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

Application for Approval by the NRC

Applicant: Croft Associates Limited

CONTENTS

0 SARP STATUS AND CONTENTS

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

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

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

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

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

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

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

0.1 SAR REVISION STATUS

<table>
<tr><td rowspan="3">Title</td><td rowspan="3">SAFKEG-HS 3977A
Docket No. 71-9338</td><td>Number</td><td>CTR 2008/11</td></tr>
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<tr><td>R A Vaughan</td></tr>
<tr><td colspan="4">Croft Associates Ltd F4 Culham Science Centre Abingdon Oxon OX14 3DB UK Tel 44 (0)1865 407740</td></tr>
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0.2 SUPPORTING DOCUMENT REVISION STATUS

Document Reference	Issue Status	Title
Section 1 - GENERAL INFORMATION		
Documents in Section 1.3 Appendix		
Documents in Section 1.3.2 Calculation Model Drawings		
0C-5949	Issue A	Safkeg-HS Construction
1C-5997	Issue A	Containment Vessel HS Lid Construction
1C-5999	Issue A	Containment Vessel HS Body Construction
3C-6850	Issue A	HS-12x95-Tu Insert Design No.3982 (construction)
3C-6851	Issue A	HS-31x114-Tu Insert Design No. 3985 (construction)
Documents in Section 1.3.3 Licensing Drawings		
1C-5940	Issue E	Cover sheet for Safkeg-HS design no. 3977A (licensing drawing)
0C-5941	Issue D	Safkeg-HS design no. 3977A (licensing drawing)
0C-5942	Issue B	Keg design no. 3977 (licensing drawing)
0C-5943	Issue B	Cork set for Safkeg-HS (licensing drawing)
1C-5944	Issue C	Containment vessel design no. 3978 (licensing drawing)
1C-5945	Issue C	Containment vessel lid (licensing drawing)

Document Reference	Issue Status	Title
1C-5946	Issue D	Containment vessel body (licensing drawing)
2C-6173	Issue D	HS-12x95-Tu Insert Design No 3982 (Licensing drawing)
2C-6174	Issue D	HS-31x114-Tu Insert Design No 3985 (Licensing drawing)
2C-6920	Issue A	Silicone Sponge Rubber Disc
Documents in Section 1.3.4 Supporting Documents		
PCS 038	Issue D	Package Contents Specification for Safkeg-HS - Package Design No 3977A
Section 2 - STRUCTURAL EVALUATION		
Documents in Section 2.12.2, Appendix		
CTR 2010/02	Issue A	Prototype Safkeg-HS 3977A/0002 NCT and HAC Regulatory Test Report
SERCO/TAS/002762/01	Issue 1	Compression Testing of Cork
Vectra, L20008/1/R1	Rev 0B	Stress Analysis of Safkeg HS 3977A Containment Vessel
CS 2012/02	Issue A	SAFKEG HS 3977A – Maximum Pressure in CV
CS 2012/03	Issue A	SAFKEG HS 3977A – Package Density
Section 3 - THERMAL EVALUATION		
Documents in Section 3.5.2, Appendix		
SERCO/TAS/5388/002	Issue 2	Thermal Analysis of the Safkeg HS Design

Document Reference	Issue Status	Title
CS 2012/01	Issue A	SAFKEG HS 3977A – Maximum Temperature of CV Inserts
Section 4 - CONTAINMENT		
Documents in Section 4.5.2, Appendix		
CS 2012/04	Issue A	SAFKEG-HS 3977A - CV seal leak size for leaktight condition
CS 2012/05	Issue A	SAFKEG-HS 3977A - Gas contents limit for leaktight condition
Section 5 - SHIELDING EVALUATION		
Documents in Section 5.5.2, Appendix		
CTR2011/01	Issue D	SAFKEG HS 3977A: Package Activity Limits Based on Shielding
CTR2013	Issue C	Uncertainties Associated with the Proposed Shielding Calculation Method for the SAFKEG-HS 3977A Package
AMEC/SF6652/001	Issue 2	Monte Carlo Modelling of Safkeg HS Container
Section 6 - CRITICALITY EVALUATION		
Documents in Section 6.9, Appendix		
None	-	
Section 7 - OPERATING PROCEDURES		
Documents in Section 7.5, Appendix		
None	-	
Section 8- ACCEPTANCE TESTS AND MAINTENANCE PROGRAM		

Document Reference	Issue Status	Title
Documents in Section 8.3, Appendix		
None	-	

CONTENTS

1 GENERAL INFORMATION

1.1 Introduction

This Safety Analysis Report (SAR) has been prepared by Croft Associates Ltd for the new approval of the Safkeg-HS 3977A package as a Type B(U) design.

The Safkeg-HS 3977A package is a general purpose container for the transport of non-fissile nuclides and limited quantities of fissile nuclides (10 CFR 71.15) as specified under NRC general licenses, under non-exclusive and exclusive use. The contents may be in solid, liquid and gaseous form. The modes of transport specified are road, rail, sea and air. A detailed list of the nuclides can be found in Section 1.2.2. The contents of the package include some nuclides in excess of 3000 A_2 and therefore the package is classified as Category I as defined in NUREG 1609 [1.1].

The Safkeg-HS 3977A package was designed in 2008 and a prototype package fabricated and tested in 2010. Analysis of the safety of the design has also been carried out: the results of the tests and the analysis are provided in this SARP.

All design, manufacturing and testing has been carried out in accordance with the Croft Quality Assurance program which complies with 10 CFR 71 subpart H [1.2] and is approved by the NRC under Approval Number 0939. This SARP has been prepared in accordance with Regulatory Guide 7.9 [1.3] and demonstrates that the package meets all the applicable requirements in 10 CFR 71 [1.2].

1.2 Package Description [71.33]

1.2.1 Packaging

1.2.1.1 General

The general arrangement of the Safkeg-HS 3977A package is provided in drawing 0C-5941 in Section 1.3.3. The drawing shows the package and details 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 (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 1-2).

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. Drawing 1C-5946 in Section 1.3.3 shows the general arrangement of the CV body.

The 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 CV lid.

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. 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 and atmospheric temperature and pressure changes.

1.2.1.4 Containment Boundary

Figure 1-3 shows the containment boundary of the Safkeg-HS 3977A package. 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

Figure 1-4 shows 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 or 1-5c 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 Figure 1-1).

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].

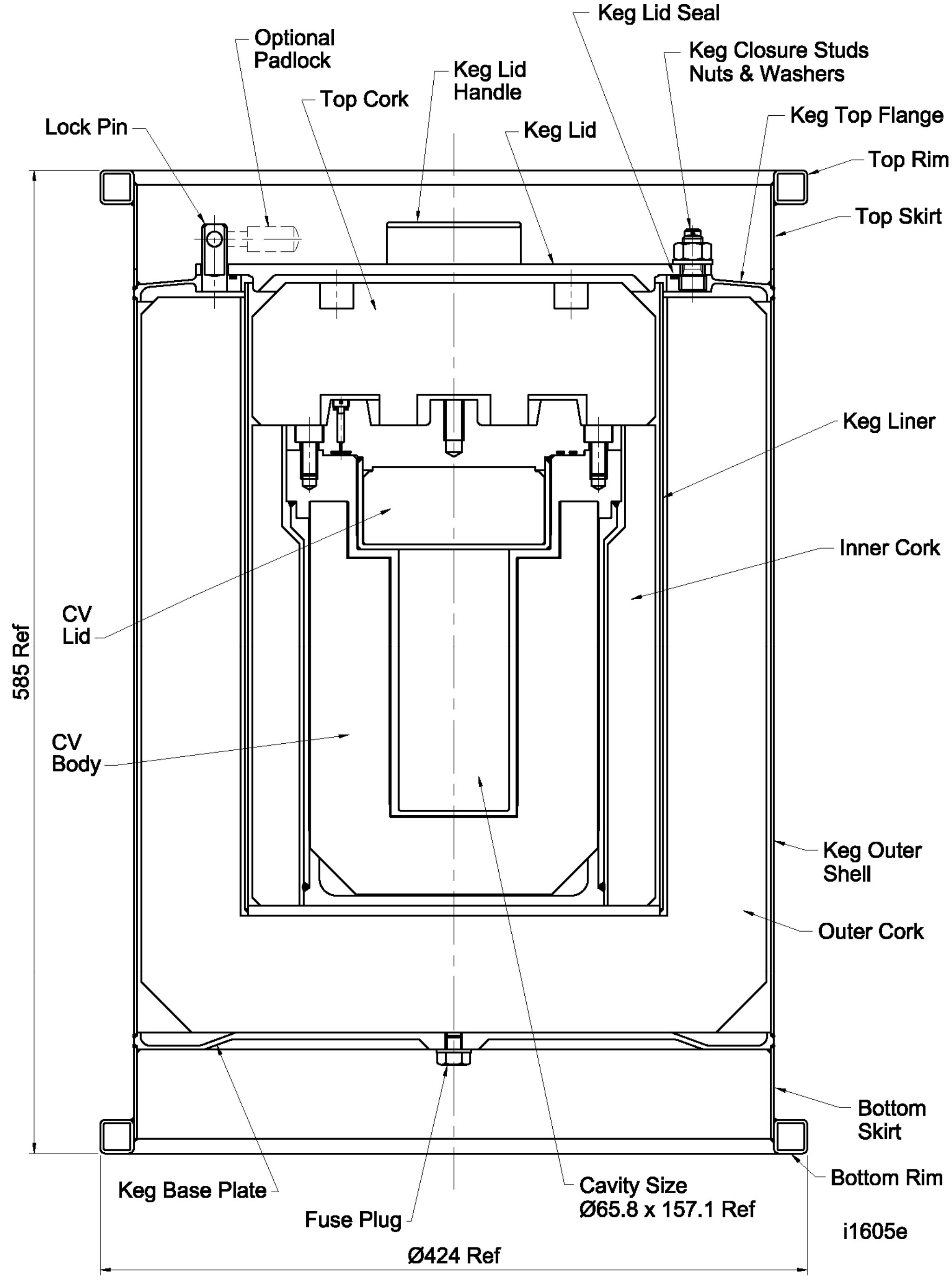


Figure 1-1a Safkeg-HS 3977A package – Section View and Nomenclature

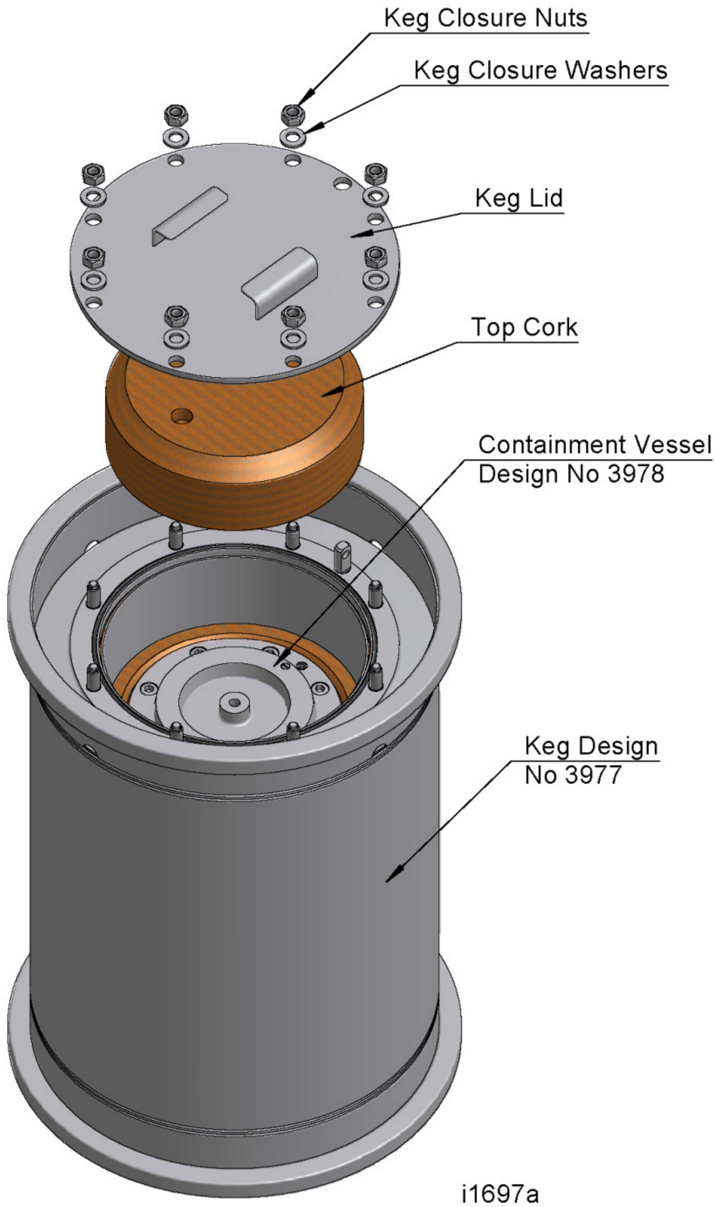


Figure 1-1b Safkeg-HS 3977A package – Isometric view

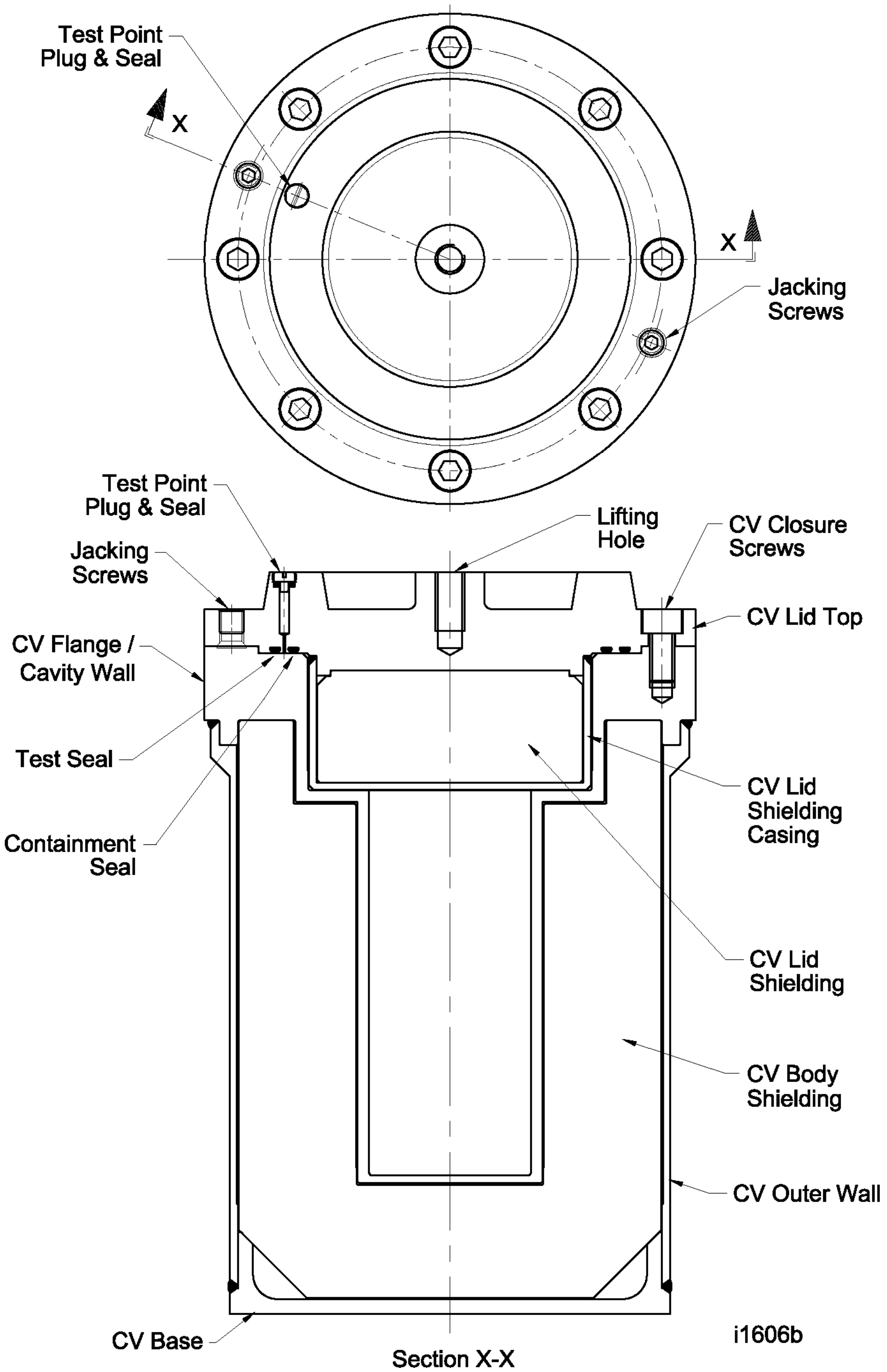
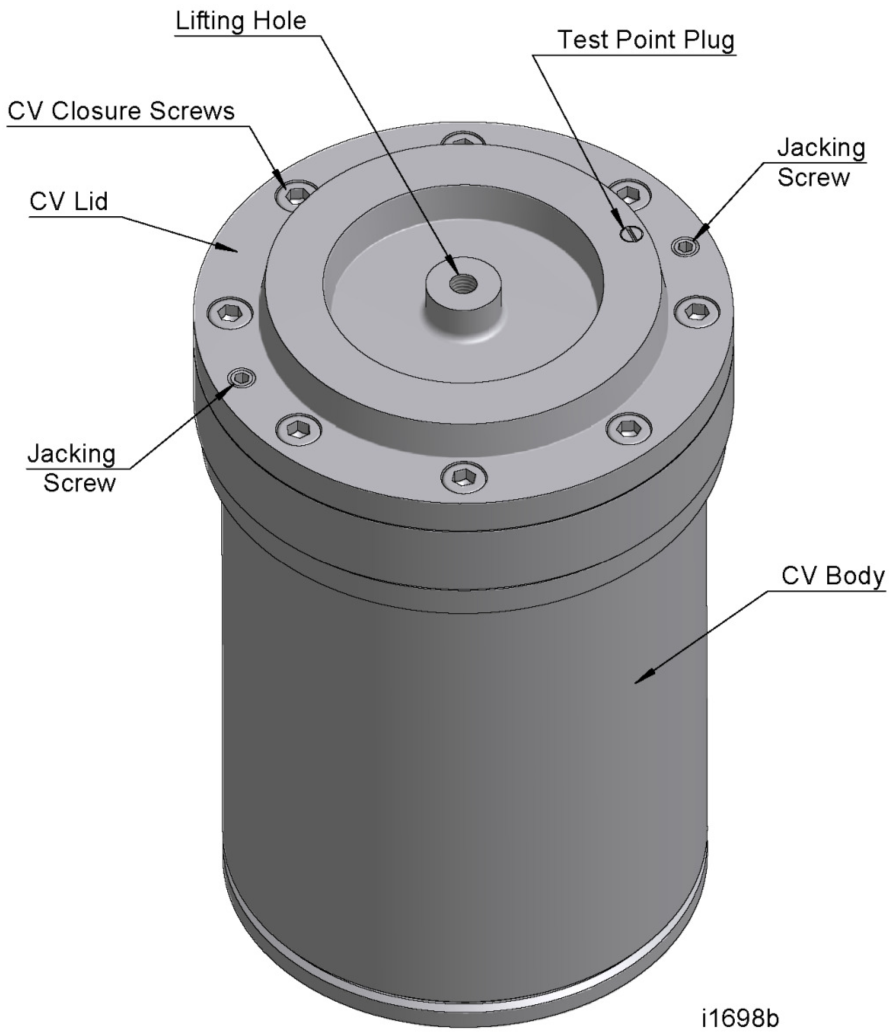


Figure 1-2a 3978 CV – Top and Section View and Nomenclature



Containment Vessel Design No 3978

Figure 1-2b 3978 CV – Isometric View

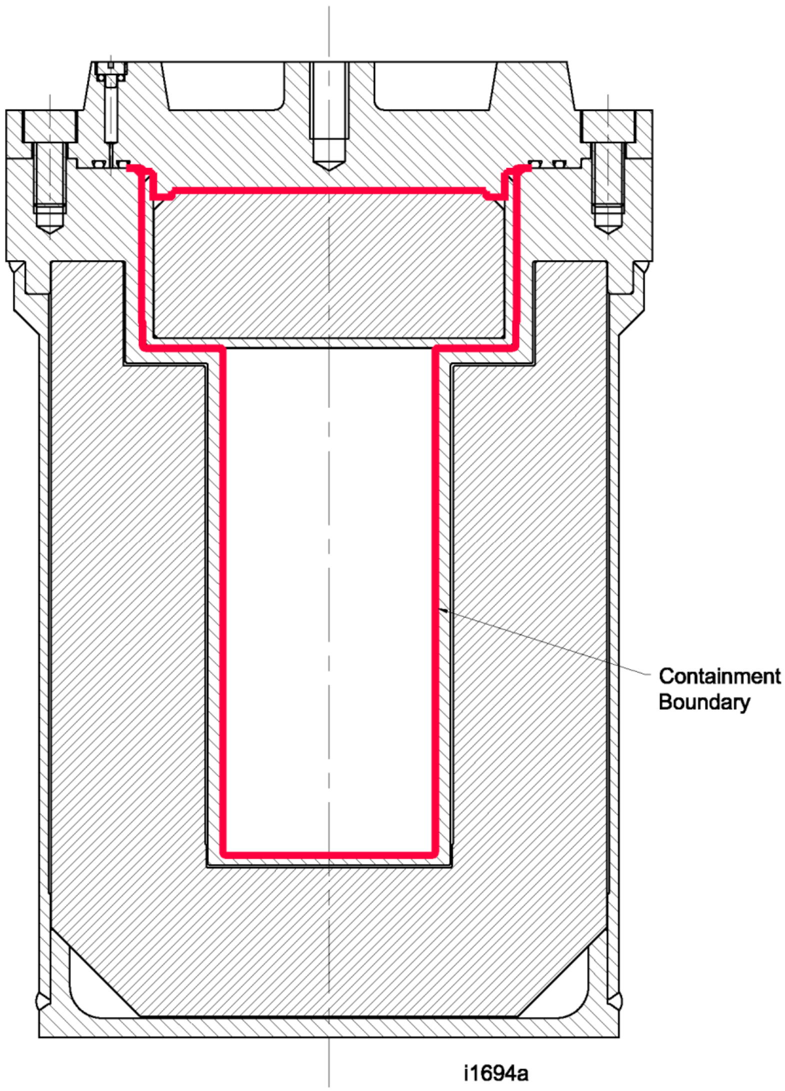


Figure 1-3 Containment boundary of the Safkeg-HS 3977A package

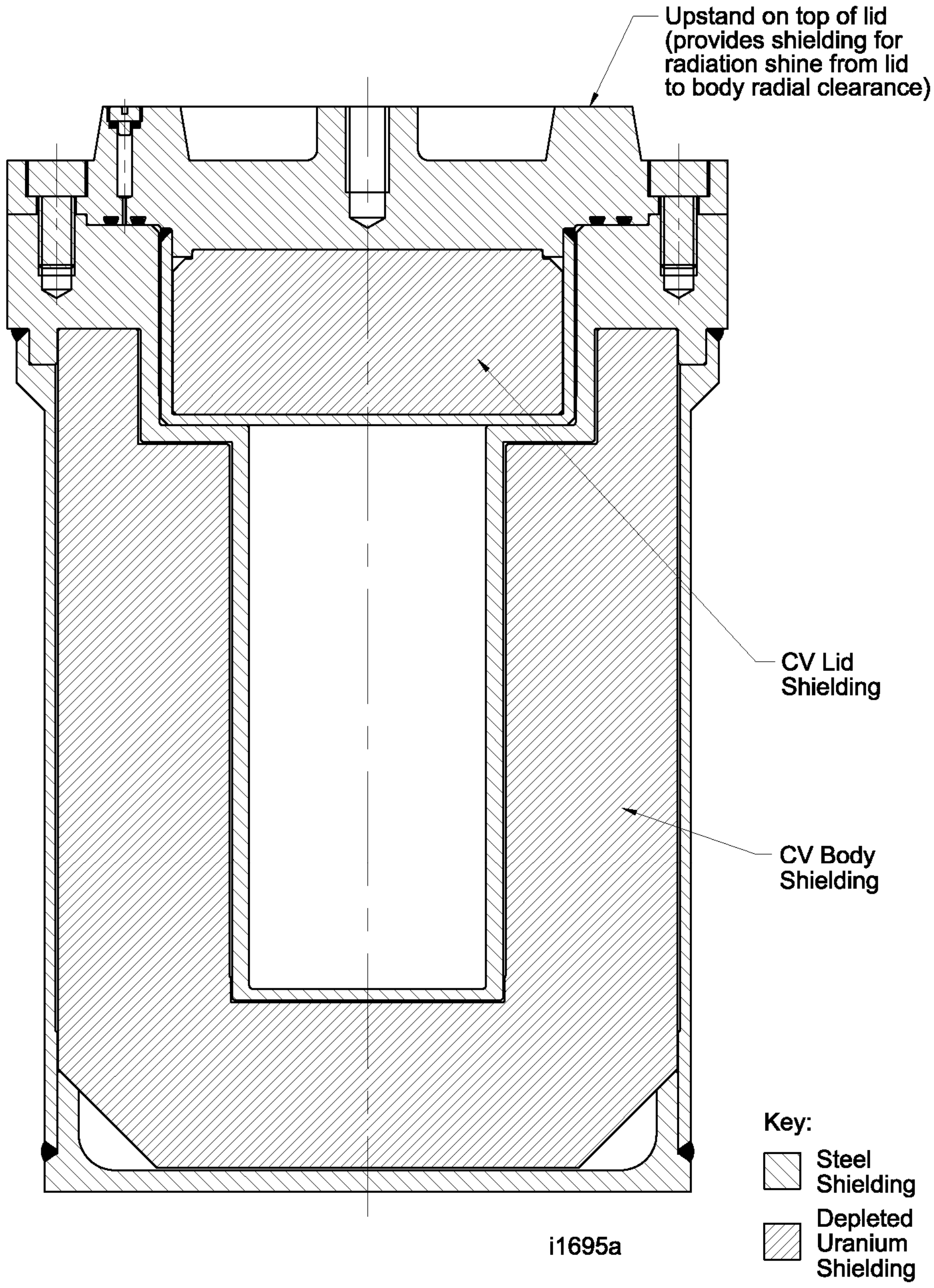


Figure 1-4 Gamma shielding present in the Safkeg-HS 3977A package

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.

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 or 1-5c. 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	Maximum mass of radionuclides (nominally 50% of Maximum mass of contents)
	g	g	kg (rounded)	g
HS-12x95-Tu Design No 3982	9,200	90	9.29	45
HS-31x114-Tu Design No 3985	7,930	690	8.62	345
HS-55x138-SS with PTFE liner Design No 3987	756	1,810	2.57	905

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 1-5a Shielding insert HS-12x95-Tu – Design # 3982

Figure 1-5b Shielding insert HS-31x114-Tu – Design # 3985

Figure 1-5c Shielding insert HS-55x138-SS with PTFE liner – Design # 3987

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	Activity Limits for each Contents Type
CT-1	Solid	HS-12x95-Tu Design No 3982	See Table 1-3-1	See Table 1-4-1
CT-2	Solid	HS-31x114-Tu Design No 3985	See Table 1-3-2	See Table 1-4-2
CT-3	Solid	HS-55x138-SS Design No 3987 with PTFE liner fitted	See Table 1-3-3	See Table 1-4-3
CT-4	Liquid	HS-31x114-Tu Design No 3985	See Table 1-3-4	See Table 1-4-4
CT-5	Liquid	HS-55x138-SS Design No 3987 with PTFE liner fitted	See Table 1-3-5	See Table 1-4-5
CT-6	Gas	HS-31x114-Tu Design No 3985	See Table 1-3-6	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	See Table 1-4-7
CT-8	Solid/ Fissile Special Form	HS-55x138-SS Design No 3987 with PTFE liner fitted	See Table 1-3-8	See Table 1-4-8

Table 1-3-1 CT-1 – Solid in heavy tungsten insert (HS-12x95-Tu Design No 3982)

Parameter	**Restrictions**
Contents Type name	CT-1 – Solid in heavy tungsten insert
Comments on contents	General use including bulk medical and industrial source material.
Insert in CV cavity	HS-12x95-Tu Design No 3982 (mass 9,200 g)
Maximum quantity of radioactive material	See Table 1-4-1 for maximum quantities of each nuclide.
Maximum mass of radioactive material	45g
Mixtures of radionuclides	Mixtures of the nuclides are allowed providing that the sum of the proportionate amounts of each nuclide with respect to the quantity allowed does not exceed unity.
Maximum decay heat of radioactive material	30W
Maximum quantity of fissile material	None
Physical form of radioactive material	Solid with melting point > 250°C and not to be volatile at < 250°C. The contents may be normal or special form however no credit is taken for special form material and so can only be carried up to normal form limits.
Chemical form of radioactive material	Element or compound Compound only for Cs, Hg, I, Na and P.
Pyrophoric contents	The contents may be pyrophoric.
Product containers	The radioactive material shall be carried in any convenient product container such as a quartz vial or aluminum capsule. Irradiated items may be carried in a plastic or metal can or wrapping to minimize the contamination of the insert.
Location of radioactive material	Within the shielding insert
Maximum weight of contents of the CV	9.29 kg This includes the insert, radioactive material, product containers and any other packing.
Maximum weight of contents of the insert	90 g
Loading restrictions	None

Table 1-3-2 CT-2 – Solid in light tungsten insert (HS-31x114-Tu Design No 3985)	
Parameter	**Restrictions**
Contents Type name	CT-2 – Solid in light tungsten insert
Comments on contents	General use including bulk medical and industrial source material.
Insert in CV cavity	HS-31x114-Tu Design No 3985 (mass 7,930 g)
Maximum quantity of radioactive material	See Table 1-4-2 for maximum quantities of each nuclide.
Maximum mass of radioactive material	345 g
Mixtures of radionuclides	Mixtures of the nuclides are allowed providing that the sum of the proportionate amounts of each nuclide with respect to the quantity allowed does not exceed unity.
Maximum decay heat of radioactive material	30W
Maximum quantity of fissile material	None
Physical form of radioactive material	Solid with melting point > 250°C and not to be volatile at < 250°C. The contents may be normal or special form however no credit is taken for special form material and so can only be carried up to normal form limits.
Chemical form of radioactive material	Element or compound Compound only for Cs, Hg, I, Na and P.
Pyrophoric contents	The contents may be pyrophoric.
Product containers	The radioactive material shall be carried in any convenient product container such as a quartz vial or aluminum capsule. Irradiated items may be carried in plastic or metal can or wrapping to minimize the contamination of the insert.
Location of radioactive material	Within the shielding insert
Maximum weight of contents of the CV	8.62 kg This includes the insert, radioactive material, product containers and any other packing.
Maximum weight of contents of the insert	690g
Loading restrictions	None

Table 1-3-3 CT-3 – Solid in steel insert (HS-55x138-SS Design No 3987)	
Parameter	**Restrictions**
Contents Type name	CT-3 – Solid in steel insert
Comments on contents	General use including bulk medical and industrial source material.
Insert in CV cavity	HS-55x138-SS Design No 3987 fitted with PTFE liner (per drawing 2C-6176)
Maximum quantity of radioactive material	See Table 1-4-3 for maximum quantities of each nuclide.
Maximum mass of radioactive material	905 g
Mixtures of radionuclides	Mixtures of the nuclides are allowed providing that the sum of the proportionate amounts of each nuclide with respect to the quantity allowed does not exceed unity.
Maximum decay heat of radioactive material	30W
Maximum quantity of fissile material	None
Physical form of radioactive material	Solid with melting point > 250°C and not to be volatile at < 250°C. The contents may be normal or special form however no credit is taken for special form material and so can only be carried up to normal form limits.
Chemical form of radioactive material	Element or compound Compound only for Cs, Hg, I, Na and P.
Pyrophoric contents	The contents may be pyrophoric.
Product containers	The radioactive material shall be carried in any convenient product container such as a quartz vial or aluminium capsule. Irradiated items may be carried in plastic or metal can or wrapping to minimize the contamination of the insert.
Location of radioactive material	Within the shielding insert
Maximum weight of contents of the CV	2.57 kg This includes the insert, radioactive material, product containers and any other packing.
Maximum weight of contents of the insert	1,810 g
Loading restrictions	None

Table 1-3-4 CT-4 - Liquid in light tungsten insert (HS-31x114-Tu Design No 3985)	
Parameter	**Restrictions**
Contents Type name	CT-4 – Liquid in light tungsten insert
Comments on contents	General use including bulk medical material.
Insert in CV cavity	HS-31x114-Tu Design No 3985 (mass 7,930g)
Maximum quantity of radioactive material	See Table 1-4-4 for maximum quantities of each nuclide.
Maximum mass of radioactive material	345g
Mixtures of radionuclides	Mixtures of the nuclides are allowed providing that the sum of the proportionate amounts of each nuclide with respect to the quantity allowed does not exceed unity.
Maximum decay heat of radioactive material	5W
Maximum quantity of fissile material	None
Physical form of radioactive material	Liquid, normal form.
Chemical form of radioactive material	Salts in solution which may be alkaline or acidic. Acids restricted to HCL, H_2SO_4, HNO_3, of maximum concentration 0.1N.
Pyrophoric contents	Not applicable
Product containers	The radioactive material shall be carried in any convenient product container such as a quartz vial or aluminum capsule. Irradiated items may be carried in plastic or metal can or wrapping to minimize the contamination of the insert.
Location of radioactive material	Within the shielding insert
Maximum weight of contents of the CV	8.62 kg This includes the insert, radioactive material, product containers and any other packing.
Maximum weight of contents of the insert	690g
Loading restrictions	The insert is to be leak tested by the bubble immersion method before shipment (after loading with radioactive contents). See Section 7.

Table 1-3-5 CT-5 – Liquid in steel insert (HS-55x138-SS Design No 3987)	
Parameter	**Restrictions**
Contents Type name	CT-5 – Liquid in steel insert
Comments on contents	General use including bulk medical material.
Insert in CV cavity	HS-55x138-SS Design No 3987 (mass 730g) fitted with PTFE liner (per drawing 2C-6176)
Maximum quantity of radioactive material	See Table 1-4-5 for maximum quantities of each nuclide.
Maximum mass of radioactive material	905 g
Mixtures of radionuclides	Mixtures of the nuclides are allowed providing that the sum of the proportionate amounts of each nuclide with respect to the quantity allowed does not exceed unity.
Maximum decay heat of radioactive material	5W
Maximum quantity of fissile material	None
Physical form of radioactive material	Liquid, normal form
Chemical form of radioactive material	Salts in solution which may be alkaline or acidic. Acids restricted to HCL, H_2SO_4, HNO_3, of maximum concentration 0.1N.
Pyrophoric contents	Not applicable
Product containers	The radioactive material shall be carried in any convenient product container such as a quartz vial or aluminum capsule. Irradiated items may be carried in plastic or metal can or wrapping to minimize the contamination of the insert.
Location of radioactive material	Within the shielding insert
Maximum weight of contents of the CV	2.57 kg This includes the insert, radioactive material, product containers and any other packing.
Maximum weight of contents of the insert	1,810 g
Loading restrictions	The insert is to be leak tested by the bubble immersion method before shipment (after loading with radioactive contents). See Section 7.

Table 1-3-6 CT-6 – Gas in light tungsten insert (HS-31x114-Tu Design No 3985)	
Parameter	**Restrictions**
Contents Type name	CT-6 – Gas in light tungsten insert
Comments on contents	General use including bulk medical material.
Insert in CV cavity	HS-31x114-Tu Design No 3985 (mass 7,930g)
Maximum quantity of radioactive material	See Table 1-4-6 for maximum quantities of each nuclide.
Maximum mass of radioactive material	Mass < 1g
Mixtures of radionuclides	Mixtures of the nuclides are allowed providing that the sum of the proportionate amounts of each nuclide with respect to the quantity allowed does not exceed unity.
Maximum decay heat of radioactive material	30W
Maximum quantity of fissile material	None
Physical form of radioactive material	Gas, Normal form
Chemical form of radioactive material	Elemental gas
Pyrophoric contents	Not applicable
Product containers	The product container shall be a quartz vial sealed by fusing or an aluminium capsule. The product container may be carried in packing (such as a plastic or metal can or wrapping) to minimize the contamination of the insert. The volume of the product containers and packing shall be <10cc.
Location of radioactive material	Within the shielding insert
Maximum weight of contents of the CV	8.62 kg This includes the insert, radioactive material, product containers and any other packing.
Maximum weight of contents of the insert	690
Loading restrictions	None

Table 1-3-7 - CT-7 – Fissile solid in Normal Form in steel insert (HS-55x138-SS Design No 3987)	
Parameter	**Restrictions**
Contents Type name	CT-7 – Fissile solid in steel insert
Comments on contents	Fissile samples and standards
Insert in CV cavity	HS-55x138-SS Design No 3987 (mass 730g) fitted with PTFE liner (per drawing 2C-6176)
Maximum quantity of radioactive material	See Table 1-4-7 (subject to the limits below which provide a maximum for each case) Limit for air transport is A2 in accordance with 10CFR 71.88
Maximum mass of radioactive material	905 g (subject to the limits below which provide a maximum for each case)
Mixtures of radionuclides	Mixtures of the nuclides are allowed providing that the sum of the proportionate amounts of each nuclide with respect to the quantity allowed does not exceed unity.
Maximum decay heat of radioactive material	30W
Maximum quantity of fissile material	Contents limited to the quantities specified in the following references.10CFR 71.15 Exemption from classification as fissile material 10CFR 71.22 General license: Fissile material 10CFR 71.23 General license: Plutonium-beryllium special form material.
Physical form of radioactive material	Solid in Normal Form with melting point > 250^{o}C and not to be volatile at < 250^{o}C.
Chemical form of radioactive material	Element or compound
Pyrophoric contents	The contents may be pyrophoric.
Product containers	The radioactive material shall be carried in any convenient product container such as a quartz vial or aluminum capsule. Irradiated items may be carried in plastic or metal can or wrapping to minimize the contamination of the insert.
Location of radioactive material	Within the shielding insert
Maximum weight of contents of the CV	2.57 kg This includes the insert, radioactive material, product containers and any other packing.
Maximum weight of contents of the insert	1,810 g
Loading restrictions	None

Table 1-3-8 - CT-8 – Fissile solid in Special Form in steel insert (HS-55x138-SS Design No 3987)	
Parameter	**Restrictions**
Contents Type name	CT-8 – Fissile solid in steel insert
Comments on contents	Fissile samples and standards in Special Form
Insert in CV cavity	HS-55x138-SS Design No 3987 (mass 730g) fitted with PTFE liner (per drawing 2C-6176)
Maximum quantity of radioactive material	See Table 1-4-8 (subject to the limits below which provide a maximum for each case) Limit for air transport is A2 in accordance with 10CFR 71.88
Maximum mass of radioactive material	905 g (subject to the limits below which provide a maximum for each case)
Mixtures of radionuclides	Mixtures of the nuclides are allowed providing that the sum of the proportionate amounts of each nuclide with respect to the quantity allowed does not exceed unity.
Maximum decay heat of radioactive material	30W
Maximum quantity of fissile material	Contents limited to the quantities specified in the following references. 10CFR 71.15 Exemption from classification as fissile material 10CFR 71.22 General license: Fissile material 10CFR 71.23 General license: Plutonium-beryllium special form material.
Physical form of radioactive material	Solid in Special Form
Chemical form of radioactive material	Element or compound
Pyrophoric contents	The contents may be pyrophoric.
Product containers	The radioactive material shall be carried in any convenient product container such as a quartz vial or aluminum capsule. Irradiated items may be carried in plastic or metal can or wrapping to minimize the contamination of the insert.
Location of radioactive material	Within the shielding insert
Maximum weight of contents of the CV	2.57 kg This includes the insert, radioactive material, product containers and any other packing.
Maximum weight of contents of the insert	1,810 g
Loading restrictions	None

Table 1-4-1 CT-1 – Solid in heavy tungsten insert (HS-12x95-Tu) – Activity Limits

1	2	3	4	5	6	7	8	9	10
Nuclide	Max Activity		A2	# A2s	Spec Ac	Mass	Heat gen	Heat output	Package Type
	TBq	Ci	TBq		TBq/g	g	W/Ci	W	A or B
Ac-225	2.51E+00	6.78E+01	6.00E-03	417.95	2.10E+03	1.19E-03	3.46E-02	2.34E+00	B
Ac-227	7.24E-01	1.96E+01	9.00E-05	8049.19	2.70E+00	2.68E-01	4.72E-04	9.24E-03	B
Ac-228	4.28E-01	1.16E+01	5.00E-01	0.86	8.40E+04	5.09E-06	8.04E-03	9.30E-02	A
Am-241	3.58E+00	9.68E+01	1.00E-03	3581.11	1.30E-01	2.75E+01	3.28E-02	3.18E+00	B
As-77	7.90E+02	2.13E+04	7.00E-01	1128.38	3.90E+04	2.03E-02	1.41E-03	3.00E+01	B
Au-198	2.56E+02	6.92E+03	6.00E-01	426.50	9.00E+03	2.84E-02	4.34E-03	3.00E+01	B
Ba-131	1.88E+02	5.08E+03	2.00E+00	94.05	3.10E+03	6.07E-02	3.06E-03	1.55E+01	B
C-14	7.20E+00	1.95E+02	3.00E+00	2.40	1.60E-01	4.50E+01	2.93E-04	5.71E-02	B
Co-60	2.38E-01	6.44E+00	4.00E-01	0.60	4.20E+01	5.68E-03	1.54E-02	9.94E-02	A
Cs-131	6.71E+03	1.81E+05	3.00E+01	223.73	3.80E+03	1.77E+00	1.65E-04	3.00E+01	B
Cs-134	7.05E+00	1.90E+02	7.00E-01	10.07	4.80E+01	1.47E-01	1.02E-02	1.94E+00	B
Cs-137	1.44E+02	3.89E+03	6.00E-01	240.00	3.20E+00	4.50E+01	1.01E-03	3.94E+00	B
Cu-67	6.91E+02	1.87E+04	7.00E-01	986.75	2.80E+04	2.47E-02	1.61E-03	3.00E+01	B
Hg-203	3.57E+01	9.66E+02	1.00E+00	35.75	5.10E+02	7.01E-02	1.99E-03	1.92E+00	B
Ho-166	2.04E+00	5.52E+01	4.00E-01	5.10	2.60E+04	7.85E-05	4.29E-03	2.37E-01	B
I-125	3.19E+03	8.61E+04	3.00E+00	1062.52	6.40E+02	4.98E+00	3.48E-04	3.00E+01	B
I-129	2.93E-04	7.91E-03	< 1	< 1	6.50E-06	4.50E+01	4.68E-04	3.70E-06	B
I-131	3.28E+02	8.85E+03	7.00E-01	468.01	4.60E+03	7.12E-02	3.39E-03	3.00E+01	B
In-111	4.27E+02	1.15E+04	3.00E+00	142.34	1.50E+04	2.85E-02	2.60E-03	3.00E+01	B
Ir-192	1.81E+02	4.90E+03	6.00E-01	302.02	3.40E+02	5.33E-01	6.13E-03	3.00E+01	B
Ir-194	3.87E+01	1.04E+03	3.00E-01	128.87	3.10E+04	1.25E-03	5.35E-03	5.59E+00	B
Lu-177	1.03E+03	2.78E+04	7.00E-01	1470.30	4.10E+03	2.51E-01	1.08E-03	3.00E+01	B
Mo-99	5.27E+01	1.42E+03	6.00E-01	87.87	1.80E+04	2.93E-03	3.27E-03	4.66E+00	B
Na-24	2.63E-02	7.12E-01	2.00E-01	0.13	3.20E+05	8.23E-08	2.77E-02	1.97E-02	A
Np-237	1.17E-03	3.16E-02	2.00E-03	0.59	2.60E-05	4.50E+01	2.88E-02	9.10E-04	A
P-32	5.58E+00	1.51E+02	5.00E-01	11.15	1.10E+04	5.07E-04	4.12E-03	6.21E-01	B
P-33	2.44E+03	6.61E+04	1.00E+00	2444.45	5.80E+03	4.21E-01	4.54E-04	3.00E+01	B
Pb-203	5.20E+02	1.40E+04	3.00E+00	173.28	1.10E+04	4.73E-02	2.14E-03	3.00E+01	B
Pb-210	8.04E+00	2.17E+02	5.00E-02	160.79	2.80E+00	2.87E+00	2.31E-04	5.01E-02	B
Pd-109	2.96E+02	7.99E+03	5.00E-01	591.05	7.90E+04	3.74E-03	2.14E-03	1.71E+01	B
Ra-223	1.02E+01	2.75E+02	7.00E-03	1451.55	1.90E+03	5.35E-03	3.50E-02	9.60E+00	B
Ra-224	8.86E-02	2.40E+00	2.00E-02	4.43	5.90E+03	1.50E-05	3.37E-02	8.08E-02	B
Ra-226	1.02E-01	2.75E+00	3.00E-03	33.89	3.70E-02	2.75E+00	2.84E-02	7.80E-02	B
Re-186	1.56E+02	4.23E+03	6.00E-01	260.64	6.90E+03	2.27E-02	2.14E-03	9.04E+00	B
Re-188	1.22E+00	3.31E+01	4.00E-01	3.06	3.60E+04	3.40E-05	4.97E-03	1.64E-01	B
Rh-105	8.12E+02	2.19E+04	8.00E-01	1014.40	3.10E+04	2.62E-02	1.37E-03	3.00E+01	B
Se-75	4.61E+02	1.25E+04	3.00E+00	153.81	5.40E+02	8.55E-01	2.41E-03	3.00E+01	B
Sm-153	6.12E-01	1.65E+01	6.00E-01	1.02	1.60E+04	3.82E-05	1.94E-03	3.21E-02	B
Sr-89	1.22E+01	3.30E+02	6.00E-01	20.34	1.10E+03	1.11E-02	3.46E-03	1.14E+00	B

1	2	3	4	5	6	7	8	9	10
Nuclide	Max Activity		A2	# A2s	Spec Ac	Mass	Heat gen	Heat output	Package Type
	TBq	Ci	TBq		TBq/g	g	W/Ci	W	A or B
Sr-90	1.73E+00	4.67E+01	3.00E-01	5.76	5.10E+00	3.39E-01	3.46E-03	1.61E-01	B
Tb-161	1.61E+01	4.36E+02	2.00E-02	806.28	4.35E+03	3.71E-03	1.16E-03	5.06E-01	B
Th-227	1.01E+01	2.73E+02	5.00E-03	2020.21	1.10E+03	9.18E-03	3.59E-02	9.79E+00	B
Th-228	6.79E-02	1.84E+00	1.00E-03	67.95	3.00E+01	2.26E-03	3.21E-02	5.90E-02	B
Tl-201	1.45E+03	3.92E+04	4.00E+00	362.71	7.90E+03	1.84E-01	7.65E-04	3.00E+01	B
W-187	2.24E+01	6.06E+02	6.00E-01	37.36	2.60E+04	8.62E-04	4.54E-03	2.75E+00	B
W-188	1.23E+00	3.31E+01	3.00E-01	4.08	3.70E+02	3.31E-03	5.98E-04	1.98E-02	B
Y-90	1.73E+00	4.67E+01	3.00E-01	5.76	2.00E+04	8.63E-05	5.54E-03	2.59E-01	B
Yb-169	4.42E+02	1.19E+04	1.00E+00	442.11	8.90E+02	4.97E-01	2.51E-03	3.00E+01	B
Yb-175	1.11E+03	2.99E+04	9.00E-01	1228.91	6.60E+03	1.68E-01	1.00E-03	3.00E+01	B
Max	6.71E+03	1.81E+05		8.05E+03		4.50E+01		3.00E+01	

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 1-4-1 re daughter nuclides

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

Table 1-4-1a – Supplement re daughter radionuclides			
1	2	3	4
Nuclide	Max Activity	Parent material	Comments
Daughter radionuclides present in contents in significant quantities			
Se-77m	As As-77	As-77	Se-77m will have the same activity as its parent As-77 as it is formed by beta decay and Se 77 is stable.
Tc-99m, Tc-99	As Mo-99	Mo-99	Tc-99 will grow in to equilibrium with Mo-99

Table 1-4-2 CT-2 – Solid in light tungsten insert (HS-31x114-Tu) – Activity Limits

1	2	3	4	5	6	7	8	9	10
Nuclide	Max Activity		A2	# A2s	Spec Ac	Mass	Heat gen	Heat output	Package Type
	TBq	Ci	TBq		TBq/g	g	W/Ci	W	A or B
Ac-225	1.09E+00	2.96E+01	6.00E-03	182.45	2.10E+03	5.21E-04	3.46E-02	1.02E+00	B
Ac-227	3.26E-01	8.81E+00	9.00E-05	3622.61	2.70E+00	1.21E-01	4.72E-04	4.16E-03	B
Ac-228	1.86E-01	5.03E+00	5.00E-01	0.37	8.40E+04	2.21E-06	8.04E-03	4.04E-02	A
Am-241	1.58E+00	4.28E+01	1.00E-03	1584.58	1.30E-01	1.22E+01	3.28E-02	1.41E+00	B
As-77	7.90E+02	2.13E+04	7.00E-01	1128.38	3.90E+04	2.03E-02	1.41E-03	3.00E+01	B
Au-198	2.43E+02	6.57E+03	6.00E-01	405.30	9.00E+03	2.70E-02	4.34E-03	2.85E+01	B
Ba-131	6.12E+01	1.65E+03	2.00E+00	30.60	3.10E+03	1.97E-02	3.06E-03	5.05E+00	B
C-14	5.52E+01	1.49E+03	3.00E+00	18.40	1.60E-01	3.45E+02	2.93E-04	4.38E-01	B
Co-60	9.37E-02	2.53E+00	4.00E-01	0.23	4.20E+01	2.23E-03	1.54E-02	3.91E-02	A
Cs-131	6.71E+03	1.81E+05	3.00E+01	223.73	3.80E+03	1.77E+00	1.65E-04	3.00E+01	B
Cs-134	2.63E+00	7.11E+01	7.00E-01	3.76	4.80E+01	5.48E-02	1.02E-02	7.24E-01	B
Cs-137	3.16E+02	8.55E+03	6.00E-01	527.06	3.20E+00	9.88E+01	1.01E-03	8.65E+00	B
Cu-67	6.91E+02	1.87E+04	7.00E-01	986.75	2.80E+04	2.47E-02	1.61E-03	3.00E+01	B
Hg-203	5.58E+02	1.51E+04	1.00E+00	557.87	5.10E+02	1.09E+00	1.99E-03	3.00E+01	B
Ho-166	9.20E-01	2.49E+01	4.00E-01	2.30	2.60E+04	3.54E-05	4.29E-03	1.07E-01	B
I-125	3.19E+03	8.61E+04	3.00E+00	1062.52	6.40E+02	4.98E+00	3.48E-04	3.00E+01	B
I-129	2.24E-03	6.06E-02	< 1	< 1	6.50E-06	3.45E+02	4.68E-04	2.84E-05	B
I-131	3.28E+02	8.85E+03	7.00E-01	468.01	4.60E+03	7.12E-02	3.39E-03	3.00E+01	B
In-111	4.27E+02	1.15E+04	3.00E+00	142.34	1.50E+04	2.85E-02	2.60E-03	3.00E+01	B
Ir-192	1.81E+02	4.90E+03	6.00E-01	302.02	3.40E+02	5.33E-01	6.13E-03	3.00E+01	B
Ir-194	1.47E+01	3.96E+02	3.00E-01	48.84	3.10E+04	4.73E-04	5.35E-03	2.12E+00	B
Lu-177	1.03E+03	2.78E+04	7.00E-01	1470.30	4.10E+03	2.51E-01	1.08E-03	3.00E+01	B
Mo-99	1.91E+01	5.17E+02	6.00E-01	31.85	1.80E+04	1.06E-03	3.27E-03	1.69E+00	B
Na-24	1.28E-02	3.45E-01	2.00E-01	0.06	3.20E+05	3.99E-08	2.77E-02	9.55E-03	A
Np-237	8.97E-03	2.42E-01	2.00E-03	4.49	2.60E-05	3.45E+02	2.88E-02	6.98E-03	B
P-32	2.49E+00	6.73E+01	5.00E-01	4.98	1.10E+04	2.26E-04	4.12E-03	2.77E-01	B
P-33	2.44E+03	6.61E+04	1.00E+00	2444.45	5.80E+03	4.21E-01	4.54E-04	3.00E+01	B
Pb-203	5.20E+02	1.40E+04	3.00E+00	173.28	1.10E+04	4.73E-02	2.14E-03	3.00E+01	B
Pb-210	3.31E+00	8.96E+01	5.00E-02	66.28	2.80E+00	1.18E+00	2.31E-04	2.07E-02	B
Pd-109	9.61E+01	2.60E+03	5.00E-01	192.26	7.90E+04	1.22E-03	2.14E-03	5.57E+00	B
Ra-223	4.14E+00	1.12E+02	7.00E-03	591.20	1.90E+03	2.18E-03	3.50E-02	3.91E+00	B
Ra-224	4.37E-02	1.18E+00	2.00E-02	2.18	5.90E+03	7.40E-06	3.37E-02	3.98E-02	B
Ra-226	4.80E-02	1.30E+00	3.00E-03	16.00	3.70E-02	1.30E+00	2.84E-02	3.68E-02	B
Re-186	5.31E+01	1.43E+03	6.00E-01	88.45	6.90E+03	7.69E-03	2.14E-03	3.07E+00	B
Re-188	5.67E-01	1.53E+01	4.00E-01	1.42	3.60E+04	1.57E-05	4.97E-03	7.60E-02	B
Rh-105	8.12E+02	2.19E+04	8.00E-01	1014.40	3.10E+04	2.62E-02	1.37E-03	3.00E+01	B
Se-75	4.61E+02	1.25E+04	3.00E+00	153.81	5.40E+02	8.55E-01	2.41E-03	3.00E+01	B
Sm-153	5.71E+02	1.54E+04	6.00E-01	952.23	1.60E+04	3.57E-02	1.94E-03	3.00E+01	B
Sr-89	5.17E+00	1.40E+02	6.00E-01	8.62	1.10E+03	4.70E-03	3.46E-03	4.83E-01	B

1	2	3	4	5	6	7	8	9	10
Nuclide	Max Activity		A2	# A2s	Spec Ac	Mass	Heat gen	Heat output	Package Type
	TBq	Ci	TBq		TBq/g	g	W/Ci	W	A or B
Sr-90	8.30E-01	2.24E+01	3.00E-01	2.77	5.10E+00	1.63E-01	3.46E-03	7.75E-02	B
Tb-161	7.39E+00	2.00E+02	2.00E-02	369.26	4.35E+03	1.70E-03	1.16E-03	2.32E-01	B
Th-227	4.17E+00	1.13E+02	5.00E-03	834.00	1.10E+03	3.79E-03	3.59E-02	4.04E+00	B
Th-228	3.35E-02	9.07E-01	1.00E-03	33.54	3.00E+01	1.12E-03	3.21E-02	2.91E-02	B
Tl-201	1.45E+03	3.92E+04	4.00E+00	362.71	7.90E+03	1.84E-01	7.65E-04	3.00E+01	B
W-187	8.56E+00	2.31E+02	6.00E-01	14.26	2.60E+04	3.29E-04	4.54E-03	1.05E+00	B
W-188	5.68E-01	1.53E+01	3.00E-01	1.89	3.70E+02	1.53E-03	5.98E-04	9.18E-03	B
Y-90	8.30E-01	2.24E+01	3.00E-01	2.77	2.00E+04	4.15E-05	5.54E-03	1.24E-01	B
Yb-169	4.42E+02	1.19E+04	1.00E+00	442.11	8.90E+02	4.97E-01	2.51E-03	3.00E+01	B
Yb-175	1.11E+03	2.99E+04	9.00E-01	1228.91	6.60E+03	1.68E-01	1.00E-03	3.00E+01	B
Max	6.71E+03	1.81E+05		3.62E+03		3.45E+02		3.00E+01	

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 1-4-2 re daughter nuclides

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

Table 1-4-2a – Supplement re additional nuclides			
1	2	3	4
Nuclide	Max Activity	Parent material	Comments
Daughter radionuclides present in contents in significant quantities			
Se-77	As As-77	As-77	Se-77m will have the same activity as its parent As-77 as it is formed by beta decay and Se 77 is stable.
Tc-99m, Tc-99	As Mo-99	Mo-99	Tc-99 will grow in to equilibrium with Mo-99

Table 1-4-3 CT-3 – Solid in steel insert (HS-55x138-SS) – Activity Limits

1	2	3	4	5	6	7	8	9	10
Nuclide	Max	Activity	A2	# A2s	Spec Ac	Mass	Heat gen	Heat output	Package Type
	TBq	Ci	TBq		TBq/g	g	W/Ci	W	A or B
Ac-225	7.65E-01	2.07E+01	6.00E-03	127.45	2.10E+03	3.64E-04	3.46E-02	7.15E-01	B
Ac-227	3.18E+01	8.59E+02	9.00E-05	353036.59	2.70E+00	1.18E+01	4.72E-04	4.05E-01	B
Ac-228	1.02E-01	2.75E+00	5.00E-01	0.20	8.40E+04	1.21E-06	8.04E-03	2.21E-02	A
Am-241	3.38E+01	9.14E+02	1.00E-03	33828.06	1.30E-01	2.60E+02	3.28E-02	3.00E+01	B
As-77	7.90E+02	2.13E+04	7.00E-01	1128.38	3.90E+04	2.03E-02	1.41E-03	3.00E+01	B
Au-198	3.64E+01	9.85E+02	6.00E-01	60.73	9.00E+03	4.05E-03	4.34E-03	4.27E+00	B
Ba-131	8.20E+00	2.22E+02	2.00E+00	4.10	3.10E+03	2.65E-03	3.06E-03	6.77E-01	B
C-14	1.45E+02	3.91E+03	3.00E+00	48.27	1.60E-01	9.05E+02	2.93E-04	1.15E+00	B
Co-60	1.81E-02	4.90E-01	4.00E-01	0.05	4.20E+01	4.32E-04	1.54E-02	7.56E-03	A
Cs-131	6.71E+03	1.81E+05	3.00E+01	223.73	3.80E+03	1.77E+00	1.65E-04	3.00E+01	B
Cs-134	4.20E-01	1.14E+01	7.00E-01	0.60	4.80E+01	8.75E-03	1.02E-02	1.16E-01	A
Cs-137	1.73E+01	4.68E+02	6.00E-01	28.88	3.20E+00	5.42E+00	1.01E-03	4.74E-01	B
Cu-67	6.91E+02	1.87E+04	7.00E-01	986.75	2.80E+04	2.47E-02	1.61E-03	3.00E+01	B
Hg-203	5.58E+02	1.51E+04	1.00E+00	557.87	5.10E+02	1.09E+00	1.99E-03	3.00E+01	B
Ho-166	1.54E+00	4.15E+01	4.00E-01	3.84	2.60E+04	5.91E-05	4.29E-03	1.78E-01	B
I-125	3.19E+03	8.61E+04	3.00E+00	1062.52	6.40E+02	4.98E+00	3.48E-04	3.00E+01	B
I-129	5.88E-03	1.59E-01	< 1	< 1	6.50E-06	9.05E+02	4.68E-04	7.44E-05	B
I-131	1.42E+02	3.83E+03	7.00E-01	202.60	4.60E+03	3.08E-02	3.39E-03	1.30E+01	B
In-111	4.27E+02	1.15E+04	3.00E+00	142.34	1.50E+04	2.85E-02	2.60E-03	3.00E+01	B
Ir-192	1.76E+02	4.74E+03	6.00E-01	292.54	3.40E+02	5.16E-01	6.13E-03	2.91E+01	B
Ir-194	2.55E+00	6.89E+01	3.00E-01	8.50	3.10E+04	8.23E-05	5.35E-03	3.68E-01	B
Lu-177	2.08E+02	5.61E+03	3.00E-01	692.20	3.10E+04	6.70E-03	5.35E-03	3.00E+01	B
Mo-99	1.47E+01	3.96E+02	3.00E-01	48.88	3.10E+04	4.73E-04	5.35E-03	2.12E+00	B
Na-24	3.47E-03	9.39E-02	3.00E-01	0.01	3.10E+04	1.12E-07	5.35E-03	5.02E-04	A
Np-237	2.08E+02	5.61E+03	3.00E-01	692.20	3.10E+04	6.70E-03	5.35E-03	3.00E+01	B
P-32	1.69E+00	4.58E+01	3.00E-01	5.64	3.10E+04	5.46E-05	5.35E-03	2.45E-01	B
P-33	2.08E+02	5.61E+03	3.00E-01	692.20	3.10E+04	6.70E-03	5.35E-03	3.00E+01	B
Pb-203	2.08E+02	5.61E+03	3.00E-01	692.20	3.10E+04	6.70E-03	5.35E-03	3.00E+01	B
Pb-210	2.08E+02	5.61E+03	3.00E-01	692.20	3.10E+04	6.70E-03	5.35E-03	3.00E+01	B
Pd-109	2.08E+02	5.61E+03	3.00E-01	692.20	3.10E+04	6.70E-03	5.35E-03	3.00E+01	B
Ra-223	3.18E+01	8.59E+02	3.00E-01	105.91	3.10E+04	1.02E-03	5.35E-03	4.59E+00	B
Ra-224	1.36E-02	3.68E-01	3.00E-01	0.05	3.10E+04	4.39E-07	5.35E-03	1.97E-03	A
Ra-226	1.96E-02	5.30E-01	3.00E-01	0.07	3.10E+04	6.33E-07	5.35E-03	2.83E-03	A
Re-186	2.08E+02	5.61E+03	3.00E-01	692.20	3.10E+04	6.70E-03	5.35E-03	3.00E+01	B
Re-188	1.43E+00	3.86E+01	3.00E-01	4.76	3.10E+04	4.60E-05	5.35E-03	2.06E-01	B
Rh-105	2.08E+02	5.61E+03	3.00E-01	692.20	3.10E+04	6.70E-03	5.35E-03	3.00E+01	B
Se-75	2.08E+02	5.61E+03	3.00E-01	692.20	3.10E+04	6.70E-03	5.35E-03	3.00E+01	B
Sm-153	5.71E+02	1.54E+04	6.00E-01	952.23	1.60E+04	3.57E-02	1.94E-03	3.00E+01	B
Sr-89	3.21E+02	8.68E+03	6.00E-01	535.22	1.10E+03	2.92E-01	3.46E-03	3.00E+01	B

1	2	3	4	5	6	7	8	9	10
Nuclide	Max	Activity	A2	# A2s	Spec Ac	Mass	Heat gen	Heat output	Package Type
	TBq	Ci	TBq		TBq/g	g	W/Ci	W	A or B
Sr-90	6.38E-01	1.72E+01	3.00E-01	2.13	5.10E+00	1.25E-01	3.46E-03	5.96E-02	B
Tb-161	9.57E+02	2.59E+04	2.00E-02	47844.83	4.35E+03	2.20E-01	1.16E-03	3.00E+01	B
Th-227	3.09E+01	8.36E+02	5.00E-03	6189.36	1.10E+03	2.81E-02	3.59E-02	3.00E+01	B
Th-228	1.02E-02	2.77E-01	1.00E-03	10.24	3.00E+01	3.41E-04	3.21E-02	8.89E-03	B
Tl-201	1.45E+03	3.92E+04	4.00E+00	362.71	7.90E+03	1.84E-01	7.65E-04	3.00E+01	B
W-187	1.43E+01	3.87E+02	3.00E-01	47.68	2.60E+04	5.50E-04	4.54E-03	1.75E+00	B
W-188	1.14E+00	3.07E+01	6.00E-01	1.89	3.70E+02	3.07E-03	5.98E-04	1.84E-02	B
Y-90	6.41E-01	1.73E+01	3.00E-01	2.14	2.00E+04	3.20E-05	5.54E-03	9.59E-02	B
Yb-169	4.42E+02	1.19E+04	1.00E+00	442.11	8.90E+02	4.97E-01	2.51E-03	3.00E+01	B
Yb-175	1.11E+03	2.99E+04	9.00E-01	1228.91	6.60E+03	1.68E-01	1.00E-03	3.00E+01	B
Max	6.71E+03	1.81E+05		3.53E+05		9.05E+02		3.00E+01	

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 1-4-3 re daughter nuclides

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

Table 1-4-3a – Supplement re additional nuclides			
1	2	3	4
Nuclide	Max Activity	Parent material	Comments
Daughter radionuclides present in contents in significant quantities			
Se-77	As As-77	As-77	Se-77m will have the same activity as its parent As-77 as it is formed by beta decay and Se 77 is stable.
Tc-99m, Tc-99	As Mo-99	Mo-99	Tc-99 will grow in to equilibrium with Mo-99

Table 1-4-4 CT-4 - Liquid in light tungsten insert (HS-31x114-Tu) – Activity Limits

1	2	3	4	5	6	7	8	9	10
Nuclide	Max	Activity	A2	# A2s	Spec Ac	Mass	Heat gen	Heat output	Package Type
	TBq	Ci	TBq		TBq/g	g	W/Ci	W	A or B
Ho-166	9.20E-01	2.49E+01	4.00E-01	2.30	2.60E+04	3.54E-05	4.29E-03	1.07E-01	B
Lu-177	1.71E+02	4.63E+03	7.00E-01	244.71	4.10E+03	4.18E-02	1.08E-03	5.00E+00	B
Mo-99	1.91E+01	5.17E+02	6.00E-01	31.85	1.80E+04	1.06E-03	3.27E-03	1.69E+00	B
Se-75	7.68E+01	2.07E+03	3.00E+00	25.59	5.40E+02	1.42E-01	2.41E-03	5.00E+00	B
Tl-201	2.42E+02	6.54E+03	4.00E+00	60.45	7.90E+03	3.06E-02	7.65E-04	5.00E+00	B
Max	6.71E+03	1.81E+05				3.45E+02		3.00E+01	

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 1-4-4 re daughter nuclides

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

Table 1-4-4a – 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

Table 1-4-5 CT-5 – Liquid in steel insert (HS-55x138-SS) – Activity Limits

Contents Type 5 - CT-5 - Liquid in 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
Ho-166	1.54E+00	4.15E+01	4.00E-01	3.84	2.60E+04	5.91E-05	4.29E-03	1.78E-01	B
Lu-177	3.46E+01	9.35E+02	3.00E-01	115.37	3.10E+04	1.12E-03	5.35E-03	5.00E+00	B
Mo-99	1.47E+01	3.96E+02	3.00E-01	48.88	3.10E+04	4.73E-04	5.35E-03	2.12E+00	B
Se-75	3.46E+01	9.35E+02	3.00E-01	115.37	3.10E+04	1.12E-03	5.35E-03	5.00E+00	B
Tl-201	2.42E+02	6.54E+03	4.00E+00	60.45	7.90E+03	3.06E-02	7.65E-04	5.00E+00	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 1-4-5 re daughter nuclides

The following nuclides may be present in the contents in the quantities 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

Table 1-4-6 CT-6 – Gas in light tungsten insert (HS-31x114-Tu) – Activity Limits

1	2	3	4	5	6	7	8	9	10
Nuclide	Max	Activity	A2	# A2s	Spec Ac	Mass	Heat gen	Heat output	Package Type
	TBq	Ci	TBq		TBq/g	g	W/Ci	W	A or B
Kr-79	2.30E+01	6.21E+02	2.00E+00	11.49	9.24E+04	2.49E-04	1.67E-03	1.04E+00	B
Xe-133	1.04E+03	2.80E+04	1.00E+01	103.74	6.90E+03	1.50E-01	1.07E-03	3.00E+01	B

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

Table 1-4-7 CT-7 – Fissile solid in Normal Form in steel insert (HS-55x138-SS) – Activity Limits

Contents Type 7 - CT-7 - Fissile solid in 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
Pu-238	34.06	920.6125142	1.00E-03	34062.66	6.30E-01	5.41E+01	3.26E-02	3.00E+01	B
Pu-240	7.6	205.4594595	1.00E-03	7602.00	8.40E-03	9.05E+02	3.06E-02	6.29E+00	B
Pu-241	Contents shall meet the requirements of 10 CFR 71.15 or 3439 TBq whichever value is lower	Contents shall meet one of the requirements of 10 CFR 71.15 or 92945 Ci whichever value is lower	6.00E-02	57316.67	3.80E+00	9.05E+02	3.10E-05	2.88E+00	B
U-235	Contents shall meet the requirements of 10 CFR 71.15 or 0.0000724 TBq whichever value is lower	Contents shall meet one of the requirements of 10 CFR 71.15 or 0.002 Ci whichever value is lower	< 1	< 1	8.00E-08	9.05E+02	2.71E-02	5.31E-05	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

Table 1-4-8 CT-8 – Fissile solid in Special Form in steel insert (HS-55x138-SS) – Activity Limits

Contents Type 7 - CT-7 - Fissile solid in 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
Pu-238	34.06	920.6125142	1.00E-03	34062.66	6.30E-01	5.41E+01	3.26E-02	3.00E+01	B
Pu-240	7.6	205.4594595	1.00E-03	7602.00	8.40E-03	9.05E+02	3.06E-02	6.29E+00	B
Pu-241	Contents shall meet the requiments of 10 CFR 71.15 or 3439 TBq whichever value is lower	Contents shall meet one of the requirments of 10 CFR 71.15 or 92945 Ci whichever value is lower	6.00E-02	57316.67	3.80E+00	9.05E+02	3.10E-05	2.88E+00	B
U-235	Contents shall meet the requiments of 10 CFR 71.15 or 0.0000724 TBq whichever value is lower	Contents shall meet one of the requirments of 10 CFR 71.15 or 0.002 Ci whichever value is lower	< 1	< 1	8.00E-08	9.05E+02	2.71E-02	5.31E-05	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

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 and CT-5) 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 drawing 0C-5941 (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

1.3.2 Calculation Model Drawings

The drawings listed below and appended to this section show the details used for setting up the calculation models for stress FEA, thermal FEA and shielding calculations (Monte Carlo and Microshield).

These drawings specify nominal dimensions with particular reference to key features (such as gaps for shielding calculations).

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

Drawing No.	Title
0C-5949	Safkeg-HS Construction
1C-5997	CV HS Lid Construction
1C-5999	CV HS Body Construction
3C-6850	HS-12x95-Tu Insert Design No.3982 (construction)
3C-6851	HS-31x114-Tu Insert Design No. 3985 (construction)

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.

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-6920	Silicone Sponge Rubber Disc

1.3.4 Supporting Documents

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

CONTENTS

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 drawing 0C-5942 (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°C±5°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 drawing 0C-5943 (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 drawing 1C-5944 (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.

The containment vessel lid is 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. The plug is welded to the lid top with a circumferential full penetration fillet weld which is liquid penetrant and visually tested.

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 three 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 one, HS-55x149-SS Design No 3987, machined from stainless steel with an PTFE liner fitted into the stainless steel body.

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 three types of inserts 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 during transport.

2.1.2 Design Criteria

In order to evaluate the containment design a package underwent a series of physical tests in accordance with 10 CFR 71.41. An FE Analysis was also performed on the containment vessel 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	X		X		X		X		X

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	
NCT6	vertical)		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 the critical cross-section locations are load-condition dependent, several "stress evaluation sections" were defined to ensure that all critical locations were evaluated for every load condition. These stress evaluation sections are illustrated in Figure 2-1. For evaluation of conditions producing a stress distribution in the vessel that is not axisymmetric, stress evaluations were performed at multiple circumferential locations.

The section stresses at each stress evaluation location were obtained using the Abaqus "stress linearization" post-processing feature (Arcadis Vectra Report L20008/1/R1 (Section 2.12.2). The stress linearization provides membrane, bending, membrane plus bending, and peak stress intensities at each section. In Abaqus, the Tresca stress is equal to the stress intensity as defined in Regulatory Guide 7.6 [2.3].

Using the critical sections from each load case, minimum design margins are calculated and reported for all bounding load combinations. The design margin (DM) is defined as follows:

$$DM = \left(\frac{Allowable\_Value}{Calculated\_Value} \right) - 1$$

Therefore a negative design margin indicates that there are areas of high stress.

Table 2-3 Containment System Allowable Design Criteria		
Stress Type	Allowable Stress Limits	
	NCT	HAC
Other Than Bolts		
Primary Membrane Stress Intensity (P_m)	S_m	Lesser of 2.4S_m and 0.7S_u
Primary Local Membrane Stress Intensity (P_L)	S_m (2)	N/A (3)
Primary + Bending Stress Intensity (P_L or P_m+P_b)	1.5 S_m	Lesser of 3.6 S_m and S_u
Primary + Secondary Stress Intensity (P_L or P_m+Q)	3.0 S_m	N/A
Average Bearing Stress	S_y	N/A
Bolts		
Average Shear Stress	0.4 S_y	Lesser of 0.42 S_u and 0.6 S_y
Average Stress(4)	2 S_m	Lesser of 3 S_m and 0.7 S_u

Maximum Stress(5)	3 S_m	N/A (6)

Notes:

1. Stress limits applicable for components and systems evaluated using elastic system analysis.
2. ASME B&PV code [2.5] gives an allowable of 1.5Sm for primary local membrane stress, P_L. However, Reg. Guide 7.6 [2.3] does not specify an allowable for this stress, so a lower allowable value of S_m has been adopted for this assessment.
3. Evaluation of secondary stress is not required for HAC.
4. The axial stress component averaged across the bolt cross-section and neglecting stress concentrations.
5. The stress due to internal pressure and gasket seating loads (e.g. bolt torque) shall not exceed one times S_m.
6. Evaluation of maximum bolt stress not required for HAC

2.1.2.3 Buckling

The containment vessel inner shell is evaluated for buckling in accordance with the requirements of ASME Code Case N-284-2 [2.6]. Capacity reduction factors are calculated in accordance with Section -1511 of ASME Code Case N-284-2 [2.6] to account for possible reductions in the capacity of the shells due to imperfections and nonlinearity in geometry and boundary conditions. Plasticity reduction factors, which account for nonlinear material properties when the product of the classical buckling stresses and capacity reduction factors exceed the proportional limit, are calculated in accordance with Section -1610 of ASME Code Case N-284-2 [2.6]. The theoretical buckling stresses of the vessel inner shell under uniform stress fields are calculated in accordance with Section -1712.1.1 of ASME Code Case N-284-2 [2.6]. The geometric parameters used in the buckling assessment are given in Table 2-4. The capacity reduction factors, plasticity reduction factors, and theoretical buckling stresses for the vessel inner shell are summarized in Table 2-4.

The allowable elastic and inelastic buckling stresses for NCT and HAC are calculated in accordance with the formulas given in Section -1713.1.1 and Section -1713.2.1 of ASME Code Case N-284-2 [2.6]. The allowable buckling stresses include factors of safety of 2.0 for NCT and 1.34 for HAC in accordance with Section -1400 of ASME Code Case N-284-2 [2.6]. Table 2-6 provides a summary of the vessel inner shell elastic and inelastic buckling stresses for NCT and HAC. Buckling interaction ratios are calculated for the containment vessel inner shell for all NCT and HAC tests that load the shells in compression. The interaction ratios for elastic buckling and inelastic buckling are calculated using the highest values of compressive stress and shear stress from the finite element analysis solutions in accordance with the formulas given in Section -1713.1.1 and Section -1713.2.1 of ASME Code Case N-284-2 [2.6].

Table 2-4 Containment vessel shell buckling geometric parameters	
Geometric Parameter	Inner Shell
Mean radius, R (mm)	35.25 mm
Shell thickness, t (mm)	4.7 mm
R/t	7.5
Unsupported axial length, l_ϕ (mm)	152.4 mm
Unsupported circumferential length, l_θ (mm)	236.3 mm

Table 2-5 Buckling reduction factors and theoretical buckling stresses			
Calculation	Parameter	Hot ambient temperature (NCT) (200°C)	Cold ambient temperature (-29°C)
Capacity reduction factors (-1511)	$\alpha_{\phi L}$	0.2	0.2
	$\alpha_{\theta L}$	0.8	0.8
	$\alpha_{\phi\theta L}$	0.8	0.8
Plasticity reduction factors (-1610)	η_ϕ	0	0.0
	η_θ	0.1	0.1
	$\eta_{\phi\theta}$	0.0	0.0
Theoretical buckling values (-1712.1.1)	$\sigma_{\phi eL}$	14762 MPa	15972 MPa
	$\sigma_{\theta eL} = \sigma_{reL}$	2162 MPa	2339 MPa
	$\sigma_{\theta eL} = \sigma_{heL}$	2056 MPa	2056 MPa
	$\sigma_{\phi\theta eL}$	5421 MPa	5866 MPa

Table 2-6 Shell allowable buckling stresses

Buckling Regime	Stress Type	Allowable Buckling Stress (MPa)			
		Hot ambient temp.		Cold ambient temp.	
		NCT	HAC	NCT	HAC
Elastic Buckling	Axial Compression, σ_{xa}	1528	2218	1818	1818
	Hydrostatic Pressure, σ_{ha}	823	1194	890	890
	Hoop Compression, σ_{ra}	865	1256	936	936
	In-plane shear, $\sigma_{\tau a}$	2169	3148	2346	2346
Inelastic Buckling	Axial Compression, σ_{xc}	60.0	84.3	86.0	86.0
	Radial external pressure, σ_{rc}	60.0	84.3	86.0	86.0
	In-plane shear, $\sigma_{\tau c}$	36.0	50.6	51.6	51.6

2.1.2.4 Fatigue

The fatigue analysis was carried out in accordance with section C3 in NRC Regulatory Guide 7.6 [2.3]. The fatigue analysis was performed as follows:

1. The alternating stress, S_{alt}, was calculated as one-half the maximum absolute value of S'_{12}, S'_{23}, S'_{31} for all possible stress states i and j where σ_1, σ_2, σ_3 are principal stresses and

$$S'_{12} = (\sigma_{1i} - \sigma_{1j}) - (\sigma_{2i} - \sigma_{2j})$$
$$S'_{23} = (\sigma_{2i} - \sigma_{2j}) - (\sigma_{3i} - \sigma_{3j})$$
$$S'_{31} = (\sigma_{3i} - \sigma_{3j}) - (\sigma_{1i} - \sigma_{1j})$$

   State i is after the bolt pre-load has been applied and state j is after all the other loads have been applied. This calculation of S_{alt} is carried out in the post processor.

2. S_{alt} is multiplied by the ratio of the modulus of elasticity given on the design fatigue curve to the modulus of elasticity used in the analysis to obtain a value of stress to be used with the design fatigue curves.

3. The highest value of S_{alt} determined in step 2 is then compared with the design fatigue curves (Figure I-9.2.2) in appendix I of ASME B&PV Section III [2.5].

The number of cycles that the Safkeg HS CV will undergo is approximately 50 cycles/year for 20 years = 1000 cycles. The number of cycles was multiplied by 10 to give 10000 cycles, to give a safety margin.

2.1.2.5 Brittle Fracture

All the structural components of the package are fabricated from austenitic stainless steel which is ductile at low temperatures. According to Regulatory Guide 7.11 [2.7] austenitic stainless steel is not susceptible to brittle facture at temperatures encountered in transport.

The HAC drop tests have been conducted at -40^{o}C to determine if brittle fracture has any effect on the package, with compliance demonstrated if the containment vessel is undamaged and leak tight on completion of testing.

2.1.3 Weights and Centers of Gravity [71.33]

The nominal weight of the package plus the individual components and the maximum content weights are shown in Table 2-7. The maximum package gross weight is 163 kg. The center of gravity of the assembled package is approximately in the center of the 3977A keg.

The weights of the components in Table 2-7 are calculated maximum weights at extreme tolerance to give maximum material condition with rounding.

Table 2-7 Weights of SAFKEG 3977A

Components	Maximum Weight Allowing for Manufacturing Tolerances	
	Kg	lbs
Keg Body, Lid, Liner, Outer Cork, Nuts & Washers	40.56	89.42
Cork Packing	2.25	4.96
Keg plus inner and top corks	42.81	94.4
Containment vessel	109.55	241.52
HS SAFKEG 3977A excluding contents	152.4	336
Insert Plus Contents (max)	9.8	21.6
HS SAFKEG 3977A including contents	163[1]	360

2.1.4 Identification of Codes and Standards for Package Design

The package has been designed to transport normal and special form material in quantities of greater than 3000A_2, therefore it is classified as a Category I package, as defined in

[1] Rounded up to next whole number

Regulatory Guide 7.11 [2.7]. The standards to which the package has been designed, fabricated, tested and maintained have been selected based on the guidance provided in Regulatory Guide 7.6 [2.3] and NUREG/CR-3854 [2.8].

The package containment system was designed in accordance with the applicable requirements of the AMSE Code, Section III subsection NB [2.9]. The non-containment structural components of the package were designed in accordance with the applicable requirements of ASME Code section III, subsection NF for plate and shell type Class 2 supports [2.10].

The design criteria used to assess the containment boundary have been taken from Regulatory Guide 7.6 and the load combinations have been taken from Regulatory Guide 7.8 as discussed in section 2.1.2.1. The buckling evaluation of the containment vessel inner shell is evaluated in accordance with the requirements of ASME code case N-284-2 as discussed in section 2.1.2.3.

Table 2-8 identifies the major components of the HS package and identifies if they provide containment or fulfill the other safety functions such as gamma shielding or support. The drawings in section 1.3 identify whether the items are important to Safety (ITS), the identification was carried out using the guidance of NUREG/CR-6407. Table 2-8 also provides the applicable sections of the ASME code used to purchase materials, fabricate the package, inspect and examine the package. Table 2-9 lists if alternative specifications have been used to the ASME code.

The package containment system is fabricated in accordance with the applicable sections of Section III, Subsection NB of the ASME code as shown in Table 2-8. There are no welds in the containment boundary so there are no requirements listed. The other safety items shown in Table 2-8 have been fabricated in accordance with the applicable requirements of Section III Subsection NF for Class 2 supports in the ASME code

The depleted uranium and the cork impact limiters are specialist materials for which an ASTM standard does not exist. The depleted uranium is fabricated and tested in accordance with standard industry practices. Chemical composition checks and fracture toughness tests are carried out on the DU batch used for the shielding prior to machining, to ensure it satisfies the shielding requirements. A density check of the depleted uranium is carried out after machining to ensure there are no cracks or voids. A shielding check of the containment vessel is carried out on completion of manufacture to ensure the shield provides the required shielding protection.

The cork is fabricated in accordance with the vendor's standard practices and tested to the requirements of drawing 0C-5943.

Table 2-8 Applicable Codes and Standards for the Manufacture of the 3977A Package

	Component Safety Group					
	Containment		Other Safety			
Components	CV cavity wall/flange, CV Lid Top, Bolts	CV O-ring	CV DU	CV outer shell	Keg outer shell, keg skirts, keg lid, keg closure nuts	Cork/Silicone Sponge Rubber Disc
Function	Containment Boundary	Containment seal	Gamma Shielding	Positioning and support of DU shielding	Secondary shell and closure	Impact limiters
Design Criteria	AMSE section III, Division 1, subsection NB-3000		AMSE section III, Division 1, subsection NF-3000			Section 2 of this SARP
Materials	NB-2000	Section 2 of this SARP	Section 2 of this SARP	NF-2000	NF-2000	Section 2 of this SARP
Forming, fitting and aligning	Not Applicable	Not Applicable	Not Applicable	NF-4200	NF-4200	Not Applicable
Welding	Not Applicable	Not Applicable	Not Applicable	NF-4400	NF-4400	Not Applicable
Qualification of weld procedure and personnel				NF-4300	NF-4300	

Table 2-8 Applicable Codes and Standards for the Manufacture of the 3977A Package

	Component Safety Group					
	Containment		Other Safety			
Components	CV cavity wall/flange, CV Lid Top, Bolts	CV O-ring	CV DU	CV outer shell	Keg outer shell, keg skirts, keg lid, keg closure nuts	Cork/Silicone Sponge Rubber Disc
Examination of welds				NF-5000	NF-5000	
Acceptance Testing	NB-6000	Section 8 of this SARP and ANSI N14.5	Section 8 of this SARP	Section 8 of this SARP	Section 8 of this SARP	Section 8 of this SARP

Table 2-9 - Alternative Requirements to the ASME Code Requirements

Component	Code Section	Code Requirement	Alternative Code Used and Justification
CV cavity wall/flange, CV Lid Top, Bolts	NB-2000	Metallic Materials shall be manufactured to an SA, SB of SFA specification.	NUREG/CR-3854 allows ASTM materials to be used. This SARP demonstrates equivalence between the materials.
	NB-2000	Requires materials to be supplied by ASME approved material supplier.	Croft approved suppliers will supply materials with certificates containing at the least information about:

Table 2-9 - Alternative Requirements to the ASME Code Requirements

Component	Code Section	Code Requirement	Alternative Code Used and Justification
			Heat number Material specification and grade Chemical analysis Mechanical properties including tensile strength and yield strength/proof stress
CV outer shell	NF-2000	Metallic Materials shall be manufactured to an SA, SB of SFA specification.	NUREG/CR-3854 allows ASTM materials to be used. This SARP demonstrates equivalence between the materials.
	NF-2000	Requires materials to be supplied by ASME approved material supplier.	Croft approved suppliers will supply materials with certificates containing at the least information about: Heat number Material specification and grade Chemical analysis Mechanical properties including tensile strength and yield strength/proof stress
	NF-5350	Liquid penetrant acceptance standards	NB-5350 has been used to accept the liquid penetrate tests. As allowed by NUREG 3019

Table 2-9 - Alternative Requirements to the ASME Code Requirements

Component	Code Section	Code Requirement	Alternative Code Used and Justification
			[2.14] welding criteria can be upgraded by Category.
Keg outer shell, keg skirts, keg lid, keg closure nuts	NF-2000	Metallic Materials shall be manufactured to an SA, SB of SFA specification.	NUREG/CR-3854 allows ASTM materials to be used. This SARP demonstrates equivalence between the materials.
	NF-2000	Requires materials to be supplied by ASME approved material supplier.	Croft approved suppliers will supply materials with certificates containing at the least information about: Heat number Material specification and grade Chemical analysis Mechanical properties including tensile strength and yield strength/proof stress
	NF-5350	Liquid penetrant acceptance standards	NB-5350 has been used to accept the liquid penetrate tests. As allowed by NUREG 3019 [2.14] welding criteria can be upgraded by Category.

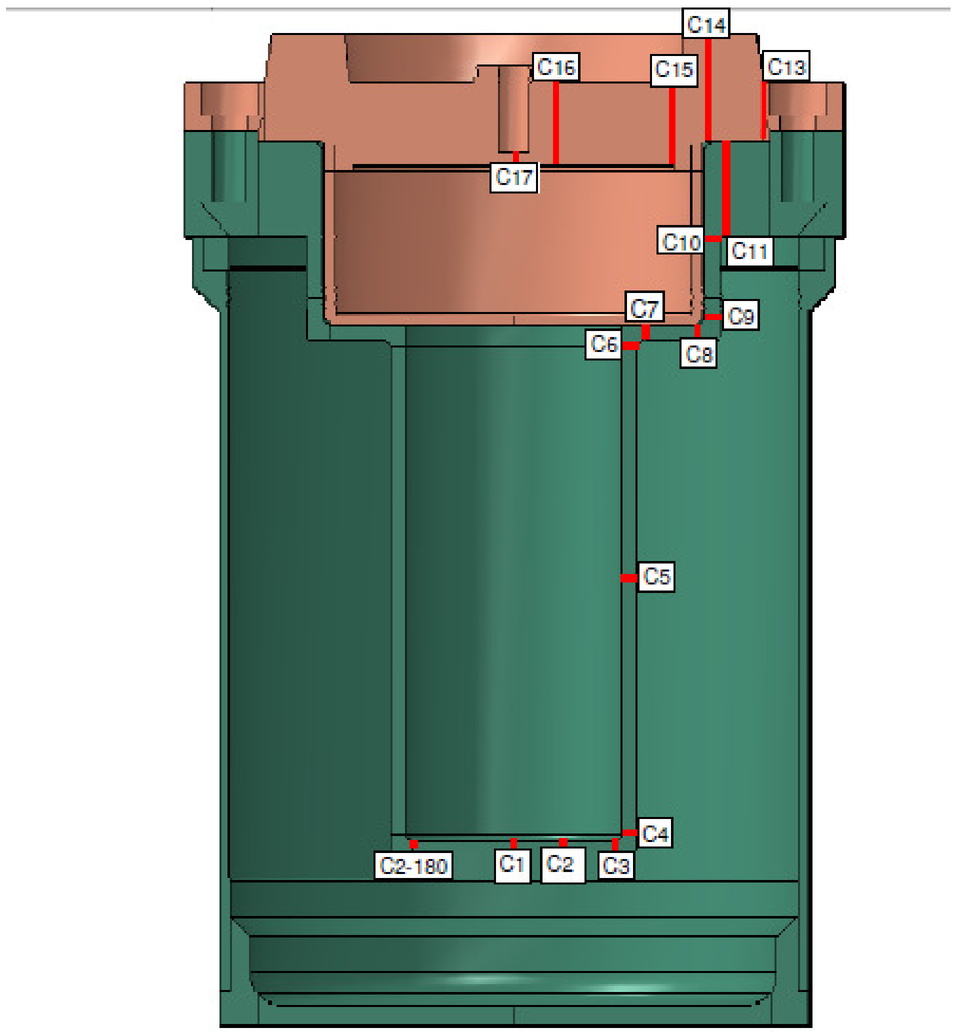


Figure 2-1 Stress Evaluation Locations

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	Silicon
Silicone Sponge Rubber Disc	Silicone

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.

2.2.1.2 Shielding Material

The shielding is formed from depleted uranium alloyed with 2±2% Molybdenum and 0.2% Carbon maximum by weight. The depleted uranium is alloyed with 2% Molybdenum to provide greater yield strength and improves ductility. The mechanical properties of the depleted uranium used in the structural evaluation are presented in Table 2-13.

2.2.1.3 Cork Packing

The inner and outer cork is machined from resin bonded cork. The cork may be formed from one piece or from several pieces glued with a contact adhesive.

The mechanical properties of the cork have been determined by testing. Loads were applied by a piston at a rate of 4.5 mm/minute to 45 mm thick racially constrained cork samples. The displacement of the cork was then recorded continuously at a rate of 20 readings/second. In order to cover the full range of service temperatures tests were carried out with corks at -29°C, 20°C and 100°C. The test details and results are discussed in the Serco Report SERCO/TAS/002762/01 [Section 2.12.2].

Table 2.14 presents the mechanical properties of the cork determined from testing. The test results show that cork is harder at low temperatures and softer at high temperatures. At an applied stress of 8 MPa, the cork at 100°C showed most deformation: which would indicate the containment vessel will travel a further distance into the cork before it is resisted by the same forces it would be resisted with at room temperature.

2.2.2 Chemical, Galvanic or Other Reactions [71.43(d)]

The package has been evaluated to determine all the material interactions of chemically or galvanic dissimilar materials. These interactions are identified in Table 2-15.

There is no potential for chemical, galvanic or other reactions between the components of the package which are stainless steel and cork in dry conditions, and stainless steel and encapsulated depleted uranium which is sealed and therefore dry. Eutectic formation shall not affect the package performance as the operating temperatures are lower than the eutectic formation temperature. The only contents which could cause reactions or generate gases are liquids carried in product containers within the tungsten or steel inserts which are fitted with a silicone O-ring seal. Under NCT and HAC, the liquids are contained within the product containers and inserts and therefore no liquid comes into contact with the containment system. If the liquid contents would react with the stainless steel of the insert a PTFE liner is fitted inside the stainless steel insert, this insert has been shown to completely contain the liquid contents even under HAC conditions.

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 (base material Viton GLT) 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 2-11 Material Properties for Grade 304L Stainless Steel									
Stainless Steel ASTM A240/A240m and ASTM A479/A479m Grade 304L Material Properties				**Values at Different Temperatures**					
				-40°C	20°C	149°C	204°C	232°C	260°C
				-40°F	68°F	300°F	400°F	450°F	500°F
				a	b	c	d	e	d
Design Stress Intensity	S_m	MN/m^2	f	115.1	115.1	115.1	108.9	105.4	102.0
		ksi	g	16.7	16.7	16.7	15.8	15.3	14.8
Yield Strength	S_y	MN/m^2	f	172.3	172.3	132.4	120.7	116.5	113.1
		ksi	h	25.0	25.0	19.2	17.5	16.9	16.4
Tensile Strength	S_u	MN/m^2	f	483	483	422	405	401	396
		ksi	i	70	70	61.2	58.7	58.1	57.5
Coefficient of Thermal Expansion (Mean)	a_m	10^{-6} m/m °C	f	14.7	15.3	16.6	17.1	17.3	17.5
		10^{-6} in/in °F	j	8.2	8.5	9.2	9.5	9.6	9.7
Thermal Conductivity	k	W/m K	f	13.9	14.9	17.0	18.0	18.5	18.9
		BTU/h ft °F	k	8.0	8.6	9.8	10.4	10.7	10.9
Modulus of Elasticity	E	GN/m^2	f	198.4	195.0	186.0	182.6	180.2	177.8
		Mpsi	l	28.8	28.3	27	26.5	26.2	25.8
Fatigue Strength @ 10^6 and 10^4 cycles	S_a	MN/m^2	f	195.1 and 441					
		ksi	m	28.3 and 64					

Some values are extrapolated or interpolated

a -40°F is the lowest temperature to be considered for packaging. Data at 40°F is extrapolated where not given specifically in the ASME code. Note that the packaging is required to remain leak tight at 40°F under no loading; however, the specified structural loadings need not be considered below -20°F.

b These data are used for calculations at normal ambient temperature

c The temperature for this data is close to the maximum NCT temperature

d These data are used to calculate the data at the maximum HAC

e This data is interpolated from 400°F and 500°F

f Calculated from the data in imperial units

g ASME Section II (2001), Part D, Subpart 2 [2.16], Table 2A (pages 312-315)

h ASME Section II (2001), Part D, Subpart 2 [2.16], Table Y-1 (pages 552-555)

i ASME Section II (2001), Part D, Subpart 2 [2.16], Table U (pages 450-451)j

k ASME Section II (2001), Part D, Subpart 2 [2.16], Table TE-1 18 Cr-8 Ni (page 651 Group 3)

l ASME Section II (2001), Part D, Subpart 2 [2.16], Table TM-1 Material Group G - Austenitic steels (page 671)

m ASME Section III (2001), Appendix I [2.9], Table I-9.1 Line I-9.2.1 (page 4)

Table 2-12 Mechanical Properties of SA-320/A320 Grade L43 Bolting Steel											
Properties				Values at Different Temperatures							
				-40°C	-30 °C	25 °C	40 °C	65 °C	100 °C	120 °C	150 °C
				-40°F	-22	77	104	149	212	248	302
				a							
Design Stress Intensity	S_m	MN/m^2	1	241	241	241	241	235	226	224	220
		ksi		34.95	34.95	34.95	34.95	34.1	32.8	32.5	31.9
Yield Strength	S_y	MN/m^2	2	723	723	723	723	704	678	671	660
		ksi		104.9	104.9	104.9	104.9	102.1	98.3	97.3	95.7
Tensile Strength	S_u	MN/m^2	3	860	860	860	860	860	860	860	860
		ksi		124.7	124.7	124.7	124.7	124.7	124.7	124.7	124.7
Coefficient of Thermal Expansion (Mean)	a_m	10^{-6} m/m °C	4	10.9	11.0	11.6	11.7	11.9	12.1	12.2	12.2
		10^{-6} in/in °F		6.06	6.1	6.4	6.5	6.6	6.7	6.8	6.8
Modulus of Elasticity	E	GN/m^2	5	195	194	191	190	189	187	186	184
		Mpsi		28.3	28.1	27.7	27.6	27.4	27.1	27.0	26.7

1 ASME Code, Section II, Part D, Table 4 [2.16]
2 In accordance with ASME code, Section II, Part D, Table 4 [2.16] general note (A), the yield strength is equal to 3 times the allowable stress value S_m
3 Minimum tensile strength from ASME code, Section II part D, table 4 [2.16]
4 ASME Code Section II, Part D, Table TM-1, Material Group G [2.16]
5 ASME Code Section II, Part D, Table TE-1, Group 1, Coefficient B (mean from 70°F) [2.16]
6 Values in italics are calculated using linear interpolation or linear extrapolation.

Table 2-13 Mechanical Properties of Depleted Uranium				
Temperature	Density (kg/m^3)	Modulus of Elasticity (GPa)	Poisson's Ratio	Mean Coef. of Thermal Expansion (m/m/°C x 10^{-6})
-40	18952	172	0.3	11.5
-29				11.7
21				12.7
38				13.0
93				14.1

Table 2.14 Average compressive Modulus of Elasticity and Compressive Strength at 10% Relative Deformation for Cork at each Test Temperature		
Test Temperature (^{o}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	Viton GLT 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 shielding insert	NH				NH	NH								
Silicone Sponge Rubber Disc			NH	NH		NH								
Stainless steel				NH	NH		NH	NH	NH	H	NH	NH	NH	NH
Viton GLT 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. 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. It shall be fabricated using standard industry practices. The cork shall be tested to demonstrate it meets the required specification in drawing 0C-6043 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:

Material Tests

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 cork the supplier is required to provide a Certificate of Conformance to confirm that the properties listed in drawing 0C-5943 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-6045 and 1C-6046. 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.

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). 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^{o}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.

The upper pressure experienced by the containment vessel is assumed to be 700 kPa gauge pressure. This value has been used in the structural evaluation.

A calculation of the actual maximum pressure expected under NCT is provided in Calculation Sheet CS 2012/02 (Section 2.12.2) – the calculated maximum pressure is 1.80 bar abs (180 kPa).

The heat load for liquid contents is limited to 5W for which the calculated maximum temperature of the CV under NCT is 78.1°C (Section 3.1.3, Table 3-1). There is therefore no pressure increase due to the vapour pressure of the liquid contents (the liquid contents are aqueous with a boiling point of 100°C).

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 model has assumed no gap is present between the depleted uranium and the stainless steel and determined the stresses within the containment vessel boundary caused as a result of the differing thermal expansion rates. The results of the stress calculations are discussed in section 2.6.1.3.

2.6.1.3 Stress Calculations

In order to determine the effect of heat on the containment vessel a finite element analysis was carried out as documented in the Arcadis Vectra Report No L20008/1/R1 (Section 2.12.2). The model was applied with a uniform temperature of 158°C across the containment vessel and an internal gauge pressure of 700 kPa.

Stresses within the containment vessel boundary were calculated at the points shown in Figure 2-1. From these calculations the maximum stress intensities were determined and presented in Table 2-16. The stresses in the bolts were calculated and are presented in Table 2-17.

A buckling evaluation was also carried out using the FEA model, as described in the Arcadis Vectra report No L20008/1/R1. The results of the calculation are presented in Table 2-18. The stresses used for the calculations were taken from point C5 in Figure 2-1, which is mid-way along the length of the inner shell of the containment vessel. Where one of the components was tensile in the finite element analysis it should be given a value of 0 Pa however in order to avoid zero errors it was given a very small positive value in the buckling calculation.

In order to determine the effect of repeated cycles of thermal loading on the containment vessel, fatigue calculations have been carried out in accordance with Section 2.1.2.4 and are detailed in the Arcadis Vectra Report L20008/1/R1 (Section 2.12.2). The values calculated are given in Table 2-19.

2.6.1.4 Comparison with Allowable Stress

The maximum stresses calculated were compared against the allowable stresses and the design margin calculated as detailed in Section 2.1.2.2. All the design margins are greater than the design criteria of 0 as shown in Table 2-16, therefore, the containment vessel satisfies the requirements of Regulatory Guide 7.6 [2.3]. The lowest design margin calculated is 0.04 which is due to the bearing stress under the bolts.

The stresses calculated in the bolts have been compared against the allowable stresses and the design margin has been calculated as described in Section 2.1.2.2. All the design margins are greater than 0 as shown in Table 2-17. Therefore the containment vessel bolts satisfy the requirements of Regulatory Guide 7.6 [2.3].

The buckling stresses were compared against the allowable stresses as detailed in Section 2.1.2.3. As all of the stress components were tensile in this case, the design margin is effectively infinite, hence the containment vessel satisfies the requirements of Regulatory Guide 7.6 [2.3] for buckling as shown in Table 2-18.

The fatigue evaluation is given in Table 2-19. As the value of the maximum alternating stress in the containment vessel was below the fatigue threshold, the design margin is

effectively infinite. Hence the containment vessel satisfies the requirements of Regulatory Guide 7.6 [2.3] for fatigue.

Table 2-16 Containment Vessel Stress Summary under Heat Conditions

NCT Case ID	Description	Stress Type	Maximum Stress Intensity (MPa)	Stress Location	Allowable stress intensity (MPa)	Minimum Design Margin
1	Heat	P_m	14.9	C6b	109	6.30
		P_m+P_b	44.7	C1	163	2.65
		P_m+P_b+Q	38.3	C3	327	7.54
		Bearing	116	Under bolts	121	0.04

Table 2-17 Containment Vessel Bolts Stress Analysis under Heat Conditions

NCT Case ID	Description	Stress Type	Maximum stress (MPa)	Allowable stress intensity (MPa)	Minimum design margin
1	Heat	Average Shear	2.09	244	115
		Average Stress	163	406	1.49
		Max Stress	175	609	2.47

Table 2-18 Containment Vessel Buckling Calculations Under Heat Conditions

NCT Case ID	Description	Stress (MPa)			Design Margin
		Axial Compression	Hoop Compression	In-plane shear	
1	Heat	0	0	0.0	n/a

Table 2-19 Containment Vessel Fatigue Evaluation under Heat Conditions

Maximum alternating stress	Required No of cycles	Cycles to failure	Design Margin
44.72	10000	$> 10^{11}$	n/a

2.6.2 Cold [71.71 (c) (2)]

10CFR 71.71 (c) (2) requires that the package performance is evaluated at an ambient temperature of -40°C in still air and with no insolation. This should be considered along with no internal heat load and the minimum internal pressure.

As discussed in Section 3, at -40°C ambient temperature the package has a minimum internal pressure of 0 kPa absolute and it is assumed the entire package temperature is -40°C. The stresses were calculated in the containment vessel using the FEA analysis described in the Vectra Report L20008/1/R1 (Section 2.12.2). It was assumed that the external pressure was 100 kPa and the internal pressure was 0 kPa absolute, so the internal gauge pressure applied to the model was -100 kPa.

The effect of temperature on the components of the containment vessel was determined with the model, as described in the Vectra Report L20008/1/R1 (Section 2.12.2]. Stresses within the containment vessel boundary were calculated at the points shown in Figure 2-1. From these calculations the maximum stress intensities were determined and presented in Table 2-20. The maximum stresses calculated were compared with the allowable stresses and the design margin calculated as detailed in Section 2.1.2.2. All the design margins are greater than 0 as shown in Table 2-20 therefore the containment vessel satisfies the requirements of Regulatory Guide 7.6 [2.3].

The stresses in the bolts were calculated and are presented in Table 2-21. These stresses have been compared against the allowable stresses and the design margin has been calculated as described in Section 2.1.2.2. All the design margins are greater than 0 as shown in Table 2-21. Therefore the containment vessel bolts satisfy the requirements of Regulatory Guide 7.6 [2.3].

A buckling evaluation was also carried out using the FEA model, as described in the Vectra report No 925-3272/R1. The results of the calculation are presented in Table 2-22. The stresses used for the calculations were taken from point C5 in Figure 2-1, which is mid-way along the length of the inner shell of the containment vessel. Where one of the components was tensile in the finite element analysis it should be given a value of 0 Pa however in order to avoid zero errors it was given a very small positive value in the buckling calculation.

The buckling stresses were compared against the allowable stresses as detailed in Section 2.1.2.3. The design margin is 125 which is greater than 0 hence the containment vessel satisfies the requirements of Regulatory Guide 7.6 [2.3] for buckling as shown in Table 2-22.

In order to determine the effect of repeated cycles of thermal loading on the containment vessel, fatigue calculations have been carried out in accordance with Section 2.1.2.4 and are detailed in the Vectra Report L20008/1/R1 (Section 2.12.2). The values calculated are given in Table 2-23. As the value of the maximum alternating stress in the containment vessel was below the fatigue threshold, the design margin is effectively infinite. Hence the containment vessel satisfies the requirements of Regulatory Guide 7.6 [2.3] for fatigue.

Brittle fracture has not been considered because the containment vessel and keg are fabricated from austenitic stainless steel which is ductile even and low temperatures and therefore not susceptible to brittle fracture [2.3].

Table 2-20 Containment Vessel Stress Summary under Cold Conditions

NCT Case ID	Description	Stress Type	Maximum Stress Intensity (MPa)	Stress Location	Allowable stress intensity (MPa)	Minimum Design Margin
2	Cold	P_m	5.21	C10	115	21.1
		P_m+P_b	6.39	C1	173	26.0
		P_m+P_b+Q	10.2	C11	345	33.0
		Bearing	19.5	Under bolts	173	7.82

Table 2-21 Containment Vessel Bolts Stress Analysis under Cold Conditions

NCT Case ID	Description	Stress Type	Maximum stress (MPa)	Allowable stress intensity (MPa)	Minimum design margin
2	Cold	Average Shear	0.80	289	358
		Average Stress	27.3	482	16.7
		Max Stress	46.0	723	14.7

Table 2-22 Containment Vessel Buckling Calculations Under Cold Conditions

NCT Case ID	Description	Stress (MPa)			Design Margin
		Axial Compression	Hoop Compression	In-plane shear	
2	Cold	0.33	0.68	0	125

Table 2-23 Containment Vessel Fatigue Evaluation under Cold Conditions

Maximum alternating stress	Required No of cycles	Cycles to failure	Design Margin
10.16	10000	$> 10^{11}$	n/a

2.6.3 Reduced External Pressure [71.71 (c) (3)]

Section 71.71 (c) (3) requires that the package is subjected to a reduced external pressure of 25 kPa absolute. According to Regulatory Guide 7.8 [2.2] the reduced external pressure should be combined with the worst case initial conditions shown in Table 2-1.

To determine the effect of the reduced external pressure with the worst case initial conditions a finite element analysis was carried out on the containment vessel as detailed in the Vectra Report L20008/1/R1 (Section 2.12.2). The analysis was carried out with an ambient temperature of 38°C in still air, with insolation and the maximum decay heat. It was assumed that under these conditions the containment vessel was at a uniform temperature of 158°C. The external pressure was 24.5 kPa with the internal pressure at 800 kPa absolute, so the internal gauge pressure applied to the model was 775.5 kPa.

The stresses were calculated at the points shown in Figure 2-1. From these calculations the maximum stress intensities were determined and presented in Table 2-24. As shown all of the design margins are greater than zero therefore satisfying the requirements of Regulatory Guide 7.6 [2.3].

A stress analysis of the containment vessel closure bolts under reduced external pressure was performed. The axial force from the finite element analysis model was extracted and divided by the bearing area of the bolt heads, to give the average bearing stress and divided by the cross sectional area of the bolts to give the average stress.

The calculated values for average shear, average stress and maximum stress of the closure bolts for the vibration load conditions are summarized in Table 2-25. The design margins are all greater than 0 therefore the bolts satisfy the requirements of Regulatory Guide 7.6 [2.3].

Buckling evaluations of the inner containment shell were carried out in accordance with the requirements of ASME Code Case N-284-2 [2.6] as detailed in Section 2.1.2.3. The stresses used for the calculations were taken from point C5 in Figure 2-1, which is mid-way along the length of the inner shell of the containment vessel. Where one of the components was tensile in the finite element analysis it should be given a value of 0 Pa however in order to avoid zero errors it was given a very small positive value in the buckling calculation.

The calculated stress from the FEA is tensile for the reduced external pressure condition. Therefore the stress is 0 MPa for axial and hoop compression, In-plane shear does have a maximum stress of 0 MPa. The design margin for the buckling stress was effectively infinite which is greater than 0, therefore satisfying the requirements of Regulatory Guide 7.6 [2.3].

In accordance with Regulatory Guide 7.8 [2.2] regular pressurization loads should be evaluated to determine how they contribute to mechanical fatigue. The fatigue analysis was carried out in accordance with section C.3 in Regulatory Guide 7.6 [2.3]. It was assumed that the containment vessel would undergo approximately 50 cycles/year, for 20 years, which equates to 1000 cycles in its lifetime. This number was multiplied by 10 to give 10000 cycles, providing a safety margin. The maximum alternating stress was calculated as 49.54 MPa, this

figure is below the fatigue threshold meaning that the design margin is effectively infinite with the number of cycles to failure of $>10^{11}$ far in excess of the actual number of cycles.

The results of the calculations resulting from the reduced external pressure have shown that the containment vessel satisfies the allowable design criteria. Reduced external pressure will not cause the permanent deformation of the containment vessel. It will not cause the failure of the containment vessel boundary or deformation of the bolts therefore it shall not result in any loss or dispersal of the radioactive contents.

Table 2-24 Containment Vessel Stress Summary for Changes to External Pressure

NCT Case ID	Description	Stress Type	Maximum Stress Intensity (MPa)	Stress Location	Allowable stress intensity (MPa)	Minimum Design Margin
3	Reduced External Pressure	P_m	16.5	C6b	109	5.6
		P_m+P_b	49.5	C1	163	2.30
		P_m+P_b+Q	42.5	C3	327	6.69
		Bearing	116	Under bolts	121	0.04
4	Increased External Pressure	P_m	3.66	C10	115	30.4
		P_m+P_b	8.94	C1	173	18.3
		P_m+P_b+Q	8.17	C3	345	41.2
		Bearing	60.0	Under bolts	172	1.86

Table 2-25 Containment Vessel Bolts Stress Analysis for Changes to External Pressure

NCT Case ID	Description	Stress Type	Maximum stress (MPa)	Allowable stress intensity (MPa)	Minimum design margin
3	Reduced External Pressure	Average Shear	2.14	244	113
		Average Stress	163	406	1.49
		Max Stress	176	609	2.46
4	Increased External Pressure	Average Shear	1.90	289	151
		Average Stress	84.1	482	4.73
		Max Stress	108.3	723	5.68

2.6.4 Increased External Pressure [71.71 (c) (4)]

10 CFR 71.71 (c) (4) requires that the package is subjected to an increased external pressure of 140 kPa absolute. According to Regulatory Guide 7.8 [2.2] the increase in external pressure should be combined with the worst case initial conditions shown in Table 2-1.

To determine the effect of the increased external pressure with the worst case initial conditions a finite element analysis was carried out on the containment vessel as detailed in the Vectra Report L20008/1/R1 (Section 2.12.2). The analysis was carried out with an ambient temperature of -29^{o}C in still air, with zero insolation and zero decay heat. The external pressure was 140 kPa with the internal pressure at 0 kPa absolute, so the internal gauge pressure applied to the model was -140 kPa. A bolt pre load of 8.12 kN was applied to the bolts at the start of the analysis prior to any other load being applied.

The stresses were calculated at the points shown in Figure 2-1. From these calculations the maximum stress intensities were calculated and are presented in Table 2-24. As shown all of the design margins are greater than zero, therefore satisfying the requirements of Regulatory Guide 7.6 [2.3].

A stress analysis of the containment vessel closure bolts under increased external pressure was performed. The axial force from the finite element analysis model was extracted and divided by the bearing area of the bolt heads, to give the average bearing stress and divided by the cross sectional area of the bolts to give the average stress.

The calculated values for average shear, average stress and maximum stress of the closure bolts for the increased external pressure conditions are summarized in Table 2-25. The design margins are all greater than 0 therefore the bolts satisfy the requirements of Regulatory Guide 7.6 [2.3].

Buckling evaluations of the inner containment shell were carried out in accordance with the requirements of ASME Code Case N-284-2 [2.6] as detailed in Section 2.1.2.3. The stresses used for the calculations were taken from point C5 in Figure 2-1, which is mid-way along the length of the inner shell of the containment vessel. Where one of the components was tensile in the finite element analysis it should be given a value of 0 Pa however in order to avoid zero errors it was given a very small positive value in the buckling calculation.

The calculated stress from the FEA is tensile for the reduced external pressure condition. Therefore the stress is 0.46 MPa for axial and 0.96 MPa for hoop compression, In-plane shear does have a maximum stress of 0. The design margin for the buckling stress was 88.6 which is greater than 0, therefore satisfying the requirements of Regulatory Guide 7.6 [2.3].

In accordance with Regulatory Guide 7.8 [2.2] regular pressurization loads should be evaluated to determine they contribute to mechanical fatigue. The fatigue analysis was carried out in accordance with Section 2.1.2.4. It was assumed that the containment vessel would undergo approximately 50 cycles/year, for 20 years, which equates to 1000 cycles in its lifetime. This number was multiplied by 10 to give 10000 cycles, providing a safely margin.

The maximum alternating stress was calculated as 28.4 MPa, this figure is below the fatigue threshold meaning that the design margin is effectively infinite with the number of cycles to failure of $>10^{11}$ far in excess of the actual number of cycles.

The results of the calculations for increased external pressure have shown that the containment vessel satisfies the allowable design criteria as defined in Regulatory Guide 7.6 [2.3]. Increased external pressure will not cause the permanent deformation of the containment vessel. It will not cause the failure of the containment vessel boundary or deformation of the bolts therefore it shall not result in any loss or dispersal of the radioactive contents.

2.6.5 Vibration [71.71 (c) (5)]

10 CFR 71.71 (c) (5) requires that the package is subjected to vibration normally incident during transport. The package will be transported by all modes of transport and tied down using cargo nets or a similar system that envelope the package.

Vibration analysis has been carried out using a bounding vertical downward acceleration of 10g. Vibration loading has been applied to the containment vessel in combination with temperature and pressure loadings in accordance with Table 2-1. The stresses in the containment vessel were determined using the finite element model discussed in the appended Vectra Report L20008/1/R1. (Section 2.12.2].

Under the hot vibration conditions, a uniform temperature of 158°C and an internal gauge pressure of 700 kPa have been applied to the containment vessel. Under the cold vibration conditions an ambient temperature of -29°C is applied, along with an internal gauge pressure of -100 kPa to the containment vessel. For both tests a body force was applied to the model which was equivalent to a downward vertical acceleration of 10g. A pre load of 8.12 kN was applied to the bolts at the start of the analysis prior to any other loads being imposed. This corresponds to an applied torque of 10 Nm.

Under these vibration loading conditions the primary membrane (Pm), primary plus bending (Pm+Pb), primary plus secondary (Pm+Pb+Q) and bearing stresses have been evaluated at the locations shown on Figure 2-1. The stress distribution is given in the Vectra Report L20008/1/R1 (Section 2.12.2). The stress distribution is similar to the hot conditions stress calculation, which indicates the stresses are dominated by the thermal stress.

The maximum stress intensities calculated, along with the location of the maximum stress is summarized for each vibration load combination in Table 2-26. Each maximum stress is compared to the allowable stress intensity and a design margin given. All the design margins are greater than 0 therefore the containment vessel satisfies the requirements of Regulatory Guide 7.6 [2.3].

A stress analysis of the containment vessel closure bolts under vibration load conditions was performed. The axial force from the finite element analysis model was extracted and divided by the bearing area of the bolt heads, to give the average bearing stress and divided by the cross sectional area of the bolts to give the average stress.

The calculated values for average shear, average stress and maximum stress of the closure bolts for the vibration load conditions are summarized in Table 2-27. The design margins are all greater than 0 therefore the bolts satisfy the requirements of Regulatory Guide 7.6 [2.3].

Buckling evaluations of the inner containment shell were carried out in accordance with the requirements of ASME Code Case N-284-2 [2.6] as detailed in Section 2.1.2.3. The stresses used for the calculations were taken from point C4 in Figure 2-1, which is mid-way along the length of the inner shell of the containment vessel. Where one of the components was tensile in the finite element analysis it should be given a value of 0, however, in order to avoid zero errors it was given a very small positive value in the buckling calculation.

The maximum calculated buckling stresses are shown in Table 2-28 along with the design margin. Table 2-28 shows that all the design margins are greater than 0 therefore the containment vessel will not buckle under an NCT free drop test and satisfies the requirements of Regulatory Guide 7.6 [2.3].

The results of the NCT Vibration structural evaluation show that the containment vessel meets all the applicable stress design criteria. The vibration loads will not result in any permanent deformation of the containment vessel or failure within the containment boundary.

Table 2-26 Containment Vessel Stress Summary for Vibration Loads

NCT Case ID	Description	Stress Type	Maximum Stress Intensity (MPa)	Stress Location	Allowable stress intensity (MPa)	Minimum Design Margin
5	Vibration (hot)	P_m	16.5	C6b	109	5.60
		P_m+P_b	49.5	C1	163	2.30
		P_m+P_b+Q	8.17	C3	327	38.9
		Bearing	116	Under bolts	121	0.04
6	Vibration (cold)	P_m	99.2	C6b	115	0.16
		P_m+P_b	59.5	C1	173	1.90
		P_m+P_b+Q	10.5	C3	345	31.8
		Bearing	60.1	Under bolts	172	1.86

Table 2-27 Containment Vessel Bolts Stress Analysis under Vibration Load Conditions

NCT Case ID	Description	Stress Type	Maximum stress (MPa)	Allowable stress intensity (MPa)	Minimum design margin
5	Vibration (hot)	Average Shear	2.14	244	113

Table 2-27 Containment Vessel Bolts Stress Analysis under Vibration Load Conditions

NCT Case ID	Description	Stress Type	Maximum stress (MPa)	Allowable stress intensity (MPa)	Minimum design margin
		Average Stress	163	406	1.49
		Max Stress	179	609	2.46
6	Vibration (cold)	Average Shear	1.40	289	205
		Average Stress	80.24	482	4.72
		Max Stress	109	723	5.62

Table 2-28 Containment Vessel Buckling Calculations under Vibration Load Conditions

NCT Case ID	Description	Stress (MPa)			Design Margin
		Axial Compression	Hoop Compression	In-plane shear	
5	Vibration (hot)	0	0	0	n/a
6	Vibration (cold)	0.26	0.40	0	214

2.6.6 Water Spray [71.71 (c) (6)]

10 CFR 71.71 (c) (6) requires that a package must be subjected to a water spray test that simulates exposure to rainfall of approximately 5 cm/hour for at least 1 hour. The package was not subjected to a water spray test. This is because all materials both inside and out are made from materials that are water resistant. The lid of the keg is fitted with an O-ring seal for weather protection which would aid in the prevention of water entry due to water spray (rain). Therefore the water spray test would have no effect on the structural design of the package or its components and has not been performed during the regulatory tests.

2.6.7 Free Drop [71.71 (c) (7)]

10 CFR 71.71 (c) (7) requires that a package of less than 5,000 kg is subjected to a free drop test from a distance of 1.2 m onto an essentially unyielding, horizontal surface, striking in a position for which the maximum damage is expected.

The package was evaluated by dropping a prototype package 1.2m onto its side, top corner and finally onto the top of the package, in all cases the centre of gravity was over the point of impact. These orientations were considered worst case because previous experience has shown that a drop on the side leads to the highest stresses in the package. A drop on the lid or the top rim of the package may distort the lid and open the seals which would be more likely to cause a loss of containment. A finite element analysis of the containment vessel was carried out on completion of the drop tests to supplement the testing data.

The NCT free drop tests were carried out on a 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 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 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

The cold conditions assumed an ambient temperature of -29°C, in still air with no insolation or decay heat. It has been assumed that the internal pressure is 0 kPa with an external pressure of 100 kPa, so the internal gauge pressure is -100 kPa. The load combinations modeled for the NCT drop tests are outlined in Table 2-1.

For the entire NCT free drop analysis a pre load of 8.12kN was applied to the bolts at the start of the analysis, prior to any other loads being imposed. The bolts were tied to the CV body along the threaded length with the bolt heads free to slide.

Stress calculations were carried out for each free drop load combination. Stress distributions presented in Vectra Report L20008/1/R1 (Section 2.12.2).

The primary membrane (Pm), primary plus bending (Pm+Pb), primary plus secondary (Pm+Pb+Q) and bearing stresses were evaluated at the locations shown on Figure 2-1, for each of the free drop load combination identified in Table 2-1 (NCT load ids 7 – 12). The maximum stress intensities calculated along with the location of the maximum stress is given for each free drop load combination in Table 2-31. Each maximum stress is compared to the allowable stress intensity and the design margin given.

From the results of the analysis all the design margins are greater than 0 for the free drop on the lid, however for the drop over the top edge and on the side some of the design margins are less than zero which indicates there are areas of high stress. However most of the high stresses are not found in the sealing area around the flange and the lid. The model itself does not take into account the action of the cork to cushion the CV. The cork was given a modulus 1000 times greater than that measured in order to allow the model to run. This meant that the model didn't allow any cushioning affect and the CV was subjected to higher loads over a smaller area, however as demonstrated by the drop tests it is the failure of the cork which protects the CV from damage. The drop tests carried out indicated no change in the dimensions of the CV and therefore no stresses that would cause deformation of the CV.

The calculated values for average shear, average stress and maximum stress of the closure bolts for each free drop condition are summarized in Table 2-32. The design margins for drop conditions are all greater than 0 therefore the bolts satisfy the requirements of Regulatory Guide 7.6 [2.3].

Buckling evaluations of the inner containment shell were carried out in accordance with the requirements of ASME Code Case N-284-2 [2.6] as detailed in Section 2.1.2.3, for all the NCT free drop load combinations. The stresses used for the calculations were taken from point C5 in Figure 2-1, which is mid-way along the length of the inner shell of the containment vessel. Where one of the components was tensile in the finite element analysis it should be given a value of 0 Pa however in order to avoid zero errors it was given a very small positive value in the buckling calculation.

The maximum calculated buckling stresses are shown in Table 2-33 along with the design margin. Table 2-33 shows that all the design margins are greater than 0 therefore the

containment vessel will not buckle under an NCT free drop test and satisfies the requirements of Regulatory Guide 7.6 [2.3].

Table 2-29 Acceleration Data Recorded during Drop Tests

Test			Drop on side	Drop on top rim	Drop on lid	Drop on side	Drop on top rim	Drop on lid
Drop Height (m)			1.2	1.2	1.2	10.2	10.2	10.2
Peak Acceleration	Axial (g)	Accelerometer 1	267	377	424	99	338	NT
		Accelerometer 2	178	374	433	106	NT	NT
	Radial (g)	Accelerometer 1	214	521	520	435	228	NT
		Accelerometer 2	293	590	750	457	NT	NT

Table 2-30 Acceleration values applied to the FEA Analysis

Case	Description	Acceleration
NCT7	Free drop on lid from 1.2m (hot)	434g axial
NCT8	Free drop on lid from 1.2m (cold)	434g axial
NCT9	Free drop on corner from 1.2m (hot)	376g axial 590g radial
NCT10	Free drop on corner from 1.2m (cold)	376g axial 590g radial
NCT11	Free drop on side from 1.2 m (hot)	294g radial
NCT12	Free drop on side from 1.2 m (cold)	294g radial
HAC1	Free drop on lid from 10.2 m (hot)	458g axial
HAC2	Free drop on lid from 10.2 m (cold)	458g axial
HAC3	Free drop on corner from 10.2 m (hot)	338g axial 228g radial
HAC4	Free drop on corner from 10.2 m (cold)	338g axial 228g radial
HAC5	Free drop on side from 10.2 m (hot)	458g radial
HAC6	Free drop on side from 10.2 m (cold)	458g radial

Table 2-31 NCT Free Drop Stress Summary

NCT Case ID[1]	Description	Stress Type	Maximum Stress Intensity (MPa)	Stress Location[2]	Allowable stress intensity (MPa)	Minimum Design Margin
7	Drop on lid from 1.2m (hot)	P_m	22.3	C10	109	3.89
		P_m+P_b	37.9	C1	163	3.31
		P_m+P_b+Q	43.2	C10	327	6.57
		Bearing	109	Under bolts	121	0.11
8	Drop on lid from 1.2m (cold)	P_m	22.1	C10	115	4.20
		P_m+P_b	26.3	C16	173	5.55
		P_m+P_b+Q	51.1	C8	345	5.74
		Bearing	53.5	Under bolts	172	2.21
9	Drop on corner (hot)	P_m	235	C4-180	109	-0.54
			196	C6b-180		-0.44
			179	C7-180		-0.39
			141	C8-180		-0.23
			152	C9-180		-0.29
		P_m+P_b	52.1	C14-180	163	2.14
		P_m+P_b+Q	396	C6b	327	-0.17
			363	C7		-0.10
			609	C7-180		-0.46
			384	C9-180		-0.15
		Bearing	121	Under bolts	121	0.0
10	Drop on corner (cold)	P_m	116	C6a	115	-0.1
			258	C6b		-0.56
			161	C7		-0.29
			129	C9		-0.11
			401	C6b-180		-0.71
			346	C7-180		-0.67
			242	C8-180		-0.53
			287	C9-180		-0.60
			180	C11-180		-0.36
		P_m+P_b	89	C2-180	173	0.93

Table 2-31 NCT Free Drop Stress Summary

NCT Case ID[1]	Description	Stress Type	Maximum Stress Intensity (MPa)	Stress Location[2]	Allowable stress intensity (MPa)	Minimum Design Margin
		P_m+P_b+Q	827	C6b	345	-0.58
			842	C7		-0.59
			459	C8		-0.25
			431	C9		-0.20
			1022	C6b-180		-0.66
			1213	C7-180		-0.72
			919	C8-180		-0.62
			793	C9-180		-0.57
			757	C10-180		-0.54
			393	C11-180		-0.12
		Bearing	96.7	Under bolts	172	0.78
11	Drop on side (hot)	P_m	113	C6b	109	-0.03
			184	C4-180		-0.41
			145	C6b-180		-0.25
			115	C7-180		-0.05
		P_m+P_b	64.0	C1	163	1.55
		P_m+P_b+Q	420	C10-180	327	-0.22
			394			-0.17
			467			-0.30
		Bearing	133	Under bolts	121	-0.09
12	Drop on side (cold)	P_m	160	C6b-180	115	-0.28
		P_m+P_b	35.8	C2-180	173	3.81
		P_m+P_b+Q	355	C6b-180	345	-0.03
			380.7	C7-180		-0.09
		Bearing	109	Under bolts	172	0.61

Notes:

1. NCT case IDs are obtained from Table 2-1
2. Stress locations are shown in Figure 2-1. Locations ending -180 are on the opposite side of the vessel to those shown in Figure 2-1, i.e. they are on the side of the vessel closest to the impact with the cork impact limiter.

Table 2-32 Containment Vessel Closure Bolts NCT Free Drop Stress Summary					
NCT Case ID[1]	Description	Stress Type	Maximum stress (MPa)	Allowable stress intensity (MPa)	Minimum design margin
7	Drop on lid from 1.2m (hot)	Average Shear	14.3	244	16.0
		Average Stress	153	406	1.65
		Max Stress	174	609	2.50
8	Drop on lid from 1.2m (cold)	Average Shear	7.39	289	38.1
		Average Stress	75.0	482	5.43
		Max Stress	116	723	5.23
9	Drop on corner (hot)	Average Shear	13.3	244	17.3
		Average Stress	170	406	1.39
		Max Stress	184	609	2.31
10	Drop on corner (cold)	Average Shear	11.3	289	24.6
		Average Stress	135	482	2.56
		Max Stress	192	723	2.76
11	Drop on side (hot)	Average Shear	14.2	244	16.3
		Average Stress	186	406	1.18
		Max Stress	222	609	1.74
12	Drop on side (cold)	Average Shear	14.1	289	19.4
		Average Stress	150	482	2.22
		Max Stress	203	723	2.51

Notes:

1. NCT case IDs are obtained from Table 2-1

Table 2-33: NCT Free Drop Buckling Evaluation Summary

NCT Case ID	Description	Stress (MPa)			Design Margin
		Axial Compression	Hoop Compression	In-plane shear	
7	Drop on lid from 1.2m (hot)	0.68	-4.51	0	87
8	Drop on lid from 1.2m (cold)	3.34	0.68	0	24
9	Drop on side (hot)	0	0	0.71	2570
10	Drop on side (cold)	0	0	0.61	7153
11	Drop on corner (hot)	0	0	0.74	2365
12	Drop on corner (cold)	0	0	0.12	1703

Notes:

1. NCT case IDs are obtained from Table 2-1

2.6.8 Corner Drop [71.71 (c) (8)]

The requirement of 10 CFR 71.71(c) is that a fiberboard, wood or fissile material rectangular package not exceeding 50 kg (110 lbs) and fiberboard, wood, or fissile material cylindrical packages not exceeding 100 kg (220 lbs) must be subjected to a free drop onto each corner of the rectangular package or onto each quarter of each rim of the cylindrical package. The package must be dropped from a height of 0.3 m onto a flat, essentially unyielding surface.

The Safkeg-HS 3977A package is a robust steel shell package which only suffered minor deformation under both 1.2 m and 10.2 m drop tests: these tests demonstrated that a 0.3m drop would have no significant effect on the package.

2.6.9 Compression [71.71 (c) (9)]

According to 71.71(c) (9), the package must be subjected to a compressive load for a period of 24 hours. This load must be applied uniformly to the top and bottom of the package in the position in which the package is normally transported. The load applied must be the greater of 5 times the weight of the package or the equivalent of 13 kPa multiplied by the vertically projected area of the package.

The maximum mass of the package is 163 kg therefore 5 times the mass is 815 kg. The vertically projected area of the package is 0.115 m^2 multiplied by 13 kPa this results in a force of 1495 N which is equivalent to a stacking weight of 153 kg. Five times the mass of the package (815 kg) is the greater of the two and was used as the appropriate test weight.

The compression test was carried out on a prototype keg. The test procedure and results are documented in the Croft Report CTR 2010/02 appended in Section 2.12.2.

An empty keg body was subjected to a compressive load of 914 kg which is well in excess of the 815 kg required. The keg was weighed and dimensions taken before and after testing. On completion of the test no part of the keg showed any visually observed evidence of plastic deformation and no changes in dimensions or weight was found. These results show that the package satisfies the compression test criteria.

2.6.10 Penetration [71.71 (c) (10)]

In accordance with section 71.71 (c) (10) a 6 kg steel bar with a diameter of 3.2 cm was dropped from a height of 1m onto the side of a prototype package. The side was considered the most vulnerable area to puncture. The penetration test was carried out during the NCT test series and is described in CTR 2009/21 appended in Section 2.12.2. The test caused a dent of 8.06 mm in depth and 290 mm width in the keg skin but the skin was not punctured or torn.

2.7 Hypothetical Accident Conditions [71.73]

Section 71.51 requires that when subjected to the HAC tests, the damage caused to the package does not lead to the loss of radioactive material exceeding a total amount of A_2 in one week, or an increase in the external radiation dose above 10 mSv/hr at 1m from the external surface of the package. In order to demonstrate compliance a prototype package was subjected to a series of HAC tests and supplementary to this the stresses in the containment vessel were modeled under the HAC test conditions.

The HAC tests were performed on the prototype keg after the NCT penetration and drop tests. The HAC tests were carried out sequentially in the order of 10.2 m drop tests and then puncture tests. Therefore the keg was tested for the cumulative effects of both the NCT and HAC tests. The drop and puncture tests were carried out with the package at -40^{o}C to take into account any brittle failure. The containment vessel was analyzed under the most unfavorable initial conditions for each individual HAC test condition.

2.7.1 Free Drop [71.73 (c)(1)]

10 CFR 71.73 (c) (1) requires that a specimen undergoes a free drop through a distance of 9 m onto a flat and essentially unyielding, horizontal surface striking in a position for which the maximum damage is expected. In order to fulfill this requirement a prototype package was dropped 10.2 meters in several orientations.

The procedure, sequence of testing and results are documented in the Croft Report CTR 2010/02 appended in Section 2.12.2. A series of 10.2 m drop tests were performed at the Croft Associates, Didcot Test Facility, as part of the NCT and HAC test series. This facility has a test target consisting of a 50 mm thick non alloy structural steel plate. This plate sits at ground level on a one piece, continuously poured, cast in situ concrete block. The mass of the target is 50 tonnes.

The mass of the test package is 5% less than the maximum mass of the package; to compensate for this the test package was dropped from 10.2m which is 13% higher than the

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^{o}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 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.

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

orientation was evaluated in combination with the worst case initial conditions. The load conditions used along with each drop test orientation is given in Table 2-2.

Once the load conditions had been applied a body force equivalent to the g value measured during the drop test was applied to the vessel. The g values applied to each test condition are given in Table 2-30.

The maximum stresses in the containment vessel are calculated and shown to satisfy the requirements of ASME Section III Div 3 [2.5] for bearing stress and bolt stress and satisfying Regulatory Guide 7.6 for all other stresses. In addition the containment vessel inner shell was evaluated for buckling in accordance with the requirements of ASME Code Case N-284-2 [2.6].

The results of each drop test and stress analysis are given in the following sections.

2.7.1.1 End Drop

The package was evaluated for a 10.2 m end drop occurring on the top of the package. This orientation is the worst case end drop because a drop on the lid may distort the lid and open the seals however this would not occur with a drop on the bottom. Testing of a prototype established the effect on the package along with a structural analysis determining the effect on the containment vessel.

Package Test

As described in Section 2.7.1. the prototype test package was cooled to -40^{o}C and dropped onto its side, top corner and then the top end with damage from each drop accumulating for the next test. The end drop is described in the appended report CTR 2010/02. The package was slung in the correct orientation and dropped onto the test target. The package impacted the target on the top end bounced and landed on its top rim and then came to rest on the side.

As the package landed the cables relaying the g data to the logging computer were sheared which meant that no acceleration values were recorded for the drop test.

The keg received some minor denting which is discussed in Section 2.7.1.5.

Containment Vessel Evaluation

A 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 the Vectra Group report L20008/1/R1 (Section 2.12.2).

The end drop was modeled under ‘hot’ and ‘cold’ conditions as required by Regulatory Guide 7.8. The hot conditions assumed the package experienced the maximum ambient temperature of 38^{o}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^{o}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

The cold conditions assumed an ambient temperature of -29^{o}C, in still air with no insolation or decay heat. It has been assumed that the internal pressure is 0 kPa with an external pressure of 100 kPa, so the internal gauge pressure is -100 kPa. The load combinations modeled for the NCT drop tests are outlined in Table 2-1.

A body force was applied to the model which was equivalent to an upward vertical acceleration of 458 g. As no g values were taken during testing a g value equivalent to that measured during the side drop has been assumed.

For the entire HAC free drop analysis a pre load of 8.12kN was applied to the bolts at the start of the analysis, prior to any other loads being imposed. The bolts were tied to the CV body along the threaded length with the bolt heads free to slide.

Stress calculations were carried out for both the hot and cold end drop load combinations. Stress distributions presented in VECTRA report L20008/1/R1 (Section 2.12.2).

The primary membrane (Pm), primary plus bending (Pm+Pb) stresses were evaluated at the locations shown on Figure 2-1, for each of the free drop load combination identified in Table 2-2. The maximum stress intensities calculated along with the location of the maximum stress is given for each free drop load combination. Each maximum stress is compared to the allowable stress intensity and the design margin given. All the design margins are greater than 0 therefore the containment vessel satisfies the requirements of Regulatory Guide 7.6.

The calculated values for average shear, average stress and maximum stress of the closure bolts for the end drop condition are summarized in Table 2-35. The design margin for the end drop condition are all greater than 0 therefore the bolts satisfy the requirements of Regulatory Guide 7.6 [2.3].

Buckling evaluations of the inner containment shell were carried out in accordance with the requirements of ASME Code Case N-284-2 [2.6]. The stresses used for the calculations were taken from point C4 in Figure 2-1, which is mid-way along the length of the inner shell of the containment vessel. Where one of the components was tensile in the finite element analysis it should be given a value of 0 Pa however in order to avoid zero errors it was given a very small positive value in the buckling calculation.

The maximum calculated buckling stresses are shown in Table 2-36 along with the design margins. A maximum buckling stress of 55.4 MPa was calculated. Table 2-36 shows that all the design margins are greater than 0 therefore the containment vessel will not buckle under an end drop and satisfies the requirements of Regulatory Guide 7.6 [2.3].

Table 2-34 End Drop Containment Vessel Stress Summary						
HAC Case ID	Description	Stress Type	Maximum Stress Intensity (MPa)	Stress Location	Allowable stress intensity (MPa)	Minimum Design Margin
1	Drop on lid from 10.2m (hot)	P_m	26.1	C10	245	9.03
		P_m+P_b	60.6	C10	367	5.47
2	Drop on lid from 10.2m (cold)	P_m	25.5	C10	331	9.82
		P_m+P_b	53.3	C11	497	6.76

Table 2-35 End Drop Containment Vessel Bolt Stress Summary					
HAC Case ID	Description	Stress Type	Maximum stress (MPa)	Allowable stress intensity (MPa)	Minimum design margin
1	Drop on lid from 10.2m (hot)	Average Shear	15.9	361	21.7
		Average Stress	173	602	2.48
2	Drop on lid from 10.2m (cold)	Average Shear	7.32	361	48.3
		Average Stress	74.3	602	7.10

Table 2-36 End Drop Containment Vessel Buckling Evaluation					
NCT Case ID	Description	Stress (MPa)			Design Margin
		Axial Compression	Hoop Compression	In-plane shear	
7	Drop on lid from 1.2m (hot)	0.88	0	0.01	100
8	Drop on lid from 1.2m (cold)	3.52	0.66	0.0	35

2.7.1.2 Side Drop

The package was evaluated for a 10.2 m side drop. Testing of a prototype established the effect on the package along with a structural analysis determining the effect on the containment vessel.

Package Test

As described in Section 2.7.1, the prototype test package was cooled to -40°C and dropped onto its side, top corner and then the top end with damage from each drop accumulating for the next test. The side drop is described in the appended report CTR 2010/02 (Section

2.12.2). The package was slung in the correct orientation and dropped onto the test target. The package impacted the target on the side and then bounced onto the top rim and came to rest on the side.

The maximum g values recorded during the end drop are given in Table 2-29. The accelerations were measured by accelerometers attached to the lid of the containment vessel. The accelerometers logged at 100,000 samples per second. The raw data was filtered using a low pass digital 4th order Butterworth filter [2.18] with a cut off frequency of 500 Hz. The maximum radial acceleration is 457 g.

The keg received some minor denting on the top and bottom rims which is discussed in Section 2.7.1.5.

<u>Containment Vessel Evaluation</u>

A 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 the Vectra Group report L20008/1/R1 (Section 2.12].

The side drop was modelled under ‘hot’ and ‘cold’ conditions as required by Regulatory Guide 7.8. The hot conditions assumed the package experienced the maximum ambient temperature of 38^{o}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 192^{o}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

The cold conditions assumed an ambient temperature of -29^{o}C, in still air with no insolation or decay heat. It has been assumed that the internal pressure is 0 kPa with an external pressure of 100 kPa, so the internal gauge pressure is -100 kPa. The load combinations modelled for the HAC drop tests are outlined in Table 2-1.

A body force was applied to the model which was equivalent to the radial value measured during the test. The measured g values are shown in Table 2-29 with the value of 458 g applied to the model as shown in Table 2-30.

For the entire HAC free drop analysis a pre load of 8.12kN was applied to the bolts at the start of the analysis, prior to any other loads being imposed. The bolts were tied to the CV body along the threaded length with the bolt heads free to slide.

The stress model indicated that under the hot and cold conditions the drop on the side causes the cavity wall to rotate causing the DU shielding to compress.

The primary membrane (Pm), primary plus bending (Pm+Pb) stresses were evaluated at the locations shown on Figure 2-1, for each of the free drop load combination identified in Table 2-2. The maximum stress intensities calculated along with the location of the

maximum stress is given for each free drop load combination in. Each maximum stress is compared to the allowable stress intensity and the design margin given. Most of the design margins are greater than 0 however the primary plus bending stress during the hot drop was marginally greater than 0 in position C6b. This position is at the corner of the containment wall so if it did distort in a localised area it should not affect the containment seal. The model itself does not take into account the action of the cork to cushion the CV. The cork was given a modulus 1000 times greater than that measured in order to allow the model to run, because it was rightly demonstrating the failure of the cork. This meant that the model didn't allow any cushioning affect and the CV was subjected to higher loads over a smaller area, however as demonstrated by the drop tests it is the failure of the cork which protects the CV from damage. The drop tests carried out indicated no change in the dimensions of the CV and therefore no stresses that would cause deformation of the CV. Therefore the containment vessel satisfies the requirements of Regulatory Guide 7.6 [2.3].

The calculated values for average shear, average stress and maximum stress of the closure bolts for each free drop condition are summarized in Table 2-38. The design margins for drop condition are all greater than 0 therefore the bolts satisfy the requirements of Regulatory Guide 7.6 [2.3].

Buckling evaluations of the inner containment shell were carried out in accordance with the requirements of ASME Code Case N-284-2 [2.6]. The stresses used for the calculations were taken from point C5 in Figure 2-1, which is mid-way along the length of the inner shell of the containment vessel. Where one of the components was tensile in the finite element analysis it should be given a value of 0 Pa however in order to avoid zero errors it was given a very small positive value in the buckling calculation.

The maximum calculated buckling stresses are shown in along with the design margin. A maximum buckling stress of 51.4 MPa was calculated. Table 2-39 shows that all the design margins are greater than 0 therefore the containment vessel will not buckle under an end drop and satisfies the requirements of Regulatory Guide 7.6 [2.3].

Table 2-37 Side Drop Containment Vessel Stress Summary

HAC Case ID	Description	Stress Type	Maximum Stress Intensity (MPa)	Stress Location	Allowable stress intensity (MPa)	Minimum Design Margin
3	Drop on side from 9m (hot)	P_m	256	C4-180	245	0.02
		P_m+P_b	457	C6b	367	-0.14
4	Drop on side from 9m (cold)	P_m	189	C6b-180	276	0.46
		P_m+P_b	394	C6b	414	0.05

Table 2-38 Side Drop Containment Vessel Bolt Stress Summary

HAC Case ID	Description	Stress Type	Maximum stress (MPa)	Allowable stress intensity (MPa)	Minimum design margin
3	Drop on side from 9m (hot)	Average Shear	20.8	361	16.3
		Average Stress	236	602	1.55
4	Drop on side from 9m (cold)	Average Shear	21.5	361	15.8
		Average Stress	216	602	1.79

Table 2-39 Side Drop Containment Vessel Buckling Evaluation

HAC Case ID	Description	Stress (MPa)			Design Margin
		Axial Compression	Hoop Compression	In-plane shear	
3	Drop on side from 9m (hot)	0	0	0.75	5131
4	Drop on side from 9m (cold)	0	0	0.60	1.65×10^4

2.7.1.3 Corner Drop

The package was evaluated for a 10.2 m corner drop occurring on the top of the package. This orientation is considered the worst case corner drop because a drop on the top rim may distort the package lid and open the keg, this however would not occur with a drop on the bottom corner. Testing of a prototype established the effect on the package, with a structural analysis determining the effect on the containment vessel.

<u>Package Test</u>

As described in Section 2.7.1, a prototype test package was cooled to -40°C and dropped onto its side, top corner and then the top end with damage from each drop accumulating for the next test.

The package was slung in the correct orientation, raised to 10.2 m and dropped onto the test target. The package impacted the target on the top rim bounced, spun and landed on its side.

The maximum g values recorded during the corner drop are given in Table 2-29. The accelerations were measured by accelerometers attached to the lid of the containment vessel. The accelerometers logged at 100,000 samples per second. The raw data was filtered using a low pass digital 4th order Butterworth filter [2.18] with a cut off frequency of 500 Hz. The maximum axial acceleration is 338 g and the maximum radial

acceleration is 228 g. During the test one of the cables sending the data to the logging computer was sheared which meant only data from one of the g sensors could be used.

The keg received some minor denting which is discussed in Section 2.7.1.5.

Containment Vessel Evaluation

A detailed analysis of the stress present in the containment vessel during the corner drop test was carried out using a finite element model of the containment vessel as described in the Vectra Group report L20008/1/R1 (Section 2.12).

The corner drop was modeled 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 192°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

The cold conditions assumed an ambient temperature of -29°C, in still air with no insolation or decay heat. It has been assumed that the internal pressure is 0 kPa with an external pressure of 100 kPa, so the internal gauge pressure is -100 kPa. The load combinations modeled for the HAC drop tests are outlined in Table 2-2.

A body force was applied to the model which was equivalent to a radial acceleration of 228g and axial acceleration of 338g. These g values are the maximum accelerations measured during the 10.2 meter free drop tests. The measured g values are shown in Table 2-29.

For the entire HAC free drop analysis a pre load of 8.12kN was applied to the bolts at the start of the analysis, prior to any other loads being imposed. The bolts were tied to the CV body along the threaded length with the bolt heads free to slide.

The primary membrane (Pm), primary plus bending (Pm+Pb) stresses were evaluated at the locations shown on Figure 2-1, for each of the free drop load combination identified in Table 2-2. The maximum stress intensities calculated along with the location of the maximum stress is given for each corner drop load combination in Table 2-40. Each maximum stress is compared to the allowable stress intensity and the design margin given. Most of the design margins are greater than 0 however at point C17-180 the stresses are less than zero however this is a point stress in the centre of the lid which would not affect containment. The model itself does not take into account the action of the cork to cushion the CV. The cork was given a modulus 1000 times greater than that measured in order to allow the model to run, because it was rightly demonstrating the failure of the cork. This meant that the model didn’t allow any cushioning affect and the CV was subjected to higher loads over a smaller area, however as demonstrated by the drop tests it is the failure of the cork which protects the CV from damage. The drop tests carried out indicated no

change in the dimensions of the CV and therefore no stresses that would cause deformation of the CV. Therefore the containment vessel satisfies the requirements of Regulatory Guide 7.6.

The calculated values for average shear, average stress and maximum stress of the closure bolts for each free drop condition are summarized in Table 2-41. The design margins for drop condition are all greater than 0 therefore the bolts satisfy the requirements of Regulatory Guide 7.6 [2.3].

Buckling evaluations of the inner containment shell were carried out in accordance with the requirements of ASME Code Case N-284-2 [2.6]. The stresses used for the calculations were taken from point C4 in Figure 2-1, which is mid-way along the length of the inner shell of the containment vessel. Where one of the components was tensile in the finite element analysis it should be given a value of 0 Pa however in order to avoid zero errors it was given a very small positive value in the buckling calculation.

The maximum calculated buckling stresses are shown in Table 2-42 along with the design margin. Table 2-42 shows that all the design margins are greater than 0 therefore the containment vessel will not buckle under a corner drop, satisfying the requirements of Regulatory Guide 7.6 [2.3].

Table 2-40 Corner Drop Containment Vessel Stress Summary

HAC Case ID	Description	Stress Type	Maximum Stress Intensity (MPa)	Stress Location	Allowable stress intensity (MPa)	Minimum Design Margin
5	Drop on corner from 9m (hot)	P_m	175	C4-180	245	0.50
		P_m+P_b	444	C17-180	367	-0.12
6	Drop on corner from 9m (cold)	P_m	174	C6b-180	276	0.59
		P_m+P_b	376	C6b	414	0.10

Table 2-41 Corner Drop Containment Vessel Bolt Stress Summary

HAC Case ID	Description	Stress Type	Maximum stress (MPa)	Allowable stress intensity (MPa)	Minimum design margin
5	Drop on corner from 9m (hot)	Average Shear	10.9	361	32.3
		Average Stress	187	602	2.22
6	Drop on corner from 9m (cold)	Average Shear	7.38	361	47.9
		Average Stress	83.9	602	6.18

Table 2-42 Corner Drop Containment Vessel Buckling Evaluation

HAC Case ID	Description	Stress (MPa)			Design Margin
		Axial Compression	Hoop Compression	In-plane shear	
5	Drop on corner from 9m (hot)	0	0	0.68	6242
6	Drop on corner from 9m (cold)	0	0	0.6	1.65×10^4

2.7.1.4 Oblique Drops

An oblique drop is considered to produce lower "g"s and less damage to the package as less of the energy of the drop is absorbed in the initial impact. As the package does not have a large length to diameter ratio, increase of impact forces due to slap down cannot occur.

2.7.1.5 Summary of Results

Testing of a prototype package confirmed that on completion of the NCT and HAC test series the containment vessel remained leak tight and undamaged as described in the Croft Associates report CTR 2010/02. The only damage suffered during the HAC drop tests was to the keg body which is discussed below.

HAC End Drop

The end drop was the final drop in the HAC test series so all the damage from the side drop and drop with the C of G over the top rim was present on the keg prior to the test. The end drop caused the top rim and skirt to crumple and flattened the lid lifting handles.

HAC Side Drop

The side drop was the first 10.2m drop carried out on the package. The test caused minimal damage and only flattened the top and bottom rims.

HAC Corner Drop

The corner drop occurred on completion of the side drop, therefore the bottom and top rims were dented. The primary impact of the top rim with the target caused the top skirt to deform. No other damage was caused to the keg.

Supplementary information is contained in the stress evaluation carried out on the containment vessel.

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.

A calculation of the actual maximum pressure expected under HAC is provided in Calculation Sheet CS 2012/02 (Section 2.12.2) – the calculated maximum pressure is 1.64 bar absolute (164 kPa).

The free volume within the CV is 78 cc – this is based on the air gap between the Tungsten Insert and CV cavity of 33cc + the cavity volume of the Tungsten Insert of 55cc less an allowance of 10 cc for solid contents of the Tungsten Insert (see restriction in Table 1-3-6 under Product containers "The volume limit of the Product containers and packing shall be <10cc). Therefore breaching of the product container containing the gas (of maximum amount 25 bar.cc) would increase the pressure in the CV by a maximum of 0.32 bar (given by the volume ratio 25/78).

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.

2.7.6 Immersion – All Packages [71.73 (c)(6)]

71.73(c)(6) requires that a package be subjected to a maximum external pressure due to immersion under 15 m (50 ft) of water (equivalent pressure is 150 kPa gauge).

The maximum pressure differential that could occur under the water immersion condition arises from external pressure of 150 kPa combined with a reduced internal pressure of 0 kPa absolute giving a maximum pressure differential of 150 kPa.

As described in section 2.6.4, the effect of an increased external pressure of 140 kPa with the worst case initial conditions has been determined: the maximum stresses encountered and the minimum design margins are presented in Table 2-24. In order to determine the effect of an external pressure of 150 kPa, the stresses calculated for an external pressure of 140 kPa have been scaled by 150/140 = 1.07: the results are given in Table 2-43. Scaling of the stresses indicates that the design margins are all greater than zero. This demonstrates the containment vessel will be acceptable under an immersion test.

Table 2-43 Containment Vessel Stress Summary for Immersion

.NCT Case ID	Description	Stress Type	Maximum Stress Intensity (MPa)	Stress Location	Allowable stress intensity (MPa)	Minimum Design Margin
4	Increased External Pressure	P_m	3.92	C10	115	28.3
		P_m+P_b	9.57	C1	173	17.1
		P_m+P_b+Q	8.74	C3	345	38.5
		Bearing	64.2	Under bolts	172	1.7

2.7.7 Deep Water Immersion Test (for Type B Packages Containing More than 10^5 A2) [71.61]

Not applicable as the contents are < $10^5 A_2$.

2.7.8 Summary of Damage

The mechanical damage sustained by the package during the NCT and HAC test series is reported in CTR 2010/02 [Section 2.12.2]. The testing was carried out in series with the NCT drop testing, followed by the HAC drop tests and the HAC puncture tests.

The NCT drop tests caused minimal denting to the rim of the keg at the points of impact. The puncture tests also caused minimal damage to the keg rim however the side puncture test did cause an indent on the side of the keg. The 10.2 meter drop tests caused more severe denting to the top and bottom rims.

On completion of the test series, examination of the containment vessel found no damage and no change in the measured dimensions. Leak tests carried out prior to and on completion of testing detected no signs of leaks, indicating that the containment vessel remained leak tight throughout the NCT and HAC tests. The examination of the containment vessel (as detailed in report CTR 2010/02, Table 11, page 38, under the table section headed Containment Vessel in rows 10 -24), showed the outside diameter of the CV body at the lower and mid diameter are all seen to be close to the nominal diameter of 179.5 mm and there are no significant changes following the drop test program. This demonstrates that there was no distortion of the CV shell.

2.8 Accident Conditions for Air Transport of Plutonium [71.74]

Not applicable – air shipment of > A_2 plutonium is not required.

2.9 Accident Conditions for Fissile Material Packages for Air Transport [1.55(f)]

Not applicable – air shipment of fissile materials is not required.

2.10 Special Form [71.75]

Special form is not claimed for the contents or for any part of the package.

2.11 Fuel Rods

Irradiated fuel rods are not to be carried in this package.

2.12 Appendix

2.12.1 References

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

[2.2] Regulatory Guide 7.8, *Load Combinations for the Structural Analysis of Shipping Casks for Radioactive Material*, Revision 1, U.S. Nuclear Regulatory Commission, Office of Standards Development, March 1989.

[2.3] Regulatory Guide 7.6, *Design Criteria for the Structural Analysis of Shipping Cask Containment Vessels*, Revision 1, March 1978.

[2.4] American Society of Mechanical Engineers (ASME) Boiler and Pressure Vessel Code, Section III, Division 3, *Containment Systems for Storage and Transport Packagings of Spent Nuclear Fuel and High Level Radioactive Material and Waste*, 1977 Edition.

[2.5] American Society of Mechanical Engineers (ASME) Boiler and Pressure Vessel Code, Section III, Division 3, *Containment Systems for Storage and Transport Packagings of Spent Nuclear Fuel and High Level Radioactive Material and Waste*, 2001 Edition with Addenda through July 1, 2003.

[2.6] American Society of Mechanical Engineers (ASME) Boiler and Pressure Vessel Code, Section III, Division 1, Code Cases: Nuclear Components, Case N-284-1, *Metal Containment Shell Buckling Design Methods, Class MC*, 2001 Edition with Addenda through July 1, 2003.

[2.7] Regulatory Guide 7.11, *Fracture Toughness Criteria of Base Material for Ferritic Steel Shipping Cask Containment Vessels with a Maximum Wall Thickness of 4 Inch (0.1 m)*, U.S. Nuclear Regulatory Commission, Office of Standards Development, June 1991.

[2.8] NUREG/CR-3854, *Fabrication Criteria for Shipping Containers,* U.S. Nuclear Regulatory Commission, Washington D.C., April 1984.

[2.9] American Society of Mechanical Engineers (ASME) Boiler and Pressure Vessel Code, Section III, Division 1, Subsection NB, *Class 1 Components,* 2001 Edition with Addenda through July 1, 2003.

[2.10] American Society of Mechanical Engineers (ASME) Boiler and Pressure Vessel Code, Section III, Division 1, Subsection NF, *Supports*, 2001 Edition with Addenda through July 1, 2003.

[2.11] NUREG/CR-6407, INEL-95/0551, Classification of Transportation Packaging and Dry Spent Fuel Storage System Components According to Importance to Safety, February 1996

[2.12] American Society of Mechanical Engineers (ASME) Boiler and Pressure Vessel Code, Section XI, *Ferrous Material Specification, 2007 Edition with Addenda through July 1, 2009*

[2.13] American National Standards Institute, for Radioactive Material*, Leakage Tests on Packages for Shipment*, ANSI N14.5-1997

[2.14] NUREG CR/3019, UCRL-53044 Recommended Welding Criteria for Use in the Fabrication of Shipping Containers for Radioactive Materials, March 1984

[2.15] Parker Hannifin Corporation, *Parker O-ring Handbook*, ORD 5700/USA, 2001.

[2.16] American Society of Mechanical Engineers (ASME) Boiler and Pressure Vessel Code, Section II, Part D, *Materials*, 2001 Edition with Addenda through July 1, 2003.

[2.17] American Society of Mechanical Engineers (ASME) Boiler and Pressure Vessel Code, Section V, *Non Destructive Examination*, 2001 Edition, with Addenda through July 1, 2001

[2.18] Vibration, Measurement and Analysis, JD Smith, Butterworth-Heinemann

2.12.2 Supporting Documents

Document Reference	Title
SERCO/TAS/002762/01	Compression Testing of Cork
Arcadis Vectra, L20008/1/R1	Stress Analysis of Safkeg HS Containment Vessel
CTR 2010/02	Prototype SAFKEG HS 3977A/0002 NCT and HAC Regulatory Test Report
CS 2012/02	SAFKEG-HS 3977A – Maximum Pressure in CV
CS 2012/03	Calculation of the Density of the 3977A Package

CONTENTS

3 THERMAL EVALUATION

This section identifies the key thermal design features for the Safkeg-HS 3977A package. The maximum temperatures at both NCT and HAC conditions have been calculated for these features by a Finite Element Analysis (FEA) and a thermal model of the package. The FEA and the thermal model were validated using the results of a steady state thermal test of a prototype Safkeg-HS 3977A package and the results of a 800°C fire test carried out on a similar design the SAFKEG-LS 3979A. The test procedures, results and the FEA model are presented and discussed within this section.

From this work maximum operational temperatures of the package have been determined for the maximum heat load of the contents. These temperatures have been shown to be lower than the maximum design temperatures of the package components.

3.1 Description of Thermal Design

The Safkeg-HS 3977A is designed to transport a range of nuclides, with a maximum allowable heat output of 30 W for solids and gases and 5 W for liquids. The following sections detail the design features affecting the thermal performance of the package.

3.1.1 Design Features

The only design features that are significant with respect to heat transfer in the Safkeg-HS 3977A are:

- The stainless steel keg outer skin
- The stainless steel keg inner liner
- The cork liner
- Top cork and side cork
- The stainless steel containment vessel
- The depleted uranium shielding in the containment vessel

These features are all axi-symmetric and are illustrated in Figure 3-1.

The keg and the cork provide the containment vessel with protection from impact and fire. Under HAC fire conditions the keg skin is designed to heat up very quickly with the cork providing insulation to the containment vessel, as a result of its low thermal conductivity and ablation properties. Since heating of the cork during the HAC fire causes gas evolution within the keg cavity, a fuse plug is provided in the bottom of the keg. On heating above 98^{o}C the fuse plug melts allowing pressure relief of the keg cavity.

The package does not have any mechanical cooling.

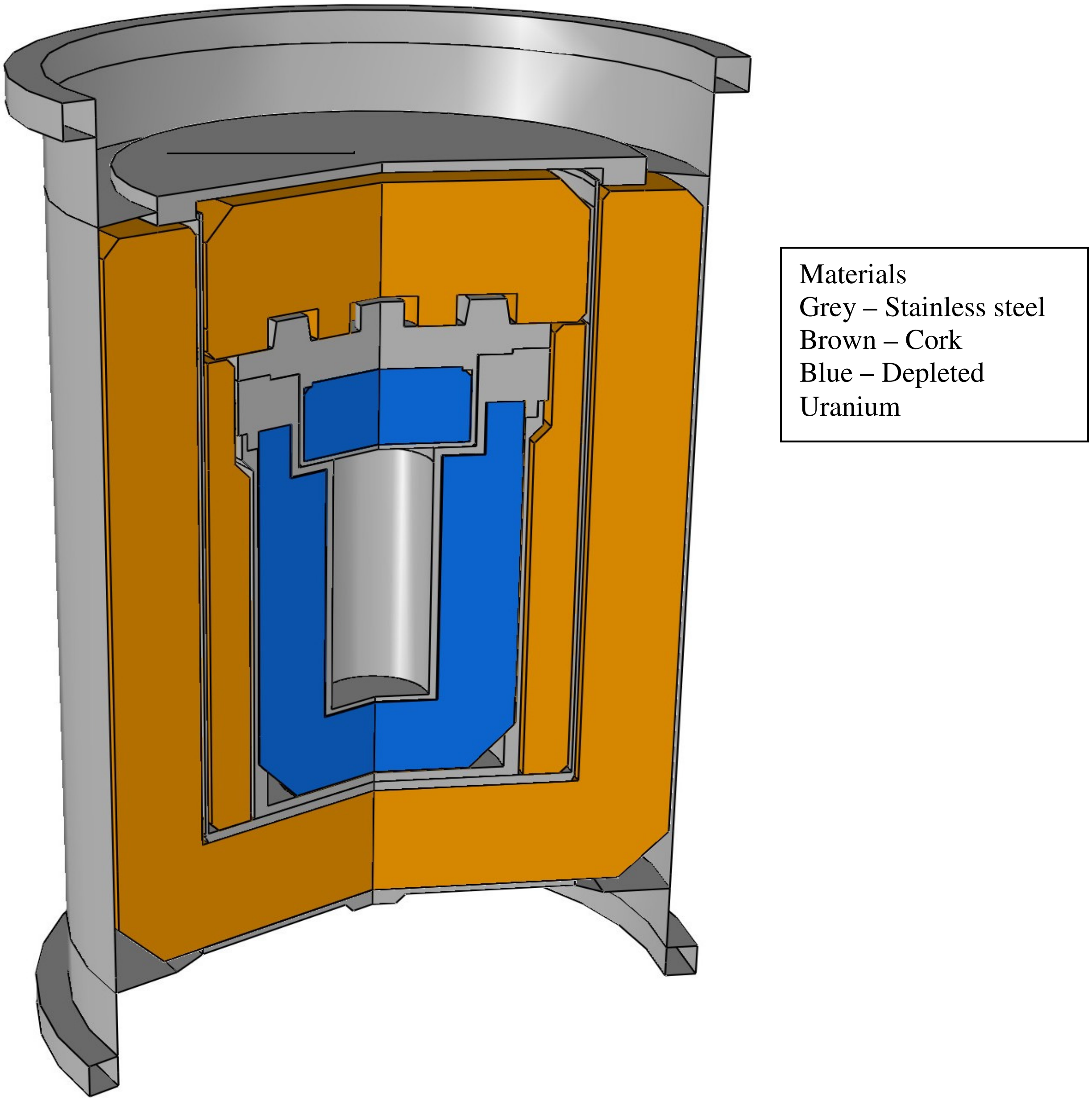


Figure 3-1 Thermal Design Properties

3.1.2 Content's Decay Heat [71.33 (b)(7)]

The contents decay heat is limited to a maximum of 30 W for solids and gases and 5 W for liquids.

3.1.3 Summary Tables of Temperatures

The maximum temperatures reached under NCT and HAC conditions have been determined using an FEA thermal model detailed in the report AMEC/6335/001 appended in Section 3.5.2. Table 3-1 summarizes the results of this report and presents the maximum temperatures reached in the containment vessel cavity with internal heat loads from 0 to 30 Watts under NCT and HAC thermal conditions.

Table 3-1 Maximum Containment Vessel Calculated Temperatures under NCT and HAC
(Ambient 38°C, with and without insolation)

	Maximum Temperature under heat load (°C)		
Heat load (W)	0	5	30
NCT – no insolation	38.0	58.9	148.4
NCT – with insolation	58.8	78.1	163.2
HAC – with insolation	115.4	132.0	208.0

The maximum temperatures within the containment vessel are generated at 30W; therefore the temperatures reached at critical locations with this heat load were calculated in the AMEC report under NCT and are summarized here in Table 3-2. The maximum temperatures calculated are all within the acceptable temperature limits for the package components.

The temperature of the Shielding Inserts under NCT and HAC conditions with contents emitting 0 W, 5 W and 30 W has been determined in Calculation Sheet CS 2012-01 [appended in Section 3.5.2] as 12°C above that of the CV body: this is based on the worst case assumption that all the heat from the contents, which is emitted as radiation, is absorbed within the Shielding Insert. The maximum resulting temperatures of the Shielding Inserts calculated are presented in Table 3-2 and Table 3-3: these temperatures are within the acceptable temperature limits for the all the components of the inserts.

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

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

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

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

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

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

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

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

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

3.1.4 Summary Tables of Maximum Pressures

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

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

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

3.2 Material Properties and Component Specifications

3.2.1 Material Properties

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

Table 3-5: Thermal Properties of Packaging Materials

Material	Property	Temperature (°C)	Value	Reference
304 Stainless Steel	Conductivity	21	14.9 W/m/K	[3.1]
		38	15.0 W/m/K	
		93	16.1 W/m/K	
		149	16.9 W/m/K	
		205	18.0 W/m/K	
		260	18.9 W/m/K	
		316	19.5 W/m/K	
		371	20.4 W/m/K	
		427	21.1 W/m/K	
		482	22.0 W/m/K	
		538	22.8 W/m/K	
		593	23.5 W/m/K	
		649	24.2 W/m/K	

Table 3-5: Thermal Properties of Packaging Materials

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

During a fire the cork experiences temperatures up to ~800°C. No measurements of cork properties at high temperatures are available. However, the HAC thermal test has been performed on the Safkeg-LS 3979A package as detailed in report CTR 2009/21, this package uses the same cork specification as the HS design. The test has then been simulated using the

LS model in order to validate the model and, to demonstrate the acceptability of the thermal properties assumed for the cork. It was found that, in order to obtain agreement with the measured temperatures, the thermal conductivity of the cork needed to be increased by 50%. It should be noted that these thermal properties, validated against the furnace test, are 'effective' properties that include any effects of charring and shrinkage of the cork.

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

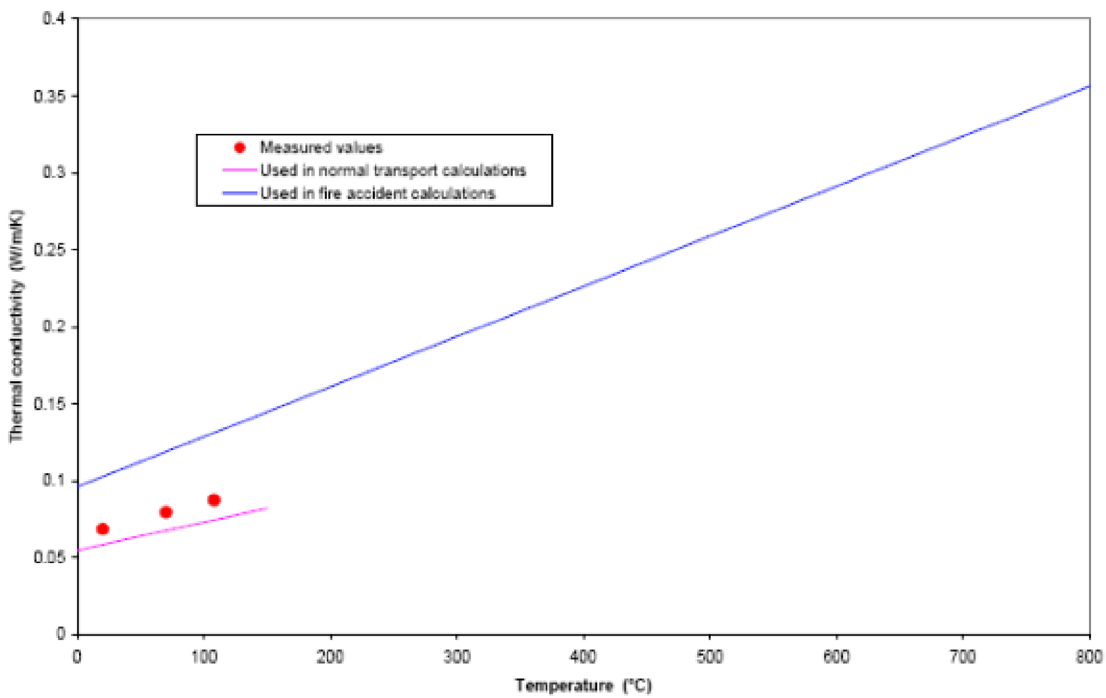


Figure 3-2 Thermal Conductivity of Cork

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

Table 3-6: Emissivities used in the Thermal Model			
Material	**Condition**	**Value**	**Reference**
304 Stainless Steel	Internal surfaces	0.2	[3.8]
	External surface – Heating test and NCT	0.25	[3.8]
	External surface – fire test	0.8	[3.9]
Cork	All conditions	0.95	[3.10]
Depleted Uranium	Internal surfaces (un-oxidised)	0.31	

3.2.2 Component Specifications

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

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

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

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

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

The cork is unaffected by temperatures up to 160°C which is higher than the maximum temperature for the cork packing under NCT where cork temperatures may reach 151°C for a

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 (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

demonstrates that the package is capable of fulfilling the requirements of 71.43 (g) as the accessible surface temperature is less than 50°C with maximum contents heat load of 30W.

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

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

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

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

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

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

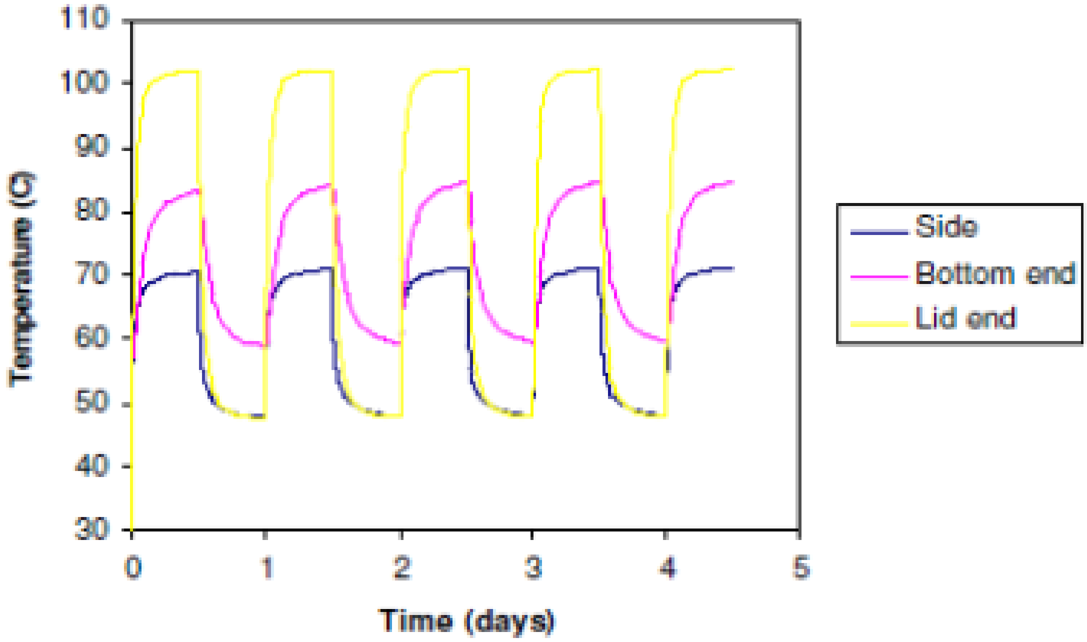


Figure 3-3 Predicted temperature on the Outside of the Keg During Normal Transport with Insolation

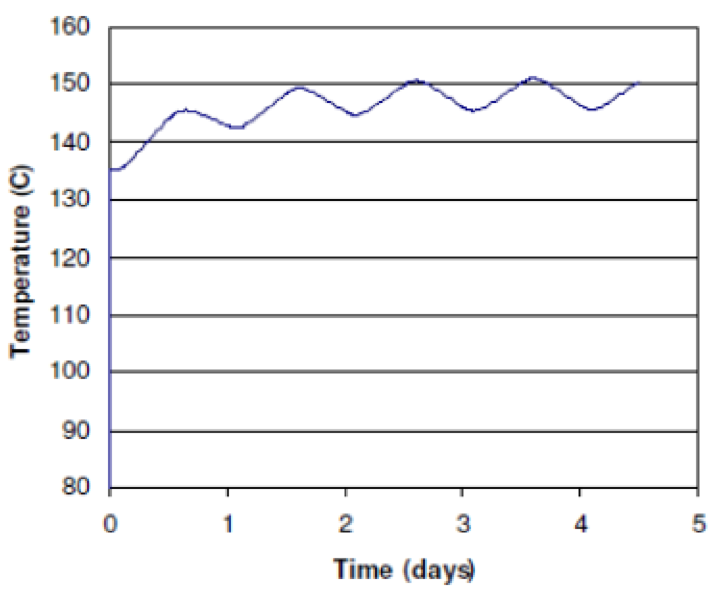


Figure 3-4 Predicted Temperature at the Containment vessel lid Seal During Normal Conditions of Transport with Insolation

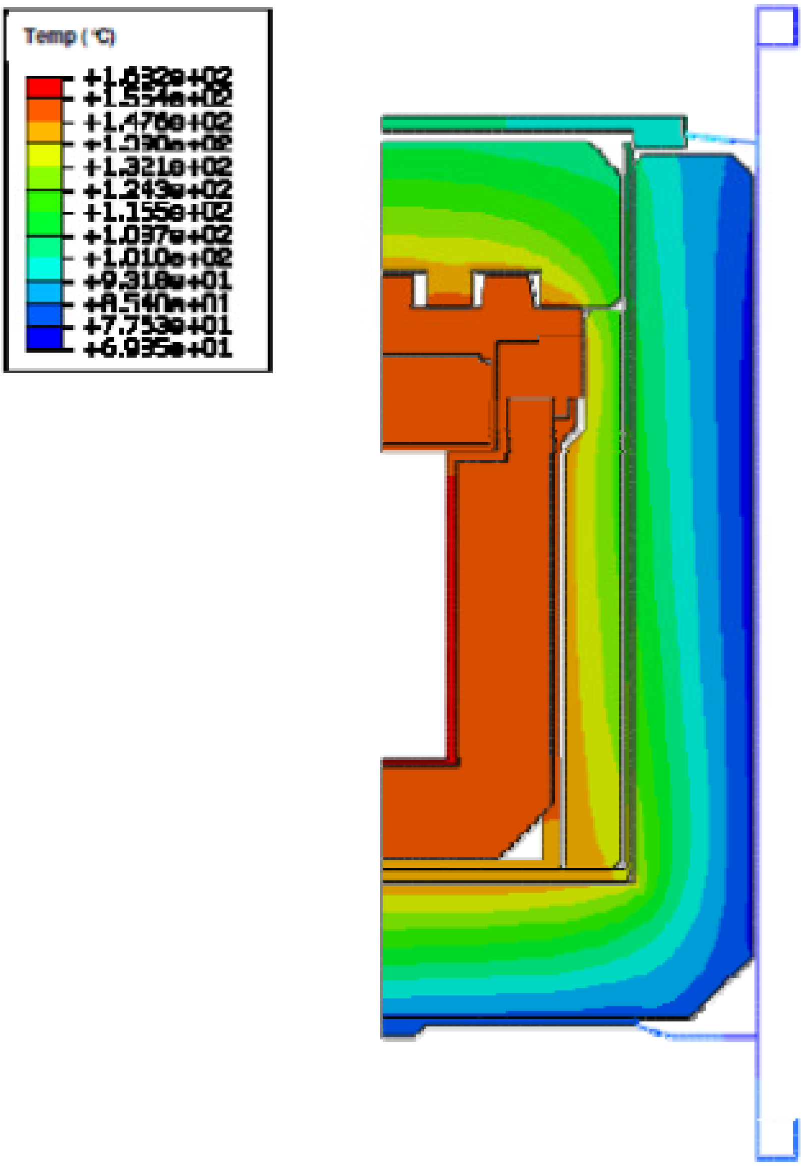


Figure 3-5 Predicted Temperature Profile under Normal Conditions of Transport With Solar Insolation and 30W heat load

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

The MNOP is 7 bar (700 kPa) gauge.

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

For liquid contents emitting 5W, 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 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 contents to be shipped include research samples in liquid form for which the details are not currently known and therefore an analysis of gas generation by radiolysis is not possible. Therefore, for liquid contents as specified for Contents Type CT-4 and CT-5, the shipper is required to limit the contents such that "Liquid contents must be such that H_2 concentration < 5% and pressure <7bar g for shipment up to 1 year".

The heat load for liquid contents is limited to 5W for which the calculated maximum temperature of the CV under NCT is 78°C (Section 3.1.3, Table 3-1). There is therefore no pressure increase due to the vapour pressure of the liquid contents (the liquid contents are aqueous with a boiling point of 100°C).

3.4 Thermal Evaluation under Hypothetical Accident Conditions

3.4.1 Initial Conditions

The initial conditions used for the thermal model of the fire test are taken at the end of a 12 hour period of insolation under Normal Conditions of Transport with a content decay heat of 30 W. All components are at their maximum temperatures as shown in Table 3-2.

A series of NCT and HAC drop and penetration tests was carried out on a prototype package (see Section 2.12.2). These tests caused denting of the top and bottom skirts of the package with minimal damage to the keg body.

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

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

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

3.4.3 Maximum Temperatures and Pressure

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

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

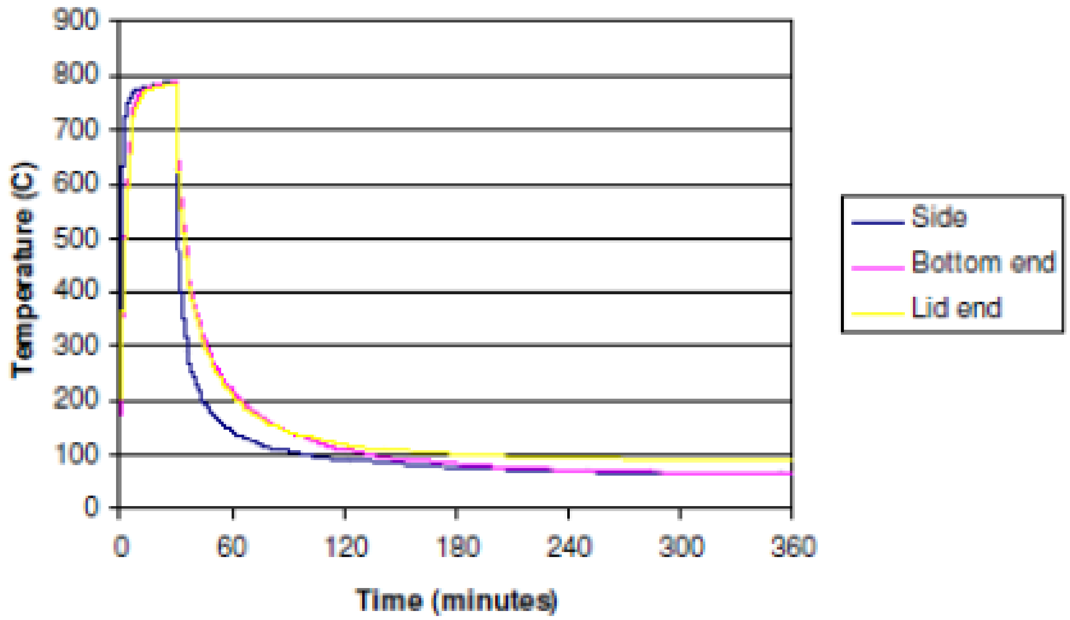


Figure 20 – Predicted Temperature on the Outside of the Keg during the Fire Accident – Internal Heat Load of 30W

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

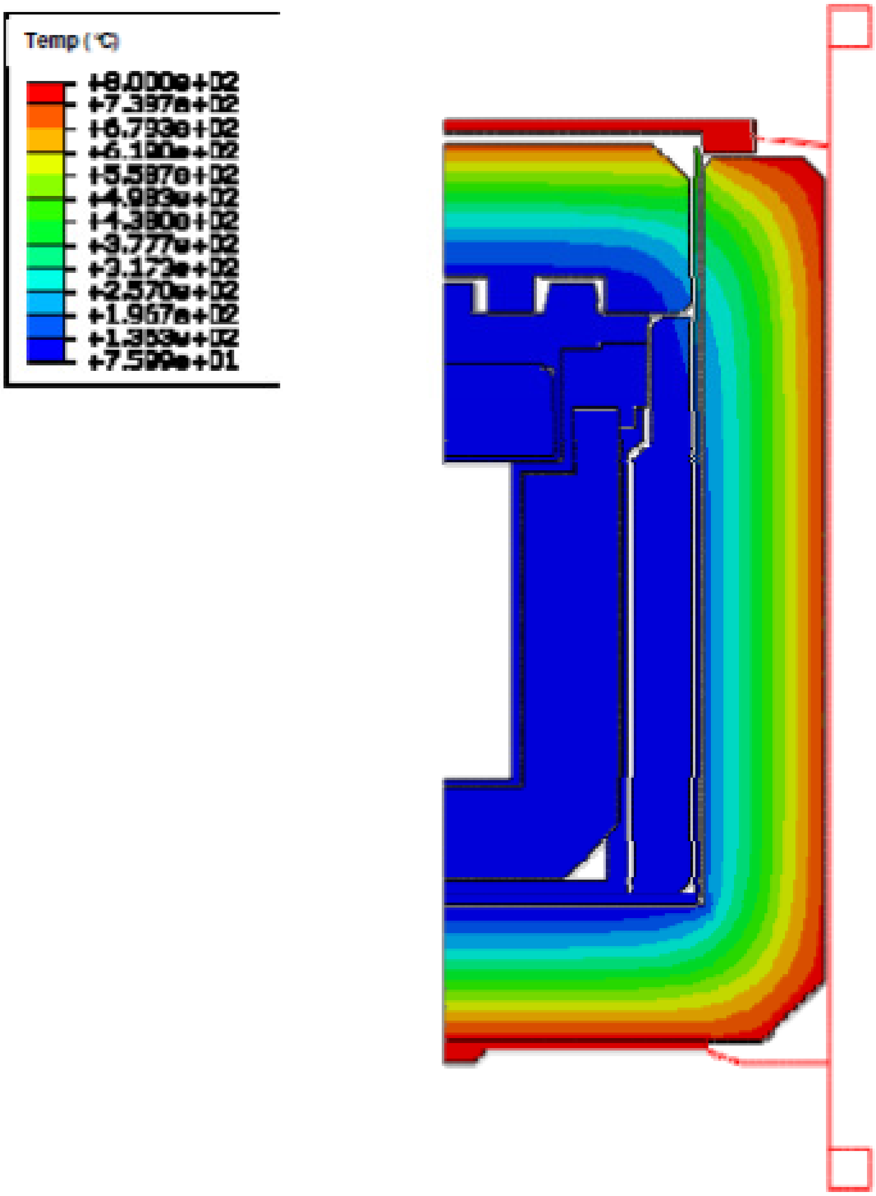


Figure 3-7 Predicted Temperature Profile at the end of the Heating Phase of the Fire Accident and a 30 W heat load

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

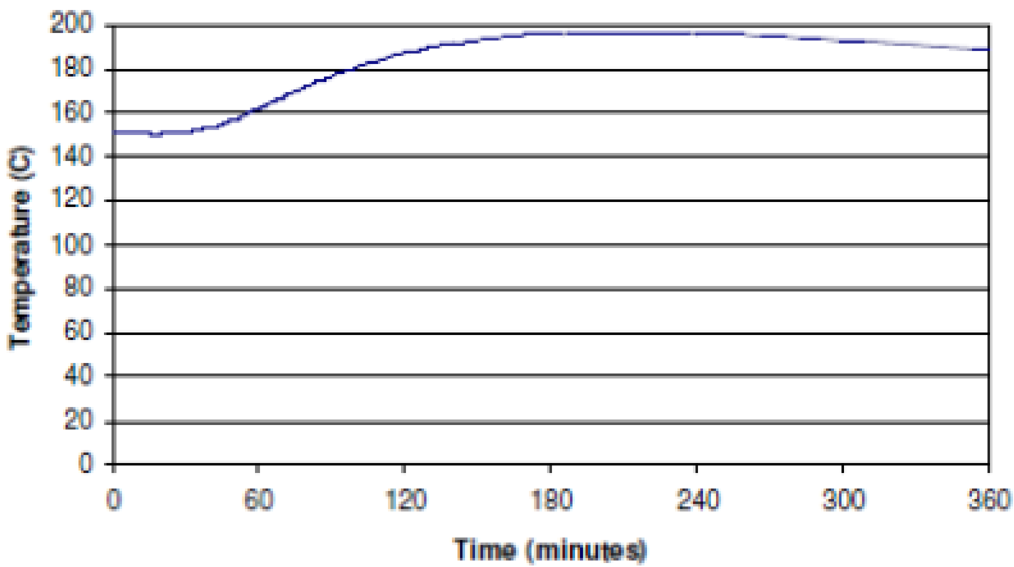


Figure 21 – Predicted Temperature of the Containment Vessel Lid Seal during the Fire Accident – Internal Heat Load of 30W

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

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

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

For 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 content were loaded at 20°C and a pressure of 1 bar abs, the pressure at the maximum temperature of the CV, calculated according to Boyle's and Charles' Laws, would be 1.38 bar (138 kPa) gauge. However, the vapour pressure of the liquid contents (the liquid contents are

aqueous) would be 3.0 bar gauge (from steam tables). Therefore the maximum pressure within the CV would be 3.0 bar gauge which is well within the design envelope.

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

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

3.4.4 Maximum Thermal Stress

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

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

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

3.5 Appendix

3.5.1 References

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

3.5.2 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

CONTENTS

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, as shown in Figure 4-1. 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 and 1C-5946 in Section 1.3.2.

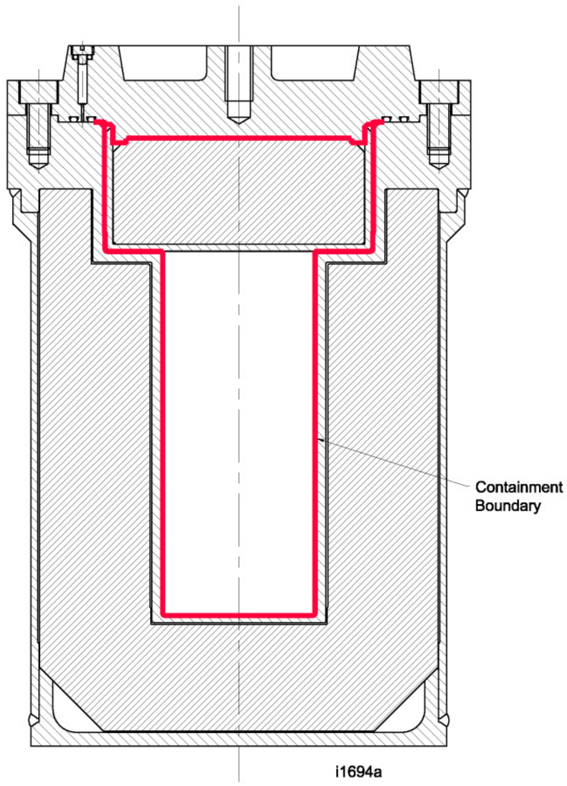

Figure 4-1 Package Containment Boundary

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.

Table 4-1 Safkeg-HS - Dose rate at the containment seal - based on Cs-137

Contents	CT-1				CT-2				CT-3			
Insert	HS-12x95-Tu Design No 3985				HS-31x114-Tu Design No 3982				LS-50x103-SS – Design # 3986			
	Source		Dose rate at containment seal		Source		Dose rate at containment seal		Source		Dose rate at containment seal	
			Sv/h	R/h			Sv/h	R/h			Sv/h	R/h
Calculated dose rate (1)	3000	Ci	1.60E-03	1.60E-01	3000	Ci	4.10E-03	4.10E-01	3000	Ci	2.89E+00	2.89E+02
Package limit	3.89E+03	Ci			8.58E+03	Ci			4.68E+02	Ci		
Dose rate for CT limit			2.07E-03	2.07E-01			1.17E-02	1.17E+00			4.51E-01	4.51E+01
			Sv	Rrad			Sv	Rrad			Sv	Rrad
Dose in 1 year	8760	hrs	1.82E+01	1.82E+03			1.03E+02	1.03E+04			3.95E+03	3.95E+05

Notes:

(1) From Table 5-10, Section 5.5.4.1.1

The Parker Handbook reports that "Practically all elastomers suffer no change of their physical properties at radiation levels up to 10^6 rad". Therefore it is concluded that the containment O-ring seal will not be unduly affected by the radiation from the contents of the package. It is noted that the containment O-ring seal is required to be replaced during the periodic maintenance activity (Section 8.2) (maximum period of 1 year).

Figure 4-2 shows the two additional O-ring seals fitted to the CV: a test point seal and a test seal. These seals are present to facilitate the leak test of the containment seal during the pre-shipment leak test. The test point is a tapped hole that allows connection of a pressure drop leak tester to the interspace volume between the test seal and the containment seal. The test seal is located close to the containment seal to provide a small interspace volume thus increasing the sensitivity of the pressure rise leakage test. The inserts as specified in Section 1.2.2 are also fitted with an O-ring seal. The test point seal, the test seal and the insert seal are not relied upon for containment.

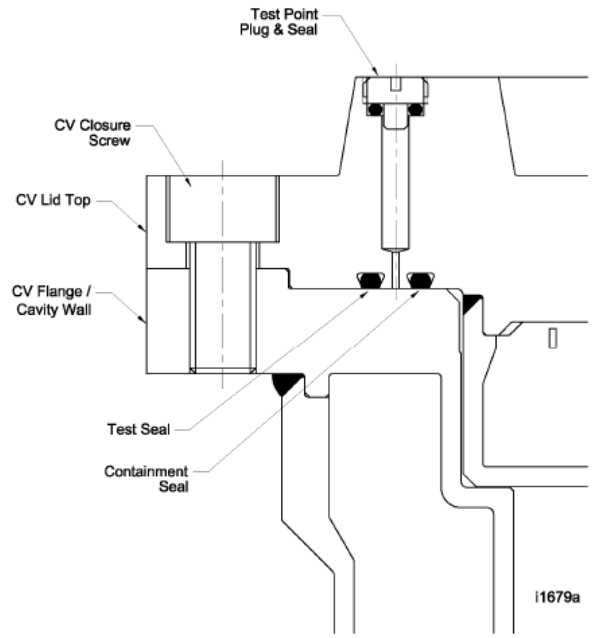

Figure 4-2 Leak Test Seal Arrangement

4.2 Containment under Normal Conditions of Transport (NCT) [71.51 (a)(1)]

4.2.1 Maximum internal pressures under NCT

The maximum internal pressure of the containment vessel under NCT is taken as the design pressure of 800kPa abs (8.0 bar abs) (see Section 3.3.2).

4.2.2 NCT Containment Criterion

The Safkeg-HS 3977A package has been designed specifically to meet the criteria for leak tightness during NCT. The CV containment boundary is tested to demonstrate it is leaktight at the testing, fabrication, and maintenance of the design. Leaktight is defined as demonstration of a leakage rate of $\leq 10^{-7}$ ref.cm^3/s as specified in ANSI N14.5 [4.5].

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

Under NCT, the shielding inserts, together with the user defined product containers, provide confinement of the radioactive material (solid, liquid or gas) within the shielding. Thus the shielding calculations are based on the contents being retained within the insert specified for the particular contents. However, containment is provided by the containment seal in the CV.

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 800kPa abs (8.0 bar abs) (see Section 3.3.2).

4.3.2 HAC Containment Criterion

The Safkeg-HS 3977A package has been designed specifically to meet the criteria for leak tightness during HAC, and to be testable to demonstrate that the CV containment boundary is leaktight for the design, testing, fabrication, and maintenance leak tests. Leaktight is defined as demonstration of a leakage rate of $\leq 10^{-7}$ ref.cm^3/s as specified in ANSI N14.5 [4.5].

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 HAC 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 lid. 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.

4.3.3 Structural Performance under HAC

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 in any of the containment system components under HAC. Therefore there would be no effect which could cause any reduction in the effectiveness of the containment system.

The structural performance of the confinement boundary of the inserts has been demonstrated by the prototype tests reported in Section 2. These tests, on the inserts that are designated for liquid contents, showed that the inserts provide complete confinement of liquid contents under the HAC 9m drop test.

4.3.4 Containment of Radioactive Material under HAC

4.3.4.1 Containment of solid and liquid contents

The thermal evaluation in Section 3.4 shows that the seals, bolts and containment system materials do not exceed their temperature limits under HAC.

The testing and analysis reported in Section 2 show that the containment system would be unaffected by HAC and provide complete containment for all solid and liquid contents.

The containment system has been shown to be unaffected by HAC and the seals are within their working temperature for the HAC thermal test: it is therefore concluded that the containment system meets the requirement for providing containment of the solid and liquid radioactive contents, within the allowable leakage limits under HAC.

The tests reported in Section 2 showed that the inserts that are designated for liquid contents, provide complete confinement of liquid contents under the HAC 9m drop test. Assurance of the ability of the inserts to provide confinement for liquid contents during shipment and under HAC is given by the requirements specified in Section 7 for leak testing the inserts that carry liquid before each shipment.

4.3.4.2 Containment of gaseous contents

Containment of gases is based upon the assumption that the closure of the containment system (i.e. the containment seal and the CV lid and top flange) would leak at the leakage rate to which the containment is proved i.e. 10^{-7} ref.cm^3/s.

The maximum amount of the radioactive gases that may be carried has been calculated based upon the allowable leakage rate limits specified in 10 CFR71 and the assumed leak in the containment seals of 10^{-7} ref.cm^3/s. The calculation of the size of a single leak having a leakage rate of 10^{-7} ref.cm^3/s is given in report CS 2012/04 (Section 4.5.2). The calculated hole diameter, for a single leak path in the 3 mm O-ring, with a hole length of 0.26 cm, is 1.1 x 10^{-4} cm.

The gas leakage rates (in terms of mass flow and A_2/hr and A_2/week) are given in report CS 20012/05 (Section 4.5.2).

The allowable leakage rates under HAC are taken as no escape of Kr-85 exceeding 10 A_2, and no escape of other radioactive material exceeding a total amount of A_2 in a week, as given in 10 CFR 71.51 (a)(2) [4.1].

4.4 Leakage Rate Tests for Type B Packages

4.4.1 Fabrication Leak Rate Test

The materials and components used to manufacture the containment boundary are required to be helium leak tested during fabrication with a pass rate of 10^{-7} ref.cm^3/s. These tests ensure that the fabricated components and the materials used, meet the required level of containment prior to the approval of the package for use.

The requirements for the fabrication leak rate test are specified in Section 8.1.4.

The confinement capability of the inserts is assured by the requirements specified in Section 8.1.4.

4.4.2 Maintenance Leak Rate Test

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

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

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

4.4.3 Periodic Leak Rate Test

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

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

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

4.4.4 Pre-shipment Leak Rate Test

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

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

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

4.5 Appendix

4.5.1 References

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

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

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

[4.4] Bronowski, D. R., Performance Testing of Elastomeric Seal Materials Under Low- and High-Temperature Conditions: Final Report, SAND94-2207, Sandia National Laboratories, June 2000

[4.5] ANSI N14.5, American National Standard for Radioactive Materials - Leakage Test on Packages for Shipment, American National Standards Institute, Inc., 1997

4.5.2 Supporting Documents

Document Reference	Title
CS 2012/04	SAFKEG-HS # 3977A - CV seal leak size for leaktight condition
CS 2012/05	SAFKEG-HS 3977A - Gas contents limit for leaktight condition

CONTENTS

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 shows the gamma shielding present in the Safkeg-HS 3977A package. 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 5-2, 5-3 or 5-4 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. These inserts also provide confinement for all contents under NCT and HAC.

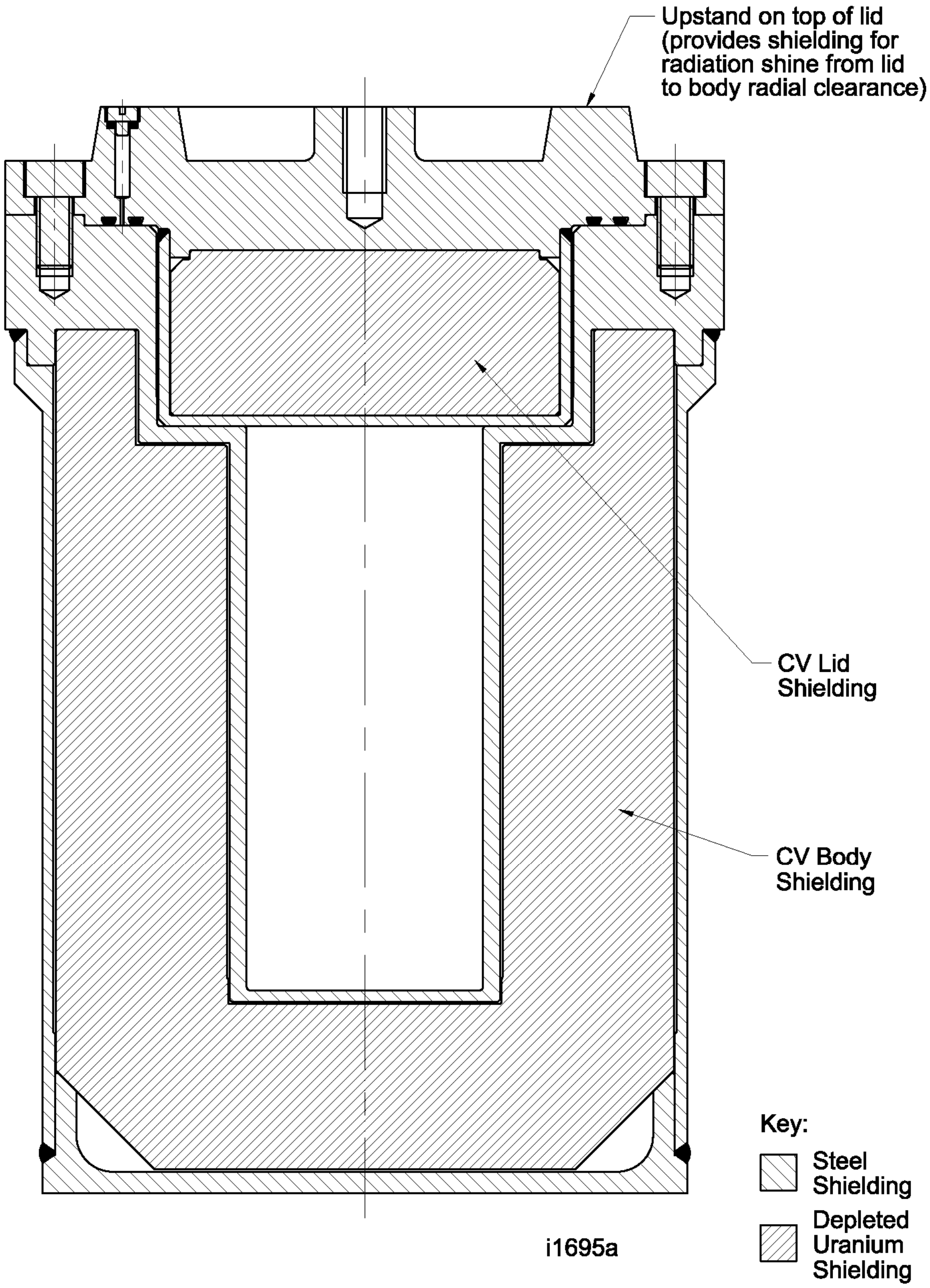

Figure 5-1 Gamma shielding present in the 3977A package

Figure 5-2 Shielding insert HS-12x95-Tu insert Design # 3982

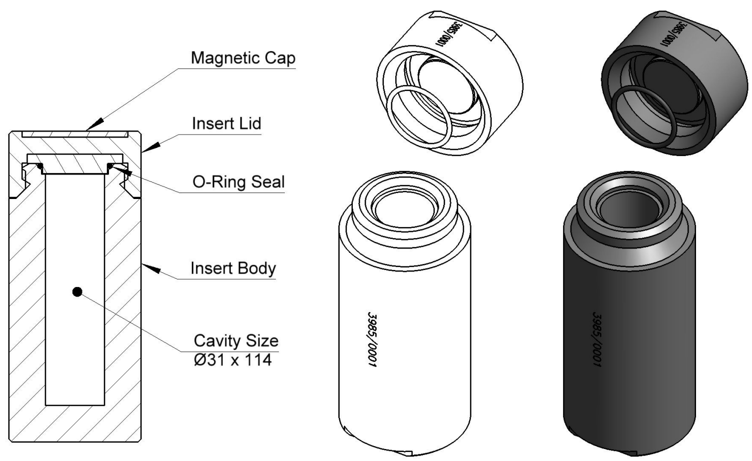

Figure 5-3 Shielding insert HS-31x114-Tu insert Design # 3985

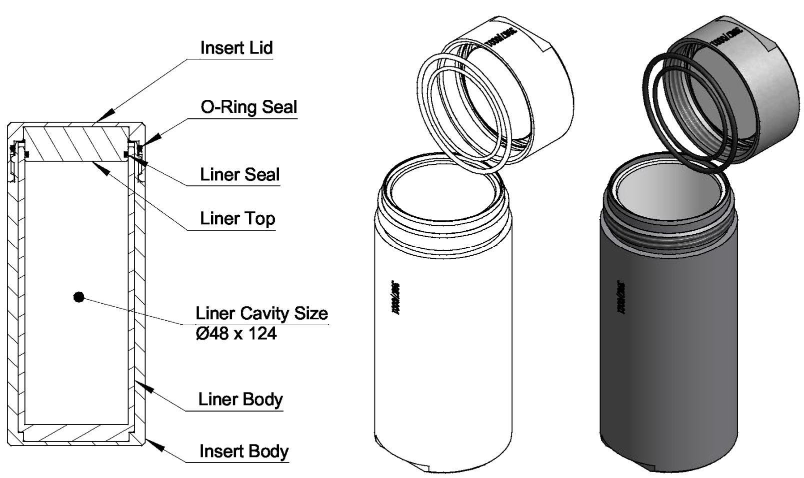

Figure 5-4 Shielding insert HS-55x138-SS Insert Design # 3987

5.2 Summary Table of Maximum Radiation Levels

5.2.1 Normal Conditions of Transport

Table 5-1**Error! Reference source not found.** 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)
	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 report AMEC/SF6652/001 and Microshield discussed in the attached reports CTR2011/01 and CTR 2013/09. The MCBEND model was used to determine the location of the point source which caused the highest surface dose rate, and to allow the Microshield model to be validated against the MCBEND reference case. The MCBEND model was not used to provide any of the shielding calculation limits for the package contents.

The MCBEND 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 work, the point to use for the highest dose was determined and then the shielding calculations 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.

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 5-5 and 5-6. 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	Solid	3000 Ci	Without Tungsten insert	top, centred
				Bottom, centred
				mid-cavity, eccentred
				Top, eccentred
			With Tungsten inserts	top, centred
			HS-31x114-Tu	bottom, centred
			HS-12x95 Tu	mid-cavity, eccentred
				Top, Eccentred

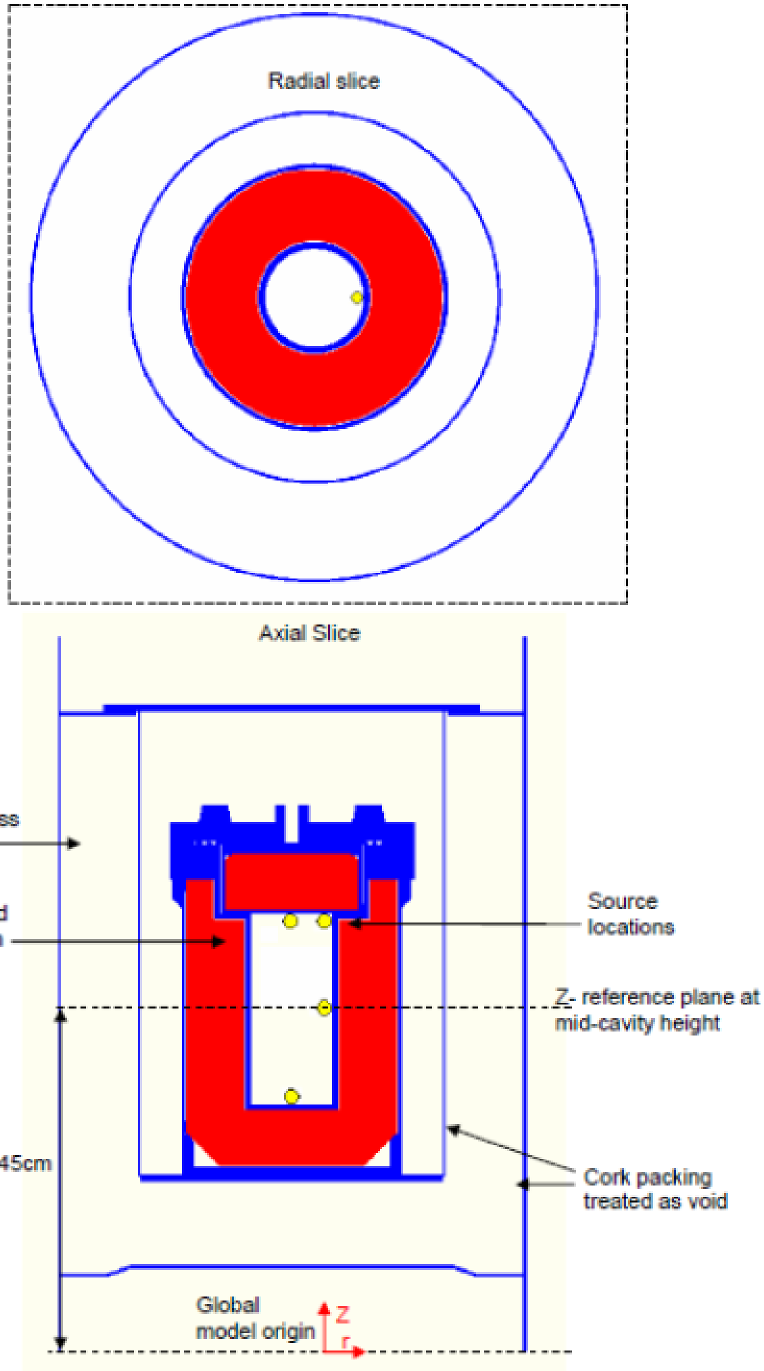

Figure 5-5 – Shielding Model and Source locations for HS package without an insert

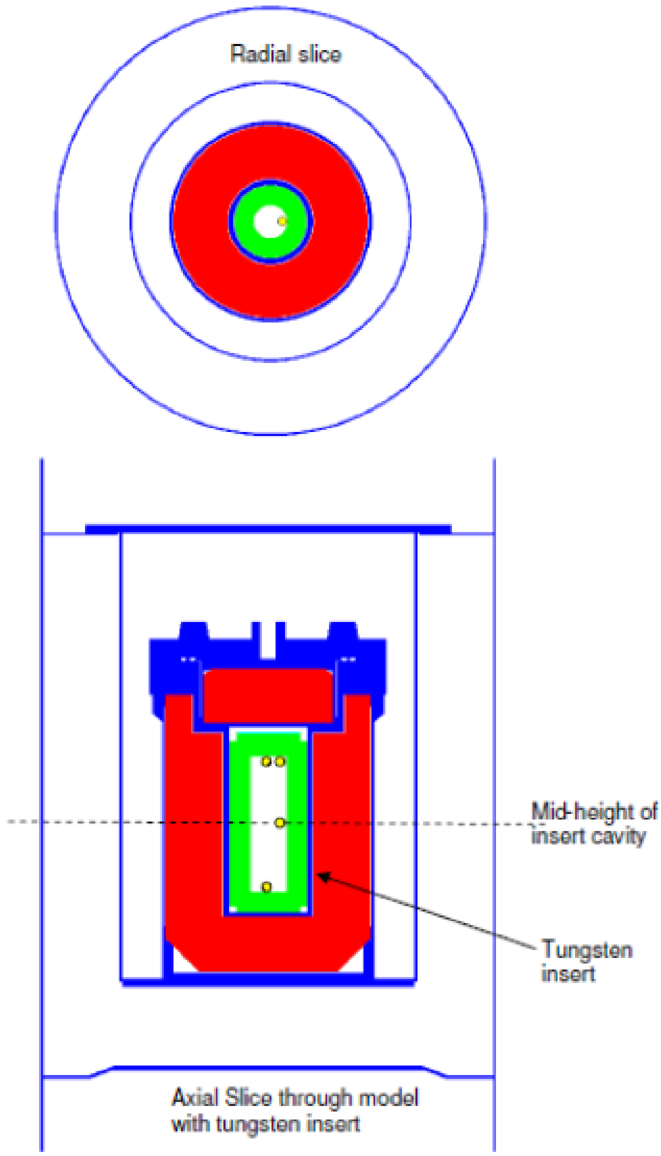

Figure 5-6 - Source Locations for MCBEND Model for HS package with insert

Once the highest surface dose rate had been located using the MCBEND model, a Microshield model was built in order to determine the surface dose rate for all the nuclides to be carried. 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 5-7. 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 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.

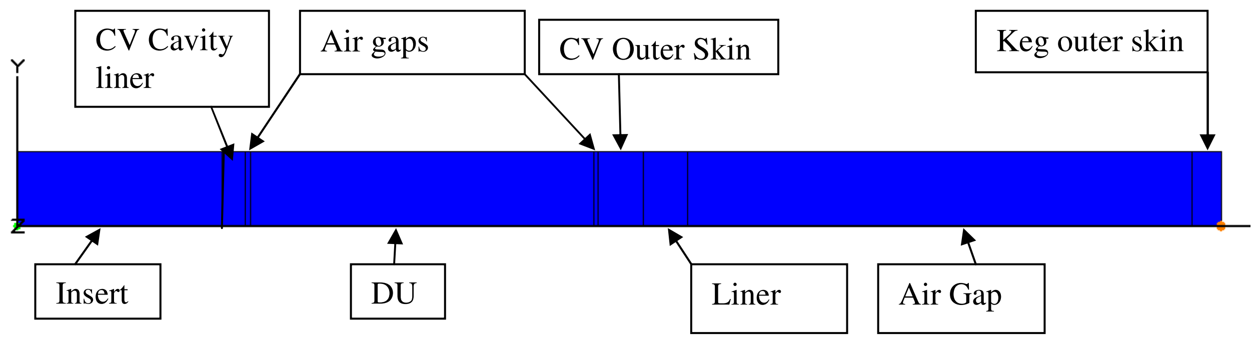

Figure 5-7 - Microshield model (3982 Insert)

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

Table 5-6 - Summary of Dimensions Used in Microshield Model				
Feature	Thickness (cm)			Notes
	3982	3985	3987	
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 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.

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	0.0012 0.17

Table 5-7 -Shielding Material Properties in MCBEND model			
Material	Density (g/m^3)	Elemental Composition	Mass Fraction
		Mn Si Fe	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. 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.

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 (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 Microsoft 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 are not used to calculate the dose rate for transport. The results are only 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. However all the gamma dose rates response functions without the tungsten inserts were taken from ICRP 74. The ANSI/ANS-6.1.1 1977 dose conversion function was used for the tungsten insert results.

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
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

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
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.

5.5.4.2 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 5-12 - 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	HS-55x138-SS Design #3987
Ac-225	2.51E+12	1.09E+12	7.65E+11
Ac-227	7.24E+11	3.26E+11	3.18E+13
Ac-228	4.28E+11	1.86E+11	1.02E+11
Am-241	3.58E+12	1.58E+12	3.54E+22
As-77	9.43E+19	1.14E+19	2.50E+17
Au-198	6.99E+14	2.43E+14	3.64E+13
Ba-131	1.88E+14	6.12E+13	8.20E+12
C-14	6.92E+27	6.13E+27	1.40E+28
Co-60	2.38E+11	9.37E+10	1.81E+10
Cs-131	8.39E+35	7.43E+35	5.94E+35
Cs-134	7.05E+12	2.63E+12	4.20E+11
Cs-137	1.58E+15	3.16E+14	1.73E+13
Cu-67	6.50E+25	2.84E+24	9.23E+21
Hg-203	3.57E+13	5.32E+34	1.14E+30
Ho-166	2.04E+12	9.20E+11	1.54E+12
I-125	4.49E+35	3.98E+35	3.18E+35
I-129	3.31E+26	2.93E+26	6.65E+26
I-131	4.11E+15	9.94E+14	1.42E+14
In-111	1.45E+28	1.29E+28	1.03E+28
Ir-192	2.71E+15	7.19E+14	1.76E+14
Ir-194	3.87E+13	1.47E+13	2.55E+12
Kr-79	6.00E+13	2.30E+13	4.04E+12
Lu-177	1.56E+24	1.38E+24	1.10E+24
Mo-99	5.27E+13	1.91E+13	1.47E+13
Na-24	2.63E+10	1.28E+10	3.47E+09
Np-237	3.58E+12	1.58E+12	3.67E+17
P-32	5.58E+12	2.49E+12	1.69E+12
P-33	5.10E+37	3.61E+37	1.03E+38
Pb-203	1.18E+17	2.45E+16	1.45E+15
Pb-210	8.04E+12	3.31E+12	1.22E+17
Pd-109	2.96E+14	9.61E+13	2.03E+18
Pu-238	1.16E+20	5.30E+19	1.30E+19
Pu-239	2.33E+25	6.04E+24	5.38E+23
Pu-240	1.15E+25	5.62E+24	1.02E+37
Pu-241	7.21E+20	1.90E+20	1.72E+19

Table 5-12 - 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	HS-55x138-SS Design #3987
Ra-223	1.02E+13	4.14E+12	3.18E+13
Ra-224	8.86E+10	4.37E+10	1.36E+10
Ra-226	1.02E+11	4.80E+10	1.96E+10
Re-186	1.56E+14	5.31E+13	1.12E+16
Re-188	1.22E+12	5.67E+11	1.13E+12
Rh-105	1.05E+31	1.17E+29	2.93E+25
Se-75	8.89E+18	7.87E+18	5.84E+18
Sm-153	6.12E+11	1.91E+15	3.56E+20
Sr-89	1.22E+13	5.17E+12	2.34E+15
Sr-90	1.73E+12	8.30E+11	6.38E+11
Tb-161	1.61E+13	7.39E+12	1.92E+17
Th-227	1.01E+13	4.17E+12	6.80E+13
Th-228	6.79E+10	3.35E+10	1.02E+10
Tl-201	1.59E+22	1.41E+22	1.13E+22
U-235	9.17E+17	2.38E+17	2.12E+16
W-187	2.24E+13	8.56E+12	1.43E+13
W-188	1.23E+12	5.68E+11	1.14E+12
Xe-133	2.25E+33	1.99E+33	1.60E+33
Y-90	1.73E+12	8.30E+11	6.41E+11
Yb-169	1.88E+19	1.66E+19	1.33E+19
Yb-175	6.04E+23	6.09E+22	2.26E+20

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

CONTENTS

6 CRITICALITY EVALUATION

This section specifies the requirements for fissile contents for the Safkeg-HS 3977A package which are restricted to solids as Contents Type CT-7 and CT-8 as specified in Section 1.2.2 and Tables 1-3-7 and 1-3-8.

Fissile material in quantities requiring a criticality evaluation, are not to be carried. However, small quantities may be carried under the conditions described below.

6.1 Description of Criticality Design

There are no special features needed or provided for fissile contents.

6.2 Fissile Material Contents

The contents are limited to the quantities as specified in the following sections

6.2.1 Fissile material under Exemption 71.15

Fissile material meeting the requirements of 10CFR 71.15 [6.1] are allowed by virtue of the Exemption provided by this regulation.

Note that the other requirements of CT-7 and CT-8 specified in Section 1.2.2 and Tables 1-3-7 and 1-3-8 have to be met.

6.2.2 Fissile material under General License 71.22

Fissile material meeting the requirements of 10 CFR 71.22 [6.1] are allowed by virtue of the General License provided by this regulation.

Note that the other requirements of CT-7 and CT-8 specified in Section 1.2.2 and Tables 1-3-7 and 1-3-8 have to be met.

6.2.3 Plutonium-beryllium special form material under General License 71.23

Plutonium-beryllium special form material meeting the requirements of 10CFR 71.23 [6.1] is included in CT-8 specified in Section 1.2.2 and Table 1-3-8 on the basis of the General license in 10 CFR 71.23.

Note that the other requirements of CT-8 specified in Section 1.2.2 and Table 1-3-8 have to be met.

6.3 General Considerations

Not required as the limited quantities of fissile material specified in 10 CFR 71.15, 10 CFR 71.22, 10 CFR 71.23 [6.1] are accepted as not requiring criticality evaluation.

6.4 Single Package Evaluation

Not required as the limited quantities of fissile material specified in 10CFR 71.15, 10 CFR 71.22, 10CFR 71.23 [6.1] are accepted as not requiring criticality evaluation.

6.5 Evaluation of Package Arrays under Normal Conditions of Transport

Not required as the limited quantities of fissile material specified in 10CFR 71.15, 10 CFR 71.22, 10 CFR 71.23 [6.1] are accepted as not requiring criticality evaluation.

6.6 Package Arrays under Hypothetical Accident Conditions

Not required as the limited quantities of fissile material specified in 10 CFR 71.15, 10 CFR 71.22, 10 CFR 71.23 [6.1] are accepted as not requiring criticality evaluation.

6.7 Fissile Material Packages for Air Transport

Air transport of plutonium is only allowed for the limited quantities specified in 10 CFR 71.88.

6.8 Benchmark Evaluations

Not applicable

6.9 Appendix

6.9.1 References

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

CONTENTS

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

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 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) The model/serial numbers of the containment vessel assembly (body and lid) 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 and lid) 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.

9) The containment vessel body and lid 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.

10) 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. If the O-rings are acceptable, lubricate with a light film of silicone O-ring lubricant.

11) 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.

12) 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.

13) 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.

14) 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), closure studs (item 16, drawing 0C-5942), closure nuts/washers (item 14 and 15, drawing 0C-5942) shall be replaced, if missing or damaged.

15) 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.

16) 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.

17) 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

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

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

7.1.3 Preparation for Transport

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. 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.

3) 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 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 the shielding screw replaced.

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

6) 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.

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

8) 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.

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

10) 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.

11) 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.

12) 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.

13) 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

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.

7.3 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.

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. Insert the top cork and ensure that it is no higher than the surface of the keg closure flange.

6) 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.

7) 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.

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

9) 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.

10) 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.

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.

7.4 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.

CONTENTS

8 ACCEPTANCE TESTS AND MAINTENANCE PROGRAM

This section details the requirements of the acceptance and maintenance test program for the Safkeg-HS 3977A package. The requirements of the sections below ensure compliance with Subpart G of 10 CFR Part 71[8.1].

It is the responsibility of the authorized maintenance organization to produce approved procedures which comply with the requirements of this SARP and 10 CFR 71 Subpart G with regard to all aspects of maintenance. The maintenance organization shall also 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.

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

8.1 Acceptance Tests [71.85]

This section describes the requirements for the acceptance tests to be performed prior to the initial use of the packaging. The tests shall be performed in accordance with written procedures produced by the manufacturing organization and in compliance with the requirements and descriptions in this section.

Initial inspection and acceptance tests are carried out during the fabrication of the packaging components by the manufacturer. These tests include dimensional, visual, liquid penetrant and radiographic inspections, structural pressure tests, and leakage tests. The tests and acceptance criteria are specified in the general arrangement drawings in the Certificate of Compliance.

8.1.1 Visual Inspections and Measurements

All components including the inserts shall be subject to visual checks to ensure that they have been fabricated and assembled in accordance with the general arrangement drawings in the certificate of compliance. The dimensions, tolerances and surface finishes shown on the drawings shall be verified by measurement of each packaging component.

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.

8.1.2 Weld Examinations

All keg welds shall be examined according to drawing 0C-5942. The containment vessel welds shall be examined in accordance with drawings 1C-5945 and 1C-5946. 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 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 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 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 drawing 0C-5943 (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). 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). 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.

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. Dimensional checks shall be carried out on the inserts in accordance with Section 8.1.1. This is considered an adequate shielding check due to the simple design of the inserts.

For the containment vessel, a 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 lid and body shielding 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.

8.1.8 Miscellaneous Tests

Not applicable.

8.2 Maintenance Program

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

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

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

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

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

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

8.2.1 Structural and Pressure Tests

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

8.2.2 Leakage Tests

8.2.2.1 Containment Vessel

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

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

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

8.2.3.2 Keg

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

2) The keg name plate shall be checked for legibility of the nameplate information.

3) 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.

4) The keg closure studs shall be checked for tightness of fit in the keg top flange and damage (i.e. stripped or distorted). A die nut (thread class 6g) shall be used to clear any tight threads. The closure studs shall be checked that they are positioned in accordance with drawing 0C-5942. If the stud is loose or the height is incorrect, the stud shall be removed, cleaned, and repositioned using Loctite 270.

5) The keg lid seal and respective groove shall be checked for visible damage such as splits or cuts in the lid seal and scratches in the lid seal groove. The lid seal shall fit correctly into the seal groove. The lid seal shall be replaced as necessary; there is no requirement for periodic replacement.

6) The keg, keg lid, and keg closure nuts shall fit up freely. Any damaged nuts or washers shall be replaced according to drawing 0C-5942.

7) The fuse plug and spring washer shall be visually inspected for presence in the keg and damage and wear. A damaged or missing fuse plug or washer shall be replaced according to the specifications in drawing 0C-5942.

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.

8.2.3.3 Containment Vessel

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 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 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.

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

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.

8.2.3.5 Inserts

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 insert (body and lid) do not match, these assemblies shall be removed from service.

2) The insert components shall be checked for visible damage and in particular that the lid screws freely by hand onto the body. Any defects affecting the operation or integrity must be corrected or a part replaced.

3) The lid and body threads shall be cleaned and coated with molybdenum disulfide dry film spray lubricant.

4) The presence of the O-ring shall be checked and replaced if missing. The O-ring shall be coated with a light film of silicone O-ring lubricant.

5) The insert shall be leak tested as specified in section 8.2.2.2.

6) 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.

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

8.2.3.6 Silicone Sponge Rubber Disc

1) The silicone sponge rubber disc shall be visually inspected and its density checked. Any damaged discs or those that do not meet the density 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
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

8.3 Appendix

8.3.1 References

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

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

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