F-3.4.1-1 Rev 3

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Plant Applicability: ☐ All AP1000 plants except:
☒ Only the following plants: UKP

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Solid Waste Activity Calculation from AP1000

UKP-GW-GL-003, Revision 0

Westinghouse Electric Company LLC
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REVISION HISTORY

Revision	Description of Changes
0	Initial Submittal

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Solid waste Activity Calculation from AP1000

AP1000 RADWASTE

AKER SOLUTIONS PROJECT NO: 63000333

CLIENT PROJECT NO:

					D Mayes 04/03/10	J McLeary 02/03/10	
2	S1	Update to include Steam Generator Sludge Activity	01/03/2010	A Carson	D Mayes	J McLeary	See Westinghouse Cover Sheet
1	S1	Solid waste Activity Calculation from AP1000	04/02/2010	A Carson	D Mayes	J McLeary	See Westinghouse Cover Sheet
Rev	PEM Status	Description	Date	By	Checked	Approved	Approved Client
DOCUMENT NUMBER			63000333 - 000 - 000 - 111 - C - 0014				
H & S File		Technical File	PER File				

EDT 009 0808

REVISION SUMMARY

Revision	Description of Change
1	First Issue. The calculation includes the activity fingerprint for General LLW, and supersedes 63000333-000-000- 111-C-0010 (UKP-GW-GL-013) and 63000333-000-000- 111-C-0013, the activity fingerprints for CPS Resin and Waste Oil respectively
2	Updated to include activity fingerprint for Steam Generator Sludge. This now supersedes 63000333-000-000-111-C-0012

Glossary

CfA	Conditions for Acceptance
CPS	Condensate Polishing System
DCD	Design Control Document
ILW	Intemediate level Waste
LLW	Low level Waste
LLWR	Low level Waste Repository
SGBD	Steam Generator Blowdown

Bq	Becquerel
Ci	Curie
Te	Tonne

Purpose of Calculation

As part of the Generic Design Assessment (GDA) for the Westinghouse AP1000 nuclear power station, it is necessary to demonstrate that all waste produced from the operation, maintenance and decommissioning of such a plant will be disposable. This process has included obtaining acceptance in principle from the Low Level Waste Repository (LLWR).

The purpose of this calculation is to determine the activity of the following Low Level Waste (LLW) streams;

1. General LLW
2. Condensate Polishing Resin
3. Waste Oil
4. Steam Generator Sludge

This calculation will determine the concentration of the isotopes present in each of the waste streams and will also determine the final weight and volume of the waste package to be disposed of.

The activities of the following isotopes are specifically required to show that the waste will be disposable at the Low Level Waste Repository (LLWR);

- Uranium
- Ra-226
- Th-232
- Other alpha
- C-14
- I-129
- H-3
- Co-60
- Other radionuclides

Introduction

General LLW

The general LLW that will arise is expected to consist of a range of slightly contaminated materials. This will include; Plastics; Paper; Incinerator ash; Metallic Items; Clothing; Rubber; Filters; Redundant Equipment; Glass; Wood.

The rates of arising for different materials will vary through the cycle. Individual drums will not be representative of the stream averages. No large items that may require special handling are expected to arise routinely.

Condensate Polishing Resin

The Condensate Polishing System (CPS) is used to remove corrosion products and ionic impurities from the condensate system during plant startup, hot standby, power operation with abnormal secondary cycle chemistry, safe shutdown, and cold shutdown operations.

The CPS resin can become contaminated with radionuclides if there is leakage from the primary circuit to the secondary circuit. Therefore the only radionuclides that will be present on the CPS resin are those present in the primary cooling circuit.

Although the radionuclides will decay over time and hence the activity will decrease, activities will initially be calculated without taking this decay into account. This will provide a conservative case in terms of the activity on the CPS resin.

Waste Oil

Waste radioactive oil arises from motor pumps in the chemical and volume control system. Waste oil may also arise from spills and leaks from gear boxes or other sources.

The oil is a standard commerically available lubricating oil that is normally expected to be non-radioactive.The volumes and activities stated are based on very conservative estimates. The oil will become contaiminated with radioactivity if there is a pump seal leak or other such failure in the equipment. As a result of this the activity it is expected to have will be similar to the activity that would be expected to arise from a primary to secondary circuit leakage i.e. similar to reactor coolant.

Steam Generator Sludge

The steam generators produce steam from the secondary side water system to drive the steam turbines. This process of generating steam can cause a buildup of sludge on the tubes within the steam generators. The material may be corrosion products containing magnetite usually non-radioactive. Also impurities from makeup water and possibly from condenser tube leaks that build up over the cycle.This sludge is periodically removed to prevent it casuing problems with heat transfer and corrosion of the tubes within the steam generators.

Assumptions

The following assumptions have been made during this calculation;

1 General LLW will have the same activity as that produced from Sizewell B
2 The CPS resin has an operating time of 30 days within an 18 month cycle (Ref 1)
3 0.25% Fuel defects (Ref 7)
4 Fission gases have been excluded as they don't hold up on the Ion Exchange Resin
5 There is a 90 day storage period in the CPS resin tank during which the radionuclides will decay prior to conditioning (Ref 1)
6 All primary to secondary circuit leakage activity is recovered on the CPS Ion Exchange resin
7 No allowance has been made for the activity removed by the Steam Generator Blowdown (SGBD) System
8 Primary to secondary circuit leakage will last no longer than 30 days
9 Realistic primary circuit activities are used as defined in tables 11.1-7 and 11.1-8 of the European DCD
10 Resin:cement ratio is 50:50 (Ref 11)
11 Density of cement mixture is 2.4 Te/m^3 (Ref 12)
12 A total of 1m3 of waste radioactive oil will be generated over the lifetime of the plant (includes 0.088m3 for s (Ref 10)
13 The activity of the oil is based on 0.15% of the rector coolant activit (Ref 14)
14 The oil is based on OMV ECO TRUCK SAE 10W-40 with density of 869kg/m3 at 20C
15 Decay of radionuclides has not been taken into account w.r.t. waste oil
16 The sludge has the same activity as the secondary side coolant
17 The sludge has the same density as the secondary side coolant
18 The activity in the sludge will decay for at least 30 days prior to disposal
19 Secondary circuit activities are used as defined in table 11.1-5 of the European DCD (Ref 19)
20 Secondary side density is assumed to be that of water

Results

The Total activity triggers for the LLWR have been taken from Reference 13 and are outlined below;

Uranium	=	90000	MBq	
Ra-226 & Th-232	=	9000	MBq	
Other Alpha	=	90000	MBq	
C-14	=	15000	MBq	
I-129	=	15000	MBq	
H-3	=	3000000	MBq	
Co-60	=	600000	MBq	
Other radionuclides	=	4500000	MBq	Note 1

Note 1: This Also includes the Co-60 Activity

The calculation of the values outlined below can be found on pages 10 to 30 of this calculation.

General LLW

The volume of general LLW to be disposed of per year from original estimate = 46.9 m^3

The total weight of this volume of waste was = 23.44 Te

The total activity concentrations of the relevent Istopes are;

Uranium	=	0.00	MBq
Ra-226	=	0.00	MBq
Th-232	=	0.00	MBq
Other alpha	=	0.33	MBq
C-14	=	0.29	MBq
I-129	=	0.00	MBq
H-3	=	0.15	MBq
Co-60	=	12.65	MBq
Other radionuclides	=	214.19	MBq

Comparing total activities of the istopes within the general LLW and the total activity triggers for the LLWR, it is evident that the activity within the waste is much lower than the triggers for the repository and therefore it is expected that this waste will be acceptable by the LLWR Also given the large difference between the actual activity and the triggers it is not expected that changes to the overall waste volumes affect the activity within the waste significantly enough to prevent it being accepted by the LLWR. This is demonstrated by the results below which show the activities using the increased volume of waste;

The volume of general LLW to be disposed of per year from improved estimate is = 51.9 m^3

The total weight of this volume of waste is = 25.95 Te

Uranium	=	0.00	MBq
Ra-226	=	0.00	MBq
Th-232	=	0.00	MBq
Other alpha	=	0.37	MBq
C-14	=	0.32	MBq
I-129	=	0.00	MBq
H-3	=	0.17	MBq
Co-60	=	14.01	MBq
Other radionuclides	=	237.18	MBq

As can be seen this increase in activity is not significant and therefore it is expected that this waste will meet the LLWR CfA.

Condensate Polishing Resin

The total conditioned volume of the waste to be disposed of is 11.60 m^3

The total weight of the waste (encapsulated) to be disposed of is 18270 kg

Prior to accounting for decay during the 90day hold up period within the CPS resin tank the total activity on the CPS resin is 23.92 GBq / Te.

After accounting for the decay of the radionuclides during the 90 hold up period within the CPS resin tank the total activity of the CPS resin is 9.4 GBq / Te.

The total activity concentrations of the relevent Istopes are;

		Expected	Maximum	
Uranium	=	0	0	MBq
Ra-226	=	0	0	MBq
Th-232	=	0	0	MBq
Other alpha	=	0	0	MBq
C-14	=	0	0	MBq
I-129	=	0	0	MBq
H-3	=	8819.0	37795.5	MBq
Co-60	=	3.88	16.6	MBq
Other radionuclides	=	15357.4	65817.3	MBq

The activity concentrations of the individual isotopes stated above do not include decay to give worst case and have been taken from table 6.
From experience it is not expected that a primary to secondary leak would not last longer than 7 days, therefore the expected values are based on the activity after a 7 day leakage and the maximum values are based on the activity after a 30 day leakage

Comparing total activities of the istopes within the CPS resin and the total activity triggers for the LLWR, it is evident that the total activity within the waste is lower than the triggers for the repository and therefore it is expected that this waste will be acceptable by the LLWR.

Waste Oil

The volume of waste oil to be disposed of per year will be = 1 m^3

The total weight of this volume of waste will be = 0.87 Te

The total activity concentrations of the relevent isotopes are;

Uranium	=	0.00E+00	MBq
Ra-226	=	0.00E+00	MBq
Th-232	=	0.00E+00	MBq
Other alpha	=	0.00E+00	MBq
C-14	=	0.00E+00	MBq
I-129	=	0.00E+00	MBq
H-3	=	4.82E+01	MBq
Co-60	=	2.12E-02	MBq
Other radionuclides	=	8.40E+01	MBq

Comparing total activities of the istopes within the Waste Oil and the total activity triggers for the LLWR, it is evident that the activity within the waste is much lower than the triggers for the repository and therefore it is expected that this waste will be acceptable by the LLWR.

<u>Steam Generator Sludge</u>

The volume of waste sluidge to be disposed of per year will be = 0.09 m^3

The total weight of this volume of waste will be = 84.85 Te

The total activity concentrations of the relevent isotopes are;

Uranium	=	0.00E+00	MBq
Ra-226	=	0.00E+00	MBq
Th-232	=	0.00E+00	MBq
Other alpha	=	0.00E+00	MBq
C-14	=	0.00E+00	MBq
I-129	=	7.53E-08	MBq
H-3	=	3.12E+03	MBq
Co-60	=	1.15E-03	MBq
Other radionuclides	=	1.33E+01	MBq

Comparing total activities of the istopes within the Waste Sludge and the total activity triggers for the LLWR, it is evident that the activity within the waste is much lower than the triggers for the repository and therefore it is expected that this waste will be acceptable by the LLWR.

Conclusion

General LLW

The total activity within the waste is much lower than the triggers for the LLWR and therefore it is expected that this waste will meet the Conditions for Acceptance of the the LLWR.

Also given the large difference between the actual activity and the triggers it is not expected that changes to the overall waste volumes affect the activity within the waste significantly enough to prevent it being accepted by the LLWR.

Condensate Polishing Resin

The upper limits for LLW are 4GBq/Te alpha emitters and 12GBq/Te Beta/gamma emitters (Ref 5). There are no alpha radiation emitters present in this waste.
Given that the total activity on the CPS resin after the 90 day decay period is 9.4GBq/Te and the upper limit for LLW is 12GBq/Te, it can be concluded from this conservative calculation that the spent CPS resin will be classified as LLW.

It is expected that the SGBD system will remove a certain proportion of the activity thus can be expected that the actual activity of the CPS resin will be lower than that calculated.

Therefore it can be concluded based on this very conservative calculation that the CPS resin will be accpeted for disposal at the LLWR

It should be noted that a D1 form with the data determined in this calculation has been accepted by the LLWR. The D1 form accepted by the LLWR contains two errors;

1. Expected Co-60 activity stated as 0.08819 MBq
2. Expected other activity stated as 15357.3 Mbq

Neither of these errors affect the conclusions of this calculation as the actual calculated values are still within the acceptance criteria for disposal at the LLWR.

The total activity within the waste is much lower than the triggers for the LLWR and therefore it is expected that this waste will meet the Conditions for acceptance of the the LLWR.

Waste Oil

Comparing total activities of the istopes within the waste oil and the total activity triggers for the LLWR, it is evident that the activity within the waste is much lower than the triggers for the repository and therefore it is expected that this waste will be acceptable by the LLWR.

Steam Generator Sludge

Comparing total activities of the istopes within the Waste Sludge and the total activity triggers for the LLWR, it is evident that the activity within the waste is much lower than the triggers for the repository and therefore it is expected that this waste will be acceptable by the LLWR.

General LLW

Source Information

Volume of Waste per year	=	46.87	m3	Note 2
Bulk Density of General LLW	=	0.5	Te/m3	Ref 16

The following data on the Isotopes and their respective activities have been reproduced from Ref 16 (Assumption 1)

Nuclide	SZB Isotpe Activity (TBq/m3)
H 3	3.30E-09
C 14	6.10E-09
Mn 54	1.30E-07
Fe 55	2.60E-06
Co 60	2.70E-07
Ni 63	2.00E-07
Zn 65	3.20E-09
Sr 90	2.10E-08
Ru 106	9.90E-09
Ag 108m	3.20E-09
Ag 110m	3.70E-10
Sb 125	2.10E-09
Cs 134	8.50E-09
Cs 137	4.30E-08
Ce 144	1.60E-09
Pm 147	2.70E-08
Pu 238	6.30E-10
Pu 239	1.50E-09
Pu 240	1.40E-09
Pu 241	1.80E-07
Am 241	2.70E-09
Cm 242	4.70E-10
Cm 243	2.40E-10
Cm 244	1.60E-10
Other β / γ	1.07E-06

Table 1: SZB Isotope Activity

Note 2: This volume has been taken from an earlier version of the process mass balance (Ref 17). See Note 3 for further details.

Calculation Method

Using the assumed volume of waste per year the activity values can be converted to MBq as follows;

Activity (MBq) = SZB Activity x Assumed volume x 1000000

Taking Tritium (H-3) as an example;

Activity of H-3 (MBq) = 3.3E-09 x 46.87 x 1000000 = 1.5E-01

The results for all the relevent Isotopes are Shown in Table 2 Below

Nuclide	SZB Isotpe Activity (TBq/m3)	Activity (MBq)
H 3	3.30E-09	1.5E-01
C 14	6.10E-09	2.9E-01
Mn 54	1.30E-07	6.1E+00
Fe 55	2.60E-06	1.2E+02
Co 60	2.70E-07	1.3E+01
Ni 63	2.00E-07	9.4E+00
Zn 65	3.20E-09	1.5E-01
Sr 90	2.10E-08	9.8E-01
Ru 106	9.90E-09	4.6E-01
Ag 108m	3.20E-09	1.5E-01
Ag 110m	3.70E-10	1.7E-02
Sb 125	2.10E-09	9.8E-02
Cs 134	8.50E-09	4.0E-01
Cs 137	4.30E-08	2.0E+00
Ce 144	1.60E-09	7.5E-02
Pm 147	2.70E-08	1.3E+00
Pu 238	6.30E-10	3.0E-02
Pu 239	1.50E-09	7.0E-02
Pu 240	1.40E-09	6.6E-02
Pu 241	1.80E-07	8.4E+00
Am 241	2.70E-09	1.3E-01
Cm 242	4.70E-10	2.2E-02
Cm 243	2.40E-10	1.1E-02
Cm 244	1.60E-10	7.5E-03
Other β / γ	1.07E-06	5.0E+01

Table 2: General LLW Activity

To determine the activity of the specific Isotopes required, the above Isotopes must be categorised as Alpha (α), Beta (β) or Gamma (γ) emitters. This has been done from Ref 6 and is shown in Table 3

Nuclide	SZB Isotpe Activity (TBq/m3)	Activity (MBq)	Decay Mode (α, β or γ)	Remarks
H 3	3.30E-09	1.5E-01	β-	
C 14	6.10E-09	2.9E-01	β-	
Mn 54	1.30E-07	6.1E+00	γ + β+	
Fe 55	2.60E-06	1.2E+02	EC	
Co 60	2.70E-07	1.3E+01	γ + β-	
Ni 63	2.00E-07	9.4E+00	β-	
Zn 65	3.20E-09	1.5E-01	γ +β+	
Sr 90	2.10E-08	9.8E-01	β-	
Ru 106	9.90E-09	4.6E-01	β-	
Ag 108m	3.20E-09	1.5E-01	γ + β+	
Ag 110m	3.70E-10	1.7E-02	γ + β-	
Sb 125	2.10E-09	9.8E-02	γ + β-	
Cs 134	8.50E-09	4.0E-01	γ + β-	
Cs 137	4.30E-08	2.0E+00	γ + β-	
Ce 144	1.60E-09	7.5E-02	β-	
Pm 147	2.70E-08	1.3E+00	β-	
Pu 238	6.30E-10	3.0E-02	α	
Pu 239	1.50E-09	7.0E-02	α	
Pu 240	1.40E-09	6.6E-02	α	
Pu 241	1.80E-07	8.4E+00	α + β-	β decay is 99.998% of the decay
Am 241	2.70E-09	1.3E-01	α	
Cm 242	4.70E-10	2.2E-02	α	
Cm 243	2.40E-10	1.1E-02	α + γ	α decay is 99.71% of the decay
Cm 244	1.60E-10	7.5E-03	α	
Other β / γ	1.07E-06	5.0E+01	β / γ	
Total	4.59E-06	2.1E+02		

Table 3: Decay Mode of Radionuclides

The activity of the specific Isotopes required are taken from table 3 above. These are outlined below;

Uranium	0.00E+00	MBq
Ra-226	0.00E+00	MBq
Th-232	0.00E+00	MBq
Other alpha	3.33E-01	MBq
C-14	2.86E-01	MBq
I-129	0.00E+00	MBq
H-3	1.55E-01	MBq
Co-60	1.27E+01	MBq
Other radionuclides	2.14E+02	MBq

After the D1 form was issued to the LLWR, improved estimates for the waste volumes where obtained.

Volume of general LLW per year = 51.9 m^3 Note 3

Using this improved volume of waste, the activity values from Table 1, and the calculation method outlined above, the Following results for the fingerprint of the waste are obtained. These are outlined in Table 4.

Nuclide	SZB Isotpe Activity (TBq/m3)	Activity (MBq)
H 3	3.30E-09	1.7E-01
C 14	6.10E-09	3.2E-01
Mn 54	1.30E-07	6.7E+00
Fe 55	2.60E-06	1.3E+02
Co 60	2.70E-07	1.4E+01
Ni 63	2.00E-07	1.0E+01
Zn 65	3.20E-09	1.7E-01
Sr 90	2.10E-08	1.1E+00
Ru 106	9.90E-09	5.1E-01
Ag 108m	3.20E-09	1.7E-01
Ag 110m	3.70E-10	1.9E-02
Sb 125	2.10E-09	1.1E-01
Cs 134	8.50E-09	4.4E-01
Cs 137	4.30E-08	2.2E+00
Ce 144	1.60E-09	8.3E-02
Pm 147	2.70E-08	1.4E+00
Pu 238	6.30E-10	3.3E-02
Pu 239	1.50E-09	7.8E-02
Pu 240	1.40E-09	7.3E-02
Pu 241	1.80E-07	9.3E+00
Am 241	2.70E-09	1.4E-01
Cm 242	4.70E-10	2.4E-02
Cm 243	2.40E-10	1.2E-02
Cm 244	1.60E-10	8.3E-03
Other b/g	1.07E-06	5.6E+01
Total	4.59E-06	2.4E+02

Table 4: Revised Activity of General LLW

Uranium	0.00E+00	MBq
Ra-226	0.00E+00	MBq
Th-232	0.00E+00	MBq
Other alpha	3.68E-01	MBq
C-14	3.17E-01	MBq
I-129	0.00E+00	MBq
H-3	1.71E-01	MBq
Co-60	1.40E+01	MBq
Other radionuclides	2.37E+02	MBq

Note 3: This information has been taken from Table 32 of Ref 17, excluding the volume of CPS resin. It is worth noting that these volumes (and those of the intial estimates) are the conditioned volumes of waste and hence some have a compaction factor applied to them. See Ref 17 for more details

Final waste package

Volume

The Assumed Volume of waste initially used = 46.87 m3

Revised Volume of Waste = 51.9 m3 Ref 10

N.B. It is the initially assumed volume of waste that appears on the D1 form i.e. 47m3

Weight

Bulk Density of waste = 0.5 Te/m^3 Ref 16

Weight of waste in waste package = volume of waste in waste package x Density of waste

Weight of waste in waste package = 46.87 x 0.50
= 23.44 Te

N.B. Using the revised volume of waste this will give a total weight of 25.95 m^3

As stated in Note 3 the estimated weights may not be strictly correct due to some of the waste being compacted and some of it not. However these estimates are sufficient enough for this stage of the design process.

Condensate Polishing Resin

Source Information

Bulk volume of CPS resin per 18 month cycle	=	204	ft^3	Ref 10
Primary to secondary leakage rate	=	75	lb/day	Ref 2
Duration of primary to secondary leak at given rate (Assumed)	=	30	days	Ref 8
Bulk density of CPS resin	=	0.75	Te/m^3	Ref 4
Decay time		90	days	Ref 1

The following data on the Isotopes and their respective activities within the primary coolant have been extrated from Ref 3

Nuclide	Reactor Coolant Activity (µCi/g)	Nuclide	Reactor Coolant Activity (µCi/g)
Br-84	0.02	Y-93	4.30E-03
I-131	0.04	Zr-95	3.30E-04
I-132	0.25	Nb-95	2.40E-04
I-133	0.14	Mo-99	5.60E-03
I-134	0.42	Tc-99m	5.10E-03
I-135	0.28	Ru-103	6.30E-03
Rb-88	0.24	Ru-106	7.50E-02
Cs-134	5.90E-03	Rh-103m	6.30E-03
Cs-136	7.40E-04	Rh-106	7.50E-02
Cs-137	7.90E-03	Ag-110m	1.10E-03
H-3	1	Te-129m	1.60E-04
Na-24	4.60E-02	Te-129	2.90E-02
Cr-51	2.60E-03	Te-131m	1.40E-03
Mn-54	1.30E-03	Te-131	9.70E-03
Fe-55	1.00E-03	Te-132	1.50E-03
Fe-59	2.50E-04	Ba-137m	7.40E-03
Co-58	3.90E-03	Ba-140	1.10E-02
Co-60	4.40E-04	La-140	2.30E-02
Zn-65	4.30E-04	Ce-141	1.30E-04
Sr-89	1.20E-04	Ce-143	2.60E-03
Sr-90	1.00E-05	Ce-144	3.40E-03
Sr-91	9.80E-04	Pr-143	3.00E-03
Y-90	1.20E-06	Pr-144	3.40E-03
Y-91m	5.70E-04	W-187	2.30E-03
Y-91	4.40E-06	Np-239	2.00E-03

Table 5: Reactor Coolant Activity

Calculation Method

Total leakage from primary to secondary	=	Primary to secondary leakage rate x CPS operation duration	
	=	2250.0	lb
	=	1021.5	kg
Volume of CPS resin per 18month cycle	=	5.78	m^3

N.B. 1lb = 0.454Kg

$1ft^3 = 0.0283\ m^3$

Initially neglecting the decay over 90 days the activity concentration of primary coolant that leaks into the secondary system can be calculated by;

Activity = Reactor coolant activity x total leakage from primary to secondary

See table 6 for results

Table 6 shows a total activity of 103.613 GBq

The activity concentration can then be converted into an activity concentration per m^3 of CPS resin by;

Activity concentration per m^3 = Total Activity / m^3 of resin

See table 6 for results

Table 6 shows a total activity concentration/ m^3 of CPS resin of 17.94 GBq / m^3

This can be converted to GBq per tonne by dividing by the bulk density of the CP resin

Bulk Density of CP resin = 0.75 Te/m^3

Therefore the total activity concentration of the CPS resin is 23.92 GBq / Te

The limits for LLW are 4GBq/te alpha emmitters and 12 GBq/te Beta/gamma emmitters Ref 5

The total activity concentration on the CPS resin is not within the limits for LLW.

Now considering the decay period of 90 days:

The half lifes of the Isotopes were determined from Ref 6 and are shown in table 7.

The activity concentration on the CPS resin after 90days of decay can be calculated from the following;

$$\text{Decayed Activity Concentration (Gbq/m3)} = \text{Undecayed Activity Concentration (Gbq/m3)} \times \text{EXP}\left(\frac{-Ln(2)\times T}{t_{\frac{1}{2}}}\right)$$

Where T = Decay time (days)

$t_{1/2}$ = Half Life (days)

The decayed activity concentrations for all the isotopes are shown in Table 2.

The total decayed activity on the CPS resin is 7.02 GBq/m^3

This can be converted to GBq per tonne by dividing by the bulk density of the CP resin

Therefore the total activity concentration of the CPS resin is 9.36 GBq / Te

Table 6 - Activity per m^3 of CPS resin

Nuclide	Reactor Coolant Activity (µCi/g)	Activity (Ci)	Activity (GBq)	Activity per m^3 resin (GBq/m^3)
Br-84	2.00E-02	2.04E-02	7.56E-01	1.31E-01
I-131	4.00E-02	4.09E-02	1.51E+00	2.62E-01
I-132	2.50E-01	2.55E-01	9.45E+00	1.64E+00
I-133	1.40E-01	1.43E-01	5.29E+00	9.16E-01
I-134	4.20E-01	4.29E-01	1.59E+01	2.75E+00
I-135	2.80E-01	2.86E-01	1.06E+01	1.83E+00
Rb-88	2.40E-01	2.45E-01	9.07E+00	1.57E+00
Cs-134	5.90E-03	6.03E-03	2.23E-01	3.86E-02
Cs-136	7.40E-04	7.56E-04	2.80E-02	4.84E-03
Cs-137	7.90E-03	8.07E-03	2.99E-01	5.17E-02
H-3	1.00E+00	1.02E+00	3.78E+01	6.54E+00
Na-24	4.60E-02	4.70E-02	1.74E+00	3.01E-01
Cr-51	2.60E-03	2.66E-03	9.83E-02	1.70E-02
Mn-54	1.30E-03	1.33E-03	4.91E-02	8.51E-03
Fe-55	1.00E-03	1.02E-03	3.78E-02	6.54E-03
Fe-59	2.50E-04	2.55E-04	9.45E-03	1.64E-03
Co-58	3.90E-03	3.98E-03	1.47E-01	2.55E-02
Co-60	4.40E-04	4.49E-04	1.66E-02	2.88E-03
Zn-65	4.30E-04	4.39E-04	1.63E-02	2.81E-03
Sr-89	1.20E-04	1.23E-04	4.54E-03	7.85E-04
Sr-90	1.00E-05	1.02E-05	3.78E-04	6.54E-05
Sr-91	9.80E-04	1.00E-03	3.70E-02	6.41E-03
Y-90	1.20E-06	1.23E-06	4.54E-05	7.85E-06
Y-91m	5.70E-04	5.82E-04	2.15E-02	3.73E-03
Y-91	4.40E-06	4.49E-06	1.66E-04	2.88E-05
Y-93	4.30E-03	4.39E-03	1.63E-01	2.81E-02
Zr-95	3.30E-04	3.37E-04	1.25E-02	2.16E-03
Nb-95	2.40E-04	2.45E-04	9.07E-03	1.57E-03
Mo-99	5.60E-03	5.72E-03	2.12E-01	3.66E-02
Tc-99m	5.10E-03	5.21E-03	1.93E-01	3.34E-02
Ru-103	6.30E-03	6.44E-03	2.38E-01	4.12E-02
Ru-106	7.50E-02	7.66E-02	2.83E+00	4.91E-01
Rh-103m	6.30E-03	6.44E-03	2.38E-01	4.12E-02
Rh-106	7.50E-02	7.66E-02	2.83E+00	4.91E-01
Ag-110m	1.10E-03	1.12E-03	4.16E-02	7.20E-03
Te-129m	1.60E-04	1.63E-04	6.05E-03	1.05E-03
Te-129	2.90E-02	2.96E-02	1.10E+00	1.90E-01
Te-131m	1.40E-03	1.43E-03	5.29E-02	9.16E-03
Te-131	9.70E-03	9.91E-03	3.67E-01	6.35E-02
Te-132	1.50E-03	1.53E-03	5.67E-02	9.81E-03
Ba-137m	7.40E-03	7.56E-03	2.80E-01	4.84E-02
Ba-140	1.10E-02	1.12E-02	4.16E-01	7.20E-02
La-140	2.30E-02	2.35E-02	8.69E-01	1.50E-01
Ce-141	1.30E-04	1.33E-04	4.91E-03	8.51E-04

Table 6 - Activity per m^3 of CPS resin (continued)

Nuclide	Reactor Coolant Activity (µCi/g)	Activity (Ci)	Activity (GBq)	Activity per m^3 resin (GBq/m^3)
Ce-143	2.60E-03	2.66E-03	9.83E-02	1.70E-02
Ce-144	3.40E-03	3.47E-03	1.29E-01	2.22E-02
Pr-143	3.00E-03	3.06E-03	1.13E-01	1.96E-02
Pr-144	3.40E-03	3.47E-03	1.29E-01	2.22E-02
W-187	2.30E-03	2.35E-03	8.69E-02	1.50E-02
Np-239	2.00E-03	2.04E-03	7.56E-02	1.31E-02
Total	**2.74E+00**	**2.80E+00**	**1.04E+02**	**1.79E+01**

N.B. 1Ci = 37GBq = 3.7E+10Bq

From Ref 6 all the Isotopes outlined in Tabe 6 have either Beta or Gamma decay modes i.e. There is no isotope which exhibits Alpha Decay

The activity of the specific Isotopes required are taken from table 6 above. These are outlined below;

Uranium	0.00E+00	MBq
Ra-226	0.00E+00	MBq
Th-232	0.00E+00	MBq
Other alpha	0.00E+00	MBq
C-14	0.00E+00	MBq
I-129	0.00E+00	MBq
H-3	3.78E+04	MBq
Co-60	1.66E+01	MBq
Other radionuclides	6.58E+04	MBq

It should be noted that the individual isotopes have been taken from the undecayed data to provide a worst case scenario.

Table 7- Activity after 90 days decay

Nuclide	Activity per m^3 resin (GBq/m^3)	Half life (Days) (Ref 6)	Decayed Activity (GBq/m^3) Leakage rate 75lb/day	Decayed Activity (GBq/m^3) Leakage rate 50lb/day	Decayed Activity (GBq/m3) Leakage rate 25lb/day
Br-84	1.31E-01	2.21E-02	0.00E+00	0.00E+00	0.00E+00
I-131	2.62E-01	8.04E+00	1.12E-04	7.45E-05	3.72E-05
I-132	1.64E+00	9.56E-02	8.24E-284	5.49E-284	2.75E-284
I-133	9.16E-01	8.67E-01	5.02E-32	3.35E-32	1.67E-32
I-134	2.75E+00	3.65E-02	0.00E+00	0.00E+00	0.00E+00
I-135	1.83E+00	2.74E-01	1.97E-99	1.31E-99	6.56E-100
Rb-88	1.57E+00	1.23E-02	0.00E+00	0.00E+00	0.00E+00
Cs-134	3.86E-02	7.54E+02	3.55E-02	2.37E-02	1.18E-02
Cs-136	4.84E-03	1.31E+01	4.14E-05	2.76E-05	1.38E-05
Cs-137	5.17E-02	1.10E+04	5.14E-02	3.43E-02	1.71E-02
H-3	6.54E+00	4.51E+03	6.45E+00	4.30E+00	2.15E+00
Na-24	3.01E-01	6.23E-01	1.03E-44	6.89E-45	3.44E-45
Cr-51	1.70E-02	2.77E+01	1.79E-03	1.19E-03	5.96E-04
Mn-54	8.51E-03	3.12E+02	6.97E-03	4.64E-03	2.32E-03
Fe-55	6.54E-03	9.96E+02	6.15E-03	4.10E-03	2.05E-03
Fe-59	1.64E-03	4.45E+01	4.03E-04	2.68E-04	1.34E-04
Co-58	2.55E-02	7.09E+01	1.06E-02	7.05E-03	3.53E-03
Co-60	2.88E-03	1.92E+03	2.79E-03	1.86E-03	9.29E-04
Zn-65	2.81E-03	2.44E+02	2.18E-03	1.45E-03	7.26E-04
Sr-89	7.85E-04	5.05E+01	2.28E-04	1.52E-04	7.61E-05
Sr-90	6.54E-05	1.05E+04	6.50E-05	4.34E-05	2.17E-05
Sr-91	6.41E-03	4.01E-01	1.93E-70	1.29E-70	6.44E-71
Y-90	7.85E-06	2.67E+00	5.43E-16	3.62E-16	1.81E-16
Y-91m	3.73E-03	3.45E-02	0.00E+00	0.00E+00	0.00E+00
Y-91	2.88E-05	5.85E+01	9.91E-06	6.61E-06	3.30E-06
Y-93	2.81E-02	4.24E-01	3.77E-66	2.51E-66	1.26E-66
Zr-95	2.16E-03	6.40E+01	8.15E-04	5.43E-04	2.72E-04
Nb-95	1.57E-03	3.50E+01	2.64E-04	1.76E-04	8.80E-05
Mo-99	3.66E-02	2.75E+00	5.15E-12	3.44E-12	1.72E-12
Tc-99m	3.34E-02	2.50E-01	2.15E-110	1.43E-110	7.17E-111
Ru-103	4.12E-02	3.93E+01	8.41E-03	5.61E-03	2.80E-03
Ru-106	4.91E-01	3.74E+02	4.15E-01	2.77E-01	1.38E-01
Rh-103m	4.12E-02	3.90E-02	0.00E+00	0.00E+00	0.00E+00
Rh-106	4.91E-01	3.45E-04	0.00E+00	0.00E+00	0.00E+00
Ag-110m	7.20E-03	2.50E+02	5.61E-03	3.74E-03	1.87E-03
Te-129m	1.05E-03	3.36E+01	1.64E-04	1.09E-04	5.45E-05
Te-129	1.90E-01	4.83E-02	0.00E+00	0.00E+00	0.00E+00
Te-131m	9.16E-03	1.25E+00	1.94E-24	1.29E-24	6.47E-25
Te-131	6.35E-02	1.74E-02	0.00E+00	0.00E+00	0.00E+00
Te-132	9.81E-03	3.20E+00	3.35E-11	2.24E-11	1.12E-11
Ba-137m	4.84E-02	1.77E-03	0.00E+00	0.00E+00	0.00E+00
Ba-140	7.20E-02	1.28E+01	5.40E-04	3.60E-04	1.80E-04
La-140	1.50E-01	1.68E+00	1.12E-17	7.50E-18	3.75E-18
Ce-141	8.51E-04	3.25E+01	1.25E-04	8.32E-05	4.16E-05

Table 7 - Activity after 90 days decay (continued)

Nuclide	Activity per m³ resin (GBq/m³)	Half life (Days) (Ref 6)	Decayed Activity (GBq/m³) Leakage rate 75lb/day	Decayed Activity (GBq/m³) Leakage rate 50lb/day	Decayed Activity (GBq/m3) Leakage rate 25lb/day
Ce-143	1.70E-02	1.38E+00	3.55E-22	2.37E-22	1.18E-22
Ce-144	2.22E-02	2.85E+02	1.79E-02	1.19E-02	5.96E-03
Pr-143	1.96E-02	1.36E+01	1.98E-04	1.32E-04	6.60E-05
Pr-144	2.22E-02	1.20E-02	0.00E+00	0.00E+00	0.00E+00
W-187	1.50E-02	9.88E-01	5.82E-30	3.88E-30	1.94E-30
Np-239	1.31E-02	2.36E+00	4.33E-14	2.89E-14	1.44E-14
Total	**1.79E+01**	**3.17E+04**	**7.02E+00**	**4.68E+00**	**2.34E+00**

N.B. 1Ci = 37GBq = 3.7E+10Bq

2. The Ba-137m value in table 2 above is incorrect, because Ba-137m is actually in secular equilibrium with it's parent, Cs-137, which is long lived in comparison to Ba-137m i.e. 30.1 yrs in comparsion to 2.5mins. This does not affect the conclusions.

Final waste package

If the CPS resin does not meet the off-site incineration facilities conditions for acceptance it is intended to encapsulate the CPS resin in a cement formulation in 200L drums which can then be sent for disposal to the LLWR.

<u>Volume</u>

The cement to resin ratio will be 50:50 as per the similar waste stream at Sizewell B — Ref 11

Volume of resin to be encapsulated = 5.8 m^3

Percentage of resin per waste package (by volume) = 50%

Total volume of waste package = Volume of resin / Percentage of resin per waste package

Total volume of waste package = 5.80 \ 50%

= 11.60 m^3

<u>Weight</u>

Bulk Density of resin = 0.75 Te/m^3 — Ref 4

The density of cement = 2.4 Te/m^3 — Ref 12

Weight of resin in waste package = volume of resin in waste package x Density of resin

Weight of resin in waste package = 5.80 x 0.75

= 4.35 Te

Weight of cement in Waste package = Volume of cement in waste package x Density of cement

= 5.80 x 2.4

= 13.92 Te

Total weight of waste package = Weight of resin in waste package + weight of cement in waste package

= 4.35 + 13.92

= 18.27 Te per 18 month cycle

= 18270 Kg per 18 month cycle

<u>Waste Oil</u>

Source Information

Volume of oil per year	=	1	m^3	Ref 1
Density of oil	=	0.869	Te/m^3	assumed

The following data on the Isotopes and their respective activities within the primary coolant have been extracted from Ref 3

Nuclide	Reactor Coolant Activity (µCi/g)	Nuclide	Reactor Coolant Activity (µCi/g)
Br-84	0.02	Y-93	4.30E-03
I-131	0.04	Zr-95	3.30E-04
I-132	0.25	Nb-95	2.40E-04
I-133	0.14	Mo-99	5.60E-03
I-134	0.42	Tc-99m	5.10E-03
I-135	0.28	Ru-103	6.30E-03
Rb-88	0.24	Ru-106	7.50E-02
Cs-134	5.90E-03	Rh-103m	6.30E-03
Cs-136	7.40E-04	Rh-106	7.50E-02
Cs-137	7.90E-03	Ag-110m	1.10E-03
H-3	1	Te-129m	1.60E-04
Na-24	4.60E-02	Te-129	2.90E-02
Cr-51	2.60E-03	Te-131m	1.40E-03
Mn-54	1.30E-03	Te-131	9.70E-03
Fe-55	1.00E-03	Te-132	1.50E-03
Fe-59	2.50E-04	Ba-137m	7.40E-03
Co-58	3.90E-03	Ba-140	1.10E-02
Co-60	4.40E-04	La-140	2.30E-02
Zn-65	4.30E-04	Ce-141	1.30E-04
Sr-89	1.20E-04	Ce-143	2.60E-03
Sr-90	1.00E-05	Ce-144	3.40E-03
Sr-91	9.80E-04	Pr-143	3.00E-03
Y-90	1.20E-06	Pr-144	3.40E-03
Y-91m	5.70E-04	W-187	2.30E-03
Y-91	4.40E-06	Np-239	2.00E-03
		Total Activity	**2.74E+00**

Table 8: Reactor Coolant activity

Calculation Method

The activity of the waste oil is assumed to be 0.15% of the activity of the reactor coolant. Thus the isotope activity shown in table 8 above are pro-rated as below

Isotopic activity in waste oil = isotopic activity in reactor coolant x 0.15%

The results are shown in table 9

This gives the activity in µCi/g

Mass of oil over lifetime of plant = volume of oil over lifetime of plant x Density of oil

Mass of oil over lifetime of plant =	1	x	0.869	=	0.869	Te
				=	869000	g

This allows the production of a fingerprint for the waste oil, as shown in Table 9

Table 9 - Activity of waste Oil

Nuclide	Reactor Coolant Activity	Waste oil activity (µCi/g)	Waste oil Activity (µCi)	Waste Oil activity (Bq)	Waste Oil activity (MBq)
Br-84	2.00E-02	3.00E-05	2.61E+01	9.65E+05	9.65E-01
I-131	4.00E-02	6.00E-05	5.21E+01	1.93E+06	1.93E+00
I-132	2.50E-01	3.75E-04	3.26E+02	1.21E+07	1.21E+01
I-133	1.40E-01	2.10E-04	1.82E+02	6.75E+06	6.75E+00
I-134	4.20E-01	6.30E-04	5.47E+02	2.03E+07	2.03E+01
I-135	2.80E-01	4.20E-04	3.65E+02	1.35E+07	1.35E+01
Rb-88	2.40E-01	3.60E-04	3.13E+02	1.16E+07	1.16E+01
Cs-134	5.90E-03	8.85E-06	7.69E+00	2.85E+05	2.85E-01
Cs-136	7.40E-04	1.11E-06	9.65E-01	3.57E+04	3.57E-02
Cs-137	7.90E-03	1.19E-05	1.03E+01	3.81E+05	3.81E-01
H-3	1.00E+00	1.50E-03	1.30E+03	4.82E+07	4.82E+01
Na-24	4.60E-02	6.90E-05	6.00E+01	2.22E+06	2.22E+00
Cr-51	2.60E-03	3.90E-06	3.39E+00	1.25E+05	1.25E-01
Mn-54	1.30E-03	1.95E-06	1.69E+00	6.27E+04	6.27E-02
Fe-55	1.00E-03	1.50E-06	1.30E+00	4.82E+04	4.82E-02
Fe-59	2.50E-04	3.75E-07	3.26E-01	1.21E+04	1.21E-02
Co-58	3.90E-03	5.85E-06	5.08E+00	1.88E+05	1.88E-01
Co-60	4.40E-04	6.60E-07	5.74E-01	2.12E+04	2.12E-02
Zn-65	4.30E-04	6.45E-07	5.61E-01	2.07E+04	2.07E-02
Sr-89	1.20E-04	1.80E-07	1.56E-01	5.79E+03	5.79E-03
Sr-90	1.00E-05	1.50E-08	1.30E-02	4.82E+02	4.82E-04
Sr-91	9.80E-04	1.47E-06	1.28E+00	4.73E+04	4.73E-02
Y-90	1.20E-06	1.80E-09	1.56E-03	5.79E+01	5.79E-05
Y-91m	5.70E-04	8.55E-07	7.43E-01	2.75E+04	2.75E-02
Y-91	4.40E-06	6.60E-09	5.74E-03	2.12E+02	2.12E-04
Y-93	4.30E-03	6.45E-06	5.61E+00	2.07E+05	2.07E-01
Zr-95	3.30E-04	4.95E-07	4.30E-01	1.59E+04	1.59E-02
Nb-95	2.40E-04	3.60E-07	3.13E-01	1.16E+04	1.16E-02
Mo-99	5.60E-03	8.40E-06	7.30E+00	2.70E+05	2.70E-01
Tc-99m	5.10E-03	7.65E-06	6.65E+00	2.46E+05	2.46E-01
Ru-103	6.30E-03	9.45E-06	8.21E+00	3.04E+05	3.04E-01
Ru-106	7.50E-02	1.13E-04	9.78E+01	3.62E+06	3.62E+00
Rh-103m	6.30E-03	9.45E-06	8.21E+00	3.04E+05	3.04E-01
Rh-106	7.50E-02	1.13E-04	9.78E+01	3.62E+06	3.62E+00
Ag-110m	1.10E-03	1.65E-06	1.43E+00	5.31E+04	5.31E-02
Te-129m	1.60E-04	2.40E-07	2.09E-01	7.72E+03	7.72E-03
Te-129	2.90E-02	4.35E-05	3.78E+01	1.40E+06	1.40E+00
Te-131m	1.40E-03	2.10E-06	1.82E+00	6.75E+04	6.75E-02
Te-131	9.70E-03	1.46E-05	1.26E+01	4.68E+05	4.68E-01
Te-132	1.50E-03	2.25E-06	1.96E+00	7.23E+04	7.23E-02
Ba-137m	7.40E-03	1.11E-05	9.65E+00	3.57E+05	3.57E-01
Ba-140	1.10E-02	1.65E-05	1.43E+01	5.31E+05	5.31E-01
La-140	2.30E-02	3.45E-05	3.00E+01	1.11E+06	1.11E+00
Ce-141	1.30E-04	1.95E-07	1.69E-01	6.27E+03	6.27E-03

Table 9 - Activity of waste Oil (continued)

Nuclide	Reactor Coolant Activity (µCi/g)	Waste oil activity (µCi/g)	Waste oil Activity (µCi)	Waste Oil activity (Bq)	Waste Oil activity (MBq)
Ce-143	2.60E-03	3.90E-06	3.39E+00	1.25E+05	1.25E-01
Ce-144	3.40E-03	5.10E-06	4.43E+00	1.64E+05	1.64E-01
Pr-143	3.00E-03	4.50E-06	3.91E+00	1.45E+05	1.45E-01
Pr-144	3.40E-03	5.10E-06	4.43E+00	1.64E+05	1.64E-01
W-187	2.30E-03	3.45E-06	3.00E+00	1.11E+05	1.11E-01
Np-239	2.00E-03	3.00E-06	2.61E+00	9.65E+04	9.65E-02
Total	**2.74E+00**	**4.11E-03**	**3.57E+03**	**1.32E+08**	**1.32E+02**

N.B. 1Ci = 37GBq = 3.7E+10Bq

The Ba-137m value in table 2 above is incorrect, because Ba-137m is actually in secular equilibrium with it's parent, Cs-137, which is long lived in comparison to Ba-137m i.e. 30.1 yrs in comparsion to 2.5mins. This does not affect the conclusions.

From Ref 6 all the Isotopes outlined in Table 9 have either Beta or Gamma decay modes i.e. There is no isotope which exhibits Alpha Decay

The activity of the specific Isotopes required are taken from table 9 above. These are outlined below;

Uranium	=	0.00E+00	MBq
Ra-226	=	0.00E+00	MBq
Th-232	=	0.00E+00	MBq
Other alpha	=	0.00E+00	MBq
C-14	=	0.00E+00	MBq
I-129	=	0.00E+00	MBq
H-3	=	4.82E+01	MBq
Co-60	=	2.12E-02	MBq
Other radionuclides	=	8.40E+01	MBq

Final waste package

<u>Volume</u>

The volume of Oil to be disposed of per year is	=	1	m3	Ref 1

<u>Weight</u>

Bulk Density of Oil	=	0.869	Te/m^3	assumed

Weight of oil in waste package = volume of oil in waste package x Density of oil

Weight of Oil in package =		1.00	x	0.87
	=	0.87	Te	
Total weight of waste package =		0.87	Te	

N.B. This weight does not include the weight of any conditioning matrix as the details of this are currently unknown

<u>Steam Generator Sludge</u>

Source Information

The following data on the Isotopes and their activity within the secondary coolant have been extracted from Ref 19

Nuclide	**Activity (μCi/g)**	**Nuclide**	**Activity (μCi/g)**
Br-83	2.30E-05	Y-91m	1.80E-06
Br-84	4.00E-06	Y-91	2.30E-07
Br-85	4.90E-08	Y-92	4.90E-07
I-129	2.40E-11	Y-93	1.50E-07
I-130	1.40E-05	Zr-95	2.70E-07
I-131	1.10E-03	Nb-95	2.70E-07
I-132	7.30E-04	Mo-99	3.40E-04
I-133	1.80E-03	Tc-99m	3.20E-04
I-134	8.10E-05	Ru-103	2.30E-07
I-135	8.70E-04	Rh-103m	2.30E-07
Rb-88	2.30E-04	Rh-106	2.00E-10
Rb-89	8.90E-06	Ag-110m	6.70E-07
Cs-134	2.10E-03	Te-127m	1.30E-06
Cs-136	3.00E-03	Te-127	3.20E-07
Cs-137	1.50E-03	Te-129m	4.40E-06
Cs-138	9.50E-05	Te-129	3.80E-06
H-3	1.00E+00	Te-131m	1.00E-05
Cr-51	2.20E-06	Te-131	2.80E-06
Mn-54	1.10E-06	Te-132	1.30E-04
Mn-56	1.30E-04	Te-134	3.20E-06
Fe-55	8.40E-07	Ba-137m	1.40E-03
Fe-59	2.20E-07	Ba-140	1.70E-06
Co-58	3.20E-06	La-140	6.00E-07
Co-60	3.70E-07	Ce-141	2.60E-07
Sr-89	3.30E-06	Ce-143	2.20E-07
Sr-90	1.50E-07	Ce-144	1.90E-07
Sr-91	3.30E-06	Pr-143	2.50E-07
Sr-92	4.00E-07	Pr-144	1.90E-07
Y-90	2.70E-08		
		Total Activity	**1.01**

Table 10: Secondary Side Coolant Activity

Volume of sludge per year =	0.085	m3		Ref 10
Density of sludge =	998.20	kg/m3		Ref 18
Decay time =	30	days	(Assumed to be a minimum)	

Calculation method

Total activity in sludge prior to decay is = 1.01E+00 µCi/g

The half lifes of the Isotopes were determined from Ref 6 and are shown in table 11.

The activity concentration on the sludge after 30 days of decay can be calculated from the following;

Decayed Activity Concentration (µCi/g) = Undecayed Activity Concentration (µCi/g) x EXP $\left(\frac{-Ln(2)\times T}{t_{\frac{1}{2}}}\right)$

Where T = Decay time (days)

$t_{1/2}$ = Half Life (days)

The decayed activity concentrations for all the isotopes are shown in Table 11.

Nuclide	Initial Activity (µCi/g)	Half Life (Days)	Decayed Activity (µCi/g)	Decayed Activity (Bq/g)	Decayed Activity (MBq)
Br-83	2.30E-05	1.00E-01	1.13E-95	4.18E-91	3.54E-92
Br-84	4.00E-06	2.21E-02	0.00E+00	0.00E+00	0.00E+00
Br-85	4.90E-08	2.01E-03	0.00E+00	0.00E+00	0.00E+00
I-129	2.40E-11	5.73E+09	2.40E-11	8.88E-07	7.53E-08
I-130	1.40E-05	5.20E-01	6.01E-23	2.22E-18	1.89E-19
I-131	1.10E-03	8.04E+00	8.28E-05	3.06E+00	2.60E-01
I-132	7.30E-04	9.56E-02	2.70E-98	9.98E-94	8.46E-95
I-133	1.80E-03	8.67E-01	6.84E-14	2.53E-09	2.15E-10
I-134	8.10E-05	3.65E-02	1.60E-252	5.92E-248	5.02E-249
I-135	8.70E-04	2.74E-01	8.91E-37	3.30E-32	2.80E-33
Rb-88	2.30E-04	1.23E-02	0.00E+00	0.00E+00	0.00E+00
Rb-89	8.90E-06	1.10E-02	0.00E+00	0.00E+00	0.00E+00
Cs-134	2.10E-03	7.54E+02	2.04E-03	7.56E+01	6.41E+00
Cs-136	3.00E-03	1.31E+01	6.13E-04	2.27E+01	1.93E+00
Cs-137	1.50E-03	1.10E+04	1.50E-03	5.54E+01	4.70E+00
Cs-138	9.50E-05	2.30E-02	0.00E+00	0.00E+00	0.00E+00
H-3	1.00E+00	4.51E+03	9.95E-01	3.68E+04	3.12E+03
Cr-51	2.20E-06	2.77E+01	1.04E-06	3.84E-02	3.26E-03
Mn-54	1.10E-06	3.12E+02	1.03E-06	3.81E-02	3.23E-03
Mn-56	1.30E-04	1.10E-01	1.03E-86	3.83E-82	3.25E-83
Fe-55	8.40E-07	9.96E+02	8.23E-07	3.04E-02	2.58E-03
Fe-59	2.20E-07	4.45E+01	1.38E-07	5.10E-03	4.33E-04
Co-58	3.20E-06	7.09E+01	2.39E-06	8.83E-02	7.49E-03
Co-60	3.70E-07	1.92E+03	3.66E-07	1.35E-02	1.15E-03
Sr-89	3.30E-06	5.05E+01	2.19E-06	8.09E-02	6.86E-03
Sr-90	1.50E-07	1.05E+04	1.50E-07	5.54E-03	4.70E-04
Sr-91	3.30E-06	4.01E-01	1.03E-28	3.80E-24	3.22E-25
Sr-92	4.00E-07	1.13E-01	4.81E-87	1.78E-82	1.51E-83
Y-90	2.70E-08	2.67E+00	1.11E-11	4.10E-07	3.48E-08
Y-91m	1.80E-06	3.45E-02	4.45E-268	1.65E-263	1.40E-264

Y-91	2.30E-07	5.85E+01	1.61E-07	5.96E-03	5.06E-04
Y-92	4.90E-07	1.50E-01	3.05E-67	1.13E-62	9.57E-64
Y-93	1.50E-07	4.24E-01	7.68E-29	2.84E-24	2.41E-25
Zr-95	2.70E-07	6.40E+01	1.95E-07	7.22E-03	6.13E-04
Nb-95	2.70E-07	3.50E+01	1.49E-07	5.51E-03	4.68E-04
Mo-99	3.40E-04	2.75E+00	1.77E-07	6.54E-03	5.55E-04
Tc-99m	3.20E-04	2.50E-01	2.76E-40	1.02E-35	8.68E-37
Ru-103	2.30E-07	3.93E+01	1.35E-07	5.01E-03	4.25E-04
Rh-103m	2.30E-07	3.90E-02	4.32E-239	1.60E-234	1.36E-235
Rh-106	2.00E-10	3.45E-04	0.00E+00	0.00E+00	0.00E+00
Ag-110m	6.70E-07	2.50E+02	6.16E-07	2.28E-02	1.94E-03
Te-127m	1.30E-06	1.09E+02	1.07E-06	3.97E-02	3.37E-03
Te-127	3.20E-07	3.90E-01	2.23E-30	8.26E-26	7.01E-27
Te-129m	4.40E-06	3.36E+01	2.37E-06	8.77E-02	7.44E-03
Te-129	3.80E-06	4.83E-02	5.41E-193	2.00E-188	1.70E-189
Te-131m	1.00E-05	1.25E+00	5.96E-13	2.21E-08	1.87E-09
Te-131	2.80E-06	1.74E-02	0.00E+00	0.00E+00	0.00E+00
Te-132	1.30E-04	3.20E+00	1.96E-07	7.24E-03	6.15E-04
Te-134	3.20E-06	3.00E-02	2.99E-307	1.10E-302	0.00E+00
Ba-137m	1.40E-03	1.77E-03	0.00E+00	0.00E+00	0.00E+00
Ba-140	1.70E-06	1.28E+01	3.33E-07	1.23E-02	1.04E-03
La-140	6.00E-07	1.68E+00	2.53E-12	9.35E-08	7.93E-09
Ce-141	2.60E-07	3.25E+01	1.37E-07	5.07E-03	4.30E-04
Ce-143	2.20E-07	1.38E+00	6.06E-14	2.24E-09	1.90E-10
Ce-144	1.90E-07	2.85E+02	1.77E-07	6.54E-03	5.54E-04
Pr-143	2.50E-07	1.36E+01	5.40E-08	2.00E-03	1.70E-04
Pr-144	1.90E-07	1.20E-02	0.00E+00	0.00E+00	0.00E+00
				Total Activity	**3.14E+03**

Table 11: Sludge Isotopic Fingerprint after 30 days

Notes 1. 1Ci = 37GBq = 3.7E+10Bq

2. The Ba-137m value in table 2 above is incorrect, because Ba-137m is actually in secular equilibrium with it's parent, Cs-137, which is long lived in comparison to Ba-137m i.e. 30.1 yrs in comparsion to 2.5mins. This does not affect the conclusions.

From Ref 6 none of the Isotopes in Table 11 are Alpha emitters

mass of sludge per year = Density x Volume

mass of sludge per year = 998.20 x 0.085

mass of sludge per year = 84.847 kg

The total activity within the sludge after 30 days decay time is 3.14E+03 MBq

The Isotopic fingerprint of the sludge can be found in table 11.

The LLWR D1 form (Acceptance in principle) asks specifically for the following istopes:

Uranium	=	0	MBq
Ra-226	=	0	MBq
Th-232	=	0	MBq
Other alpha	=	0	MBq
C-14	=	0	MBq
I-129	=	7.53E-08	MBq
H-3	=	3.12E+03	MBq
Co-60	=	1.15E-03	MBq
Other radionuclides	=	1.33E+01	MBq

References

1 EPS-GW-GL-700 Rev 0. Euro DCD, section 11.4.2.1, Pg 11.4-4 and Table 11.4-1.

2 EPS-GW-GL-700 Rev 0. Euro DCD, table 11.1-7

3 EPS-GW-GL-700 Rev 0. Euro DCD, table 11.1-8 - Realistic source terms

4 Perry's Chemical Engineers' Handbook, Seventh Edition. Pg 16-10.

5 http://www.defra.gov.uk/environment/radioactivity/waste/pdf/definitions0905.pdf

6 http://nucleardata.nuclear.lu.se/NuclearData/toi/index.asp

7 EPS-GW-GL-700 Rev 0. Euro DCD, table 11.1-1

8 EPS-GW-GL-700 Rev 0. Euro DCD, Page 11.4-13

9 T/WPS/320/E/02 - Nirex Waste Package Specification and Guidance Documentation Specification for 3m^3 Drum

10 UKP-GW-GL-790. AP1000 Environment report.

11 2007 UK Radioactive Waste Inventory. Waste data sheet 3S06 - LLW resins.

12 http://www.theconstructioncivil.com/2009/09/density-of-concrete.html

13 Conditions for acceptance for disposal of Radioactive Active Waste at the Low Level Waste Respository.Issue 01/08

14 Ans standard for waste liquid (ans/ansi 55.6 1993) for liquid and misc. drains.

15 EPS-GW-GL-700 Euro DCD rev 0. Table 11.1-8 Realistic Source terms

16 2007 UK Radioactive Waste INventory. Waste data sheet 3S07 - Station Maintenance and Operations LLW. .

17 UKP-GW-GL-004. Process Mass Balance for AP1000 Solid Waste ((63000333-000-000-111-C-0001))

18 Perry's Chemical Engineers' Handbook, Seventh Edition. Pg 2-91.

19 EPS-GW-GL-700. Euro DCD, Rev 0. Table 11.1-5