Uncertainties Associated with the Proposed Shielding Calculation Method for the SAFKEG-LS 3979A Package

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1 Introduction

This report has been produced in response to the Nuclear Regulatory Commission, Request for Additional information question 5.1. The method of converting the photon flux to a dose rate used for the shielding calculations in the initial LS application was the ICRP 51 Dose Conversion Factors (DCF) however the NRC requires the use of the ANSI/ANS-6.1.1-1977 DCF.

This report will discuss the maximum change required to the current shielding calculations in order to take the ANS DCF into account.

2 Selection of the Nuclides

The package contains a large number of nuclides so in order to ascertain the effect of these dose rate conversion factors 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 across the entire range of energies a further 2 nuclides were selected, these were not limited by shielding but provided 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 2009/22 issue B 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/cm²-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. A 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, 2 and 3. This also compares the dose rate calculated using ICRP 51 against ANSI/ANS-6.1.1.

Table 1 - ANS vs ICRP Dose Rates for Insert 3983

Insert	3983		
Nuclide	ICRP dose Rate result	ANS dose rate result	Percentage difference
Cs-137	1.04E+00	1.30E+00	24.69%
Ir-192	1.72E-01	2.16E-01	25.79%
Pb-210	3.97E-05	4.84E-05	21.93%
Tl-201	7.13E-20	9.78E-20	37.08%
Th-228	3.98E+01	4.56E+01	14.49%

Table 2 - ANS vs ICRP Dose Rates for Insert 3984

Insert	3984		
Nuclide	ICRP dose Rate result	ANS dose rate result	Percentage difference
Cs-137	5.22E-01	6.51E-01	24.64%
Ir-192	7.71E-02	9.69E-02	25.67%
Pb-210	2.24E-05	2.73E-05	21.95%
TI-201	6.68E-20	9.16E-20	37.08%
Th-228	2.92E+01	3.34E+01	14.43%

Table 3 - ANS vs ICRP Dose Rates for Insert 3987

Insert	3987		
Nuclide	ICRP dose Rate result	ANS dose rate result	Percentage difference
Cs-137	1.26E+01	1.58E+01	24.66%
Ir-192	3.52E+00	4.43E+00	26.02%
Pb-210	3.10E-04	3.77E-04	21.97%
TI-201	6.39E-15	8.61E-15	34.66%
Th-228	1.24E+02	1.43E+02	15.00%

As shown in table 1 and 2 the maximum difference between the figure provided in CTR 2009/22 and those calculated using ANSI/ANS is 37%. As shown in Table 3 the steel insert has maximum difference between the figure provided in CTR 2009/22 and those calculated using ANSI/ANS as 35%.

4 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 inserts:

Insert	ANS Correction
3983	37%
3984	37%
3987	35%

With these corrections taking into account the dose rates were recalculated and are given in Table 4, 5 and 6.

Table 4 - Dose Rates for LS Package with 3983 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)
Insert:	3983					
Ac-225	3.70E+10	8.86E-01	1.21E+00	8.35E+10	2.26E+00	2.74E+00
Ac-227	3.70E+10	1.58E-01	2.16E-01	4.70E+11	1.27E+01	2.74E+00
Ac-228	3.70E+10	1.07E+01	1.47E+01	6.90E+09	1.86E-01	2.74E+00
Am-241	3.70E+10	3.94E-09	5.40E-09	1.88E+19	5.08E+08	2.74E+00
As-77	3.70E+10	9.44E-04	1.29E-03	7.84E+13	2.12E+03	2.74E+00
Au-198	3.70E+10	5.62E-02	7.70E-02	1.32E+12	3.56E+01	2.74E+00
Ba-131	3.70E+10	2.89E-01	3.95E-01	2.56E+11	6.93E+00	2.74E+00
C-14	3.7E+13	1.74E-23	2.38E-23	4.26E+36	1.15E+26	2.74E+00
Co-60	3.70E+10	4.85E+01	6.65E+01	1.53E+09	4.12E-02	2.74E+00
Cs-131	3.70E+10	1.63E-25	2.23E-25	4.54E+35	1.23E+25	2.74E+00
Cs-134	3.70E+10	5.73E+00	7.85E+00	1.29E+10	3.49E-01	2.74E+00
Cs-137	3.70E+10	1.04E+00	1.43E+00	7.09E+10	1.92E+00	2.74E+00
Cu-67	3.70E+10	6.12E-06	8.38E-06	1.21E+16	3.27E+05	2.74E+00
Hg-203	3.70E+10	8.96E-08	1.23E-07	8.26E+17	2.23E+07	2.74E+00
Ho-166	3.70E+10	4.45E-01	6.10E-01	1.66E+11	4.49E+00	2.74E+00
I-125	3.70E+10	3.03E-25	4.15E-25	2.44E+35	6.60E+24	2.74E+00
I-129	3.70E+10	1.73E-25	2.37E-25	4.28E+35	1.16E+25	2.74E+00
I-131	3.70E+10	1.10E-01	1.51E-01	6.71E+11	1.81E+01	2.74E+00
In-111	3.70E+10	1.54E-10	2.11E-10	4.81E+20	1.30E+10	2.74E+00
Ir-192	3.7E+13	1.72E+02	2.36E+02	4.30E+11	1.16E+01	2.74E+00
Ir-194	3.70E+10	4.46E-01	6.11E-01	1.66E+11	4.48E+00	2.74E+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)
Insert:	3983					
Kr-79	3.70E+10	3.70E-01	5.07E-01	2.00E+11	5.41E+00	2.74E+00
Lu-177	3.70E+10	4.27E-08	5.84E-08	1.73E+18	4.69E+07	2.74E+00
Mo-99	3.70E+10	4.85E-01	6.65E-01	1.52E+11	4.12E+00	2.74E+00
Na-24	3.70E+10	1.31E+02	1.79E+02	5.66E+08	1.53E-02	2.74E+00
Np-237	3.70E+10	1.14E-08	1.56E-08	6.49E+18	1.75E+08	2.74E+00
P-32	3.7E+13	5.50E+03	7.53E+03	1.35E+10	3.64E-01	2.74E+00
P-33	3.7E+13	8.07E-09	1.10E-08	9.18E+21	2.48E+11	2.74E+00
Pb-203	3.70E+10	1.01E-02	1.38E-02	7.34E+12	1.98E+02	2.74E+00
Pb-210	3.70E+10	3.97E-05	5.43E-05	1.87E+15	5.04E+04	2.74E+00
Pd-109	3.70E+10	1.62E-04	2.22E-04	4.58E+14	1.24E+04	2.74E+00
Pu-238	3.70E+10	4.41E-08	6.05E-08	1.68E+18	4.53E+07	2.74E+00
Pu-239	3.70E+10	1.59E-11	2.18E-11	4.64E+21	1.25E+11	2.74E+00
Pu-240	3.70E+10	3.07E-13	4.21E-13	2.41E+23	6.51E+12	2.74E+00
Pu-241	3.70E+10	1.01E-10	1.38E-10	7.33E+20	1.98E+10	2.74E+00
Ra-223	3.70E+10	1.56E-01	2.14E-01	4.74E+11	1.28E+01	2.74E+00
Ra-224	3.70E+10	3.03E+01	4.15E+01	2.44E+09	6.60E-02	2.74E+00
Ra-226	3.70E+10	2.92E+01	4.00E+01	2.54E+09	6.85E-02	2.74E+00
Re-186	3.70E+10	1.03E-03	1.41E-03	7.21E+13	1.95E+03	2.74E+00
Re-188	3.70E+10	2.09E-01	2.86E-01	3.55E+11	9.59E+00	2.74E+00
Rh-105	3.70E+10	3.17E-06	4.35E-06	2.33E+16	6.30E+05	2.74E+00
Se-75	3.70E+10	4.36E-04	5.97E-04	1.70E+14	4.59E+03	2.74E+00
Sm-153	3.70E+10	2.68E-05	3.68E-05	2.76E+15	7.45E+04	2.74E+00
Sr-89	3.70E+10	1.12E-03	1.53E-03	6.64E+13	1.79E+03	2.74E+00
Sr-90	3.7E+13	1.07E+01	1.47E+01	6.89E+12	1.86E+02	2.74E+00
Tb-161	3.70E+10	2.47E-04	3.39E-04	2.99E+14	8.08E+03	2.74E+00
Th-227	3.70E+10	7.36E-02	1.01E-01	1.01E+12	2.72E+01	2.74E+00
Th-228	3.70E+10	3.98E+01	5.45E+01	1.86E+09	5.02E-02	2.74E+00
Tl-201	3.70E+10	7.13E-20	9.77E-20	1.04E+30	2.80E+19	2.74E+00
U-235	3.70E+10	2.36E-04	3.23E-04	3.14E+14	8.47E+03	2.74E+00
W-187	3.70E+10	7.30E-01	1.00E+00	1.01E+11	2.74E+00	2.74E+00
W-188	3.70E+10	1.99E-01	2.72E-01	3.72E+11	1.01E+01	2.74E+00
Xe-133	3.70E+10	2.58E-25	3.53E-25	2.87E+35	7.76E+24	2.74E+00
Y-90	3.7E+13	1.16E+04	1.58E+04	6.41E+09	1.73E-01	2.74E+00
Yb-169	3.70E+10	7.78E-07	1.07E-06	9.51E+16	2.57E+06	2.74E+00
Yb-175	3.70E+10	2.03E-04	2.78E-04	3.65E+14	9.87E+03	2.74E+00

Table 5 - Dose Rates for LS Package with 3984 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	6.08E-01	8.33E-01	1.22E+11	3.29E+00	2.74E+00
Ac-227	3.70E+10	8.83E-02	1.21E-01	8.38E+11	2.27E+01	2.74E+00
Ac-228	3.70E+10	6.92E+00	9.48E+00	1.07E+10	2.89E-01	2.74E+00
Am-241	3.70E+10	1.05E-09	1.43E-09	7.07E+19	1.91E+09	2.74E+00
As-77	3.70E+10	3.79E-04	5.19E-04	1.95E+14	5.28E+03	2.74E+00
Au-198	3.70E+10	3.18E-02	4.36E-02	2.33E+12	6.29E+01	2.74E+00
Ba-131	3.70E+10	1.64E-01	2.24E-01	4.52E+11	1.22E+01	2.74E+00
C-14	3.7E+13	1.63E-23	2.23E-23	4.55E+36	1.23E+26	2.74E+00
Co-60	3.70E+10	3.24E+01	4.44E+01	2.28E+09	6.17E-02	2.74E+00
Cs-131	3.70E+10	1.53E-25	2.09E-25	4.85E+35	1.31E+25	2.74E+00
Cs-134	3.70E+10	3.30E+00	4.52E+00	2.24E+10	6.06E-01	2.74E+00
Cs-137	3.70E+10	5.22E-01	7.16E-01	1.42E+11	3.83E+00	2.74E+00
Cu-67	3.70E+10	1.63E-06	2.24E-06	4.53E+16	1.23E+06	2.74E+00
Hg-203	3.70E+10	6.95E-09	9.52E-09	1.06E+19	2.88E+08	2.74E+00
Ho-166	3.70E+10	3.06E-01	4.19E-01	2.42E+11	6.53E+00	2.74E+00
I-125	3.70E+10	2.84E-25	3.89E-25	2.61E+35	7.04E+24	2.74E+00
I-129	3.70E+10	1.62E-25	2.22E-25	4.57E+35	1.24E+25	2.74E+00
I-131	3.70E+10	5.52E-02	7.57E-02	1.34E+12	3.62E+01	2.74E+00
In-111	3.70E+10	5.38E-12	7.37E-12	1.38E+22	3.72E+11	2.74E+00
Ir-192	3.7E+13	7.71E+01	1.06E+02	9.60E+11	2.59E+01	2.74E+00
Ir-194	3.70E+10	2.87E-01	3.93E-01	2.58E+11	6.96E+00	2.74E+00
Kr-79	3.70E+10	2.22E-01	3.04E-01	3.34E+11	9.03E+00	2.74E+00
Lu-177	3.70E+10	6.11E-09	8.38E-09	1.21E+19	3.27E+08	2.74E+00
Mo-99	3.70E+10	2.64E-01	3.62E-01	2.80E+11	7.58E+00	2.74E+00
Na-24	3.70E+10	9.48E+01	1.30E+02	7.80E+08	2.11E-02	2.74E+00
Np-237	3.70E+10	1.07E-08	1.46E-08	6.93E+18	1.87E+08	2.74E+00
P-32	3.7E+13	3.90E+03	5.35E+03	1.90E+10	5.12E-01	2.74E+00
P-33	3.7E+13	3.13E-10	4.28E-10	2.37E+23	6.40E+12	2.74E+00
Pb-203	3.70E+10	5.11E-03	7.00E-03	1.45E+13	3.91E+02	2.74E+00
Pb-210	3.70E+10	2.24E-05	3.06E-05	3.31E+15	8.94E+04	2.74E+00
Pd-109	3.70E+10	6.32E-05	8.65E-05	1.17E+15	3.17E+04	2.74E+00
Pu-238	3.70E+10	3.09E-08	4.23E-08	2.40E+18	6.48E+07	2.74E+00
Pu-239	3.70E+10	1.14E-11	1.57E-11	6.47E+21	1.75E+11	2.74E+00
Pu-240	3.70E+10	2.19E-13	3.01E-13	3.37E+23	9.12E+12	2.74E+00
Pu-241	3.70E+10	2.67E-11	3.66E-11	2.77E+21	7.49E+10	2.74E+00
Ra-223	3.70E+10	8.75E-02	1.20E-01	8.46E+11	2.29E+01	2.74E+00
Ra-224	3.70E+10	2.22E+01	3.05E+01	3.33E+09	8.99E-02	2.74E+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)
Ra-226	3.70E+10	2.04E+01	2.80E+01	3.62E+09	9.79E-02	2.74E+00
Re-186	3.70E+10	5.35E-04	7.33E-04	1.38E+14	3.74E+03	2.74E+00
Re-188	3.70E+10	1.29E-01	1.77E-01	5.74E+11	1.55E+01	2.74E+00
Rh-105	3.70E+10	4.38E-07	6.00E-07	1.69E+17	4.57E+06	2.74E+00
Se-75	3.70E+10	1.16E-04	1.59E-04	6.39E+14	1.73E+04	2.74E+00
Sm-153	3.70E+10	7.93E-06	1.09E-05	9.33E+15	2.52E+05	2.74E+00
Sr-89	3.70E+10	6.66E-04	9.12E-04	1.11E+14	3.00E+03	2.74E+00
Sr-90	3.7E+13	4.58E+00	6.27E+00	1.62E+13	4.37E+02	2.74E+00
Tb-161	3.70E+10	1.13E-04	1.54E-04	6.57E+14	1.77E+04	2.74E+00
Th-227	3.70E+10	4.13E-02	5.65E-02	1.79E+12	4.85E+01	2.74E+00
Th-228	3.70E+10	2.92E+01	4.00E+01	2.53E+09	6.84E-02	2.74E+00
Tl-201	3.70E+10	6.68E-20	9.15E-20	1.11E+30	2.99E+19	2.74E+00
U-235	3.70E+10	1.32E-04	1.81E-04	5.60E+14	1.51E+04	2.74E+00
W-187	3.70E+10	3.77E-01	5.16E-01	1.96E+11	5.31E+00	2.74E+00
W-188	3.70E+10	1.23E-01	1.69E-01	6.02E+11	1.63E+01	2.74E+00
Xe-133	3.70E+10	2.32E-25	3.17E-25	3.20E+35	8.64E+24	2.74E+00
Y-90	3.7E+13	8.45E+03	1.16E+04	8.76E+09	2.37E-01	2.74E+00
Yb-169	3.70E+10	1.15E-07	1.57E-07	6.46E+17	1.75E+07	2.74E+00
Yb-175	3.70E+10	5.26E-05	7.20E-05	1.41E+15	3.80E+04	2.74E+00

Table 6 - Dose Rates for LS Package with 3986 Insert

Nuclide	Original Activity, Bq	Effective Dose Equivalent Rate, mSv/h	Dose Rate with errors corrected, mSv/hr	Activity limit (Bq)	Activity limit (Ci)	Dose on Surface with activity carried
Ac-225	3.70E+10	3.56E+00	4.81E+00	2.08E+10	5.61E-01	2.70E+00
Ac-227	3.70E+10	1.37E+00	1.85E+00	5.40E+10	1.46E+00	2.70E+00
Ac-228	3.70E+10	5.25E+01	7.09E+01	1.41E+09	3.81E-02	2.70E+00
Am-241	3.70E+10	6.26E-07	8.45E-07	1.18E+17	3.20E+06	2.70E+00
As-77	3.70E+10	2.59E-02	3.50E-02	2.85E+12	7.71E+01	2.70E+00
Au-198	3.70E+10	9.72E-01	1.31E+00	7.61E+10	2.06E+00	2.70E+00
Ba-131	3.70E+10	3.20E+00	4.33E+00	2.31E+10	6.24E-01	2.70E+00
Bi-210	3.70E+10	2.70E+00	3.65E+00	2.74E+10	7.41E-01	2.70E+00
C-14	3.7E+13	5.03E-16	6.79E-16	1.47E+29	3.98E+18	2.70E+00
Co-60	3.70E+10	2.01E+02	2.71E+02	3.68E+08	9.95E-03	2.70E+00
Cs-131	3.70E+10	2.06E-25	2.79E-25	3.59E+35	9.69E+24	2.70E+00
Cs-134	3.70E+10	4.58E+01	6.18E+01	1.62E+09	4.37E-02	2.70E+00

Nuclide	Original Activity, Bq	Effective Dose Equivalent Rate, mSv/h	Dose Rate with errors corrected, mSv/hr	Activity limit (Bq)	Activity limit (Ci)	Dose on Surface with activity carried
Cs-137	3.70E+10	1.26E+01	1.71E+01	5.85E+09	1.58E-01	2.70E+00
Cu-67	3.70E+10	9.65E-04	1.30E-03	7.67E+13	2.07E+03	2.70E+00
Hg-203	3.70E+10	1.23E-03	1.66E-03	6.03E+13	1.63E+03	2.70E+00
Ho-166	3.70E+10	1.66E+00	2.24E+00	4.46E+10	1.21E+00	2.70E+00
I-125	3.70E+10	3.84E-25	5.19E-25	1.93E+35	5.20E+24	2.70E+00
I-129	3.70E+10	2.19E-25	2.96E-25	3.38E+35	9.13E+24	2.70E+00
I-131	3.70E+10	1.47E+00	1.99E+00	5.03E+10	1.36E+00	2.70E+00
In-111	3.70E+10	4.35E-05	5.87E-05	1.70E+15	4.60E+04	2.70E+00
Ir-192	3.7E+13	3.52E+03	4.75E+03	2.10E+10	5.68E-01	2.70E+00
Ir-194	3.70E+10	2.21E+00	2.98E+00	3.35E+10	9.05E-01	2.70E+00
Kr-79	3.70E+10	2.98E+00	4.02E+00	2.49E+10	6.72E-01	2.70E+00
Lu-177	3.70E+10	5.75E-05	7.76E-05	1.29E+15	3.48E+04	2.70E+00
Mo-99	3.70E+10	4.34E+00	5.86E+00	1.70E+10	4.60E-01	2.70E+00
Na-24	3.70E+10	4.13E+02	5.58E+02	1.79E+08	4.84E-03	2.70E+00
Np-237	3.70E+10	1.48E-08	1.99E-08	5.02E+18	1.36E+08	2.70E+00
P-32	3.7E+13	3.36E+03	4.54E+03	2.20E+10	5.95E-01	2.70E+00
P-33	3.7E+13	5.39E-04	7.28E-04	1.37E+17	3.71E+06	2.70E+00
Pb-203	3.70E+10	1.30E-01	1.75E-01	5.70E+11	1.54E+01	2.70E+00
Pb-210	3.70E+10	3.10E-04	4.18E-04	2.39E+14	6.46E+03	2.70E+00
Pd-109	3.70E+10	4.93E-03	6.65E-03	1.50E+13	4.06E+02	2.70E+00
Po-210	3.70E+10	3.76E-04	5.07E-04	1.97E+14	5.33E+03	2.70E+00
Pu-239	3.70E+10	8.96E-11	1.21E-10	8.26E+20	2.23E+10	2.70E+00
Pu-240	3.70E+10	1.08E-12	1.45E-12	6.88E+22	1.86E+12	2.70E+00
Pu-241	3.70E+10	1.71E-08	2.31E-08	4.32E+18	1.17E+08	2.70E+00
Ra-223	3.70E+10	1.36E+00	1.83E+00	5.46E+10	1.47E+00	2.70E+00
Ra-224	3.70E+10	9.45E+01	1.28E+02	7.83E+08	2.12E-02	2.70E+00
Ra-226	3.70E+10	1.09E+02	1.47E+02	6.81E+08	1.84E-02	2.70E+00
Re-186	3.70E+10	1.07E-02	1.44E-02	6.93E+12	1.87E+02	2.70E+00
Re-188	3.70E+10	1.23E+00	1.66E+00	6.02E+10	1.63E+00	2.70E+00
Rh-105	3.70E+10	4.99E-03	6.74E-03	1.48E+13	4.00E+02	2.70E+00
Se-75	3.70E+10	5.77E-02	7.79E-02	1.28E+12	3.47E+01	2.70E+00
Sm-153	3.70E+10	2.35E-03	3.17E-03	3.15E+13	8.52E+02	2.70E+00
Sr-89	3.70E+10	6.99E-03	9.44E-03	1.06E+13	2.86E+02	2.70E+00
Sr-90	3.7E+13	8.28E+01	1.12E+02	8.94E+11	2.42E+01	2.70E+00
Tb-161	3.70E+10	4.37E-03	5.90E-03	1.69E+13	4.58E+02	2.70E+00
Th-227	3.70E+10	6.41E-01	8.65E-01	1.16E+11	3.12E+00	2.70E+00
Th-228	3.70E+10	1.24E+02	1.68E+02	5.96E+08	1.61E-02	2.70E+00
Tl-201	3.70E+10	6.39E-15	8.63E-15	1.16E+25	3.13E+14	2.70E+00
U-235	3.70E+10	2.06E-03	2.78E-03	3.60E+13	9.72E+02	2.70E+00
W-187	3.70E+10	8.34E+00	1.13E+01	8.88E+09	2.40E-01	2.70E+00

Nuclide	Original Activity, Bq	Effective Dose Equivalent Rate, mSv/h	Dose Rate with errors corrected, mSv/hr	Activity limit (Bq)	Activity limit (Ci)	Dose on Surface with activity carried
W-188	3.70E+10	1.17E+00	1.58E+00	6.31E+10	1.71E+00	2.70E+00
Xe-133	3.70E+10	4.60E-15	6.20E-15	1.61E+25	4.35E+14	2.70E+00
Y-90	3.7E+13	1.23E+04	1.66E+04	6.02E+09	1.63E-01	2.70E+00
Yb-169	3.70E+10	1.46E-03	1.97E-03	5.06E+13	1.37E+03	2.70E+00
Yb-175	3.70E+10	2.89E-02	3.90E-02	2.56E+12	6.92E+01	2.70E+00

Appendix A ANSI/ANS-6.1.1 Sample Results

Table 7- Th-228 ANS Results 3983 Insert

Energy MeV	Activity (Photons/sec)	Fluence Rate	(mrem/hr)/ (photon/cm2-s)	Dose Rate (mrem/hr)	Dose Rate (mSv/hr)
0.015	1.22E+10	8.90E-22	1.95E-03	1.16E-22	1.16E-24
0.04	3.64E+08	7.45E-23	3.61E-04	6.73E-25	6.73E-27
0.08	1.46E+10	7.25E-21	2.61E-04	2.36E-23	2.36E-25
0.1	2.48E+08	4.88E-06	2.83E-04	1.38E-08	1.38E-10
0.15	8.66E+07	1.96E-21	3.79E-04	4.96E-24	4.96E-26
0.2	1.75E+10	4.70E-13	5.01E-04	1.18E-15	1.18E-17
0.3	2.34E+09	6.71E-03	7.59E-04	1.70E-05	1.70E-07
0.4	3.36E+07	1.82E-01	9.85E-04	4.47E-04	4.47E-06
0.5	2.92E+09	4.25E+02	1.15E-03	9.79E-01	9.79E-03
0.6	1.08E+10	9.44E+03	1.36E-03	2.14E+01	2.14E-01
0.8	7.01E+09	4.34E+04	1.68E-03	9.12E+01	9.12E-01
1	5.48E+08	1.00E+04	1.98E-03	1.98E+01	1.98E-01
1.5	1.22E+09	8.45E+04	2.64E-03	1.48E+02	1.48E+00
2	7.05E+07	9.16E+03	3.21E-03	1.47E+01	1.47E-01
3	1.28E+10	3.05E+06	4.19E-03	4.26E+03	4.26E+01
			Total	4.56E+03	4.56E+01

Table 8 - Ir-192 ANS results 3983 Insert

Energy MeV	Activity (Photons/sec)	Fluence Rate	(mrem/hr)/ (photon/cm2-s)	Dose Rate (mrem/hr)	Dose Rate (mSv/hr)
0.015	2.06E+09	1.50E-22	1.95E-03	1.95E-23	1.95E-25
0.06	3.79E+09	1.26E-21	2.65E-04	5.55E-24	5.55E-26
0.08	1.04E+09	5.16E-22	2.61E-04	1.68E-24	1.68E-26
0.15	6.68E+07	1.51E-21	3.79E-04	3.83E-24	3.83E-26
0.2	1.39E+09	3.74E-14	5.01E-04	9.38E-17	9.38E-19
0.3	5.25E+10	1.50E-01	7.59E-04	3.80E-04	3.80E-06
0.4	5.44E+08	2.94E+00	9.85E-04	7.23E-03	7.23E-05
0.5	1.91E+10	2.78E+03	1.15E-03	6.41E+00	6.41E-02
0.6	6.70E+09	5.88E+03	1.36E-03	1.33E+01	1.33E-01
0.8	1.48E+08	9.17E+02	1.68E-03	1.93E+00	1.93E-02
			Total	2.16E+01	2.16E-01

Table 9 - Tl-201 ANS Results 3983 Insert

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	6.36E-32	9.70E-02	3.86E-30	3.86E-32
0.01	1.64E+10	7.96E-22	3.96E-03	3.15E-22	3.15E-24
0.0306	8.14E+07	1.24E-22	5.59E-04	2.27E-24	2.27E-26
0.0322	8.14E+07	1.31E-23	5.06E-04	2.07E-25	2.07E-27
0.0689	1.01E+10	4.04E-21	2.58E-04	1.51E-23	1.51E-25
0.0708	1.72E+09	7.14E-21	2.58E-04	2.60E-23	2.60E-25
0.0803	9.81E+08	3.78E-21	2.61E-04	1.23E-23	1.23E-25
0.1353	9.81E+08	3.81E-15	3.47E-04	9.78E-18	9.78E-20
0.1659	5.92E+07	7.88E-23	4.16E-04	1.98E-25	1.98E-27
0.1674	3.70E+09	4.94E-21	4.20E-04	1.24E-23	1.24E-25
			Total	9.78E-18	9.78E-20

Table 10 - Cs-137 ANS Results 3983 Insert

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	7.87E-24	1.60E-02	2.79E-23	2.79E-25
0.0318	7.25E+08	1.16E-22	5.18E-04	1.88E-24	1.88E-26
0.0322	1.34E+09	2.16E-22	5.06E-04	3.39E-24	3.39E-26
0.0364	4.87E+08	8.99E-23	4.12E-04	1.02E-24	1.02E-26
0.6616	3.15E+10	5.89E+04	1.46E-03	1.30E+02	1.30E+00
			Total	1.30E+02	1.30E+00

Table 11 - Pb-210 ANS Results 3983 Insert

Energy MeV	Activity (Photons/sec)	Fluence Rate	(mrem/hr)/ (photon/cm2-s)	Dose Rate (mrem/hr)	Dose Rate (mSv/hr)
0.0108	8.46E+09	4.43E-22	3.46E-03	1.42E-22	1.42E-24
0.0465	1.41E+09	3.15E-22	2.71E-04	1.83E-24	1.83E-26
0.8031	3.64E+05	2.30E+00	1.69E-03	4.84E-03	4.84E-05
			Total	4.84E-03	4.84E-05