HS Container Shielding Assessment with Mo-99

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1. Background

Previous reports (References 1 to 3) present the results of MCBEND (Reference 4) calculations of external dose rate from various point sources in different locations within the Safkeg HS container.

This report presents the results of MCBEND calculations for the same HS container, but with a modified lid and a new internal configuration including a tungsten insert and a sealed stainless steel insert (Reference 5). The tungsten and stainless steel inserts were included in the model, but the bottle inside the stainless steel insert was omitted. The source was defined as described below.

- Mo-99 liquid source (and its significant daughter nuclides) contained in a natrium molybdenate solution.
- Solution density 1.02 g/cm^3
- Assumed solution composition: Mo 0.163, Na 0.078, O 0.687 H 0.072 by weight
- Activity 1000Ci
- Maximum source volume 75ml
- Maximum specific activity 60Ci/ml

Calculations were carried out to determine the worst case source position causing the highest surface dose rate under normal operating conditions. The following configurations were included:

- HS Container upright. Source liquid inside the sealed stainless steel insert, at its base
- HS Container on its side. The tungsten liner was assumed to be fixed to the base of the stainless steel liner. Source liquid within the sealed stainless steel insert at its side.
- HS Container upside down on its lid. The tungsten liner was assumed to be fixed to the base of the stainless steel liner. Source liquid within the sealed stainless steel insert at its top.

In all configurations it was assumed that the source liquid could not penetrate beyond the ‘O’ ring seal of the stainless steel insert. All calculations were carried out for two values of the source volume:

- Maximum source volume (75ml) corresponding to a specific activity of 13.333Ci/ml
- Minimum source volume (16.667ml) corresponding to the maximum specific activity of 60Ci/ml

For each configuration, the following dose rates were determined:

- The maximum dose rate on contact with the Safkeg HS container, on the top, side and bottom surfaces.

For the worst-case source position, the highest surface dose rate was determined under Normal Conditions of Transport (NCT) and Hypothetical Accident Conditions (HAC). The NCT and HAC are determined by tests on the package as described in Reference 6.

The NCT are those after, amongst others, a penetration test and a 1.2m drop test. The 1.2m drop test produced minimal damage to the package. The penetration test produced a dent of depth ~8mm and diameter ~290mm in the side of the package. However, there were no rips or tears in the steel skin of the package. Thus there was no loss of steel shielding in NCT. There was some compression of the cork shock absorber.

The HAC are those after, amongst others, a 10.2m drop test and a 1m punch test. The 10.2m drop test produced significant damage to the top skirt of the package, as shown in Photographs 27-29 of Reference 6. The skirt was crushed to approximately the level of the lid. There is also visual evidence that the top steel annulus (between the lid and the outer skin) has buckled. The 1m punch test produced a dent in the side of the package of depth 11mm but, as for the penetration test, there was no breach of the skin. After the HAC tests the containment vessel and insert were undamaged. Thus the HAC resulted in the outer skin height being reduced to that of the lid. The top steel annulus may not have been intact due to buckling and will be conservatively assumed to have been lost. The cork shock absorber did not survive the drop test intact.

Dose rates were calculated using dose conversion factors based on ANSI/ANS-6.1.1 1977. Bremsstrahlung was taken into account in the calculations.

2. Geometry and Source Terms

The geometry of the MCBEND model is shown in Figure 1 to Figure 3 for the bottom, side and top sources respectively, with the maximum source volume of 75ml. The model does not include the cork shock absorber, for simplicity and conservatism. This is consistent with previous work. This model was used for the initial calculations.

As described in the previous section, the NCT do not involve any loss of steel shielding. Since the MCBEND model does not include the cork shock absorber any degradation of the cork will not affect the calculated dose-rates. Thus the dose-rates obtained using the initial MCBEND model bound those during NCT.

As described in the previous section, the HAC involve loss of the top skirt of the steel shielding and was conservatively assumed to result in loss of the top steel annulus, between the lid and outer skin. It was assumed that similar damage could occur at the bottom of the container. However, it was found that the locations of the dose rate maxima, as described in the following section, are in areas which would not be affected by the loss of steel. Therefore a separate calculation for the maximum dose rate under HAC was not carried out.

Mo-99 decays by beta emission and its dominant decay product is Tc-99m, with a branching ratio of 88%. The Tc-99m then decays to Tc-99 by internal conversion, with a branching ratio of almost 100%. The remainder of the Mo-99 decays, with a branching ratio of 12%, are directly to Tc-99. The decay of Tc-99 was excluded from consideration because its photon intensities are negligible and its half life (2.14×10^5 years) is much longer than the half life of Mo-99 (2.75 days). The photon source spectrum was therefore taken from Mo-99 and its daughter product Tc-99m only. The data for these two nuclides were taken from JEF3.1.1 data using the JANIS4.0 tool (Reference 7). The combined spectrum, which includes both discrete gamma and discrete X-ray lines, is shown in Table 1. Lines below 10keV have been omitted.

Calculations were first carried out with the photon source described above. Beta source calculations were then carried out, for the side and bottom sources only, to determine the dose rate contribution from beta bremsstrahlung. It was conservatively assumed that all beta particles are emitted at the end-point energy

(1.2145MeV). Beta emissions from Tc-99m were neglected, on the grounds that the beta emission intensity is negligible.

For the side and bottom sources, the calculated dose rate contribution from the beta source was found to increase the maximum dose rate on each surface by up to 3.5%. For the top source, the dose rate contribution from the beta source was conservatively estimated as 3.5% of the contribution from the photon source.

3. Results

Initial Model

The results of the calculations using the initial model are shown in Table 2. The overall maximum dose rate is 1214 µSv/hr from the 16.667ml source at the side of the container. The maximum dose rate occurs at the container side at about the mid-height of the source and in the azimuthal interval closest to the source, as shown in Figure 2. The maximum dose rate at the bottom surface has a slightly lower value (1143 µSv/hr) and is produced by the 16.667ml source at the bottom of the container. The maximum is located at the centre of the base.

Normal Conditions of Transport

As described above, dose-rates from the initial model, which does not include cork, are judged to bound those arising from Normal Conditions of Transport. Thus the maximum surface dose-rate in Normal Conditions of Transport is 1214 µSv/hr.

Hypothetical Accident Conditions

The dose rate maxima at the side and bottom of the container are at locations well away from the areas which would suffer significant damage to their shielding effectiveness under HAC. Dose-rates from the initial model, which does not include cork, are therefore judged to bound those arising from Hypothetical Accident Conditions. Thus the maximum surface dose-rate in Hypothetical Accident Conditions is 1214 µSv/hr.

4. References

1 D J Picton, Monte Carlo Modelling of Safkeg HS Container, AMEC/SF6652/001 Issue 2, August 2013.

2 D J Picton, Monte Carlo Modelling of Alternative Point Sources in the Safkeg HS Container, Technical Note AMEC/SF8665/TN_001 Issue 1, November 2013

3 G.A. Wright, HS Container Shielding Assessment with I-131, Technical Note AMEC/CRM37327/TN_001 Issue 1, September 2015

4 MCBEND - A Monte Carlo Program for General Radiation Transport Solutions. User Guide for Version 11. ANSWERS/MCBEND/REPORT/008, Issue 2, May 2015

5 File “i2031b - ref Sarah - acad2014.dwg”, Autocad 2014.drawing showing Mallinckrodt CV shielding option B.

6 S H Marshall, Prototype Safkeg HS 3977A/0002 NCT and HAC Regulatory Test Report, CTR 2010/02 Issue A, March 2012

7 JANIS 4.0 http://www.oecd-nea.org/janis/

Gamma-Ray Energy (MeV)	Intensity	Gamma-Ray Energy (MeV)	Intensity
1.0562000	1.0796E-05	0.3917000	3.1538E-05
1.0170000	6.0650E-06	0.3801300	1.0432E-04
1.0013400	5.4585E-05	0.3664210	1.1912E-02
0.9864400	1.4556E-05	0.3224000	8.5365E-07
0.9607540	9.4614E-04	0.2490300	3.8816E-05
0.8612000	7.2780E-05	0.2422900	2.5473E-05
0.8229720	1.3343E-03	0.2328000	7.4939E-08
0.7779210	4.2576E-02	0.1810680	5.9922E-02
0.7617700	4.0029E-06	0.1623700	1.1887E-04
0.7395000	1.2130E-01	0.1587820	1.8923E-04
0.6896000	4.2455E-06	0.1426300	1.6469E-04
0.6217710	1.8195E-04	0.1405110	8.2948E-01
0.6200300	2.3047E-05	0.0896000	9.1194E-06
0.5805100	3.1538E-05	0.0405845	1.0529E-02
0.5377900	3.2751E-05	0.0217000	1.4275E-06
0.5287880	5.7011E-04	0.0206000	1.6597E-02
0.4696300	2.6686E-05	0.0192792	4.6569E-06
0.4576000	8.1271E-05	0.0191504	2.4449E-06
0.4114910	1.4556E-04	0.0183671	5.5319E-02
0.4102700	1.9408E-05	0.0182508	2.8932E-02

Table 1 Photon spectrum specified for Mo-99 including its significant daughter product (Tc-99m).

Liquid source at bottom of insert Volume=16.6667cc

Liquid source at bottom of insert Volume=75cc

Bottom - Surface	sd%[1]	Bottom - Surface	sd%
1143	0.3	905	0.3

Liquid source at top of insert Volume=16.6667cc

Liquid source at top of insert Volume=75cc

Side - Surface	sd%	Side - Surface	sd%
819	0.3	880	0.3
Top - Surface	**sd%**	**Top - Surface**	**sd%**
581	0.2	346	0.2

Liquid source at side of insert Volume=16.6667cc

Liquid source at side of insert Volume=75cc

Side - Surface	sd%	Side - Surface	sd%
1214	0.3	947	0.3
Top - Surface	**sd%**	**Top - Surface**	**sd%**
246	0.9	219	0.8

Table 2 Maximum Surface Dose-Rates for Initial Model. Dose rates are given in units of µSV/hr.

[1] Standard deviation (sd) values represent the Monte Carlo stochastic uncertainty on the result.

Figure 1: MCBEND model for Safkeg HS container with tungsten and stainless steel inserts – bottom source case

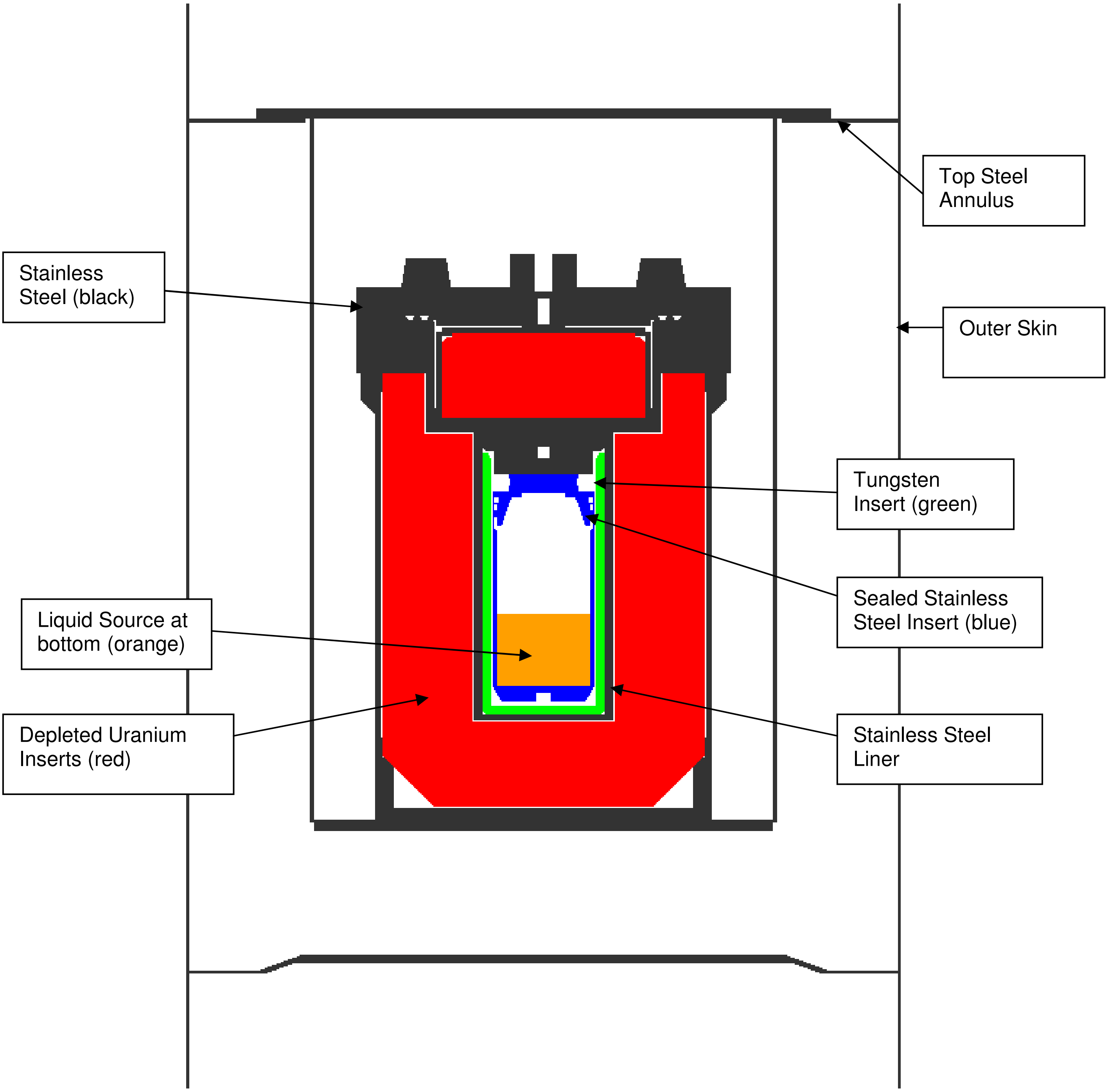

Figure 2: MCBEND model for Safkeg HS container with tungsten and stainless steel inserts – side source case

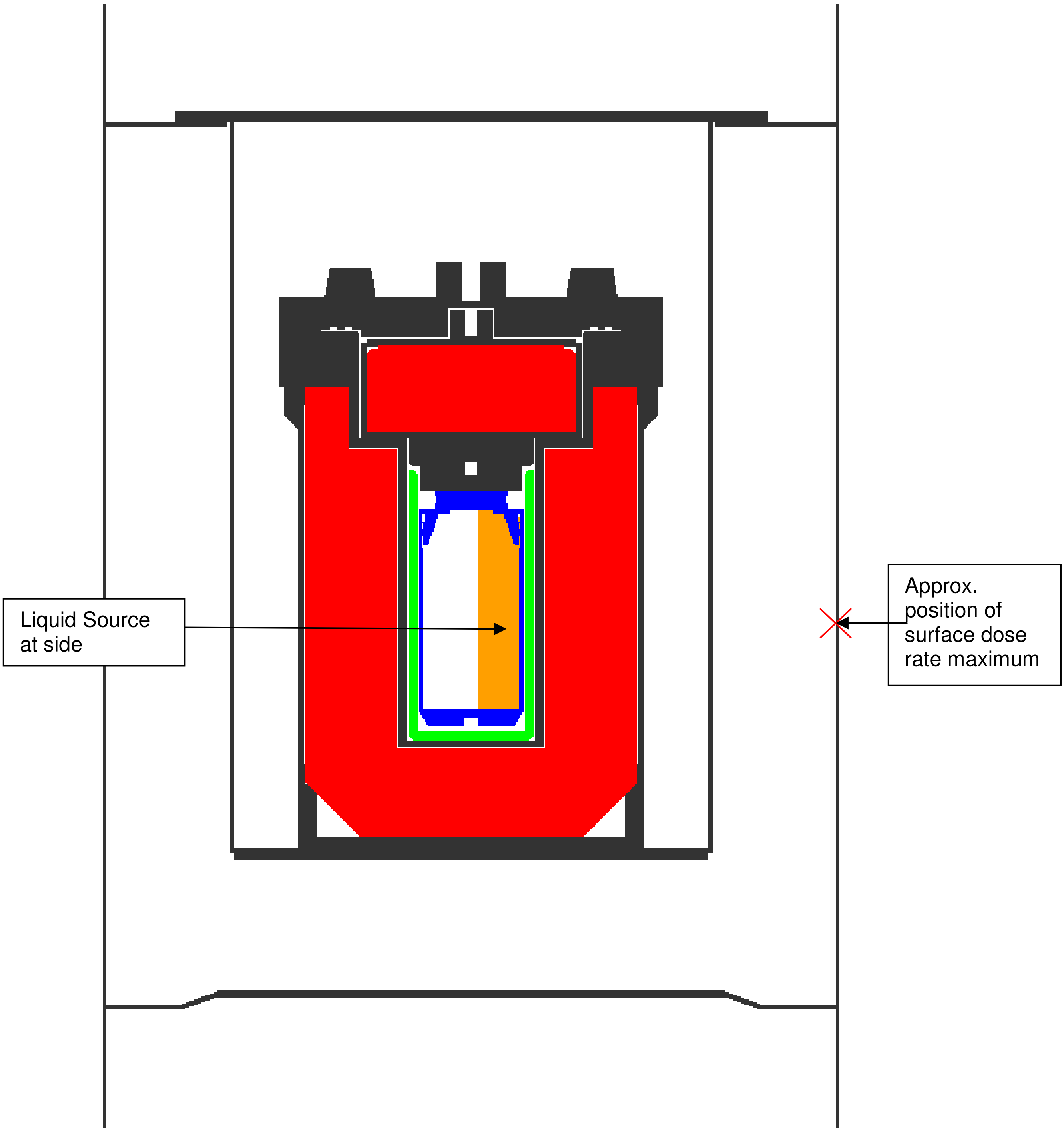

Figure 3: MCBEND model for Safkeg HS container with tungsten and stainless steel inserts – top source case