Safety Analysis Report
Safkeg–HS Design No. 3977A
Package Docket 71-9338

Application for Approval by the NRC

Applicant: Croft Associates Limited

CONTENTS

0 SARP STATUS AND CONTENTS

This Safety Analysis Report (SAR) has been prepared by Croft Associates Ltd for the new approval of the SAFKEG-HS Design No. 3977A transport package as a Type B(U) design.

This section (Section 0) defines the document status and lists the contents of the SAR (SAR sections and appended documents included in the SAR).

This SAR is a controlled document under the Croft Associates Ltd Quality Assurance Program approved by the NRC under Approval Number 71-9338.

Revisions are on a page control basis, with revisions indicated by a vertical change bar in the right hand margin.

Reference documents, which are listed in the Appendices to each section, are those available in the general literature and are not provided in the SAR.

Supporting documents are those developed specifically for the SAR and are provided in the section that is most closely associated with the document. These supporting documents are listed in this section, together with their revision status.

Document control for the supporting documents, which have been produced by different organizations at different times with different styles, is established by reference designations and issue status and/or date: there is no significance in the various policies of adding the names of author, checker or approver or whether they are manually or electronically signed.

0.1 SAR REVISION STATUS

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0.2 SUPPORTING DOCUMENT REVISION STATUS

Page/Document Reference	Issue Status	Title
Section 0 – SUPPORTING DOCUMENT REVISION STATUS		
Page 0-1	Rev 6	
Page 0-2	Rev 9	
Page 0-3	Rev 9	
Page 0-4	Rev 9	
Page 0-5	Rev 9	
Page 0-6	Rev 9	
Page 0-7	Rev 9	
Page 0-8	Rev 9	
Page 0-9	Rev 9	
Page 0-10	Rev 9	
Page 0-11	Rev 9	
Page 0-12	Rev 9	
Page 0-13	Rev 9	
Page 0-14	Rev 9	
Page 0-15	Rev 9	
Section 1 - GENERAL INFORMATION		
Page 1-1	Rev 5	
Page 1-2	Rev 7	
Page 1-3	Rev 7	
Page 1-3a	Rev 7	
Page 1-4	Rev 7	
Page 1-5	Rev 7	
Page 1-5a	Rev 7	
Page 1-6	Rev 7	

Page/Document Reference	**Issue Status**	**Title**
Page 1-7	Rev 7	
Page 1-7a	Rev 7	
Page 1-8	Rev 7	
Page 1-9	Rev 7	
Page 1-9a	Rev 7	
Page 1-10	Rev 7	
Page 1-10a	Rev 7	
Page 1-11	Rev 7	
Page 1-12	Rev 7	
Page 1-13	Rev 6	
Page 1-13a	Rev 9	
Page 1-14	Rev 7	
Page 1-15	Rev 5	
Page 1-16	Rev 5	
Page 1-17	Rev 5	
Page 1-18	Rev 5	
Page 1-19	Rev 8	
Page 1-20	Rev 5	
Page 1-21	Rev 5	
Page 1-22	Rev 9	
Page 1-23	Rev 5	
Page 1-24	Rev 5	
Page 1-25	Rev 5	
Page 1-26	Rev 5	
Page 1-27	Rev 5	
Page 1-28	Rev 5	

Page/Document Reference	Issue Status	Title
Page 1-29	Rev 5	
Page 1-30	Rev 6	
Page 1-31	Rev 5	
Page 1-32	Rev 5	
Page 1-33	Rev 7	
Page 1-34	Rev 7	
Page 1-35	Rev 7	
Page 1-36	Rev 6	
Page 1-37	Rev 7	
Page 1-38	Rev 7	
Documents in Section 1.3 Appendix		
Documents in Section 1.3.2 Calculation Model Drawings		
0C-5949	Issue A	Safkeg-HS Construction
1C-5997	Issue A	Containment Vessel HS Lid Construction
1C-5999	Issue A	Containment Vessel HS Body Construction
3C-6850	Issue A	HS-12x95-Tu Insert Design No.3982 (construction)
3C-6851	Issue A	HS-31x114-Tu Insert Design No. 3985 (construction)
3C-6852	Issue A	HS-55x128-SS Insert Design No. 3987 (construction)
Documents in Section 1.3.3 Licensing Drawings		
1C-5940	Issue G	Cover sheet for Safkeg-HS design no. 3977A (licensing drawing)

Page/Document Reference	**Issue Status**	**Title**
0C-5941	Issue E	Safkeg-HS design no. 3977A (licensing drawing)
0C-5942	Issue C	Keg design no. 3977 (licensing drawing)
0C-5943	Issue B	Cork set for Safkeg-HS (licensing drawing)
1C-5944	Issue C	Containment vessel design no. 3978 (licensing drawing)
1C-5945	Issue D	Containment vessel lid (licensing drawing)
1C-5946	Issue E	Containment vessel body (licensing drawing)
2C-6173	Issue D	HS-12x95-Tu Insert Design No 3982 (Licensing drawing)
2C-6174	Issue D	HS-31x114-Tu Insert Design No 3985 (Licensing drawing)
2C-6176	Issue E	HS-55x128-SS insert design no 3987 (licensing drawing)
2C-6920	Issue A	Silicone Sponge Rubber Disc
1C-7500	Issue B	Cover sheet for Safkeg-HS design no. 3977A - Mallinckrodt Version
0C-7501	Issue B	Safkeg-HS design no. 3977A - Mallinckrodt Version
0C-7502	Issue A	Keg design no. 3977 - Mallinckrodt Version
0C-7503	Issue A	Cork set for Safkeg-HS - Mallinckrodt Version
1C-7504	Issue A	CV design no. 3978 - Mallinckrodt Version

Page/Document Reference	Issue Status	Title
1C-7505	Issue A	CV lid - Mallinckrodt Version
1C-7506	Issue A	CV body - Mallinckrodt Version
1C-7507	Issue A	Containment vessel plug – Mallinckrodt version
2C-7508	Issue B	HS-50x85-SS insert design no 4081
2C-7509	Issue A	Snap Ring
2C-7510	Issue A	Tungsten Liner
Documents in Section 1.3.4 Supporting Documents		
PCS 038	Issue G	Package Contents Specification for Safkeg-HS - Package Design No 3977A
Section 2 - STRUCTURAL EVALUATION		
Page 2-1	Rev 7	
Page 2-2	Rev 7	
Page 2-3	Rev 7	
Page 2-3a	Rev 7	
Page 2-4	Rev 7	
Page 2-5	Rev 7	
Page 2-6	Rev 5	
Page 2-7	Rev 5	
Page 2-8	Rev 5	
Page 2-9	Rev 5	
Page 2-10	Rev 5	
Page 2-11	Rev 5	

Page/Document Reference	Issue Status	Title
Page 2-12	Rev 5	
Page 2-13	Rev 5	
Page 2-14	Rev 5	
Page 2-15	Rev 5	
Page 2-16	Rev 5	
Page 2-17	Rev 5	
Page 2-18	Rev 9	
Page 2-19	Rev 9	
Page 2-19a	Rev 9	
Page 2-20	Rev 5	
Page 2-21	Rev 7	
Page 2-22	Rev 5	
Page 2-23	Rev 5	
Page 2-24	Rev 7	
Page 2-25	Rev 7	
Page 2-26	Rev 7	
Page 2-27	Rev 7	
Page 2-28	Rev 7	
Page 2-29	Rev 5	
Page 2-30	Rev 5	
Page 2-31	Rev 5	
Page 2-32	Rev 5	
Page 2-33	Rev 5	
Page 2-34	Rev 5	
Page 2-35	Rev 5	
Page 2-36	Rev 5	

Page/Document Reference	Issue Status	Title
Page 2-37	Rev 5	
Page 2-38	Rev 5	
Page 2-39	Rev 7	
Page 2-40	Rev 5	
Page 2-41	Rev 5	
Page 2-42	Rev 5	
Page 2-43	Rev 5	
Page 2-44	Rev 5	
Page 2-45	Rev 5	
Page 2-46	Rev 5	
Page 2-47	Rev 7	
Page 2-47a	Rev 7	
Page 2-48	Rev 5	
Page 2-49	Rev 5	
Page 2-50	Rev 5	
Page 2-51	Rev 5	
Page 2-52	Rev 5	
Page 2-53	Rev 5	
Page 2-54	Rev 5	
Page 2-55	Rev 5	
Page 2-56	Rev 5	
Page 2-57	Rev 7	
Page 2-58	Rev 7	
Page 2-59	Rev 5	
Page 2-60	Rev 5	
Page 2-61	Rev 5	

Page/Document Reference	Issue Status	Title
Page 2-62	Rev 5	
Page 2-63	Rev 5	
Documents in Section 2.12.2, Appendix		
CTR 2010/02	Issue A	Prototype Safkeg-HS 3977A/0002 NCT and HAC Regulatory Test Report
SERCO/TAS/002762/01	Issue 1	Compression Testing of Cork
Vectra, L20008/1/R1	Rev 0B	Stress Analysis of Safkeg HS 3977A Containment Vessel
CS 2012/02	Issue A	SAFKEG HS 3977A – Maximum Pressure in CV
CS 2012/03	Issue A	SAFKEG HS 3977A – Package Density
Section 3 - THERMAL EVALUATION		
Page 3-1	Rev 5	
Page 3-2	Rev 5	
Page 3-3	Rev 5	
Page 3-4	Rev 5	
Page 3-5	Rev 9	
Page 3-6	Rev 9	
Page 3-7	Rev 9	
Page 3-8	Rev 9	
Page 3-9	Rev 9	
Page 3-10	Rev 9	
Page 3-11	Rev 9	
Page 3-12	Rev 9	
Page 3-13	Rev 9	

Page/Document Reference	Issue Status	Title
Page 3-14	Rev 9	
Page 3-15	Rev 9	
Page 3-16	Rev 9	
Page 3-17	Rev 9	
Page 3-18	Rev 9	
Page 3-19	Rev 9	
Page 3-20	Rev 9	
Page 3-21	Rev 9	
Page 3-22	Rev 9	
Page 3-23	Rev 9	
Documents in Section 3.5.2, Appendix		
SERCO/TAS/5388/002	Issue 2	Thermal Analysis of the Safkeg HS Design
CS 2012/01	Issue A	SAFKEG HS 3977A – Maximum Temperature of CV Inserts
MURR Report		Hydrogen Generation Analysis – MURR Technical Note
MURR Report	April 2, 2016	Analysis Of The Possibility Of, And Consequences From, Hydrogen Deflagration And Detonation Resulting From Radiolysis-Produced Hydrogen In An Iodine-131 Radiopharmaceutical Solution
CS 2016/27	Issue A	Temperature of Mo-99 Contents in the HS Package
Mallinckrodt Report	V2.2	Radiolytic Gas Formation in Mallinckrodt Produced Mo99 Solutions
Section 4 - CONTAINMENT		
Page 4-1	Rev 7	
Page 4-2	Rev 7	
Page 4-2a	Rev 7	

Page/Document Reference	Issue Status	Title
Page 4-3	Rev 5	
Page 4-4	Rev 5	
Page 4-5	Rev 7	
Page 4-6	Rev 5	
Page 4-7	Rev 5	
Page 4-8	Rev 9	
Page 4-9	Rev 5	
Documents in Section 4.5.2, Appendix		
CS 2012/04	Issue A	SAFKEG-HS 3977A - CV seal leak size for leaktight condition
CS 2012/05	Issue A	SAFKEG-HS 3977A - Gas contents limit for leaktight condition
Section 5 - SHIELDING EVALUATION		
Page 5-1	Rev 7	
Page 5-2	Rev 7	
Page 5-3	Rev 7	
Page 5-4	Rev 7	
Page 5-5	Rev 7	
Page 5-6	Rev 7	
Page 5-7	Rev 7	
Page 5-8	Rev 8	
Page 5-9	Rev 8	
Page 5-10	Rev 7	
Page 5-10a	Rev 7	
Page 5-11	Rev 7	
Page 5-12	Rev 7	

Page/Document Reference	Issue Status	Title
Page 5-13	Rev 7	
Page 5-14	Rev 7	
Page 5-15	Rev 7	
Page 5-16	Rev 7	
Page 5-16a	Rev 7	
Page 5-17	Rev 8	
Page 5-18	Rev 8	
Page 5-19	Rev 9	
Page 5-20	Rev 8	
Page 5-21	Rev 7	
Page 5-22	Rev 7	
Page 5-23	Rev 9	
Page 5-24	Rev 9	
Page 5-25	Rev 9	
Page 5-26	Rev 9	
Page 5-27	Rev 9	
Page 5-28	Rev 7	
Documents in Section 5.5.2, Appendix		
CTR2011/01	Issue D	SAFKEG HS 3977A: Package Activity Limits Based on Shielding
CTR2013	Issue C	Uncertainties Associated with the Proposed Shielding Calculation Method for the SAFKEG-HS 3977A Package
AMEC/SF6652/001	Issue 2	Monte Carlo Modelling of Safkeg HS Container
AMEC/CRM37327/TN_001	Issue 1	HS Container Shielding Assessment with I-131

Page/Document Reference	Issue Status	Title
AMEC/CRM37327/TN_001	Issue 1	HS Container Shielding Assessment with Mo-99
Section 6 - CRITICALITY EVALUATION		
Page 6-1	Rev 5	
Page 6-2	Rev 5	
Documents in Section 6.9, Appendix		
None	-	
Section 7 - OPERATING PROCEDURES		
Page 7-1	Rev 7	
Page 7-2	Rev 9	
Page 7-3	Rev 9	
Page 7-4	Rev 9	
Page 7-5	Rev 9	
Page 7-6	Rev 9	
Page 7-6a	Rev 9	
Page 7-7	Rev 8	
Page 7-7a	Rev 8	
Page 7-8	Rev 9	
Page 7-9	Rev 7	
Page 7-10	Rev 7	
Page 7-11	Rev 7	
Documents in Section 7.5, Appendix		
None	-	
Section 8- ACCEPTANCE TESTS AND MAINTENANCE PROGRAM		

Page/Document Reference	Issue Status	Title
Page 8-1	Rev 5	
Page 8-2	Rev 9	
Page 8-3	Rev 9	
Page 8-4	Rev 9	
Page 8-4a	Rev 7	
Page 8-5	Rev 9	
Page 8-5a	Rev 9	
Page 8-6	Rev 7	
Page 8-7	Rev 8	
Page 8-7a	Rev 7	
Page 8-8	Rev 9	
Page 8-9	Rev 5	
Page 8-10	Rev 7	
Page 8-11	Rev 7	
Page 8-12	Rev 9	
Documents in Section 8.3, Appendix		
None	-	

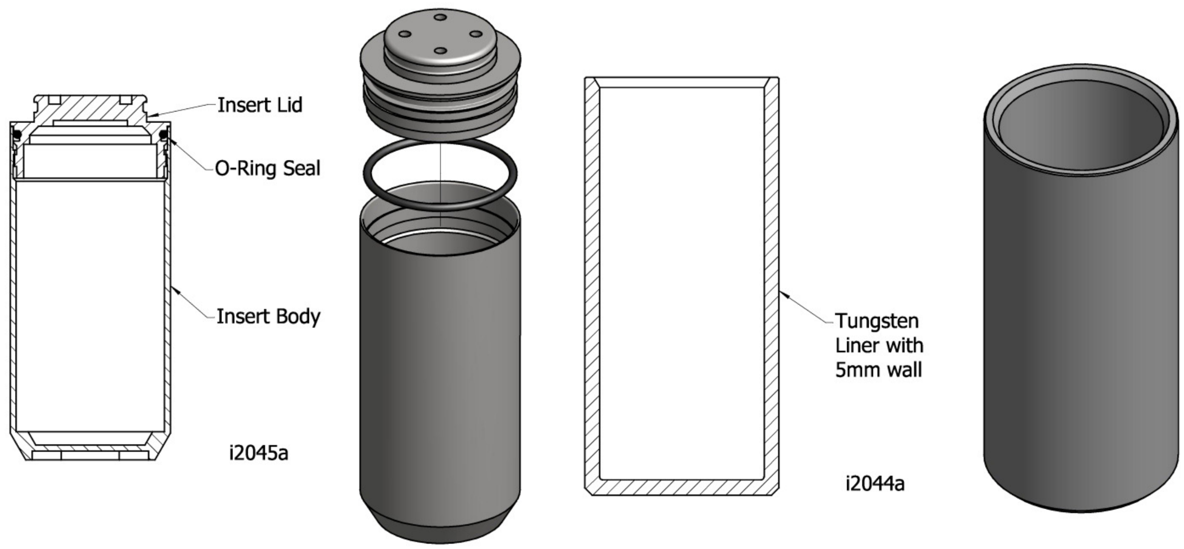

Figure 1-5d Shielding insert HS-50x85-SS– Design # 4081 with Tungsten liner

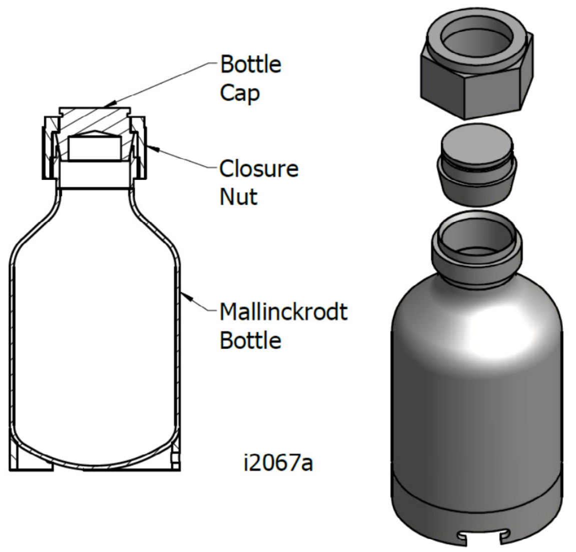

Figure 1-6 Mallinckrodt Product Bottle

Table 1-3-8 CT-8 – Liquid Mo-99 in steel insert (Design No 4081) With Split Lid CV	
Parameter	**Restrictions**
Contents Type name	CT-8 – Liquid Mo-99 in a steel insert with a Tungsten liner
Comments on contents	Mo-99 for use in medical imaging
Insert in CV cavity	HS-50x85-SS Design No 4081 with a tungsten liner shown in drawing 2C-7510
CV Design	CV with split lid shown in drawing 1C-7504.
Maximum quantity of radioactive material	See Table 1-4-8. The maximum specific activity shall be 60 Ci/ml Mo-99.
Maximum mass of radioactive material	808 g (subject to the limits below which provide a maximum for each case)
Mixtures of radionuclides	Mo-99 with its daughter products
Maximum decay heat of radioactive material	5 W
Maximum quantity of fissile material	None
Physical form of radioactive material	Liquid
Chemical form of radioactive material	Mo-99 with its daughter products as natrium molybdate ($NaNO_3$ 1M/NaOH 0.2M)
Pyrophoric contents	The contents shall not be pyrophoric.
Product containers	The Mo-99 liquid shall be carried in a 110 ml stainless steel product bottle (figure 1-6) which locates into the insert using a snap ring.
Location of radioactive material	Within the insert
Maximum weight of contents of the CV	4.89 kg This includes the insert, radioactive material, product containers and tungsten liner.
Maximum weight of contents of the insert	1,615 g
Loading restrictions	None

2.2 Materials

2.2.1 Material Properties and Specifications

The materials used in the construction of the package are listed in Table 2-10. The mechanical properties of the materials used in the structural evaluation of the containment vessel are presented in Sections 2.2.1.1 to 2.2.1.3.

Table 2-10 Packaging Material Specifications

Packaging Component	Material
Keg 3977	
Top and bottom rim	Stainless Steel ASTM A554 Type MT304
Top and bottom skirt	Stainless steel ASTM A240/A240M Type 304L
Keg outer shell	Stainless steel ASTM A240/A240M Type 304L
Keg top flange	Stainless Steel ASTM A240/A240M Type 304L
Keg base plate	Stainless Steel ASTM A240/A240M Type 304L
Outer cork	Agglomerated Cork
Keg liner	Stainless Steel ASTM A240/A240M Type 304L
Keg liner disc	Stainless Steel ASTM A240/A240M Type 304L
Keg lid	Stainless Steel ASTM A240/A240M Type 304L
Keg lid handle	Stainless Steel ASTM A240/A240M Type 304L
Keg lid seal	Nitrile 70 ± 10 IRHD
Keg closure stud	Stainless Steel ASTM A479/A479M 304L
Keg closure nut	Stainless Steel A2-70
Keg closure washers	Stainless Steel A2
Lock pin	Stainless Steel ASTM A479/A479M Type 304L
Fuse plug	Stainless steel A2
Fuse plug alloy	Low melting point alloy with melting point of 95±5^{o}C
Inner Cork Packing	
Cork body and lid	Agglomerated Cork
Containment Vessel 3978	
Flange/cavity wall	Stainless Steel ASTM A479/A479M Type 304L
Outer wall	Stainless steel ASTM A511/A511M Type MT304L
Body shielding	Depleted Uranium alloyed with 2% Molybdenum by weight
Base	Stainless Steel ASTM A479/A479M 304L

Table 2-10 Packaging Material Specifications	
Packaging Component	**Material**
Lid shielding casing	Stainless Steel ASTM A479/A479M 304L
Lid shielding	Depleted Uranium alloyed with 2% Molybdenum by weight
Lid Top	Stainless Steel ASTM A479/A479M 304L
Test point plug	Stainless Steel
Containment seal	Fluoroelastomer (base material VITON GLT)
Test seal	Fluoroelastomer (base material VITON GLT)
Test point seal	Fluoroelastomer (base material VITON GLT)
Closure screws	Alloy steel ASTM A320/A320M Type L43
Jacking screw	Steel
12x95 Tu Insert	ASTM B777 Class 3 Tungsten Alloy
31x114 Tu Insert	ASTM B777 Class 3 Tungsten Alloy
55x138 SS Insert	Stainless Steel
55x138 SS Insert liner	PTFE
Insert O-ring for 12x95 Tu, 31x114 Tu and 55x138 SS Inserts	Silicone
Silicone Sponge Rubber Disc	Silicone
50x85 SS Insert	Stainless Steel
Tungsten Liner	ASTM B777 Class 3 Tungsten Alloy
50x85 SS Insert O-ring	EPM/EPDM

2.2.1.1 Structural Materials

The containment vessel is fabricated entirely from stainless steel. The structural members in the main are fabricated from Type 304L stainless steel in either plate or bar form. The only exception is the containment vessel bolts which are fabricated from a high strength grade L43 alloy bolting steel material. All the insulating and shock absorbing material is fabricated from resin bonded cork.

The structural evaluation of the containment vessel was assessed under NCT using a temperature range of – 40°C to 158°C. In order to carry out the stress analysis a Poisson ratio of 0.3 and a density of 8030 kg/m^3 were used for the stainless steel 304L components. A Poisson ratio of 0.3 and a density of 7860 kg/m^3 were taken for Grade L43 bolting steel.

The mechanical properties used in the structural analysis are taken from the ASME Section II Part D [2.16]. Table 2-11 provides the mechanical properties of stainless steel 304L, which makes up the majority of the structural component materials, over a range of temperatures. Table 2-12 summarizes the mechanical information for SA-320/A320 Grade L43 Bolting Steel which is used for the bolts in the containment vessel.

Table 3-2 Summary of Package Temperatures under NCT
(Ambient 38°C, with and without insolation)

Location	**Maximum Temperature (°C)**						**Temperature Limit of component (°C)**
	No insolation			**With Insolation**			
Internal Heat Load W	0	5	30	0	5	30	
Shielding Insert	38	60.9	158.4	58.8	80.1	173.2	427 (1)
Shielding Insert Liner	38	60.9	158.4	58.8	80.1	173.2	250
Shielding Insert seal for 12x95 Tu, 31x114 Tu and 55x138 SS Inserts	38	60.9	158.4	58.8	80.1	173.2	204 (5)
Shielding Insert seal for 50x85 SS Insert	38	60.9	NA	58.8	80.1	NA	150 (7)
Containment vessel cavity	38	58.9	148.4	58.8	78.1	163.2	427 (1)
Silicone Sponge Rubber Disc	38	58.9	148.4	58.8	78.1	163.2	200 (6)
Containment vessel lid seal	38	56.2	135.0	59.5	76.4	151.1	205 (4)
Cork (2)	38	56.2	135.0	59.5	76.4	151.1	160 (3)
Keg lid	38	39.7	46.5	97.5	98.4	102.4	427 (1)
Keg bottom	38	41.5	56.8	69.9	72.0	84.5	427 (1)
Mid height on keg surface	38	39.8	46.8	65.4	66.4	71.2	427 (1)

1. The allowable temperature limit for steel when relied upon for structural support is 427°C as specified in ASME Section II Part D [3.1].
2. Maximum cork temperature is same as the CV which it carries.
3. [3.7]
4. Viton GLT O-ring temperature limit for continuous operation
5. Silicon O-ring temperature limit for continuous operation

6. Manufacturers temperature limit for continuous operation

7. EPM/EPDM O-ring temperature limit for continuous operation

The minimum package temperature is limited by the ambient conditions, therefore the minimum temperature of the package is assumed to be -40°C.

Table 3-3 summarizes the data obtained from the AMEC report (section 3.5.2) for the peak temperatures in the package resulting from the HAC thermal test and the period of post test heating, of the internal parts of the package. As can be seen, all the CV components remain within acceptable temperature limits.

Table 3-3 Summary of Package Temperatures for HAC Thermal Test
(Ambient 38°C, with insolation)

Internal Heat Load W	0W		5W		30W		**Temperature Limit of component (°C)**
Location	Max T (ºC)	Time After Fire Start (mins)	Max T (ºC)	Time After Fire Start (mins)	Max T (ºC)	Time After Fire Start (mins)	
Shielding Insert	115.4	210	134.0	210	218.0	180 (2)	427
Shielding Insert Liner	115.4	210	134.0	210	218.0	180 (2)	250
Shielding Insert seal	115.4	210	134.0	210	218.0	180 (2)	250
Containment vessel cavity	115.4	210	132.0	210	208.0	180	1427
Silicone Sponge Rubber Disc	115.4	210	132.0	210	208.0	180	300
Containment vessel lid seal	115.3	254	130.1	244	196.3	210	205
Cork	787.4	30	787.6	30	788.2	30	N/A (1)
Depleted Uranium Shielding	115.3	210	130.3	210	198.2	180	1120
Keg lid	784.3	30	784.4	30	785.0	30	1427
Keg bottom	788.6	30	788.7	30	789.3	30	1427
Mid height on keg surface	786.6	30	786.6	30	786.1	30	1427

1 Cork ablates under high temperatures and leaves a low density carbonaceous layer which provides insulation equivalent to still CO_2

2 The inserts would reach a maximum temperature nominally at the same time as the peak in the CV temperature with possibly a small lag.

3.1.4 Summary Tables of Maximum Pressures

Table 3-4 shows the maximum design pressure under NCT and HAC.

Table 3-4 Summary Table of Maximum Pressures in the Containment Vessel

Case	Maximum Pressure kPa (bar) abs
MNOP	7 bar (700 kPa) gauge 8 bar (800 kPa) abs
HAC	10 bar (1,000 kPa) gauge 11 bar (1,100 kPa) abs

3.2 Material Properties and Component Specifications

3.2.1 Material Properties

The materials affecting heat transfer within and from the package are cork, depleted uranium and stainless steel type 304L. The thermal properties for each material are summarized in Table 3-5.

Table 3-5: Thermal Properties of Packaging Materials

Material	Property	Temperature (°C)	Value	Reference
304 Stainless Steel	Conductivity	21	14.9 W/m/K	[3.1]
		38	15.0 W/m/K	
		93	16.1 W/m/K	
		149	16.9 W/m/K	
		205	18.0 W/m/K	
		260	18.9 W/m/K	
		316	19.5 W/m/K	
		371	20.4 W/m/K	
		427	21.1 W/m/K	
		482	22.0 W/m/K	
		538	22.8 W/m/K	

Table 3-5: Thermal Properties of Packaging Materials

Material	Property	Temperature (°C)	Value	Reference
		593	23.5 W/m/K	
		649	24.2 W/m/K	
		705	25.1 W/m/K	
		760	25.8 W/m/K	
		816	26.5 W/m/K	
	Density	-	7900 kg/m^3	[3.2]
	Specific Heat	21	483 J/kg/K	[3.1]
		38	486 J/kg/K	
		93	506 J/kg/K	
		149	520 J/kg/K	
		205	535 J/kg/K	
		260	544 J/kg/K	
		316	551 J/kg/K	
		371	559 J/kg/K	
		427	562 J/kg/K	
		482	570 J/kg/K	
		538	577 J/kg/K	
		593	583 J/kg/K	
		649	585 J/kg/K	
		705	591 J/kg/K	
		760	596 J/kg/K	
		816	601 J/kg/K	
Depleted Uranium	Conductivity	0	23.1 W/m/K	[3.3]
		400	32.5 W/m/K	[3.3]
	Density	-	18,650 kg/m^3	[3.4]
	Specific Heat	0	117.5 J/kg/K	[3.3]
		300	142.0 J/kg/K	
Cork	Conductivity	-	See Figure 3-3	[3.7]
	Density	-	290 kg/m3	[3.7]
	Specific Heat	-	1650 J/kg/K	[3.7]e

During a fire the cork experiences temperatures up to ~800°C. No measurements of cork properties at high temperatures are available. However, the HAC thermal test has been performed on the Safkeg-LS 3979A package as detailed in report CTR 2009/21, this package uses the same cork specification as the HS design. The test has then been simulated using the LS model in order to validate the model and, to demonstrate the acceptability of the thermal properties assumed for the cork. It was found that, in order to obtain agreement with the measured temperatures, the thermal conductivity of the cork needed to be increased by 50%. It should be noted that these thermal properties, validated against the furnace test, are ‘effective’ properties that include any effects of charring and shrinkage of the cork.

The NCT thermal test performed on the Safkeg-HS 3977A package has also been simulated using the model. As with the LS design it was found that, to produce the best agreement with the measured temperatures, the thermal conductivity of the cork needed to be reduced by 15%. Because cork is a natural material, this degree of variation in conductivity may well be possible. To ensure that all the calculations performed with the model are pessimistic, the lower, fitted conductivity has been assumed for the calculations of temperature during normal transport and the higher, measured thermal conductivity assumed for the calculations of temperature during the fire accident. Values used for the thermal conductivity of the cork are shown in Figure 3-2.

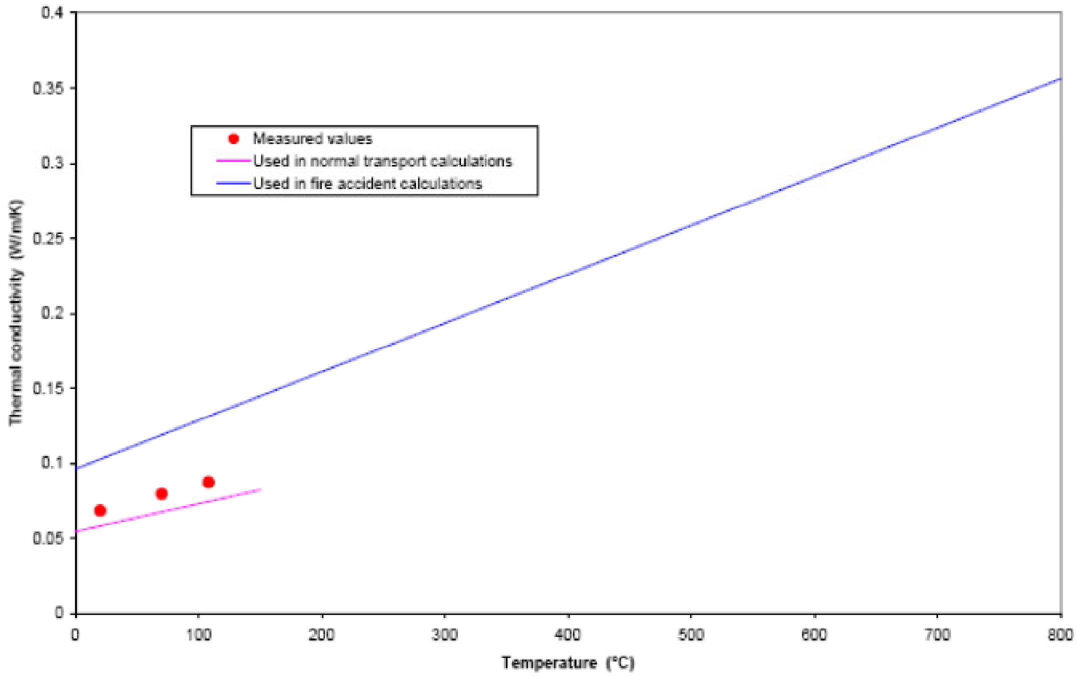

Figure 3-2 Thermal Conductivity of Cork

The package surface and internal emissivity values used in the thermal evaluation are given in Table 3-6. The emissivity of stainless steel can vary significantly depending upon the surface finish and level of oxidation. The values presented in Table 3-6 are shown to produce good agreement with the measured temperatures in the steady state heating test carried out in report CTR 2010/02 and are discussed in depth in Sections 3.3 and 3.4.2.

Table 3-6: Emissivities used in the Thermal Model

Material	Condition	Value	Reference
304 Stainless Steel	Internal surfaces	0.2	[3.8]
	External surface – Heating test and NCT	0.25	[3.8]
	External surface – fire test	0.8	[3.9]
Cork	All conditions	0.95	[3.10]
Depleted Uranium	Internal surfaces (un-oxidised)	0.31	

3.2.2 Component Specifications

The components that are important to thermal performance are the outer keg, the cork packing material, the containment vessel and the containment seal. The outer keg and the containment vessel are manufactured from stainless steel 304L with the containment seal manufactured from Viton GLT.

The allowable service temperatures for all the components cover the maximum and minimum temperatures anticipated during NCT and HAC conditions of transport. The minimum allowable service temperature for all components is less than or equal to -40°C. The maximum service temperature for each component is determined from the temperatures calculated from the thermal model.

The upper temperature reached by the stainless steel in the keg is 102°C for continuous operations and 788°C for short term operations. The upper temperature reached by the stainless steel in the containment vessel is < 163°C for continuous operations and 210°C for short term operations under HAC conditions.

The allowable temperature limit for steel when relied upon for structural support is 427°C as specified in ASME Section II Part D [3.1]. During the HAC test the temperature of the keg skin exceeds this temperature for a short period of time. During a fire the steel is providing shielding to the cork from the direct exposure of the flames, its main function is not providing structural support therefore the maximum allowable temperature it can reach is 1427°C, which is the melting point of steel.

The depleted uranium shielding reaches a maximum temperature of 198°C during HAC conditions. The depleted uranium does not provide any structural function therefore it is limited by its melting point of 1130°C.

The cork is unaffected by temperatures up to 160°C which is higher than the maximum temperature for the cork packing under NCT where cork temperatures may reach 151°C for athin layer of the cork adjacent to the CV. Under HAC conditions the cork reaches a maximum temperature of 788°C. Cork ablates under high temperatures and leaves a low density carbonaceous layer which provides insulation equivalent to still CO_2.

The upper temperature reached by the containment seal is 151°C for continuous operation (NCT conditions), and 196°C for short term operation (HAC conditions). These temperatures are within the allowable range of the O-ring material properties.

3.3 Thermal Evaluation under Normal Conditions of Transport

The Safkeg-HS 3977A package has been evaluated for compliance with 10 CFR 71 by thermally modeling the package. The thermal model has been validated by comparison against both an experimental self heating test carried out on the 3977A package with a standard containment vessel lid (simulating normal conditions of transport) and a furnace test (simulating the fire accident), carried out on a similar package 3979A.

NCT Thermal Test

A 30 W cartridge heater located inside an aluminum block was placed in the cavity of the containment vessel. The package was orientated in the vertical position on a wooden board covered with aluminum foil. The temperature of the package was monitored using thermocouples located in seven positions on and in the package three thermocouples on the containment vessel surface, one on the top cork, one on the keg liner and two on the keg surface. Temperatures were logged every minute until the package temperature reached equilibrium. The surface temperature of the package was then mapped using thermocouples attached to the surface of the package and a hand held digital thermometer. The package was repositioned in the horizontal orientation and the temperatures logged until the package reached thermal equilibrium. The surface temperature of the keg was mapped using thermocouples attached to the surface of the package and a hand held digital thermometer.

Thermal Model

The analytical model is described in detail the Report AMEC/6335/001 (Section 3.5.2). The model used was that of the standard lid containment vessel. This bounds that of the split lid because the 0.5 mm air gap added in the lid of the CV would reduce the temperature of the O-rings and the CV closure. The temperature of the CV plug would increase however the thermal model assumed 5W would be applied over the whole cavity of the CV, in reality the Mo-99 contents would be at the bottom of the insert therefore the top of the insert and the plug would be cooler that determined in the thermal model, plus the DU and stainless steel have melting points that far exceed the possible temperature of the plug.

3.3.1 Heat and Cold

The finite element model has been used to determine the temperature of the container under normal conditions of transport in the absence of solar insolation as described in the report AMEC/6335/001 (Section 3.5.2).

The maximum temperatures reached, under NCT with no insolation and ambient of 38°C, at the containment seal and on the keg surface are given in Table 3-2. As shown the maximum temperature of the accessible surface is 42°C which is reached on the keg lid, the base of the keg reaches 45°C however this surface is not accessible and therefore not considered. This demonstrates that the package is capable of fulfilling the requirements of 71.43 (g) as the accessible surface temperature is less than 50°C with maximum contents heat load of 30W.

The package temperatures have also been modeled under normal conditions of transport and subject to solar insolation as described in the report AMEC/6335/001 (Section 3.5.2).

Figure 3-3 shows the transient temperature at various locations on the outer surface of the keg with a 30W heat load. The highest temperatures occur on the top of the container because the insolation flux is greater on the top than on the side. The maximum predicted temperature, which occurs on the top, is 102°C. Figure 3-4 shows the transient temperature at the inner containment vessel lid seal. It can be seen that the maximum temperature has effectively been reached after 1½ days. The maximum seal temperature is predicted to be 151°C. Figure 3-5 shows the maximum temperatures throughout the package under NCT.

The peak temperatures experienced during NCT conditions with insolation are shown in Table 3-2 along with the allowable maximum temperatures for each component listed. Each component has a thermal margin with the smallest being the containment seal with a thermal margin at 4°C.

For the NCT cold evaluation the package is assumed to be in an ambient of -40°C, with zero insolation and zero heat decay. No analysis has been carried out because it has pessimistically been assumed that the package and all the components will eventually reach thermal equilibrium at -40°C. This temperature is within the allowable service limits for all the components.

The temperatures reached are within the bounding conditions for the package which are as follows:

NCT Operating Condition	CV
Assumed Max. Temperature	°C
Max. Pressure	7 bar (700kPa) gauge 8.0 bar (800kPa) abs
Min. Temperature	-40°C
Min. Pressure	-1 bar (-100kPa) gauge 0 kPa (0 bar) abs

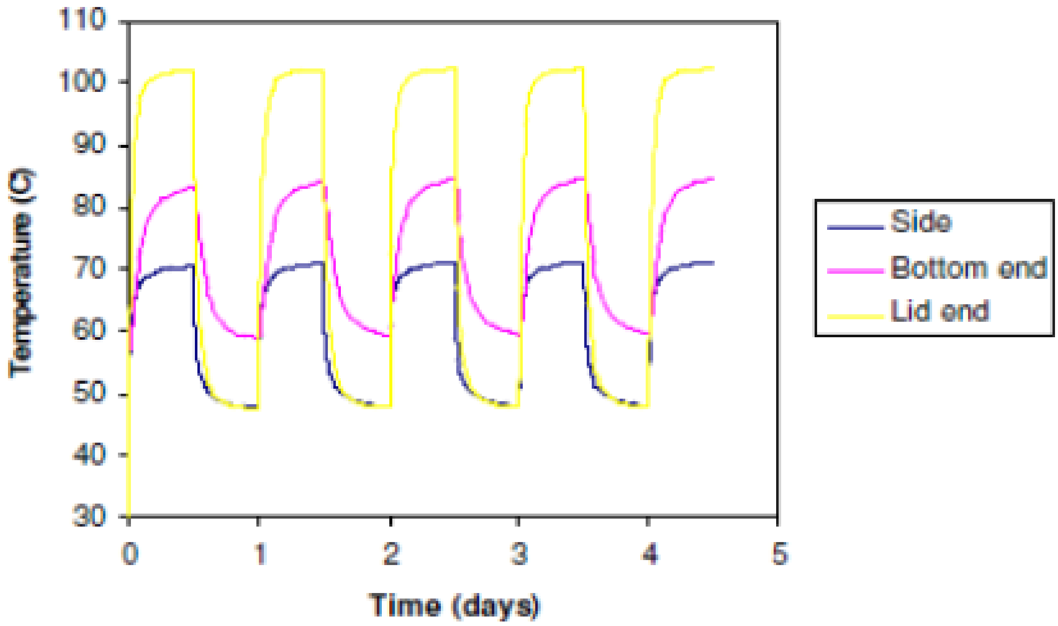

Figure 3-3 Predicted temperature on the Outside of the Keg During Normal Transport with Insolation

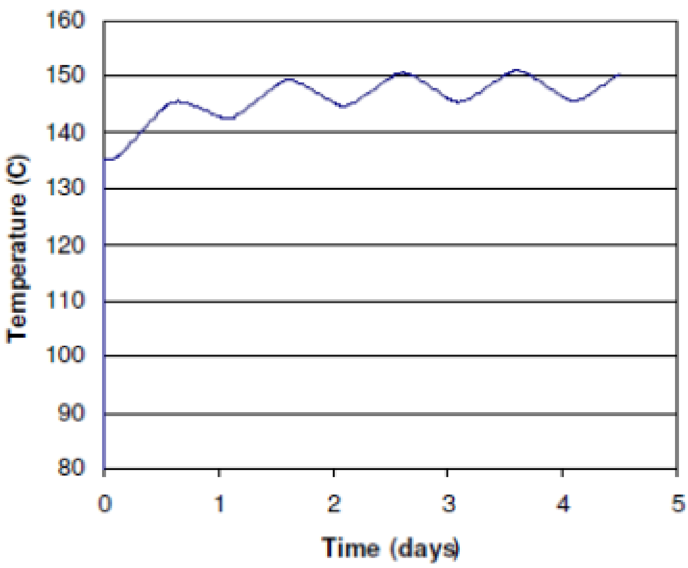

Figure 3-4 Predicted Temperature at the Containment vessel lid Seal During Normal Conditions of Transport with Insolation

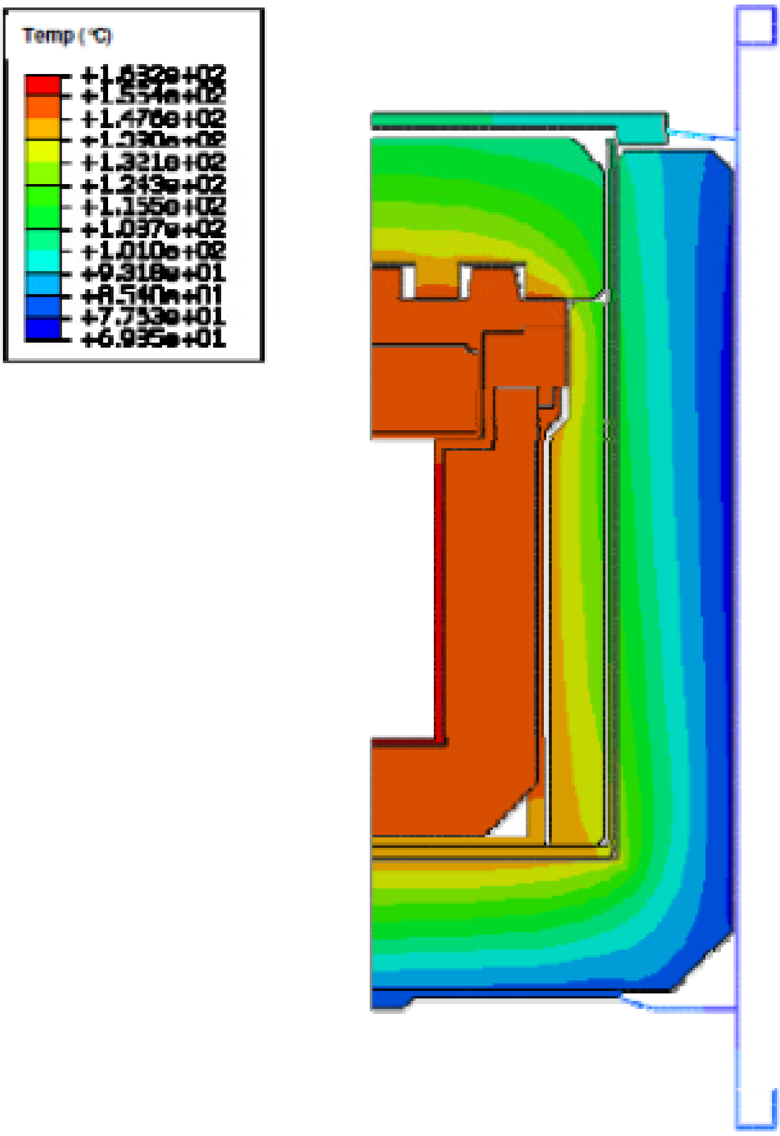

Figure 3-5 Predicted Temperature Profile under Normal Conditions of Transport With Solar Insolation and 30W heat load

3.3.2 Maximum Normal Operating Pressure [71.33 (b)(5)]

The MNOP is 7 bar (700 kPa) gauge.

For solid contents emitting 30W, under NCT the maximum temperature of the CV is 163°C and the maximum temperature of the Shielding Insert and air within the CV is 173°C. Assuming the content were loaded at 20°C and a pressure of 1 bar abs, the pressure at the maximum temperature of the Shielding Insert, calculated according to Boyle's and Charles' Laws, would be 1.63 bar (163 kPa) gauge (see Calculation Sheet CS 2012/02),which is well within the design envelope.

With regards to the liquid content the maximum normal operating pressure is calculated using the maximum temperature during NCT, the free volume of the containment vessel cavity and vials and all possible sources of gas generation and gases that are present on loading the containment vessel. For I-131 this includes gases present in the CV on loading, Xe-131 generation and radiolytic decomposition over a 28 day period.

For the I-131, under NCT maximum temperature of the CV is 78°C and the maximum temperature of the Shielding Insert and air within the CV is 80°C. (Section 3.1.3, Table 3-1). There is no pressure increase due to the vapour pressure of the liquid contents (the liquid contents are aqueous with a boiling point of 100°C) as the temperature is < 100°C.

The maximum free volume of the containment vessel cavity is 216.4 cm^3. This corresponds to the free volume that surrounds the insert, the volume around the containment vessel lid up to the seals and the free volume inside the insert and product bottles.

MURR have calculated that each I-131 vial will generate 89 cm^3 of Hydrogen over 28 days as detailed in the technical note listed in section 3.5.2. If 2 vials are shipped this equates to 178 cm^3 of hydrogen. In a free volume of 216.4 cm^3 along with heating of the gases on loading this would lead to a MNOP of 1 barg, which is below the design pressure of 7 barg. The generation of Xe-131 only leads to an increase in pressure of 4×10^{-6} bar, therefore it can be neglected from the calculation of the MNOP.

For Mo-99 the maximum temperature of the contents within the insert is 84.56°C as calculated in CS 2016/28 (section 3.5.2). This temperature assumes a constant 5W heating over the course of a year, however in reality the thermal power of the contents decreases over time. The maximum free volume of the containment vessel is 233 cm^3. This corresponds to the free volume inside the insert, product bottle, the free volume that surrounds the insert and the volume around the containment vessel lid up to the seals.

The Mo-99 contents generate hydrogen due to radiolysis. The Mo-99 producer has carried out experiments, to determine the radiolytic gas generation of the Mo-99 solution contained in the stainless steel bottles described in section 1 of this SAR. The results of these experiments are attached in section 3.5.2. From these experiments a linear fit of the gas formation verses the specific activity of the solution has been determined, which allows the gas formation to be calculated for a specific activity. All the data used to prepare the analytical fit have been extrapolated to t=∞, therefore the results conservatively include 100% of the decay of the Mo-99 and daughter product.

For a range of specific activities from 60 Ci/ml to 13.33 Ci/ml (which is the lowest activity the liquid could have with a volume of 75 ml) the gas formation was calculated using the linear fit equation. All the experimental testing was carried out between 28.1°C and 33.8°C. Work carried out on similar solutions indicate that gas generation rates increase by 50% from 25 to 300°C[3.1][3.14], therefore from 20°C to 84.56°C we would expect it to increase by (84.56-20)/(300-20)=0.2 or 20%, therefore the gas generation amount calculated was increased by 20% to account for the variation in gas generation rates with temperature. Using the free volume in the containment vessel and the volume of the solution the pressure was determined at 20°C. It was then assumed this gas would be heated to a peak temperature of 84.56°C. The results of these calculations are shown below:

Volume (ml)	16.667	25	35	45	55	65	75
Specific Activity (Ci/ml)	60.00	40.00	28.57	22.22	18.18	15.38	13.33
Free volume (cm^3)	216.333	208	198	188	178	168	158
Pressure in insert 20°C (Barg)	4.22	4.08	3.90	3.70	3.48	3.23	2.95
Pressure in insert 84.56°C (barg)	5.15	4.98	4.76	4.52	4.25	3.94	3.60

The highest pressure calculated was 5.15 barg for a solution with an activity of 60 Ci/ml and a dispensed product volume of 16.667 ml. This pressure is below the bounding maximum pressure for NCT operating conditions.

The bounding temperatures and pressures for the package are as follows.

NCT Operating Condition	CV
Assumed Max. Temperature	160°C
Max. Pressure	800kPa (8.0 bar) abs
Min. Temperature	-40°C
Min. Pressure	0 kPa (0 bar) abs

The producer of the Mo-99 performed mass spectrometer measurements of the gas samples obtained during the radiolytic gas generation calculations. Of the 2 samples tested the results were 1.8% and 0.8% hydrogen by volume of the pure evolved gas. This is an average of 1.3%, with a 2σ uncertainty of 1.4%. So the concentration of hydrogen in the pure evolved radiolysis product is conservatively estimated to be 2.7% by volume. This is well below 5% by volume and therefore does not constitute a risk of flammability or ignition.

The hydrogen generation calculations for the I-131 contents indicate the hydrogen concentration is 45%. Under normal conditions of transport (NCT) all hydrogen will be trapped in the product container within the insert, and no source for ignition exists. If somehow the product container fails, and the hydrogen escaped into the insert, and then the insert were to leak as well, into the containment vessel, and somehow ignition were to occur, the total energy release would be 966 Joules (231 calories).

The energy content of combustion of evolved hydrogen is negligible compared to the heating of the cask from the decay of I-131. For example, the decay heating rate of 200 Ci of I-131 was previously calculated to be 0.656 watts or 0.656 J/sec which would release 966 Joules of energy in less than one-half hour. Thus, the heating created by ignition of all of the hydrogen generated over 28 days would be negligible compared to the heating of the package by the decay of I-131. Additional perspective is gained by noting that the spontaneous combustion of all hydrogen produced over 28 days would heat a cup of water 4^{o}C.

These calculations and experiments indicate that hydrogen ignition in the case of I-131 liquid contents is not a credible source of risk to the public, see section 3.5.2.

3.4 Thermal Evaluation under Hypothetical Accident Conditions

3.4.1 Initial Conditions

The initial conditions used for the thermal model of the fire test are taken at the end of a 12 hour period of insolation under Normal Conditions of Transport with a content decay heat of 30 W. All components are at their maximum temperatures as shown in Table 3-2. A series of NCT and HAC drop and penetration tests was carried out on a prototype package (see Section 2.12.2). These tests caused denting of the top and bottom skirts of the package with minimal damage to the keg body.

These ‘skirts’ are not significant to the thermal performance and it is judged that the damaged ‘skirt’ would provide greater protection in a fire than an undamaged ‘skirt’ (since, when bent over, it will provide shielding of the top and bottom of the keg from the fire). The finite element model used to model the fire accident was therefore unchanged from that used to model Normal Conditions of Transport.

3.4.2 Fire Test Conditions [71.73 (c)(4)]

The thermal assessment of the package under fire conditions has been carried out using a finite element model and validated against a fire test carried out on a prototype Safkeg-LS 3979A package. The model and analysis used is described in detail in section 5 of the Report SERCO/TAS/5388/002 (Section 3.5.2).

3.4.3 Maximum Temperatures and Pressure

The maximum temperatures experienced by the components of the Safkeg-HS 3977A package calculated under a HAC fire test, with an ambient temperature of 38^{o}C and insolation, are given in Table 3-3. The temperature each component reaches during the HAC thermal test is within it maximum allowable service temperature.

At the end of the heating phase the external surface of the keg is close to the temperature of the fire (800°C). Figure 3-6 shows the predicted temperature on the exterior surface of the keg. The outer skin of the keg heats up and cools down rapidly because it is insulated from the inner containment vessel by the cork. The temperature of the keg lid changes more slowly than that of the side or base because the lid is thicker than the outer shell and therefore has a greater thermal capacity.

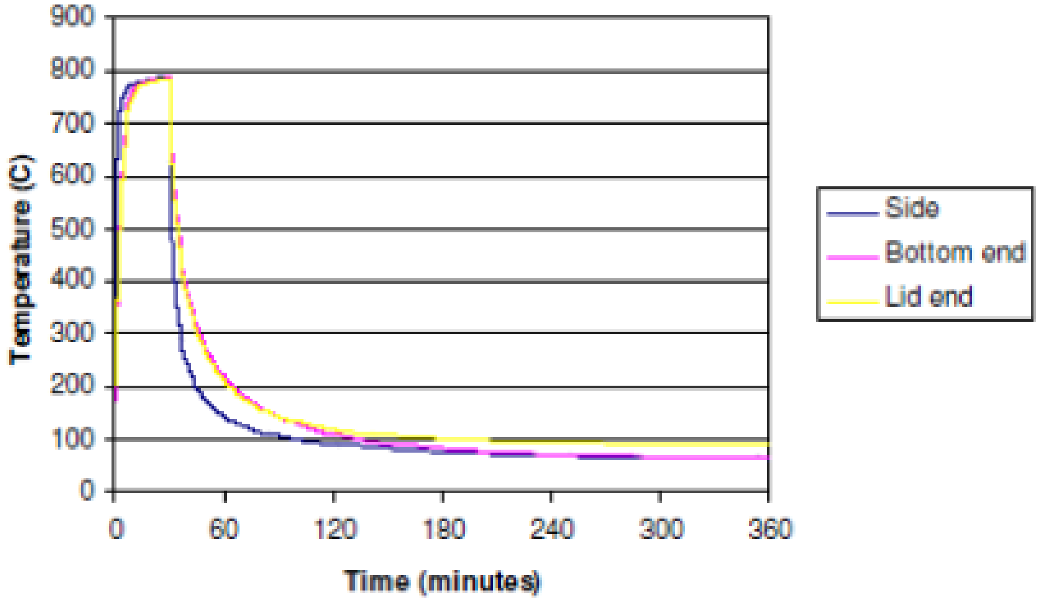

Figure 20 – Predicted Temperature on the Outside of the Keg during the Fire Accident – Internal Heat Load of 30W

Figure 3-6 Predicted Temperature of the Outside of the Keg during the Fire Test and 30W heat load

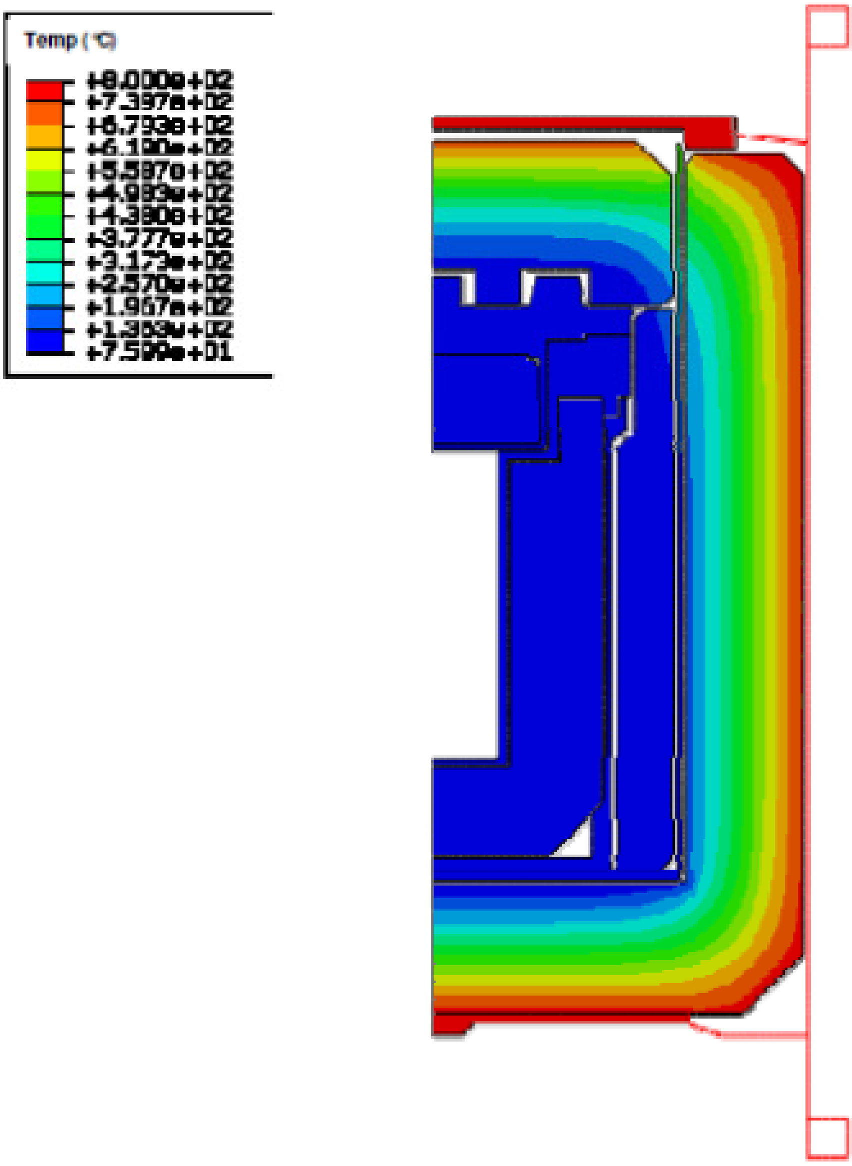

Figure 3-7 Predicted Temperature Profile at the end of the Heating Phase of the Fire Accident and a 30 W heat load

Figure 3-8 shows the predicted temperature of the inner containment vessel seal during and after the thermal test. The lid seal reaches a maximum temperature of 192°C after 3 ½ hours. A similar maximum temperature is experienced by the depleted uranium shielding this temperature is well below its melting point of 1130°C.

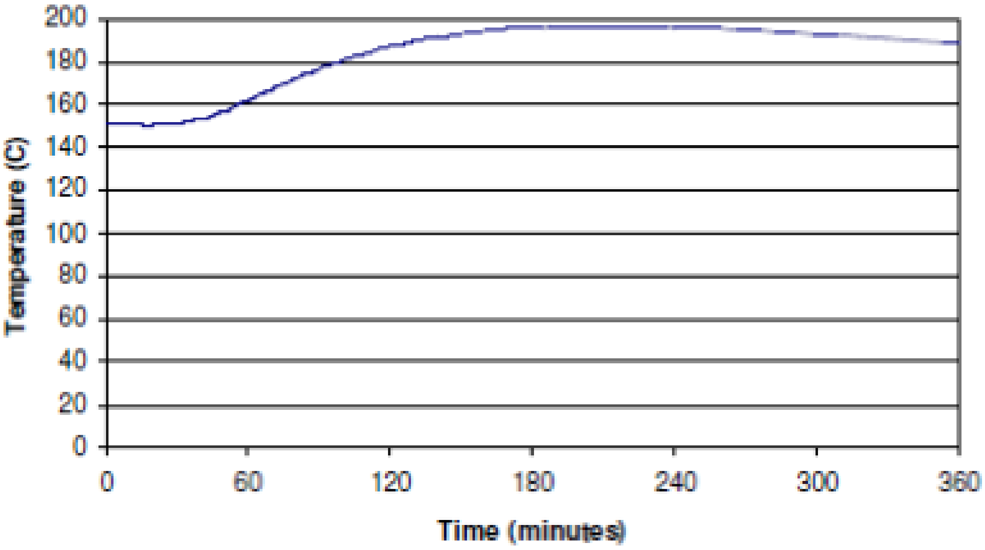

Figure 21 – Predicted Temperature of the Containment Vessel Lid Seal during the Fire Accident – Internal Heat Load of 30W

Figure 3-8 Predicted Temperature of the Containment Vessel Lid Seal during the Fire Test with a 30 W source

The Design Pressure of the CV is 10 bar (1,000 kPa) gauge.

For solid contents emitting 30W, under HAC the maximum temperature of the CV is 208°C and the maximum temperature of the Shielding Insert and air within the CV is 218°C. Assuming the content were loaded at 20°C and a pressure of 1 bar abs, the pressure at the maximum temperature of the Shielding Insert, calculated according to Boyle's and Charles' Laws, would be 1.8 bar (180 kPa) gauge (see Calculation Sheet CS 2012/02 in section 2.12.2), which is well within the design envelope.

For I-131 liquid contents emitting 5W, under HAC the maximum temperature of the CV is 132°C and the maximum temperature of the insert is 134 °C (Section 3.1.3, Table 3-1). Assuming the pressure at NCT is calculated as the maximum of 4.19 barg, the pressure at the maximum temperature of the CV, calculated according to Boyle's and Charles' Laws, would be 4.8 bar (138 kPa) gauge. However, the vapour pressure of the liquid contents (the liquid contents are aqueous) would be 2 bar gauge (from steam tables). Therefore the maximum pressure within the CV would be 6.83 bar gauge which is well within the design envelope.

For Mo-99 liquid contents emitting 5W, under HAC the maximum temperature of the CV is 132°C and the maximum temperature of the contents is 143.82°C (CS 2016/28 section 3.5.2). Assuming the pressure at NCT is calculated as the maximum of 5.15 barg, the pressure at the maximum temperature of the contents, calculated according to Boyle's and Charles' Laws, would be 5.99 bar gauge. However, the vapour pressure of the liquid contents (the liquid contents are aqueous) would be 3 bar gauge (from steam tables). Therefore the maximum pressure within the CV would be 8.99 bar gauge which is well within the design envelope. The temperatures reached are within the bounding conditions for the package which are as follows:

HAC Operating Condition	CV
Assumed Max. Temperature	200°C
Max. Pressure	10 bar (1,000 kPa) gauge 11 bar (1,100 kPa) abs
Min. Temperature	-40°C
Min. Pressure	-1 bar (-100 kPa) gauge 0 bar (0 kPa) abs

3.4.4 Maximum Thermal Stress

As discussed in section 2.7.4.3 the NCT heat calculations bound the HAC test results. The resulting stresses from the NCT heat results are discussed in section 2.6.1.3 and 2.6.1.4. All the stresses calculated are within the allowable limits for the containment vessel.

3.4.5 Accident Conditions for Fissile Material Packages for Air Transport [71.55(f)]

Not applicable – air shipment of fissile material is not specified.

3.5 Appendix

3.5.1 References

[3.1] American Society of Mechanical Engineers (ASME) Boiler and Pressure Vessel Code, Section II, Part D, 2001 Edition

[3.2] Design Manual for Structural Stainless Steel (Second edition), The Steel Construction Institute, Building series, Vol 3

[3.3] Edwards A.L, 'For Computer Heat-Conduction Calculations a Compilation of Thermal Properties Data', UCRL-50589, 1969

[3.4] Goodfellows data sheet, http://www.goodfellow.com/AntimonialLead.html

[3.5] The Equilibrium Diagram of the System Lead-Tin, London Institute of Metals, 1951

[3.6] CRC, Handbook of Chemistry and Physics, 75th Edition, 1994-1995 CRC Press

[3.7] Croft Associates Ltd, Effects of Temperature on Resin Bonded Cork, TR 97/03/01.

[3.8] Touloukian & DeWitt, Thermal Radiative Properties – Metallic elements and alloys, Thermophysical properties of matter, Vol 7, Pub IFI/PLENUM, 1970

[3.9] Title 10, Code of Federal Regulations, Part 71, Office of the Federal Register, Washington, DC, 2009

[3.10] The Emissivity of Various Materials Commonly Encountered in Industry', Land pyrometers Technical Note 101

[3.11] Parker Hannifin Corporation, Parker O-ring Handbook, ORD 5700/USA, 2001

[3.12] Abaqus version 6.8-1, Dassault Systemes Simulia Corp

[3.13] Advisory Material for the IAEA Regulations for the Safe Transport of Radioactive Material', 2005 Edition, IAEA Safety Guide No. TS-G-1.1 (Rev. 1), 2008

[3.14] g-Values for gamma-irradiated water as a function of temperature, A. JOHN ELLIOTM, ONIQUE P. CHENIER, and DENIS C. OUELLETTE. Can. J. Chem. 68, 712 (1990).

3.5.2 Supporting Documents

Document Reference	Title
AMEC/6335/001	Thermal Analysis of the SAFKEG HS Design
CS 2012/01	SAFKEG-HS 3977A – Maximum temperature of CV inserts
	Hydrogen Generation Analysis – MURR Technical Note
	Analysis Of The Possibility Of, And Consequences From, Hydrogen Deflagration And Detonation Resulting From Radiolysis-Produced Hydrogen In An Iodine-131 Radiopharmaceutical Solution
CS 2016/27	Temperature of Mo-99 Contents in the HS Package
V2.2	Radiolytic Gas Formation in Mallinckrodt Produced Mo99 Solutions

4.4.2 Maintenance Leak Rate Test

If any maintenance activities are undertaken on the containment boundary, a helium leak rate test is required to confirm that any repairs or replacements have not degraded the containment system performance. The required leak rate has a pass rate of $\leq 10^{-7}$ ref.cm^3/s.

The requirements for the maintenance leak rate test are specified in Section 8.2.2.

The confinement capability of the inserts is assured by the requirements specified in Section 8.2.2.

4.4.3 Periodic Leak Rate Test

A periodic helium leak rate test is required to be carried out annually with a pass rate of $\leq 10^{-7}$ ref.cm^3/s. This test confirms that the containment boundary capabilities have not deteriorated over an extended period.

The requirements for the periodic leak rate test are specified in Section 8.2.2.

The confinement capability of the inserts is assured by the requirements specified in Section 8.2.2.

4.4.4 Pre-shipment Leak Rate Test

Prior to shipment, each package is required to be leak rate tested using the gas pressure rise or gas pressure drop method, with a pass rate of 5×10^{-4} ref.cm^3/s. This test confirms the CV is correctly assembled prior to shipment.

The requirements for the pre-shipment leak rate test are specified in Section 7.1.3.

The confinement capability of the inserts is assured by the requirements specified in Section 7.1.2.

4.5 Appendix

4.5.1 References

[4.1] Title 10, Code of Federal Regulations, Part 71, Office of the Federal Register, Washington D.C.

[4.2] ASME III Division 1 – Subsection NB, Class One Components, Rules for Construction of Nuclear Facility Components, ASME Boiler and Pressure Vessel Code, 2001 edition, the American Society of Mechanical Engineers, New York, New York

[4.3] Parker Hannifin Corporation, Parker O Ring Handbook, ORD 5700/USA, 2001

Table 5-6 - Summary of Dimensions Used in Microshield Model				
Feature	Thickness (cm)			Notes
	3982	3985	3987	
				air in the model
3977 outer skin	0.4	0.4	0.4	Iron was used for this material in Microshield

5.4.2 Material Properties

The material properties used for the MCBEND shielding evaluation are given in Table 5-7. The MCBEND model was used to determine the location of the point source that gave the highest dose rate and validate the Microshield model for the tungsten inserts and also determine the package surface dose for 200 Ci of I-131 and 1000Ci of Mo-99 in the stainless steel inserts.

The Microshield model was set up using the source locations in MCBEND and a runs were performed with 3000 Ci of Cs-137. The results obtained were compared to the MCBEND results. The Microshield results gave a higher dose rate than MCBEND. Therefore in order to match the results given in MCBEND the density of the uranium and tungsten were reduced to far below the actual density of the components.

For the Microshield model iron was used in place of stainless steel, iron has a lesser density than stainless steel. The densities used in the Microshield model are given in Table 5-8. The cork has been conservatively modelled as air in both MCBEND and Microshield.

Table 5-7 -Shielding Material Properties in MCBEND model			
Material	Density (g/m^3)	Elemental Composition	Mass Fraction
Stainless steel	8.027	Cr Mn Fe Ni	0.19 0.02 0.6975 0.0925
Depleted Uranium	18.65	U Mo	0.98 0.02
Tungsten	18	W Fe Ni	0.95 0.015 0.035
Stainless Steel 430 (magnetic cap)	7.75	C Cr Mn Si Fe	0.0012 0.17 0.01 0.01 0.8088

The highest dose rate at the surface of the package for a point source in all positions within an insert is seen on the side surface when the point source is eccentred at the side of the CV cavity or insert.

Table 5-11 - Summary Table of External Radiation Levels at 1m from the Surface - Monte Carlo calculations for reference case (Cs-137)

Source position in CV cavity or Insert	External Radiation Levels at 1m from package surface (mSv/h)		
	No insert	HS-31x114-Tu Design No 3982	HS-12x95-Tu Design No 3985
	(least shielding)	(median shielding)	(most shielding)
Centre at the top of the cavity	2.52E-01	1.33E-02	3.46E-03
Centre at the bottom of the cavity	1.96E-01	1.27E-02	2.91E-03
Centre at side of the cavity	2.19E-01	1.55E-02	3.48E-03
Eccentred at the top of the cavity	1.25E+00	5.11E-02	5.83E-03

The highest dose rate at 1m from the surface of the package for a point source in all positions within the insert and empty containment vessel is seen to be with the source eccentred at the top of the cavity.

5.5.4.1.2 Monte Carlo calculations for I-131 in a Stainless Steel Insert

The results of the Monte Carlo shielding calculations are reported in AMEC/SF6652/001 (Section 5.5.2) for a 200 Ci (7.4 TBq) I-131 point source, with the source positioned all at several points inside the stainless steel insert. The results from this report are summarised in Table 5-12 (surface radiation levels for NCT) and Table 5-13 (surface radiation levels for HAC).

Table 5-12 - Summary Table of Maximum Surface Dose Rates for I-131 in the stainless steel Insert under Normal Conditions of Transport

Source Position in insert HS 55x128 No 3987 cavity	Maximum Surface Dose Rate (µSv/hr)
Bottom of cavity, centred	72
Side of cavity, halfway up cavity	49
Top of cavity , centred	173
Top corner of cavity	205.4

Table 5-13 - Maximum Package Surface Dose Rate for I-131 in a Steel insert under Hypothetical Accident Conditions	
Source Position in insert HS 55x128 No 3987 cavity	Maximum Surface Dose Rate (μSv/hr)
Top Corner of Cavity	218

5.5.4.2 Monte Carlo calculations for Mo-99 in a Stainless Steel Insert

The results of the Monte Carlo shielding calculations are reported in AMEC/CRM37327/TN_001 (Section 5.5.2) for a 1000 Ci (37 TBq) Mo-99 liquid source with its significant daughters, contained in a natrium molybdenate solution.

The maximum source volume for the solution is 75 ml. The maximum specific activity of the solution that may be shipped is 60 Ci/ml. Therefore, calculations were carried out with a maximum source volume of 75 ml with a corresponding specific activity of 13.333 Ci/ml and minimum source volume with a corresponding maximum specific activity of 60 Ci/ml. The maximum surface dose rate was then calculated with the package upright, on its side and upside down on its lid. The results from this report are summarised in Table 5-14 (surface radiation levels for NCT) and Table 5-15 (surface radiation levels for HAC).

Table 5-14- Summary Table of Maximum Surface Dose Rates for Mo-99 in the stainless steel Insert under Normal Conditions of Transport			
Source Volume Position in insert HS 50x128 No 4081 cavity	Location of dose rate measurement	16.6667 ml Source Maximum Surface Dose Rate (μSv/hr)	75 ml Source Maximum Surface Dose Rate (μSv/hr)
Bottom of insert cavity	Bottom surface	1143	905
Top of insert cavity	Side surface	819	880
	Top surface	581	346
Side of insert cavity	Side surface	1214	947
	Top surface	246	219

Table 5-15 - Maximum Package Surface Dose Rate for Mo-99 in a Steel insert under Hypothetical Accident Conditions	
Source Position in insert HS 50x128 No 4081 cavity	16.6667 ml Source Maximum Surface Maximum Surface Dose Rate (μSv/hr)
Side of insert cavity	1214

5.5.4.3 MicroShield calculations

The results of the MicroShield shielding calculations (reported in CTR 2011/01 (Section 5.5.2), considering all of the nuclides to be represented as a point source positioned at the centre of the bottom of each insert, are given in Table 5-12.

Under NCT and HAC, it is assumed that both liquids and gaseous contents are contained in sealed product containers within the applicable insert and that the liquids and gaseous contents do not leak from the insert. Therefore the shielding calculations for liquid and gaseous contents are represented by the calculations for a point source positioned at the centre of the bottom of each insert. These results had further adjustments made due to any uncertainties in the shielding calculations and the results were altered as indicated in CTR 2013/09 (Section 5.5.6). The shielding limits were taken from this document and are those given in Table 5-16.

The activities given in Table 5-16 are used to determine the package limit, taking into account mass limit, heat limit, gas limit and shielding limit – see report PCS 036 (see Section 1.3.3).

Table 5-16 - Summary Table of Nuclide Activities required to give a surface dose rate of 8 mSv/h - MicroShield calculations

Nuclide	Insert	
	HS-12x95 -Tu Design #3982	HS-31x114-Tu Design #3985
Ac-225	2.51E+12	1.09E+12
Ac-227	7.24E+11	3.26E+11
Ac-228	4.28E+11	1.86E+11
Am-241	3.58E+12	1.58E+12
As-77	9.43E+19	1.14E+19
Au-198	6.99E+14	2.43E+14
Ba-131	1.88E+14	6.12E+13
C-14	6.92E+27	6.13E+27

Table 5-16 - Summary Table of Nuclide Activities required to give a surface dose rate of 8 mSv/h - MicroShield calculations

Nuclide	Insert	
	HS-12x95 -Tu Design #3982	HS-31x114-Tu Design #3985
Co-60	2.38E+11	9.37E+10
Cs-131	8.39E+35	7.43E+35
Cs-134	7.05E+12	2.63E+12
Cs-137	1.58E+15	3.16E+14
Cu-67	6.50E+25	2.84E+24
Hg-203	3.57E+13	5.32E+34
Ho-166	2.04E+12	9.20E+11
I-125	4.49E+35	3.98E+35
I-129	3.31E+26	2.93E+26
I-131	4.11E+15	9.94E+14
In-111	1.45E+28	1.29E+28
Ir-192	2.71E+15	7.19E+14
Ir-194	3.87E+13	1.47E+13
Kr-79	6.00E+13	2.30E+13
Lu-177	1.56E+24	1.38E+24
Mo-99	5.27E+13	1.91E+13
Na-24	2.63E+10	1.28E+10
Np-237	3.58E+12	1.58E+12
P-32	5.58E+12	2.49E+12
P-33	5.10E+37	3.61E+37
Pb-203	1.18E+17	2.45E+16
Pb-210	8.04E+12	3.31E+12
Pd-109	2.96E+14	9.61E+13
Pu-238	1.16E+20	5.30E+19
Pu-239	2.33E+25	6.04E+24
Pu-240	1.15E+25	5.62E+24
Pu-241	7.21E+20	1.90E+20
Ra-223	1.02E+13	4.14E+12
Ra-224	8.86E+10	4.37E+10
Ra-226	1.02E+11	4.80E+10
Re-186	1.56E+14	5.31E+13
Re-188	1.22E+12	5.67E+11
Rh-105	1.05E+31	1.17E+29
Se-75	8.89E+18	7.87E+18
Sm-153	6.12E+11	1.91E+15
Sr-89	1.22E+13	5.17E+12
Sr-90	1.73E+12	8.30E+11
Tb-161	1.61E+13	7.39E+12

Table 5-16 - Summary Table of Nuclide Activities required to give a surface dose rate of 8 mSv/h - MicroShield calculations

Nuclide	Insert	
	HS-12x95 -Tu Design #3982	HS-31x114-Tu Design #3985
Th-227	1.01E+13	4.17E+12
Th-228	6.79E+10	3.35E+10
Tl-201	1.59E+22	1.41E+22
U-235	9.17E+17	2.38E+17
W-187	2.24E+13	8.56E+12
W-188	1.23E+12	5.68E+11
Xe-133	2.25E+33	1.99E+33
Y-90	1.73E+12	8.30E+11
Yb-169	1.88E+19	1.66E+19
Yb-175	6.04E+23	6.09E+22

7.1.1 Preparation for Loading For A Standard or a Split CV Lid

1) Prior to preparing the package for loading, check that the intended contents meet all the requirements of the certificate of compliance for this package.

2) The external surface of the package shall be inspected for radioactive contamination, and decontaminated if necessary. All components shall also be checked for contamination, and decontaminated if necessary.

3) A survey of the radiation levels of the package shall be conducted to confirm that the package is empty. If, at any stage of disassembly, levels of radiation above that permitted are detected, then the appropriate action shall be taken to safeguard personnel, and to rectify the situation.

4) The security seals, padlock (if fitted), closure nuts/washers, lid and top cork shall be removed from the keg.

5) The containment vessel shall be removed from within the inner cork. Remove the shielding screw from the lifting hole, if present, and then screw a 12 mm eye bolt into the containment vessel lid.

6) The containment vessel closure screws and lid shall be removed.

7) If the containment vessel lid is not readily released, as may occur if the containment vessel was loaded at a lower atmospheric pressure, gently jack the lid from the containment vessel body using 2 jacking screws fitted in the jacking holes on the containment vessel lid. The jacking screws should be left in the containment vessel lid withdrawn to be flush with the lid top surface.

8) Additional Step for Split CV lid: Using the shield plug lifting point remove the shield plug. Remove the tungsten liner from the CV cavity.

9) The model/serial numbers of the containment vessel assembly (body, lid and if a split lid the shielding plug) shall be checked to ensure the serial number on the body matches the serial number on the lid. Where the model/serial numbers of the containment vessel assembly (body, lid and if a split lid the shielding plug) do not match, these components shall be removed from service and, in accordance with the users NCR (Non Conformance Report) system, the complete packaging shall be subjected to maintenance in accordance with the requirements of Section 8.2.

10) The containment vessel body and all lid components shall be checked for damage that may have occurred during transport. Check the closure screws are in good condition and that no fatigue cracks have developed during transport. Check that the closure components assemble freely by hand. Repair or replace any damaged items.

11) The O-rings shall be visually inspected for any cuts, blemishes, debris or permanent local deformation on the sealing surface. Damaged seals shall be replaced with seals

meeting the specifications in drawing 1C-5944 for the standard lid CV or drawing 1C-7504 for the split lid CV. If the O-rings are acceptable, lubricate with a light film of silicone O-ring lubricant.

12) If the containment seal O-ring is replaced or the containment O-ring has not been leak tested within 12 months prior to the shipment, a helium leak test shall be performed in accordance with Section 8.1.4.

    NOTE: Completion of a helium leak test DOES NOT relieve the need to perform the pre-shipment leak test in Section 7.1.3 step 1.

13) The model/serial numbers of the keg assembly (keg body and keg lid) shall be checked to ensure the serial number on the keg body matches the serial number on the keg lid: where the model/serial numbers of the keg (body and lid) do not match, these assemblies shall be removed from service and, in accordance with the users NCR system, the complete packaging shall be subjected to maintenance in accordance with the requirements of Section 8.2.

14) The keg outer shell shall be visually checked for unacceptable defects. Unacceptable defects are dents; cracking of welded joints; penetration of the keg skin; or abrasion or scratches that reduces the thickness of the keg below its licensed dimensions, including tolerances, as shown in the general arrangement drawings in the Certificate of Compliance.

15) Check that the keg lid fits without interference with the closure studs. Check that the closure studs and bolts are undamaged i.e. no fatigue cracks have developed and the studs are not stripped. The closure nuts and studs shall fit up without interference. The keg lid seal shall be fitted into the O-ring groove in the top of the keg. It shall be checked for any visible damage. The keg lid seal (item 13, drawing 0C-5942 or 0C-7502), closure studs (item 16, drawing 0C-5942 or 0C-7502), closure nuts/washers (item 14 and 15, drawing 0C-5942 or 0C-7502) shall be replaced, if missing or damaged.

16) Check that the cork packing pieces inner cork and top cork are in good condition i.e. intact and not chipped or cracked. Replace as required.

17) Remove the keg steel liner and turn the liner upside down to check for the presence of water. If water is present the inner cork packing shall be removed and placed in a controlled oven and held at 80^{o}C for 24 hours.

18) Check the keg liner and the keg liner welds for signs of corrosion. Repair or replace any damaged liner.

7.1.2 Loading of Contents with A Standard Lid Containment Vessel

NOTE: The standard lid containment vessel shall only be loaded with insert design numbers 3982, 3985 or 3987.

1) The containment vessel cavity shall be checked to ensure it is dry and clean before loading with the radioactive contents.

2) The contents shall be limited as required by the Certificate of Compliance. The contents shall be chemically compatible (i.e. not chemically reactive) with their immediate packaging and the containment boundary (e.g. tungsten, Silicon O-ring).

3) From the contents type to be shipped, determine the insert required for the shipment in accordance with the Certificate of Compliance. The model/serial numbers of the insert body and lid shall be checked to ensure that the number marked on the body matches that on the lid: where the model/serial numbers of the insert (body and lid) do not match, these assemblies shall be removed from service.

4) Visually inspect the insert to be used for the shipment for any damage. Check that the lid screws freely by hand onto the body. If there is any damage or the closure does not operate correctly carry out a maintenance operation according to Section 8.2.3. Check that the O-ring is present and undamaged. If the O-ring is not present or if it is damaged, it shall be replaced.

5) Check that the contents meet the restrictions for its content type as listed in the Certificate of Compliance.

6) If the content is Special Form, check the Special Form certificate to ensure it is current.

7) If loading liquid contents the insert shall be tested in accordance with the criteria specified in ANSI N14.5 [7.4], using a bubble method. The test sensitivity shall be 10^{-3} ref.cm^3/s and the acceptance rate shall be no visible stream of bubbles.

8) Load the contents into the insert and screw the insert lid tight ensuring that the match marks on the lid and the body meet to form a straight line.

9) Load the insert into the containment vessel and place the silicone sponge rubber disc onto the insert.

10) The lid shall be fitted to the containment vessel and the containment bolts tightened to a torque of 10 ± 0.5 Nm.

7.1.3 Loading of Contents with a Split CV Lid

NOTE: The split lid containment vessel shall only be loaded with insert design number 4081.

1) The containment vessel cavity shall be checked to ensure it is dry and clean before loading with the radioactive contents.

2) Confirm the contents meet the requirements of the Certificate of Compliance for the split lid CV.

3) The model/serial numbers of the insert body and lid shall be checked to ensure that the number marked on the body matches that on the lid: where the model/serial numbers of the insert (body and lid) do not match, these assemblies shall be removed from service.

4) Visually inspect the insert to be used for the shipment for any damage. Check that the lid screws freely by hand onto the body. If there is any damage or the closure does not operate correctly carry out a maintenance operation according to Section 8.2.3. Check that the O-ring is present and undamaged. If the O-ring is not present or if it is damaged, it shall be replaced.

5) The insert shall be tested in accordance with the criteria specified in ANSI N14.5 [7.4], using a bubble method. The test sensitivity shall be 10^{-3} ref.cm^3/s and the acceptance rate shall be no visible stream of bubbles.

6) Place the tungsten liner inside the CV cavity.

7) Load the contents into the insert and screw the insert lid tight. Screw the snap ring into the shielding plug of the CV. Engage the insert with the snap ring.

8) Lower the shielding plug and insert into the CV using the shielding plug lifting point.

9) The lid shall be fitted to the containment vessel and the containment bolts tightened to a torque of 10 ± 0.5 Nm.

7.1.4 Preparation for Transport For a Standard or Split CV Lid Package

1) Perform a pre-shipment leak test on the double O-ring closure of the loaded containment vessel at room temperature and atmospheric ambient conditions. The closure shall be leak tested in accordance with the criteria specified in ANSI N14.5 [7.4], using a gas pressure rise or gas pressure drop method with a sensitivity of 10^{-3} ref.cm^3/s and a pass rate of $5x10^{-4}$ ref.$cm^3.s^{-1}$.

2) If the leak rate is unacceptable, recheck the test equipment to ensure there are no leaks. If there are no leaks disconnect from the containment vessel and open the containment vessel.

3) Inspect the O-rings and replace as necessary following steps 9, 10 and 11 from section 7.1.1. Repeat step one of this section. If the leak test continues to fail, remove the package from service and raise an NCR.

   The inner cork packing and containment vessel shall be fitted into Keg 3977 in the following order: inner cork, containment vessel, ensuring that the containment vessel sits down on the keg liner. A lifting ring may be fitted into the lifting hole to assist lifting the containment vessel. If a lifting ring is used the shielding screw fitting in the standard CV lid shall be removed in order to fit it.

4) If the lifting ring is used, it shall be removed from the containment vessel lifting hole and if using the standard CV lid the shielding screw shall be replaced.

5) FOR THE STANDARD CV LID ONLY: Check that the shielding screw is present in the lifting hole on the containment vessel lid. If it is not present insert a shielding screw in accordance with the drawings listed in the Certificate of Compliance.

6) Insert the top cork ensuring that it is no higher than the surface of the keg closure flange.

7) The keg lid seal and the keg lid shall be fitted, the keg closure washers emplaced, and the keg closure nuts tightened to a torque of 23 ± 1 Nm.

8) A security seal shall be fitted through the security seal holes in any adjacent pair of lid closure studs.

9) A contamination survey shall be conducted on the external surfaces of the package to ensure that the level of non-fixed radioactive contamination is as low as reasonably achievable and within the limits specified in 10 CFR 71.87 and 49 CFR 173.443.

10) A radiation survey shall be conducted for gamma radiation to verify compliance with 10 CFR 71.47.and 49 CFR 173.441 requirements.

11) Optional step: PVC tape may be applied to the body and/or lid of the keg to cover the surface and to facilitate the removal of transport labels.

12) The packaging shall be marked and labeled in accordance with 49 CFR requirements. Any inappropriate markings or labels shall be removed. If the keg has been taped ensure all labels are placed on the tape and not on the keg skin. This allows for easy removal of shipping labels.

13) A survey of the outside temperature of the package to meet the requirements of 49 CFR 173.442 is not required as conformance with this requirement is assured by the design and proving tests reported in Sections 2 and 3.

14) Release the package to the carrier for shipment to the consignee.

7.2 Package Unloading

This section describes the requirements for unloading the package and the contents. It also details the tests and inspections that must be carried out during unloading and opening. Each packaging user shall prepare specific instructions and checklists, in accordance with the organizations Quality Assurance Program, to ensure compliance with the requirements detailed in Sections 7.2.1, 7.2.2 and to meet the requirements of 10 CFR 20.1906.

8) The contents shall be removed from the insert in accordance with user's facility procedures, and shall take into account any special requirements for the materials being handled.

9) Radiation and contamination surveys of the containment vessel, insert and silicone sponge rubber disc shall be carried out to internal procedures. Decontamination shall be carried out if required.

7.2.3 Removal of Contents For a Split CV Lid

1) The security seals, keg closure nuts, washers, and keg lid shall be removed. The opened top of the keg shall be monitored

2) The top cork shall be removed.

3) Fit a 12 mm diameter eyebolt to the lid of the CV. Using this eyebolt lift the containment vessel from the keg. The containment vessel shall be monitored for contamination as it is removed from the cork body.

4) The containment vessel closure screws and the lid shall be removed.

5) If the containment vessel lid is not readily released, as may occur if the containment vessel was loaded at a lower atmospheric pressure, gently jack the lid from the containment vessel body using 2 jacking screws fitted in the jacking holes on the containment vessel lid. The jacking screws should be left in the containment vessel lid withdrawn to be flush with the lid top surface.

6) The containment vessel shall be monitored while the lid is removed.

7) Lift the shielding plug including the insert from the CV cavity. The contents shall be removed from the insert in accordance with user's facility procedures, and shall take into account any special requirements for the materials being handled.

8) Radiation and contamination surveys of the containment vessel, insert and all packing items shall be carried out to internal procedures. Decontamination shall be carried out if required.

7.3 Preparation of Empty Package for Transport

Empty packagings shall meet the requirements of 49 CFR 173.428.

Each packaging user's facility shall prepare specific instructions or procedures and checklists, in accordance with that organization's approved Quality Assurance Program, and ensure compliance with the following requirements when shipping an empty package.

8.1.2 Weld Examinations

All keg welds shall be examined according to drawings 0C-5942 and 0C-7502. The containment vessel welds shall be examined in accordance with drawings 1C-5945 and 1C-5946 for the standard CV lid and drawings 1C-7506 and 1C-7507 for the split CV lid. Non-conforming components shall be rejected using the approved manufacturer's organization's non-conformance system. Disposition of rejected components should be reworked, used as is, or scrapped and replaced. The SARP owner should be notified of all disposition actions.

8.1.3 Structural and Pressure Tests [71.85 (b)]

A Pressure test of the containment vessel shall be performed in accordance with the ASME B&PV Code, Subsection NB-6000[8.2]. These tests shall be conducted at 12.5 bar gauge (181 psig) which is 1.25 times the maximum design pressure of 10 bar gauge (145 psig). The pressure shall be held for a minimum of 10 minutes. The pass criteria for the test shall be no gross leakage (i.e. no visible leakage detected without use of instruments) and no permanent deformation of the lid of the containment vessel under test. This test pressure exceeds the requirements of 10 CFR 71.85(b) [8.1] which requires a test pressure of 1.5 x MNOP (7 barg) which is 10.5 bar gauge (152 psig).

Non-conforming components shall be rejected and controlled for rework, or scrapped and replaced. Components that are reworked or replaced shall meet the specifications given in the general arrangement drawings in the Certificate of Compliance.

8.1.4 Leakage Tests

Leakage testing of the containment boundary defined in Section 4 shall be carried out in accordance with ANSI N14.5 [8.3]. The containment vessel flange/cavity wall shall be leak tested after fabrication using the gas filled envelope test A.5.3 in ANSI N14.5 [8.3] as described in section 8.1.5.3. The containment vessel lid top shall be helium leak tested prior to and after machining for the standard CV lid and after machining for the split CV lid, using the gas filled envelope test A.5.3 in ANSI N14.5 as described in section 8.1.5.2. Leak rate testing of the containment vessel closure shall be performed using the evacuated envelope gas detector method A.5.4 with helium as the tracer gas and a helium leak detector. The test sensitivity shall be 5×10^{-8} ref.cm^3/s and the acceptance rate shall be 1×10^{-7} ref.cm^3/s. The helium leak test procedures shall be written and approved by a level III examiner [8.4]

Leakage testing of the insert shall be carried out in accordance with ANSI N14.5 [8.3]. Leak rate testing shall be performed using the vacuum bubble method. The test sensitivity shall be 10^{-3} ref.cm^3/s and the acceptance rate shall be no visible stream of bubbles.

Non-conforming components shall be rejected and controlled for rework, or scrapped and replaced. Components that are reworked or replaced shall meet the specifications given in the general arrangement drawings in the Certificate of Compliance.

8.1.5 Component and Material Tests

8.1.5.1 Package weight

The package shall be weighed on a set of calibrated scales with a resolution of 10g. The weight of the package shall not exceed 163 kg (359.4 lbs). Any non-conforming packages shall be reworked or rejected.

8.1.5.2 Containment Vessel Lid Top

The standard containment vessel lid top shall be helium leak tested prior to machining in accordance with the gas filled envelope test A.5.3 in ANSI N14.5 [8.3], to ensure it is leak tight prior to further manufacture. The helium leak test procedure shall be written and approved by a level III examiner [8.4].

The leak test sensitivity shall be a minimum of 5 x 10^{-8} ref.cm^3/s air and the acceptance leak rate shall be 1 x 10^{-7} ref-cm^3/s. Any non-conforming components not meeting this criterion shall be reworked or rejected.

On completion of the machining operation the standard and split containment vessel lid top shall be helium leak tested in accordance with the gas filled envelope test A.5.3 in ANSI N14.5 [8.3], to ensure it is leak tight prior to further manufacture. The helium leak test procedure shall be written and approved by a level III examiner [8.4]

The leak test sensitivity shall be a minimum of 5 x 10^{-8} ref.cm^3/s air and the acceptance leak rate shall be 1 x 10^{-7} ref-cm^3/s. Any non-conforming components not meeting this criterion shall be reworked or rejected.

8.1.5.3 Containment Vessel Flange/Cavity Wall

The containment vessel flange/cavity wall shall be helium leak tested in accordance with the gas filled envelope test A.5.3 in ANSI N14.5 [8.3], to ensure it is leak tight prior to further manufacture. The helium leak test procedure shall be written and approved by a level III examiner [8.4]

The leak test sensitivity shall be a minimum of 5 x 10^{-8} ref.cm^3/s air and the acceptance leak rate shall be 1 x 10^{-7} ref-cm^3/s. Any non-conforming components not meeting this criterion shall be reworked or rejected.

8.1.5.4 Cork

Each batch of the inner, outer and top cork shall have its specific weight measured according to drawings 0C-5943 and 0C-7503 (Certificate of Compliance) and meet the criterion of 250 to 290 kg/m^3. Any cork not meeting this criterion shall be rejected.

8.1.5.5 DU Shielding

The chemical composition and fracture toughness of each batch of depleted uranium shall be analyzed to assure that the alloy meets the specifications. The chemical composition and fracture toughness shall meet the requirements given in drawings 1C-5945 and 1C-5946 (Certificate of Compliance) for the standard CV lid and drawings 1C-7506 and 1C-7507 for the split CV lid. The density of the depleted uranium contents shall be determined using measurement of the weight and volume. The density shall meet the requirements given in drawings 1C-5945 and 1C-5946 (Certificate of Compliance) for the standard CV lid and drawings 1C-7506 and 1C-7507 for the split CV lid. The finished DU components shall be visually inspected to verify that the surfaces are free of cracks and voids. Any items not meeting the acceptance criterion will be rejected.

8.1.5.6 Stock Material Used to Manufacture the Containment Boundary

The stock material, Stainless Steel 304L, used to manufacture items that make up the containment boundary as defined in Section 4.1, shall be examined with liquid penetrant and ultrasonic tests according to drawings 1C-5945 and 1C-5946 for the standard CV lid and drawings 1C-7506 and 1C-7507 for the split CV lid.

8.1.5.7 Silicone Sponge Rubber Disc

Each batch of the silicone rubber shall have its density measured according to drawing 2C-6920 (Certificate of Compliance) and meet the criterion of 16±6 lbs per cubic foot. Any silicone rubber not meeting this criterion shall be rejected.

8.1.6 Shielding Tests

Shielding is provided by the inserts and Depleted Uranium (DU) in the containment vessel body and lid. A tungsten liner is also used in conjunction with insert 4081 to provide additional shielding. Dimensional checks shall be carried out on the inserts and tungsten liner in accordance with Section 8.1.1. This is considered an adequate shielding check due to the simple design of the inserts and the tungsten liner.

For the containment vessel either, ultrasonic testing of the DU at the component stage or a gamma scan of the containment vessel shall be carried out.

The gamma scan shall be performed over the surface of the containment vessel lid and body on completion of manufacture. The measured dose rates are compared to the dose rates calculated for the surface of the containment vessel lid and body with the minimum dimensions and the minimum density of the DU and stainless steel, as well as the chemical composition, specified in the CoC drawings. The calculations and the measurements (the scan) shall use the same source, the same source quantity, and the same geometry and configuration (of the source, shielding and detector). The DU lid and body shielding are acceptable if the measured dose rates do not exceed the calculated dose rates.

8.1.8 Miscellaneous Tests

Not applicable.

8.2 Maintenance Program

The maintenance program for the SAFKEG 3977A packaging applies to periodic maintenance, and to packagings that have failed the pre-shipment inspection specified in Section 7.1.1. It ensures the continued performance of the package throughout its lifetime.

The maintenance program includes periodic testing, inspection and replacement schedules. Criteria are also included for the repair of components and parts on an ‘as needed’ basis. A summary of the maintenance requirements is given in Table 8-1.

This section provides the minimum requirements required in order to maintain the package. From these requirements each organization, authorized to perform maintenance, shall prepare specific instructions and checklists, in accordance with that organization's Quality Assurance Program, that will ensure compliance with the requirements of Section 8.2.

Non-conforming components shall be rejected and controlled for rework, or scrapped and replaced. Components that are reworked or replaced shall meet the specifications given in the general arrangement drawings in the Certificate of Compliance.

The maintenance organization is required to notify the SAR owner of any instance in which the packaging fails to meet the criteria of Section 8.2 is found during maintenance.

The periodic maintenance activities, as specified in Section 8.2, shall have been performed not more than 1 year prior to shipment.

8.2.1 Structural and Pressure Tests

Structural and pressure testing do not form part of the periodic maintenance requirements.

8.2.2 Leakage Tests

8.2.2.1 Containment Vessel

Maintenance leakage testing of the containment vessel shall be in accordance with the evacuated envelope (gas detector) test A.5.4 in ANSI N14.5 [8.3]. The helium leak test procedure shall be written and approved by a level III examiner [8.4]. The test shall use a suitable helium leak detector. The test sensitivity shall be 5 x 10^{-8} ref.cm^3/s and the test pass rate shall be 1 x 10^{-7} ref.cm^3/s. The O-rings shall be coated with a light film of silicone O-ring lubricant for lubrication, and replaced if damaged.

The leakage rate testing shall be performed during the periodic maintenance tests, this shall not exceed 12 months prior to package use. The leakage rate test shall also be performed after the following maintenance activities:

2) The Containment Vessel components shall be checked for visible damage and in particular that the closure components assemble freely by hand. Any defects affecting the operation or integrity must be corrected or a part replaced.

3) The welds on the containment vessel body and lid for the standard CV lid or shielding plug for the split CV lid shall be visually checked for defects and evidence of cracking.

4) The threads in the closure of the containment vessel and the closure screws shall be cleaned and the threads shall be coated with molybdenum disulfide dry film spray lubricant.

5) The surface finish of the faces against which the O-rings seat shall be visually inspected. These faces shall be circular and there shall be no scratches across the lay. Scratches shall be polished out to return the surface to the specification in the drawings or the component rejected.

6) The three O-rings, marked on drawing 1C-5944 for the standard CV lid or drawing 1C-7504 for the split CV lid, shall be replaced. These O-rings must be replaced annually. The O-rings shall be coated with a light film of silicone O-ring lubricant (Parker Super O-Lube). The O-rings shall be within the valid expiration date as specified by the manufacturer. O-rings shall be procured and tested in accordance with drawing 1C-5944 for the standard CV lid or drawing 1C-7504 for the split CV lid.

7) Leakage testing of the containment vessel shall be carried out in accordance with ANSI N14.5 [8.3]. The helium leak test procedure shall be written and approved by a level III examiner [8.4]. The test sensitivity shall be 5 x 10^{-8} ref.cm^3/s and the test pass rate shall be 1 x 10^{-7} ref.cm^3/s.

8) Non-conforming components shall be rejected and controlled for rework, or scrapped and replaced. Components that are reworked or replaced shall meet the specifications given in the general arrangement drawings in the Certificate of Compliance.

9) The inspection results and any necessary replacement or repairs, shall be recorded in the package maintenance records.

8.2.3.4 Cork Set

1) The cork packing pieces (top cork, inner cork and outer cork) shall be visually inspected for chipping and cracking. The pieces shall be checked for fit within the assembled package. They shall fit without interference.

2) Non-conforming components shall be rejected and controlled for rework, or scrapped and replaced. Components that are reworked or replaced shall meet the

8.3 Appendix

8.3.1 References

[8.1] Title 10, Code of Federal Regulations, Part 71, Office of the Federal Register, Washington D.C.

[8.2] ASME III Division 1 – Subsection NB, Class One Components, Rules for Construction of Nuclear Facility Components, ASME Boiler and Pressure Vessel Code, 2001 edition, the American Society of Mechanical Engineers, New York, New York.

[8.3] ANSI N14.5, American Standards for Radioactive Materials – Leakage Tests on Packages for Shipment, American National Standards Institute, 1997.

[8.4] ANSI/ASNT CP-189-2006, Standard for Qualification and Certification of Nondestructive Testing Personnel, The American Society for Non Destructive Testing Inc.