Uncertainties Associated with the Proposed Shielding Calculation Method for the SAFKEG-HS 3977A Package

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1 Introduction

This report has been produced in response to the Nuclear Regulatory Commission, Requests for Additional information. These comments require a Croft response concerning all the uncertainties found with the model used to calculate the dose rate on the surface of the package. These uncertainties include, the method of converting the photon flux to a dose rate, the point at which the source has been located and the point the dose rate was calculated, the changes caused by using the minimum tolerances for all the materials and the effect of the damage on the package from the NCT and HAC tests.

This report will discuss the selection of the nuclides to assess the uncertainty and provide the uncertainty introduced by the dose rate calculation, the tolerances and the damage sustained to the package.

2 Selection of the Nuclides

The package contains a large number of nuclides so in order to ascertain the effect of these uncertainties on all the nuclides, nuclides over a range of energies shall be selected. The majority of the nuclides on the contents list have their major energy peak between 2 to 0.4 MeV, therefore 3 nuclides have been selected with the major energy in this range Th-228 with the main peak at 3 MeV as shown in Figure 1, Cs-137 with the main peak at 0.662, as shown in Figure 2 and Ir-192 with the major peak at 0.3 as shown in Figure 3. In order to investigate the effect of changing various factors across the entire range of energies a further 2 nuclides were selected that were not limited by shielding but did provide a range across the full energy spectrum. These were Pb-210 with its main energy peak at 0.0108, as shown in Figure 4 and TI-210 with its main energy peak at 0.0708, as shown in Figure 5. For those nuclides that have daughter products their energies have been included as illustrated in figures 1, 2 and 4.

Library : Grove

Nuclide	curies	becquerels
Bi-212	9.7232e-001	3.5976e+010
Pb-212	9.7235e-001	3.5977e+010
Po-212	6.2296e-001	2.3050e+010
Po-216	9.7269e-001	3.5990e+010
Ra-224	9.7269e-001	3.5990e+010
Rn-220	9.7269e-001	3.5990e+010
Th-228	9.7454e-001	3.6058e+010
Tl-208	3.4935e-001	1.2926e+010

Group #	Energy (MeV)	Activity Photons/sec	Point Source Photons/sec	% Energy Activity
1	0.015			
2	0.02			
3	0.03			
4	0.04	3.6785e+008	3.6785e+008	.024
5	0.05			
6	0.06			
7	0.08	1.4760e+010	1.4760e+010	1.954
8	0.1	2.5088e+008	2.5088e+008	.042
9	0.15	8.6121e+007	8.6121e+007	.021
10	0.2	1.7651e+010	1.7651e+010	5.843
11	0.3	2.3669e+009	2.3669e+009	1.175
12	0.4	3.4020e+007	3.4020e+007	.023
13	0.5	2.9522e+009	2.9522e+009	2.443
14	0.6	1.0888e+010	1.0888e+010	10.812
15	0.8	7.0932e+009	7.0932e+009	9.392
16	1.0	5.5486e+008	5.5486e+008	.918
17	1.5	1.2330e+009	1.2330e+009	3.061
18	2.0	7.1311e+007	7.1311e+007	.236
19	3.0	1.2900e+010	1.2900e+010	64.055
20	4.0			
21	5.0			
22	6.0			
23	8.0			
24	10.0			
25	15.0			

Figure 1 - Th-228 Energy Spectrum

Library : Grove

Nuclide	curies	becquerels
Ba-137m	9.4600e-001	3.5002e+010
Cs-137	1.0000e+000	3.7000e+010

Group #	Energy (MeV)	Activity Photons/sec	Point Source Photons/sec	% Energy Activity
1	0.0045	3.6336e+008	3.6336e+008	.008
2	0.0318	7.2465e+008	7.2465e+008	.110
3	0.0322	1.3370e+009	1.3370e+009	.206
4	0.0364	4.8653e+008	4.8653e+008	.085
5	0.6616	3.1495e+010	3.1495e+010	99.592

Figure 2 - Cs-137 Energy Spectrum

Library : Grove

Nuclide	curies	becquerels
Ir-192	1.0000e+000	3.7000e+010

Group #	Energy (MeV)	Activity Photons/sec	Point Source Photons/sec	% Energy Activity
1	0.015	2.0557e+009	2.0557e+009	.102
2	0.02			
3	0.03			
4	0.04			
5	0.05			
6	0.06	3.7897e+009	3.7897e+009	.751
7	0.08	1.0387e+009	1.0387e+009	.274
8	0.1			
9	0.15	6.6829e+007	6.6829e+007	.033
10	0.2	1.3892e+009	1.3892e+009	.918
11	0.3	5.2469e+010	5.2469e+010	51.991
12	0.4	5.4410e+008	5.4410e+008	.719
13	0.5	1.9098e+010	1.9098e+010	31.540
14	0.6	6.7013e+009	6.7013e+009	13.281
15	0.8	1.4806e+008	1.4806e+008	.391
16	1.0			
17	1.5			
18	2.0			
19	3.0			
20	4.0			
21	5.0			
22	6.0			
23	8.0			
24	10.0			
25	15.0			

Figure 3 - Ir-192 Energy Spectrum

Library : Grove

Nuclide	curies	becquerels
Bi-210	9.3385e-001	3.4552e+010
Pb-210	9.3328e-001	3.4531e+010
Po-210	9.3176e-001	3.4475e+010

Group #	Energy (MeV)	Activity Photons/sec	Point Source Photons/sec	% Energy Activity
1	0.0108	8.3994e+009	8.3994e+009	58.134
2	0.0465	1.3985e+009	1.3985e+009	41.678
3	0.8031	3.6509e+005	3.6509e+005	.188

Figure 4 - Pb-210 Energy Spectrum

Library : Grove

Nuclide	curies	becquerels
Tl-201	1.0000e+000	3.7000e+010

Group #	Energy (MeV)	Activity Photons/sec	Point Source Photons/sec	% Energy Activity
1	0.0306	8.1400e+007	8.1400e+007	.076
2	0.0322	8.1400e+007	8.1400e+007	.080
3	0.0689	1.0122e+010	1.0122e+010	21.186
4	0.0708	1.7214e+010	1.7214e+010	37.036
5	0.0803	7.5721e+009	7.5721e+009	18.472
6	0.1353	9.8050e+008	9.8050e+008	4.031
7	0.1659	5.9200e+007	5.9200e+007	.298
8	0.1674	3.7000e+009	3.7000e+009	18.820

Figure 5 - Tl-201 Energy Spectrum

3 Use of ANSI/ANS-6.1.1-1977

The original shielding calculations given in CTR 2011/01 issue A used ICRP 51 (1987) Table 2 and the anterior/posterior values to convert photon energy to dose rate. This however provides an organ dose rate rather than a measured dose rate. The NRC also advocates the use of ANSI/ANS-6.1.1-1977 as this provides higher surface dose rates than those in ICRP 51. Therefore the dose rates calculated were compared to those determined using the ANSI/ANS-6.1.1-1977 standard.

For the nuclides discussed in section 2 the photon flux was converted into dose rate using the following equation given in ANSI/ANS-6.1.1

Table 4
Gamma-Ray-Flux-to-Dose-Rate Conversion Factors. Polynomial Coefficients in Analytic fit - - $\ln DF_g(E) = A + B X + C X^2 + D X^3$.
$DF_g(E)$ = (rem/hr)/(photons/cm^2-s), E = Photon energy in MeV, and X = ln E

Photon Energy (MeV)	A	B	C	D
0.01 to 0.03	−2.0477 +01	−1.7454		
0.03 to 0.5	−1.3626 +01	−5.7117 −01	−1.0954	−2.4897 −01
0.5 to 5.0	−1.3133 +01	7.2008 −01	−3.3603 −02	
5.0 to 15.0	−1.2791 +01	2.8309 −01	1.0873 −01	

The photon flux was taken for each nuclide and daughters from Microshield using the model discussed in CTR 2011/01 issue A. The calculation for each nuclide is given in appendix A. The total dose rate for each nuclide (and daughters if applicable) is given in Table 1. This also compares the dose rate calculated using ICRP 51 against ANSI/ANS-6.1.1.

Table 1 - ANS vs ICRP Dose Rates

Nuclide	ICRP dose Rate result mSv/hr	ANS dose rate result mSv/hr	Percentage difference
Cs-137	4.27E-03	5.32E-03	24.64%
Ir-192	4.22E-04	5.22E-04	23.83%
Pb-210	6.06E-07	7.39E-07	21.97%
Tl-201	6.56E-12	8.99E-12	37.06%
Th-228	7.23E+00	4.10E-02	14.25%

As shown in table 1 the maximum difference between the figure provided in CTR 2011/01 and those calculated using ANSI/ANS is 37%.

4 Minimum Dimensions, NCT damage and ACT Damage

The shielding model for the tungsten inserts has been altered and run for the 5 nuclides to identify the effect of changing the dimensions from the nominal to the minimum thicknesses and to include damage sustained by the prototype package during NCT

testing. Another run was carried out with the minimum thicknesses and the damage that was sustained to the package during HAC testing.

Using the minimum thickness given in the licensing drawings the model was altered, added to these reductions the small air thicknesses have been removed and the final cork thickness reduced by 0.8 cm. This is to take into account the 0.8 cm dent recorded during the NCT testing of the package. Under HAC conditions this cork thickness has been reduced by 1.1 cm to take into account the 1.1 cm dent recorded during the HAC testing of the package. The model thicknesses are given in Table 2.

The results of the Microshield calculations are given in Table 3 and Table 4. As shown in Table 3 the maximum difference from the nominal result reported in CTR 2011/01 for the 3982 insert is 53.38% and the maximum difference from the nominal result reported in CTR 2011/01 to the 3985 insert is 55.53%.

Table 2 - Thicknesses used for Minimum Model

Shield	Nomenclature	3982 nominal thicknesses (cm)	3982 Minimum thicknesses and NCT damage (cm)	3982 Minimum thickness and ACT Damage (cm)	3985 nomical thicknesses (cm)	3985 Min thickness and NCT damage (cm)	3985 Min thicknesses and ACT damage (cm)	Material/ Regional Density (g/cm^3)
1	Insert	2.73	2.7	2.7	1.78	1.75	1.75	W/17.23
2	CV Cavity Liner	0.31	0.28	0.28	0.31	0.28	0.28	Fe/7.86
3	air gap	0.07	0	0	0.07	0	0	Air/0.00122
4	CV Shield	4.6	4.57	4.57	4.6	4.57	4.57	U/17.93
5	Air gap	0.06	0	0	0.06	0	0	Air/0.00122
6	CV Outer Skin	0.6	0.5	0.5	0.6	0.5	0.5	Fe/7.86
7	3977 Cavity Liner	0.6	0.575	0.575	0.6	0.575	0.575	Fe/7.86
8	Outer Cork Liner	6.75	5.45	5.15	6.75	5.45	5.15	Air/0.00122
9	3977 Outer Skin	0.4	0.38	0.38	0.4	0.38	0.38	Fe/7.86
	Detector #1	16.12	14.455	14.155	15.17	13.505	13.205	
	Detector #2	116.12	114.455	114.155	115.17	113.505	113.205	Air/0.00122

Table 3 - Microshield Results for Minimum Tolerances for 3982 Insert

Insert	3982				
Nuclide	Dose rate with Nominal Dimensions	Dose rate with Minimum Dimensions at NCT (mSv/hr)	Percentage Difference from Nominal to Minimum dose rates	Dose rate under HAC (mSv/hr)	Percentage Difference from Nominal to HAC results
Th-228	1.02	1.38E+00	35.09%	1.44E+00	40.86%
Cs-137	4.65E-05	7.13E-05	53.38%	7.43E-05	59.97%
Ir-192	6.64E-06	9.96E-06	50.02%	1.04E-05	56.40%
Tl-201	4.65E-12	5.78E-12	24.37%	6.03E-12	29.70%
Pb-210	1.42E-08	2.11E-08	48.52%	2.20E-08	54.93%

Table 4 - Microshield Results for Minimum Tolerances for 3985 Insert

Insert	3985				
Nuclide	Dose rate with Nominal Dimensions (mSv/hr)	Dose with Minimum Tolerances at NCT (mSv/hr)	Percentage Difference from Nominal to Minimum dose rates	Dose rate at HAC (mSv/hr)	Percentage Difference from Nominal to HAC results
Th-228	2.06E+00	2.83E+00	37.00%	2.95E+00	43.26%
Cs-137	2.33E-04	3.63E-04	55.53%	3.79E-04	62.69%
Ir-192	2.81E-05	4.30E-05	52.79%	4.50E-05	59.79%
Tl-201	5.25E-12	6.63E-12	26.19%	6.93E-12	31.97%
Pb-210	5.44E-08	8.20E-08	50.59%	8.57E-08	57.52%

5 Location of the Source

The original MCBEND calculations did not assess the surface dose rate if the source was located at the top corner of the insert with the insert touching the CV lid [1].

The dose rate over the surface of the package with a Cs-137 point source located in the top corner of the insert was analysed for Cs-137 in issue 2 of the AMEC shielding report [2]. This report has shown that this source location led to the highest surface dose rate which could be found on the side of the package. From comparison of the dose rate at bottom surface of the package with the point source located on the base against that at the side with the source in the top corner position, the dose rate was found to increase by 71% for the thicker tungsten insert and 274% for the thinner tungsten insert.

A further technical note [3] was then produced to assess the change in dose rate for the nuclides Th-228, Ir-193, TI-201 and Pb-210, when the point source was located in the top corner of the insert. Table 5 shows the % increase in the dose rates between the highest dose rate with the point source located at the bottom of the insert verses when it is located at the top corner. TI-201 is not given in the table because the dose rate could not be

calculated by MCBEND. This was because the highest line energy is relatively low at 0.1675 MeV. The resulting attenuation through tungsten and uranium reduces the dose rate through too many orders of magnitude for a successful calculation, even when acceleration is used.

As shown by Table 5 Cs-137 has the largest percentage increase in the dose rate between the bottom and side values. Therefore these values will be applied to all the nuclides in order to correct the dose rate.

Table 5 – Dose Rate Variation with Source Location

Nuclide	Insert	% Increase in Dose Rate
Th-228	31x114-Tu	-3 %
	12x95-Tu	-7%
Cs-137	31x114-Tu	274%
	12x95-Tu	71%
Ir-192	31x114-Tu	64%
	12x95-Tu	11%
Pb-210	31x114-Tu	85%
	12x95-Tu	17%

6 Dose Rates for all Nuclides

From the calculations in the previous sections the following corrections shall be made to the dose rates on the surface of the package containing the Tungsten inserts:

Insert	ANS Correction	Minimum Thicknesses and NCT damage	Location of Source
3982	37%	53.38%	71%
3985	37%	55.53%	274%

With these corrections taking into account the uncertainties the dose rates were recalculated and are given in Table 6 and Table 7. As seen in Table 7 the surface dose rate of the package with the 3985 insert exceeds the 10 mSv/hr allowed under exclusive use. Therefore the activity of each nuclide has been reduced so that the package surface dose rate it is now below 10 mSv/hr. The new activity limits for the 3985 insert are provided in Table 8.

Table 6 - Dose Rates for HS Package with 3982 Insert

Nuclide	Original Activity, Bq	Effective Dose Equivalent Rate, mSv/h CTR 2011/01	Dose Rate with errors corrected, mSv/hr	Activity limit in PCS 038 (Bq)	Activity limit in PCS 038 (Ci)	Dose rate on Surface with activity carried (mSv/hr)
Ac-225	3.70E+10	2.95E-02	1.06E-01	2.51E+12	6.78E+01	7.19E+00
Ac-227	3.70E+10	8.42E-03	3.03E-02	8.79E+12	2.38E+02	7.19E+00
Ac-228	3.70E+10	1.73E-01	6.22E-01	4.28E+11	1.16E+01	7.19E+00
Am-241	3.70E+10	2.11E-01	7.58E-01	3.51E+11	9.48E+00	7.19E+00
As-77	3.70E+10	7.85E-10	2.82E-09	9.43E+19	2.55E+09	7.19E+00
Au-198	3.70E+10	1.06E-04	3.80E-04	6.99E+14	1.89E+04	7.19E+00
Ba-131	3.70E+10	3.93E-04	1.41E-03	1.88E+14	5.08E+03	7.19E+00
C-14	3.70E+10	1.07E-17	3.84E-17	6.92E+27	1.87E+17	7.19E+00
Co-60	3.70E+09	3.10E-01	1.12E+00	2.38E+10	6.44E-01	7.19E+00
Cs-131	3.70E+10	8.83E-26	3.17E-25	8.39E+35	2.27E+25	7.19E+00
Cs-134	3.70E+10	1.05E-02	3.77E-02	7.05E+12	1.90E+02	7.19E+00
Cs-137	1.11E+14	1.40E-01	5.04E-01	1.58E+15	4.28E+04	7.19E+00
Cu-67	3.70E+10	1.14E-15	4.09E-15	6.50E+25	1.76E+15	7.19E+00
Hg-203	3.70E+10	2.07E-03	7.44E-03	3.57E+13	9.66E+02	7.19E+00
Ho-166	3.70E+10	3.62E-02	1.30E-01	2.04E+12	5.52E+01	7.19E+00
I-125	3.70E+10	1.65E-25	5.92E-25	4.49E+35	1.21E+25	7.19E+00
I-129	3.70E+10	2.24E-16	8.04E-16	3.31E+26	8.94E+15	7.19E+00
I-131	3.70E+10	1.80E-05	6.47E-05	4.11E+15	1.11E+05	7.19E+00

Nuclide	Original Activity, Bq	Effective Dose Equivalent Rate, mSv/h CTR 2011/01	Dose Rate with errors corrected, mSv/hr	Activity limit in PCS 038 (Bq)	Activity limit in PCS 038 (Ci)	Dose rate on Surface with activity carried (mSv/hr)
In-111	3.70E+10	5.10E-18	1.83E-17	1.45E+28	3.93E+17	7.19E+00
Ir-192	3.70E+10	2.73E-05	9.82E-05	2.71E+15	7.32E+04	7.19E+00
Ir-194	3.70E+10	1.91E-03	6.88E-03	3.87E+13	1.04E+03	7.19E+00
Kr-79	3.70E+10	1.23E-03	4.43E-03	6.00E+13	1.62E+03	7.19E+00
Lu-177	3.70E+10	4.76E-14	1.71E-13	1.56E+24	4.21E+13	7.19E+00
Mo-99	3.70E+10	1.40E-03	5.05E-03	5.27E+13	1.42E+03	7.19E+00
Na-24	3.70E+10	2.81E+00	1.01E+01	2.63E+10	7.12E-01	7.19E+00
Np-237	3.70E+10	2.07E-02	7.43E-02	3.58E+12	9.68E+01	7.19E+00
P-32	3.70E+10	1.33E-02	4.77E-02	5.58E+12	1.51E+02	7.19E+00
P-33	3.70E+10	1.45E-27	5.22E-27	5.10E+37	1.38E+27	7.19E+00
Pb-203	3.70E+10	6.29E-07	2.26E-06	1.18E+17	3.18E+06	7.19E+00
Pb-210	3.70E+10	9.20E-03	3.31E-02	8.04E+12	2.17E+02	7.19E+00
Pd-109	3.70E+10	2.50E-04	9.00E-04	2.96E+14	7.99E+03	7.19E+00
Pu-238	3.70E+10	6.35E-10	2.28E-09	1.16E+20	3.15E+09	7.19E+00
Pu-239	3.70E+10	3.18E-15	1.14E-14	2.33E+25	6.29E+14	7.19E+00
Pu-240	3.70E+10	6.45E-15	2.32E-14	1.15E+25	3.10E+14	7.19E+00
Pu-241	3.70E+10	1.03E-10	3.69E-10	7.21E+20	1.95E+10	7.19E+00
Ra-223	3.70E+10	7.28E-03	2.62E-02	1.02E+13	2.75E+02	7.19E+00
Ra-224	3.70E+10	8.35E-01	3.00E+00	8.86E+10	2.40E+00	7.19E+00
Ra-226	3.70E+10	7.28E-01	2.62E+00	1.02E+11	2.75E+00	7.19E+00
Re-186	3.70E+10	4.73E-04	1.70E-03	1.56E+14	4.23E+03	7.19E+00
Re-188	3.70E+10	4.32E-02	1.55E-01	1.71E+12	4.63E+01	7.19E+00
Rh-105	3.70E+10	7.02E-21	2.52E-20	1.05E+31	2.85E+20	7.19E+00
Se-75	3.70E+10	8.32E-09	2.99E-08	8.89E+18	2.40E+08	7.19E+00
Sm-153	3.70E+10	4.32E-02	1.55E-01	1.71E+12	4.63E+01	7.19E+00
Sr-89	3.70E+10	6.06E-03	2.18E-02	1.22E+13	3.30E+02	7.19E+00
Sr-90	3.70E+10	4.29E-02	1.54E-01	1.72E+12	4.66E+01	7.19E+00
Tb-161	3.70E+10	4.59E-03	1.65E-02	1.61E+13	4.36E+02	7.19E+00
Th-227	3.70E+10	7.33E-03	2.63E-02	1.01E+13	2.73E+02	7.19E+00
Th-228	3.70E+10	1.09E+00	3.92E+00	6.79E+10	1.84E+00	7.19E+00
Tl-201	3.70E+10	4.65E-12	1.67E-11	1.59E+22	4.30E+11	7.19E+00
U-235	3.70E+10	8.07E-08	2.90E-07	9.17E+17	2.48E+07	7.19E+00
W-187	3.70E+10	3.30E-03	1.19E-02	2.24E+13	6.06E+02	7.19E+00
W-188	3.70E+10	5.62E-02	2.02E-01	1.32E+12	3.56E+01	7.19E+00
Xe-133	3.70E+10	3.29E-23	1.18E-22	2.25E+33	6.09E+22	7.19E+00
Y-90	3.70E+10	4.29E-02	1.54E-01	1.73E+12	4.67E+01	7.19E+00
Yb-169	3.70E+10	3.95E-09	1.42E-08	1.88E+19	5.07E+08	7.19E+00
Yb-175	3.70E+10	1.23E-13	4.40E-13	6.04E+23	1.63E+13	7.19E+00

Table 7 - Dose Rates for HS Package with 3985 Insert

Nuclide	Original Activity, Bq	Effective Dose Equivalent Rate, mSv/h	Dose Rate with errors corrected, mSv/hr	Activity limit in PCS 038 (Bq)	Activity limit in PCS 038 (Ci)	Dose on Surface with activity carried (mSv/hr)
Ac-225	3.70E+10	6.76E-02	5.39E-01	1.09E+12	2.96E+01	1.59E+01
Ac-227	3.70E+10	2.11E-02	1.68E-01	3.51E+12	9.49E+01	1.59E+01
Ac-228	3.70E+10	3.98E-01	3.17E+00	1.86E+11	5.03E+00	1.59E+01
Am-241	3.70E+10	4.67E-02	3.72E-01	1.58E+12	4.28E+01	1.59E+01
As-77	3.70E+10	6.47E-09	5.16E-08	1.14E+19	3.09E+08	1.59E+01
Au-198	3.70E+10	3.04E-04	2.43E-03	2.43E+14	6.57E+03	1.59E+01
Ba-131	3.70E+10	1.21E-03	9.64E-03	6.12E+13	1.65E+03	1.59E+01
C-14	3.70E+10	1.21E-17	9.62E-17	6.13E+27	1.66E+17	1.59E+01
Co-60	3.70E+10	7.90E-01	6.30E+00	9.37E+10	2.53E+00	1.59E+01
Cs-131	3.70E+10	9.96E-26	7.94E-25	7.43E+35	2.01E+25	1.59E+01
Cs-134	3.70E+10	2.81E-02	2.24E-01	2.63E+12	7.11E+01	1.59E+01
Cs-137	1.11E+14	7.02E-01	5.60E+00	3.16E+14	8.55E+03	1.59E+01
Cu-67	3.70E+10	2.61E-14	2.08E-13	2.84E+24	7.67E+13	1.59E+01
Hg-203	3.70E+10	1.39E-24	1.11E-23	5.32E+34	1.44E+24	1.59E+01
Ho-166	3.70E+10	8.05E-02	6.41E-01	9.20E+11	2.49E+01	1.59E+01
I-125	3.70E+10	1.86E-25	1.48E-24	3.98E+35	1.07E+25	1.59E+01
I-129	3.70E+10	2.53E-16	2.01E-15	2.93E+26	7.92E+15	1.59E+01
I-131	3.70E+10	7.44E-05	5.93E-04	9.94E+14	2.69E+04	1.59E+01
In-111	3.70E+10	5.75E-18	4.59E-17	1.29E+28	3.48E+17	1.59E+01
Ir-192	3.70E+10	1.03E-04	8.20E-04	7.19E+14	1.94E+04	1.59E+01
Ir-194	3.70E+10	5.05E-03	4.03E-02	1.47E+13	3.96E+02	1.59E+01
Kr-79	3.70E+10	3.22E-03	2.57E-02	2.30E+13	6.21E+02	1.59E+01
Lu-177	3.70E+10	5.37E-14	4.28E-13	1.38E+24	3.72E+13	1.59E+01
Mo-99	3.70E+10	3.87E-03	3.09E-02	1.91E+13	5.17E+02	1.59E+01
Na-24	3.70E+10	5.80E+00	4.63E+01	1.28E+10	3.45E-01	1.59E+01
Np-237	3.70E+10	4.67E-02	3.72E-01	1.58E+12	4.28E+01	1.59E+01
P-32	3.70E+10	2.97E-02	2.37E-01	2.49E+12	6.73E+01	1.59E+01
P-33	3.70E+10	2.05E-27	1.63E-26	3.61E+37	9.76E+26	1.59E+01
Pb-203	3.70E+10	3.02E-06	2.41E-05	2.45E+16	6.63E+05	1.59E+01
Pb-210	3.70E+10	2.23E-02	1.78E-01	3.31E+12	8.96E+01	1.59E+01
Pd-109	3.70E+10	7.70E-04	6.14E-03	9.61E+13	2.60E+03	1.59E+01
Pu-238	3.70E+10	1.40E-09	1.11E-08	5.30E+19	1.43E+09	1.59E+01
Pu-239	3.70E+10	1.23E-14	9.77E-14	6.04E+24	1.63E+14	1.59E+01
Pu-240	3.70E+10	1.32E-14	1.05E-13	5.62E+24	1.52E+14	1.59E+01
Pu-241	3.70E+10	3.89E-10	3.10E-09	1.90E+20	5.14E+09	1.59E+01
Ra-223	3.70E+10	1.79E-02	1.43E-01	4.14E+12	1.12E+02	1.59E+01
Ra-224	3.70E+10	1.69E+00	1.35E+01	4.37E+10	1.18E+00	1.59E+01
Ra-226	3.70E+10	1.54E+00	1.23E+01	4.80E+10	1.30E+00	1.59E+01

Nuclide	Original Activity, Bq	Effective Dose Equivalent Rate, mSv/h	Dose Rate with errors corrected, mSv/hr	Activity limit in PCS 038 (Bq)	Activity limit in PCS 038 (Ci)	Dose on Surface with activity carried (mSv/hr)
Re-186	3.70E+10	1.39E-03	1.11E-02	5.31E+13	1.43E+03	1.59E+01
Re-188	3.70E+10	1.02E-02	8.14E-02	7.25E+12	1.96E+02	1.59E+01
Rh-105	3.70E+10	6.34E-19	5.06E-18	1.17E+29	3.15E+18	1.59E+01
Se-75	3.70E+10	9.40E-09	7.50E-08	7.87E+18	2.13E+08	1.59E+01
Sm-153	3.70E+10	3.88E-05	3.09E-04	1.91E+15	5.16E+04	1.59E+01
Sr-89	3.70E+10	1.43E-02	1.14E-01	5.17E+12	1.40E+02	1.59E+01
Sr-90	3.70E+10	8.92E-02	7.11E-01	8.30E+11	2.24E+01	1.59E+01
Tb-161	3.70E+10	1.00E-02	7.99E-02	7.39E+12	2.00E+02	1.59E+01
Th-227	3.70E+10	1.77E-02	1.41E-01	4.17E+12	1.13E+02	1.59E+01
Th-228	3.70E+10	2.21E+00	1.76E+01	3.35E+10	9.07E-01	1.59E+01
Tl-201	3.70E+10	5.25E-12	4.19E-11	1.41E+22	3.81E+11	1.59E+01
U-235	3.70E+10	3.11E-07	2.48E-06	2.38E+17	6.44E+06	1.59E+01
W-187	3.70E+10	8.65E-03	6.89E-02	8.56E+12	2.31E+02	1.59E+01
W-188	3.70E+10	4.33E-02	3.46E-01	1.71E+12	4.61E+01	1.59E+01
Xe-133	3.70E+10	3.71E-23	2.96E-22	1.99E+33	5.39E+22	1.59E+01
Y-90	3.70E+10	8.92E-02	7.11E-01	8.30E+11	2.24E+01	1.59E+01
Yb-169	3.70E+10	4.46E-09	3.55E-08	1.66E+19	4.49E+08	1.59E+01
Yb-175	3.70E+10	1.22E-12	9.69E-12	6.09E+22	1.64E+12	1.59E+01

Table 8 - Updated Contents Activities for 3985 Insert

Nuclide	Original Activity, Bq	Effective Dose Equivalent Rate, mSv/h	Dose Rate with errors corrected, mSv/hr	Activity limit in PCS 038 (Bq)	Activity limit in PCS 038 (Ci)	Dose on Surface with activity carried (mSv/hr)
Ac-225	3.70E+10	6.76E-02	5.39E-01	5.47E+11	1.48E+01	7.97E+00
Ac-227	3.70E+10	2.11E-02	1.68E-01	1.76E+12	4.75E+01	7.97E+00
Ac-228	3.70E+10	3.98E-01	3.17E+00	9.30E+10	2.51E+00	7.97E+00
Am-241	3.70E+10	4.67E-02	3.72E-01	7.92E+11	2.14E+01	7.97E+00
As-77	3.70E+10	6.47E-09	5.16E-08	5.72E+18	1.55E+08	7.97E+00
Au-198	3.70E+10	3.04E-04	2.43E-03	1.22E+14	3.29E+03	7.97E+00
Ba-131	3.70E+10	1.21E-03	9.64E-03	3.06E+13	8.27E+02	7.97E+00
C-14	3.70E+10	1.21E-17	9.62E-17	3.07E+27	8.29E+16	7.97E+00
Co-60	3.70E+10	7.90E-01	6.30E+00	4.69E+10	1.27E+00	7.97E+00
Cs-131	3.70E+10	9.96E-26	7.94E-25	3.71E+35	1.00E+25	7.97E+00
Cs-134	3.70E+10	2.81E-02	2.24E-01	1.32E+12	3.56E+01	7.97E+00
Cs-137	1.11E+14	7.02E-01	5.60E+00	1.58E+14	4.27E+03	7.97E+00
Cu-67	3.70E+10	2.61E-14	2.08E-13	1.42E+24	3.83E+13	7.97E+00

Nuclide	Original Activity, Bq	Effective Dose Equivalent Rate, mSv/h	Dose Rate with errors corrected, mSv/hr	Activity limit in PCS 038 (Bq)	Activity limit in PCS 038 (Ci)	Dose on Surface with activity carried (mSv/hr)
Hg-203	3.70E+10	1.39E-24	1.11E-23	2.66E+34	7.19E+23	7.97E+00
Ho-166	3.70E+10	8.05E-02	6.41E-01	4.60E+11	1.24E+01	7.97E+00
I-125	3.70E+10	1.86E-25	1.48E-24	1.99E+35	5.37E+24	7.97E+00
I-129	3.70E+10	2.53E-16	2.01E-15	1.46E+26	3.96E+15	7.97E+00
I-131	3.70E+10	7.44E-05	5.93E-04	4.97E+14	1.34E+04	7.97E+00
In-111	3.70E+10	5.75E-18	4.59E-17	6.43E+27	1.74E+17	7.97E+00
Ir-192	3.70E+10	1.03E-04	8.20E-04	3.60E+14	9.72E+03	7.97E+00
Ir-194	3.70E+10	5.05E-03	4.03E-02	7.33E+12	1.98E+02	7.97E+00
Kr-79	3.70E+10	3.22E-03	2.57E-02	1.15E+13	3.10E+02	7.97E+00
Lu-177	3.70E+10	5.37E-14	4.28E-13	6.89E+23	1.86E+13	7.97E+00
Mo-99	3.70E+10	3.87E-03	3.09E-02	9.56E+12	2.58E+02	7.97E+00
Na-24	3.70E+10	5.80E+00	4.63E+01	6.38E+09	1.72E-01	7.97E+00
Np-237	3.70E+10	4.67E-02	3.72E-01	7.92E+11	2.14E+01	7.97E+00
P-32	3.70E+10	2.97E-02	2.37E-01	1.24E+12	3.36E+01	7.97E+00
P-33	3.70E+10	2.05E-27	1.63E-26	1.81E+37	4.88E+26	7.97E+00
Pb-203	3.70E+10	3.02E-06	2.41E-05	1.23E+16	3.31E+05	7.97E+00
Pb-210	3.70E+10	2.23E-02	1.78E-01	1.66E+12	4.48E+01	7.97E+00
Pd-109	3.70E+10	7.70E-04	6.14E-03	4.81E+13	1.30E+03	7.97E+00
Pu-238	3.70E+10	1.40E-09	1.11E-08	2.65E+19	7.17E+08	7.97E+00
Pu-239	3.70E+10	1.23E-14	9.77E-14	3.02E+24	8.16E+13	7.97E+00
Pu-240	3.70E+10	1.32E-14	1.05E-13	2.81E+24	7.60E+13	7.97E+00
Pu-241	3.70E+10	3.89E-10	3.10E-09	9.51E+19	2.57E+09	7.97E+00
Ra-223	3.70E+10	1.79E-02	1.43E-01	2.07E+12	5.59E+01	7.97E+00
Ra-224	3.70E+10	1.69E+00	1.35E+01	2.18E+10	5.90E-01	7.97E+00
Ra-226	3.70E+10	1.54E+00	1.23E+01	2.40E+10	6.48E-01	7.97E+00
Re-186	3.70E+10	1.39E-03	1.11E-02	2.65E+13	7.17E+02	7.97E+00
Re-188	3.70E+10	1.02E-02	8.14E-02	3.62E+12	9.79E+01	7.97E+00
Rh-105	3.70E+10	6.34E-19	5.06E-18	5.83E+28	1.58E+18	7.97E+00
Se-75	3.70E+10	9.40E-09	7.50E-08	3.93E+18	1.06E+08	7.97E+00
Sm-153	3.70E+10	3.88E-05	3.09E-04	9.55E+14	2.58E+04	7.97E+00
Sr-89	3.70E+10	1.43E-02	1.14E-01	2.58E+12	6.99E+01	7.97E+00
Sr-90	3.70E+10	8.92E-02	7.11E-01	4.15E+11	1.12E+01	7.97E+00
Tb-161	3.70E+10	1.00E-02	7.99E-02	3.69E+12	9.98E+01	7.97E+00
Th-227	3.70E+10	1.77E-02	1.41E-01	2.09E+12	5.64E+01	7.97E+00
Th-228	3.70E+10	2.21E+00	1.76E+01	1.68E+10	4.53E-01	7.97E+00
Tl-201	3.70E+10	5.25E-12	4.19E-11	7.05E+21	1.90E+11	7.97E+00
U-235	3.70E+10	3.11E-07	2.48E-06	1.19E+17	3.22E+06	7.97E+00
W-187	3.70E+10	8.65E-03	6.89E-02	4.28E+12	1.16E+02	7.97E+00
W-188	3.70E+10	4.33E-02	3.46E-01	8.54E+11	2.31E+01	7.97E+00

Nuclide	Original Activity, Bq	Effective Dose Equivalent Rate, mSv/h	Dose Rate with errors corrected, mSv/hr	Activity limit in PCS 038 (Bq)	Activity limit in PCS 038 (Ci)	Dose on Surface with activity carried (mSv/hr)
Xe-133	3.70E+10	3.71E-23	2.96E-22	9.97E+32	2.70E+22	7.97E+00
Y-90	3.70E+10	8.92E-02	7.11E-01	4.15E+11	1.12E+01	7.97E+00
Yb-169	3.70E+10	4.46E-09	3.55E-08	8.31E+18	2.24E+08	7.97E+00
Yb-175	3.70E+10	1.22E-12	9.69E-12	3.04E+22	8.22E+11	7.97E+00

7 References

1. Monte Carlo Modelling of Safkeg HS Container, AMEC/SF6652/001, Issue 1
2. Monte Carlo Modelling of Safkeg HS Container, AMEC/SF6652/001, Issue 2
3. Monte Carlo Modelling of Alternative Point Sources in the SAFKEG HS Container, AMEC/SF8665/TN_001, Issue 1

Appendix A ANSI/ANS-6.1.1 Results

Table 9- Th-228 ANS Results

Energy MeV	Activity (Photons/sec)	Fluence Rate	(mrem/hr)/ (photon/cm^2-s)	Dose Rate (mrem/hr)	Dose Rate (mSv/hr)
0.015	1.23E+10	6.99E-22	1.95E-03	9.10E-23	9.10E-25
0.04	3.68E+08	5.72E-23	3.61E-04	5.17E-25	5.17E-27
0.08	1.48E+10	5.24E-21	2.61E-04	1.71E-23	1.71E-25
0.1	2.51E+08	1.22E-22	2.83E-04	3.44E-25	3.44E-27
0.15	8.61E+07	3.12E-11	3.79E-04	7.88E-14	7.88E-16
0.2	1.77E+10	2.51E-20	5.01E-04	6.30E-23	6.30E-25
0.3	2.37E+09	2.98E-13	7.59E-04	7.53E-16	7.53E-18
0.4	3.40E+07	3.77E-07	9.85E-04	9.28E-10	9.28E-12
0.5	2.95E+09	7.51E-02	1.15E-03	1.73E-04	1.73E-06
0.6	1.09E+10	1.60E+01	1.36E-03	3.63E-02	3.63E-04
0.8	7.09E+09	6.55E+02	1.68E-03	1.38E+00	1.38E-02
1	5.55E+08	4.22E+02	1.98E-03	8.34E-01	8.34E-03
1.5	1.23E+09	9.93E+03	2.64E-03	1.74E+01	1.74E-01
2	7.13E+07	1.45E+03	3.21E-03	2.32E+00	2.32E-02
3	1.29E+10	5.75E+05	4.19E-03	8.04E+02	8.04E+00
				8.26E+02	8.26E+00

Table 10 - Ir-192 ANS results

Energy MeV	Activity (Photons/sec)	Fluence Rate	(mrem/hr)/ (photon/cm^2-s)	Dose Rate (mrem/hr)	Dose Rate (mSv/hr)
0.015	2.06E+09	1.17E-22	1.95E-03	1.52E-23	1.52E-25
0.06	3.79E+09	9.41E-22	2.65E-04	4.15E-24	4.15E-26
0.08	1.04E+09	3.68E-22	2.61E-04	1.20E-24	1.20E-26
0.15	6.68E+07	2.42E-11	3.79E-04	6.11E-14	6.11E-16
0.2	1.39E+09	1.98E-21	5.01E-04	4.96E-24	4.96E-26
0.3	5.25E+10	6.60E-12	7.59E-04	1.67E-14	1.67E-16
0.4	5.44E+08	6.03E-06	9.85E-04	1.48E-08	1.48E-10
0.5	1.91E+10	4.86E-01	1.15E-03	1.12E-03	1.12E-05
0.6	6.70E+09	9.87E+00	1.36E-03	2.23E-02	2.23E-04
0.8	1.48E+08	1.37E+01	1.68E-03	2.87E-02	2.87E-04
				5.22E-02	5.22E-04

Table 11 - Tl-201 ANS Results

Energy MeV	Activity (Photons/sec)	Fluence Rate	(mrem/hr)/(photon/cm2-s)	Dose Rate (mrem/hr)	Dose Rate (mSv/hr)
0.0016	8.36E+00	4.97E-32	9.70E-02	3.01E-30	3.01E-32

Energy MeV	Activity (Photons/sec)	Fluence Rate	(mrem/hr)/(photon/cm2-s)	Dose Rate (mrem/hr)	Dose Rate (mSv/hr)
0.01	1.64E+10	6.22E-22	3.96E-03	2.46E-22	2.46E-24
0.0306	8.14E+07	9.50E-24	5.59E-04	1.73E-25	1.73E-27
0.0322	8.14E+07	1.00E-23	5.06E-04	1.58E-25	1.58E-27
0.0689	1.01E+10	2.99E-21	2.58E-04	1.12E-23	1.12E-25
0.0708	1.72E+10	5.25E-21	2.58E-04	1.91E-23	1.91E-25
0.0803	7.57E+09	2.70E-21	2.61E-04	8.77E-24	8.77E-26
0.1353	9.81E+08	3.51E-07	3.47E-04	8.99E-10	8.99E-12
0.1659	5.92E+07	4.89E-15	4.16E-04	1.23E-17	1.23E-19
0.1674	3.70E+09	1.29E-13	4.20E-04	3.23E-16	3.23E-18
				8.99E-10	8.99E-12

Table 12 - Cs-137 ANS Results

Energy MeV	Activity (Photons/sec)	Fluence Rate	(mrem/hr)/(photon/cm2-s)	Dose Rate (mrem/hr)	Dose Rate (mSv/hr)
0.0045	3.63E+08	6.15E-24	1.60E-02	2.18E-23	2.18E-25
0.0318	7.25E+08	8.82E-23	5.18E-04	1.44E-24	1.44E-26
0.0322	1.34E+09	1.65E-22	5.06E-04	2.59E-24	2.59E-26
0.0364	4.87E+08	6.84E-23	4.12E-04	7.73E-25	7.73E-27
0.6616	3.15E+10	2.41E+02	1.46E-03	5.32E-01	5.32E-03
				5.32E-01	5.32E-03

Table 13 - Pb-210 ANS Results

Energy MeV	Activity (Photons/sec)	Fluence Rate	(mrem/hr)/(photon/cm2-s)	Dose Rate (mrem/hr)	Dose Rate (mSv/hr)
0.0108	8.40E+09	3.43E-22	3.46E-03	1.10E-22	1.10E-24
0.0465	1.40E+09	2.56E-22	2.71E-04	1.49E-24	1.49E-26
0.8031	3.65E+05	3.52E-02	1.69E-03	7.39E-05	7.39E-07
				7.39E-05	7.39E-07