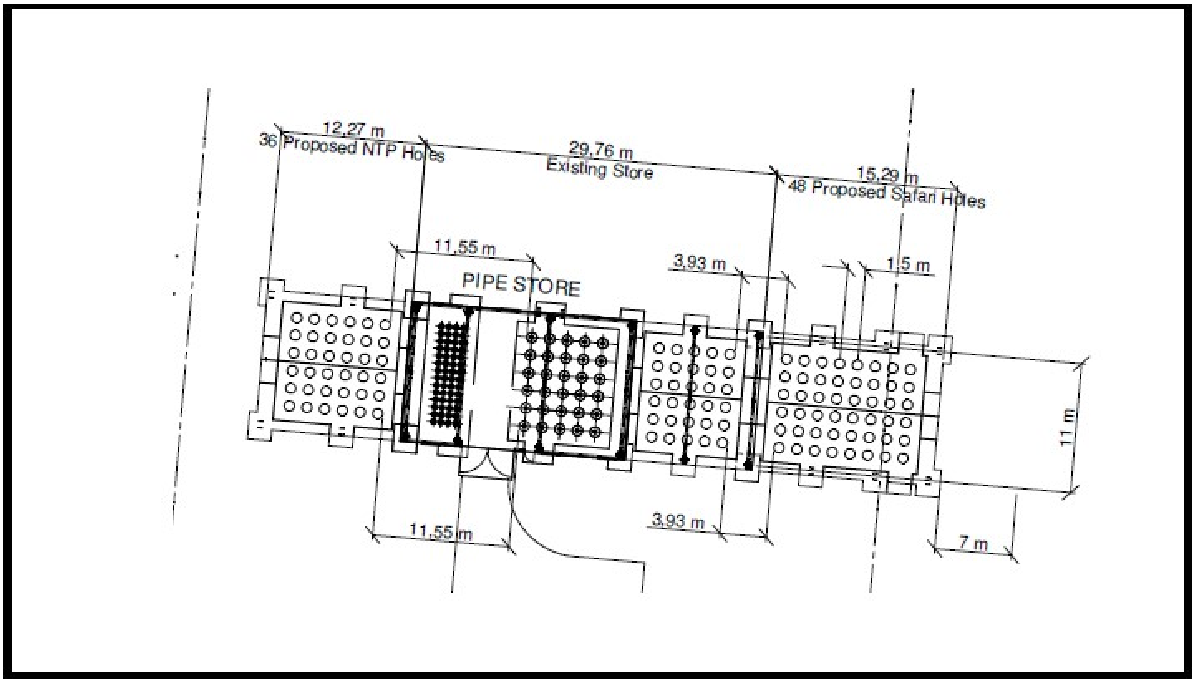

Figure 1: POSITION OF THE 84 ADDITIONAL PIPES RELATIVE TO THE 60 EXISTING PIPES IN THE EXTENDED PIPESTORE.

16.0 APPENDIX 2: HotSpot results

```
HotSpot  Version 3.1.2 General Plume
erial-at-Risk   (MAR)   : 9.4500E+06 Bq
Damage Ratio        (DR)   : 1.000
Airborne Fraction  (ARF)   : 1.000
Respirable Fraction (RF)   : 1.000
Leakpath Factor    (LPF)   : 1.000
Respirable Source Term     : 9.45E+06 Bq
Non-respirable Source Term : 0.00E+00 Bq
Effective Release Height   : 0.00 m
Wind Speed (h=50 m)        : 3.10 m/s
Distance Coordinates       : All distances are on the Plume Centerline
Wind Speed (h=H-eff)       : 0.53 m/s
Stability Class            : F
Respirable Dep. Vel.       : 0.00 cm/s
Non-respirable Dep. Vel.   : 8.00 cm/s
Receptor Height            : 1.5 m
Inversion Layer Height     : None
Sample Time                : 10.000 min
Breathing Rate             : 3.33E-04 m3/sec
```

```
Maximum Dose Distance      : 0.068 km
Maximum  TED              : 1.77E-10 Sv
Inner  Contour Dose        : 0.010 Sv
Middle Contour Dose        : 5.00E-03 Sv
Outer  Contour Dose        : 1.00E-03 Sv
Exceeds Inner  Dose Out To : Not Exceeded
Exceeds Middle Dose Out To : Not Exceeded
Exceeds Outer  Dose Out To : Not Exceeded

FGR-13 Dose Conversion Data - Total Effective Dose (TED)

                        RESPIRABLE
 DISTANCE     T E D       TIME-INTEGRATED      ARRIVAL TIME
                      AIR CONCENTRATION
   km        (Sv)        (Bq-sec)/m3        (hour:min)
 ----------------------------------------------------------------
   0.030      1.7E-11       6.9E+04            <00:01
   0.100      1.4E-10       5.8E+05             00:03
   0.200      5.1E-11       2.1E+05             00:06
   0.300      2.5E-11       1.0E+05             00:09
   0.400      1.5E-11       6.1E+04             00:12
   0.500      9.9E-12       4.1E+04             00:15
   0.600      7.1E-12       3.0E+04             00:18
   0.700      5.4E-12       2.2E+04             00:22
   0.800      4.3E-12       1.8E+04             00:25
   0.900      3.5E-12       1.4E+04             00:28
   1.000      2.9E-12       1.2E+04             00:31

HotSpot  Version 3.1.2 General Fire
Source Term                : Thabana Pipestore New.txt (Mixture Scale Factor = 1,0000E+00)
                      Thabana Pipestore 1 element
Fuel                    : 100 gal
Fire Duration             : 6,00E+01 min
Air Temperature            : 25,0 deg C
Release Radius             : 1,00E+01 m
Physical Height of Fire    : 0 m
Effective Release Height   : 40 m
Wind Speed (h=50 m)        : 3,10 m/s
Avg Wind Speed (h=H-eff)   : 2,75 m/s
Stability Class            : F
Receptor Height            : 1,5 m
Inversion Layer Height     : None
Sample Time                : 10,000 min
Breathing Rate             : 3,33E-04 m3/sec
```

Distance Coordinates : All distances are on the Plume Centerline

Maximum Dose Distance : 2,4 km
Maximum TEDE : 1,26E-06 Sv
Inner Contour Dose : 1,00E-03 Sv
Middle Contour Dose : 8,00E-04 Sv
Outer Contour Dose : 5,00E-04 Sv
Exceeds Inner Dose Out To : Not Exceeded
Exceeds Middle Dose Out To : Not Exceeded
Exceeds Outer Dose Out To : Not Exceeded

FGR-11 Dose Conversion Data - Total Effective Dose Equivalent (TEDE)

DISTANCE km	T E D E (Sv)	RESPIRABLE TIME-INTEGRATED AIR CONCENTRATION (Bq-sec)/m3	GROUND SURFACE DEPOSITION (kBq/m2)	GROUND SHINE DOSE RATE (Sv/hr)	ARRIVAL TIME (hour:min)
0,030	1,2E-15	1,1E-04	8,3E-11	0,0E+00	<00:01
0,100	6,4E-13	5,6E-02	7,2E-08	3,2E-18	<00:01
0,200	1,1E-10	9,7E+00	1,8E-05	8,1E-16	00:01
0,300	2,1E-09	1,9E+02	4,3E-04	1,9E-14	00:01
0,400	1,4E-08	1,2E+03	3,0E-03	1,3E-13	00:02
0,500	4,7E-08	4,1E+03	1,1E-02	4,9E-13	00:03
0,600	1,1E-07	9,7E+03	2,7E-02	1,2E-12	00:03
0,700	2,0E-07	1,8E+04	5,0E-02	2,2E-12	00:04
0,800	3,2E-07	2,8E+04	8,0E-02	3,5E-12	00:04
0,900	4,4E-07	3,9E+04	1,1E-01	5,0E-12	00:05
1,000	5,7E-07	5,0E+04	1,5E-01	6,5E-12	00:06
2,000	1,2E-06	1,1E+05	3,2E-01	1,4E-11	00:12