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

Application for Approval by the NRC

Applicant: Croft Associates Limited

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2C-6176	Issue D	HS-55x128-SS insert design no 3987 (licensing drawing)
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1C-7505	Issue A	CV lid - Mallinckrodt Version

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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
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AMEC/CRM37327/TN_001	Issue 1	HS Container Shielding Assessment with I-131
AMEC/CRM37327/TN_001	Issue 1	HS Container Shielding Assessment with Mo-99
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1.2 Package Description [71.33]

1.2.1 Packaging

1.2.1.1 General

The general arrangement of the Safkeg-HS 3977A is provided in drawings 0C-5941 for a package with a standard CV lid and 0C-7501 for a package with a split CV lid. Both drawings are attached in Section 1.3.3. The drawings show the package and detail all the nominal dimensions and the major design features.

The Safkeg-HS 3977A package (generally called the package in this SARP) consists of a single resealable containment vessel with either a standard or split lid (generally called the CV in this SARP) Design No. 3978 (stainless steel with encased depleted uranium shielding), carried within insulating cork packing in an outer stainless steel keg Design No.3977 (generally called the Keg in this SARP).

Section views of the package and the CV are shown in Figures 1-1 and 1-2 respectively. These figures also give the nomenclature used throughout this report.

The maximum weight of the package excluding the contents is 154 kg (339 lbs). The maximum contents weight is 9.29 kg (21 lbs), therefore the maximum gross weight of the package is 163 kg (360 lbs).

1.2.1.2 3977 Keg

The keg Design No.3977 has a stainless steel outer shell and a stainless steel liner between which insulating cork is fitted. The keg is sealed as it has an O-ring weather seal in its closure, however, there is a fuse plug fitted at the bottom of the keg. This fuse plug contains a low melting point alloy which will vent during the HAC fire test providing pressure relief.

The keg is closed by a flat stainless steel lid which is bolted down with 8 stainless steel studs and nuts against a single O-ring which provides a weather seal to keep rain from entering the keg. The studs are fitted with seal holes for the fitting of a tamper indicating device in accordance with 10 CFR 71.43(b). The lid may also be further secured, to prevent unauthorized removal, by a padlock attached to a lock pin welded to the keg closure flange.

Due to the relatively low weight and size of the package, there are no specific design features to allow for the tie down and handling of the package.

An inner cork liner is fitted between the keg liner and the CV. The inner cork liner consists of a body and a top cork. There is no cork directly underneath the CV as it sits on the keg liner. The top cork varies in thickness between 48 mm and 84.5 mm; the variation in thickness is to accommodate the design of the CV lid. The side wall thickness of the

inner cork varies from 18 mm at the top of the CV to 28 mm of cork at the bottom of the CV. The surface of the cork is sealed with a water-based sealant to enhance its appearance and reduce the potential to produce dust.

1.2.1.3 3978 CV

The CV is composed of a body and a lid (see Figure 1-2a and Figure 1-2b).

The CV body is fabricated from three pieces of stainless steel: the CV flange/cavity wall, the CV outer wall and the CV base. The CV flange/cavity wall and the CV base are machined from solid. The CV flange/cavity wall is welded to the CV outer wall to form the cavity into which the body DU shielding is fitted. The base is then welded to the outer wall. Drawings 1C-5946 and 1C-7506 in Section 1.3.3 show the general arrangement of the CV body.

The CV lid may be either standard or split. The standard CV lid is fabricated from two pieces of stainless steel, the CV lid top and the CV lid shielding casing. Both pieces are machined from solid. The CV lid shielding casing has 45.9 mm depth of depleted uranium placed inside; the CV lid shielding casing is then welded to the CV lid top. Drawing 1C-5945 in Section 1.3.3 shows the general arrangement of the standard CV lid.

The split CV lid is similar to standard CV lid with the stainless steel being machined from solid and with 45.9 mm thick depleted uranium clad in stainless steel, however, it varies in design from the standard CV lid in the following points:

- The CV lid top is not welded to the CV lid shielding. The CV lid shielding sits within the containment vessel body in the same position as the standard CV lid.
- The CV lid shielding plug casing extends to form a stainless steel plug in the CV body cavity. This plug ensures the correct location of the insert during transport.
- Two threaded holes are machined into the CV lid shielding plug. These holes allow the insert to be attached to the CV lid shielding plug and, once the CV lid top has been removed, a lifting attachment can be fitted to the top of the CV shielding lid plug to enable it and the insert to be lifted out.

Drawing 1C-7505 in Section 1.3.3 shows the general arrangement of the split CV lid.

For both designs the CV lid is held in position by eight recessed alloy steel screws. The seal between the CV body and the CV lid is effected by two Fluoroelastomer (base material Viton GLT) O-ring seals of 3 mm cord diameter. Access to the interspace between the two O-rings is provided for operational and maintenance leak testing. Leak testing is required for the CV to ensure that it meets the regulatory release limits specified in 10 CFR 71.51.

The CV has a cavity of overall length of 157.1 mm and a diameter of 65.8 mm with the standard CV lid and an overall length of 132 mm and a diameter of 65.8 mm with the split CV lid. The vessel operates at atmospheric pressure, although the internal pressure may vary due to heating of the gases within the CV by decay heat of the contents, gas generation and atmospheric temperature and pressure changes.

1.2.1.4 Containment Boundary

Figure 1-3a and Figure 1-3b show the containment boundary of the Safkeg-HS 3977A package for the standard and split CV lid respectively. As shown, the containment boundary consists of the CV flange/cavity wall, the CV lid top and the inner O-ring containment seal of CV. The containment seal is tested on manufacture, during periodic maintenance and in operation, to ensure it remains within regulatory limits regarding leak rate under both NCT and HAC. Section 4 discusses the containment boundary in further detail.

1.2.1.5 Gamma Shielding

Figures 1-4a and 1-4b show the gamma shielding present in the Safkeg-HS 3977A package. Gamma shielding is provided principally by the depleted uranium present in the CV body and lid; the steel of the CV provides some additional shielding. The depleted uranium is machined from solid and placed within the CV body with the base being welded into position. The CV is designed so that the shielding in the lid and body are stepped to reduce radiation

streaming. The upstanding ring on the lid also provides some additional steel shielding to reduce the radiation streaming from the gap between the CV Lid and CV Body.

The contents of the package are defined as being everything that is carried within the CV cavity. For all contents, one of the inserts specified in Section 1.2.2 and shown in Figures 1-5a, 1-5b, 1-5c or 1-5d, is required. These inserts provide different amounts of shielding and also provide confinement for all contents under NCT and HAC.

1.2.1.6 Energy Absorbing Features

The outer cork, top cork and inner cork provide insulation and energy absorption - thus providing protection to the CV during NCT and HAC (see Figures 1-1a and 1-1b).

The outer cork is located between the keg liner and the keg outer shell. The outer cork is protected by the keg liner and not intended to be replaced. The inner cork and top cork are readily removable and intended to be replaced if required at pre-shipment or annual maintenance if required.

1.2.1.7 Heat Transfer Features

The contents of the Safkeg-HS 3977A package are limited to have a maximum heat output of 30 W for solid or gaseous contents and 5W for liquid contents. With such a small heat source, no specific heat transfer design features are required.

Thermal protection of the contents from external heat sources such as insolation or fire is provided by the outer cork, top cork and inner cork. During HAC, the keg is designed to vent by melting of the low melting point alloy in the fuse plug, thus preventing any pressure build up within the keg cavity due to gasses arising from pyrolysis of the cork.

1.2.1.8 Labelling

The keg is fitted with a name plate to comply with the requirement in 10 CFR 71.85 [1.2] and 49 CFR 172.310 [1.4].

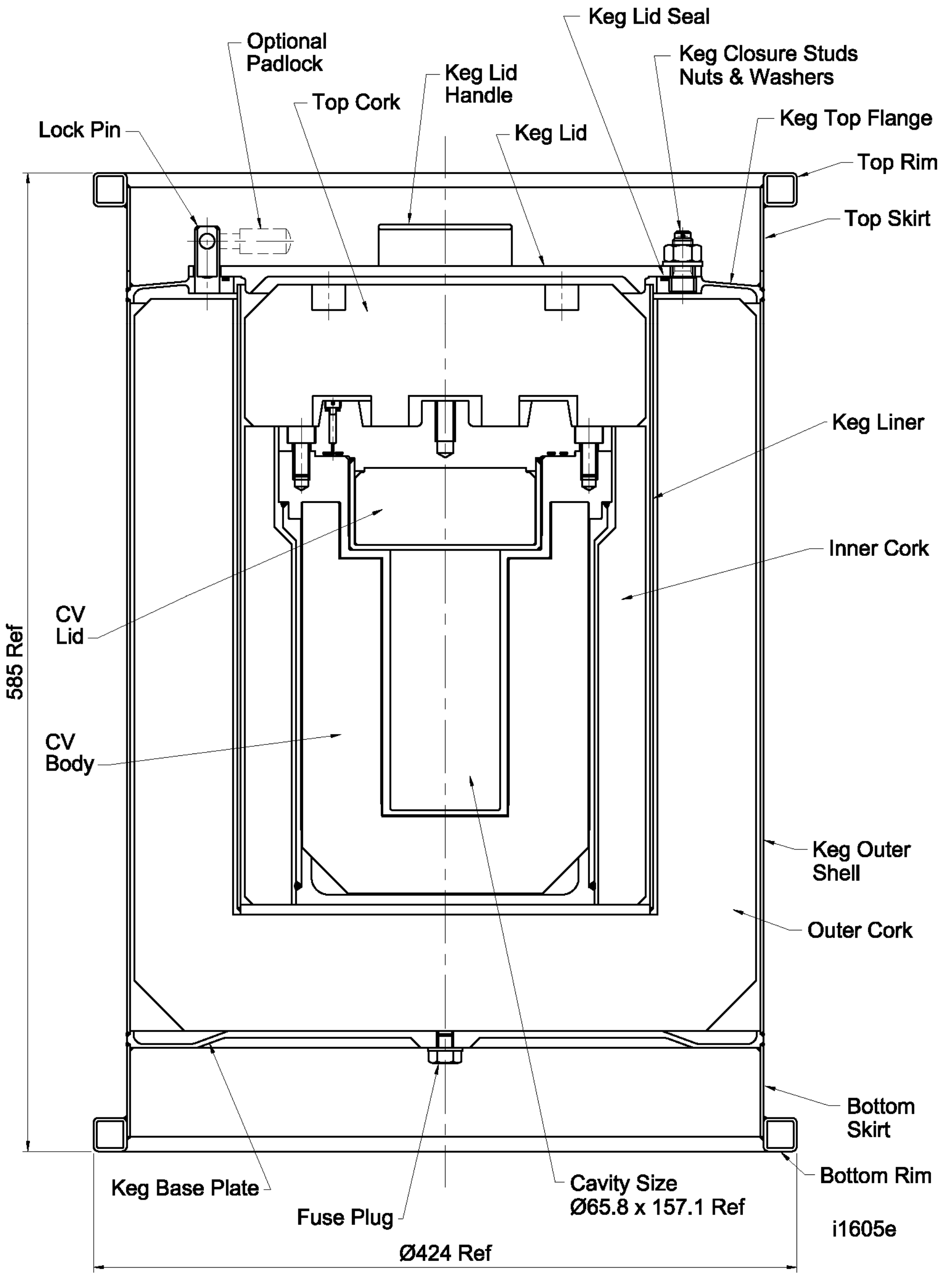


Figure 1-1a Safkeg-HS 3977A package with Standard Containment Vessel Lid– Section View and Nomenclature

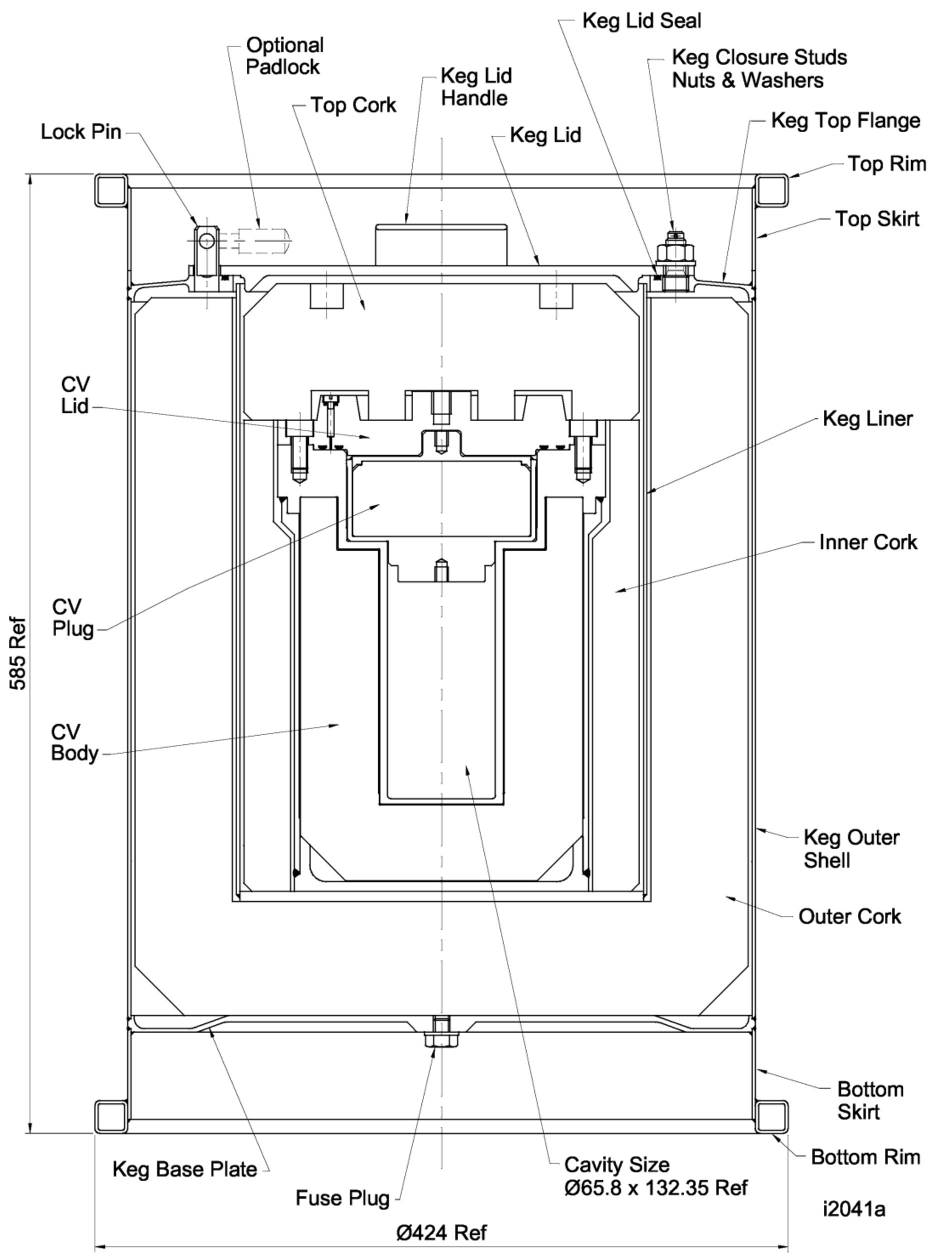
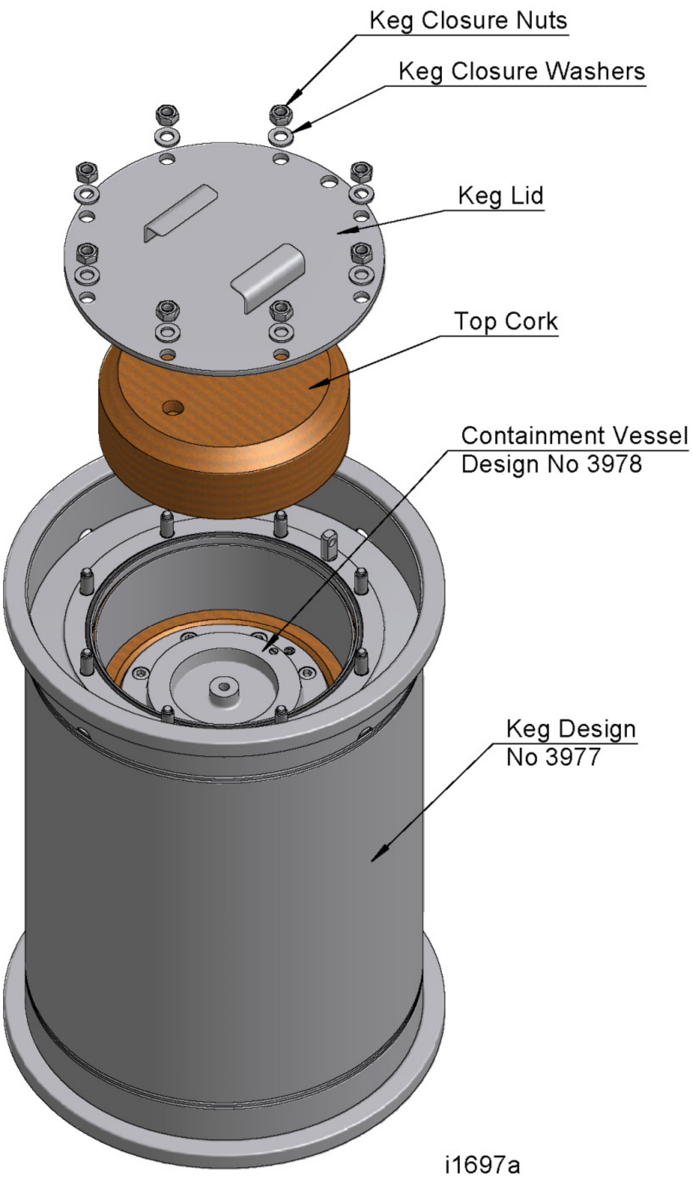


Figure 1-1b Safkeg-HS 3977A package with Split Containment Vessel Lid– Section View and Nomenclature



Safkeg HS Design No 3977A

Figure 1-1c Safkeg-HS 3977A package – Isometric view

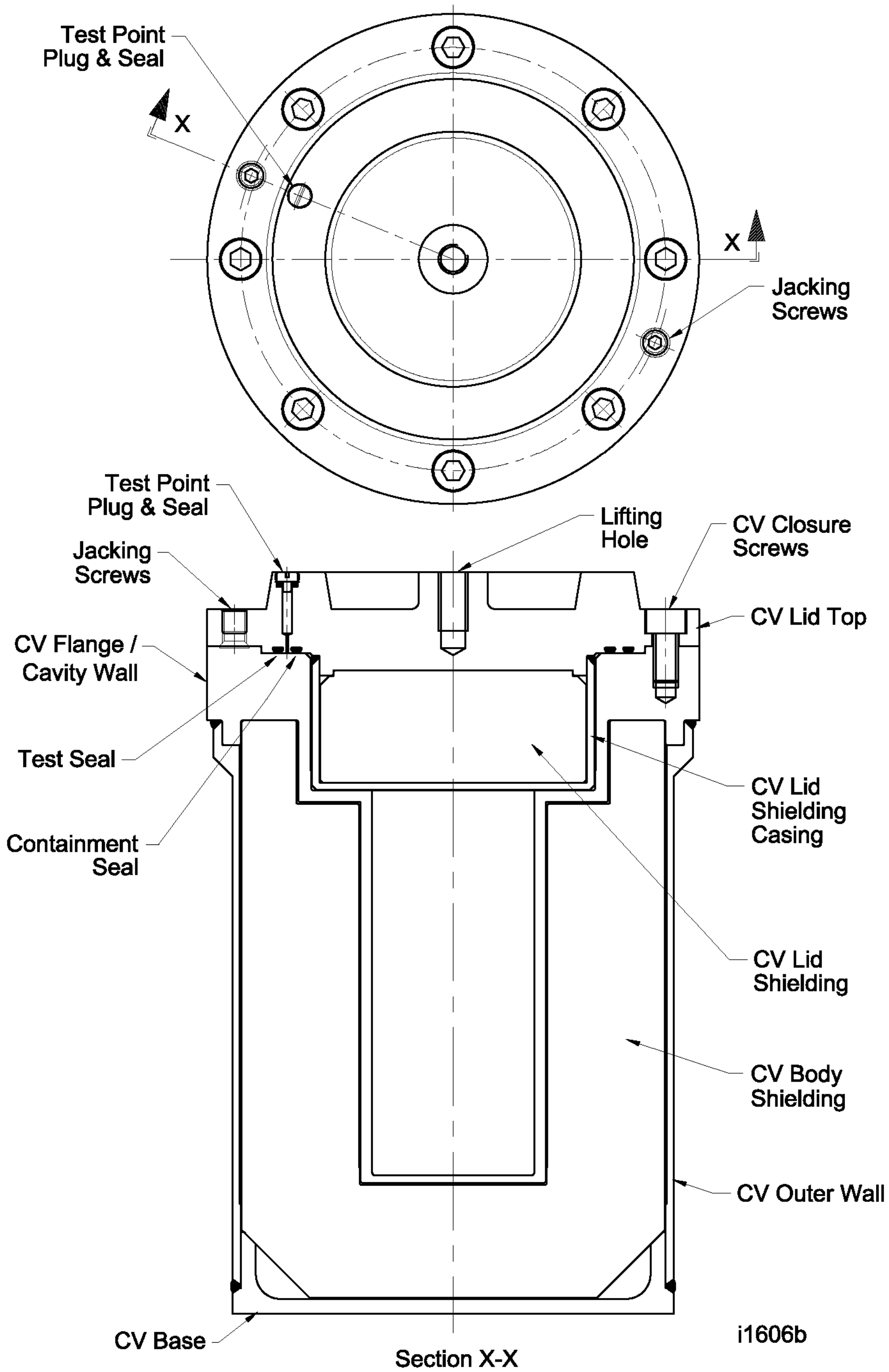


Figure 1-2a 3978 Standard CV Lid – Top and Section View and Nomenclature

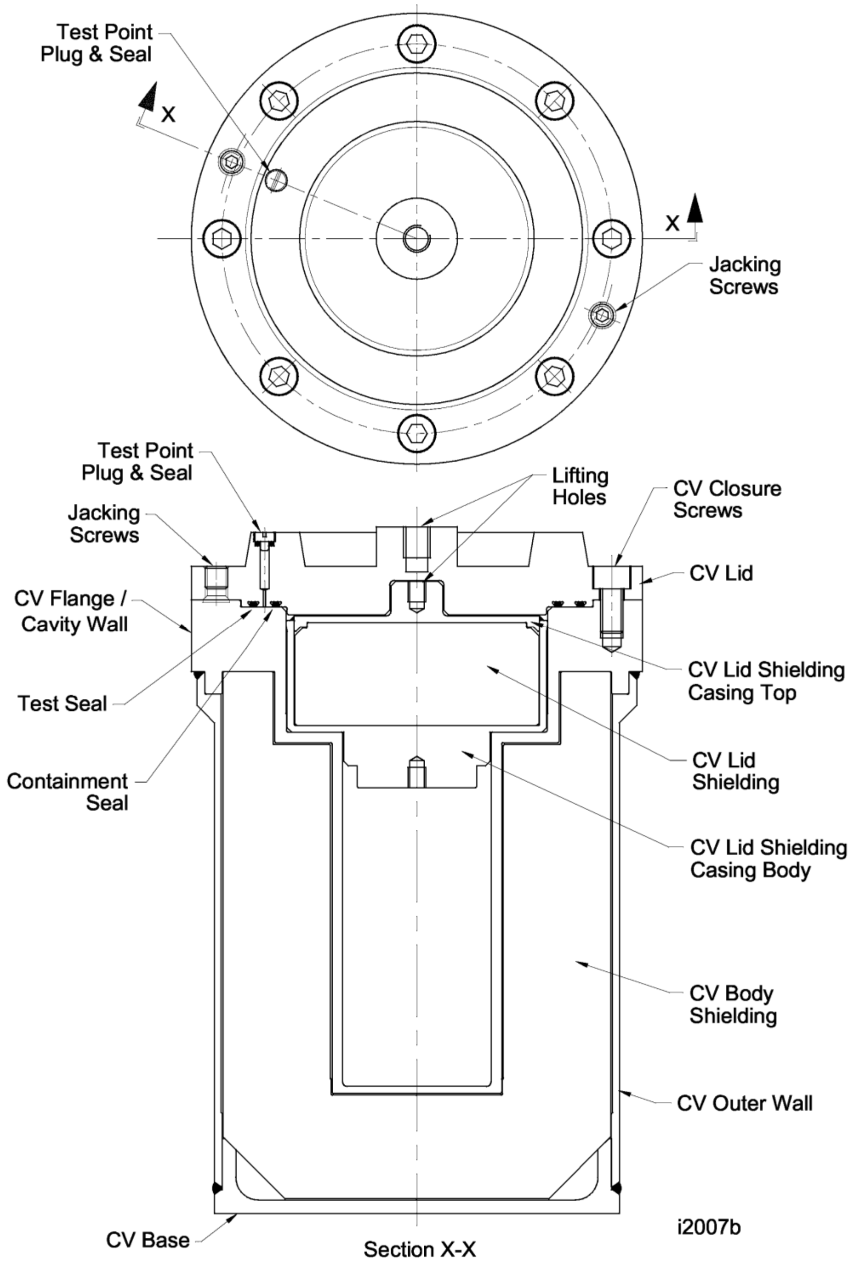
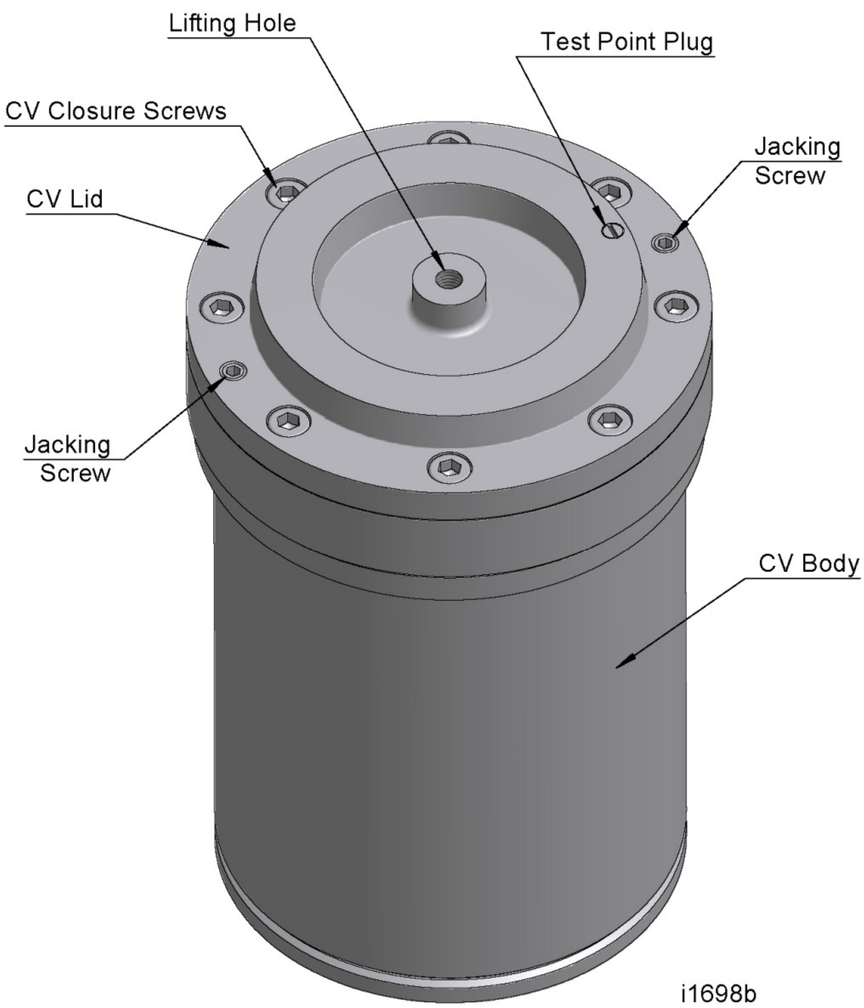


Figure 1-2b 3978 Split CV Lid– Top and Section View and Nomenclature



Containment Vessel Design No 3978

Figure 1-2c 3978 CV – Isometric View

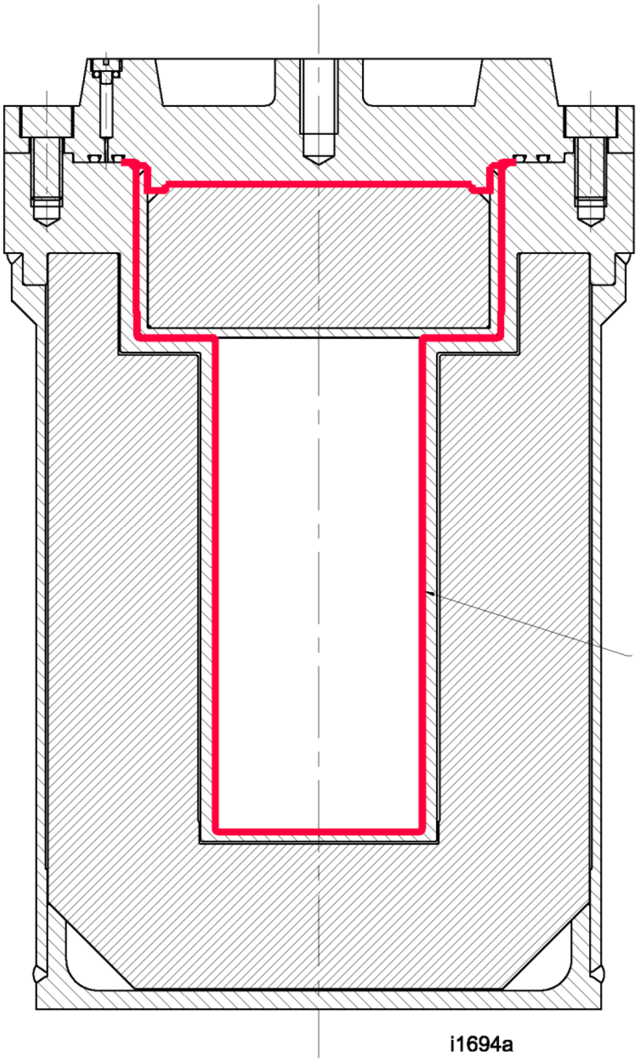


Figure 1-3a Containment boundary of the Safkeg-HS 3977A package with a Standard CV Lid

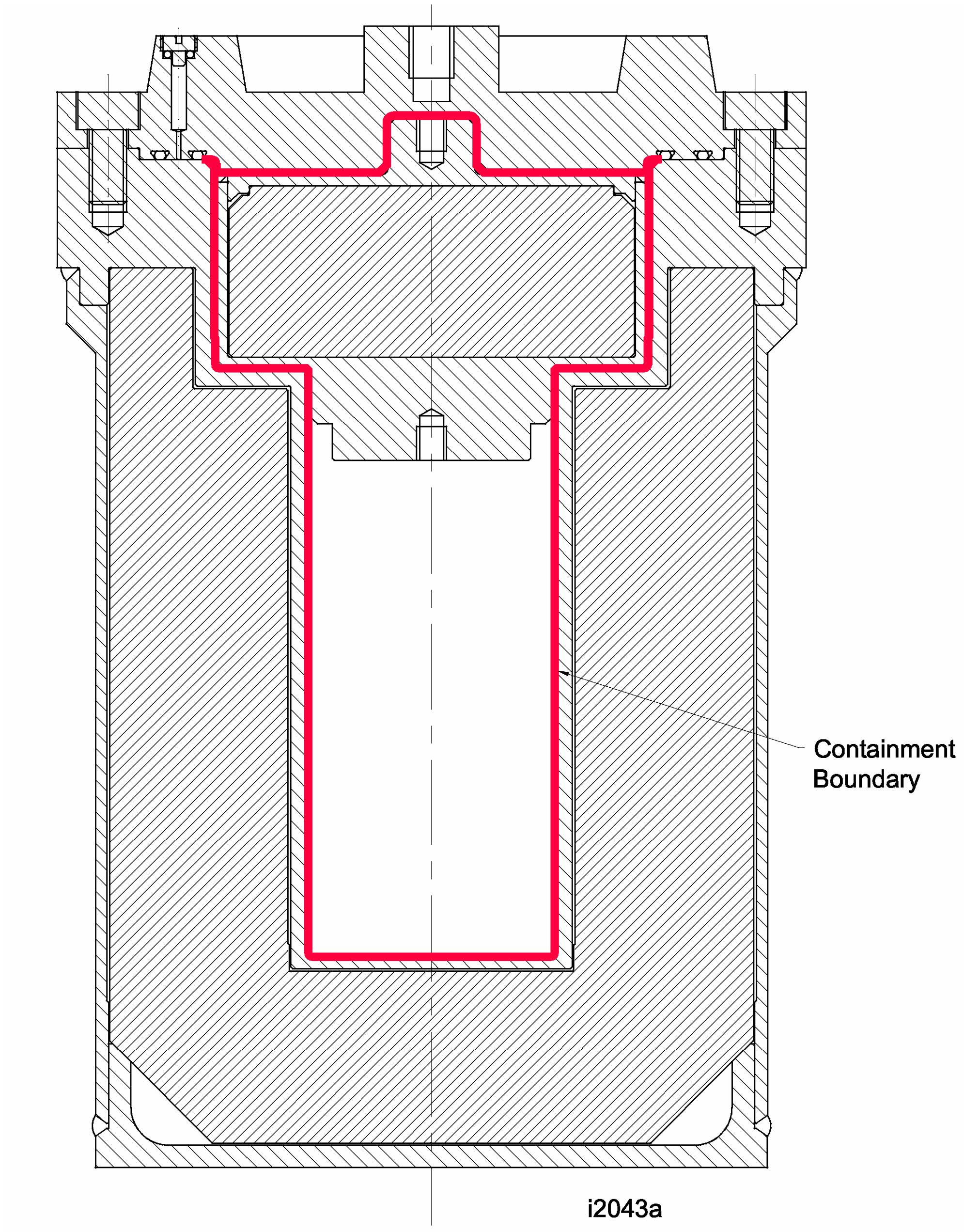


Figure 1-3b Containment boundary of the Safkeg-HS 3977A package with a Split CV Lid

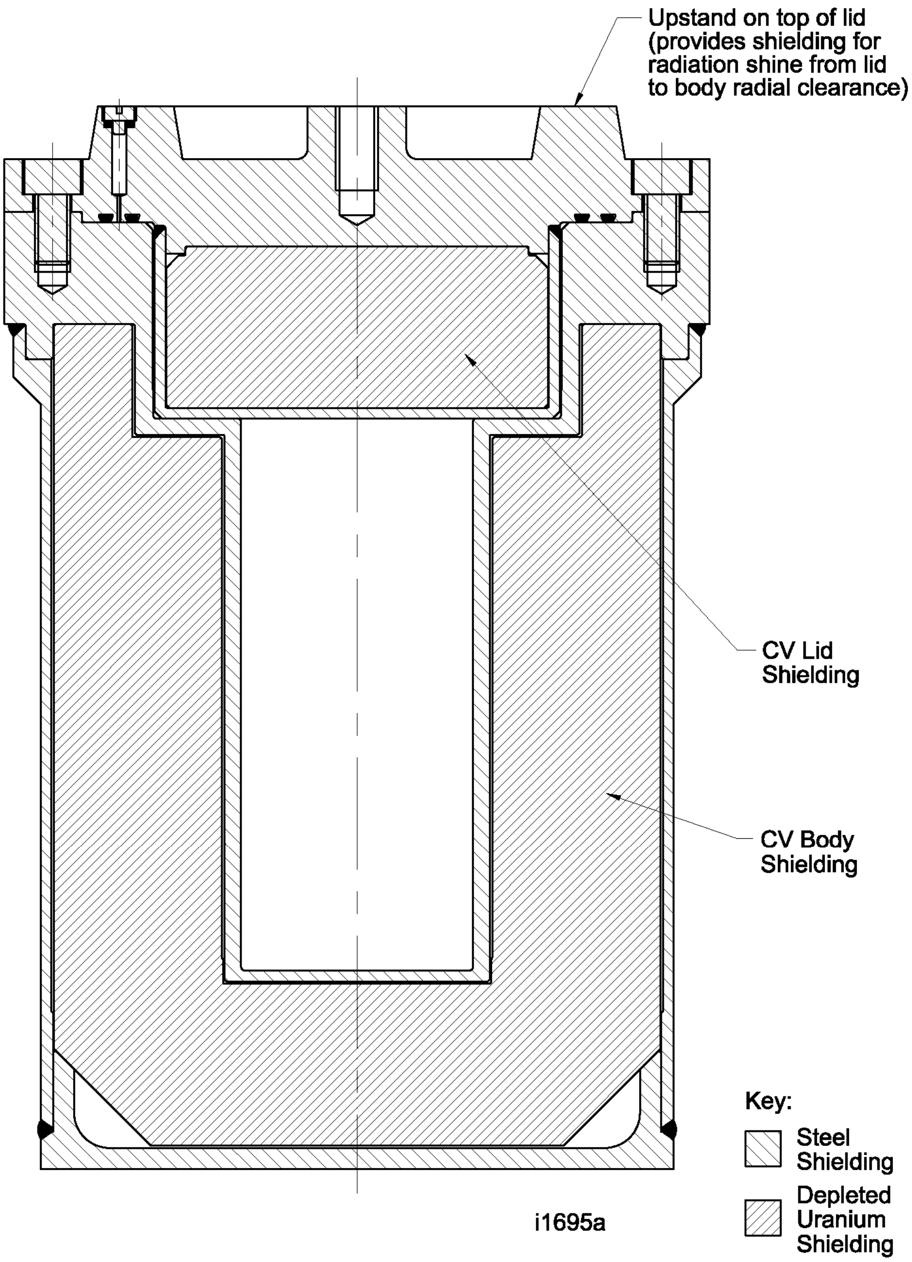


Figure 1-4a Gamma shielding present in the Safkeg-HS 3977A package with a standard CV lid

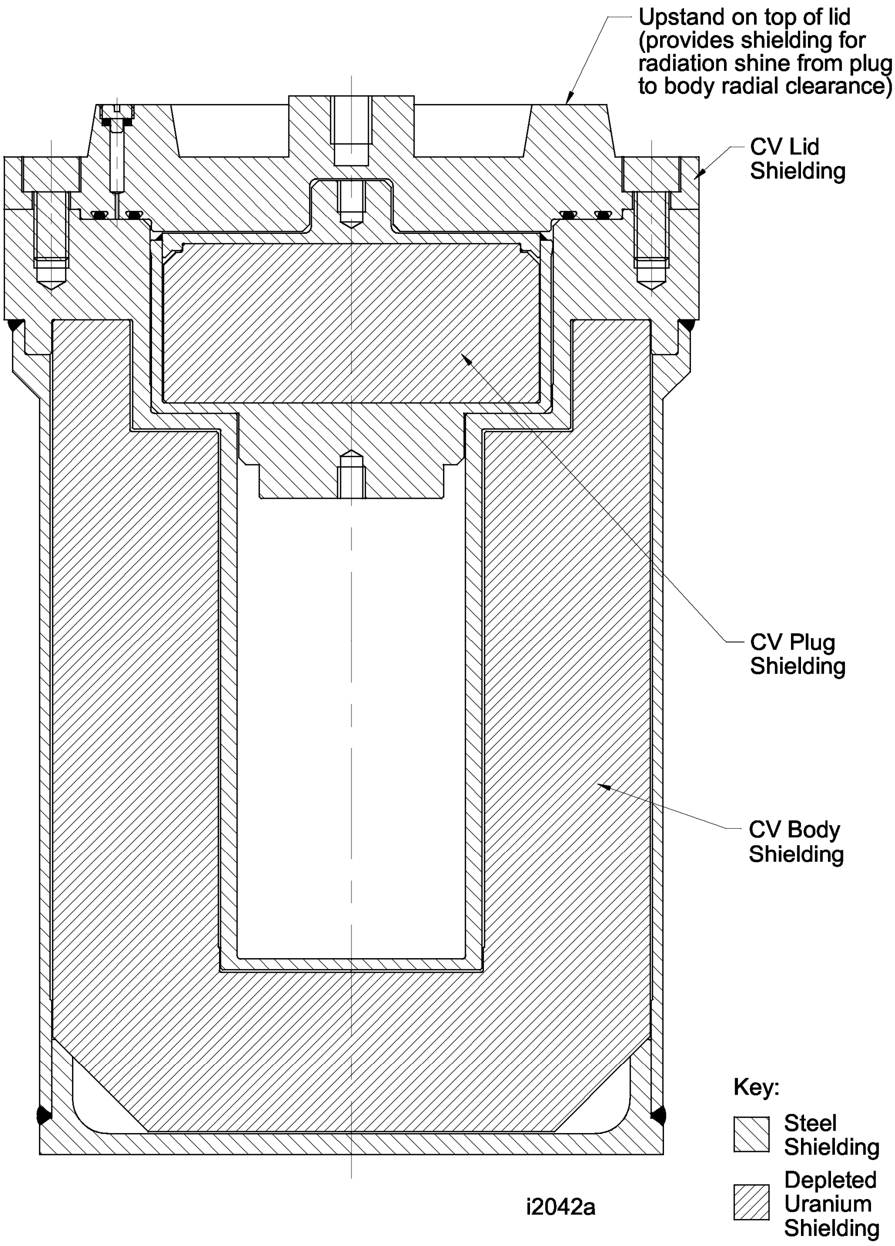


Figure 1-4b Gamma shielding present in the Safkeg-HS 3977A package with a Split CV Lid

1.2.2 Contents

1.2.2.1 Contents - General

The Safkeg-HS 3977A package is designed as a general purpose package for radioactive material that requires shielding. The package is designed for radioactive material that emits neutrons, alpha, beta and gamma radiation.

The contents may be in solid, liquid or gaseous form.

The contents may also include inorganic non-radioactive materials associated with the radioactive materials, such as contents holders or fixtures and packing materials. No organic/hydrogenous materials are allowed in the cavity of the CV.

Fissile materials are permitted within the limits specified in Tables 1-3-7 and 1-3-8.

Pyrophoric materials are permitted under the conditions specified.

As the maximum contents are > 3,000 A_2, the package is designated as Category I as defined in NUREG 1609 [1.1].

The contents are limited so that the surface dose on the external surface of the package is less than or equal to 10 mSv/hr under exclusive use.

The contents heat limit is 30 W for solid or gaseous contents and 5W for liquid contents.

The contents will be carried in a product container appropriate for the contents and chosen by the shipper.

The product containers will, in all cases, be carried in shielding inserts as specified in the licensing drawings in section 1.3.3. Contents Types 1 to 7 will be carried in a CV using the standard lid design with Contents Type 8 carried in a CV with the split lid design.

The maximum mass of all material (radioactive contents, product capsules or containers, shielding inserts, and all associated items such as product container holders and packing) inside the CV is 9.29 kg (21 lbs).

Various restrictions and limits of quantity of radionuclides apply according to the insert used and the form of the radioactive material (solid, liquid or gas). These restrictions and contents limits are detailed in Section 1.2.2 in the tables for the different Contents Types (defined as CT-1, etc).

The maximum pressure assumed for the CV under NCT and HAC is 7 barg (100 psig): this is the design envelope.

1.2.2.2 Inserts

The different inserts, which are required for all contents (in suitable product containers), provide different degrees of shielding and confinement under NCT.

The inserts are as shown in Figures 1-5a, 1-5b, 1-5c or 1-5d. The weights of the inserts and the contents of the inserts are given in Table 1-1. The maximum mass of the contents is determined by calculating the mass of steel which would completely fill the cavity of the insert.

Table 1-1 Maximum mass of the radionuclides

Shielding Insert	Mass of Insert	Maximum Mass of Contents	Mass of insert + Maximum mass of contents
	g	g	kg (rounded)
HS-12x95-Tu Design No 3982	9,200	90	9.29
HS-31x114-Tu Design No 3985	7,930	690	8.62
HS-55x128-SS with PTFE liner Design No 3987	1,451	1,810	3.26
HS-50x85-SS Design No 4081 with Tungsten liner	3,271	1,615	4.89

The insert designation is coded as below.

1st 2 letters eg HS	Designate the insert fits the Safkeg-HS
Numbers eg 12x65	indicate the cavity size of the insert (dia mm x ht mm)
Last 2 letters	Tu indicates tungsten and SS indicates stainless steel

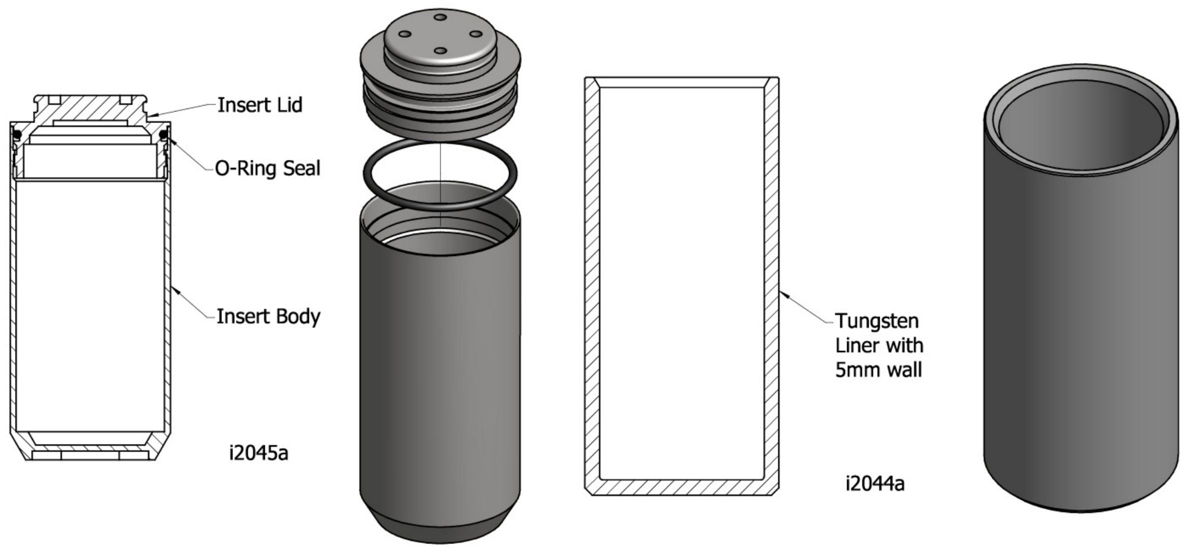


Figure 1-5d Shielding insert HS-50x85-SS– Design # 4081 with Tungsten liner

1.2.2.3 Contents Types

The contents to be carried shall be as specified in the Contents Types listed in Table 1-2.

The general requirements for each Contents Types listed in Table 1-2 are given in Tables 1-3-1 to 1-3-8. The package activity limit for each Contents Type is given in the Tables 1-4-1 to 1-4-8. These tables specify the shipping limits for the package.

The activity limit for each nuclide given in Tables 1-4-1 to 1-4-8 is determined as the least of the limits determined on the basis of heat output, mass limit, shielding limit and, for gas contents, the limit based on allowable leakage under NCT or HAC. The details of the determinations are given in report PCS 038 (Section 1.3.4).

Note that the shipping limits must not exceed any of the limits in Tables 1-3-1 to 1-3-8.

Table 1-2 Contents Types

Contents Type Designation	Material Form	Shielding Insert	General Requirements for each Contents Type	CV Lid arrangement	Activity Limits for each Contents Type
CT-1	Solid	HS-12x95-Tu Design No 3982	See Table 1-3-1	Standard	See Table 1-4-1
CT-2	Solid	HS-31x114-Tu Design No 3985	See Table 1-3-2	Standard	See Table 1-4-2
CT-3	Solid	HS-55x138-SS Design No 3987 with PTFE liner fitted	See Table 1-3-3	Standard	See Table 1-4-3
CT-4	Liquid	HS-31x114-Tu Design No 3985	See Table 1-3-4	Standard	See Table 1-4-4
CT-5	Liquid	HS-55x128-SS Design No 3987 with PTFE liner fitted	See Table 1-3-5	Standard	See Table 1-4-5
CT-6	Gas	HS-31x114-Tu Design No 3985	See Table 1-3-6	Standard	See Table 1-4-6
CT-7	Solid/ Fissile Normal Form	HS-55x138-SS Design No 3987 with PTFE liner fitted	See Table 1-3-7	Standard	See Table 1-4-7
CT-8	Liquid	HS-50x85-SS Design No 4081 with Tu liner	See Table 1-3-8	Split	See Table 1-4-8

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 product bottle 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

Table 1-4-8 CT-8 – Liquid Mo-99 in a steel insert (HS-50x85-SS) – Activity Limits

Contents Type 8 - CT-8 - Liquid Mo-99 in a steel insert									
1	2	3	4	5	6	7	8	9	10
Nuclide	Max	Activity	A2	# A2s	Spec Ac	Mass	Heat gen	Heat output	PackageType
	TBq	Ci	TBq		TBq/g	g	W/Ci	W	A or B
Mo-99	3.70E+01	1000	3.00E-01	123.33	3.10E+04	1.19E-03	3.43E-03	3.43	B

Notes

Column	
1	Identifies nuclide
2	Package activity limit for this Contents Type - from Col 17
3	Calculated from Bq amount in Col 2
4	A2 from 10CFR71
5	# of A2's of nuclide at package activity limit
6	Specific activity from 10CFR71
7	Mass of nuclide at package activity limit
8	Heat generation rate of nuclide - from Microshield.
9	Heat output of nuclide at package activity limit
10	Package Type [A or B] based on individual nuclide limit

Supplement to Table 1-4-8 re daughter nuclides

The following nuclides may be present in the contents as indicated in the table below.

Table 1-4-5a – Supplement re additional nuclides			
1	2	3	4
Nuclide	Max Activity	Parent material	Comments
Daughter radionuclides present in contents in significant quantities			
Tc-99m, Tc-99	As Mo-99	Mo-99	Tc-99 will grow in to equilibrium with Mo-99

1.2.3 Special Requirements for Plutonium

The 10 CFR 71 [1.2] regulatory limit for plutonium in liquid form of 0.74 TBq (20 Ci) of plutonium is met, as the liquid contents as specified in Section 1.2.2 (in contents types CT-4, CT-5 and CT-8) do not include plutonium.

1.2.4 Operational Features

The package has no complex operational features. All the operational features of the package are given in the General Arrangement drawings 0C-5941 and 0C-7501 (Section 1.3.3) and the operational instructions are presented in Section 7.

1.3 Appendix

1.3.1 References

[1.1] NUREG-1609, Standard Review Plan for Transportation Packages for Radioactive Material, 1999

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

[1.3] Regulatory Guide 7.9, Standard Format And Content Of Part 71 Applications For Approval Of Packages For Radioactive Material

[1.4] Title 49, Code of Federal Regulations, Part 171, Office of the Federal Register, Washington, DC, 2009

1.3.3 Licensing Drawings

The package is defined by the drawings listed below for which the revision status is given in Section 0. The drawings are appended to this section.

The drawings specify dimensions, fasteners, welding requirements, non-destructive examination requirements, O-ring specifications, method of O-ring retention, and closure surface requirements.

The drawings also specify the materials: details of the materials are given in Section 2.

1.3.3.1 Standard CV Lid Design

Drawing No.	Title
1C-5940	Cover sheet for Safkeg-HS design no. 3977A (licensing drawing)
0C-5941	Safkeg-HS design no. 3977A (licensing drawing)
0C-5942	Keg design no. 3977 (licensing drawing)
0C-5943	Cork set for Safkeg-HS (licensing drawing)
1C-5944	CV design no. 3978 (licensing drawing)
1C-5945	CV lid (licensing drawing)
1C-5946	CV body (licensing drawing)
2C-6173	HS-12x95-Tu insert design no. 3982 (licensing drawing)
2C-6174	HS-31x114-Tu insert design no. 3985 (licensing drawing)
2C-6176	HS-55x128-SS insert design no 3987 (licensing drawing)
2C-6920	Silicone Sponge Rubber Disc

1.3.3.2 Split CV Lid Design

Drawing No.	Title
1C-7500	Cover sheet for Safkeg-HS design no. 3977A - Mallinckrodt Version

Drawing No.	Title
0C-7501	Safkeg-HS design no. 3977A - Mallinckrodt Version
0C-7502	Keg design no. 3977 - Mallinckrodt Version
0C-7503	Cork set for Safkeg-HS - Mallinckrodt Version
1C-7504	CV design no. 3978 - Mallinckrodt Version
1C-7505	CV lid - Mallinckrodt Version
1C-7506	CV body - Mallinckrodt Version
1C-7507	Containment vessel plug – Mallinckrodt version
2C-7508	HS-50x85-SS insert design no 4081
2C-7509	Snap Ring
2C-7510	Tungsten Liner

1.3.4 Supporting Documents

Document Reference	Title
PCS 038	Package Contents Specification for Safkeg-HS - Package Design No 3977A

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2 STRUCTURAL EVALUATION

This section identifies the principal structural members of the Safkeg-HS 3977A package, and the materials and fabrication methods of each are described. The ability of the package to satisfy the regulatory requirements of 10 CFR 71 [2.1], regarding Normal Conditions of Transport (NCT) and Hypothetical Accident Conditions (HAC) tests, is demonstrated in Sections 2.6 and 2.7 by testing of a prototype keg which has been supplemented by a Finite Element Analysis (FEA) of the containment vessel.

2.1 Description of Structural Design

2.1.1 Discussion

The principal structural members of the Safkeg-HS 3977A package are the 3977 keg, inner cork packing and the 3978 containment vessel. The radioactive contents are carried within product containers and inserts placed inside the containment vessel (see Section 1.2.1).

The keg is designed to absorb impacts, provide protection during handling operations and insulate the containment vessel during the HAC thermal test. The inner cork packing is designed to absorb the impact loads preventing damage to the containment vessel under HAC tests. The containment vessel is designed to provide the containment and shielding of the radioactive material and the insert is designed to provide a confinement boundary and additional shielding for the contents. A description of the structural design of each of these members is provided in the following sections.

3977 Keg

The keg comprises of a body, lid, outer cork and liner assembly as shown in drawings 0C-5942 and 0C-7501 (Section 1.3.2). The body of the keg is constructed from rolled austenitic

stainless steel welded to form a cylinder. A base, top flange, skirts and rims are welded to the rolled cylinder to form the keg body. The outer cork is placed into the keg with the steel assembly liner fitting inside the cork to protect the outer cork during handling operations. The inner liner is formed from 2mm thick austenitic stainless steel.

The keg closure is facilitated by eight closure studs screwed and glued into position on the top flange and a lock pin which is welded into position. The keg lid is a circular plate with eight holes machined for the closure studs and one hole for the lock pin. The lid is attached to the body with eight M12 austenitic stainless steel nuts and washers. A nitrile O-ring is fitted to a groove in the flange ensuring that a weather tight seal is provided on closure of the keg. Two handles are welded to the lid to allow handling of the lid.

A fuse plug is located in the base plate of the keg body. It is present to prevent the over pressurization of the keg during the HAC thermal test. The fuse plug is austenitic stainless steel with a hole drilled through the centre which is filled with a low melting point alloy. This alloy has a melting point of $95^{o}C \pm 5^{o}C$ which once melted will allow any gases generated within the keg to vent, reducing the pressure in the keg body.

Top and Inner Cork

The inner cork fits inside the keg liner and surrounds the containment vessel. It is designed to reduce impact loads on the keg liner and the containment vessel and provide thermal insulation. The cork surrounds the side walls and the lid of the containment vessel. It varies in width from 56 mm to 36 mm on the side walls due to the variation in diameter of the containment vessel and is 84.5 mm thick above the lid. The cork is agglomerated and coated in a water based varnish. The cork components are shown in detail in drawings 0C-5943 and 0C-7503 (Section 1.3.2).

3978 Containment Vessel

The containment vessel consists of a body and a removable lid assembly bolted together with 8 closure screws and sealed with an inner and outer O-ring, as shown in drawings 1C-5944 and 1C-7504 (Section 1.3.2).

The body assembly is formed from a stainless steel shell filled with depleted uranium which is alloyed with 2% molybdenum by weight. The stainless steel shell consists of three austenitic stainless steel pieces, the inner cavity wall/flange, outer wall and base. Each piece is machined from solid austenitic stainless steel. The inner cavity wall/flange and outer wall are welded together with a circumferential full penetration fillet weld which is both visually and liquid penetrant tested. The shielding cavity is filled with the machined to size shielding and the base is welded into position with a circumferential full penetration fillet weld which is both visually and liquid penetrant tested.

The depleted uranium which is alloyed with 2% molybdenum by weight forms the shielding for the walls and base of the containment vessel.

The inner cavity wall/flange and the bolted flange for the containment vessel closure form the cavity into which the radioactive contents are placed. The flange is machined with 8 closure holes into which CV closure screws are fitted.

Either a standard or split CV lid can be fitted to the containment vessel. Both containment vessel lid types are comprised of two pieces a lid top and a stainless steel clad depleted uranium plug. The CV lid top is a circular plate machined from a stock billet of 304L stainless steel. Eight equally spaced counter bored holes are machined to accommodate the closure screws. Four further holes are machined in the lid, the first accommodates the test port in order to leak test the closure system. The second is a blind hole in the centre of the lid and is fitted with a threaded insert. This allows a lifting eye to be fitted for the handling of the containment vessel. The last two allow jacking screws to be fitted which assist in the removal of the lid. Two grooves are machined onto the underside of the lid top into which the O-rings are fitted.

The depleted uranium is machined to shape and placed within the machined stainless steel casing to form the shielding plug. In the standard lid the plug is welded to the lid top with a circumferential full penetration fillet weld which is liquid penetrant and visually tested. With the split lid the plug is not welded to the lid top. The DU shielding is clad with stainless steel which extends down the CV to form a plug which both locates the HS-50x85-SS insert and allows it to be lifted from the CV.

The containment vessel lid is attached to the body with eight L43 alloy steel screws which are tightened to a torque of 10 ± 0.5 Nm.

The design pressure for the containment vessel is 10 bar (1,000 kPa) gauge which envelopes the MNOP of 7 bar (700 kPa) gauge. The containment boundary is formed by the inner cavity wall/flange, lid and containment O-ring. This containment boundary is leak tested on manufacture, during annual maintenance and on loading.

Insert

Any one of the four inserts specified in Section 1.3.2 shall be used to provide further shielding and confinement for the contents. Two of the inserts, HS-12x95-Tu Design No 3982 and HS-31x114-Tu Design No 3985, are machined from tungsten with two of the inserts, HS-55x149-SS Design No 3987 and HS-50x85-SS design No 4081, machined from stainless steel. The HS-55x149-SS insert also has a PTFE liner fitted into the stainless steel body. The HS-50x85-SS insert is located inside a tungsten liner to provide additional shielding.

All of the inserts consist of a body and a lid which are machined from a solid. The lid screws onto the body with an O-ring seal. The four types of insert each have different cavity sizes and provide varying levels of shielding.

Silicone Sponge Rubber Disc

A silicone sponge rubber disc is placed within the CV cavity to provide vibration protection for the insert when loaded with the standard lid during transport.

2.1.2 Design Criteria

In order to evaluate the containment design a package with a standard CV lid underwent a series of physical tests in accordance with 10 CFR 71.41. An FE Analysis was also performed on the containment vessel with a standard CV lid, under NCT and HAC using the software code Abaqus: as discussed in Arcadis Vectra Report L20008/1/R1 (Section 2.12.2). This report is regarded as supplementary to the physical tests. The initial load combinations used during the evaluation are discussed in Section 2.1.2.1. The resultant calculated stresses are compared against the allowable stresses presented in Section 2.1.2.2. Further evaluation is carried out to determine buckling, fatigue and brittle fracture as discussed in Sections 2.1.2.3, 2.1.2.4 and 2.1.2.5 respectively.

As the structural materials of the package are all austenitic stainless steel, the package is not susceptible to failure by brittle fracture. The keg, being a composite structure with the outer skin supported by the cork and the inner shell, it is not susceptible to buckling.

2.1.2.1 Load Combinations

The load combinations used in the structural evaluation of the containment boundary were developed in accordance with Regulatory Guide 7.8 [2.2]. The NCT and HAC load combinations used to determine the stresses within the containment boundary are summarized in Table 2-1 and Table 2-2.

Table 2-1 Load Combinations for NCT

Load Case ID	NCT	Initial Conditions								
		Ambient Temperature		Insolation		Decay Heat		Internal Pressure		Fabric-ation Stress
		38°C	-29°C	Max	Zero	Max	Zero	Max	Min	
NCT1	Hot environment (38°C ambient temperature)			X		X		X		X
NCT2	Cold environment (-40°C ambient temperature)				X		X		X	X
NCT3	Reduced external pressure (24.5 kPa)	X		X		X		X		X
NCT4	Increased external pressure (140 kPa)		X		X		X		X	X
NCT5	Vibration (10g vertical)	X		X		X		X		X
NCT6			X		X		X		X	X
NCT7	Free drop on lid (1.2m)	X		X		X		X		X
NCT8			X		X		X		X	X
NCT9	Free drop on side (1.2m)	X		X		X		X		X
NCT10			X		X		X		X	X
NCT11	Free drop on corner (1.2 m)	X		X		X		X		X
NCT12			X		X		X		X	X

Table 2-2 Load Combinations for HAC

Load Case ID	HAC	Initial Conditions								
		Ambient Temperature		Insolation		Decay Heat		Internal Pressure		Fabric-ation Stress
		38°C	-29°C	Max	Zero	Max	Zero	Max	Min	
HAC1	Free drop on lid (9m)	X		X		X		X		X
HAC2			X		X		X		X	X
HAC3	Free drop on side (9m)	X		X		X		X		X
HAC4			X		X		X		X	X
HAC5	Free drop on corner (9m)	X		X		X		X		X
HAC6			X		X		X		X	X

2.1.2.2 Allowable Stress

The allowable stresses used to calculate the design margins within the containment boundary are given in Table 2-3. The allowable stresses were taken from Regulatory Guide 7.6 [2.3]. These are based on the 1977 edition of the ASME Boiler and Pressure Vessel Code [2.4]. This guide only gives allowable stress values for primary membrane stress, primary membrane plus primary bending stress and primary plus secondary stress for both NCT and HAC loading conditions. The allowable values for bearing stress and for the bolts have been taken from ASME Section III Div 3 [2.5] as these are not given in Reg. Guide 7.6 [2.3]. Guidance for classification of stresses was taken from Table WB-3217-1 in ASME Section III Div 3 [2.5]. To demonstrate conformance with the allowable stress limits, it was necessary to determine the stress intensities at critical cross-sections of the containment vessel. Since

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°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	Silicone
Silicone Sponge Rubber Disc	Silicone
50x85 SS Insert	Stainless Steel
Tungsten Liner	ASTM B777 Class 3 Tungsten Alloy

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.

2.2.3 Effects of Radiation on Materials

The contents of the package emit one or all of alpha, beta, gamma and neutron radiation. Austenitic stainless steel, depleted uranium and cork were chosen for the construction of the package because they are durable materials that are able to withstand the damaging effects from the radiation.

The Fluoroelastomer O-ring seals fitted to the containment system are the only material on which the radiation may have an effect; however it has been shown in Section 4.1 that for the radioactive contents limited according to Section 1.2.2, the maximum dose to the containment seal is $<< 10^4$ Gy (10^6 rad) whereas no change of physical properties of the Fluoroelastomer containment seal is expected at radiation levels up to 10^4 Gy (10^6 rad). These seals are required to be replaced annually at maintenance (Section 8.2).

Table 2.14 Average compressive Modulus of Elasticity and Compressive Strength at 10% Relative Deformation for Cork at each Test Temperature

Test Temperature (°C)	Compressive Modulus of Elasticity E (MPa)	Compressive Strength at 10% relative deformation (MPa)
- 29	23.4	1.60
20	15.0	0.57
100	4.6	0.34

Table 2-15 Summary of Material Interactions

	Contents	PTFE Liner	Stainless Steel Insert	Tungsten shielding insert	Silicone Sponge Rubber disc	Stainless steel	Fluoroelastomer O-rings	O-ring lubricant	Depleted Uranium	Cork	Cork sealant	Fuse plug alloy	Nitrile lid seal	Thread lubricant
Contents		NH	NH	NH										
PTFE liner	NH		NH											
Stainless steel Insert	NH	NH			NH	NH								
Tungsten Liner			NH			NH								
Tungsten shielding insert	NH				NH	NH								
Silicone Sponge Rubber Disc			NH	NH		NH								
Stainless steel				NH	NH		NH	NH	NH	NH	NH	NH	NH	NH
Fluoroelastomer O-rings								NH						
O-ring lubricant														
Depleted Uranium														
Cork											NH	H		
Cork sealant												NH		NH
Fuse plug alloy														NH
Nitrile lid seal														

N = NCT, H = HAC

2.3 Fabrication and Examination

2.3.1 Fabrication

All work performed in the fabrication of the 3977A is required to be carried out under an NRC approved quality assurance program. The containment system shall be fabricated in

accordance with the applicable sections of Division III Subsection NB [2.9] as shown in Table 2-8.

The other safety items are fabricated in accordance with the applicable sections of Section III subsection NF of the ASME code for plate and shell Type class 2 supports [2.10]. These components are the keg and the outer shell of the containment vessel. All welding procedures and personnel shall be qualified in accordance with AMSE section IX. Welding consumables their supply, certification, control during storage and use, shall comply with the appropriate requirements of ASME III, Division 1 subsection NF 2400.The keg shall be fabricated in accordance with drawing 0C-6042 or drawing 0C-7502. All welding procedures and personnel shall be qualified in accordance with AMSE section IX.

The Depleted Uranium used shall be alloyed with 2±0.2% Molybdenum and 0.2% carbon maximum by weight as specified in the drawings 1C-5945 and 1C-5946 for the standard CV lid and drawings 1C-7506 and 1C-7507 for the split CV lid. It shall be fabricated using standard industry practices. The cork shall be tested to demonstrate it meets the required specification in drawing 0C-6043 or drawing 0C-7503 and marked with a unique identification number which will match it to the corresponding keg.

Any consumables used during manufacture such as thread inserts and O-rings shall be procured from commercial suppliers that are approved to a level commensurate with the safety functions of the consumable purchased.

2.3.2 Examination

All examinations shall be carried out under the scope of an NRC approved quality assurance program. Examinations shall be carried out on materials, components and finished assemblies throughout the manufacturing process. These tests will assure that the manufactured article meets the critical characteristics to allow the safe transport of radioactive material. All tests shall be carried out to approved procedures, with calibrated equipment. The records of the tests will be maintained with the manufacturing records for each package.

The examinations required during manufacture are described below:

<u>Material Tests</u>

Material examinations, from a sample of the stock material, used to fabricate the containment vessel lid top and the flange/cavity are required. These integrity tests will be an Ultrasonic straight beam test to ASME III Division 1 NB 2542 [2.9] and a liquid penetrant test to ASME III Division 1 subsection NB 2546 [2.9].

A specimen of the depleted uranium used as the shield is required to be tested to assure that it meets the required chemical composition, density and Charpy V notch impact energy as defined in drawings 1C-5945 and 1C-5946 for the standard CV lid and drawings 1C-7506 and 1C-7507 for the split CV lid.

For the cork the supplier is required to provide a Certificate of Conformance to confirm that the properties listed in drawing 0C-5943 or drawing 0C-7503 are met.

For the silicone sponge rubber disc the supplier is required to provide a Certificate of Conformance to confirm that the properties listed in drawing 2C-6920 are met.

Fabrication Tests and Examinations

Once the containment vessel lid and flange are machined, a helium leak test is required to be carried out in accordance with ANSI N14.5 [2.13]. This leak test is required to demonstrate that the leak rate of the machined items is less than or equal to 1 x 10^{-7} ref-cm^3/s. No additional examinations are required for items which are not primary containment items.

All welds are subjected to non destructive visual and liquid penetrant examination in accordance with ASME section V [2.17]. The applicable acceptance criteria for the visual examinations are given in drawings 1C-5945 and 1C-5946 for the standard lid and drawings 1C-7506 and 1C-7507 for the split lid. The acceptance standards for the liquid penetrant examination of the welds is in accordance with AMSE Section III Division 1 sub section NB 5350 of the ASME code.

All components and assemblies are required to be visually inspected and the dimensions measured using calibrated equipment to assure compliance with the dimensions shown on the general arrangement drawings. The weight of the finished containment vessel and fully assembled package are required to be measured to ensure the weight requirements are met.

Acceptance Tests

The completed containment vessels are required to be pressure tested to a maximum pressure of 12.5 barg which meets both the requirement of 10 CFR 71.85 (b) and ASME Section III sub section NB 6000 [2.9].

On completion of manufacture the containment vessel closures are required to be leak tested in accordance with ANSI 14.5 [2.13] to demonstrate the leak rate is less than or equal to 1 x 10^{-7} ref-cm^3/s.

On completion of manufacture the insert is required to be leak tested in accordance with ANSI N14.5 **Error! Reference source not found.**. Leak rate testing will 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.

2.4 General Requirements for All Packages [71.43]

2.4.1 Minimum Package Size [71.43 (a)]

10 CFR 71.43(a) states: "The smallest overall dimension of a package may not be less than 10 cm (4 in)." The Keg 3977 has an outer diameter of 424 mm (16.69 in.) and a length of 585 mm (23 in.). Therefore, the smallest overall dimension of the package is not less than 10 cm (4 in), as required in 10 CFR 71.

2.4.2 Tamper Indicating Feature [71.43 (b)]

10 CFR 71.43(b) states: "The outside of a package must incorporate a feature, such as a seal, that is not readily breakable and that, while intact, would be evidence that the package has not been opened by unauthorized persons."

The tamper-proof feature of Keg 3977 is the hole provided in each closure stud which enables a wire security seal to be fitted through the studs. In addition, the keg closure is provided with a lock pin that may be fitted with a padlock. Therefore, the package can be fitted with a tamper indicating seal to provide indication that the package has not been opened.

2.4.3 Positive Closure [71.43 (c)]

10 CFR 71.43(c) states: "Each package must include a containment system securely closed by a positive fastening device that cannot be opened unintentionally or by a pressure that may arise within the package." The lid of the containment vessel is held in place using 8 screws which are screwed into the CV flange. The CV closure screws are tightened or released using appropriate tools to the torque prescribed in the operating requirements (Section 7.1). The keg lid is attached by permanently fitted studs and secured by nuts (see Figure 1-1a and figure 1-1b). Therefore, the package cannot be inadvertently opened.

The package cannot be opened unintentionally by any pressure that may arise within the package. The information presented in Section 2.6.3 shows that the containment vessels remain closed under the design pressure (which bounds the maximum internal pressure that can be generated). The keg lid will remain in place under any pressure that may arise within the package. This has been demonstrated by the thermal test reported in Section 2.7.4.

2.5 Lifting and Tie-Down Standards for All Packages

2.5.1 Lifting Devices [71.45 (a)]

The package itself has no structural devices designed for lifting the package therefore it is anticipated that the package will be man handled into position and lifted on a truck tail lift or lifted using a fork lift truck with drum clamps fitted. These methods of handling do not stress the structure of the package.

2.5.2 Tie-Down Devices [71.45 (b)]

The SAFKEG has no specifically designed tie-down devices. The normal method of securing the package during transport is expected to be by the use of dunnage, cargo nets or an equivalent system that envelope the package without being attached to it: such a system cannot stress the structure of the package. The package may be secured in either the horizontal or vertical position. Testing of both package positions during the steady state thermal test as described in CTR 2010/02 has demonstrated that either position is safe.

2.6 Normal Conditions of Transport

2.6.1 Heat [71.71 (c)(1)]

According to 10CFR 71.71 (c) (1), the package must be evaluated in an ambient temperature of 38°C, in still air and insolation. Under these conditions the maximum temperature and pressure generated have been calculated and discussed in Section 2.6.1.1. These temperatures and pressures have then been used to determine the differential thermal expansion in Section 2.6.1.2 and therefore the stresses present in the containment vessel. The calculated stresses are then used to determine if the containment vessel meets the structural design criteria.

2.6.1.1 Summary of Pressures and Temperatures

The calculated maximum temperatures in the containment vessel and keg with maximum heat load of 30W under NCT are shown in Section 3, Table 3-2. The maximum temperature for the containment vessel is 163.2°C. The stress calculations were carried out assuming a temperature of 158°C. The temperatures are divergent by 5°C, which would not cause the results of the test to be any different from those presented here.

As presented in section 3.3.2 the maximum normal operating pressure that would develop in the containment vessel in a period of one year under the heat condition is less than 7 barg. Therefore 7 barg has been used as a bounding pressure in the structural evaluation.

2.6.1.2 Differential Thermal Expansion

The finite element analysis model investigated the deformations caused within the containment vessel as a result of the differing expansion rates of the depleted uranium shielding and the stainless steel cladding. The results of the analysis included the effect of differential thermal expansion in both the radial and longitudinal directions. The results of analysis indicate no significant distortion of either the body or the lid.

The 3977 keg is designed to have a 2.5 mm clearance between the cork and containment vessel and another 7 mm clearance between the cork and the keg lid. As the cork is free standing within the keg liner this allows movement of the top cork of up to 7 mm and hence expansion of the containment vessel of 9.5 mm. There was no significant expansion of the vessel therefore it will not impact the structural integrity of the package.

The NCT free drop tests were carried out on a standard CV lid prototype package within the series of NCT and HAC tests, as described in the Croft Report CTR 2010/02, appended in Section 2.12.2. The test package of 153.9 kg mass was dropped 1.2 meters onto a steel target with a mass of 500 kg, which was located on a thick concrete base. The NCT free drop tests were all carried out at an ambient temperature of 5°C.

In order to determine the effect of testing on the package several modifications were made to the containment vessel, cork and keg. To accommodate the wiring for the test equipment small holes of up to 25 mm were drilled though the center of the containment vessel lid, top cork and keg lid. A drain hole on the side of the keg was enlarged to allow the test equipment wiring to pass through it. Finally two cavities and threaded holes were machined into the containment vessel lid to allow the attachment of the accelerometers. The changes are discussed in more detail in the Croft Report CTR 2010/02 (Section 2.12.2). These changes are would not affect the structural integrity of the package or the test results: if anything they would slightly weaken the integrity causing the tests to have a greater effect on the test package than the actual package.

The total mass of the tested package was 153.9 kg which is 5% lighter than the design weight of 163kg given in section 2.1.3. The design weight is greater than the tested package weight to allow for variations due to manufacturing tolerances. In order to account for the lower weight of the test package it was dropped from 10.2 m under the HAC tests, this is a 13% increase in the drop height and energy of the package at impact.

Aside from minor weight differences and the modifications discussed for testing, the prototype package was identical to the standard lid manufactured package.

The drop tests caused minimal damage to the top rim of the 3977 keg. No visible damage or deformation was present on the body of the keg after each of the drop tests. This indicates there would be no significant change in the radiation level. Helium leakage testing was carried out prior to and after the entire test series. The leakage testing demonstrated the containment vessel remained leak tight throughout the test series. These tests therefore demonstrate that the package meets the requirements of 10 CFR 71.71(c)(7).

A supplemental detailed analysis of the stress present in the containment vessel during the free drop test was carried out using a finite element model of the containment vessel as described in Vectra Report L20008/1/R1 appended in Section 2.12.2.

The three drop orientations were modeled, using the standard lid containment vessel, under ‘hot’ and ‘cold’ conditions as required by Regulatory Guide 7.8 [2.2]. The hot conditions assumed the package experienced the maximum ambient temperature of 38°C, in still air with maximum insolation and decay heat. With these conditions it was assumed that the containment vessel was at a uniform temperature of 158°C. Along with the hot temperature it was assumed that the containment vessel had an internal pressure of 800 kPa. The external pressure was taken as 100 kPa, so the internal gauge pressure was 700 kPa

9m specified in the regulations. As a result the energy at impact was 13% greater than required.

Regulatory Guide 7.8 suggests that the following orientations are considered, top end, top corner, side, bottom end and bottom corner. Previous tests on other Safkeg packages have shown that the highest shock is produced by the side impact, based on the assumption that the minimum measured deformation of the package produces the highest deceleration. On the basis of this evidence, and consideration of the damage mechanisms that could lead to loss of containment or failure to meet other regulatory criteria, the first orientation of the 10.2 m drop test was chosen to be a side impact (with axis horizontal). It was considered that a drop on the bottom or bottom rim of the package would cause less damage than a drop on the lid or the rim of the package. A drop on the lid or rim may distort the lid and open the seals however this would not occur with a drop on the bottom or the bottom corner. Therefore the 10.2 m drop tests were carried out in the order of drop with the C of G over the side, C of G over the top rim and finally C of G over the top end.

The drop tests were performed with the test package cooled to -40°C. This temperature was considered the most challenging because brittle fracture is more likely at lower temperatures and the cork is also harder at lower temperatures thus providing less impact protection.

The package for the 10.2 m drop consisted of the fully assembled standard CV lid package with some modifications made to allow for test equipment to be fitted and data to be recorded. Several modifications were made to the containment vessel, cork and keg. To accommodate the wiring of the test equipment small holes of up to 25 mm were drilled though the center of the containment vessel lid, top cork and keg lid. A drain hole on the side of the keg was enlarged to allow the test equipment wiring to pass through it. Finally two cavities and threaded holes were machined into the containment vessel lid to allow the attachment of the accelerometers. The changes are discussed in more detail in the Croft Report CTR 2010/02 (Section 2.12.2). These changes would not affect the structural integrity of the package or the test results.

Aside from minor weight differences, some minor differences in design as discussed in report CTR 2010/02 (Section 2.12.2) and modifications discussed for testing, the prototype package will be identical to the manufactured package. The test package was loaded with the 12 x 95 tungsten insert filled with 68 g (0.09 lb) of lead shot, to simulate the maximum permissible mass of contents. The split CV lid design has not been tested because the performance of the standard CV lid would bound that of the split CV lid design. The standard CV lid had a loading on the closure screws, during the impact tests of 24.26 kg whereas the split CV lid has a loading of 19.74 kg on the closure screws, which, is less than the standard CV lid. The materials and geometry for both lids are identical therefore they would respond identically in an impact scenario. The surface area for both designs interacting with the cork is identical therefore all forces transmitted to both CV lid designs will be consistent. During testing there was no damage to the CV which demonstrates the damage was contained to the keg, for both lid designs the keg and cork are identical.

Prior to the NCT and HAC test series the package and its components were measured and weighed. The containment vessel was also helium leak tested to ensure it was leak tight. On completion of the test series these tests were repeated to determine the damage sustained to the package and if the containment vessel remained leak tight.

The physical tests were used to prove the capability of the package under HAC conditions however supplementary to this a stress analysis of the containment vessel under HAC test conditions, was carried out, using a finite element analysis detailed in the Vectra Report L20008/1/R1 (Section 2.12.2). In accordance with Regulatory Guide 7.8 [2.2] each drop

2.7.2 Crush [71.73 (c)(2)]

The crush test is not required as the package has a density of 2,968 kg/m^3. The calculation of the density of the package is described in CS 2012/03 [Section 2.12.2].

2.7.3 Puncture [71.73 (c)(3)]

10 CFR 71.73 (c) (3) requires that a package is dropped from 1m onto the upper end of a solid, vertical, cylindrical mild steel bar mounted on an essentially unyielding, horizontal surface. The package must be dropped onto the bar in the orientation in which the maximum damage is expected.

In order to fulfill this requirement a prototype package was dropped onto a steel punch with a diameter of 150 mm and 150 mm in length in 3 different orientations on its side, on the top rim and finally on the top of the keg. The test procedure and results of the puncture tests are reported in the report CTR 2010/02 (Section 2.12.2) and summarized in this section.

The package was dropped onto the punch in orientations expected to cause the maximum damage to the package. The puncture tests were carried out with the package at -40^{o}C after the 10.2m drop test series. This test allowed the effects of brittle fracture during the punch test to be assessed.

The penetration drops on the bottom end and the top rim resulted in minimal damage to the keg. The side penetration drop resulted in a dent of 11 mm in depth in the side of the keg. No tearing or penetration of the keg skin was observed.

2.7.4 Thermal [71.73 (c)(4)]

10 CFR 71.73 (c) (4) requires that the package can withstand a 30 minute fire with an average flame temperature of 800^{o}C. The requirement was demonstrated by carrying out a thermal analysis on a HS package. This analysis has been bench marked using an actual thermal test on a similar package the 3979A LS package. The thermal results have been reported in Section 3.10.2. The analyses of the structural design during the thermal test are presented within this section.

2.7.4.1 Summary of Pressures and Temperatures

During the thermal test the keg skin reaches a maximum temperature similar to that of the fire (800^{o}C). The containment vessel insulated from the full effect of the fire by the cork reaches a maximum temperature of 208^{o}C with a heat load of 30W from the contents. The temperature each component reaches during the HAC thermal test is within it maximum allowable service temperature. The maximum pressure reached during the HAC fire is 7.47 barg (section 3.4.3). The containment vessel maximum internal pressure during the HAC fire is assumed to be 10 bar or 1000 kPa gauge for the design evaluation.

HAC Operating Condition	CV
Assumed Max. Temperature	208°C
Max. Pressure	10 bar (1,000kPa) gauge 11 bar (1,100kPa) abs
Min. Temperature	-40°C
Min. Pressure	-1 bar (-100 kPa) gauge 0 bar (0 kPa) abs

2.7.4.2 Differential Thermal Expansion

The HAC thermal evaluation shows that on initiation and on completion of the fire there is no significant temperature gradient over the depleted uranium shielding and the stainless steel cladding. Therefore it is expected that the differential thermal expansion is bounded by the results for the NCT heat test discussed in section 2.6.1.2.

2.7.4.3 Stress Calculations

In accordance with the ASME code the stresses in the package resulting from temperature loading are classified as secondary and need not be evaluated under HAC. The HAC thermal evaluation shows that the thermal gradient of the containment vessel under HAC will be negligible and therefore bounded by the NCT heat test discussed in section 2.6.1.3.

2.7.4.4 Comparison with Allowable Stress

The HAC thermal test stresses are bounded by the stresses in the NCT thermal test. As detailed in Section 2.6.1.4 all the maximum stresses are less than the allowable stresses. Therefore the package meets the requirements under HAC conditions.

2.7.5 Immersion – Fissile Material [71.73 (c)(5)]

The quantity of fissile material to be carried does not depend on water exclusion for criticality safety and therefore this water immersion test is not required.

thin 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).

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

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°C along with heating of the gases on loading this would lead to a MNOP of 2.23 bara. The generation of Xe-131 only leads to an increase in pressure of $4x10^{-6}$ bar, therefore it can be neglected from the calculation of the MNOP.

For Mo-99, under NCT the 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 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 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.

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. 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 80.1°C. The highest pressure calculated was 4.19 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°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.

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.

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.

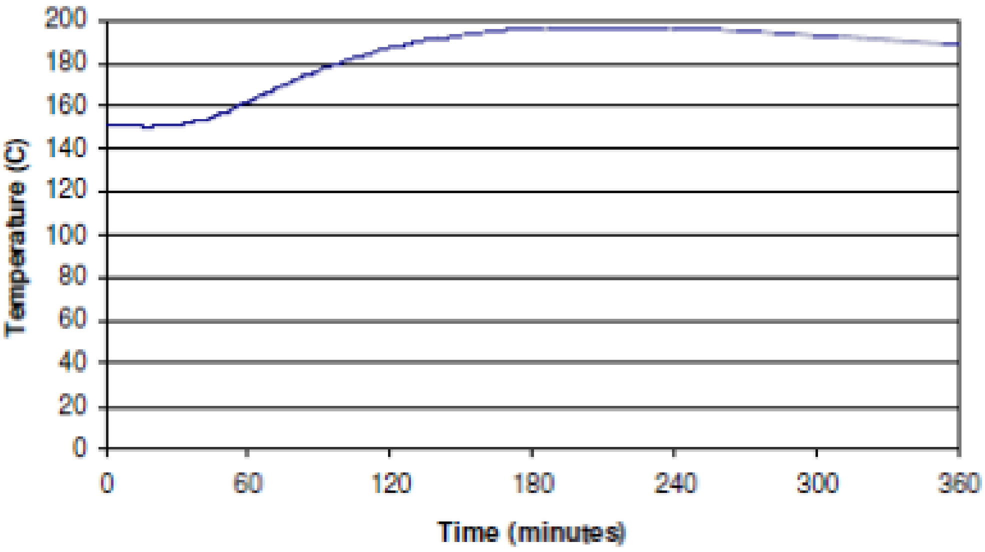

Figure 21 – Predicted Temperature of the Containment Vessel Lid Seal during the Fire Accident – Internal Heat Load of 30W

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 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 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.

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
V2.2	Radiolytic Gas Formation in Mallinckrodt Produced Mo99 Solutions

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4 CONTAINMENT

The containment boundary of the SAFKEG-HS 3977A package is identified and discussed in this chapter. The design, materials selected and the method of fastening are discussed with regards to meeting the containment requirements during the operation of the package. The ability of the package to provide the required containment during Normal Conditions of Transport (NCT) and Hypothetical Accident Conditions (HAC) as defined in 10 CFR 71.71 and 10 CFR 71.73 [4.1] respectively is presented. The criteria that verify the containment requirements during fabrication, maintenance and use are presented within this section.

4.1 Description of the Containment System [71.33 (a)(4)]

The containment boundary of the Safkeg-HS 3977A package is formed from the containment vessel flange/cavity wall, lid top and containment seal O-ring with both the standard and split CV lid, as shown in Figure 4-1 and Figure 4-2. The lid top is sealed to the flange/cavity wall by the containment seal O-ring which is fitted in a face seal configuration with the O-ring recessed into the flange. The lid top is held in position with 8 alloy steel closure screws which screw into the containment vessel flange/cavity wall and lid and are tightened to a torque of 10±0.5 Nm. On tightening the closure screws a uniform and repeatable compression of the O-rings is provided.

The closure screws are recessed into the lid top to physically protect them from damage. There is also a shear lip in the lid top and flange protecting the screws from shear failure due to transverse impact loads. The closure screws are positive fasteners, that cannot be opened unintentionally, or by any pressure that may arise within the package.

There are no welds, valves or pressure relief devices present in the containment boundary and the package does not rely on any filter or mechanical cooling system to meet the containment requirements.

The containment system is designed, fabricated, examined, tested and inspected in accordance with ASME B&PV Code Section III, Subsection NB [4.2]. The complete specifications such as closure screw torques, materials of construction, O-ring specifications and design dimensions for the containment system are given in drawings 1C-5944, 1C-5945, 1C-5946, 1C-7504, 1C-7505 and 1C-7506 in Section 1.3.2

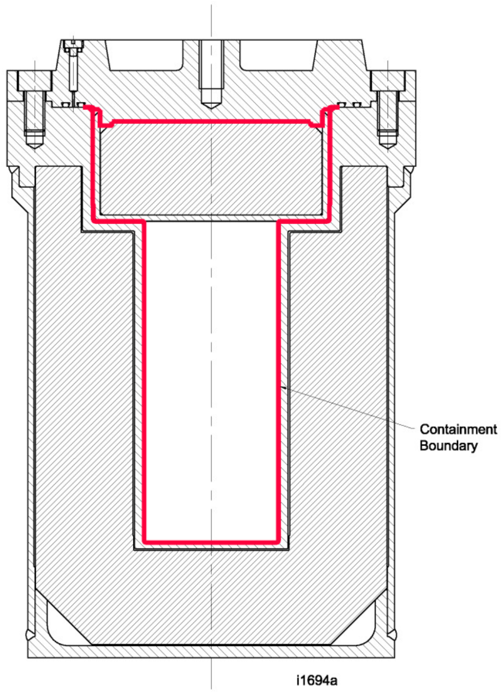

Figure 4-1 Package Containment Boundary With a Standard CV Lid

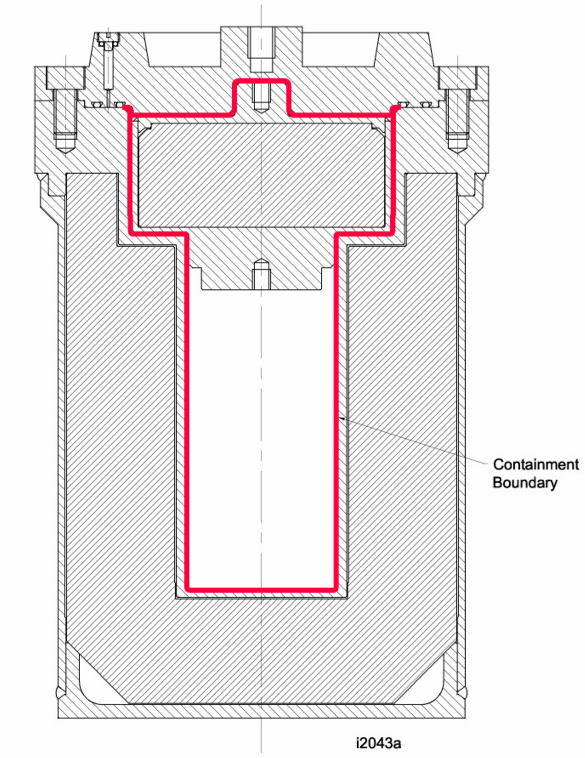

Figure 4-2 - Package Containment Boundary With a Split CV Lid

The flange/cavity wall and lid top are machined from 304L solid stainless steel. The containment O-ring is manufactured from the Fluoroelastomer, Viton GLT. The materials of construction of the containment system are evaluated in Section 2.2.2. All the materials have been selected for compatibility with each other, the inserts and the payload in order to avoid chemical, galvanic or other reactions.

Viton GLT has been selected as the containment O-ring material because it offers a temperature range of -40°C to 205°C [4.3]. The radiation dose to the containment seal, assuming that the package is loaded with maximum contents as specified in Section 1.2.2 for a full year, is estimated to be << 10^4 Gy (10^6 rad). This estimate is based on the dose rate data presented in Section 5.5.4.1.1 for Cs-137 contents. It is judged that Cs-137 would produce the highest dose rate to the containment seal (which is outside the shielding) as it has a penetrating radiation. The maximum dose rate at the containment seal for each of the three inserts specified in Section 1.2.2 for the maximum Cs-137 contents, limited by the package maximum allowable surface dose rate, is given in Table 4-1.

4.2.3 Structural Performance under NCT

The structural performance of the containment boundary of the CV has been demonstrated by prototype testing and analysis.

A prototype Safkeg-HS 3977A package was subjected to the NCT and HAC tests, as reported in Sections 2.6 and 2.7, in an uninterrupted test series, the containment seals were shown to be leaktight on conclusion of the tests.

The structural analysis reported in Sections 2.6 and 2.7 showed that there would be no permanent deformation of any of the containment system components under NCT conditions.

4.2.4 Containment of Radioactive Material under NCT

The structural performance of the containment boundary of the CV has been demonstrated by prototype testing and analysis.

A prototype Safkeg-HS 3977A package was subjected to the NCT and HAC tests, as reported in Sections 2.6 and 2.7, in an uninterrupted test series. Following the tests, the containment vessel was leakage tested in accordance with ANSI N14.5 and the containment system seals were found to be leaktight (having a leakage rate of $\leq 10^{-7}$ ref.cm^3/s).

The structural analysis reported in Sections 2.6 and 2.7 showed that there would be no permanent deformation of any of the containment system components under NCT, therefore there would be no effect which could cause any reduction in the effectiveness of the containment system.

The contents are carried within inserts as specified in Section 1.2.2 which are required for all contents.

For solid and liquid radioactive material, under NCT the shielding inserts (together with the user defined product containers) provide confinement of the radioactive material within the shielding. Thus the shielding calculations are based on the contents being retained within the insert specified for the particular contents.

For gaseous radioactive material, under HAC the gas is assumed to leak from shielding inserts (and the user defined product containers) and fill the cavity of the CV. The gas is assumed to leak from the CV at the containment seal at the leakage rate to which the containment is proved [i.e. 10^{-7} ref.cm^3/s].

4.3 Containment under Hypothetical Accident Conditions (HAC) [71.51 (a)(2)]

4.3.1 Maximum internal pressures under HAC

The maximum internal pressure of the containment vessel under HAC is taken as the design pressure of 1100kPa abs (11.0 bar abs) (see Section 3.3.2)

5 SHIELDING EVALUATION 5-1
5.1 Description of Shielding Design 5-1
5.2 Source Specification [71.33 (b)(1)] 5-6
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5 SHIELDING EVALUATION

This section of the application identifies the principal radiation shielding design features of the packaging that are important to safety and provides the results of analysis that shows the packaging meets the shielding requirements of the regulations.

5.1 Description of Shielding Design

5.1.1 Design Features

Figure 5.1 and Figure 5-2 show the gamma shielding present in the Safkeg-HS 3977A package with the standard and split lid containment vessel. The materials of construction and dimensions are fully specified in the drawings in Section 1. Gamma shielding is provided principally by the depleted uranium present in the containment vessel body and lid; the steel of the CV provides some additional shielding.

The depleted uranium is machined to specification and then positioned inside the stainless steel cladding of the body and the lid. Gaps of 0.75 mm exist between the CV cavity and the depleted uranium and between the depleted uranium and the CV outer wall. There is a 0.7 mm axial gap between the depleted uranium and the base of the CV cavity wall. The method of fitting the CV base leaves no gap between the base and depleted uranium. For the CV lid, a radial gap of 0.05 mm exists between the depleted uranium and the stainless steel cladding. There is no axial gap as the depleted uranium is machined such that fitting to the CV lid top leaves no gap. The containment vessel is designed so that the shielding in the lid and body are stepped to reduce radiation streaming. The upstanding ring on the lid also provides some additional steel shielding to reduce the radiation streaming from the gap between the CV Lid and CV Body.

The contents of the package are defined as everything that is carried within the CV cavity. For all contents, one of the inserts shown in Figures 5-3, 5-4, 5-5 or 5-6 is used – these are fully specified in Section 1.2.2.2. These inserts provide different amounts of shielding with either tungsten material for the 3982 and 3985 or stainless steel in the case of the 3987 and 4081inserts. For the 4081 stainless steel insert a tungsten liner is also placed in the containment vessel to provide additional shielding. The inserts provide confinement for all contents under NCT and HAC.

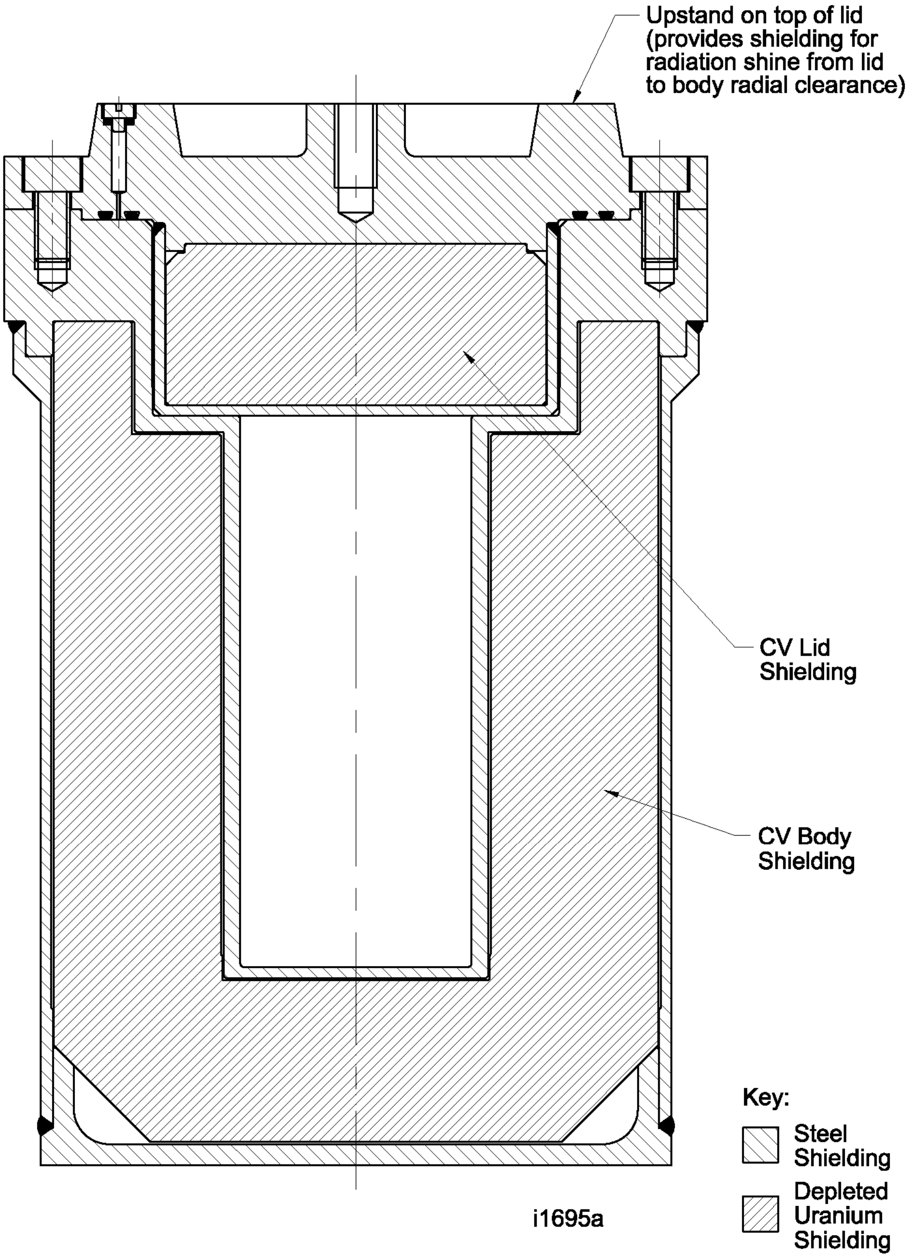

Figure 5-1 Gamma shielding present in the 3977A package with a standard CV lid

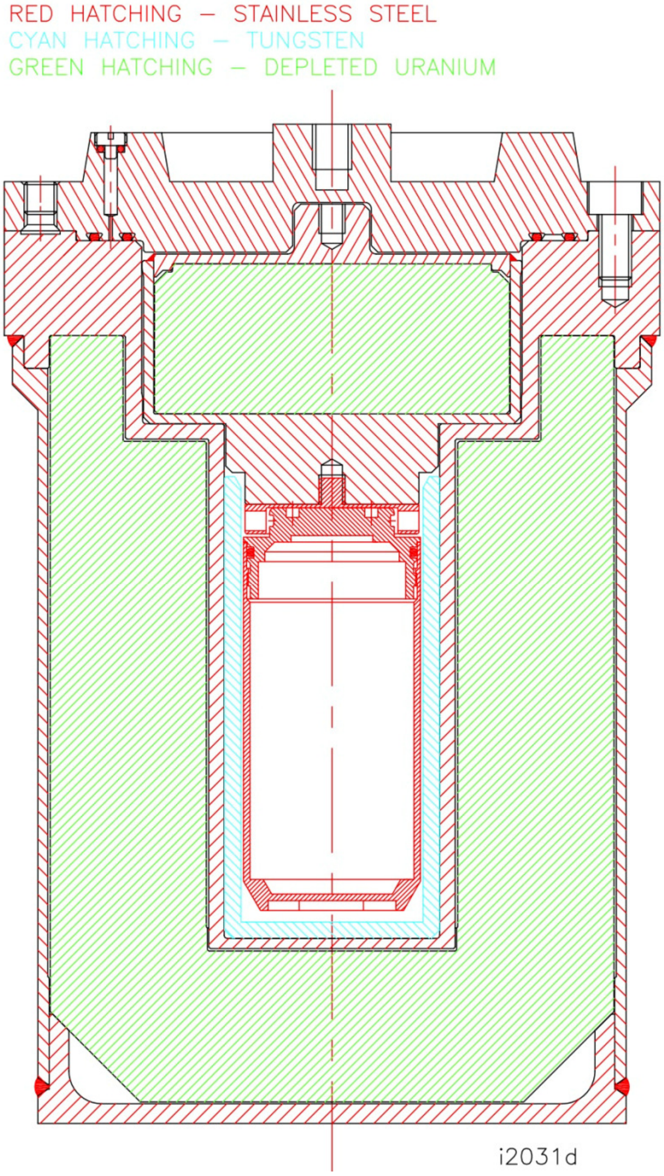

Figure 5-2 - Gamma shielding present in the 3977A package with a split CV lid and Tungsten liner

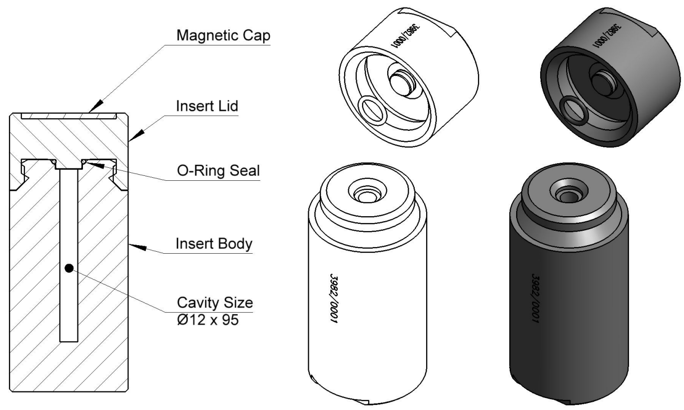

Figure 5-3 - Shielding insert HS-12x95-Tu insert Design # 3982

Figure 5-4 - Shielding insert HS-31x114-Tu insert Design # 3985

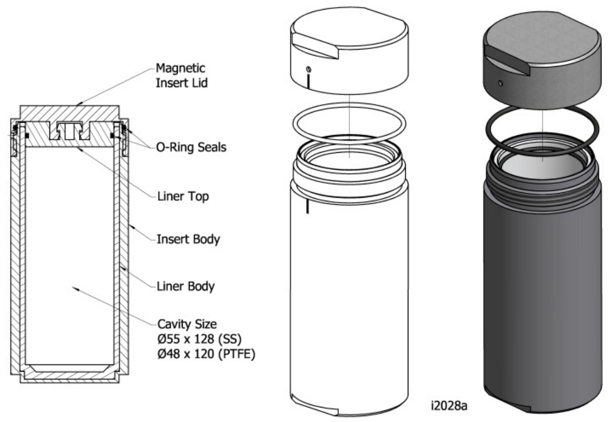

Figure 5-5 - Shielding insert HS-55x128-SS Insert Design # 3987

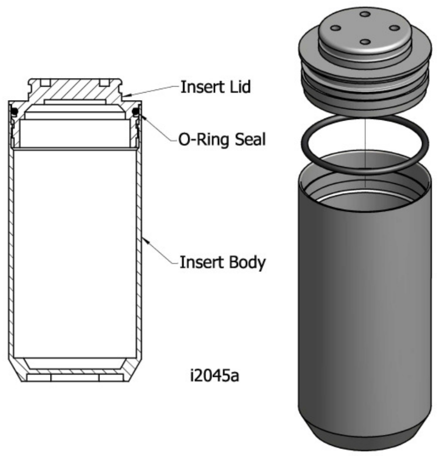

Figure 5-6 - Shielding insert HS-50x128-SS Insert Design # 4081

5.2 Summary Table of Maximum Radiation Levels

5.2.1 Normal Conditions of Transport

Table 5-1 shows the package maximum NCT dose rates for exclusive use. The maximum quantities of the allowable contents were derived assuming a surface dose rate of 2 mSv/hr. However due to analytical uncertainties, package tolerances and the method of calculation the surface dose rates required increasing in accordance with CTR 2013/09. Therefore the surface dose rates exceeded that of non exclusive use so they were assessed against those of Exclusive use.

Under 10 CFR 71.47(b) if a package exceeds the limits specified in 71.47(a) it shall be shipped under exclusive use and the radiation levels shall not exceed the following during shipment:

1) 2 mSv/h (200 mrem/h) on the external surface of the package, unless the following conditions are met, in which case the limit is 10 mSv/h (1000 mrem/h):

(i) The shipment is made in a closed transport vehicle;

(ii) The package is secured within the vehicle so that its position remains fixed during transportation; and

(iii) There are no loading or unloading operations between the beginning and end of the transportation;

(2) 2 mSv/h (200 mrem/h) at any point on the outer surface of the vehicle, including the top and underside of the vehicle; or in the case of a flat-bed style vehicle, at any point on the vertical planes projected from the outer edges of the vehicle, on the upper surface of the load or enclosure, if used, and on the lower external surface of the vehicle; and

(3) 0.1 mSv/h (10 mrem/h) at any point 2 meters (80 in) from the outer lateral surfaces of the vehicle (excluding the top and underside of the vehicle); or in the case of a flat-bed style vehicle, at any point 2 meters (6.6 feet) from the vertical planes projected by the outer edges of the vehicle (excluding the top and underside of the vehicle); and

(4) 0.02 mSv/h (2 mrem/h) in any normally occupied space, except that this provision does not apply to private carriers, if exposed personnel under their control wear radiation dosimetry devices in conformance with 10 CFR 20.1502.

The Safkeg-HS package will be transported in a closed sided truck. The smallest truck that shall be used is an 18 foot (5.5 m) truck. The minimum internal dimensions of this truck are 7’4” (2.24 m) wide and 7’ (2.13 m) high. The package shall be secured in position using a transport pallet it shall secure the pallet so that it is at least 20 cm from the base, side and top of the truck.

Within Table 5-1 it has been assumed that the dose rate for each surface is the highest rate calculated. The surface dose rate of the truck has been calculated assuming that the package is only 20 cm from the surface of the truck, therefore accounting for the worst case scenario.

Table 5-1 Summary Table of Maximum Radiation Levels Under Normal Conditions of Transport Under Exclusive Use

	Total Gamma + Neutron mSv/h (mrem/h)			10 CFR 71.47(b) Limit
Location	Top	Side	Bottom	
Package Surface	7.97 (797)	7.97 (7.97)	7.97 (797)	10 (1000)
Outer Surface of the Truck	1.35 (135)	1.35 (135)	1.35 (135)	2 (200)
2m from Edge of the Truck	0.03 (3)	0.03 (3)	0.03 (3)	0.1 (10)

5.2.2 Hypothetical Accident Conditions

The tests discussed in section 2 demonstrated that during the HAC tests the only significant damage sustained was to the rims and skirts of the package. These items play no role in the shielding of the contents. However an 11 mm dent was suffered to the side of the package. This dent would cause a 5% increase in dose rate on the package. The only other damage that would affect the shielding is the loss of the cork material during a fire. The model used for the NCT conditions assumes air in place of cork. The dose rates for accident conditions are shown in Table 5-2.

Table 5-2 - Summary Table of Maximum Dose Rates for Hypothetical Accident Conditions

Hypothetical Accident Conditions	1 Meter from Package Surface mSv/h (mrem/h)		
Radiation	Top	Side	Bottom
Total Gamma + Neutron	0.16 (16)	0.16 (16)	0.16 (16)
10 CFR 71.51(a) Limit	10 (1000)	10 (1000)	10 (1000)

5.3 Source Specification [71.33 (b)(1)]

5.3.1 Gamma Source

The shielding calculations were carried out using two different shielding models, MCBEND discussed in the attached reports AMEC/SF6652/001, AMEC/CRM37327/TN_001, AMEC/CRM42622/TN_001 and Microshield discussed in the attached reports CTR2011/01 and CTR 2013/09. A MCBEND model was used to determine the location of the point source which caused the highest surface dose rate for the tungsten inserts, and to allow the Microshield model to be validated against the MCBEND reference case (AMEC/SF6652/001). The MCBEND model was also used to determine the maximum surface dose rate for 7.4 TBq of I-131 (AMEC/CRM37327/TN_001) and 1000 Ci of Mo-99 (AMEC/CRM42622/TN_001) in the required stainless steel insert.

The MCBEND tungsten insert calculations were carried out using a 3kCi Cs-137 source in equilibrium with the daughter nuclide Ba-137m, with a gamma energy of 0.662 MeV and line intensity of 0.852.

On completion of the MCBEND tungsten inserts calculations, the point to use for the highest dose was determined and then the shielding calculations for the tungsten inserts were carried out using Microshield for 1 Ci of each nuclide listed in the contents. The gamma decay source data within Microshield version 8.03 is the Grove Library or ICRP 38. The source library chosen for each nuclide was the one that led to the highest surface dose rate.

For all nuclides the time at which the highest surface dose rate occurred was determined. For the majority of the contents this was at time = 0 however due to daughter products some nuclides had a peak surface dose rate hours, days or years into their life due to the formation of daughter products. Once the point of the decay process which provided the highest dose rate was identified, the nuclide was decayed to this point and the dose rate on the surface of the package determined. Table 5-3 shows all the daughter products that were included in the shielding calculation for applicable nuclides.

The betas and alphas were neglected as shielding source terms as it was assumed they were 100% absorbed into the packaging shielding material and did not contribute to the dose rate on the surface of the package. However, Bremsstrahlung radiation was calculated for all the beta emitters.

Table 5-3 - Daughter Nuclides Included in Shielding Model

Parent Nuclide	Daughter Nuclides
Ac-225	At-217, Bi-213, Fr-221, Pb-209, Po-213, Tl-209
Ac-227	Bi-211, Fr-223, Pb-211, Po-211, Po-215, Ra-223, Rn-219, Th-227, Tl-207
Am-241	Ac-225, At-217, Bi-213, Fr221, Np-237, Pa-233, Pb-209, Po-213, Ra-225, Th-229, Tl-209, U-233
As-77	Se-77m
Cs-137	Ba-137m
Mo-99	Tc-99m, Tc-99

Np-237	Ac-225, At-217, Bi-213, Fr-221, Pa-233, Pb-209, Po-213, Ra-225, Th-229, Tl-209, U-233
Pb-210	Bi-210, Po-210
Pu-238	Bi-210, Bi-214, Pb-210, Pb-214, Po-210, Po-214, Po-218, Pu-238, Ra-226, Rn-222, Th-230, U-234
Pu-239	Ac-227, Bi-211, Fr-223, Pa-231, Pb-211, Po-211, Po-215, Ra-223, Rn-219, Th-227, Th-231, Tl-207, U-235
Pu-240	Ac-228, Bi-212, Pb-212, Po-212, Po-216, Ra-224, Ra-228, Rn-220, Th-228, Th-232, Tl-208, U-236
Pu-241	Ac-225, Am-241, At-217, Bi-213, Fr-221, Np-237, Pa-233, Pb-209, Po-213, Pu-241, Ra-225, Th-229, Tl-209, U-233, U-237
Ra-223	Bi-211, Pb-211, Po-211, Po-215, Rn-219, Tl-207
Ra-224	Rn-220, Po-216, Pb-212, Bi-212, Po-212, Tl-208
Ra-226	Bi-210, Bi-214, Pb-210, Pb-214, Po-210, Po-214, Po-218, Rn-222, At-218
Th-227	Bi-211, Pb-211, Po-211, Po-215, Ra-223, Rn-219, Tl-207
Th-228	Bi-212, Pb212, Po-212, Po-216, Ra-224, Rn-220, Tl-208
U-235	Ac-227, Bi-211, Fr-223, Pa-231, Pb-211, Po-211, Po-215, Ra-223, Rn-219, Th-227, Th-231, Tl-207
W-188	Re-188

5.3.2 Neutron Source

The only contents that emit neutrons are the plutonium Pu-238 and Pu-240 nuclides (limited to solid form). The source strength for each nuclide was taken from ICRP 38 and given in Table 5-4.

Table 5-4 - Neutron Flux		
Nuclide	Energy	neutrons/sec
Pu-238	1.927	4.20×10^{-9}
Pu-240	1.915	1.09×10^{-7}

5.4 Shielding Model

5.4.1 Configuration of Source and Shielding

The MCBEND model detailed in the attached report AMEC/SF6652/001 was used to determine the location of a point source which provided the highest surface dose rate for the tungsten inserts. The model was also used to determine the maximum package surface dose rates for I-131 and Mo-99, as discussed in reports AMEC/CRM37327/TN_001 and AMEC/CRM42622/TN_001 respectively.

The 3D model was generated using the calculation drawings in section 1.3.2. The small chamfers and rounding at corners were ignored, except in the vicinity of the containment vessel O-rings. Nuts and bolts were omitted, but the central hole at the top of the containment vessel was included. Very small (< 0.1 mm) air-gaps and voids were ignored, except for the

regions where the containment vessel lid interfaces to the vessel body – in these regions the tolerance gaps were modelled explicitly. Cork is omitted for conservatism and modelled as void instead. O-ring material is not modelled and is treated as void. The 20x20 mm square cross-section tubing at either end of the Safkeg HS container has no significant impact on the calculations and is not modelled. Nominal thicknesses for each item were used.

The MCBEND model was then run with several different source locations as given in Table 5-5 and illustrated in figures 5-6 and 5-7 for the Cs-137 source in the tungsten inserts. Figure 5-8 illustrates the source location used for the I-131 point source in the 55x128 steel insert and figures 5- 9 to 5-11 demonstrate the location of the Mo-99 liquid in a 50x85 steel insert with the split lid CV. It must be noted that when the source was located at the top of the insert the insert was moved so that it touched the lid. When the source was located at the bottom the insert was moved so that it touched the liner.

Table 5-5 - Summary of Source Configurations used in MCBEND model

Source	Form	Activity	Container Configuration	Source location
Cs-137[1]	Solid	3000 Ci	With standard CV lid Without Tungsten insert	top, centred
				Bottom, centred
				mid-cavity, eccentred
				Top, eccentred
			With standard CV lid With Tungsten inserts HS-31x114-Tu HS-12x95 Tu	top, centred
				bottom, centred
				mid-cavity, eccentred
				Top, Eccentred
I-131[2]	Point Source	200 Ci (7.4 TBq)	With standard CV lid With Stainless steel insert HS-55x128 SS	top, centred
				bottom, centred
				mid-cavity, eccentred
				top, Eccentred
Mo-99[3]	Liquid	1000 Ci,	With split CV lid,	liquid, at base

[1] AMEC/SF6652/001
[2] AMEC/CRM37327/TN_001

Table 5-5 - Summary of Source Configurations used in MCBEND model

Source	Form	Activity	Container Configuration	Source location
		Maximum specific activity 60 Ci/ml	tungsten liner and Stainless steel insert HS-50x85 SS	liquid, on side
				liquid, on top

[3] AMEC/CRM42622/TN_001

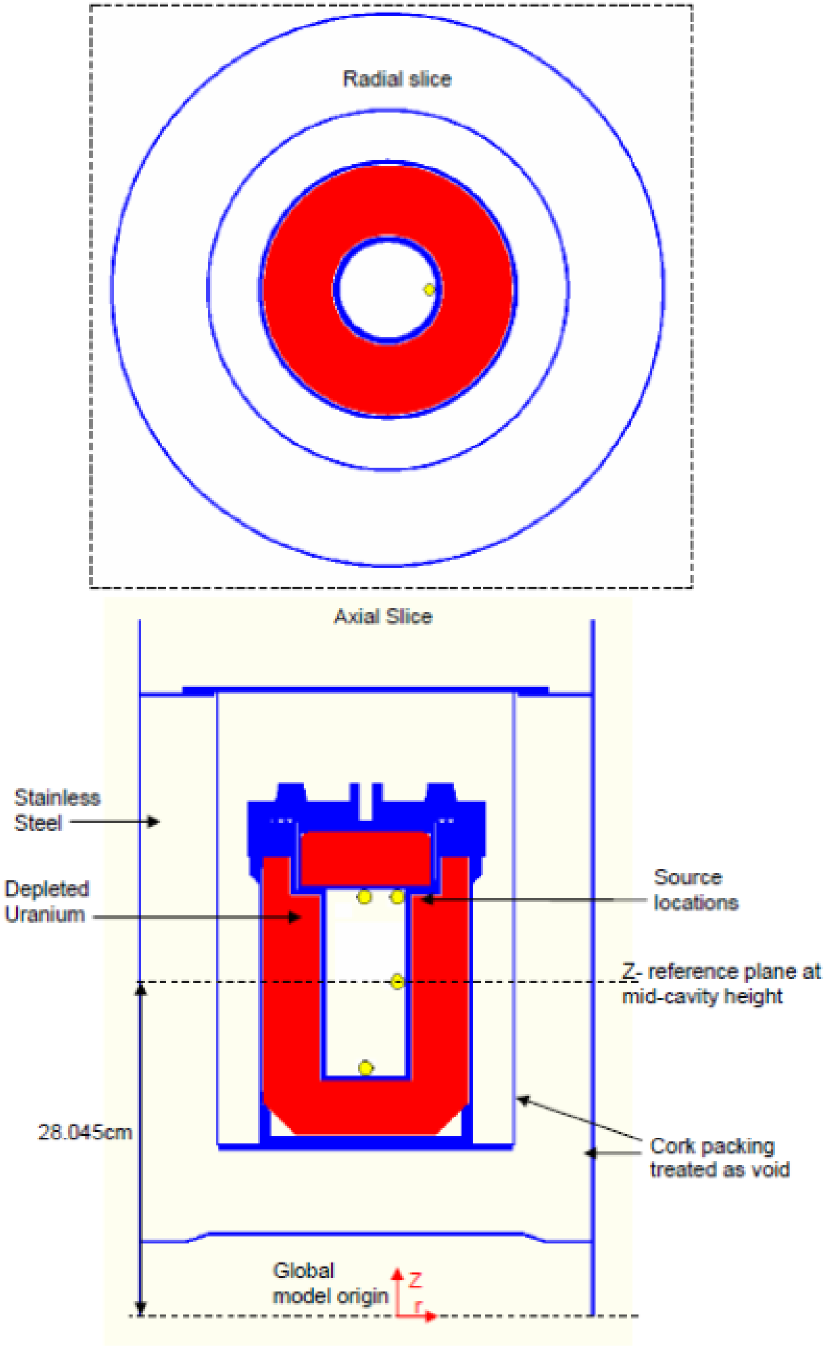

Figure 5-7 - Shielding Model and Source locations for HS package without an insert

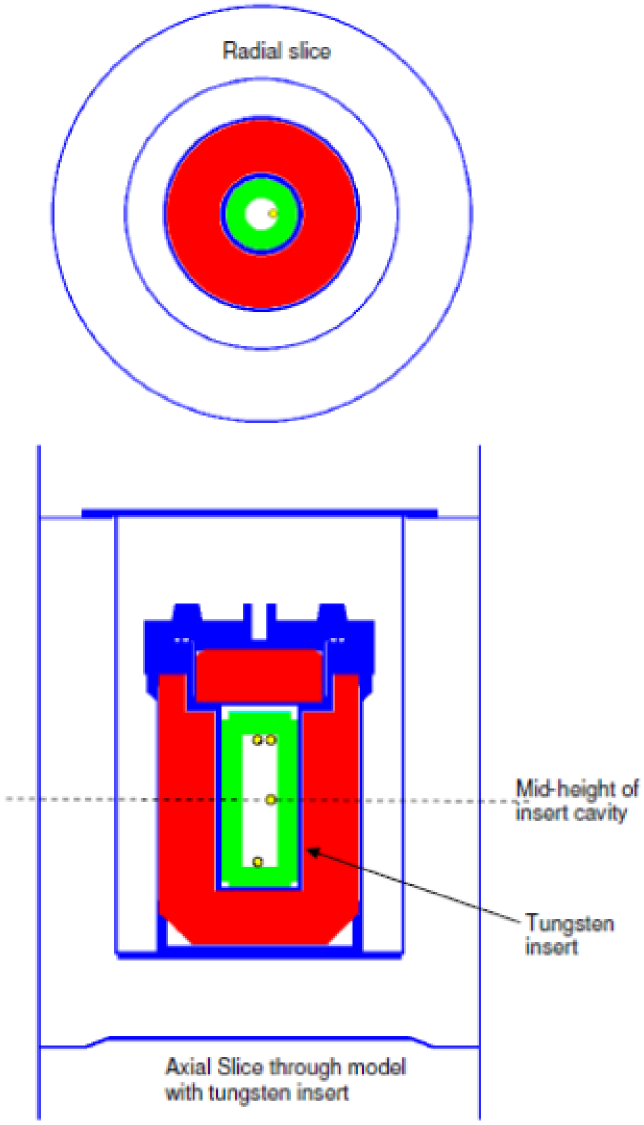

Figure 5-8 - Source Locations for MCBEND Model for HS package with Tungsten insert

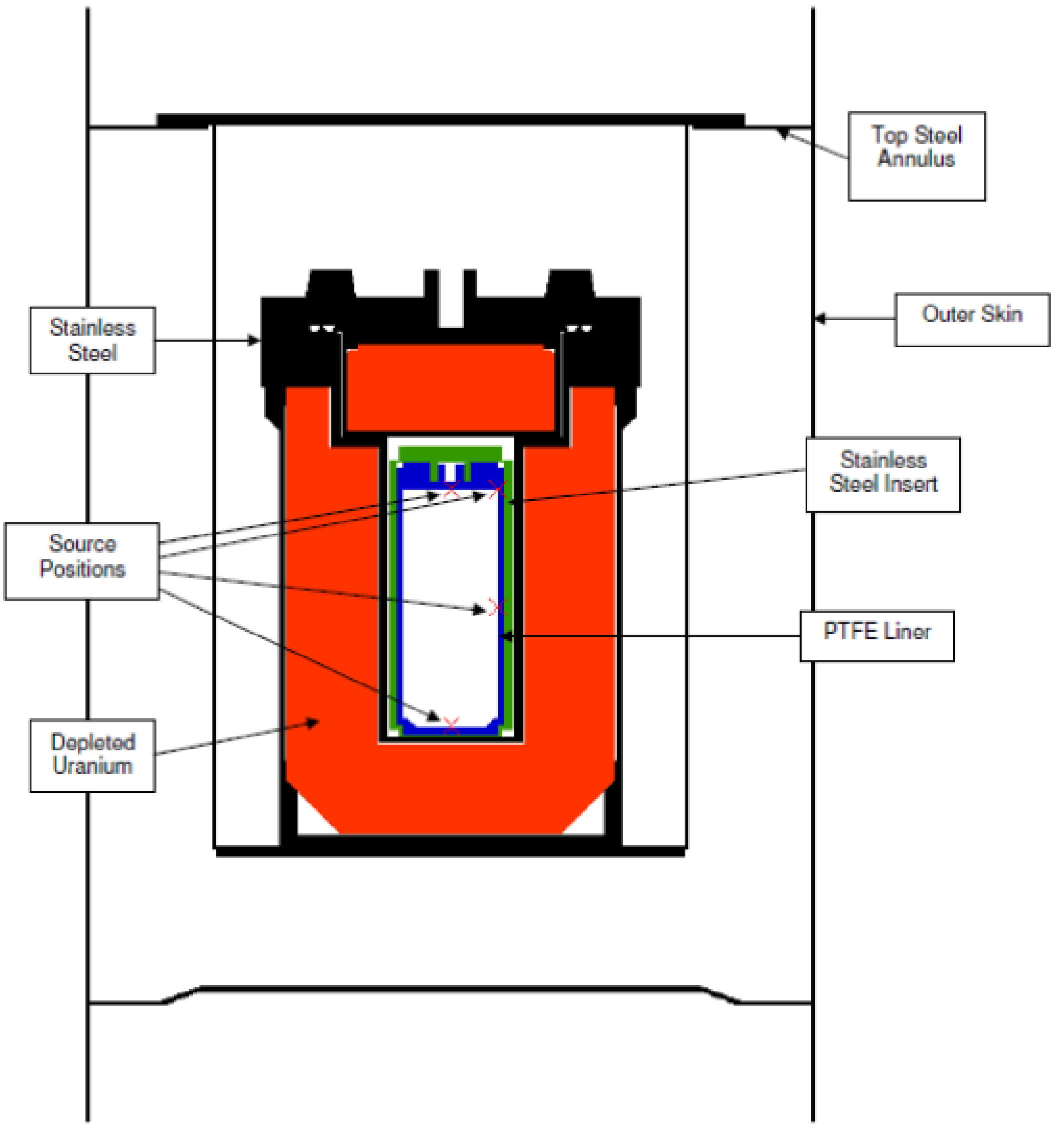

Figure 5-9 - I-131 Source Locations for MCBEND Model for HS Package with stainless Steel Insert

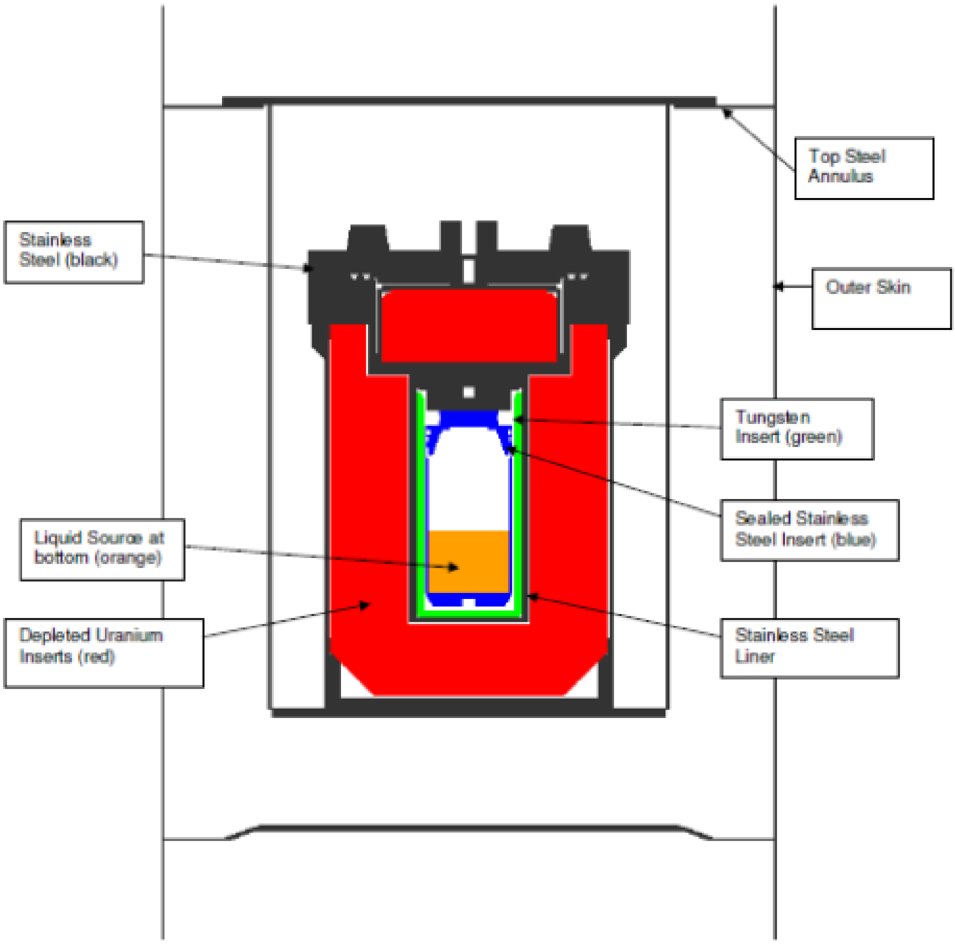

Figure 5-10 – Mo-99 Bottom Source Location for MCBEND Model for HS Package with stainless Steel Insert, Tungsten Liner and Split Containment Vessel Lid

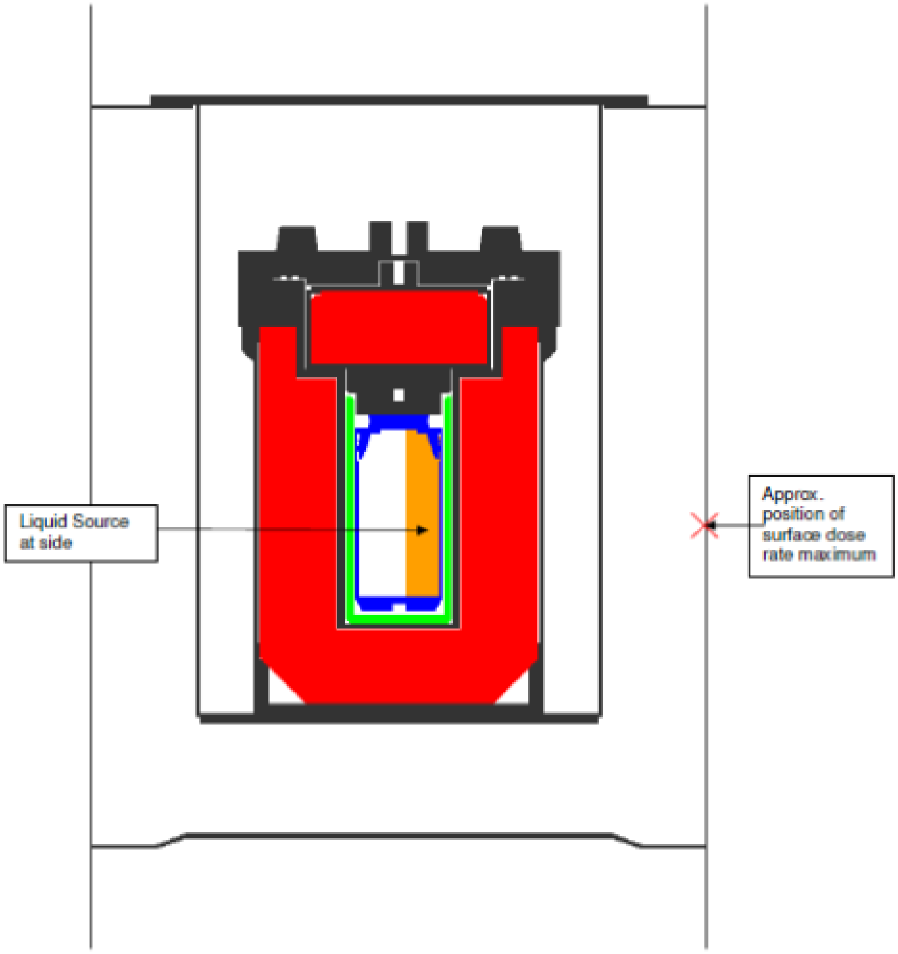

Figure 5-11 - Mo-99 Side Source Location for MCBEND Model for HS Package with stainless Steel Insert, Tungsten Liner and Split Containment Vessel Lid

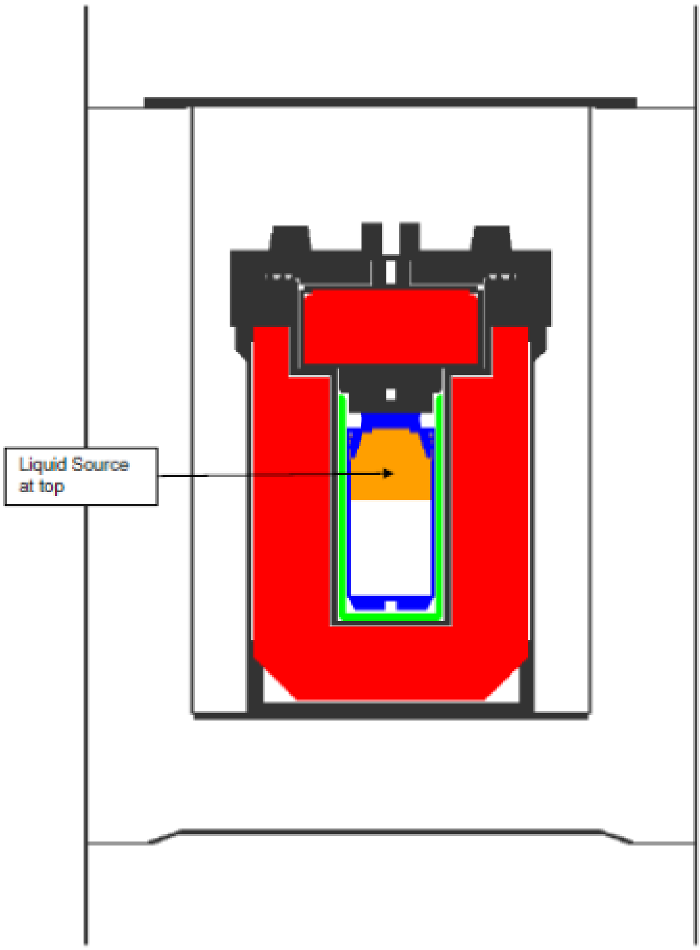

Figure 5-12 - Mo-99 Top Source Location for MCBEND Model for HS Package with stainless Steel Insert, Tungsten Liner and Split Containment Vessel Lid

For the tungsten inserts once the highest surface dose rate had been located using the MCBEND model with the Cs-137 source, a Microshield model was then built in order to determine the surface dose rate for all the nuclides to be carried in the tungsten inserts. The Microshield calculations were only carried out at the point which gave the highest dose rate as this would bound dose rates measured at other locations with other source locations. Again, a point source was used with the shield dimensions taken from the nominal thicknesses. The shields in the point source option are slabs and are shown along with the dose point in Figure 5-8. The cork was modelled as an air gap whereas in reality the density of the cork is 250 kg/m^3. A different model was produced for each tungsten insert to determine the surface dose rate for each. The thicknesses used for each slab in the different insert models are provided in Table 5-6. The results from the MCBEND calculations showed that a point source located centrally on the bottom of the insert lead to the highest surface dose rate and so the thicknesses were taken from the bottom of the package.

The Microshield model does contain several uncertainties which involved the application of several adjustment factors to the results. These uncertainties and the adjustment factors are discussed in CTR 2013/03 section 5.5.6.

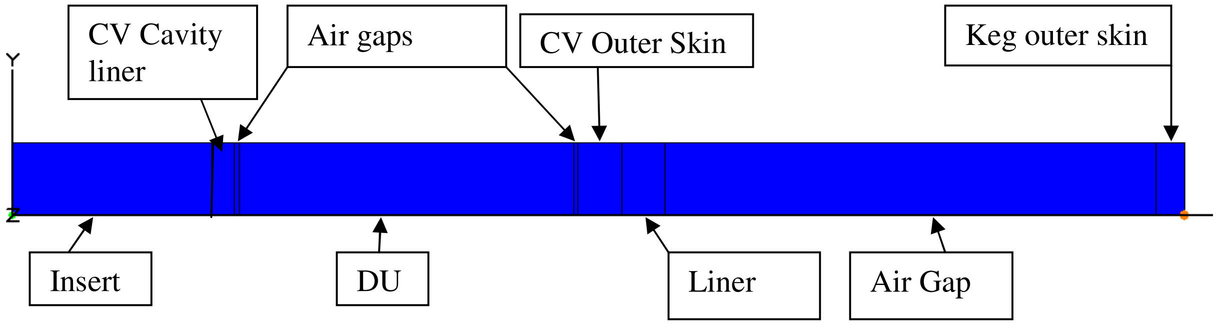

Figure 5-13 - Microshield model (3982 Insert)

Table 5-6 - Summary of Dimensions Used in Microshield Model

Feature	Thickness (cm)			Notes
	3982	3985	3987	
Insert	2.73	1.78	0.18	Tungsten was used for the insert material for 3982 and 3985. Iron was used as the insert material for 3987
CV cavity liner	0.31	0.31	0.31	Iron was used for this material in Microshield
air gap	0.07	0.07	0.07	
CV shield	4.6	4.6	4.6	Depleted uranium
Air gap	0.06	0.06	0.06	
CV outer skin	0.6	0.6	0.6	Iron was used for this material in Microshield
3977 Cavity liner	0.6	0.6	0.6	Iron was used for this material in Microshield
Outer cork liner	6.75	6.75	6.75	Cork was assumed to be

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

Table 5-8 - Shielding Material Properties in Microshield			
Material	Density (g/m^3)	Elemental Compostion	Mass Fraction
Iron	7.86	Fe	1
Depleted Uranium	17.93	U	1
Tungsten	17.23	W	1
Air	0.0012	N O	0.77 0.23

5.5 Shielding Evaluation

5.5.1 Methods

The MCBEND model was used to determine the location of a point source that causes the highest dose rate on the surface of the package for the tungsten inserts. It was also used to calculate the maximum package surface dose for 1-131 and Mo-99 in the stainless steel inserts. The model also provided a reference case with which to validate the Microshield model. The Microshield model was then used to determine all the surface dose rates for the contents in the tungsten inserts.

MCBEND is a Monte Carlo radiation transport code. The calculations have been carried out using the latest version of MCBEND, version 10A_RU1. The code and data are maintained to a level of quality assurance consistent with the standards of the ANSWERS Software Service. This ensures that reference versions of the code, data libraries and test data are held, and that updating and archiving of the code and data are strictly controlled.

Microshield is a photon/gamma shielding and dose assessment program. It was validated using the output from the MCBEND code for the 3000 Ci Cs-137 contents.

5.5.2 Input and Output Data

The input and output data for the MCBEND shielding calculations are reported in AMEC/SF6652/001, AMEC/CRM37327/TN_001 and AMEC/CRM42622/TN_001 (Section 5.5.2).

The input and output data for the MicroShield shielding calculations is reported are CTR 2011/01 (Section 5.5.2).

The adjustment to the Microshield outputs is discussed in CTR 2013/09 (Section 5.5.2).

5.5.3 Flux to Dose Rate Conversion

The dose rates from the MCBEND report AMEC/SF6652/001 are not used to calculate the dose rate for transport. The results are used to identify the location of the source that provides the highest dose and validate the Microshield result for 3000 Ci of Cs-137. Therefore the flux to dose rate conversion is not required. The ANSI/ANS-6.1.1 1977 dose conversion function was used in reports AMEC/CRM37327/TN_001 and AMEC/CRM42622/TN_001 to determine the surface dose for the stainless steel inserts .

The flux to dose rate conversion for Microshield is taken from Table 2 in ICRP 51 (1987) as given in Table 5-9 below, the Anterior/Posterior values were taken as these gave the highest dose rate. ICRP 51 provides a lower surface dose rate than using the conversion factors in ANSI/ANS 6.6.1-1977. Therefore, a correction factor was applied to the results as detailed in CTR 2013/09.

Table 5-9 - Effective dose equivalent per unit fluence for photons

Photon Energy (MeV)	Conversion coefficient, 10^{-12} Sv cm^2				
	Anterior Posterior	Posterior Anterior	Lateral	Rotational	Isotropic
0.01	0.062	0	0.02	0.029	0.022
0.015	0.157	0.031	0.033	0.071	0.057
0.02	0.238	0.0868	0.0491	0.11	0.0912
0.03	0.329	0.161	0.0863	0.166	0.138
0.04	0.365	0.222	0.123	0.199	0.163
0.05	0.384	0.26	0.152	0.222	0.18
0.06	0.4	0.286	0.17	0.24	0.196
0.08	0.451	0.344	0.212	0.293	0.237
0.1	0.533	0.418	0.258	0.357	0.284
0.15	0.777	0.624	0.396	0.534	0.436
0.2	1.03	0.844	0.557	0.731	0.602
0.3	1.56	1.3	0.891	1.14	0.949
0.4	2.06	1.76	1.24	1.55	1.3
0.5	2.54	2.2	1.58	1.96	1.64
0.6	2.99	2.62	1.92	2.34	1.98
0.8	3.83	3.43	2.6	3.07	2.64
1	4.6	4.18	3.24	3.75	3.27
1.5	6.24	5.8	4.7	5.24	4.68

Photon Energy (MeV)	Conversion coefficient, 10^{-12} Sv cm^2				
	Anterior Posterior	Posterior Anterior	Lateral	Rotational	Isotropic
2	7.66	7.21	6.02	6.56	5.93
3	10.2	9.71	8.4	8.9	8.19
4	12.5	12	10.6	11	10.2
5	14.7	14.1	12.6	13	12.1
6	16.7	16.2	14.6	14.9	14
8	20.8	20.2	18.5	18.9	17.8
10	24.7	24.2	22.3	22.9	21.6

5.5.4 External Radiation Levels

5.5.4.1 Monte Carlo calculations

5.5.4.1.1 Monte Carlo calculations for reference case (Cs-137)

The results of the Monte Carlo shielding calculations are reported in AMEC/SF6652/001 (Section 5.5.2) for the reference case of 3kCi Cs-137 point source, with the source positioned all around the surface of the CV. The results from this report are summarised in Table 5-10 (surface radiation levels) and Table 5-11 (Radiation Levels at 1m from the Surface).

The calculations also provide the dose rate at the seal O-ring position – see Table 5-10.

Table 5-10 - Summary Table of External Surface Radiation Levels and Maximum O-ring Dose Rate - Monte Carlo calculations for reference case (Cs-137)

Source position in CV cavity or Insert	External Surface Radiation Levels (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	9.75E+00	5.21E-01	1.34E-01
Centre at the bottom of the cavity	1.45E+01	8.17E-01	1.66E-01
Centre at side of the cavity	1.38E+01	7.49E-01	1.57E-01
Eccentred at the top of cavity	6.61E+02	3.06E+00	2.84E-01
CV O-ring	2.89E+03	4.01E+00	1.61E+00

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	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	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 5-12 (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 Mo-99 in the stainless steel Insert under Normal Conditions of Transport

Source Volume Position	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 volume	Bottom surface	1143	905
Top of insert	Side surface	819	880
	Top surface	581	346
Side of insert	Side surface	1214	947
	Top surface	246	219

Table 5-13 - Maximum Package Surface Dose Rate for Mo-99 in a Steel insert under Hypothetical Accident Conditions	
Source Position	16.6667 ml Source Maximum Surface Maximum Surface Dose Rate (µSv/hr)
Side of insert	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 5-12.

The activities given in Table 5-12 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 5-14 - 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
Co-60	2.38E+11	9.37E+10

Table 5-14 - 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
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
Th-227	1.01E+13	4.17E+12

Table 5-14 - 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-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

Appendix

5.5.5 References

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

[3.2] ICRP Publication 74, "Conversion Coefficients for use in Radiological Protection against External Radiation", Annals of the ICRP 26 3/4, 1996

[3.3] ICRP Publication 51, "Data for Use in Protection against External Radiation", Annals of the ICRP, 1984

5.5.6 Supporting Documents

Document Reference	Title
CTR2011/01	SAFKEG HS 3977A: Package Activity Limits Based on Shielding
CTR2013/09	Uncertainties Associated with the Proposed Shielding Calculation Method for the SAFKEG-HS 3977A Package
AMEC/SF6652/001	Monte Carlo Modelling of Safkeg HS Container
AMEC/CRM37327/TN_001	HS Container Shielding Assessment with I-131
AMEC/CRM37327/TN_001	HS Container Shielding Assessment with Mo-99

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7 PACKAGE OPERATIONS

This section specifies the requirements for loading and unloading the Safkeg-HS 3977A package, and preparation of an empty package for transport.

Each packaging user shall comply with the operational descriptions in this chapter for the loading, unloading, and preparation of the package for transport. It shall be achieved using approved operating procedures that ensure compliance with the requirements of Subpart G to 10 CFR Part 71 [Ref 7.1] and 49 CFR Parts 171 through 178 [Ref 7.2]. They shall ensure that occupational radiation exposures are maintained as low as reasonably achievable as required by 10 CFR 20 [Ref 7.3].

Each packaging user shall ensure compliance with the requirements of this safety analysis report and the user's organization with regard to documentation, records, safety, and work procedures. Each user shall have a quality assurance program that meets the requirements of 10 CFR 71 Subpart H and shall maintain records that meet the requirements of 10 CFR 71.91.

If during use any instance is found where there is a significant reduction in the effectiveness of the package, where defects are identified with safety significance after first use or there are instances in which the conditions of approval in the Certificate of Compliance were not observed in making a shipment. Then each packaging user shall first request the certificate holders input regarding the incident and then submit a written report to the Nuclear Regulatory Commission in accordance with 10 CFR 71.95.

All drawings referred to in this section are those that are listed in the Certificate of Compliance.

7.1 Package Loading [71.87]

This section provides the minimum requirements needed to load the package. From these requirements each organization shall prepare specific instructions and checklists, in accordance with that organization's Quality Assurance Program. This will ensure compliance with the following requirements.

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

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. The recommended method for lifting the containment vessel is to 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°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

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.

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.

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.

7.2.1 Receipt of Package from Carrier

1) Confirm that the package is the one identified on the accompanying documentation. Any special requirements of the receiving organization shall be fulfilled.

2) The exterior of the package shall be checked for damage that may have occurred during shipment. Damaged packages shall be handled in accordance with the user's facility procedures for handling packages that may not be in a safe condition.

3) The radiation and contamination levels on the outer surface of the keg shall be monitored. If, at any stage of unloading, levels of radiation or contamination are detected above those permitted, then the appropriate action shall be taken to safeguard personnel, and to rectify the situation. Radiation level limits are specified in 10 CFR 71.47 and 49 CFR 173.441. The maximum level of removable radioactive contamination on the package surface is specified in 10 CFR 71.87(i) and 49 CFR 173.443.

4) The security seals shall be checked to ensure they are intact. If NOT intact investigate the cause and follow internal procedures. No further disassembly of the package shall be attempted until the situation has been resolved.

7.2.2 Removal of Contents for a Standard 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) Remove the shielding screw from the top of the containment vessel and fit a 12 mm diameter eyebolt. 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) A silicone sponge rubber disc and the insert shall be removed from the containment vessel.

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.

   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.

The package may be shipped empty in a damaged condition providing all the components are packed within the keg and keg lid can be fastened securely.

Empty packages should be stored in an area where they are protected from the weather and physical damage. It is recommended that the package be stored in a controlled area to prevent unauthorized tampering or use and that a security seal be in place to provide evidence of tampering.

7.3.1 Preparation of an Empty Package with a Standard CV LId

During handling of the package it is recommended that the containment vessel is lifted with a 12mm eyebolt threaded into the lid. In order to fit this eyebolt the shielding screw shall be removed. The shielding screw shall be replaced once the eyebolt is removed.

1) A contamination survey of the internal surfaces of the containment vessel i.e. the flange/cavity wall and underside of the closure lid shall be performed. If the non fixed surface contamination exceeds the requirements 49 CFR 173.428(d) then decontaminate the containment vessel.

2) A contamination survey of the silicone sponge rubber disc and the internal and external surfaces of the insert shall be performed. If the non fixed surface contamination exceeds the requirements of 49 CFR 173.428(d) then decontaminate the insert and if applicable the liner.

3) The insert shall be placed into the cavity of the containment vessel along with the silicone sponge rubber disc. The lid of the containment vessel shall be placed onto the containment vessel flange and the closure screws shall be tightened. Torque measurements are not required, but ensure all the nuts are tight.

4) The containment vessel shall be fitted inside the inner cork of keg 3977. Ensure that the containment vessel sits down on the keg liner. If the containment vessel has been lifted with the 12 mm eyebolt remove it and replace it with the shielding screw.

5) Check that the shielding screw is present in the CV 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 and ensure 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 contamination survey of the external surfaces of the package shall be performed. Determine if the surface contamination levels meet the requirements of 49 CFR 173.428(a). If not, clean the outside of the package and repeat the contamination survey.

9) A radiation survey shall be conducted for gamma radiation to verify compliance with 49 CFR 173.428(a) requirements.

10) The empty label as specified in 49 CFR 172.450 shall be attached to the package. Ensure that any labels that have previously been applied are removed, covered or obliterated as required by 49 CFR 173.428.

11) The assembled keg should be delivered to a carrier in such condition that subsequent transport will not reduce the effectiveness of the packaging. An empty package should be handled, stored, and shipped according to proper procedures to prevent damage that could affect the subsequent use of the packaging.

7.3.2 Preparation of Empty Package with a Split CV lid for Transport

During handling of the package it is recommended that the containment vessel is lifted with a 12mm eyebolt threaded into the lid.

1) A contamination survey of the internal surfaces of the containment vessel i.e. the flange/cavity wall and underside of the closure lid shall be performed. If the non fixed surface contamination exceeds the requirements 49 CFR 173.428(d) then decontaminate the containment vessel.

2) A contamination survey of the internal and external surfaces of the insert shall be performed. If the non fixed surface contamination exceeds the requirements of 49 CFR 173.428(d) then decontaminate the insert and if applicable the liner.

3) The tungsten liner shall be placed into the cavity of the containment vessel. Insert the shielding plug, optionally the insert and payload internals may be loaded.

4) Place the lid of the containment vessel onto the containment vessel flange and tighten the closure screws. Torque measurements are not required, but ensure all the nuts are tight.

5) The containment vessel shall be fitted inside the inner cork of keg 3977. Ensure that the containment vessel sits down on the keg liner. If the containment vessel has been lifted with the 12 mm eyebolt remove it.

6) Insert the top cork and ensure 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 contamination survey of the external surfaces of the package shall be performed. Determine if the surface contamination levels meet the requirements of 49 CFR 173.428(a). If not, clean the outside of the package and repeat the contamination survey.

9) A radiation survey shall be conducted for gamma radiation to verify compliance with 49 CFR 173.428(a) requirements.

10) The empty label as specified in 49 CFR 172.450 shall be attached to the package. Ensure that any labels that have previously been applied are removed, covered or obliterated as required by 49 CFR 173.428.

11) The assembled keg should be delivered to a carrier in such condition that subsequent transport will not reduce the effectiveness of the packaging. An empty package should be handled, stored, and shipped according to proper procedures to prevent damage that could affect the subsequent use of the packaging.

7.4 Other Operations

There are no other required operations for the package.

7.5 Appendix

7.5.1 References

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

[7.2] Title 49, Code of Federal Regulations, Parts 106 – 180, Office of the Federal Register, Washington D.C.

[7.3] Title 10, Code of Federal Regulations, Part 20, Office of the Federal Register, Washington D.C.

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

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

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 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 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 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.

8.1.7 Thermal Tests

A prototype package has been fully tested as described in Section 2 and shown to perform satisfactorily under both Normal Conditions of Transport (NCT) and Hypothetical Accident Conditions (HAC).

The package design is such that specific tests of manufactured components are not required to prove adequate thermal performance. This package has no special thermal features other than the cork insulation. With the low heat load and the design margins on allowable material temperature, the package requires no special thermal testing as part of the post-manufacture acceptance test.

- replacement of the containment seal
- repair of the containment sealing surface
- repair or replacement of the containment vessel lid or body

8.2.2.2 Inserts

The maintenance leakage testing of the inserts shall be in accordance with the vacuum bubble test A.5.6(b) in ANSI N14.5 [8.3]. The test sensitivity shall be 10^{-3} ref.cm^3/s and the acceptance rate shall be no visible stream of bubbles.

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:

- replacement of the insert seal
- repair of the insert sealing surface
- repair or replacement of the insert lid or body

8.2.3 Component and Material Tests

The following sections describe the periodic maintenance requirements for package operation. Additional maintenance may be required on packagings that have failed the pre-shipment inspection process. Any additional maintenance requirements shall follow the periodic maintenance and its associated record keeping requirements.

8.2.3.1 Stainless Steel Surfaces

All of the stainless steel surfaces of the keg and containment vessels shall be visually inspected for corrosion. The presence of any surface corrosion on any component shall be cause for further inspection. If the corrosion can be easily wiped off, and no pitting is apparent beneath it, the component is acceptable. If the corrosion cannot be easily wiped off, or if scaling is present, or if pitting is observed, then the surface shall be reworked and the component must undergo a dimensional inspection and dye penetrant and/or radiographic testing to determine the extent of the damage.

In the case of the containment vessel, a hydrostatic test shall be performed. All acceptance criteria for a newly fabricated component (drawing 1C-5944 for a standard CV lid or drawing 1C-7504 for a split CV lid) shall apply to the reworked component. If the corrosion has compromised the structural integrity of the component (e.g. the component no longer meets dimensional criteria for a new part as specified on drawing 1C-5944 for the standard CV lid and 1C-7504 for the split CV lid), then the component shall be rejected. The inspection results and any necessary replacement or repairs, shall be recorded in the package maintenance records.

8.2.3.3 Containment Vessel with a Standard or Split Lid

1) The model/serial numbers of the 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 containment vessel assembly (body and lid) do not match, these assemblies shall be removed from service.

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 test sensitivity shall be 5×10^{-8} ref.cm^3/s and the test pass rate shall be 1×10^{-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

8.2.3.7 Tungsten Liner

1) The tungsten liner shall be visually inspected for damage. The dimensions, shown on the drawing 2C-7510 shall be verified by measurement. Any damaged liners or those that do not meet the measurement checks shall be replaced.

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.

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

8.2.4 Thermal Tests

This package has no special thermal features other than the cork insulation. Therefore, the package requires no special thermal testing as part of the routine maintenance. Visual inspection is sufficient to check that components are in satisfactory condition.

8.2.5 Miscellaneous Tests

This section discusses the requirements for replacing component parts on the package. These parts may be newly manufactured or substituted components from other packages. The keg which bears the serial number of the package will form the host component.

8.2.5.1 Replacement of a Closure Lid

If a closure lid is replaced, a maintenance leak rate test shall be performed in accordance with Section 8.1.4. The replacement shall be noted in the maintenance log along with the results of the leak test.

8.2.5.2 Replacement of the Containment Vessel Body

If the containment vessel body is replaced, it shall first be checked to ensure that the lid, closure screws and O-rings all fit. A maintenance leak test shall then be performed according to Section 8.1.4. The replacement shall be noted in the maintenance log along with the results of the leak test.

8.2.5.3 Replacement of a Containment Vessel

If the containment vessel is substituted the replacement shall be noted in the package maintenance log. The replacement containment vessel shall be manufactured to the requirements shown in the general arrangement drawings in the Certificate of Compliance.

8.2.5.4 Replacement of a Keg Lid

If the keg lid is replaced, the replacement shall be noted in the package maintenance log.

Table 8-1 Package Maintenance Summary

Item	SARP Section	Pre Shipment Action	Annual Maintenance Action	Tests on repair/replacement
Insert	8.2.3.5	V, Leak Test (for liquid contents only)	V, Leak test	Leak Test
Tungsten Liner	8.2.3.7	V	V	
Silicone Sponge Rubber Disc	8.2.3.6	V	V	
Containment Vessel Surfaces	8.2.3.3	V	V	Leak Test
Containment O-ring	8.2.3.3	V, Leak Test	R, Leak Test	Leak Test
Leak test O-ring	8.2.3.3	V	R	
Test Port O-ring	8.2.3.3	V	R	
O-ring sealing surfaces	8.2.3.3	V	V	
Containment Vessel threaded inserts	8.2.3.3	O	V	
Containment vessel screws	8.2.3.3	O, V	V	
Keg surfaces	8.2.3.2	V	V	
Keg lid seal	8.2.3.2	V	V	
Lid seal sealing surfaces	8.2.3.2	V	V	
Keg Studs	8.2.3.2	O, V	V	
Keg bolts and washers	8.2.3.2	O	V	
Fuse plug	8.2.3.2		V	
Fuse plug washer	8.2.3.2		V	
Cork	8.2.3.4	V	V	

Notes: V = Visual Inspection, R = Replace, O = Operational test