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Safkeg-HS 3977A: Package Activity Limits Based on Shielding

Title	Safkeg-HS 3977A: Package Activity Limits Based on Shielding	**Number**	CTR 2011/01
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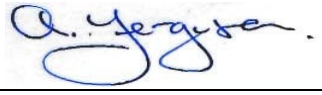
		File Reference	CTR2011-01-A-d1-SAFKEG HS 3977A-Package Activity Limits-Shielding.docx
Compiled		**Checked**	
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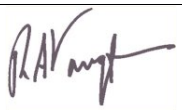
Approved		**Date**	31 August 2012
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Contents

1 Introduction

The Safkeg-HS 3977A package is a general purpose container for the transport of non-fissile and fissile excepted nuclides under non-exclusive use, in solid, liquid and gaseous form, via all modes of transport (road, rail, sea and air).

The Safkeg-HS 3977A package consists of an outer stainless steel double-skinned insulated keg (3977) which is 585 mm long and 424 mm in diameter. Carried within the keg is an insulating cork liner into which a single resealable containment vessel 3978 (made of depleted uranium clad in stainless steel) is located. The maximum weight of the package is 153 kg (337 lbs) excluding the contents. The maximum contents weight is 10 kg (22 lbs), therefore the gross weight of the package is 163 kg (359 lbs).

Section views of the package and the containment vessel are shown in Figure 1, 2 and 3 and the dimensions employed in the shielding models are shown in Figures 7 and 8. Figures 1 and 2 also give the nomenclature used throughout this report.

The package is designed as a general purpose package for radioactive material that requires some shielding, however, the design includes additional optional tungsten or stainless steel inserts, for radioactive material that requires additional shielding.

The package is designed for radioactive material that emits alpha, beta or gamma radiation. The specified contents do not include materials that emit a significant amount of neutrons.

The contents may be in solid, liquid or gaseous form and carried in various inserts: Design No's 3982, 3985 and 3987, as depicted in Figures 4, 5 and 6.

This report assesses the shielding performance of the Safkeg-HS 3977A package in complying with the non-exclusive use provisions of the 10 CFR71 transport regulations [1] (specifically, the dose limits detailed in10 CFR71.47), when transporting the nuclides detailed in Tables 3 to 6.

The package performance when carrying 3000 Ci of ^{137}Cs was assessed independently in order to establish the worst case orientation of the package in terms of shield performance, as reported in reference 2. The shielding calculations and activity for the additional radionuclides to be carried were performed using Grove Software's code "MicroShield" [3], employing a 1 Ci point source of each nuclide.

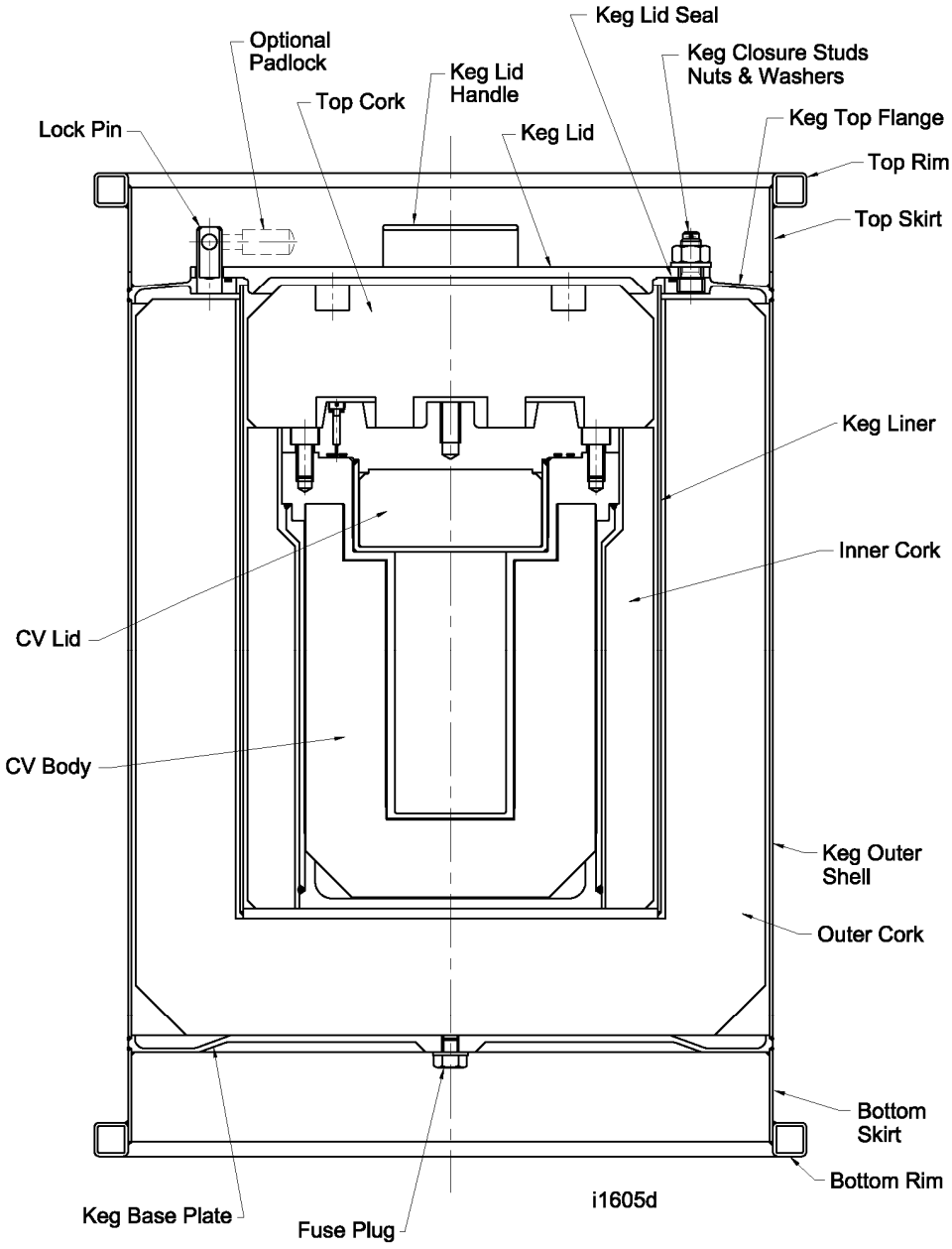
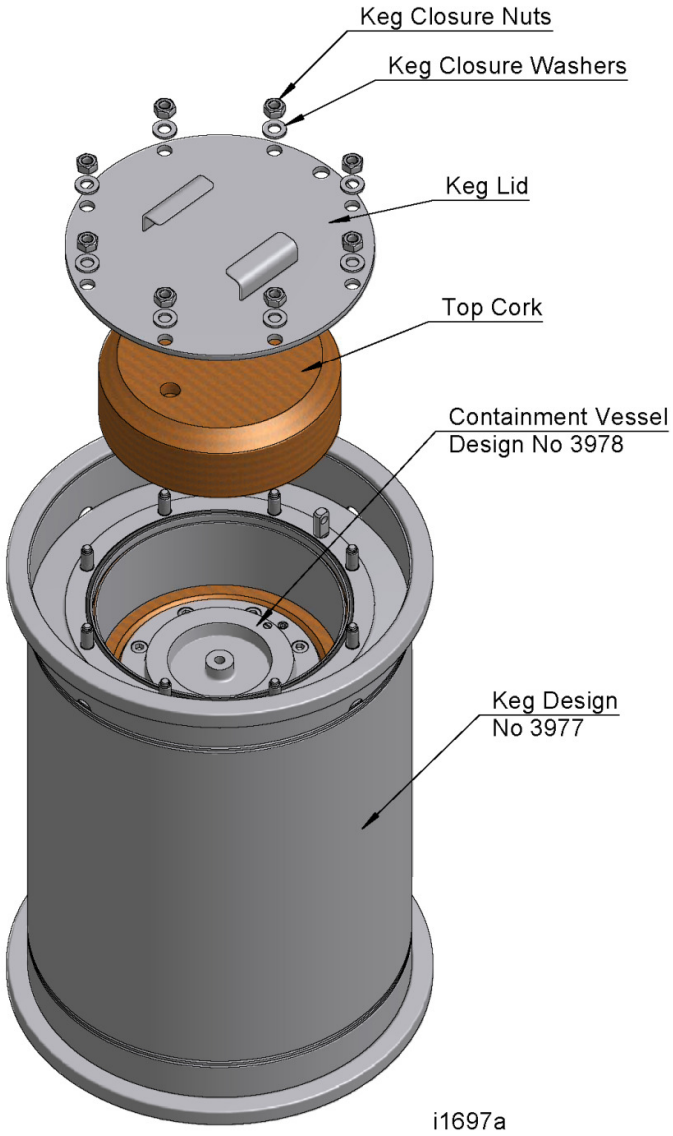


Figure 1: Safkeg-HS 3977A package - Sectional View and Nomenclature



Safkeg HS Design No 3977A

Figure 2: Safkeg-HS 3977A package - Isometric View with Nomenclature

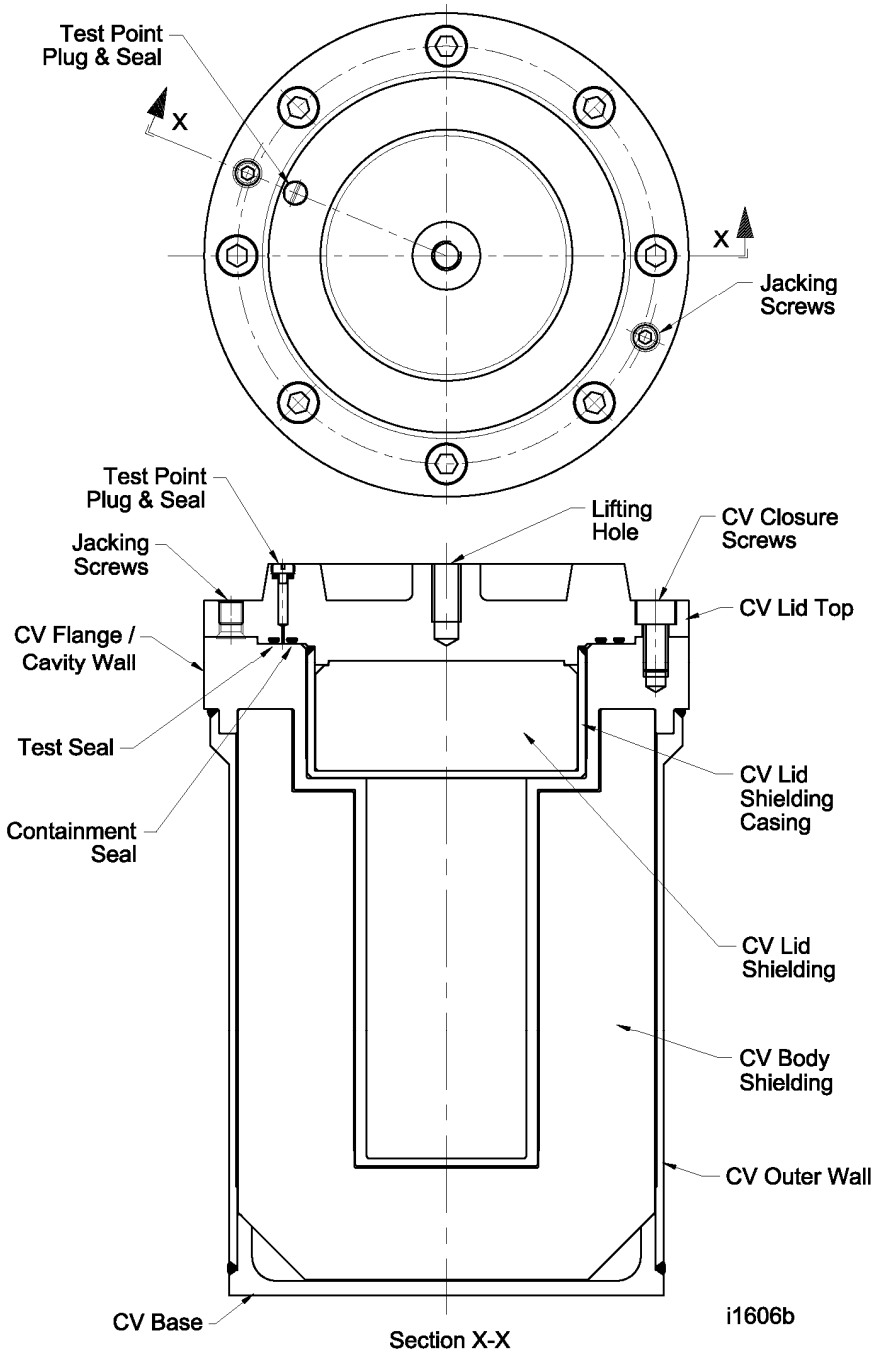


Figure 3: 3978 Containment Vessel - Top and Sectional View with Nomenclature

Figure 4: Shielding Insert HS-12 x 95 - Tu, Design No 3982

Figure 5: Shielding Insert HS - 31 x 114 -Tu, Design No 3985

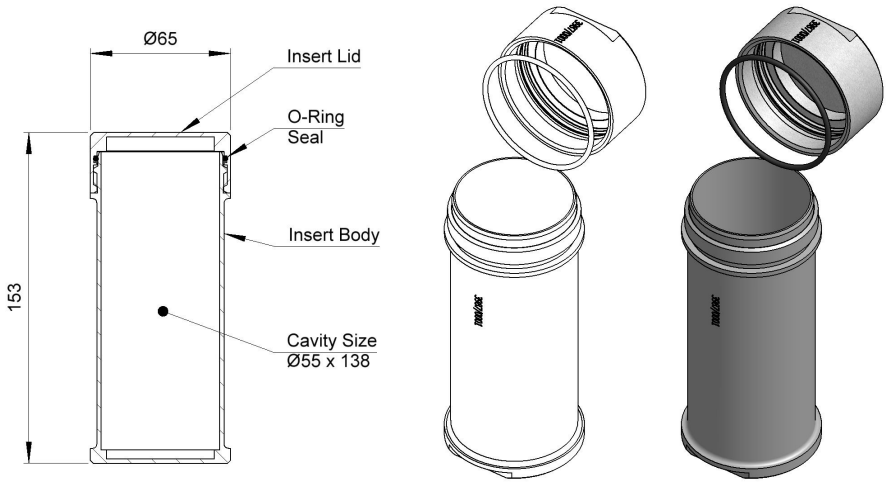


Figure 6: Shielding Insert HS – 55 x 138 - SS, Design No 3987

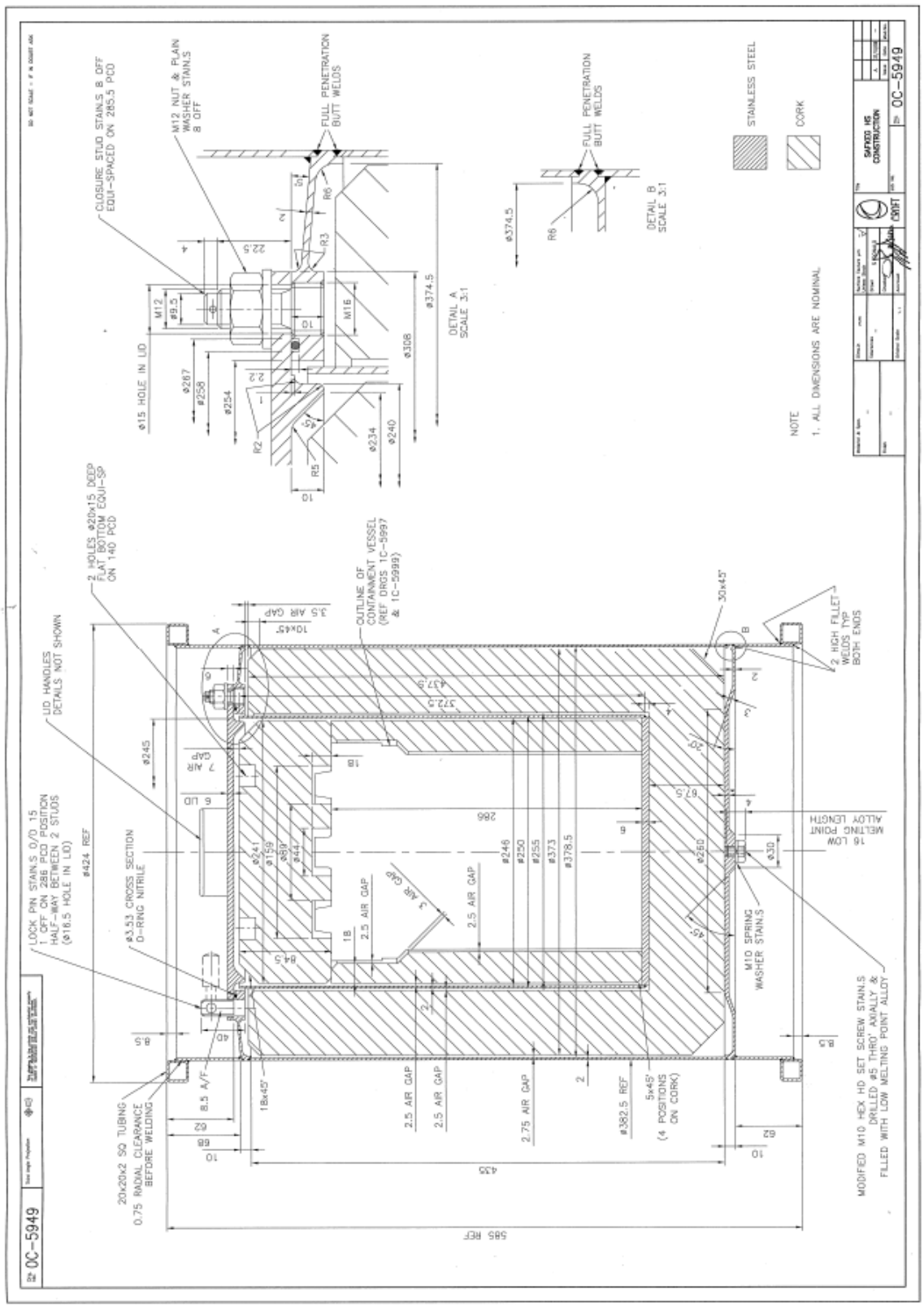


Figure 7: SAFKEG-HS 3977A PACKAGE, Design No 3977

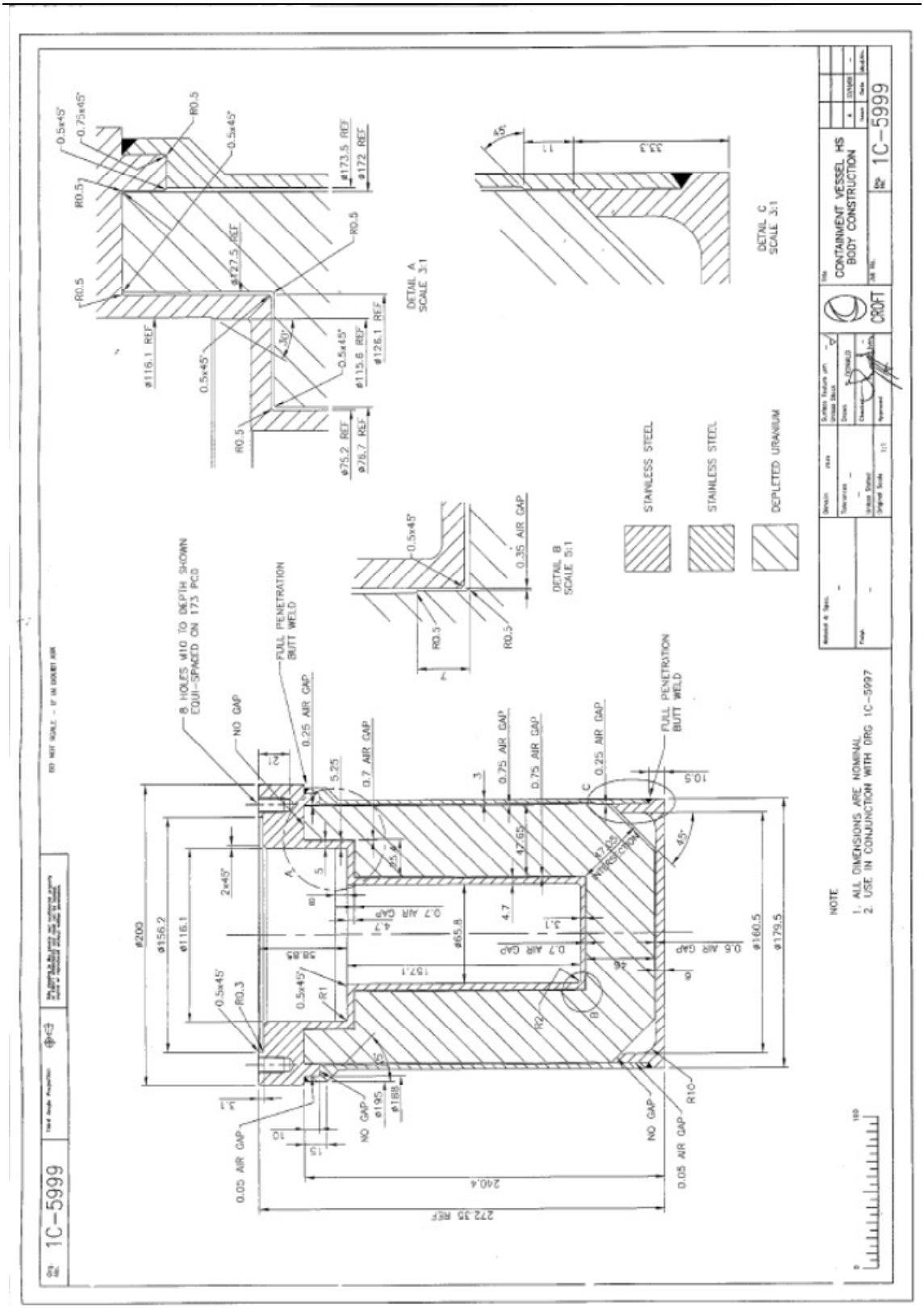


Figure 8: SAFKEG-HS 3977A PACKAGE, Containment Vessel Design No 3978

2 Shielding Assessment

2.1 Comparison with Monte Carlo Based Calculations on ^{137}Cs

The modelling performed in this assessment was validated against Monte Carlo calculations performed by Serco Assurance, using the code MCBEND. The Serco work, which is reported in reference 2, demonstrated that the worst case dose rates occur with a point source at the centre of the package base with the source at the centre of the base of the insert; therefore this assessment only addresses dose rates from a point source through the base of the package.

The MicroShield [3] model was initially compared with the work done by Serco in order to check the model, using a 3000 Ci point source of ^{137}Cs, with a tungsten insert (Design No 3982) located in the package cavity (as used in the Serco work [2]). The dose rates calculated by MicroShield [3] are in accordance with those calculated by Serco [2], as shown below in Table 1.

Insert	Nuclide	Activity (Ci)	Effective Dose Equivalent (ICRP 51) mSv/h	Microshield Case Reference No	Serco Report (Table 6 [2]) mSv/h
3982 (12x95 Tu)	Cs-137	3000	1.39E-01	12	1.39E-01
3985 (31x114 Tu)	Cs-137	3000	7.00E-01	68	6.69E-01
3987 (55x138 SS)	Cs-137	3000	1.28E+01	124	N/A
No Insert	Cs-137	3000	1.45E+01	180	1.45E+01

Table 1: Code Comparisons

1.1. Source and Shield Model

The Safkeg-HS 3977A package geometry employed in the shielding models together with the regional shield materials, the position of the measured dose rates (the detector position) and their properties are summarized in Table 2. To predict the maximum dose rates at the detector positions, a point source is assumed, positioned at the base of the cavity in contact with the inner surface of the cavity or insert. The use of a point source provides the greatest pessimism in the calculated dose rates as in reality, the sources used will consist of primary capsules or containers, with the source distributed within the container: additionally, using a point source takes no account of any self shielding from the distributed source or its container.

The source data employed in the calculations are incorporated within the libraries built into the MicroShield code[3], the gamma energy lines, probabilities and shield build up factors are detailed within the MicroShield calculations for each nuclide: these calculations are provided in Appendix C.

Table 2: Shield regions and detector positions through base of package (input data)

Table 1: Radiation through bottom of package

Shield	Nomenclature	Without Insert (cm)	3982 (cm)	3985 (cm)	Material/ Regional Density (g/cm^3)	3987	Material/ Regional Density (g/cm^3)	Comment	Drawing Reference
Source	Point							Positioned at the centerline on the base	
1	Insert	0	2.73	1.78	W/17.23	0.18	Fe/7.86	Adjusted from 18 in Serco report for Tungsten insert	2C-5899 2C-5896
2	CV Cavity Liner	0.31	0.31	0.31	Fe/7.86	0.31	Fe/7.86	Default microshield value	1C-5999
3	air gap	0.07	0.07	0.07	Air/0.00122	0.07	Air/0.00122		1C-5999
4	CV Shield	4.6	4.6	4.6	U/17.93	4.6	U/17.93	Adjusted from 18.65 in Serco report	1C-5999
5	Air gap	0.06	0.06	0.06	Air/0.00122	0.06	Air/0.00122		1C-5999
6	CV Outer Skin	0.6	0.6	0.6	Fe/7.86	0.6	Fe/7.86		1C-5999
7	3977 Cavity Liner	0.6	0.6	0.6	Fe/7.86	0.6	Fe/7.86		0C-5949
8	Outer Cork Liner	6.75	6.75	6.75	Air/0.00122	6.75	Air/0.00122		0C-5949
9	3977 Outer Skin	0.4	0.4	0.4	Fe/7.86	0.4	Fe/7.86		0C-5949

2.2 Dose Rates from Gamma, Neutron and Bremsstrahlung Radiation

Calculations of the radiation levels at the exterior of the as built Safkeg-HS 3977A package due to gamma radiation have been carried out using the MicroShield code [3]. The results of the calculations performed and their cumulative effect, are detailed in Tables 3 to 6: a typical output from the MicroShield code is shown in Figure 9. The MicroShield calculations are listed in Appendix C.

The dose rate at the exterior surface of the package resulting from neutron radiation is estimated based upon the neutron energy, its intensity and published dose conversion factors from IAEA SS37 [4] and Cember's Health Physics text [5]: the methodology and results of these calculations are detailed in Appendix A.

The calculations show that the dose rate from spontaneous fission from ^{238}Pu and ^{240}Pu, dominate over the gamma rates given in Tables 3 to 6. The total dose rates from these nuclides, gamma plus neutron are shown in Table 7.

A few of the nuclides carried are either pure beta emitters or emit bremsstrahlung radiation. The MicroShield code does not assess beta or x-ray radiation directly. However, Cember's Health Physics text [5] provides equations for estimating the photon flux from bremsstrahlung radiation and this can be imported into MicroShield, together with the beta energy line, to predict a worst case dose rate. The approach used and the results of the MicroShield calculations are detailed in Appendix B.

MicroShield 8.03
Croft (8.03-0000)

Filename	Run Date	Run Time	Duration
HS-3977A-Base with 3982 insert -Na-24.msd	March 9, 2011	14:32:21	-01:59:6

Date	By	Checked

Project Info

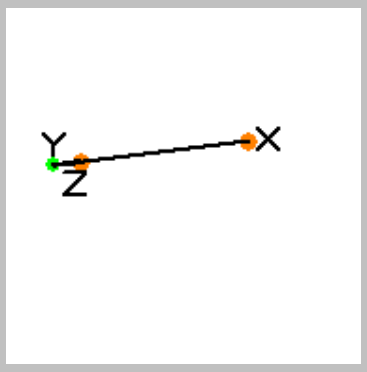
Case Title	HS 3977A
Description	Base Shielding, point source with 3982 insert
Geometry	1 - Point

Dose Points

A	X	Y	Z
#1	16.12 cm (6.3 in)	0.0 cm (0 in)	0.0 cm (0 in)
#2	116.12 cm (3 ft 9.7 in)	0.0 cm (0 in)	0.0 cm (0 in)

Shields

Shield N	Dimension	Material	Density
Shield 1	2.73 cm	Tungsten	17.23
Shield 2	.31 cm	Iron	7.86
Shield 3	.07 cm	Air	0.00122
Shield 4	4.6 cm	Uranium	17.93
Shield 5	.06 cm	Air	0.00122
Shield 6	.6 cm	Iron	7.86
Shield 7	.6 cm	Iron	7.86
Shield 8	6.75 cm	Air	0.00122
Shield 9	.4 cm	Iron	7.86
Air Gap		Air	0.00122



Source Input: Grouping Method - Actual Photon Energies

Nuclide	Ci	Bq
Na-24	1.0000e+000	3.7000e+010

Buildup: The material reference is Shield 4
Integration Parameters

Results - Dose Point # 1 - (16.12,0,0) cm

Energy (MeV)	Activity (Photons/sec)	Fluence Rate MeV/cm²/sec No Buildup	Fluence Rate MeV/cm²/sec With Buildup	Exposure Rate mR/hr No Buildup	Exposure Rate mR/hr With Buildup
1.3685	3.700e+10	5.488e+03	1.628e+04	9.458e+00	2.805e+01
2.7541	3.695e+10	6.650e+04	2.034e+05	9.274e+01	2.836e+02
3.8236	2.371e+07	6.978e+01	2.036e+02	8.763e-02	2.557e-01
Totals	**7.397e+10**	**7.206e+04**	**2.198e+05**	**1.023e+02**	**3.119e+02**
Results - Dose Point # 2 - (116.12,0,0) cm					
Energy (MeV)	**Activity (Photons/sec)**	**Fluence Rate MeV/cm²/sec No Buildup**	**Fluence Rate MeV/cm²/sec With Buildup**	**Exposure Rate mR/hr No Buildup**	**Exposure Rate mR/hr With Buildup**
1.3685	3.700e+10	1.051e+02	3.118e+02	1.811e-01	5.373e-01
2.7541	3.695e+10	1.276e+03	3.903e+03	1.779e+00	5.443e+00
3.8236	2.371e+07	1.340e+00	3.911e+00	1.682e-03	4.912e-03
Totals	**7.397e+10**	**1.382e+03**	**4.219e+03**	**1.962e+00**	**5.986e+00**

Figure 9: MicroShield Output (Example)

Table 3: Insert Design No 3982 – Surface and 1m Dose Rates from gamma and bremsstrahlung

Nuclide	Microshield File Ref.	Original Activity, Bq	Dose Point 1: Package surface		Dose Point 2: 1m from Surface
			Exposure Rate, mR/hr + Buildup	Effective Dose Equivalent Rate, mSv/h	Exposure Rate, mR/hr + Buildup
Insert:	3982				
Ac-225	HS-3977A-Base with 3982 insert-Ac-225	3.70E+10	9.94E-01	8.85E-03	1.90E-02
Ac-227	HS-3977A-Base with 3982 insert-Ac-227	3.70E+10	1.14E-02	1.03E-04	2.18E-04
Ac-228	HS-3977A-Base with 3982 insert-Ac-228	3.70E+10	6.10E+00	5.44E-02	1.17E-01
Am-241	HS-3977A-Base with 3982 insert-Am-241	3.70E+10	2.14E-11	1.91E-13	4.10E-13
As-77	HS-3977A-Base with 3982 insert-As-77	3.70E+10	8.45E-08	7.85E-10	1.61E-09
Au-198	HS-3977A-Base with 3982 insert-Au-198.msd	3.70E+10	1.18E-02	1.06E-04	2.26E-04
Ba-131	HS-3977A-Base with 3982 insert-Ba-131.msd	3.70E+10	4.38E-02	3.93E-04	8.38E-04
C-14	LS-3979A-Base with 3982 Insert-C-14 - Brem.msd	3.70E+10	9.55E-16	1.07E-17	1.84E-17
Co-60	HS-3977A-Base with 3982 insert-Co-60.msd	3.70E+09	3.35E+01	2.99E-01	6.41E-01
Cs-131	HS-3977A-Base with 3982 insert-Cs-131.msd	3.70E+10	4.84E-23	8.83E-26	9.24E-25
Cs-134	HS-3977A-Base with 3982 insert-Cs-134.msd	3.70E+10	1.18E+00	1.05E-02	2.25E-02
Cs-137	HS 3977A-Cs137 Validation bottom 3982.msd	1.11E+14	1.53E+01	1.39E-01	2.91E-01
Cu-67	HS-3977A-Base with 3982 insert-Cu-67.msd	3.70E+10	1.19E-13	1.14E-15	2.28E-15
Hg-203	HS-3977A-Base with 3982 insert-Hg-203.msd	3.70E+10	8.72E-23	6.72E-25	1.68E-24
Ho-166	HS-3977A-Base with 3982 insert-Ho-166.msd	3.70E+10	4.81E-01	4.28E-03	9.21E-03
I-125	HS-3977A-Base with 3982 insert-I-125.msd	3.70E+10	9.54E-23	1.65E-25	1.84E-24
I-129	LS-3979A-Base with 3982 Insert-I-129 - Brem.msd	3.70E+10	1.98E-14	2.24E-16	3.81E-16
I-131	HS-3977A-Base with 3982 insert-I-131.msd	3.70E+10	7.56E-04	6.90E-06	1.45E-05
In-111	HS-3977A-Base with 3982 insert-In-111.msd	3.70E+10	4.56E-16	5.10E-18	8.79E-18
Ir-192	HS-3977A-Base with 3982 insert-Ir-192.msd	3.70E+10	7.31E-04	6.64E-06	1.40E-05
Ir-194	HS-3977A-Base with 3982 insert-Ir-194.msd	3.70E+10	2.14E-01	1.91E-03	4.10E-03
Kr-79	HS-3977A-Base with 3982 insert-Kr-79.msd	3.70E+10	1.38E-01	1.23E-03	2.64E-03
Lu-177	HS-3977A-Base with 3982 insert-Lu-177.msd	3.70E+10	4.09E-12	4.76E-14	7.88E-14
Mo-99	HS-3977A-Base with 3982 insert-Mo-99.msd	3.70E+10	1.05E-02	9.56E-05	2.01E-04
Na-24	HS-3977A-Base with 3982 insert-Na-24.msd	3.70E+10	3.12E+02	2.81E+00	5.99E+00
Np-237	HS-3977A-Base with 3982 insert-Np-237.msd	3.70E+10	2.07E-06	1.84E-08	3.96E-08
P-32	LS-3979A-Base with 3982 Insert-P-32 - Brem.msd	3.70E+10	1.49E+00	1.33E-02	2.86E-02
P-33	LS-3979A-Base with 3982 Insert-P-33 - Brem.msd	3.70E+10	1.44E-25	1.45E-27	2.77E-27
Pb-203	HS-3977A-Base with 3982 insert-Pb-203.msd	3.70E+10	6.89E-05	6.29E-07	1.32E-06
Pb-210	HS-3977A-Base with 3982 insert-Pb-210.msd	3.70E+10	1.57E-06	1.42E-08	3.00E-08
Pd-109	HS-3977A-Base with 3982 insert-Pd-109.msd	3.70E+10	8.67E-09	8.06E-11	1.65E-10
Pu-238	HS-3977A-Base with 3982 insert-Pu-238.msd	3.70E+10	7.13E-08	6.35E-10	1.37E-09
Pu-239	HS-3977A-Base with 3982 insert-Pu-239.msd	3.70E+10	3.51E-13	3.18E-15	6.71E-15
Pu-240	HS-3977A-Base with 3982 insert-Pu-240.msd	3.70E+10	7.15E-13	6.45E-15	1.37E-14
Pu-241	HS-3977A-Base with 3982 insert-Pu-241.msd	3.70E+10	1.13E-08	1.03E-10	2.17E-10
Ra-223	HS-3977A-Base with 3982 insert-Ra-223.msd	3.70E+10	5.94E-03	5.39E-05	1.14E-04
Ra-224	HS-3977A-Base with 3982 insert-Ra-224.msd	3.70E+10	8.53E+01	7.69E-01	1.64E+00
Ra-226	HS-3977A-Base with 3982 insert-Ra-226.msd	3.70E+10	4.72E+01	4.20E-01	9.04E-01
Re-186	HS-3977A-Base with 3982 insert-Re-186.msd	3.70E+10	1.03E-05	9.41E-08	1.97E-07
Re-188	HS-3977A-Base with 3982 insert-Re-188.msd	3.70E+10	5.97E-02	5.35E-04	1.14E-03
Rh-105	HS-3977A-Base with 3982 insert-Rh-105.msd	3.70E+10	7.17E-19	7.02E-21	1.36E-20
Se-75	HS-3977A-Base with 3982 insert-Se-75.msd	3.70E+10	6.93E-07	8.32E-09	1.34E-08
Sm-153	HS-3977A-Base with 3982 insert-Sm-153.msd	3.70E+10	7.95E-12	7.52E-14	1.52E-13
Sr-89	HS-3977A-Base with 3982 insert-Sr-89.msd	3.70E+10	1.20E-04	1.08E-06	2.30E-06
Sr-90	LS-3979A-Base with 3982 Insert-Sr-90 - Brem.msd	3.70E+10	3.68E-07	3.40E-09	7.01E-09
Tb-161	HS-3977A-Base with 3982 insert-Tb-161.msd	3.70E+10	2.76E-07	2.53E-09	5.26E-09
Th-227	HS-3977A-Base with 3982 insert-Th-227.msd	3.70E+10	1.07E-02	9.70E-05	1.84E-04
Th-228	HS-3977A-Base with 3982 insert-Th-228.msd	3.70E+10	1.13E+02	1.02E+00	2.18E+00
Tl-201	HS-3977A-Base with 3982 insert-Tl-201.msd	3.70E+10	3.99E-10	4.65E-12	7.68E-12
U-235	HS-3977A-Base with 3982 insert-U-235.msd	3.70E+10	8.90E-06	8.07E-08	1.70E-07
W-187	HS-3977A-Base with 3982 insert-W-187.msd	3.70E+10	1.01E-02	9.16E-05	1.93E-04
W-188	HS-3977A-Base with 3982 insert-W-188.msd	3.70E+10	5.69E-02	5.10E-04	1.09E-03
Xe-133	HS-3977A-Base with 3982 insert-Xe-133.msd	3.70E+10	3.05E-12	3.29E-23	5.87E-23
Y-90	LS-3979A-Base with 3982 Insert-Y-90 - Brem.msd	3.70E+10	4.79E+00	4.29E-02	9.19E-02
Yb-169	HS-3977A-Base with 3982 insert-Yb-169.msd	3.70E+10	3.27E-07	3.95E-09	6.29E-09
Yb-175	HS-3977A-Base with 3982 insert-Yb-175.msd	3.70E+10	1.15E-11	1.23E-13	2.21E-13

Table 4: Insert Design No 3985 – Surface and 1m Dose Rates from gamma and bremsstrahlung

Nuclide	Microshield File Ref.	Original Activity, Bq	Dose Point 1: Package surface		Dose Point 2: 1m from Surface
			Exposure Rate, mR/hr + Buildup	Effective Dose Equivalent Rate, mSv/h	Exposure Rate, mR/hr + Buildup
Insert:	3985				
Ac-225	HS-3977A-Base with 3985 insert-Ac-225	3.70E+10	2.35E+00	2.09E-02	4.05E-02
Ac-227	HS-3977A-Base with 3985 insert-Ac-227	3.70E+10	2.29E-02	2.07E-04	3.94E-04
Ac-228	HS-3977A-Base with 3985 insert-Ac-228	3.70E+10	1.52E+01	1.36E-01	2.64E-01
Am-241	HS-3977A-Base with 3985 insert-Am-241	3.70E+10	5.06E-11	4.51E-13	8.73E-13
As-77	HS-3977A-Base with 3985 insert-As-77	3.70E+10	6.96E-07	6.47E-09	1.20E-08
Au-198	HS-3977A-Base with 3985 insert-Au-198.msd	3.70E+10	3.40E-02	3.04E-04	5.85E-04
Ba-131	HS-3977A-Base with 3985 insert-Ba-131.msd	3.70E+10	1.34E-01	1.21E-03	2.32E-03
C-14	LS-3979A-Base with 3985 Insert-C-14 - Brem.msd	3.70E+10	1.08E-15	1.21E-17	1.87E-17
Co-60	HS-3977A-Base with 3985 insert-Co-60	3.70E+10	8.56E+01	7.64E-01	1.48E+00
Cs-131	HS-3977A-Base with 3985 insert-Cs-131.msd	3.70E+10	5.47E-23	9.96E-26	9.48E-25
Cs-134	HS-3977A-Base with 3985 insert-Cs-134.msd	3.70E+10	3.14E+00	2.81E-02	5.42E-02
Cs-137	HS 3977A-Cs137 Validation bottom 3985.msd	1.11E+14	7.65E+01	7.00E-01	1.32E+00
Cu-67	HS-3977A-Base with 3985 insert-Cu-67.msd	3.70E+10	2.74E-12	2.61E-14	4.69E-14
Hg-203	HS-3977A-Base with 3985 insert-Hg-203.msd	3.70E+10	1.62E-22	1.39E-24	2.78E-24
Ho-166	HS-3977A-Base with 3985 insert-Ho-166.msd	3.70E+10	1.15E+00	1.02E-02	1.98E-02
I-125	HS-3977A-Base with 3985 insert-I-125.msd	3.70E+10	1.08E-22	1.86E-25	1.87E-24
I-129	LS-3979A-Base with 3985 Insert-I-129 - Brem.msd	3.70E+10	2.23E-14	2.53E-16	3.87E-16
I-131	HS-3977A-Base with 3985 insert-I-131.msd	3.70E+10	3.52E-03	3.21E-05	6.05E-05
In-111	HS-3977A-Base with 3985 insert-In-111.msd	3.70E+10	5.15E-16	5.75E-18	8.94E-18
Ir-192	HS-3977A-Base with 3985 insert-Ir-192.msd	3.70E+10	3.09E-03	2.81E-05	5.32E-05
Ir-194	HS-3977A-Base with 3985 insert-Ir-194.msd	3.70E+10	5.65E-01	5.05E-03	9.74E-03
Kr-79	HS-3977A-Base with 3985 insert-Kr-79.msd	3.70E+10	3.61E-01	3.22E-03	6.22E-03
Lu-177	HS-3977A-Base with 3985 insert-Lu-177.msd	3.70E+10	4.62E-12	5.37E-14	8.01E-14
Mo-99	HS-3977A-Base with 3985 insert-Mo-99.msd	3.70E+10	4.34E-02	3.94E-04	7.47E-04
Na-24	HS-3977A-Base with 3985 insert-Na-24.msd	3.70E+10	6.44E+02	5.79E+00	1.11E+01
Np-237	HS-3977A-Base with 3985 insert-Np-237.msd	3.70E+10	4.88E-06	4.35E-08	8.42E-08
P-32	LS-3979A-Base with 3985 Insert-P-32 - Brem.msd	3.70E+10	3.34E+00	2.97E-02	5.76E-02
P-33	LS-3979A-Base with 3985 Insert-P-33 - Brem.msd	3.70E+10	2.03E-25	2.05E-27	2.89E-27
Pb-203	HS-3977A-Base with 3985 insert-Pb-203.msd	3.70E+10	3.31E-04	3.02E-06	5.69E-06
Pb-210	HS-3977A-Base with 3985 insert-Pb-210.msd	3.70E+10	6.01E-06	5.44E-08	1.03E-07
Pd-109	HS-3977A-Base with 3985 insert-Pd-109.msd	3.70E+10	7.60E-08	7.07E-10	1.31E-09
Pu-238	HS-3977A-Base with 3985 insert-Pu-238.msd	3.70E+10	1.57E-07	1.40E-09	2.70E-09
Pu-239	HS-3977A-Base with 3985 insert-Pu-239.msd	3.70E+10	1.35E-12	1.23E-14	2.33E-14
Pu-240	HS-3977A-Base with 3985 insert-Pu-240.msd	3.70E+10	1.46E-12	1.32E-14	2.52E-14
Pu-241	HS-3977A-Base with 3985 insert-Pu-241.msd	3.70E+10	4.30E-08	3.89E-10	7.39E-10
Ra-223	HS-3977A-Base with 3985 insert-Ra-223.msd	3.70E+10	2.29E-02	2.07E-04	3.94E-04
Ra-224	HS-3977A-Base with 3985 insert-Ra-224.msd	3.70E+10	1.72E+02	1.55E+00	2.97E+00
Ra-226	HS-3977A-Base with 3985 insert-Ra-226.msd	3.70E+10	1.04E+02	9.23E-01	1.79E+00
Re-186	HS-3977A-Base with 3985 insert-Re-186.msd	3.70E+10	4.72E-05	4.30E-07	8.11E-07
Re-188	HS-3977A-Base with 3985 insert-Re-188.msd	3.70E+10	1.70E-01	1.52E-03	2.92E-03
Rh-105	HS-3977A-Base with 3985 insert-Rh-105.msd	3.70E+10	6.48E-17	6.34E-19	1.11E-18
Se-75	HS-3977A-Base with 3985 insert-Se-75.msd	3.70E+10	7.83E-07	9.40E-09	1.36E-08
Sm-153	HS-3977A-Base with 3985 insert-Sm-153.msd	3.70E+10	1.31E-10	1.24E-12	2.25E-12
Sr-89	HS-3977A-Base with 3985 insert-Sr-89.msd	3.70E+10	4.02E-04	3.63E-06	6.93E-06
Sr-90	LS-3979A-Base with 3985 Insert-Sr-90 - Brem.msd	3.70E+10	2.65E-06	2.45E-08	4.54E-08
Tb-161	HS-3977A-Base with 3985 insert-Tb-161.msd	3.70E+10	1.65E-06	1.52E-08	2.83E-08
Th-227	HS-3977A-Base with 3985 insert-Th-227.msd	3.70E+10	7.92E-03	7.18E-05	1.36E-04
Th-228	HS-3977A-Base with 3985 insert-Th-228.msd	3.70E+10	2.29E+02	2.06E+00	3.95E+00
Tl-201	HS-3977A-Base with 3985 insert-Tl-201.msd	3.70E+10	4.50E-10	5.25E-12	7.81E-12
U-235	HS-3977A-Base with 3985 insert-U-235.msd	3.70E+10	3.43E-05	3.11E-07	5.90E-07
W-187	HS-3977A-Base with 3985 insert-W-187.msd	3.70E+10	4.21E-02	3.82E-04	7.24E-04
W-188	HS-3977A-Base with 3985 insert-W-188.msd	3.70E+10	1.62E-01	1.45E-03	2.78E-03
Xe-133	HS-3977A-Base with 3985 insert-Xe-133.msd	3.70E+10	3.46E-21	3.71E-23	6.01E-23
Y-90	LS-3979A-Base with 3985 Insert-Y-90 - Brem.msd	3.70E+10	9.97E+00	8.92E-02	1.72E-01
Yb-169	HS-3977A-Base with 3985 insert-Yb-169.msd	3.70E+10	3.69E-07	4.46E-09	6.40E-09
Yb-175	HS-3977A-Base with 3985 insert-Yb-175.msd	3.70E+10	1.26E-10	1.22E-12	2.16E-12

Table 5: Insert Design No 3987 – Surface and 1m Dose Rates from gamma and bremsstrahlung

Nuclide	Microshield File Ref.	Original Activity, Bq	Dose Point 1: Package surface		Dose Point 2: 1m from Surface
			Exposure Rate, mR/hr + Buildup	Effective Dose Equivalent Rate, mSv/h	Exposure Rate, mR/hr + Buildup
Insert:	3987				
Ac-225	HS-3977A-Base with 3987 insert-Ac-225	3.70E+10	1.09E+01	9.68E-02	1.54E-01
Ac-227	HS-3977A-Base with 3987 insert-Ac-227	3.70E+10	2.57E-01	2.33E-03	3.64E-03
Ac-228	HS-3977A-Base with 3987 insert-Ac-228	3.70E+10	8.15E+01	7.28E-01	1.16E+00
Am-241	HS-3977A-Base with 3987 insert-Am-241	3.70E+10	2.35E-10	2.09E-12	3.34E-12
As-77	HS-3977A-Base with 3987 insert-As-77	3.70E+10	3.19E-05	2.97E-07	4.51E-07
Au-198	HS-3977A-Base with 3987 insert-Au-198.msd	3.70E+10	2.27E-01	2.03E-03	3.21E-03
Ba-131	HS-3977A-Base with 3987 insert-Ba-131.msd	3.70E+10	1.00E+00	9.02E-03	1.42E-02
C-14	LS-3979A-Base with 3987 Insert-C-14 - Brem.msd	3.70E+10	4.72E-16	5.28E-18	6.74E-18
Co-60	HS-3977A-Base with 3987 insert-Co-60	3.70E+10	4.57E+02	4.08E+00	6.49E+00
Cs-131	HS-3977A-Base with 3987 insert-Cs-131.msd	3.70E+10	6.83E-23	1.25E-25	9.75E-25
Cs-134	HS-3977A-Base with 3987 insert-Cs-134.msd	3.70E+10	1.97E+01	1.76E-01	2.79E-01
Cs-137	HS 3977A-Cs137 Validation bottom 3987.msd	1.11E+14	1.40E+03	1.28E+01	1.98E+01
Cu-67	HS-3977A-Base with 3987 insert-Cu-67.msd	3.70E+10	8.41E-10	8.01E-12	1.19E-11
Hg-203	HS-3977A-Base with 3987 insert-Hg-203.msd	3.70E+10	6.54E-18	6.52E-20	9.22E-20
Ho-166	HS-3977A-Base with 3987 insert-Ho-166.msd	3.70E+10	5.41E+00	4.82E-02	7.67E-02
I-125	HS-3977A-Base with 3987 insert-I-125.msd	3.70E+10	1.35E-22	2.33E-25	1.92E-24
I-129	LS-3979A-Base with 3987 Insert-I-129 - Brem.msd	3.70E+10	9.83E-15	1.11E-16	1.40E-16
I-131	HS-3977A-Base with 3987 insert-I-131.msd	3.70E+10	5.72E-02	5.22E-04	8.09E-04
In-111	HS-3977A-Base with 3987 insert-In-111.msd	3.70E+10	6.44E-16	7.19E-18	9.19E-18
Ir-192	HS-3977A-Base with 3987 insert-Ir-192.msd	3.70E+10	4.62E-02	4.22E-04	6.54E-04
Ir-194	HS-3977A-Base with 3987 insert-Ir-194.msd	3.70E+10	3.25E+00	2.90E-02	4.61E-02
Kr-79	HS-3977A-Base with 3987 insert-Kr-79.msd	3.70E+10	2.05E+00	1.83E-02	2.91E-02
Lu-177	HS-3977A-Base with 3987 insert-Lu-177.msd	3.70E+10	5.78E-12	6.72E-14	8.25E-14
Mo-99	HS-3977A-Base with 3987 insert-Mo-99.msd	3.70E+10	5.56E-01	5.05E-03	7.86E-03
Na-24	HS-3977A-Base with 3987 insert-Na-24.msd	3.70E+10	2.37E+03	2.13E+01	3.37E+01
Np-237	HS-3977A-Base with 3987 insert-Np-237.msd	3.70E+10	2.26E-05	2.02E-07	3.21E-07
P-32	LS-3979A-Base with 3987 Insert-P-32 - Brem.msd	3.70E+10	4.91E+00	4.37E-02	6.98E-02
P-33	LS-3979A-Base with 3987 Insert-P-33 - Brem.msd	3.70E+10	7.12E-26	7.20E-28	1.02E-27
Pb-203	HS-3977A-Base with 3987 insert-Pb-203.msd	3.70E+10	5.57E-03	5.09E-05	7.89E-05
Pb-210	HS-3977A-Base with 3987 insert-Pb-210.msd	3.70E+10	6.69E-05	6.06E-07	9.47E-07
Pd-109	HS-3977A-Base with 3987 insert-Pd-109.msd	3.70E+10	3.92E-06	3.64E-08	5.53E-08
Pu-238	HS-3977A-Base with 3987 insert-Pu-238.msd	3.70E+10	6.40E-07	5.70E-09	9.09E-09
Pu-239	HS-3977A-Base with 3987 insert-Pu-239.msd	3.70E+10	1.52E-11	1.38E-13	2.15E-13
Pu-240	HS-3977A-Base with 3987 insert-Pu-240.msd	3.70E+10	5.29E-12	7.28E-27	7.53E-14
Pu-241	HS-3977A-Base with 3987 insert-Pu-241.msd	3.70E+10	4.74E-07	4.29E-09	6.71E-09
Ra-223	HS-3977A-Base with 3987 insert-Ra-223.msd	3.70E+10	2.57E-01	2.33E-03	3.64E-03
Ra-224	HS-3977A-Base with 3987 insert-Ra-224.msd	3.70E+10	6.03E+02	5.44E+00	8.57E+00
Ra-226	HS-3977A-Base with 3987 insert-Ra-226.msd	3.70E+10	4.23E+02	3.77E+00	6.01E+00
Re-186	HS-3977A-Base with 3987 insert-Re-186.msd	3.70E+10	7.28E-04	6.64E-06	1.03E-05
Re-188	HS-3977A-Base with 3987 insert-Re-188.msd	3.70E+10	1.11E+00	9.91E-03	1.57E-02
Rh-105	HS-3977A-Base with 3987 insert-Rh-105.msd	3.70E+10	2.58E-13	2.53E-15	3.64E-15
Se-75	HS-3977A-Base with 3987 insert-Se-75.msd	3.70E+10	1.08E-06	1.27E-08	1.53E-08
Sm-153	HS-3977A-Base with 3987 insert-Sm-153.msd	3.70E+10	2.20E-08	2.08E-10	3.10E-10
Sr-89	HS-3977A-Base with 3987 insert-Sr-89.msd	3.70E+10	3.50E-03	3.16E-05	4.96E-05
Sr-90	LS-3979A-Base with 3987 Insert-Sr-90 - Brem.msd	3.70E+10	3.31E-05	3.06E-07	4.68E-07
Tb-161	HS-3977A-Base with 3987 insert-Tb-161.msd	3.70E+10	4.19E-05	3.86E-07	5.93E-07
Th-227	HS-3977A-Base with 3987 insert-Th-227.msd	3.70E+10	1.20E-01	1.09E-03	1.70E-03
Th-228	HS-3977A-Base with 3987 insert-Th-228.msd	3.70E+10	8.01E+02	7.23E+00	1.14E+01
Tl-201	HS-3977A-Base with 3987 insert-Tl-201.msd	3.70E+10	5.63E-10	6.56E-12	8.03E-12
U-235	HS-3977A-Base with 3987 insert-U-235.msd	3.70E+10	3.85E-04	3.49E-06	5.45E-06
W-187	HS-3977A-Base with 3987 insert-W-187.msd	3.70E+10	5.69E-01	5.17E-03	8.05E-03
W-188	HS-3977A-Base with 3987 insert-W-188.msd	3.70E+10	1.06E+00	9.45E-03	1.50E-02
Xe-133	HS-3977A-Base with 3987 insert-Xe-133.msd	3.70E+10	4.33E-21	4.64E-23	6.18E-23
Y-90	LS-3979A-Base with 3987 Insert-Y-90 - Brem.msd	3.70E+10	1.29E+01	1.16E-01	1.84E-01
Yb-169	HS-3977A-Base with 3987 insert-Yb-169.msd	3.70E+10	4.61E-07	5.57E-09	6.58E-09
Yb-175	HS-3977A-Base with 3987 insert-Yb-175.msd	3.70E+10	3.43E-08	3.27E-10	4.84E-10

Table 6: Without Inserts – Surface and 1m Dose Rates from gamma and bremsstrahlung

Nuclide	Microshield File Ref.	Original Activity, Bq	Dose Point 1: Package surface		Dose Point 2: 1m from Surface
			Exposure Rate, mR/hr + Buildup	Effective Dose Equivalent Rate, mSv/h	Exposure Rate, mR/hr + Buildup
Insert:	No Insert				
Ac-225	HS-3977A-Base with no insert-Ac-225.msd	3.70E+10	1.19E+01	1.06E-01	1.65E-01
Ac-227	HS-3977A-Base with no insert-Ac-227.msd	3.70E+10	2.89E-01	2.62E-03	4.00E-03
Ac-228	HS-3977A-Base with no insert-Ac-228.msd	3.70E+10	8.96E+01	8.00E-01	1.24E+00
Am-241	HS-3977A-Base with no insert-Am-241.msd	3.70E+10	2.57E-10	2.29E-12	3.56E-12
As-77	HS-3977A-Base with no insert-As-77.msd	3.70E+10	3.67E-05	3.41E-07	5.07E-07
Au-198	HS-3977A-Base with no insert-Au-198.msd	3.70E+10	2.51E-01	2.25E-03	3.48E-03
Ba-131	HS-3977A-Base with no insert-Ba-131.msd	3.70E+10	1.12E+00	1.00E-02	1.55E-02
C-14	HS-3977A-Base without Insert-C-14 - Brem.msd	3.70E+10	4.85E-16	5.43E-18	6.76E-18
Co-60	HS-3977A-Base with no insert-Co-60.msd	3.70E+10	5.03E+02	4.49E+00	6.97E+00
Cs-131	HS-3977A-Base with no insert-Cs-131.msd	3.70E+10	7.01E-23	1.28E-25	9.78E-25
Cs-134	HS-3977A-Base with no insert-Cs-134.msd	3.70E+10	2.17E+01	1.95E-01	3.01E-01
Cs-137	HS 3977A-Cs137 Validation bottom - no shielding insert.msd	1.11E+14	1.59E+03	1.45E+01	2.20E+01
Cu-67	HS-3977A-Base with no insert-Cu-67.msd	3.70E+10	9.84E-10	9.38E-12	1.36E-11
Hg-203	HS-3977A-Base with no insert-Hg-203.msd	3.70E+10	7.86E-18	7.82E-20	1.08E-19
Ho-166	HS-3977A-Base with no insert-Ho-166.msd	3.70E+10	5.91E+00	5.27E-02	8.20E-02
I-125	HS-3977A-Base with no insert-I-125.msd	3.70E+10	1.38E-22	2.39E-25	1.93E-24
I-129	HS-3977A-Base without Insert-I-129 - Brem.msd	3.70E+10	1.01E-14	1.14E-16	1.41E-16
I-131	HS-3977A-Base with no insert-I-131.msd	3.70E+10	6.48E-02	5.91E-04	8.95E-04
In-111	HS-3977A-Base with no insert-In-111.msd	3.70E+10	6.61E-16	7.38E-18	9.22E-18
Ir-192	HS-3977A-Base with no insert-Ir-192.msd	3.70E+10	5.23E-02	4.77E-04	7.23E-04
Ir-194	HS-3977A-Base with no insert-Ir-194.msd	3.70E+10	3.58E+00	3.20E-02	4.96E-02
Kr-79	HS-3977A-Base with no insert-Kr-79.msd	3.70E+10	2.26E+00	2.02E-02	3.13E-02
Lu-177	HS-3977A-Base with no insert-Lu-177.msd	3.70E+10	5.93E-12	6.90E-14	8.27E-14
Mo-99	HS-3977A-Base with no insert-Mo-99.msd	3.70E+10	6.26E-01	5.69E-03	8.66E-03
Na-24	HS-3977A-Base with no insert-Na-24.msd	3.70E+10	2.55E+03	2.30E+01	3.55E+01
Np-237	HS-3977A-Base with no insert-Np-237.msd	3.70E+10	5.07E-08	6.13E-10	7.06E-10
P-32	HS-3977A-Base without Insert-P-32-Brem.msd	3.70E+10	5.34E+00	4.75E-02	7.41E-02
P-33	HS-3977A-Base without Insert-P-33-Brem.msd	3.70E+10	7.31E-26	7.40E-28	1.02E-27
Pb-203	HS-3977A-Base with no insert-Pb-203.msd	3.70E+10	6.32E-03	5.77E-05	8.73E-05
Pb-210	HS-3977A-Base with no insert-Pb-210.msd	3.70E+10	7.52E-05	6.81E-07	1.04E-06
Pd-109	HS-3977A-Base with no insert-Pd-109.msd	3.70E+10	4.51E-06	4.20E-08	6.22E-08
Pu-238	HS-3977A-Base with no insert-Pu-238.msd	3.70E+10	6.95E-07	6.19E-09	9.64E-09
Pu-239	HS-3977A-Base with no insert-Pu-239.msd	3.70E+10	1.71E-11	1.55E-13	2.36E-13
Pu-240	HS-3977A-Base with no insert-Pu-240.msd	3.70E+10	5.70E-12	5.13E-14	7.91E-14
Pu-241	HS-3977A-Base with no insert-Pu-241.msd	3.70E+10	5.32E-07	4.82E-09	7.36E-09
Ra-223	HS-3977A-Base with no insert-Ra-223.msd	3.70E+10	2.89E-01	2.62E-03	4.00E-03
Ra-224	HS-3977A-Base with no insert-Ra-224.msd	3.70E+10	6.47E+02	5.84E+00	8.99E+00
Ra-226	HS-3977A-Base with no insert-Ra-226.msd	3.70E+10	4.60E+02	4.10E+00	6.38E+00
Re-186	HS-3977A-Base with no insert-Re-186.msd	3.70E+10	8.24E-04	7.51E-06	1.14E-05
Re-188	HS-3977A-Base with no insert-Re-188.msd	3.70E+10	1.23E+00	1.10E-02	1.70E-02
Rh-105	HS-3977A-Base with no insert-Rh-105.msd	3.70E+10	3.06E-13	3.00E-15	4.22E-15
Se-75	HS-3977A-Base with no insert-Se-75.msd	3.70E+10	1.12E-06	1.32E-08	1.56E-08
Sm-153	HS-3977A-Base with no insert-Sm-153.msd	3.70E+10	2.56E-08	2.42E-10	3.52E-10
Sr-89	HS-3977A-Base with no insert-Sr-89.msd	3.70E+10	3.91E-03	3.53E-05	5.41E-05
Sr-90	HS-3977A-Base without Insert-Sr-90-Brem.msd	3.70E+10	3.79E-05	3.51E-07	5.24E-07
Tb-161	HS-3977A-Base with no insert-Tb-161.msd	3.70E+10	4.79E-05	4.40E-07	6.61E-07
Th-227	HS-3977A-Base with no insert-Th-227.msd	3.70E+10	1.35E-01	1.22E-03	1.87E-03
Th-228	HS-3977A-Base with no insert-Th-228.msd	3.70E+10	8.61E+02	7.76E+00	1.20E+01
Tl-201	HS-3977A-Base with no insert-Tl-201.msd	3.70E+10	5.78E-10	6.74E-12	8.06E-12
U-235	HS-3977A-Base with no insert-U-235.msd	3.70E+10	4.33E-04	3.92E-06	5.98E-06
W-187	HS-3977A-Base with no insert-W-187.msd	3.70E+10	6.42E-01	5.84E-03	8.88E-03
W-188	HS-3977A-Base with no insert-W-188.msd	3.70E+10	1.17E+00	1.05E-02	1.62E-02
Xe-133	HS-3977A-Base with no insert-Xe-133.msd	3.70E+10	4.44E-21	4.76E-23	6.20E-23
Y-90	HS-3977A-Base without Insert-Y-90-Brem.msd	3.70E+10	1.39E+01	1.25E-01	1.93E-01
Yb-169	HS-3977A-Base with no insert-Yb-169.msd	3.70E+10	4.73E-07	5.72E-09	6.60E-09
Yb-175	HS-3977A-Base with no insert-Yb-175.msd	3.70E+10	4.01E-08	3.82E-10	5.53E-10

Table 7: Summation of Gamma and Neutron Dose Rates

Nuclide	Original Activity, Bq, gamma	Effective Dose Equivalent Rate, mSv/h, gamma	Gamma Dose rate at neutron Activity mSv/h	Neutron Activity, Bq	Neutron Dose Rate, surface, mSv/h	Neutron+ gamma Dose Limit	Package Activity Limit, Bq
3982							
Pu-238	3.70E+10	6.35E-10	1.18E-05	6.85E+14	2	2.00E+00	6.85E+14
Pu-240	3.70E+10	6.45E-15	4.60E-12	2.64E+13	2	2.00E+00	2.64E+13
3985							
Pu-238	3.70E+10	1.40E-09	2.28E-05	6.05E+14	2	2.00E+00	6.05E+14
Pu-240	3.70E+10	1.32E-14	8.32E-12	2.34E+13	2	2.00E+00	2.34E+13
3987							
Pu-238	3.70E+10	5.70E-09	7.48E-05	4.85E+14	2	2.00E+00	4.85E+14
Pu-240	3.70E+10	7.28E-27	3.68E-24	1.87E+13	2	2.00E+00	1.87E+13
No Insert							
Pu-238	3.70E+10	6.19E-09	7.90E-05	4.72E+14	2	2.00E+00	4.72E+14
Pu-240	3.70E+10	5.13E-14	2.52E-11	1.82E+13	2	2.00E+00	1.82E+13

2. References

1. Title 10, Code of Federal Regulations, Part 71, Office of the Federal Register, Washington, DC, 2009
2. Serco Assurance, SERCO/ 003191/002 Issue 1, *Monte Carlo Modelling of Safkeg HS Container*
3. Grove Software Inc, MicroShield v8.03, *Radiation Shielding Software Container*, June 2009
4. Advisory Material for the IAEA *Regulations for the Safe Transport of Radioactive Material* (1985 Edition, as Amended 1990), IAEA Safety Series No. 37
5. *Introduction to Health Physics*, Herman Cember, Third Edition, McGraw-Hill

Appendix A Neutron Dose Calculations

Appendix A Table 1: Package with HS-12 x 95-Tu Design No 3982

3982 Insert

3977 radius, r =	16.12	cm	- distance from source centre to measurement position	
Surface area =	3265.426696	cm2	- assuming a spherical source, to determine the neutron flux after a NCT damage at radius, r (cm)	

A	B	C	D	E	F	G	H	I	J	K	L	
Nuclide	Element	Package Limits (Surface Transport)		Neutron emission/ transformation, SF-n (ICRP 38, 1983 [1])	MeV	Total Netrons per sec, n/s (C x E)	Neutron Flux, n/s/cm2 (G/Surface area)	SS37 [2] Conversion factor from Table A-I (cm-2.s-1 per uSv/h)	Cember [3], Table 9.5,Fluence rate producing 1mSv in 40h	Dose Rate based on I, mSv/h (H x I/1000)	Dose Rate based on J, mSv/h (H/(J*40))	Dose Rate at 1m (Based on distance squared ratio), mSv/h
		(Bq)	(g)									
		Note - adjust this limit to get surface dose of 2mSv/h										
Pu-238	Plutonium	6.85E+14	1079.3	4.20E-09	1.927	2.88E+06	8.81E+02	8.08E-01	1.10E+01	7.11E-01	2.00E+00	3.86E-02
Pu-240		2.64E+13	3.12E+03	1.09E-07	1.915	2.88E+06	8.81E+02	8.08E-01	1.10E+01	7.12E-01	2.00E+00	3.86E-02

[1]	ICRP 38, Radionuclide Transformations - Energy and Intensity of Emissions
[2]	IAEA SS37, Third Edition, as Amended 1990.
[3]	Herman Cember, Introduction to Health Physics, Third Edition.

Appendix A Table 2: Shielding Insert HS - 31 x 114 -Tu, Design No 3985

3985 Insert

3977 radius, r =	15.17	cm	- distance from source centre to measurement position
Surface area =	2891.885046	cm2	- assuming a spherical source, to determine the neutron flux after a NCT damage at radius, r (cm)

A	B	C	D	E	F	G	H	I	J	K	L	
Nuclide	Element	Package Limits (Surface Transport)		Neutron emission/ transformation, SF-n (ICRP 38, 1983 [1])	MeV	Total Netrons per sec, n/s (C x E)	Neutron Flux, n/s/cm2 (G/Surface area)	SS37 [2] Conversion factor from Table A-I (cm-2.s-1 per uSv/h)	Cember [3], Table 9.5,Fluence rate producing 1mSv in 40h	Dose Rate based on I, mSv/h (H x I/1000)	Dose Rate based on J, mSv/h (H/(J*40))	Dose Rate at 1m (Based on distance squared ratio), mSv/h
		(Bq)	(g)									
		Note - adjust this limit to get surface dose of 2mSv/h										
Pu-238	Plutonium	6.05E+14	953.2	4.20E-09	1.927	2.54E+06	8.79E+02	8.08E-01	1.10E+01	7.10E-01	2.00E+00	3.46E-02
Pu-240		2.34E+13	2.77E+03	1.09E-07	1.915	2.55E+06	8.82E+02	8.08E-01	1.10E+01	7.12E-01	2.00E+00	3.48E-02

[1] ICRP 38, Radionuclide Transformations - Energy and Intensity of Emissions
[2] IAEA SS37, Third Edition, as Amended 1990.
[3] Herman Cember, Introduction to Health Physics, Third Edition.

Appendix A Table 3: Shielding Insert HS – 55 x 138 - SS, Design No 3987

3987 Insert

3977 radius, r =	13.57	cm	- distance from source centre to measurement position
Surface area =	2314.03306	cm2	- assuming a spherical source, to determine the neutron flux after a NCT damage at radius, r (cm)

A	B	C	D	E	F	G	H	I	J	K	L	
Nuclide	Element	Package Limits (Surface Transport)		Neutron emission/ transformation, SF-n (ICRP 38, 1983 [1])	MeV	Total Netrons per sec, n/s (C x E)	Neutron Flux, n/s/cm2 (G/Surface area)	SS37 [2] Conversion factor from Table A-I (cm-2.s-1 per uSv/h)	Cember [3], Table 9.5,Fluence rate producing 1mSv in 40h	Dose Rate based on I, mSv/h (H x I/1000)	Dose Rate based on J, mSv/h (H/(J*40))	Dose Rate at 1m (Based on distance squared ratio), mSv/h
		(Bq)	(g)									
		Note - adjust this limit to get surface dose of 2mSv/h										
Pu-238	Plutonium	4.85E+14	764.1	4.20E-09	1.927	2.04E+06	8.80E+02	8.08E-01	1.10E+01	7.11E-01	2.00E+00	2.86E-02
Pu-240		1.87E+13	2.21E+03	1.09E-07	1.915	2.04E+06	8.81E+02	8.08E-01	1.10E+01	7.11E-01	2.00E+00	2.86E-02

[1]	ICRP 38, Radionuclide Transformations - Energy and Intensity of Emissions
[2]	IAEA SS37, Third Edition, as Amended 1990.
[3]	Herman Cember, Introduction to Health Physics, Third Edition.

Appendix A Table 4: Package with No Insert

No Insert

3977 radius, r =	13.39	cm	- distance from source centre to measurement position
Surface area =	2253.050977	cm2	- assuming a spherical source, to determine the neutron flux after a NCT damage at radius, r (cm)

A	B	C	D	E	F	G	H	I	J	K	L	
Nuclide	Element	Package Limits (Surface Transport)		Neutron emission/ transformation, SF-n (ICRP 38, 1983 [1])	MeV	Total Netrons per sec, n/s (C x E)	Neutron Flux, n/s/cm2 (G/Surface area)	SS37 [2] Conversion factor from Table A-I (cm-2.s-1 per uSv/h)	Cember [3], Table 9.5,Fluence rate producing 1mSv in 40h	Dose Rate based on I, mSv/h (H x I/1000)	Dose Rate based on J, mSv/h (H/(J*40))	Dose Rate at 1m (Based on distance squared ratio), mSv/h
		(Bq)	(g)									
		Note - adjust this limit to get surface dose of 2mSv/h										
Pu-238	Plutonium	4.72E+14	7.4E+02	4.20E-09	1.927	1.98E+06	8.80E+02	8.08E-01	1.10E+01	7.10E-01	2.00E+00	2.79E-02
Pu-240		1.82E+13	2.15E+03	1.09E-07	1.915	1.98E+06	8.80E+02	8.08E-01	1.10E+01	7.11E-01	2.00E+00	2.79E-02

[1]	ICRP 38, Radionuclide Transformations - Energy and Intensity of Emissions
[2]	IAEA SS37, Third Edition, as Amended 1990.
[3]	Herman Cember, Introduction to Health Physics, Third Edition.

Appendix B Bremsstrahlung Dose Rates

Where:
Z = Atomic Number of the absorber
A = Activity, Bq
Em = Maximum Beta erergy, MeV (Kaye & Laby, 16th Edition)
E = Average Beta Energy, MeV (ICRP 38, 1983)

Photon Flux

Using the above formula, the total flux for each beta emitter can be calculated, as shown below:

Steel Insert

Nuclide	Z	E_M	F_B	A	E	Flux, photons/s
C-14	26	0.156	0.00142	3.70E+10	4.95E-02	1.66E+07
I-129	26	0.15	0.001365	3.70E+10	4.89E-02	1.65E+07
P-32	26	1.71	0.015561	3.70E+10	0.6947	2.34E+08
P-33	26	0.249	0.002266	3.70E+10	7.66E-02	2.58E+07
Sr-90	26	0.55	0.005005	3.70E+10	1.96E-01	6.59E+07
Y-90	26	2.28	0.020748	3.70E+10	9.35E-01	3.15E+08

Tungsten Insert

Nuclide	Z	E_M	F_B	A	E	Flux, photons/s
C-14	74	0.156	0.00404	3.70E+10	4.95E-02	4.74E+07
I-129	74	0.15	0.003885	3.70E+10	4.89E-02	4.68E+07
P-32	74	1.71	0.044289	3.70E+10	0.6947	6.66E+08
P-33	74	0.249	0.006449	3.70E+10	7.66E-02	7.34E+07
Sr-90	74	0.55	0.014245	3.70E+10	1.96E-01	1.88E+08
Y-90	74	2.28	0.059052	3.70E+10	9.35E-01	8.96E+08

Dose Rates

Importing the Photon Flux derived above into Microshield, the following dose rates are derived.
From Cember, p131: "For Health Physics purposes, it is assumed that all bremsstrahlung photons are of the maximum energy".

No Insert	Exposure Rate mR/h		Effective Dose Equivalent Rate	
Microshield Case No	Surface	1m	Surface, mSv/h	1m, mSv/h
HS-3977A-Base without Insert-C-14 - Brem.msd	4.85E-16	6.76E-18	5.43E-18	7.57E-20
HS-3977A-Base without Insert-I-129 - Brem.msd	1.01E-14	1.41E-16	1.14E-16	1.59E-18
HS-3977A-Base without Insert-P-32-Brem.msd	5.34E+00	7.41E-02	4.75E-02	6.59E-04
HS-3977A-Base without Insert-P-33-Brem.msd	7.31E-26	1.02E-27	7.40E-28	1.03E-29
HS-3977A-Base without Insert-Sr-90-Brem.msd	3.79E-05	5.24E-07	3.51E-07	4.84E-09
HS-3977A-Base without Insert-Y-90-Brem.msd	1.39E+01	1.93E-01	1.25E-01	1.73E-03

3982 Tungsten Insert	Exposure Rate mR/h		Effective Dose Equivalent Rate	
Microshield Case No	Surface	1m	Surface, mSv/h	1m, mSv/h
LS-3979A-Base with 3982 Insert-C-14 - Brem.msd	9.55E-16	1.84E-17	1.07E-17	2.06E-19
LS-3979A-Base with 3982 Insert-I-129 - Brem.msd	1.98E-14	3.81E-16	2.24E-16	4.31E-18
LS-3979A-Base with 3982 Insert-P-32 - Brem.msd	1.49E+00	2.86E-02	1.33E-02	2.54E-04
LS-3979A-Base with 3982 Insert-P-33 - Brem.msd	1.44E-25	2.77E-27	1.45E-27	2.80E-29
LS-3979A-Base with 3982 Insert-Sr-90 - Brem.msd	3.68E-07	7.01E-09	3.40E-09	6.48E-11
LS-3979A-Base with 3982 Insert-Y-90 - Brem.msd	4.79E+00	9.19E-02	4.29E-02	8.22E-04

3987 Steel Insert	Exposure Rate mR/h		Effective Dose Equivalent Rate	
Microshield Case No	Surface	1m	Surface, mSv/h	1m, mSv/h
LS-3979A-Base with 3987 Insert-C-14 - Brem.msd	4.72E-16	6.74E-18	5.28E-18	7.54E-20
LS-3979A-Base with 3987 Insert-I-129 - Brem.msd	9.83E-15	1.40E-16	1.11E-16	1.59E-18
LS-3979A-Base with 3987 Insert-P-32 - Brem.msd	4.91E+00	6.98E-02	4.37E-02	6.21E-04
LS-3979A-Base with 3987 Insert-P-33 - Brem.msd	7.12E-26	1.02E-27	7.20E-28	1.03E-29
LS-3979A-Base with 3987 Insert-Sr-90 - Brem.msd	3.31E-05	4.68E-07	3.06E-07	4.32E-09
LS-3979A-Base with 3987 Insert-Y-90 - Brem.msd	1.29E+01	1.84E-01	1.16E-01	1.64E-03

3985 Tungsten Insert	Exposure Rate mR/h		Effective Dose Equivalent Rate	
Microshield Case No	Surface	1m	Surface, mSv/h	1m, mSv/h
LS-3979A-Base with 3985 Insert-C-14 - Brem.msd	1.08E-15	1.87E-17	1.21E-17	2.10E-19
LS-3979A-Base with 3985 Insert-I-129 - Brem.msd	2.23E-14	3.87E-16	2.53E-16	4.38E-18
LS-3979A-Base with 3985 Insert-P-32 - Brem.msd	3.34E+00	5.76E-02	2.97E-02	5.13E-04
LS-3979A-Base with 3985 Insert-P-33 - Brem.msd	2.03E-25	2.89E-27	2.05E-27	2.93E-29
LS-3979A-Base with 3985 Insert-Sr-90 - Brem.msd	2.65E-06	4.54E-08	2.45E-08	4.20E-10
LS-3979A-Base with 3985 Insert-Y-90 - Brem.msd	9.97E+00	1.72E-01	8.92E-02	1.54E-03

Appendix C: MicroShield Calculations

Contents

#	Microshield File Ref. 3982	#	Microshield File Ref. 3985
1	HS-3977A-Base with 3982 insert-Ac-225	57	HS-3977A-Base with 3985 insert-Ac-225
2	HS-3977A-Base with 3982 insert-Ac-227	58	HS-3977A-Base with 3985 insert-Ac-227
3	HS-3977A-Base with 3982 insert-Ac-228	59	HS-3977A-Base with 3985 insert-Ac-228
4	HS-3977A-Base with 3982 insert-Am-241	60	HS-3977A-Base with 3985 insert-Am-241
5	HS-3977A-Base with 3982 insert-As-77	61	HS-3977A-Base with 3985 insert-As-77
6	HS-3977A-Base with 3982 insert-Au-198.msd	62	HS-3977A-Base with 3985 insert-Au-198.msd
7	HS-3977A-Base with 3982 insert-Ba-131.msd	63	HS-3977A-Base with 3985 insert-Ba-131.msd
8	LS-3979A-Base with 3982 Insert-C-14 - Brem.msd	64	LS-3979A-Base with 3985 Insert-C-14 - Brem.msd
9	HS-3977A-Base with 3982 insert-Co-60.msd	65	HS-3977A-Base with 3985 insert-Co-60
10	HS-3977A-Base with 3982 insert-Cs-131.msd	66	HS-3977A-Base with 3985 insert-Cs-131.msd
11	HS-3977A-Base with 3982 insert-Cs-134.msd	67	HS-3977A-Base with 3985 insert-Cs-134.msd
12	HS 3977A-Cs137 Validation bottom 3982.msd	68	HS 3977A-Cs137 Validation bottom 3985.msd
13	HS-3977A-Base with 3982 insert-Cu-67.msd	69	HS-3977A-Base with 3985 insert-Cu-67.msd
14	HS-3977A-Base with 3982 insert-Hg-203.msd	70	HS-3977A-Base with 3985 insert-Hg-203.msd
15	HS-3977A-Base with 3982 insert-Ho-166.msd	71	HS-3977A-Base with 3985 insert-Ho-166.msd
16	HS-3977A-Base with 3982 insert-I-125.msd	72	HS-3977A-Base with 3985 insert-I-125.msd
17	LS-3979A-Base with 3982 Insert-I-129 - Brem.msd	73	LS-3979A-Base with 3985 Insert-I-129 - Brem.msd
18	HS-3977A-Base with 3982 insert-I-131.msd	74	HS-3977A-Base with 3985 insert-I-131.msd
19	HS-3977A-Base with 3982 insert-In-111.msd	75	HS-3977A-Base with 3985 insert-In-111.msd
20	HS-3977A-Base with 3982 insert-Ir-192.msd	76	HS-3977A-Base with 3985 insert-Ir-192.msd
21	HS-3977A-Base with 3982 insert-Ir-194.msd	77	HS-3977A-Base with 3985 insert-Ir-194.msd
22	HS-3977A-Base with 3982 insert-Kr-79.msd	78	HS-3977A-Base with 3985 insert-Kr-79.msd
23	HS-3977A-Base with 3982 insert-Lu-177.msd	79	HS-3977A-Base with 3985 insert-Lu-177.msd
24	HS-3977A-Base with 3982 insert-Mo-99.msd	80	HS-3977A-Base with 3985 insert-Mo-99.msd
25	HS-3977A-Base with 3982 insert-Na-24.msd	81	HS-3977A-Base with 3985 insert-Na-24.msd
26	HS-3977A-Base with 3982 insert-Np-237.msd	82	HS-3977A-Base with 3985 insert-Np-237.msd
27	LS-3979A-Base with 3982 Insert-P-32 - Brem.msd	83	LS-3979A-Base with 3985 Insert-P-32 - Brem.msd
28	LS-3979A-Base with 3982 Insert-P-33 - Brem.msd	84	LS-3979A-Base with 3985 Insert-P-33 - Brem.msd
29	HS-3977A-Base with 3982 insert-Pb-203.msd	85	HS-3977A-Base with 3985 insert-Pb-203.msd
30	HS-3977A-Base with 3982 insert-Pb-210.msd	86	HS-3977A-Base with 3985 insert-Pb-210.msd
31	HS-3977A-Base with 3982 insert-Pd-109.msd	87	HS-3977A-Base with 3985 insert-Pd-109.msd
32	HS-3977A-Base with 3982 insert-Pu-238.msd	88	HS-3977A-Base with 3985 insert-Pu-238.msd
33	HS-3977A-Base with 3982 insert-Pu-239.msd	89	HS-3977A-Base with 3985 insert-Pu-239.msd
34	HS-3977A-Base with 3982 insert-Pu-240.msd	90	HS-3977A-Base with 3985 insert-Pu-240.msd
35	HS-3977A-Base with 3982 insert-Pu-241.msd	91	HS-3977A-Base with 3985 insert-Pu-241.msd
36	HS-3977A-Base with 3982 insert-Ra-223.msd	92	HS-3977A-Base with 3985 insert-Ra-223.msd
37	HS-3977A-Base with 3982 insert-Ra-224.msd	93	HS-3977A-Base with 3985 insert-Ra-224.msd
38	HS-3977A-Base with 3982 insert-Ra-226.msd	94	HS-3977A-Base with 3985 insert-Ra-226.msd
39	HS-3977A-Base with 3982 insert-Re-186.msd	95	HS-3977A-Base with 3985 insert-Re-186.msd
40	HS-3977A-Base with 3982 insert-Re-188.msd	96	HS-3977A-Base with 3985 insert-Re-188.msd
41	HS-3977A-Base with 3982 insert-Rh-105.msd	97	HS-3977A-Base with 3985 insert-Rh-105.msd
42	HS-3977A-Base with 3982 insert-Se-75.msd	98	HS-3977A-Base with 3985 insert-Se-75.msd
43	HS-3977A-Base with 3982 insert-Sm-153.msd	99	HS-3977A-Base with 3985 insert-Sm-153.msd
44	HS-3977A-Base with 3982 insert-Sr-89.msd	100	HS-3977A-Base with 3985 insert-Sr-89.msd
45	LS-3979A-Base with 3982 Insert-Sr-90 - Brem.msd	101	LS-3979A-Base with 3985 Insert-Sr-90 - Brem.msd
46	HS-3977A-Base with 3982 insert-Tb-161.msd	102	HS-3977A-Base with 3985 insert-Tb-161.msd
47	HS-3977A-Base with 3982 insert-Th-227.msd	103	HS-3977A-Base with 3985 insert-Th-227.msd
48	HS-3977A-Base with 3982 insert-Th-228.msd	104	HS-3977A-Base with 3985 insert-Th-228.msd
49	HS-3977A-Base with 3982 insert-Tl-201.msd	105	HS-3977A-Base with 3985 insert-Tl-201.msd
50	HS-3977A-Base with 3982 insert-U-235.msd	106	HS-3977A-Base with 3985 insert-U-235.msd
51	HS-3977A-Base with 3982 insert-W-187.msd	107	HS-3977A-Base with 3985 insert-W-187.msd
52	HS-3977A-Base with 3982 insert-W-188.msd	108	HS-3977A-Base with 3985 insert-W-188.msd
53	HS-3977A-Base with 3982 insert-Xe-133.msd	109	HS-3977A-Base with 3985 insert-Xe-133.msd
54	LS-3979A-Base with 3982 Insert-Y-90 - Brem.msd	110	LS-3979A-Base with 3985 Insert-Y-90 - Brem.msd
55	HS-3977A-Base with 3982 insert-Yb-169.msd	111	HS-3977A-Base with 3985 insert-Yb-169.msd
56	HS-3977A-Base with 3982 insert-Yb-175.msd	112	HS-3977A-Base with 3985 insert-Yb-175.msd

#	Microshield File Ref.	#	Microshield File Ref.
	3987		No Insert
113	HS-3977A-Base with 3987 insert-Ac-225	169	HS-3977A-Base with no insert-Ac-225.msd
114	HS-3977A-Base with 3987 insert-Ac-227	170	HS-3977A-Base with no insert-Ac-227.msd
115	HS-3977A-Base with 3987 insert-Ac-228	171	HS-3977A-Base with no insert-Ac-228.msd
116	HS-3977A-Base with 3987 insert-Am-241	172	HS-3977A-Base with no insert-Am-241.msd
117	HS-3977A-Base with 3987 insert-As-77	173	HS-3977A-Base with no insert-As-77.msd
118	HS-3977A-Base with 3987 insert-Au-198.msd	174	HS-3977A-Base with no insert-Au-198.msd
119	HS-3977A-Base with 3987 insert-Ba-131.msd	175	HS-3977A-Base with no insert-Ba-131.msd
120	LS-3979A-Base with 3987 Insert-C-14 - Brem.msd	176	HS-3977A-Base without Insert-C-14 - Brem.msd
121	HS-3977A-Base with 3987 insert-Co-60	177	HS-3977A-Base with no insert-Co-60.msd
122	HS-3977A-Base with 3987 insert-Cs-131.msd	178	HS-3977A-Base with no insert-Cs-131.msd
123	HS-3977A-Base with 3987 insert-Cs-134.msd	179	HS-3977A-Base with no insert-Cs-134.msd
124	HS 3977A-Cs137 Validation bottom 3987.msd	180	HS 3977A-Cs137 Validation bottom - no shielding insert.msd
125	HS-3977A-Base with 3987 insert-Cu-67.msd	181	HS-3977A-Base with no insert-Cu-67.msd
126	HS-3977A-Base with 3987 insert-Hg-203.msd	182	HS-3977A-Base with no insert-Hg-203.msd
127	HS-3977A-Base with 3987 insert-Ho-166.msd	183	HS-3977A-Base with no insert-Ho-166.msd
128	HS-3977A-Base with 3987 insert-I-125.msd	184	HS-3977A-Base with no insert-I-125.msd
129	LS-3979A-Base with 3987 Insert-I-129 - Brem.msd	185	HS-3977A-Base without Insert-I-129 - Brem.msd
130	HS-3977A-Base with 3987 insert-I-131.msd	186	HS-3977A-Base with no insert-I-131.msd
131	HS-3977A-Base with 3987 insert-In-111.msd	187	HS-3977A-Base with no insert-In-111.msd
132	HS-3977A-Base with 3987 insert-Ir-192.msd	188	HS-3977A-Base with no insert-Ir-192.msd
133	HS-3977A-Base with 3987 insert-Ir-194.msd	189	HS-3977A-Base with no insert-Ir-194.msd
134	HS-3977A-Base with 3987 insert-Kr-79.msd	190	HS-3977A-Base with no insert-Kr-79.msd
135	HS-3977A-Base with 3987 insert-Lu-177.msd	191	HS-3977A-Base with no insert-Lu-177.msd
136	HS-3977A-Base with 3987 insert-Mo-99.msd	192	HS-3977A-Base with no insert-Mo-99.msd
137	HS-3977A-Base with 3987 insert-Na-24.msd	193	HS-3977A-Base with no insert-Na-24.msd
138	HS-3977A-Base with 3987 insert-Np-237.msd	194	HS-3977A-Base with no insert-Np-237.msd
139	LS-3979A-Base with 3987 Insert-P-32 - Brem.msd	195	HS-3977A-Base without Insert-P-32-Brem.msd
140	LS-3979A-Base with 3987 Insert-P-33 - Brem.msd	196	HS-3977A-Base without Insert-P-33-Brem.msd
141	HS-3977A-Base with 3987 insert-Pb-203.msd	197	HS-3977A-Base with no insert-Pb-203.msd
142	HS-3977A-Base with 3987 insert-Pb-210.msd	198	HS-3977A-Base with no insert-Pb-210.msd
143	HS-3977A-Base with 3987 insert-Pd-109.msd	199	HS-3977A-Base with no insert-Pd-109.msd
144	HS-3977A-Base with 3987 insert-Pu-238.msd	200	HS-3977A-Base with no insert-Pu-238.msd
145	HS-3977A-Base with 3987 insert-Pu-239.msd	201	HS-3977A-Base with no insert-Pu-239.msd
146	HS-3977A-Base with 3987 insert-Pu-240.msd	202	HS-3977A-Base with no insert-Pu-240.msd
147	HS-3977A-Base with 3987 insert-Pu-241.msd	203	HS-3977A-Base with no insert-Pu-241.msd
148	HS-3977A-Base with 3987 insert-Ra-223.msd	204	HS-3977A-Base with no insert-Ra-223.msd
149	HS-3977A-Base with 3987 insert-Ra-224.msd	205	HS-3977A-Base with no insert-Ra-224.msd
150	HS-3977A-Base with 3987 insert-Ra-226.msd	206	HS-3977A-Base with no insert-Ra-226.msd
151	HS-3977A-Base with 3987 insert-Re-186.msd	207	HS-3977A-Base with no insert-Re-186.msd
152	HS-3977A-Base with 3987 insert-Re-188.msd	208	HS-3977A-Base with no insert-Re-188.msd
153	HS-3977A-Base with 3987 insert-Rh-105.msd	209	HS-3977A-Base with no insert-Rh-105.msd
154	HS-3977A-Base with 3987 insert-Se-75.msd	210	HS-3977A-Base with no insert-Se-75.msd
155	HS-3977A-Base with 3987 insert-Sm-153.msd	211	HS-3977A-Base with no insert-Sm-153.msd
156	HS-3977A-Base with 3987 insert-Sr-89.msd	212	HS-3977A-Base with no insert-Sr-89.msd
157	LS-3979A-Base with 3987 Insert-Sr-90 - Brem.msd	213	HS-3977A-Base without Insert-Sr-90-Brem.msd
158	HS-3977A-Base with 3987 insert-Tb-161.msd	214	HS-3977A-Base with no insert-Tb-161.msd
159	HS-3977A-Base with 3987 insert-Th-227.msd	215	HS-3977A-Base with no insert-Th-227.msd
160	HS-3977A-Base with 3987 insert-Th-228.msd	216	HS-3977A-Base with no insert-Th-228.msd
161	HS-3977A-Base with 3987 insert-Tl-201.msd	217	HS-3977A-Base with no insert-Tl-201.msd
162	HS-3977A-Base with 3987 insert-U-235.msd	218	HS-3977A-Base with no insert-U-235.msd
163	HS-3977A-Base with 3987 insert-W-187.msd	219	HS-3977A-Base with no insert-W-187.msd
164	HS-3977A-Base with 3987 insert-W-188.msd	220	HS-3977A-Base with no insert-W-188.msd
165	HS-3977A-Base with 3987 insert-Xe-133.msd	221	HS-3977A-Base with no insert-Xe-133.msd
166	LS-3979A-Base with 3987 Insert-Y-90 - Brem.msd	222	HS-3977A-Base without Insert-Y-90-Brem.msd
167	HS-3977A-Base with 3987 insert-Yb-169.msd	223	HS-3977A-Base with no insert-Yb-169.msd
168	HS-3977A-Base with 3987 insert-Yb-175.msd	224	HS-3977A-Base with no insert-Yb-175.msd