serco

bringing service to life

Monte Carlo Modelling of Safkeg LS Container

A report produced for Croft Associates

Our Reference: SERCO/TAS/003191/001 Issue 1

Date: June 2009

This page is intentionally left blank to allow double-sided pagination.

Title	Monte Carlo Modelling of Safkeg LS Container
Customer	Croft Associates
Customer reference	
Confidentiality, copyright and reproduction	This document has been prepared by Serco Assurance in connection with a contract to supply goods and/or services and is submitted only on the basis of strict confidentiality. The contents must not be disclosed to third parties other than in accordance with the terms of the contract.
File reference	J:\PSSD - Performance & Safety Services\Projects (Live)\3191 - Croft Safkeg Shielding\Report\ 003191_001_Iss1.doc
Report number	SERCO/TAS/003191/001
Report status	Issue 1

Pat Cowan
Serco Assurance
Nuclear Safety and Technology Department
A32, Winfrith Technology Centre
Winfrith
Dorchester
Dorset, DT2 8DH
United Kingdom
Telephone +44 (0) 1305 851147
Facsimile +44 (0) 1305 851105

Serco Assurance is a division of Serco Ltd.
Serco Assurance is certificated to BS EN ISO9001:(1994)

	Name	Signature	Date
Authors	M D Whitfield	M Whitfield	29/06/09
	D Picton	D. J. Picton	29/06/09
Checked by	P Cowan	P. Cowan	3/7/09
Approved by	J N Lillington	[illegible]	6/7/09

Executive Summary

The following gamma radiation calculations have been carried out for the Croft Safkeg LS container:

- Maximum gamma dose-rates and dose-rate profiles on the top, side and bottom surfaces of the Safkeg LS container
- Maximum gamma dose-rates and dose-rate profiles at a distance of 1m from the top, side and bottom of the Safkeg LS container
- Maximum gamma dose-rates at specified o-ring locations on the inner containment vessel lid and at specified locations on the lid up-stands

These calculations were carried out for the following source configurations:

- ^{192}Ir point source located at; top centred, top eccentred, bottom centred and mid-height eccentred positions within the inner containment vessel (without a tungsten insert)
- ^{192}Ir point source in the cavity of a tungsten insert fitted into the inner containment vessel, with the source located separately at; top centred, bottom centred and mid-height eccentred locations. Two tungsten inserts have been modelled.
- Five separate liquid sources (^{99}Mo, ^{75}Se, ^{166}Ho, ^{177}Lu, ^{201}Tl) filling the upper section of the inner containment vessel cavity (no tungsten insert) and the clearance gaps between the containment vessel body and lid

Contents

Tables

Figures

Appendix A

Croft Safkeg LS drawings

1 Introduction

Calculations have been carried out to determine the maximum gamma dose-rates and dose-rate profiles at the top, side and bottom of the Croft Safkeg LS container on contact and at a distance of 1m from the container. Maximum dose-rates at the inner o-ring and trapezoidal lid up-stand locations, on the inner containment vessel lid, were also calculated.

The dose-rates were determined for a solid point source (^{192}Ir) located at different positions within the containment vessel - both with and without a tungsten insert. Dose-rates were also calculated for five different liquid sources (^{99}Mo, ^{75}Se, ^{166}Ho, ^{177}Lu, ^{201}Tl) filling the top part of the containment vessel cavity (with no tungsten insert) and filling the clearance gaps between the containment vessel body and lid.

The assessment was carried out using the Monte Carlo radiation transport code MCBEND [1], which has been extensively used for similar assessments in the past.

2 Description of the Problem

The Safkeg LS container consists of an outer container and an inner containment vessel. The outer container consists of an outer stainless steel casing with a nominal outer diameter of 382.5mm and a maximum height of 483mm. It has an inner stainless steel casing of diameter 250mm and height 274.5mm that houses the inner containment vessel. The walls of the outer and inner casings are 2mm thick, the bases are nominally 4mm thick and a single 6mm thick lid covers both inner and outer casing. The spaces between the outer and inner casings and the inner containment vessel are packed with cork.

The inner containment vessel consists of a body and a lid. The containment vessel body is a double-walled stainless steel cylinder, which is closed at the bottom and open at the top, with a tapered and stepped profile, equipped with a flange to accept a lid. The containment vessel body has overall approximate dimensions: height 171.3 mm, outer diameter 118.5 mm, inner diameter 64.5 mm. The flange outer diameter is 175mm. The body is filled with lead between the inner and outer walls to an approximate thickness of 21 mm. The lid is of stainless steel construction and is stepped, with an inner lead-filled cavity that fits into the top of the containment vessel body. The lid dimensions are: diameter 175mm and height 65mm. The lid is a tolerance fit into the stepped body and is secured by M10 bolts. A double o-ring seal between the lid and body flange provide a positive seal when the lid bolts are tightened.

The inner cavity of the containment vessel is designed to accept a removable insert in the form of a cylindrical tungsten source holder with its own o-ring sealed tungsten lid and stainless steel magnetic cap. Two different tungsten inserts are considered in this study – LS-31x73-Tu and LS-12x65-Tu. The 31x73 and 12x65 refers to size of the internal cavity of the insert.

The general assembly and detailed construction of the inner containment vessel, the complete Safkeg LS transport container and the two tungsten inserts were provided by the customer in a set of dimensioned engineering drawings [2] and an email [3] from which all geometry for the MCBEND model was derived. The model geometry for the Safkeg LS container, with and without a tungsten insert, is shown in Figure 1.

The Safkeg LS container can carry both solid and liquid gamma sources. The problem is to determine the (maximum) contact and 1m dose-rates and certain other specified positions for the Safkeg LS transport container for a range of solid and liquid sources under both normal and accident conditions.

Under normal conditions the source would be contained within a source housing and would be confined contained within the inner cavity of the containment vessel, or confined within a tungsten insert in the inner cavity of the containment vessel. Under accident conditions the liquid source could escape the source housing and, in the case of a liquid source, it could penetrate the gaps between the containment vessel body and lid. For a 'worst case' accident condition for liquid contents, the transport container is assumed to be upside down and a worst case gap between the containment vessel body and lid is assumed. This condition corresponds with assuming worst case manufacturing tolerances and a maximum eccentred lid with respect to the body, in accordance with dimensioned drawings provided by the customer [4].

3 MCBEND Calculations

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 of Serco. 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.

3.1 MCBEND GEOMETRY MODELLING

3D models of the Safkeg LS container and its component parts were set up in MCBEND using the dimensioned drawings and material information provided by the customer [2, 3, 4]. All MCBEND geometry models were checked using the geometry-checking programs VISAGE [5] and VISTA-RAY [6]. The material compositions used in the models are listed in Table 1. The following assumptions and simplifications were made in specifying the model:

- Small chamfers and rounding at corners are ignored, except in the vicinity of the containment vessel o-rings
- Nuts and bolts are omitted, but the central hole at the top of the containment vessel is included
- Very small (< 0.1 mm) air-gaps and voids are ignored, except for the regions where the containment vessel lid interfaces to the vessel body – in these regions the tolerance gaps are modelled explicitly
- Cork is omitted for conservatism and modelled as void instead
- 0-ring material is not modelled and is treated as void
- The 20x20 mm square cross-section tubing at either end of the Safkeg LS container has no significant impact on the calculations and is not modelled

Radial and axial slices through the models, without and with a tungsten insert, are shown in Figure 2 & Figure 3 respectively. The global origin of the model is located at the intersection of the cylindrical axis of the container and the plane closing its bottom end – as shown on Figure 2. A right-handed cylindrical coordinate system is used. Note that the z-reference plane at mid-cavity height (no w-insert) marked on Figure 2, is fixed at 22.725cm above the global origin and is used as an alternative reference for the presentation of axial dose-rates.

3.2 SOURCES

One solid source (^{192}Ir) and five liquid sources (^{99}Mo, ^{75}Se, ^{166}Ho, ^{177}Lu, ^{201}Tl) were used in the MCBEND calculations. The significant gamma emission lines for these sources are taken from Reference [7] and are shown in Table 2.

For pessimism the ^{192}Ir source was modelled in MCBEND as a point source. No source housing was modelled. Calculations were done for the source located at several positions inside the containment vessel cavity, both with and without a tungsten insert.. These positions were chosen as worst case positions for top, bottom and side dose-rates. The top eccentred position (no tungsten insert) was chosen as a worst case position for lid streaming and o-ring dose-rates. In this case the source was located axially so that it was on the centre-line of the clearance gap between the containment vessel body and lid. The different locations are marked as small yellow circles on Figure 2 & Figure 3. Note that the mid-height positions, in each case, are for the respective cavity heights with lids fitted.

The source configurations with a point ^{192}Ir source are summarised in Table 3. These cover normal conditions and worst case accident conditions with a solid source. In all cases the source activity was 1kCi.

All calculations carried out with the liquid sources were for accident conditions, assuming that the sources have escaped their source housing, the Safkeg LS container is upside down and the liquid is lying in the containment vessel cavity and has penetrated the gaps between the containment vessel body and lid. To simulate the worst case penetration of a liquid source into the tolerance gaps between the lid and containment vessel the MCBEND geometry was altered. Worst case tolerances and a maximum eccentred lid with respect to the containment vessel body were assumed and the resulting voids (as far as the inner o-ring) were 'filled' with the liquid source. An example of one of the liquid sources (^{99}Mo) partially filling the containment vessel is shown in Figure 4 – the VISAGE slice shows that the liquid source extends into the clearance voids as far as the first o-ring seal between the containment vessel body and lid. Figure 5 illustrates the eccentred lid with respect to the containment vessel body in the MCBEND model.

In MCBEND the liquid sources were defined as water for the relevant material properties and assigned an activity/unit volume consistent with the source data supplied by the customer [8]. The volume of the source was adjusted (by altering the level of the liquid lying in the containment vessel cavity) to achieve the required total activity. The source configurations with the five liquid sources are summarised in Table 3. These cover worst case accident conditions with a liquid source. For each source the activity/unit volume, the total activity and the level of the liquid in the containment vessel cavity is given.

Beta emission was not modelled – it will not contribute significantly to the total dose-rates and would have required a separate set of calculations in MCBEND.

3.3 SCORING

Maximum gamma dose-rates and dose-rate profiles are required at the top, side and bottom of the Safkeg LS container on contact and at a distance of 1m from the container. Maximum dose-rates at the inner o-ring and trapezoidal lid up-stand locations, on the inner containment vessel lid, are also required.

Contact scoring regions were defined on the top surface, bottom surface and outer cylindrical surface of the Safkeg LS container. The top scoring was divided into a central disc radius 5cm and three annuli with outer radii 10 cm, 15 cm and 18.925 cm respectively. These were sub-divided azimuthally into twelve sectors of 30° offset from $\theta = 0°$ by 15° - except for the central disc for which the twelve sectors were merged. The bottom scoring regions were defined similarly except that there is no azimuthal sub-division. The side contact scoring regions were defined as a set of sixteen axial divisions of 2.5 cm height extending from the bottom to the top of the outer casing. These were further sub-divided into twelve azimuthal divisions of 30°, offset from $\theta = 0°$ by 15°.

Scoring regions at a distance of 1m from the top, bottom and side surfaces were defined analogously; however in this case there were 23 axial divisions each 10cm high, except for the bottom and top divisions which are 13.6cm and 12.6cm respectively.

Scoring regions were defined on the inner containment vessel lid at the inner o-ring location and the tops of the trapezoidal up-stands. The o-ring scoring was divided into eighteen azimuthal sectors each of 20°, offset from $\theta = 0°$ by 10°. The up-stands scoring was divided into twelve azimuthal sectors each of 30°, offset from $\theta = 0°$ by 15°.

This arrangement of scoring regions allows dose-rate profiles and maximum dose-rates to be determined with a reasonable compromise between the requirements of adequate spatial resolution and statistics.

3.4 CALCULATIONS

Separate MCBEND calculations were performed for each of the ten ^{192}Ir source configurations (as given in Table 3) to determine the maximum gamma dose-rates and dose-rate profiles at the top, side, bottom, o-ring and up-stand scoring regions, both with and without a tungsten insert in the inner containment vessel.

A single MCBEND calculation was carried out for each of the five liquid sources to determine the maximum gamma dose-rates and dose-rate profiles at the top, side, bottom, o-ring and up-stand scoring regions.

The gamma dose-rate response function was taken from ICRP 74 [9] and gives results in μSv/hr.

MCBEND calculations were run for sufficient time to achieve reasonable statistics in the scoring regions of most interest - typically the standard deviation was less than 1%. For the weakest of the liquid sources larger standard deviation were seen on the calculated dose rates. The worst case is for the ^{201}Tl source where the standard deviation on the maximum 1m side dose-rate is 5.4%.

4. Results

4.1 Dose-Rate Results for Solid ^{192}Ir Source

The maximum contact and 1m dose-rates were extracted from the MCBEND results for each of the source locations. These are summarised in Table 4 for the container without the tungsten insert in the containment vessel, and in Table 5 and Table 6 for the container with the tungsten inserts in the containment vessel. Note, that where there is azimuthally divided scoring, the figures quoted in Table 4 are always the highest values recorded, even where symmetry would justify quoting a weighted mean over all the relevant scoring regions. The highest contact dose-rate is 4.30 x 10^6 μSv.hr^{-1} and occurs on the bottom surface of the Safkeg LS container when the source is centred at the bottom of the inner containment vessel, without the tungsten insert in place.

The calculated dose-rate profiles for the top, side and bottom contact scoring regions and at a distance of 1m from the container are presented in Table 7 - Table 10 and plotted in Figure 6 - Figure 10. Where the model is fully axi-symmetric (including the source location) the values given in the detailed dose-rate profile tables are averaged, where relevant, over all azimuthal regions. Where the model is not axi-symmetric the radial and axial profiles are given in the azimuthal mesh containing the maximum dose.

4.2 Dose-Rate Results for Liquid Sources

The maximum contact and 1m dose-rates were extracted from the MCBEND results for each of the liquid sources – the results are summarised in Table 11. The highest contact dose-rate is 4.82 x 10^5 μSv.hr^{-1} and occurs on the top surface of the Safkeg LS container for the ^{99}Mo source. Contact and 1m dose-rate profiles for the top, bottom and side of the container are summarised for the five liquid sources in Table 12 - Table 14 and plotted in Figure 11 - Figure 13. Again the radial and axial profiles are given in the azimuthal mesh containing the maximum dose.

5 References

1 "MCBEND - A Monte Carlo Program for General Radiation Transport Solutions. User Guide for Version 10". ANSWERS/MCBEND/REPORT/004.

2 Croft Safkeg LS Drawings as follows:

0C-6049, Issue A - Safkeg-LS Construction [included at the end of this report]

1C-6099, Issue A - Containment Vessel LS Body Construction [included at the end of this report]

1C-6097, Issue A - Containment Vessel LS Lid Construction [included at the end of this report]

2C-6180, Issue A - LS-12x65-Tu Insert Design No. 3984 Prototype [included at the end of this report]
2C-5888 Issue P6 - LS-12x65-Tu Insert Design No. 3984
2C-5892, Issue P4 - LS-12x65-Tu Insert Body
2C-5893, Issue P5 - LS-12x65-Tu Insert Top Assy
3C-6142 Issue P1 - LS-12x65-Tu Insert Top Blank
3C-7006 Issue P5 – LS Tu Magnetic Cap

2C-5889, Issue A - LS-31x73-Tu Insert Design No. 3983 Prototype [included at the end of this report]
2C-5894, Issue P3 - LS-31x73-Tu Insert Body
2C-5895, Issue P3 - LS-31x73-Tu Insert Top Assy
3C-7009 Issue P2 – LS Tu Magnetic Cap

3 Emails from Bob Vaughan (Croft Ltd) to Pat Cowan (Serco) " RE:Query on LS container Tungsten insert" 18/11/08, "Safkeg-LS CV – gap around the lead in shielding plug" 20/11/08.

4 Croft drawing i1623a – "Containment Vessel LS (with all dimensions eccentric)"

5 "VISAGE - A Program for the Graphical Validation of MONK, MCBEND and RANKERN Geometry Models. User Guide for Version 5A". ANSWERS/VISAGE/REPORT/002.

6 "VISTA -RAY - A Ray-tracing Geometry Visualisation Package for MONK, MCBEND and RANKERN. User Guide for Version 3A". ANSWERS/VISTA/REPORT/003.

7 The Radiochemical Manual 1998, AEA Technology

8 Email from Bob Vaughan (Croft Ltd) to Pat Cowan (Serco) "SAFKEG LS – Shielding Calculations" 23/10/08.

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

Table 1: Specification of materials used in the MCBEND model

Material	Density g/cm^3	Elemental Composition	Mass fraction
Stainless Steel (SafKeg walls)	8.027	Cr Mn Fe	0.19 0.02 0.6975
Lead (BS3909/2) (vessel shieding)	11.04	Pb Sb	0.96 0.04
Tungsten (for insert)	18	W Fe Ni	0.95 0.016 0.034
Stainless Steel 430 (magnetic cap)	7.75	C Cr Mn Si Fe	0.012 0.17 0.01 0.01 0.798
Air (voids)	1.225 × 10-3	N O	0.765172 0.234828
Water (for liquid sources)	1	O H	0.8881 0.1119

Table 2: Summary of gamma line energies and intensities used in MCBEND model

Solid		Liquid									
Ir-192		Mo-99		Se-75		Ho-166		Lu-177		Tl-201	
line energy (MeV)	line intensity	line energy (MeV)	line intensity	line energy (MeV)	line intensity	line energy (MeV)	line intensity	line energy (MeV)	line intensity	line energy (MeV)	line intensity
0.6125	0.0526	0.961	0.00096	0.4007	0.115	1.8306	0.00008	0.3213	0.00253	0.1675	0.102
0.6044	0.0809	0.823	0.00129	0.3039	0.0131	1.7499	0.00025	0.2497	0.00213	0.1659	0.0016
0.5886	0.0448	0.778	0.042	0.2795	0.25	1.6624	0.00116	0.2084	0.111	0.1412	0.0007
0.4846	0.0314	0.7396	0.119	0.2647	0.59	1.5819	0.00181	0.1367	0.00048	0.1353	0.0265
0.4681	0.477	0.6212	0.00024	0.1986	0.0149	1.3794	0.0093	0.113	0.068	0.0322	0.0026
0.3165	0.83	0.5288	0.00052	0.136	0.588	0.7859	0.00013	0.0716	0.00155	0.0306	0.00258
0.3085	0.2975	0.3664	0.0119	0.1211	0.171	0.7053	0.00015				
0.296	0.2873	0.1811	0.0596	0.0967	0.0341	0.674	0.0002				
0.2058	0.0318	0.1405	0.045	0.0661	0.011	0.0806	0.062				
		0.0406	0.0104								

Table 3: Summary of source configurations used in MCBEND model

Source	Form	Activity		Container configuration	Source location
Ir-192	solid/point	1000 Ci		without tungsten insert	top, centred
					bottom, centred
					mid-cavity, eccentred
					top, eccentred
				with tungsten inserts LS-31x73-Tu LS-12x65-Tu	top, centred
					bottom, centred
					mid-cavity, eccentred
Mo-99	liquid	6 Ci/ml	120 Ci	container inverted, no Tungsten insert	level in cavity = 0.5cm
Se-75		3 Ci/ml	300 Ci	container inverted, no Tungsten insert	level in cavity = 2.94cm
Ho-166		2 Ci/ml	100 Ci	container inverted, no Tungsten insert	level in cavity = 1.42cm
Lu-177		3Ci/ml	300 Ci	container inverted, no Tungsten insert	level in cavity = 2.94cm
Tl-201		1 Ci/ml	100 Ci	container inverted, no Tungsten insert	level in cavity = 2.94cm

Table 4: Calculated maximum dose-rates for ^{192}Ir source in Safkeg LS Container - without tungsten insert in containment vessel

1kCi point ^{192}Ir Source
Dose-Rates in μSv/hr

Source - Eccentred near top, lined up with air gaps
Maximum dose-rate is at same azimuthal region as source

Side - Surface 3.29E+06	**sd%** 0.2	**Side - 1m** 5.97E+04	**sd%** 0.3
Top - Surface 2.17E+06	**sd%** 0.3	**Top - 1m** 3.29E+04	**sd%** 0.4
O Ring 3.43E+08	**sd%** 0.1		
Trapezoidal upstand 1.29E+07	**sd%** 0.2		

Source - Centred at top of cavity

Top - Surface 9.25E+05	**sd%** 0.2	**Top - 1m** 1.38E+04	**sd%** 0.4

Source - Centred at bottom of cavity

Bottom - Surface 4.30E+06	**sd%** 0.1	**Bottom - 1m** 4.22E+04	**sd%** 0.2

Source - Eccentred at side of cavity at mid-height
Maximum dose-rate is at same azimuthal region as source

Side - Surface 2.82E+06	**sd%** 0.2	**Side - 1m** 5.08E+04	**sd%** 0.4

Table 5: Calculated maximum dose-rates for ^{192}Ir source in Safkeg LS Container - with tungsten insert LS-31x73-Tu in containment vessel

1kCi point ^{192}Ir Source
Dose-Rates in µSv/hr

Source - Centred at top of cavity

Top - Surface	sd%	Top - 1m	sd%
3.29E+04	1.3	5.33E+02	1.9
Trapezoidal upstand	**sd%**		
5.73E+04	3.8		

Source - Centred at bottom of cavity

Bottom - Surface	sd%	Bottom - 1m	sd%
1.67E+05	0.6	1.97E+03	1.0

Source - Eccentred at side of cavity at mid-height
Maximum dose-rate is at same azimuthal region as source

Side - Surface	sd%	Side - 1m	sd%
1.21E+05	1.2	2.57E+03	1.6
O Ring	**sd%**		
3.05E+05	4.9		

Table 6: Calculated maximum dose-rates for ^{192}Ir source in Safkeg LS Container - with tungsten insert LS-12x65-Tu in containment vessel

1kCi point ^{192}Ir Source
Dose-Rates in μSv/hr

Source - Centred at top of cavity

Top - Surface 1.50E+04	**sd%** 1.9	**Top - 1m** 2.40E+02	**sd%** 2.9
Trapezoidal upstand 2.55E+04	**sd%** 5.7		
O Ring 1.46E+05	**sd%** 7.1		

Source - Centred at bottom of cavity

Bottom - Surface 7.72E+04	**sd%** 0.9	**Bottom - 1m** 9.74E+02	**sd%** 1.5

Source - Eccentred at side of cavity at mid-height
Maximum dose-rate is at same azimuthal region as source

Side - Surface 2.08E+04	**sd%** 2.9	**Side - 1m** 4.68E+02	**sd%** 3.8

Table 7: Calculated top and bottom radial dose-rate profiles at contact and 1m for ^{192}Ir source

Source - Centred at bottom of cavity

Contact dose-rates at bottom

mean radial position (cm)	No insert		With insert LS-31x73-Tu		With insert LS-12x65-Tu	
	gamma dose	SD (%)	gamma dose	SD (%)	gamma dose	SD (%)
0	4.30E+06	0.1	1.67E+05	0.6	7.72E+04	0.9
7.5	1.78E+06	0.1	6.29E+04	0.6	2.81E+04	0.9
12.5	5.09E+05	0.2	1.61E+04	1.1	6.81E+03	1.6
16.9625	2.33E+05	0.3	8.21E+03	1.3	3.45E+03	2.1

1m dose-rates at bottom

mean radial position (cm)	No insert		With insert LS-31x73-Tu		With insert LS-12x65-Tu	
	gamma dose	SD (%)	gamma dose	SD (%)	gamma dose	SD (%)
0	4.22E+04	0.2	1.97E+03	1.0	9.74E+02	1.5
37.5	3.31E+04	0.1	1.43E+03	0.7	6.61E+02	1.1
62.5	2.14E+04	0.1	7.97E+02	0.8	3.45E+02	1.2
87.5	1.24E+04	0.2	4.08E+02	0.9	1.70E+02	1.4
109.5625	7.54E+03	0.2	2.29E+02	1.2	8.89E+01	2.0

Source - Centred at top of cavity

Contact dose-rates at top

mean radial position (cm)	No insert		With insert LS-31x73-Tu		With insert LS-12x65-Tu	
	gamma dose	SD (%)	gamma dose	SD (%)	gamma dose	SD (%)
0	9.25E+05	0.2	3.29E+04	1.3	1.50E+04	1.9
7.5	5.28E+05	0.2	1.65E+04	1.1	7.12E+03	1.6
12.5	1.31E+05	0.3	5.83E+03	1.5	2.71E+03	2.2
16.9625	6.59E+04	0.4	3.99E+03	1.8	1.55E+03	3.0

1m dose-rates at top

mean radial position (cm)	No insert		With insert LS-31x73-Tu		With insert LS-12x65-Tu	
	gamma dose	SD (%)	gamma dose	SD (%)	gamma dose	SD (%)
0	1.38E+04	0.4	5.33E+02	1.9	2.40E+02	2.9
37.5	1.07E+04	0.3	4.28E+02	1.3	1.92E+02	1.9
62.5	6.77E+03	0.2	2.02E+02	1.4	8.38E+01	2.2
87.5	3.20E+03	0.3	1.37E+02	1.4	5.54E+01	2.4
109.5625	2.12E+03	0.4	1.04E+02	1.7	3.69E+01	3.0

Table 8: Calculated top radial dose-rate profiles at contact and 1m for ^{192}Ir source (through point of maximum dose)

Source - Eccentred near top of cavity, lined up with air gaps

Contact dose-rates at top		
mean radial position (cm)	No insert	
	gamma dose	SD (%)
0.0	1.37E+06	0.2
7.5	2.03E+06	0.3
12.5	2.17E+06	0.3
16.9625	8.35E+05	0.4

1m dose-rates at top		
mean radial position (cm)	No insert	
	gamma dose	SD (%)
0.0	2.33E+04	0.3
37.5	2.57E+04	0.5
62.5	3.29E+04	0.4
87.5	1.82E+04	0.4
109.5625	9.63E+03	0.7

Table 9: Calculated side axial dose-rate profiles on contact for ^{192}Ir source (through point of maximum dose)

Contact dose-rates at side								
Axial position (cm)	source eccentred @ cavity mid-height						source eccentred @ cavity top	
	No insert		With insert LS-31x73-Tu		With insert LS-12x65-Tu		No insert	
	Gamma dose	SD (%)	Gamma dose	SD (%)	Gamma dose	SD (%)	Gamma dose	SD (%)
-14.275	5.77E+05	0.6	1.93E+04	3.2	2.82E+03	8.2	2.84E+05	0.9
-11.775	8.91E+05	0.5	3.36E+04	2.4	5.20E+03	6.1	4.30E+05	0.7
-9.275	1.32E+06	0.4	5.13E+04	1.9	7.78E+03	4.8	6.87E+05	0.5
-6.775	1.86E+06	0.3	7.69E+04	1.5	1.30E+04	3.6	1.08E+06	0.4
-4.275	2.38E+06	0.3	1.04E+05	1.3	1.75E+04	3.1	1.70E+06	0.3
-1.775	2.75E+06	0.2	1.19E+05	1.2	2.05E+04	2.9	2.48E+06	0.3
0.725	2.82E+06	0.2	1.21E+05	1.2	2.08E+04	2.9	3.02E+06	0.2
3.225	2.55E+06	0.3	1.05E+05	1.3	1.81E+04	3.1	3.00E+06	0.2
5.725	2.07E+06	0.3	8.09E+04	1.5	1.29E+04	3.7	3.29E+06	0.2
8.225	1.53E+06	0.3	5.65E+04	1.8	8.35E+03	4.6	2.84E+06	0.2
10.725	1.05E+06	0.4	3.45E+04	2.3	6.08E+03	5.5	2.01E+06	0.3
13.225	6.92E+05	0.5	2.13E+04	3.1	3.67E+03	7.4	1.03E+06	0.4
15.725	4.39E+05	0.7	1.31E+04	3.9	1.80E+03	11.2	7.94E+05	0.4
18.225	2.84E+05	0.9	7.00E+03	5.4	6.59E+02	16.3	7.04E+05	0.5
20.725	1.58E+05	1.2	3.05E+03	8.2	5.99E+02	19.2	6.35E+05	0.5
23.225	7.90E+04	1.7	1.97E+03	10.8	2.95E+02	26.8	4.80E+05	0.6

Table 10: Calculated side axial dose-rate profiles at 1m for ^{192}Ir source (through point of maximum dose)

1m dose-rates at side								
Axial position (cm)	source eccentred @ cavity mid-height						source eccentred @ cavity top	
	No insert		With insert LS-31x73-Tu		With insert LS-12x65-Tu		No insert	
	Gamma dose	SD (%)	Gamma dose	SD (%)	Gamma dose	SD (%)	Gamma dose	SD (%)
-109.325	9.08E+03	0.8	2.49E+02	4.9	3.40E+01	12.7	1.06E+04	0.7
-99.325	1.20E+04	0.8	3.48E+02	4.7	5.53E+01	11.5	1.38E+04	0.7
-89.325	1.52E+04	0.7	4.71E+02	4	7.17E+01	10.1	1.76E+04	0.6
-79.325	1.90E+04	0.6	6.97E+02	3.3	9.58E+01	8.6	2.22E+04	0.6
-69.325	2.33E+04	0.6	8.95E+02	2.9	1.53E+02	6.9	2.85E+04	0.5
-59.325	2.85E+04	0.5	1.15E+03	2.5	1.68E+02	6.4	3.58E+04	0.4
-49.325	3.40E+04	0.4	1.47E+03	2.2	2.49E+02	5.3	4.38E+04	0.4
-39.325	3.92E+04	0.4	1.76E+03	2	3.16E+02	4.7	4.94E+04	0.4
-29.325	4.40E+04	0.4	2.09E+03	1.8	3.82E+02	4.2	5.50E+04	0.3
-19.325	4.76E+04	0.4	2.33E+03	1.7	4.27E+02	4	5.36E+04	0.3
-9.325	5.00E+04	0.4	2.48E+03	1.6	4.47E+02	3.9	5.28E+04	0.3
0.675	5.08E+04	0.4	2.57E+03	1.6	4.68E+02	3.8	5.97E+04	0.3
10.675	4.94E+04	0.4	2.38E+03	1.7	4.41E+02	3.9	5.51E+04	0.3
20.675	4.62E+04	0.4	2.13E+03	1.8	3.97E+02	4.1	5.12E+04	0.3
30.675	4.14E+04	0.4	1.91E+03	1.9	3.15E+02	4.7	4.70E+04	0.4
40.675	3.66E+04	0.4	1.60E+03	2.1	2.63E+02	5.1	3.82E+04	0.4
50.675	3.13E+04	0.5	1.30E+03	2.3	2.19E+02	5.7	2.49E+04	0.5
60.675	2.57E+04	0.5	9.75E+02	2.7	1.57E+02	6.8	1.88E+04	0.6
70.675	2.11E+04	0.6	7.50E+02	3.2	1.26E+02	7.7	1.59E+04	0.6
80.675	1.70E+04	0.7	5.20E+02	3.8	9.93E+01	8.8	1.41E+04	0.7
90.675	1.35E+04	0.8	4.21E+02	4.3	5.96E+01	11.3	1.27E+04	0.7
100.675	1.07E+04	0.9	3.41E+02	4.8	4.13E+01	13.2	1.10E+04	0.8
113.275	8.15E+03	0.9	2.56E+02	4.9	2.79E+01	14.2	1.02E+04	0.7

Table 11 Calculated maximum dose-rates for liquid sources in Safkeg LS container

Dose-Rates in μSv/hr

Liquid Source 120Ci Mo-99

Location	Dose-rate	sd%	Location	Dose-rate	sd%
Top - Surface	4.82E+05	0.1	Top- 1m	6.23E+03	0.2
Side - Surface	2.46E+05	0.3	Side - 1m	5.82E+03	0.4
Bottom - Surface	1.39E+05	0.3	Bottom - 1m	2.97E+03	0.3
O Ring	2.65E+07	0.3			
Trapezoidal upstand	1.53E+06	0.3			

Liquid Source 300Ci Se-75

Location	Dose-rate	sd%	Location	Dose-rate	sd%
Top - Surface	1.59E+05	0.4	Top - 1m	1.60E+03	0.6
Side - Surface	2.52E+04	1.6	Side - 1m	4.94E+02	2.2
Bottom - Surface	7.43E+03	1.9	Bottom - 1m	1.66E+02	2.3
O Ring	2.88E+07	0.3			
Trapezoidal upstand	5.35E+05	0.8			

Liquid Source 100Ci Ho-166

Location	Dose-rate	sd%	Location	Dose-rate	sd%
Top - Surface	7.58E+04	0.1	Top - 1m	1.24E+03	0.2
Side - Surface	6.72E+04	0.3	Side - 1m	1.67E+03	0.3
Bottom - Surface	4.72E+04	0.2	Bottom - 1m	1.04E+03	0.2
O Ring	1.64E+06	0.4			
Trapezoidal upstand	2.09E+05	0.3			

Liquid Source 300Ci Lu-177

Location	Dose-rate	sd%	Location	Dose-rate	sd%
Top - Surface	6.44E+03	0.5	Top - 1m	5.59E+01	0.9
Side - Surface	8.50E+02	2.4	Side - 1m	1.61E+01	3.3
Bottom - Surface	3.22E+01	2.9	Bottom - 1m	1.75E+00	2.1
O Ring	2.07E+06	0.4			
Trapezoidal upstand	2.03E+04	1.1			

Liquid Source 100Ci Tl-201

Location	Dose-rate	sd%	Location	Dose-rate	sd%
Top - Surface	5.67E+02	0.8	Top - 1m	4.41E+00	3
Side - Surface	5.90E+01	3.9	Side - 1m	1.12E+00	5.4
Bottom - Surface	1.96E+00	4.9	Bottom - 1m	1.18E-01	3.6
O Ring	4.09E+05	0.4			
Trapezoidal upstand	1.61E+03	1.7			

Table 12: Calculated top radial dose-rate profiles at contact and 1m for liquid sources (through point of maximum dose)

Contact dose-rates at top										
mean radial position (cm)	**Mo-99**		**Se-75**		**Ho-166**		**Lu-177**		**Tl-201**	
	gamma dose	SD (%)	gamma dose	SD (%)	gamma dose	SD (%)	gamma dose	SD (%)	gamma dose	SD (%)
0	4.82E+05	0.1	1.59E+05	0.4	7.58E+04	0.1	6.44E+03	0.5	5.67E+02	0.8
7.5	3.02E+05	0.4	9.00E+04	1.0	5.07E+04	0.3	3.17E+03	1.5	2.38E+02	2.4
12.5	1.68E+05	0.4	4.65E+04	1.1	2.84E+04	0.4	1.48E+03	1.8	1.02E+02	3.0
16.9625	9.28E+04	0.6	2.31E+04	1.7	1.74E+04	0.5	7.45E+02	2.6	5.45E+01	4.1

1m dose-rates at top										
mean radial position (cm)	**Mo-99**		**Se-75**		**Ho-166**		**Lu-177**		**Tl-201**	
	gamma dose	SD (%)	gamma dose	SD (%)	gamma dose	SD (%)	gamma dose	SD (%)	gamma dose	SD (%)
0	6.23E+03	0.2	1.60E+03	0.6	1.24E+03	0.2	5.59E+01	0.9	4.27E+00	1.5
37.5	5.14E+03	0.5	1.39E+03	1.4	1.01E+03	0.5	4.80E+01	2.1	3.98E+00	3.1
62.5	3.95E+03	0.5	1.11E+03	1.3	7.50E+02	0.4	3.67E+01	1.9	3.31E+00	2.8
87.5	2.68E+03	0.5	7.47E+02	1.4	5.04E+02	0.5	2.52E+01	2.1	1.94E+00	3.2
109.5625	1.60E+03	0.7	3.70E+02	2.1	3.16E+02	0.6	1.25E+01	3.1	8.63E-01	5.1

Table 13: Calculated bottom radial dose-rate profiles at contact and 1m for liquid sources

Contact dose-rates at bottom										
mean radial position (cm)	**Mo-99**		**Se-75**		**Ho-166**		**Lu-177**		**Tl-201**	
	gamma dose	SD (%)	gamma dose	SD (%)	gamma dose	SD (%)	gamma dose	SD (%)	gamma dose	SD (%)
0	1.39E+05	0.3	7.43E+03	1.9	4.72E+04	0.2	1.22E+01	12.7	2.29E-01	65.2
7.5	5.75E+04	0.2	2.92E+03	1.8	2.28E+04	0.2	1.74E+01	5.5	7.87E-01	9.4
12.5	2.71E+04	0.3	1.36E+03	1.9	1.35E+04	0.2	2.32E+01	3.5	1.11E+00	6.7
16.9625	3.47E+04	0.2	1.65E+03	1.6	1.57E+04	0.1	3.22E+01	2.9	1.96E+00	4.9

1m dose-rates at bottom										
mean radial position (cm)	**Mo-99**		**Se-75**		**Ho-166**		**Lu-177**		**Tl-201**	
	gamma dose	SD (%)	gamma dose	SD (%)	gamma dose	SD (%)	gamma dose	SD (%)	gamma dose	SD (%)
0	2.97E+03	0.3	1.66E+02	2.3	1.04E+03	0.2	1.35E+00	5.7	6.38E-02	10.6
37.5	1.88E+03	0.2	1.15E+02	1.5	6.94E+02	0.2	1.29E+00	3.3	7.30E-02	6.0
62.5	1.15E+03	0.2	7.15E+01	1.4	4.78E+02	0.2	1.22E+00	2.7	7.51E-02	4.8
87.5	1.12E+03	0.2	7.00E+01	1.2	4.51E+02	0.1	1.58E+00	2.1	1.01E-01	3.7
109.5625	1.29E+03	0.2	7.44E+01	1.2	4.92E+02	0.1	1.75E+00	2.1	1.18E-01	3.6

Table 14: Calculated side axial dose-rate profiles at 1m for liquid sources (through point of maximum dose)

Contact dose-rates at side										
mean axial position (cm)	Mo-99		Se-75		Ho-166		Lu-177		Tl-201	
	gamma dose	SD (%)	gamma dose	SD (%)	gamma dose	SD (%)	gamma dose	SD (%)	gamma dose	SD (%)
-14.275	5.44E+04	0.8	2.28E+03	6	2.17E+04	0.5	4.01E+01	12.1	2.68E+00	19.8
-11.775	7.25E+04	0.7	3.31E+03	5	2.78E+04	0.4	5.49E+01	10.1	4.15E+00	17
-9.275	9.92E+04	0.6	4.99E+03	4.1	3.52E+04	0.4	8.02E+01	7.9	5.65E+00	14.5
-6.775	1.32E+05	0.5	6.81E+03	3.3	4.36E+04	0.3	1.05E+02	6.8	5.66E+00	12.9
-4.275	1.71E+05	0.4	9.77E+03	2.8	5.25E+04	0.3	1.50E+02	5.5	1.02E+01	9.8
-1.775	2.13E+05	0.4	1.43E+04	2.2	6.08E+04	0.3	2.75E+02	4.1	1.58E+01	7.4
0.725	2.46E+05	0.3	2.00E+04	1.8	6.72E+04	0.3	4.59E+02	3.2	3.48E+01	5
3.225	2.36E+05	0.3	2.39E+04	1.6	6.63E+04	0.3	5.71E+02	2.8	3.91E+01	4.8
5.725	2.13E+05	0.4	2.06E+04	1.8	5.79E+04	0.3	4.17E+02	3.2	2.51E+01	5.5
8.225	1.71E+05	0.4	1.75E+04	1.9	4.98E+04	0.3	3.61E+02	3.5	2.13E+01	6.1
10.725	1.22E+05	0.5	1.69E+04	1.9	3.60E+04	0.3	4.36E+02	3.1	2.52E+01	5.5
13.225	8.95E+04	0.5	1.72E+04	1.8	2.26E+04	0.4	5.05E+02	2.9	3.14E+01	5.2
15.725	8.82E+04	0.5	2.14E+04	1.6	1.81E+04	0.5	7.03E+02	2.5	4.18E+01	4.5
18.225	9.14E+04	0.6	2.52E+04	1.6	1.65E+04	0.5	8.50E+02	2.4	5.90E+01	3.9
20.725	8.13E+04	0.6	2.03E+04	1.8	1.50E+04	0.6	6.53E+02	2.8	4.75E+01	4.5
23.225	5.25E+04	0.8	1.11E+04	2.5	1.07E+04	0.7	3.38E+02	4.1	1.89E+01	7.6

Side dose-rates at 1m										
mean axial position (cm)	Mo-99		Se-75		Ho-166		Lu-177		Tl-201	
	gamma dose	SD (%)	gamma dose	SD (%)	gamma dose	SD (%)	gamma dose	SD (%)	gamma dose	SD (%)
-109.325	1.66E+03	0.8	9.80E+01	4.6	5.82E+02	0.6	2.31E+00	7.8	1.46E-01	13.8
-99.325	2.06E+03	0.8	1.30E+02	4.6	7.05E+02	0.6	2.88E+00	7.8	1.96E-01	13.4
-89.325	2.47E+03	0.7	1.49E+02	4.2	8.24E+02	0.5	3.76E+00	6.8	1.88E-01	13.4
-79.325	2.98E+03	0.7	1.92E+02	3.6	9.54E+02	0.5	4.21E+00	6.3	2.46E-01	11.4
-69.325	3.54E+03	0.6	2.42E+02	3.3	1.09E+03	0.4	5.11E+00	5.7	3.37E-01	9.7
-59.325	4.12E+03	0.5	3.05E+02	2.9	1.22E+03	0.4	7.96E+00	4.6	4.88E-01	8.1
-49.325	4.76E+03	0.5	3.62E+02	2.6	1.37E+03	0.4	8.42E+00	4.5	7.17E-01	6.6
-39.325	5.26E+03	0.5	4.29E+02	2.4	1.51E+03	0.4	9.57E+00	4.1	7.40E-01	6.4
-29.325	5.70E+03	0.4	4.60E+02	2.3	1.61E+03	0.3	1.16E+01	3.7	7.11E-01	6.5
-19.325	5.82E+03	0.4	4.82E+02	2.2	1.67E+03	0.3	9.69E+00	4	7.11E-01	6.4
-9.325	5.33E+03	0.4	4.56E+02	2.3	1.63E+03	0.3	9.29E+00	4	5.75E-01	7
0.675	4.90E+03	0.5	4.25E+02	2.4	1.53E+03	0.3	8.15E+00	4.3	5.43E-01	7.1
10.675	4.66E+03	0.5	4.25E+02	2.3	1.38E+03	0.4	8.78E+00	4.1	5.09E-01	7.3
20.675	4.02E+03	0.5	4.23E+02	2.3	1.25E+03	0.4	9.43E+00	3.9	4.64E-01	7.7
30.675	3.51E+03	0.5	4.31E+02	2.3	1.09E+03	0.4	9.89E+00	3.9	6.48E-01	6.5
40.675	2.87E+03	0.6	4.33E+02	2.2	8.75E+02	0.4	1.11E+01	3.7	5.88E-01	6.9
50.675	2.49E+03	0.6	4.43E+02	2.2	6.84E+02	0.5	1.21E+01	3.6	7.76E-01	6.1
60.675	2.31E+03	0.7	4.64E+02	2.2	5.62E+02	0.6	1.51E+01	3.3	9.27E-01	5.7
70.675	2.21E+03	0.7	4.94E+02	2.2	4.88E+02	0.6	1.61E+01	3.3	1.12E+00	5.4
80.675	2.03E+03	0.7	4.85E+02	2.2	4.33E+02	0.6	1.43E+01	3.5	9.90E-01	5.9
90.675	1.91E+03	0.8	4.29E+02	2.4	3.94E+02	0.7	1.38E+01	3.7	9.74E-01	6
100.675	1.76E+03	0.8	4.04E+02	2.5	3.57E+02	0.7	1.27E+01	3.9	9.95E-01	6
113.275	1.55E+03	0.8	3.55E+02	2.4	3.17E+02	0.7	1.16E+01	3.7	8.15E-01	6.1

Figure 1: MCBEND geometry for Safkeg LS transport container

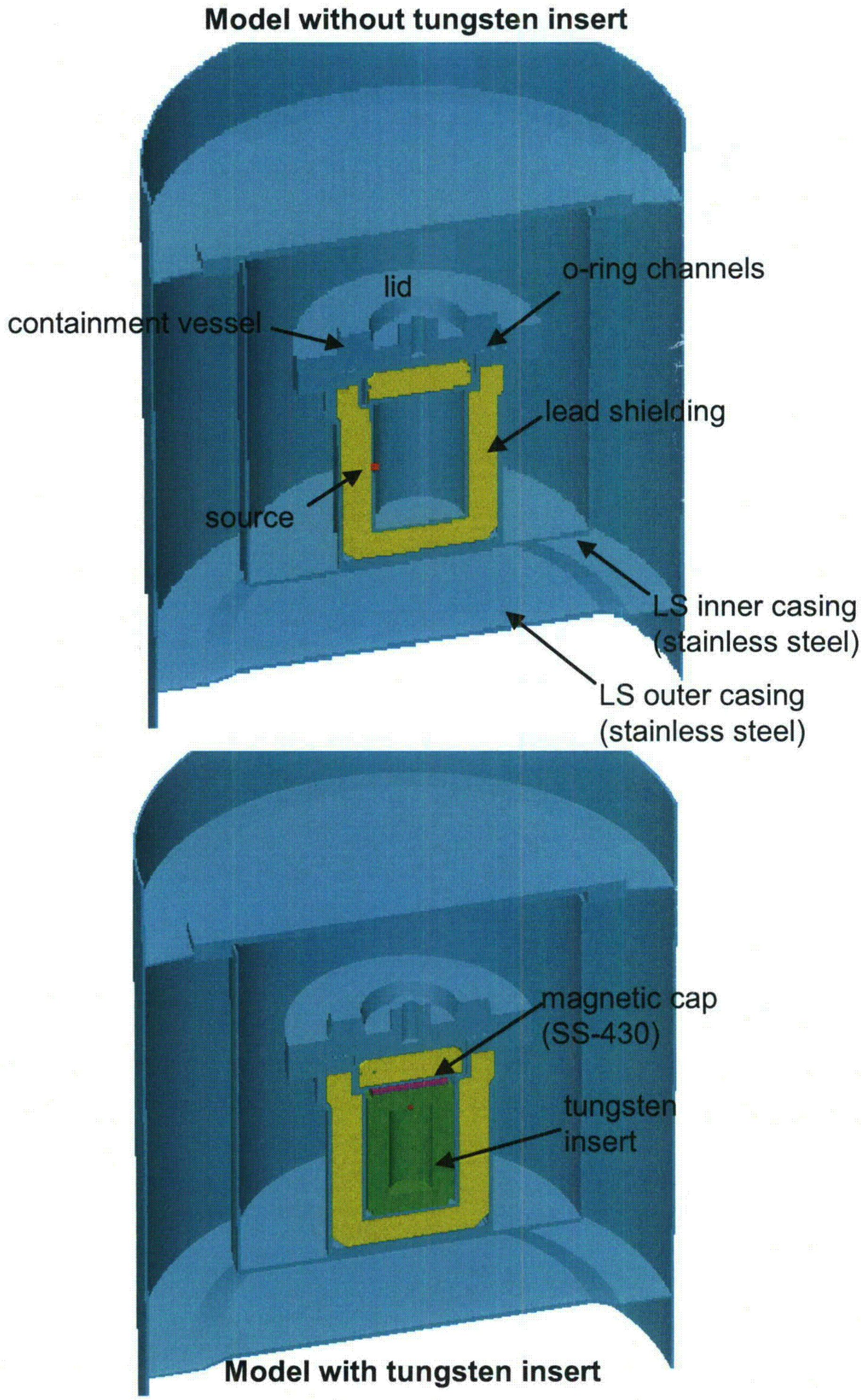


Figure 2: Slices through MCBEND model for Safkeg LS container without tungsten insert

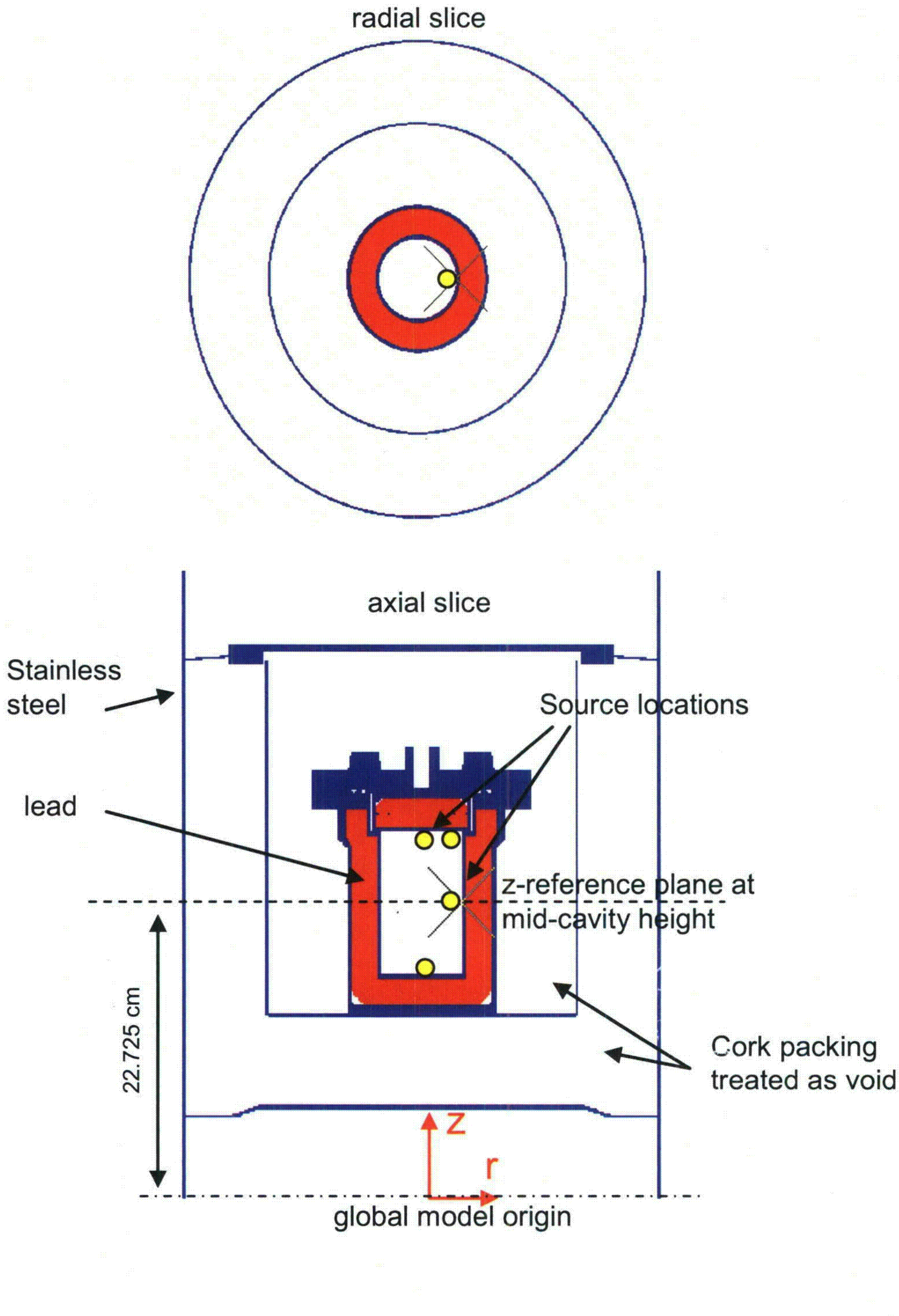


Figure 3: Slices through MCBEND model for Safkeg LS container with tungsten insert

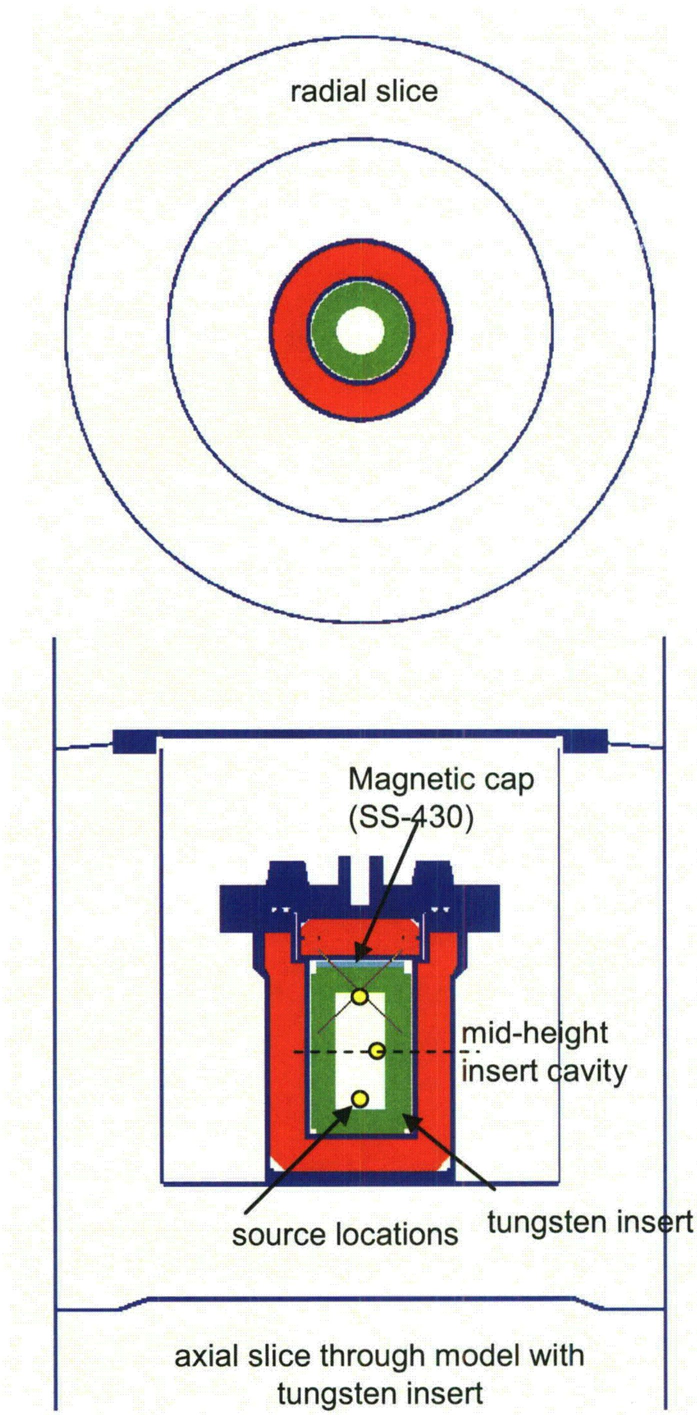


Figure 4: Slice showing Mo-99 liquid source and penetration to first o-ring seal

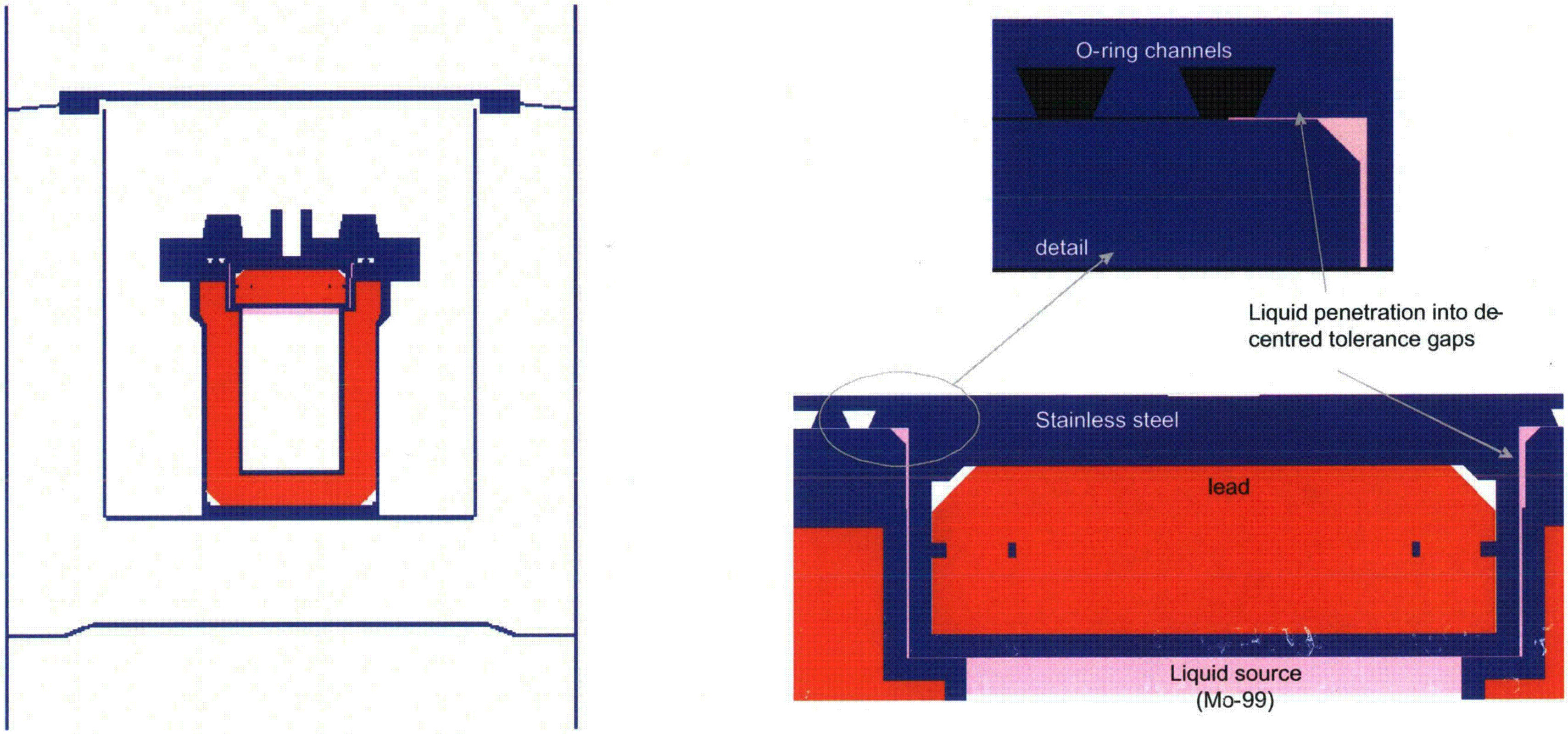


Figure 5: Slice showing liquid source filling gap due to worst case tolerance and eccentred lid

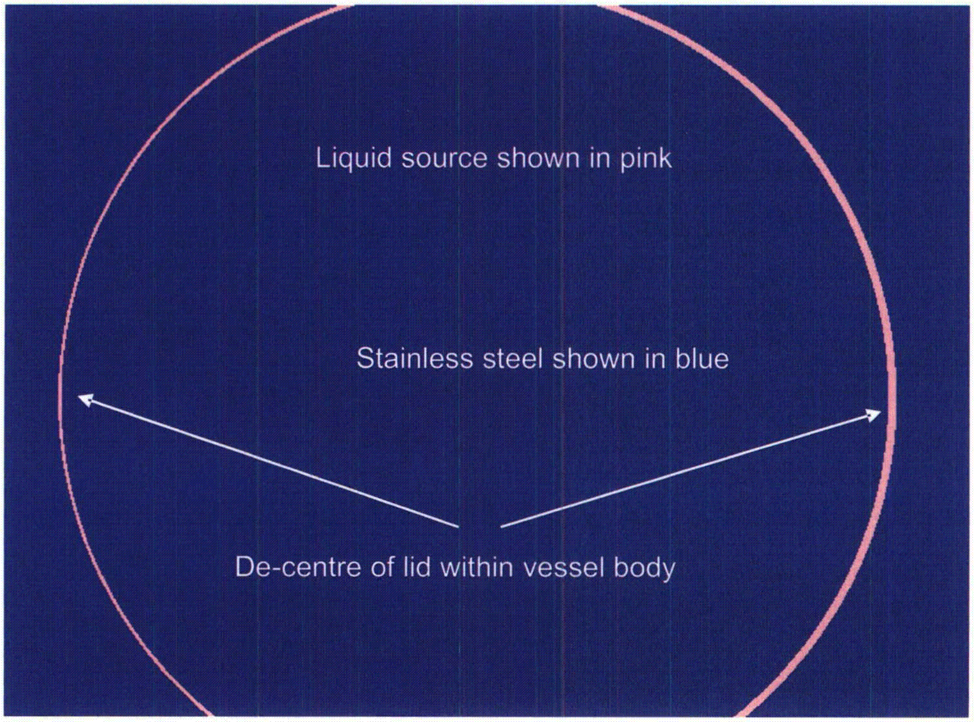


Figure 6: Radial dose-rate profiles at bottom surface and 1m for 192Ir source

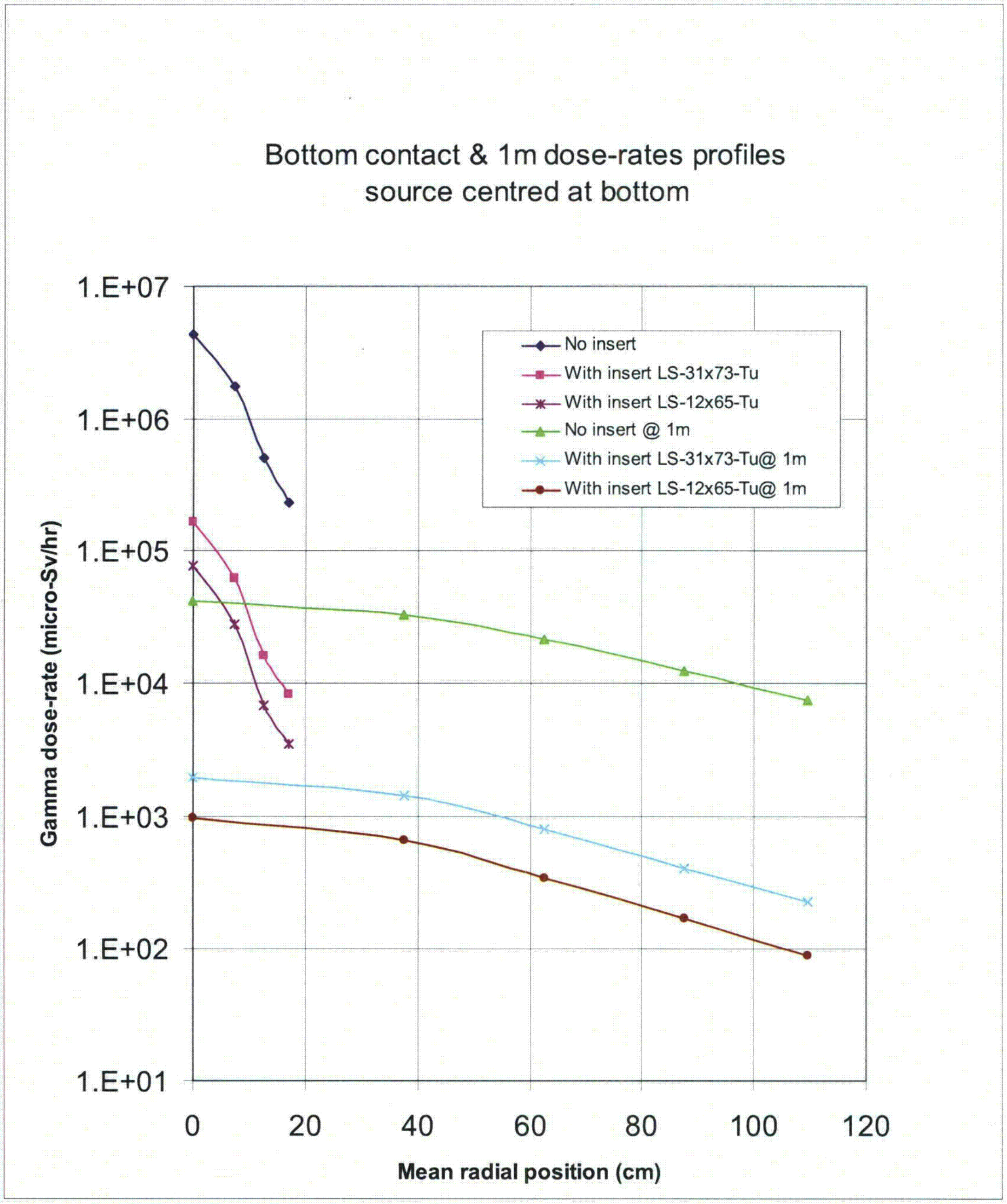


Figure 7: Radial dose-rate profiles at top surface and 1m for 192Ir source

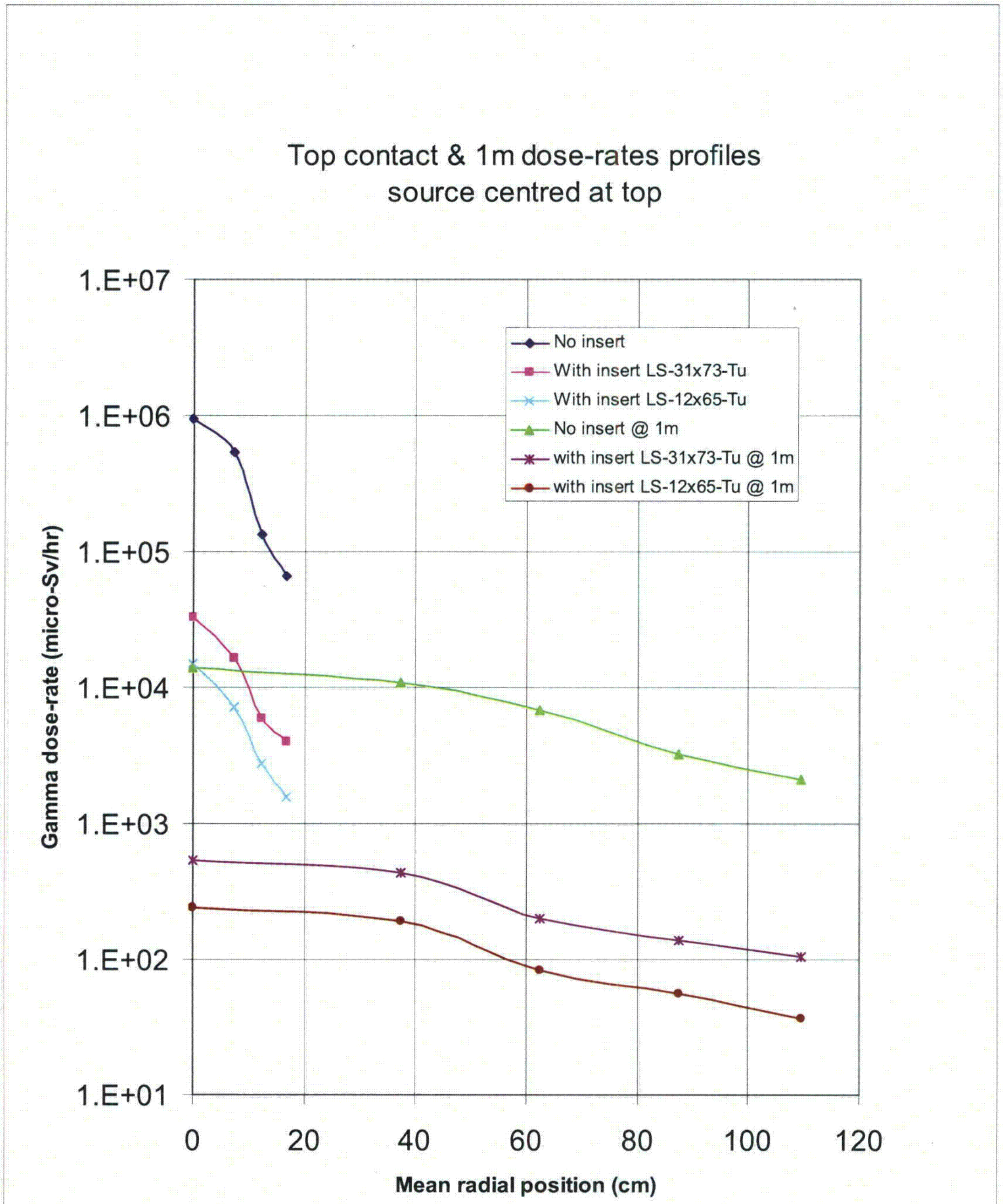


Figure 8: Radial dose-rate profiles at top surface and 1m for 192Ir source

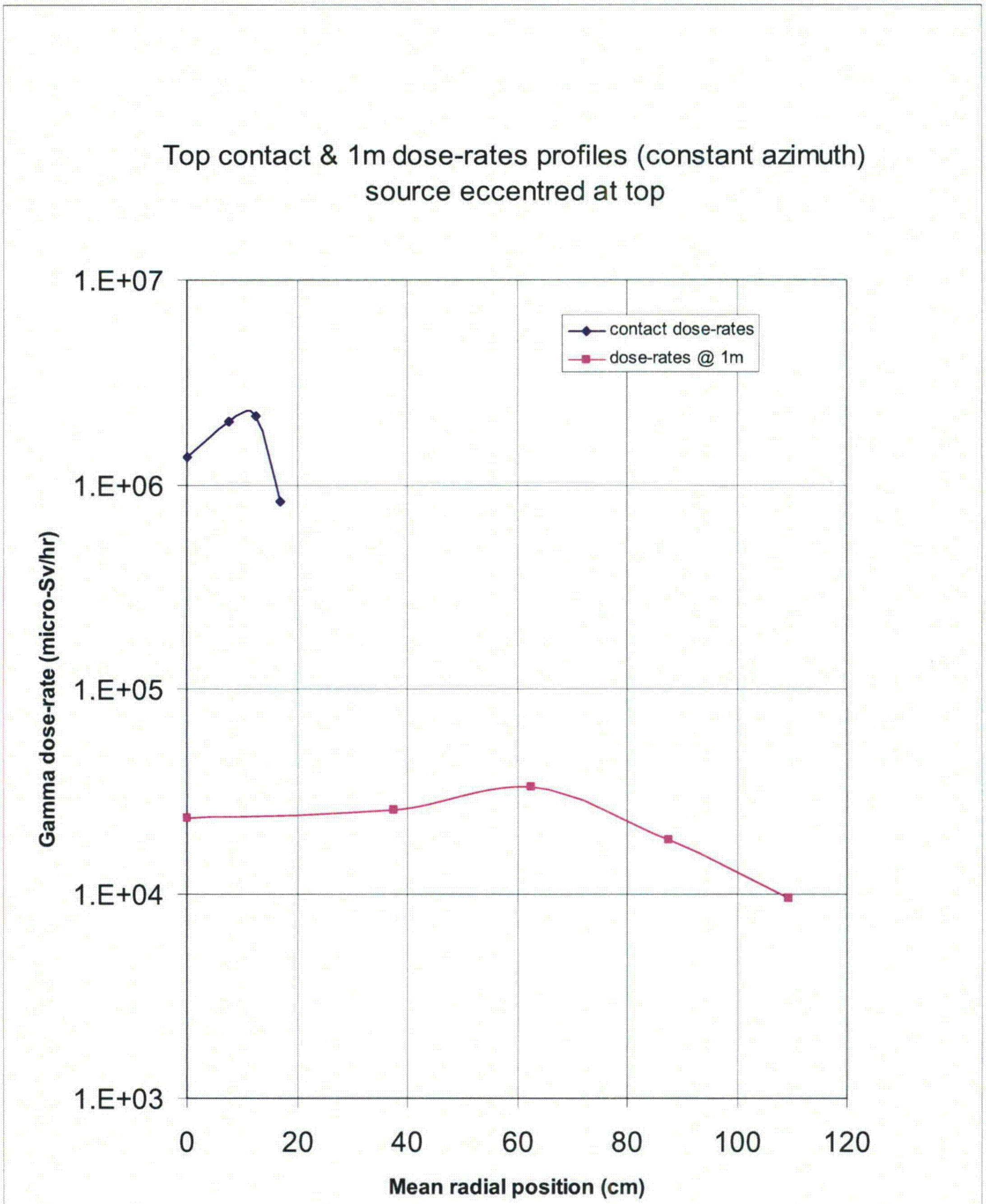


Figure 9: Axial dose-rate profiles at side surface for 192Ir source

Figure 10: Axial dose-rate profiles at 1m for 192Ir source

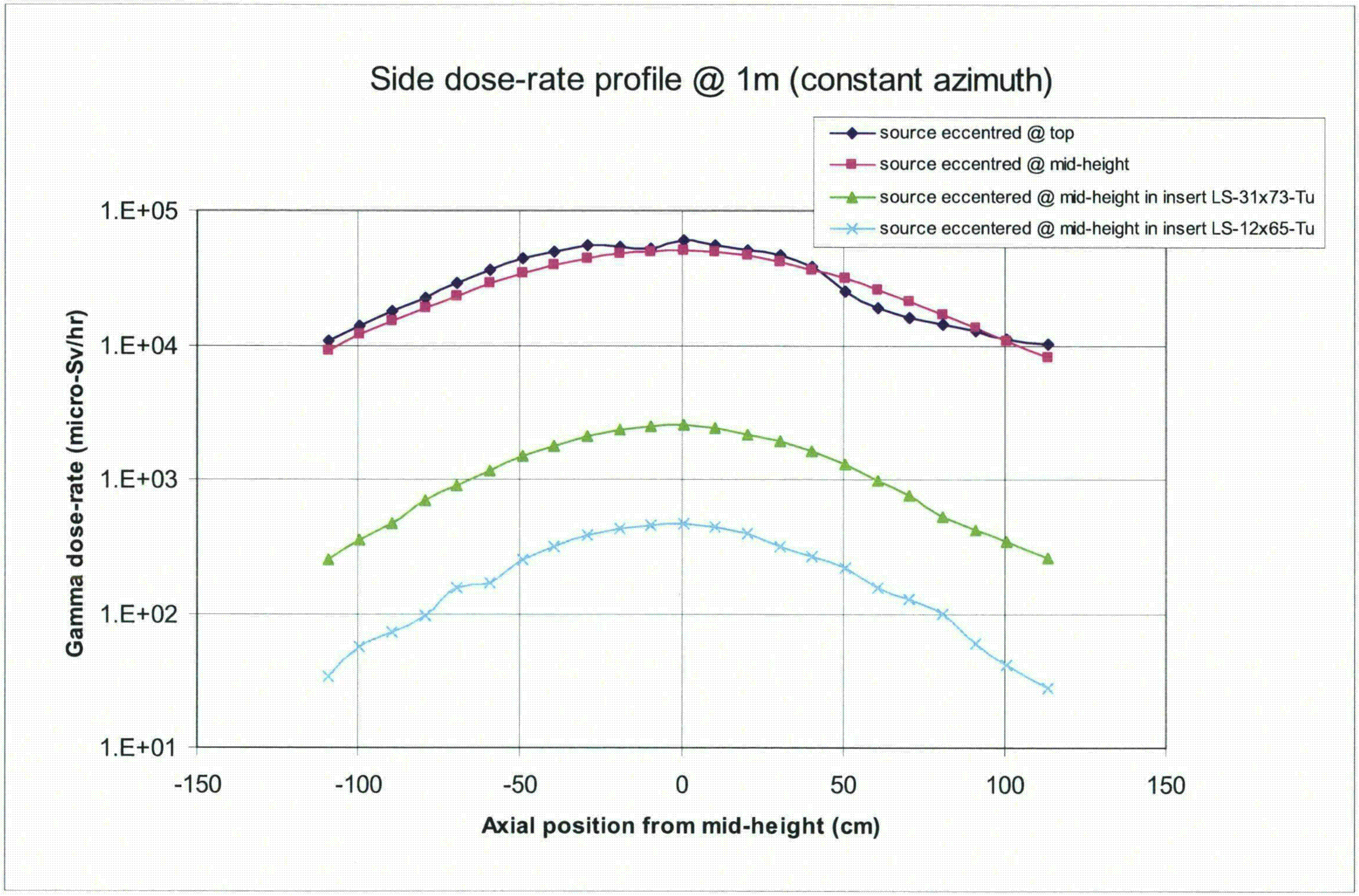


Figure 11: Radial dose-rate profiles at top surface and 1m for liquid sources

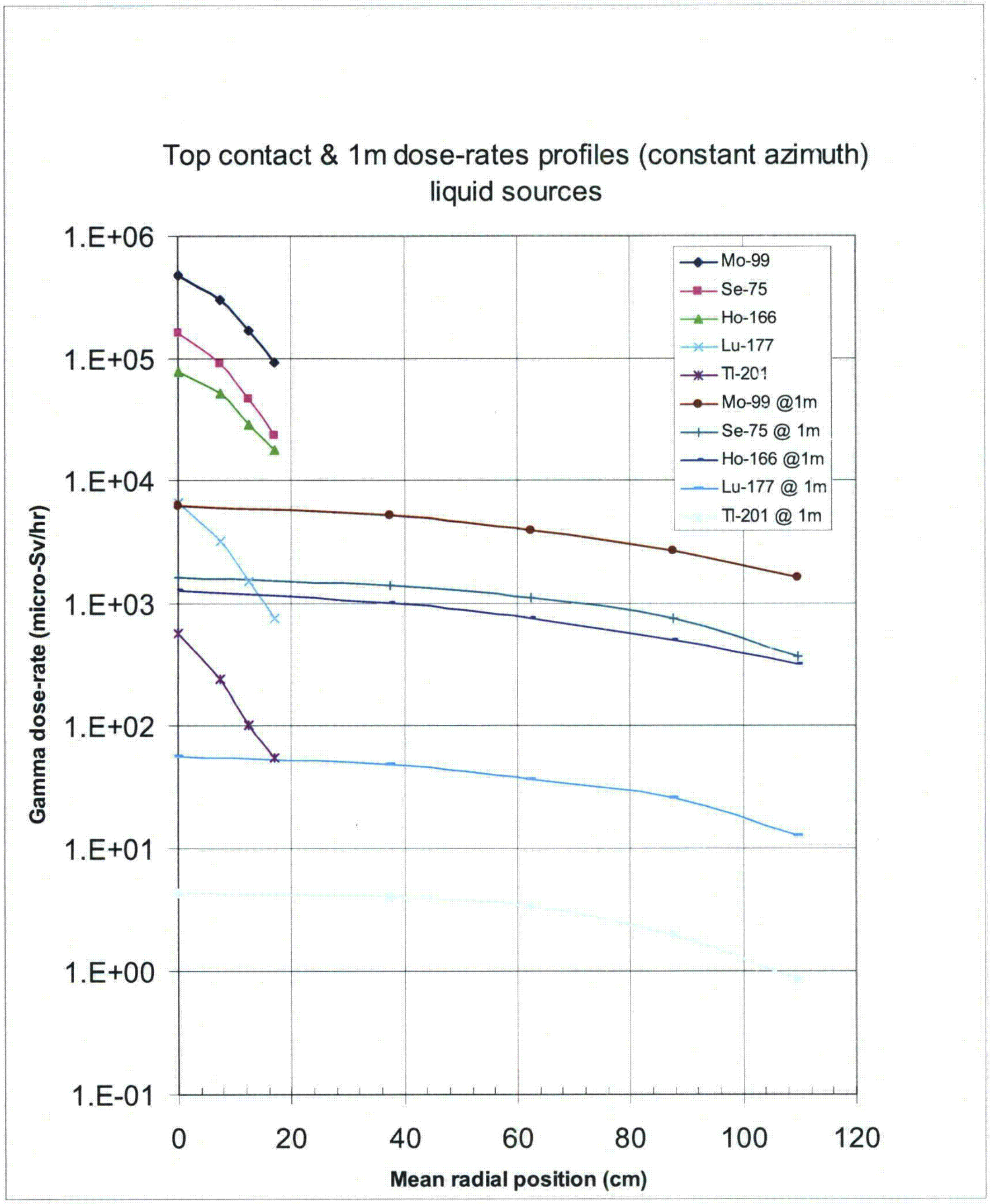


Figure 12: Radial dose-rate profiles at bottom surface and 1m for liquid sources

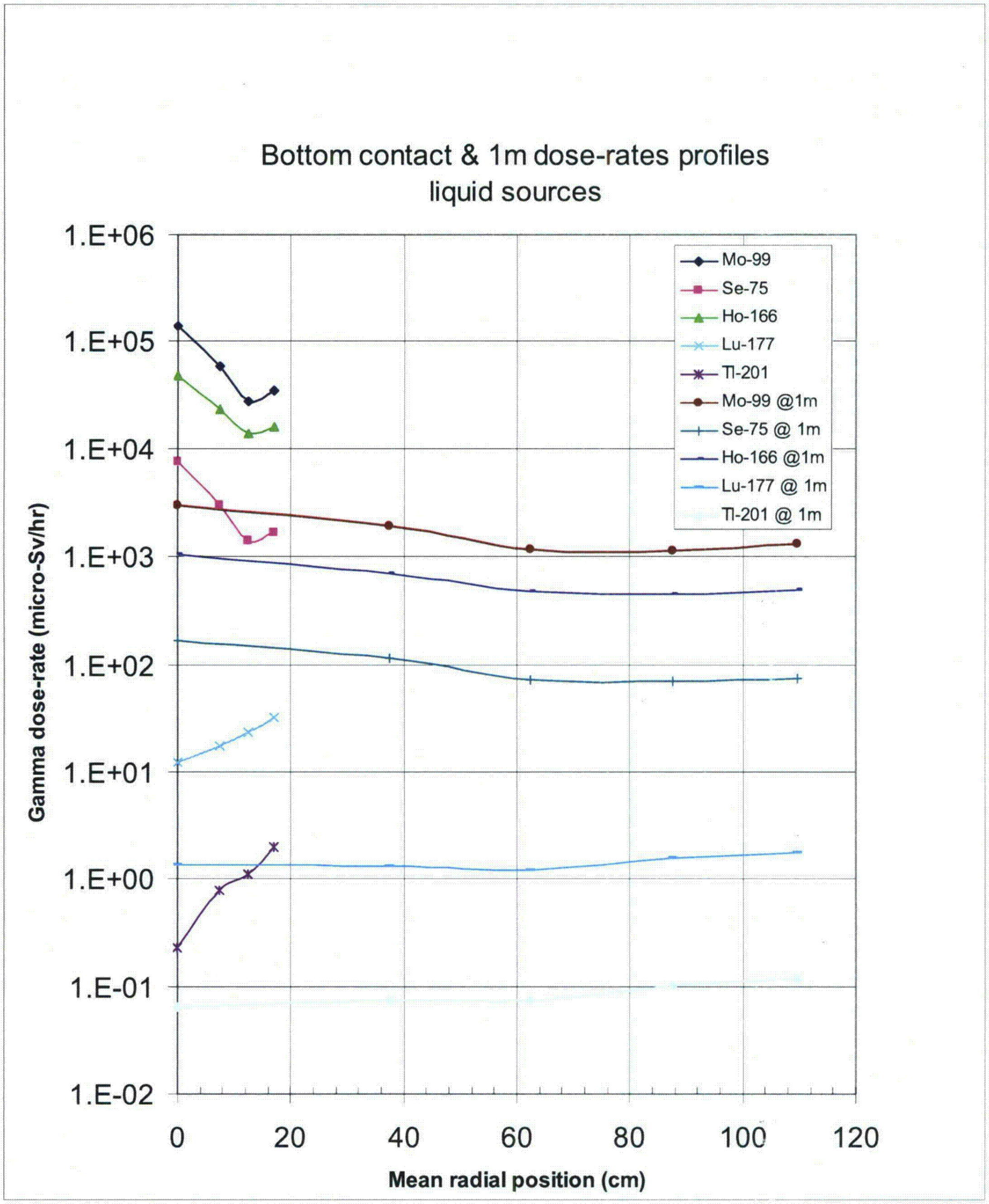
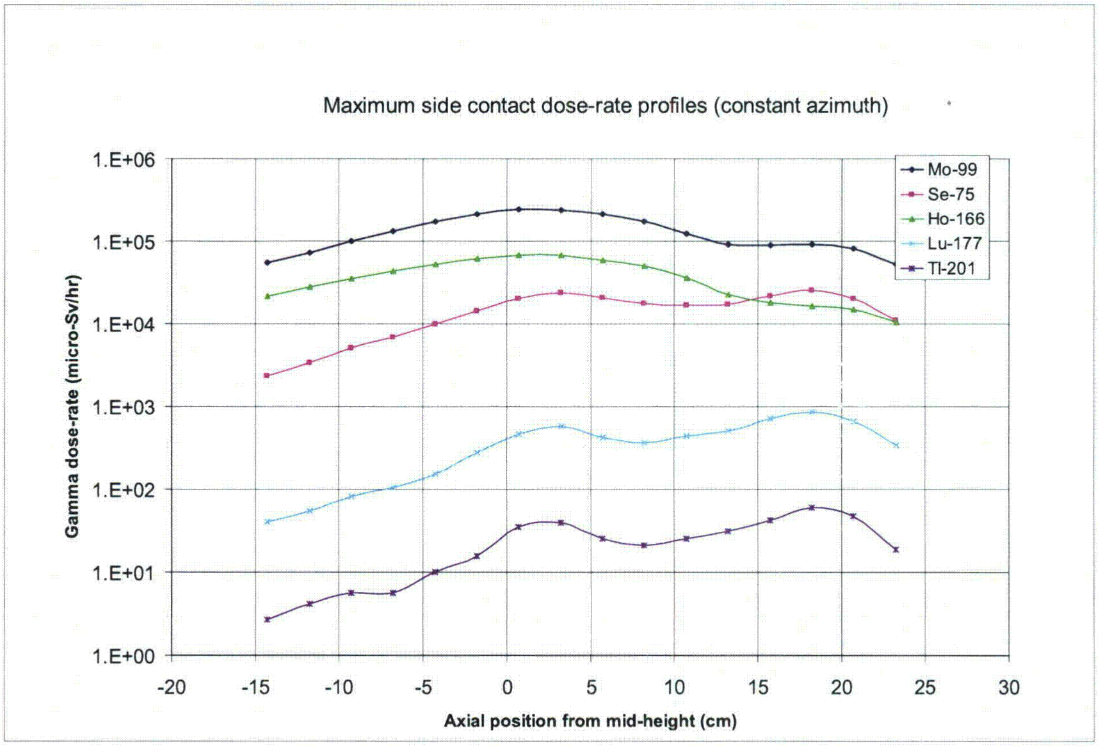
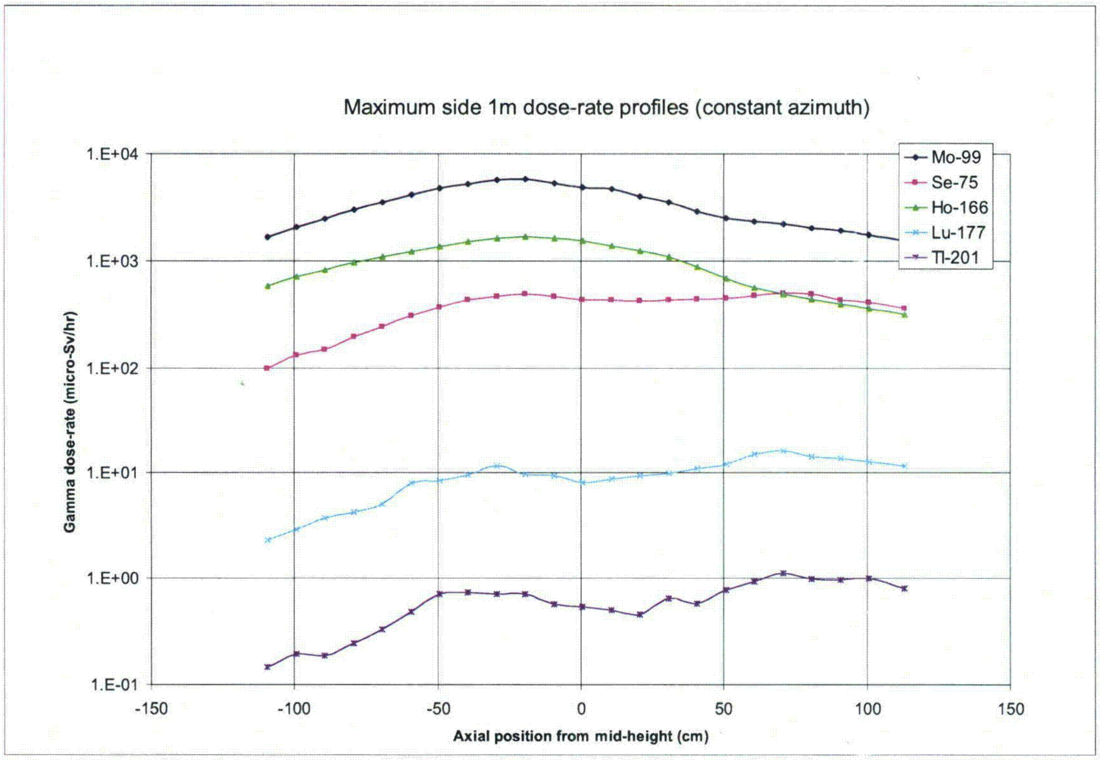


Figure 13: Axial dose-rate profiles at side surface and 1m for liquid sources





Appendix A

Croft Safkeg LS drawings

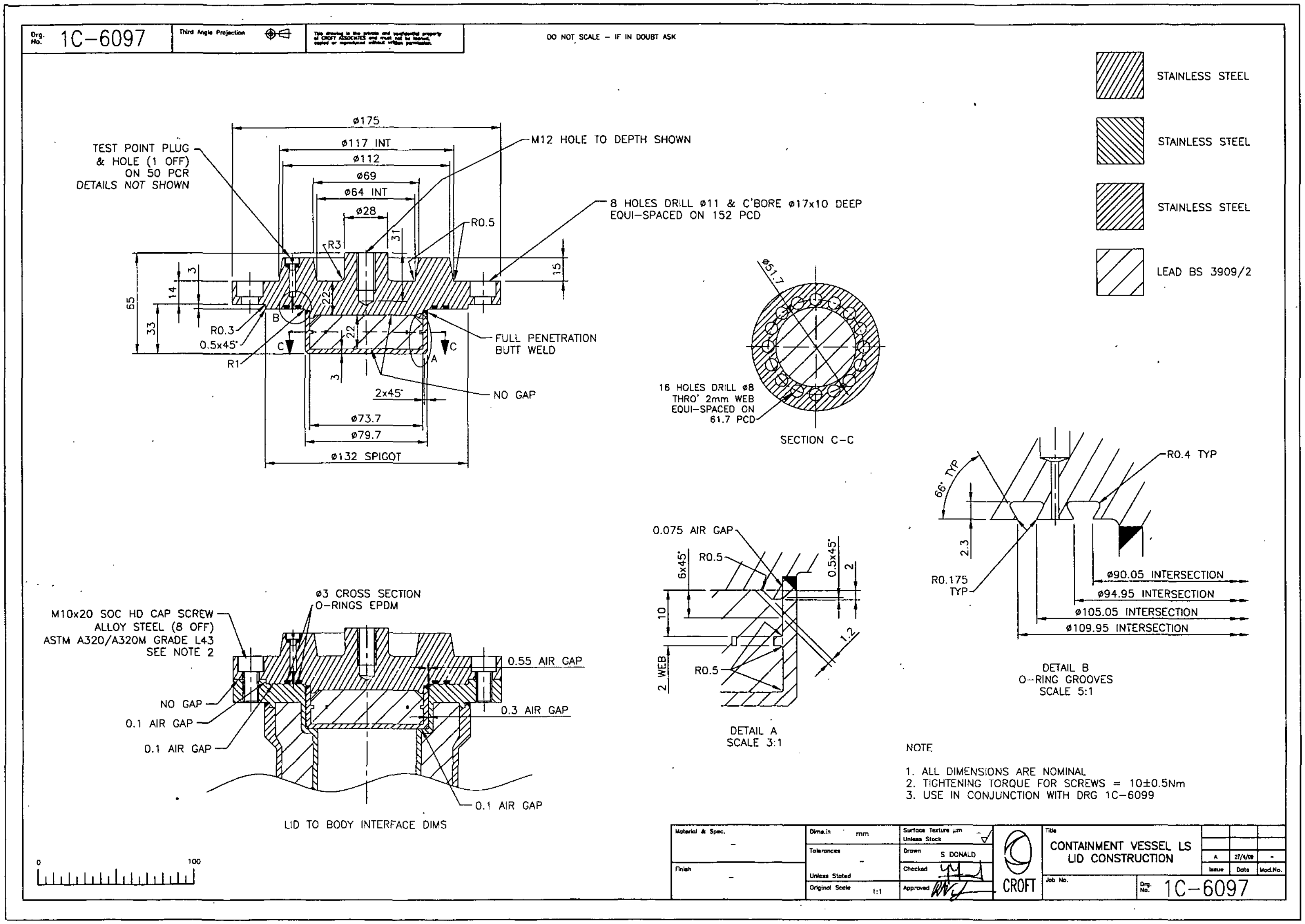
0C-6049, Issue A - Safkeg-LS Construction

1C-6099, Issue A - Containment Vessel LS Body Construction

1C-6097, Issue A - Containment Vessel LS Lid Construction

2C-6180, Issue A - LS-12x65-Tu Insert Design No. 3984 Prototype

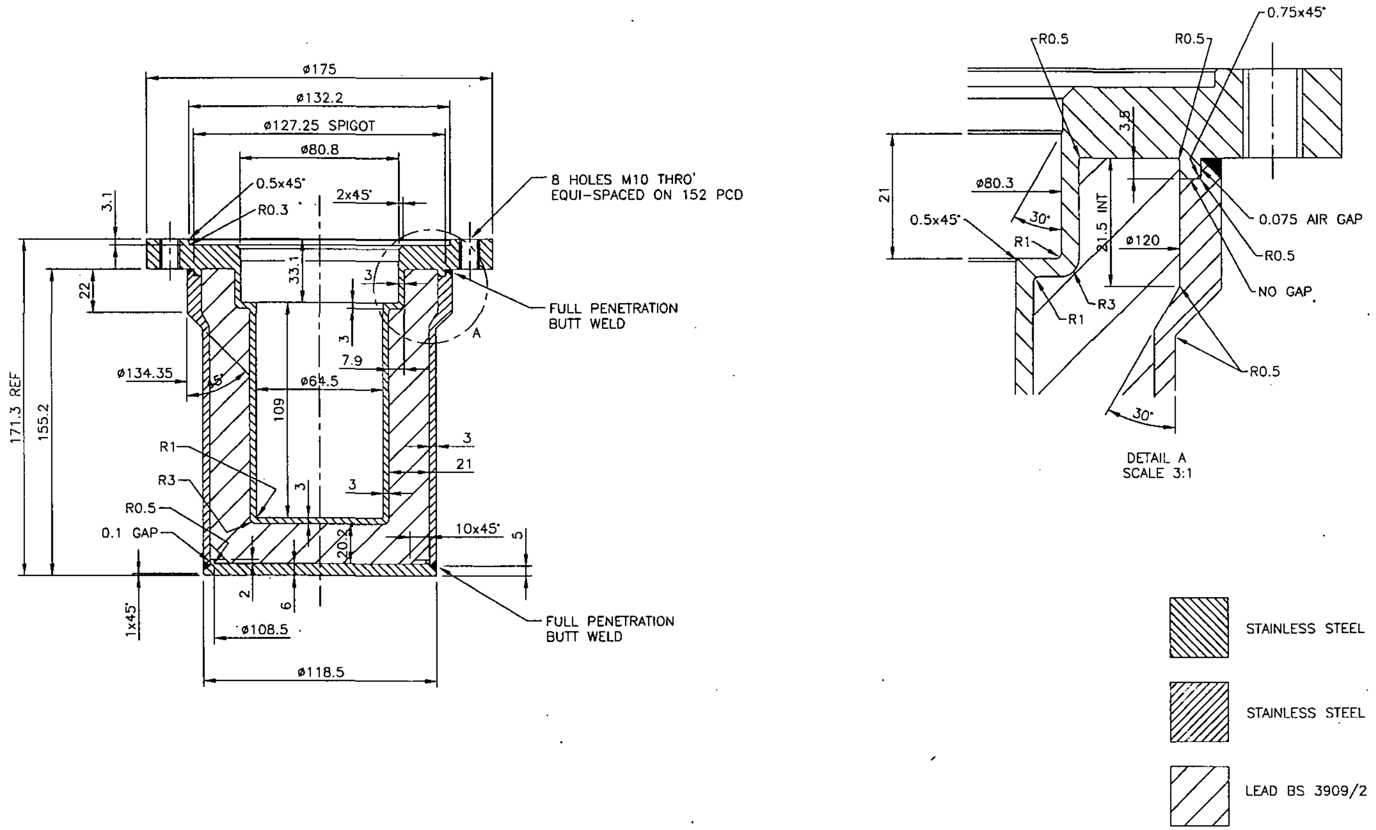
2C-5889, Issue A - LS-31x73-Tu Insert Design No. 3983 Prototype


Drg. No. 1C-6097
Third Angle Projection
DO NOT SCALE - IF IN DOUBT ASK
STAINLESS STEEL
STAINLESS STEEL
STAINLESS STEEL
LEAD BS 3909/2
ø175
ø117 INT
ø112
ø69
ø64 INT
ø28
M12 HOLE TO DEPTH SHOWN
TEST POINT PLUG & HOLE (1 OFF) ON 50 PCR DETAILS NOT SHOWN
8 HOLES DRILL ø11 & C'BORE ø17x10 DEEP EQUI-SPACED ON 152 PCD
R0.5
R3
31
15
65
14
33
3
22
R0.3
0.5x45°
R1
B
C
A
FULL PENETRATION BUTT WELD
NO GAP
2x45°
ø73.7
ø79.7
ø132 SPIGOT
ø51.7
16 HOLES DRILL ø8 THRO' 2mm WEB EQUI-SPACED ON 61.7 PCD
SECTION C-C
R0.4 TYP
66° TYP
2.3
R0.175 TYP
ø90.05 INTERSECTION
ø94.95 INTERSECTION
ø105.05 INTERSECTION
ø109.95 INTERSECTION
DETAIL B
O-RING GROOVES
SCALE 5:1
0.075 AIR GAP
R0.5
6x45°
0.5x45°
2
10
1.2
2 WEB
DETAIL A
SCALE 3:1
M10x20 SOC HD CAP SCREW ALLOY STEEL (8 OFF) ASTM A320/A320M GRADE L43 SEE NOTE 2
ø3 CROSS SECTION O-RINGS EPDM
0.55 AIR GAP
0.3 AIR GAP
NO GAP
0.1 AIR GAP
0.1 AIR GAP
0.1 AIR GAP
LID TO BODY INTERFACE DIMS
0
100
NOTE
1. ALL DIMENSIONS ARE NOMINAL
2. TIGHTENING TORQUE FOR SCREWS = 10±0.5Nm
3. USE IN CONJUNCTION WITH DRG 1C-6099
Material & Spec. -
Finish -
Dims.in mm
Tolerances -
Unless Stated
Original Scale 1:1
Surface Texture µm Unless Stated
Drawn S DONALD
Checked
Approved
CROFT
Title
CONTAINMENT VESSEL LS LID CONSTRUCTION
A 27/4/09 -
Issue Date Mod.No.
Job No.
Drg. No. 1C-6097

Third Angle Projection

This drawing is the private and confidential property of CROFT ASSOCIATES and must not be loaned, copied or reproduced without written permission.

DO NOT SCALE – IF IN DOUBT ASK

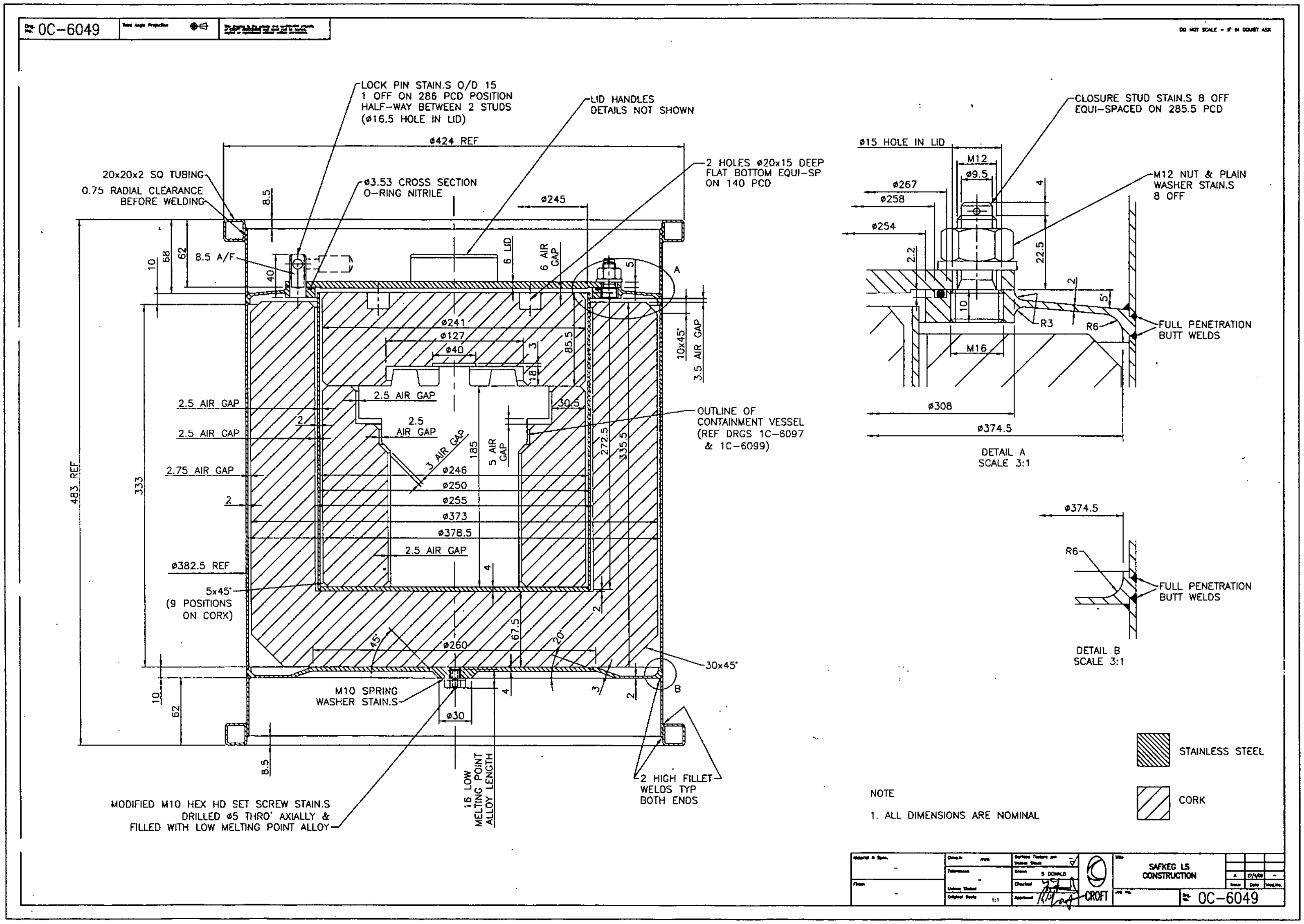


NOTE

1. ALL DIMENSIONS ARE NOMINAL
2. USE IN CONJUNCTION WITH DRG 1C-6097

0 100

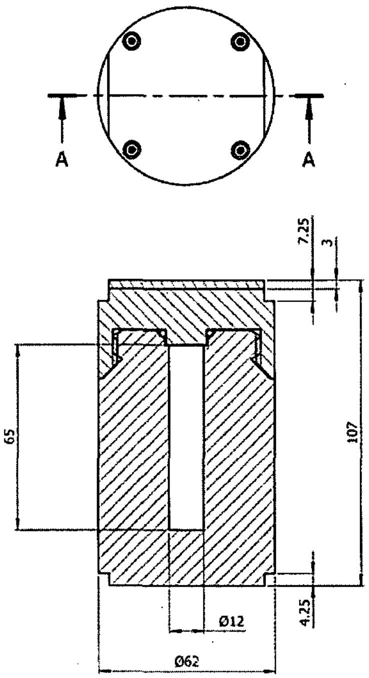
Material & Spec.	Dims.in mm	Surface Texture µm Unless Stock		Title
–	Tolerances – Unless Stated	Drawn S DONALD	CROFT	CONTAINMENT VESSEL LS BODY CONSTRUCTION
Finish –	Original Scale 1:1	Checked		Issue A, Date 27/4/08, Mod.No. –
		Approved		Job No. — Drg. No. 1C-6099



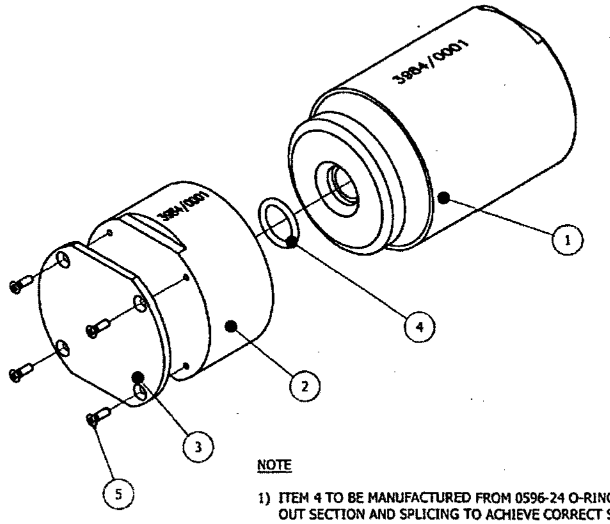
0C-6049
LOCK PIN STAIN.S O/D 15
1 OFF ON 286 PCD POSITION
HALF-WAY BETWEEN 2 STUDS
(ø16.5 HOLE IN LID)
LID HANDLES
DETAILS NOT SHOWN
ø424 REF
20x20x2 SQ TUBING
0.75 RADIAL CLEARANCE
BEFORE WELDING
ø3.53 CROSS SECTION
O-RING NITRILE
2 HOLES ø20x15 DEEP
FLAT BOTTOM EQUI-SP
ON 140 PCD
ø245
8.5 A/F
6 LID
6 AIR GAP
ø241
ø127
ø40
10x45°
3.5 AIR GAP
2.5 AIR GAP
2.5 AIR GAP
2.75 AIR GAP
3 AIR GAP
5 AIR GAP
OUTLINE OF
CONTAINMENT VESSEL
(REF DRGS 1C-6097
& 1C-6099)
ø246
ø250
ø255
ø373
ø378.5
ø382.5 REF
5x45°
(9 POSITIONS
ON CORK)
483 REF
333
ø260
30x45°
M10 SPRING
WASHER STAIN.S
ø30
2 HIGH FILLET
WELDS TYP
BOTH ENDS
MODIFIED M10 HEX HD SET SCREW STAIN.S
DRILLED ø5 THRO' AXIALLY &
FILLED WITH LOW MELTING POINT ALLOY
16 LOW MELTING POINT ALLOY LENGTH
CLOSURE STUD STAIN.S 8 OFF
EQUI-SPACED ON 285.5 PCD
ø15 HOLE IN LID
M12
ø9.5
ø267
ø258
ø254
M12 NUT & PLAIN
WASHER STAIN.S
8 OFF
R3
R6
M16
FULL PENETRATION
BUTT WELDS
ø308
ø374.5
DETAIL A
SCALE 3:1
ø374.5
R6
FULL PENETRATION
BUTT WELDS
DETAIL B
SCALE 3:1
STAINLESS STEEL
CORK
NOTE
1. ALL DIMENSIONS ARE NOMINAL
SAFKEG LS
CONSTRUCTION
S DONALD
CROFT
0C-6049

Drg. No. 2C-6180	Third Angle Projection	This drawing is the private and confidential property of CROFT ASSOCIATES and must not be loaned, copied or reproduced without written permission.	DO NOT SCALE - IF IN DOUBT ASK

Item	Drawing No.	Description	No. Off
1	2C-6177	LS-12x65-Tu INSERT BODY - PROTOTYPE	1
2	2C-6178	LS-12-65-Tu INSERT TOP - PROTOTYPE	1
3	3C-6179	LS-Tu MAGNETIC CAP - PROTOTYPE	1
4	THIS	O-RING BS4518 0136-24 - NBR - 70IRHD	1
5	THIS	CSK HD SCREW - BS 4183 - M2.5 x 8 - Zn PL. STEEL	4



SECTION A-A



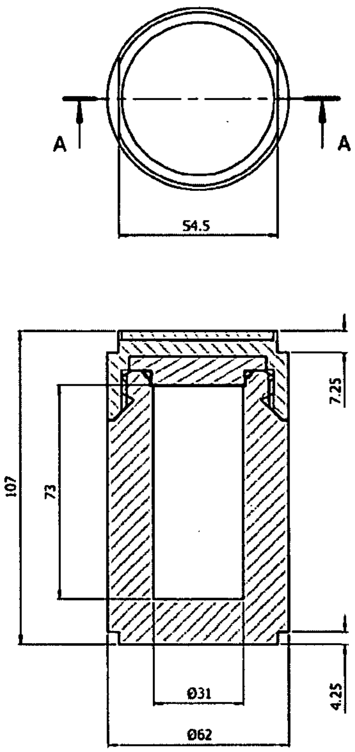
NOTE

1) ITEM 4 TO BE MANUFACTURED FROM 0596-24 O-RING BY CUTTING OUT SECTION AND SPLICING TO ACHIEVE CORRECT SIZE. CUT EDGES TO BE ADHERED USING SUITABLE CYANOACRYLATE ADHESIVE.

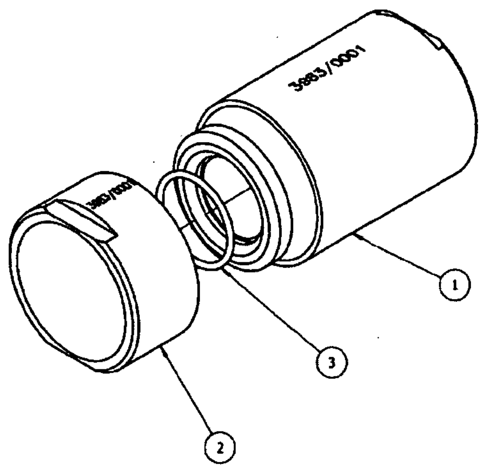
Material & Spec.	Dims.in mm	Surface Texture Unless Stock		Title LS-12x65-Tu INSERT DESIGN No. 3984 PROTOTYPE			
-	Tolerances ±0.5 ANG ±1° Unless Stated	Drawn TIM FROUD	CROFT		A	9/04/09	-
Finish CLEAN		Checked			Issue	Date	Mod.No.
	Original Scale 1:1	Approved		Job No.	Drg. No. 2C-6180		

Drg. No. 2C-5889	Third Angle Projection	This drawing is the private and confidential property of CROFT ASSOCIATES and must not be loaned, copied or reproduced without written permission	DO NOT SCALE - IF IN DOUBT ASK

Item	Drawing No.	Description	No. Off
1	2C-5894	LS-31x73-Tu INSERT BODY	1
2	2C-5895	LS-31x73-Tu INSERT TOP ASSY	1
3	0316-24	O-RING BS4518 0316-24 - NBR - 70 IRHD	1



SECTION A-A



Material & Spec. –	Dims.in mm	Surface Texture Unless Stock	CROFT	Title LS-31x73-Tu INSERT ASSY DESIGN No. 3983	Issue A, Date 18/06/03, Mod.No.
Finish CLEAN	Tolerances ±0.5 ANG ±1° Unless Stated	Drawn TIM FROUD		Job No.	Drg. No. 2C-5889
	Original Scale 1:1	Checked / Approved			

SERCO/TAS/00391/001 Issue 1

Distribution

R Vaughan	Croft Associates Ltd
P Cowan	Serco, Winfrith
D Picton	Serco, Winfrith
NSER Database	Serco, Winfrith

CONTENTS

6 CRITICALITY EVALUATION

This section specifies the requirements for fissile contents for the Safkeg-LS 3979A package which are restricted to solids as Contents Type CT-7 as specified in Section 1.2.2 and Table 1-3-7.

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 specified in Section 1.2.2 and Table 1-3-7 have to be met.

6.2.2 Fissile material under General License 71.22

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

Note that the other requirements of CT-7 specified in Section 1.2.2 and Table 1-3-7 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-7 specified in Section 1.2.2 and Table 1-3-7 on the basis of the General license in 10 CFR 71.23.

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

6.3 General Considerations

Not required as the limited quantities of fissile material specified in 10CFR 71.15, 10CFR 71.22, 10CFR 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, 10CFR 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, 10CFR 71.22, 10CFR 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 10CFR 71.15, 10CFR 71.22, 10CFR 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 10CFR 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-LS 3979A package, and preparation of an empty package for transport.

Each packaging user shall load, unload, and prepare the package for transport in accordance with 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 835 [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.

Each packaging user is required to notify the SARP owner of any instance in which the packaging fails to meet the criteria of Section 7.1.3 during use.

All drawings referred to in this section are included in Section 1.3.2 of the SARP.

7.1 Package Loading [71.87]

This section provides the minimum requirements required in order 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) 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.

2) 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.

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

4) The containment vessel shall be removed from within the inner cork. The recommended method for lifting the containment vessel is using a 12 mm eye bolt threaded into the containment vessel lid.

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

6) 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.

7) The model/serial numbers of the containment vessel assembly (body and lid) shall be checked to ensure they match. 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 system, the complete packaging shall be subjected to maintenance in accordance with the requirements of Section 8.2.

8) 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.

9) 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-6044. If the O-rings are acceptable, lubricate with a light film of silicone O-ring lubricant.

10) 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.

11) The model/serial numbers of the keg assembly (keg body and keg lid) shall be checked to ensure they match: where the model/serial numbers of the containment vessel assembly (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.

12) The outer surfaces of the keg body and lid shall be visually inspected for unacceptable defects. Unacceptable defects are dents greater than 8.9 mm in depth, penetration of the keg body, abrasion/scratches greater than half the thickness of the keg shell (the shell thickness is 2mm) or cracks in the accessible welds.

13) 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-6042), closure studs (item 16, drawing 0C-6042), closure nuts/washers (item 14 and 15, drawing 0C-6042) shall be replaced, if missing or damaged.

14) 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.

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 Section 1.2.2 of this SARP and 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. stainless steel 304L, tungsten, silicon O-ring).

3) From the contents type to be shipped, determine the insert required for the shipment in accordance with Table 1-2 in Section 1.2.2.3 .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, if not it, shall be replaced.

4) Check that the contents meet the restrictions for its content type as listed in tables 1-3-1 to 1-3-8 and Tables 1-4-1 to 1-4-8 in Section 1.2.2.3.

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

6) Load the contents into the insert and fit the insert lid ensuring that it is hand tight and cannot tighten any further. Load the insert into the containment vessel.

7) 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 from 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 3979 in the following order: inner cork, containment vessel, ensuring that the containment vessel sits down on the keg liner. Finally insert the top cork ensuring that it is no higher than the surface of the keg closure flange.

4) 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.

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

6) 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.

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

8) 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.

9) 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.

10) 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.

11) 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 and 7.2.2.

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) The containment vessel shall be lifted from the keg using a 12 mm diameter eyebolt threaded into the lid. 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) The insert shall be removed from the containment vessel. The insert has a magnetic top surface to facilitate removal.

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 and insert 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.

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 and the insert. If the non fixed surface contamination exceeds the requirements of 10 CFR 71.87 and 49 CFR 173.443 then decontaminate the containment vessel.

2) The insert shall be placed into the cavity of the containment vessel. 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.

3) The inner cork packing and containment vessel shall be fitted into Keg 3979 in the following order: inner cork, containment vessel, ensuring that the containment vessel sits down on the keg liner. Finally insert the top cork ensuring that it is no higher than the surface of the keg closure flange.

4) 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.

5) A contamination survey of the external surfaces of the package shall be performed. Determine if the surface contamination levels meet the requirements of 10 CFR 71.87 and 49 CFR 173.443. If not clean the outside of the package and repeat the contamination survey.

6) 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.

7) 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 835, 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-LS 3979A 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.

All drawings referred to in this section are included in Section 1.3.2 of the SARP.

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.

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.

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 Section 1.3.3. 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-6042. The containment vessel welds shall be examined in accordance with drawings 1C-6045 and 1C-6046. 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], except that the pressure shall be 1.5 x design pressure in accordance with 10 CFR 71.85(b) [8.1]. These tests shall be conducted at 10.5 bar gauge (152 psig) which is 1.5 times the nominal design pressure of 7 bar gauge (102 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.

Non-conforming components shall be rejected and controlled for rework, or scrapped and replaced. Components that are reworked or replaced shall meet the specifications in the manufacturing drawings and specifications referenced in the certificate and Section 1 of the SARP.

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]. Leak rate testing shall be performed using the evacuated envelope gas detector method 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 in the manufacturing drawings and specifications referenced in the certificate and Section 1 of the SARP.

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 68 kg (150 lbs). Any non-conforming packages shall be reworked or rejected.

8.1.5.2 Containment Vessel Inner O-ring seal

In addition to ensuring that the EPM inner O-ring seal meets the specification in drawing 1C-6044, the critical characteristic of ability to remain leaktight, after 24 hours in a test rig representing the CV at 200°C, shall be established by a batch test on procurement.

8.1.5.3 Containment Vessel Lid Top

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

8.1.5.4 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 5×10^{-8} ref.cm^3/s air and the acceptance leak rate shall be 1×10^{-7} ref-cm^3/s. Any non-conforming components not meeting this criterion shall be reworked or rejected.

8.1.5.5 Cork

Each batch of the inner, outer and top cork shall be tested and meet the following criteria:

- Specific weight of 250 to 290 kg/m^3, tested to ISO 7322 [8.4].
- Tensile strength $\geq$ 0.8 MPa, tested to ASTM F152 [8.5].
- Recovery $\geq$ 75%, tested to ASTM F36 [8.6].
- Compression of 15 – 30%, tested to ASTM F36 [8.6].

Any cork not meeting these criteria shall be rejected.

8.1.5.6 Lead Shielding

A full chemical analysis shall be carried out for each batch of lead. The chemical composition shall be analyzed to ensure that the lead meets the specification of the British Standard, BS 3909/2 [8.7].

8.1.5.7 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-6045 and 1C-6046.

The integrity testing shall be a helium leakage test in accordance with the gas filled envelope test A.5.3 in ANSI N14.5 [8.3]. This ensures the material is leak tight prior to 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 material not meeting these criteria shall be rejected.

8.1.6 Shielding Tests

Shielding is provided by the inserts and lead in the containment vessel body. 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.

The lead shielding shall be checked for defects by placing a small iridium source (essentially a point source) in approximately the centre of the containment vessel cavity. The iridium source shall be held in a polyethylene spacer and a radiation survey shall be carried out on the outside of the containment vessel.

Shielding integrity testing identifies weakness in the lead (e.g. porosity, inclusions, blowholes, gaps between successive pours, airlocks and shrinkage cavities) and the complete fill of the cavity. The acceptance criteria shall be < 20% increase in the radiation count rate.

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 3979A 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.

Any non-conforming components shall be rejected and controlled for rework, or scrapped and replaced. Components that are reworked or replaced shall meet the specifications in the manufacturing drawings and specifications referenced in the certificate and Section 1 of the SARP.

The 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 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 5×10^{-8} ref.cm^3/s and the test pass rate shall be 1×10^{-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-6044) 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-6044), 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 matched: 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 greater than 8.9 mm (1 in.) in depth; cracking of welded joints; penetration of the keg skin; or abrasion or scratches greater than half the thickness of the keg skin [shell thickness is 2 mm (0.080 in.)].

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-6042. 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-6042.

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-6042.

8. Nonconforming components shall be rejected and controlled for rework, or scrapped and replaced. Components that are reworked or replaced shall meet the specifications in the manufacturing drawings and specifications referenced in the certificate and Section 1 of the SARP.

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 be matched: 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-6044 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 in accordance with drawing 1C-6044. In addition to ensuring that the EPM inner O-ring seal meets the specification in drawing 1C-6044, the critical characteristic of ability to remain leaktight, after 24 hours in a test rig representing the CV at 200°C, shall be established by a batch test on procurement.

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. Nonconforming components shall be rejected and controlled for rework, or scrapped and replaced. Components that are reworked or replaced shall meet the specifications in the manufacturing drawings and specifications referenced in the certificate and Section 1 of the SARP.

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 drawing 0C-6043 and specifications referenced in the certificate and Section 1 of the SARP.

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 be matched: 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 on drawing 2C-6171, 2C-6172 and 2C-6175 and the specifications referenced in the certificate and Section 1 of the SARP.

7. 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 Section 1.3.2.

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**
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	
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	
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.

[8.4] ISO 7322:2000, Composition Cork – Test methods, International Standards Organization.

[8.5] ASTM F152 – 95 (Reapproved 2002), Standard Test Methods for Tension Testing of Nonmetallic Gasket Materials, American Society for Testing and Materials.

[8.6] ASTM F36 – 99, Standard Test Method for Compressibility and Recovery of Gasket Materials, American Society for Testing and Materials.

[8.7] BS 3909:1965, Specification for Ingot Lead for Radiation Shielding, British Standards Institute.