Prototype SAFKEG HS 3977A/0002

NCT and HAC Regulatory Test Report

Title	Prototype Safkeg HS 3977A/0002 NCT and HAC Regulatory Test Report	Number	CTR 2010/02
		Issue	A
		File Ref	CTR 2010-02-A-v1-SAFKEG 3977A-Regulatory Test Report
Compiled	S H Marshall	Checked	I Dingwall
Approved	R A Vaughan	Date	30 March 2012
Croft Associates Ltd, F4 Culham Science Centre, Abingdon, Oxfordshire, OX14 3DB. 01865 407740			

Table of Contents

<u>List of Figures</u>

<u>List of Tables</u>

List of Photographs

1 INTRODUCTION

The SAFKEG 3977A is being designed and licensed as a general purpose container for the transport of a range of non fissile and fissile excepted nuclides in solid, liquid and gaseous form. Evaluation of the design under Normal Conditions of Transport and Hypothetical Accident Conditions has been carried by a series of tests performed on a prototype 3977A package. All tests have been carried out in accordance with 10 CFR 71 [Ref 7] by Croft Associates Ltd. This report provides detailed information regarding the prototype keg, the test series, test methods and the resultant effects on the keg.

2 DESCRIPTION OF TEST PACKAGE

The same test package was used for all the tests. The package was a full scale version of the SAFKEG HS package. The test package was manufactured for testing according to drawings listed in the drawing list DL-0C-5900 issue B [Ref 1] with modifications for testing according to the drawings in drawing list DL-0C-5987 issue A [Ref 2]. The prototype package consisted of keg 3977 serial number 0002 and containment vessel 3978 serial number 0002 listed under the Certificate of Conformity QAC 1482 [Ref 3]. The containment O-ring fitted to the containment vessel was a James Walker EPM O-ring to specification EP18/H/75 [Ref 4] under the James Walker Certificate of Conformity 960279137 [Ref 5]. The insert used within the test package was certified for use under the Certificate of Conformity QAC 1457 [Ref 6].

Differences between the test package and the design specified by the licensing drawings are given in sections 2.1 and 2.2.

2.1 Modifications Required for Test

Modifications were required to the package to allow thermocouples and accelerometers to be fitted to the package. Holes were also machined to allow access for the cables required to log the test data.

2.1.1 Modifications to Containment Vessel

A hole of 7 mm in diameter was drilled through the flange of the containment vessel body to allow the thermocouple and heater wires to be fed through into the containment vessel during the steady state thermal test. This hole was also used to introduce the helium during the helium leak test.

Two holes were drilled 6 mm deep in the lid of the containment vessel to allow the accelerometers to be attached.

2.1.2 Modifications to Cork Packing

To accommodate the wiring from the accelerometers and thermocouples a 25 mm diameter hole was drilled 53 mm through the centre of the top cork. The 25 mm diameter was then widened to 77 mm over the final 15 mm.

2.1.3 Modifications to Keg

To allow exit of the accelerometer and thermocouple wires a 25 mm diameter hole was drilled through the center of the keg lid. The wires were taped to the keg lid and fed through a hole in the keg body. This hole was a drain hole enlarged to accommodate the wires required for the testing instrumentation. The wiring was taped to the keg until half way down the body. Two stainless steel cable ties were tack welded to the lid of the keg to allow the umbilical cord to be tied to the keg.

2.2 Comparison of Test Package to Production Package

In comparing the test package with the design specified by the licensing drawings, the drawing differences, weight of the keg, cork, containment vessel and insert were considered along with the dimensions of the keg, containment vessel, liner and top cork.

Table 1 shows the design changes that exist between the test and production packages. These changes either are expected to have no affect on the results or cause the test package to be weaker than the manufactured package.

Table 1 - Design Changes Between the Tested and Manufactured Packages

Item	Tested Keg Drawings	Licensed Keg Drawings	Summary of Deviation	Justification of Deviation
Lock Pin	Material to 1.4307 to EN 10088	Material to 304L to ASTM A479/A479M	Difference material specification	Considered to have the same material specifications
Keg Closure Stud	Material to 1.4307 to EN 10088	Material to 304L to ASTM A479/A479M	Difference material specification	Considered to have the same material specifications
CV Lid	No Jacking holes	Jacking holes	No jacking holes	Allows ease of lid removal without undermining the CV strength
CV Body Shielding	Plain inner bore	Annular step at bottom of inner bore	No annular step an bottom of inner bore	Reduces excessive stress in CV cavity wall. The tested package therefore would be more likely to fail than the manufactured package

Table 2 shows the design weights of the package compared to those taken from the test package. Overall the tested package was 5% lighter than the design weight.

Table 2 -Comparison of Test Package Weight with Design Weights

Item	Design Mass (kg)	Actual Mass (kg) of tested packaging[1]
Keg Body, Lid, Liner, Nuts & Washers	40.6	38.63
Cork packing	2.3	2.15
Containment Vessel	109.5	104.33
HS Safkeg Design No 3977A (excluding contents)	152.4	145.11
Insert plus contents	9.8	8.76

[1] From Reference 14

Item	Design Mass (kg)	Actual Mass (kg) of tested packaging[1]
HS Safkeg Design No 3977A (including contents)	162.2	153.9

The comparison of the dimensions between the tested package and the licensing drawings are shown in Table 3. All the dimensions are within expected manufacturing tolerances.

Table 3 - Comparison of Test Package Dimensions with Licensing Drawings

Item	Dimension on Licensing Drawings (mm)	Measured Dimension (mm)[Ref 14]	% diff
Keg Rim Diameter	424 [Ref 8]	420	-0.94
Keg Body Diameter	382.5 [Ref 8]	382	-0.13
Keg Height	585 [Ref 8]	582	-0.51
Liner Height	376.5 [Ref 8]	376.6	0.03
Liner Diameter	250 [Ref 8]	250	0.00
Top Cork Diameter	241 [Ref 9]	239.7	-0.54
Top Cork Height	84.5 [Ref 9]	86.4	2.25
Containment vessel Height	287.55 [Ref 10][Ref 11]	287.98	0.15
Containment vessel lower diameter	179.5 [Ref 10]	179.49	-0.01
Containment vessel upper diameter	200 [Ref 10]	195.06	-2.47
Containment vessel lid diameter	200 [Ref 11]	199.88	-0.06

2.3 Test Package Non-Conformance Reports

The prototype keg had several Non-Conformance Reports and product deviations raised against its manufacture. The Non Conformances are summarized in Table 4 and the Product deviations in Table 5. All the non-conformances and product deviations were allowed because they either had no affect on the performance of the package or would cause the tested package to be less effective than the actual manufactured packages.

Table 4 - Non Conformance Reports raised During Manufacture of the Tested Package

NCR Number	Item affected	Summary of Non Conformance	Justification of Non Conformance
297	Keg Outer cork	The outer cork is formed from blocks of cork bonded together and machined into shape. Bonding gaps of 1 mm were found in the cork.	These non conformances were accepted for the test package because the cork is deemed to be less effective than the cork in the production kegs. Therefore if the test package shows no failure the manufactured packages would be more effective.
300	Keg	The C of C for the glass bead	AMS-S-13165 is an operational

NCR Number	Item affected	Summary of Non Conformance	Justification of Non Conformance
		peening of the keg called up the procedure AMS-S-13165. The croft procedure called by MIL-PRF-9954C.	procedure whereas MIL-PRF-9954C provides the specification for the glass beads only. The use of AMS-S-13165 ensured that the correct glass beads were used.
301	Keg liner disc	The stock used on the prototype had a 1D finish rather than a 2B or 2D finish.	2D or 2B finishes are not readily available in small quantities. The surface finish of the keg liner base will not affect the performance of the liner. Plus the liners are all glass peened which removes the roughness.
303	Keg top flange, keg base plate and keg lid	The dimensions were not within the tolerances stated on the drawings. This arose due to the used of manually operated machines for the prototype packages only.	The errors were small and should have no effect on the performance of the package.
305	Inner cork	Dimensions were not within the tolerances stated on the drawings. The cork was 2.33 mm shorter in overall height, 0.55 mm smaller in the inner diameter on the body, 1.61 mm smaller on the top inner diameter and 0.84 mm smaller on the outer diameter and the height of the wider section of the cork is 0.93 mm longer.	The thickness of the cork itself remains in specification, it is just closer to the CV and there will be a larger gap to the keg liner. The effect of these dimensional errors is to make the cork less effective during the tests and therefore more likely to cause a failure.

Table 5 - Product Deviations raised During Manufacture of the Tested Package

PDR Number	Item Affected	Summary of Product Deviation	Justification for Deviation
291	Keg	A drawing error was identified with weld W15 being incorrectly marked as W17 on the drawing.	Drawing error which caused no issue to the hardware.
303	Containment vessel	Incorrect standard listed on drawings, standard was for sheet and plate however material specified was hollow bar, therefore the standard supplied to was hollow bar.	Using a different standard to that marked on the drawings allowed the correct material to be purchased.
320	Containment vessel	Allow the use of a different type of glass beads	This is to enhance the visual appearance of the CV and have no effect on the performance during the drop test.

3 TEST FACILITY

The Croft Associates Ltd test facilities were used in order to test the 3977A HS SAFKEG. The Croft Associates Ltd testing facility is located on the Southmead Industrial Estate, Didcot, UK.

This facility has a test target consisting of a 50 mm thick non alloy structural steel plate of area 2000 mm x 1500 mm. 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.

4 REGULATORY TEST METHOD

4.1 Testing Sequence

The package was assembled, inspected and tested in the sequence shown in Table 6.

Table 6 - Test Sequence

Sequence Number	Test Type	Test Number	Test
1	NCT	1	Steady state thermal test
2			Inspect, measure and weigh all the test items
3	NCT	2	Compression test of keg at ambient temperature
4			Assemble containment vessel
5			Helium leakage test of containment vessel **Note: The containment vessel shall remain closed until completion of the test programme**.
6			Assemble the package. **Note: The package shall remain closed until completion of the test programme (Test Number 12).**
7	NCT	3	Penetration Test at ambient
8	NCT	4	1.2m drop test 1 at ambient, C of G over side.
9	NCT	5	1.2m drop test 2 at ambient, C of G over top rim edge
10	NCT	6	1.2m drop test 3 at ambient, C of G over top end
11	HAC	7	10.2m drop test 1 at -40℃, C of G over side
12	HAC	8	10.2m drop test 2 at -40℃, C of G over top rim edge.
13	HAC	9	10.2m drop test 3 at -40℃, C of G over top end
14	HAC	10	1m puncture test at -40^{o}C C of G over side
15	HAC	11	1m puncture test at -40^{o}C C of G over top edge
16	HAC	12	1m puncture test at -40^{o}C C of G over top end
19			Inspect and weigh assembled package after completion of tests.
20			Disassemble the keg and inspect and weigh components.
21			Helium leakage test containment vessel after testing
22			Inspect and weigh the containment vessel, insert and contents

5 Test Methods and Results

The methods used and the results from the testing will be discussed in this section

5.1 Test 1 – Steady State Thermal Test [Ref 13]

5.1.1 Test Method

The test keg was marked up with datum lines as shown in figures 1 to 5 and then orientated and assembled according to Figure 6. A heater was used in place of the contents, in the containment vessel cavity. The heater provided a minimum wattage of 30 W. The seven calibrated thermocouples (T1, T2 etc) shown in Figure 7 were fixed to the HS test package on the 0^o axis to provide temperature readings during the course of the test. A further thermocouple was used to measure the ambient temperature 2 meters from the package. Readings from the thermocouples were logged continuously at 5 minute intervals during the test. Thermocouples were also attached to the outside of the keg as show in Figure 8 in order to map the surface temperature of the keg once it had reached equilibrium.

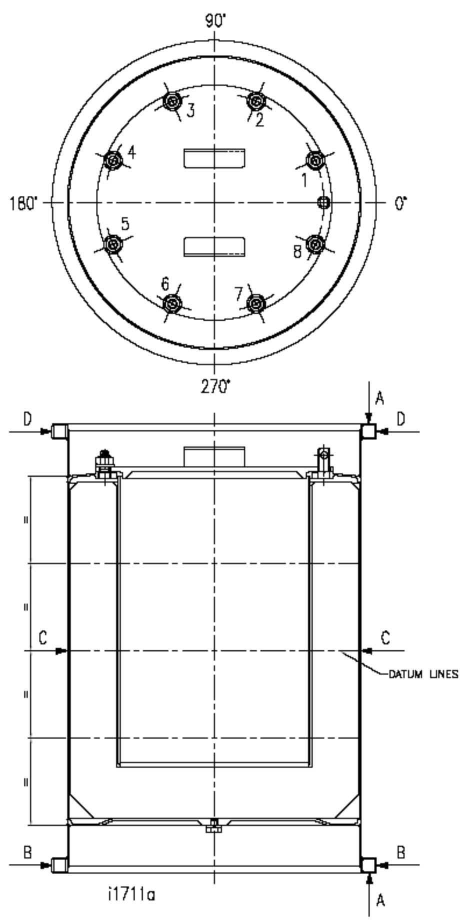


Figure 1 - Datum Lines – Keg

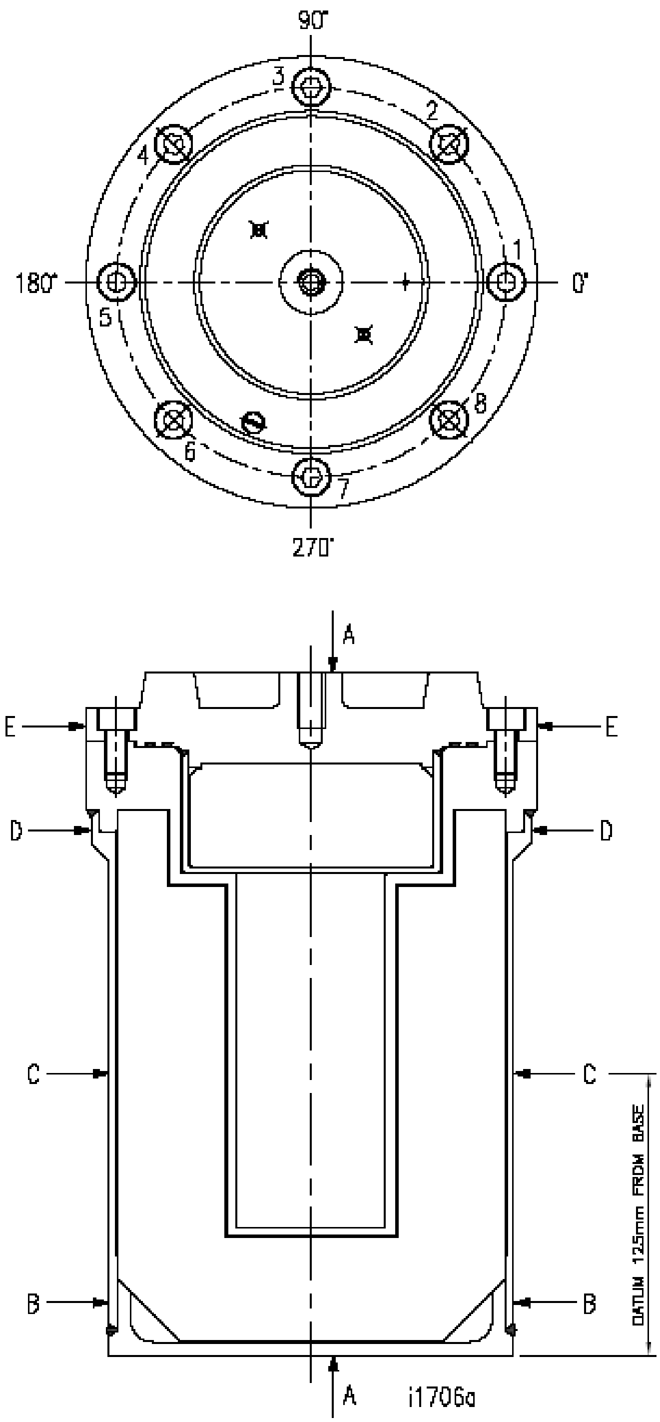


Figure 2 - Datum Lines - Containment Vessel

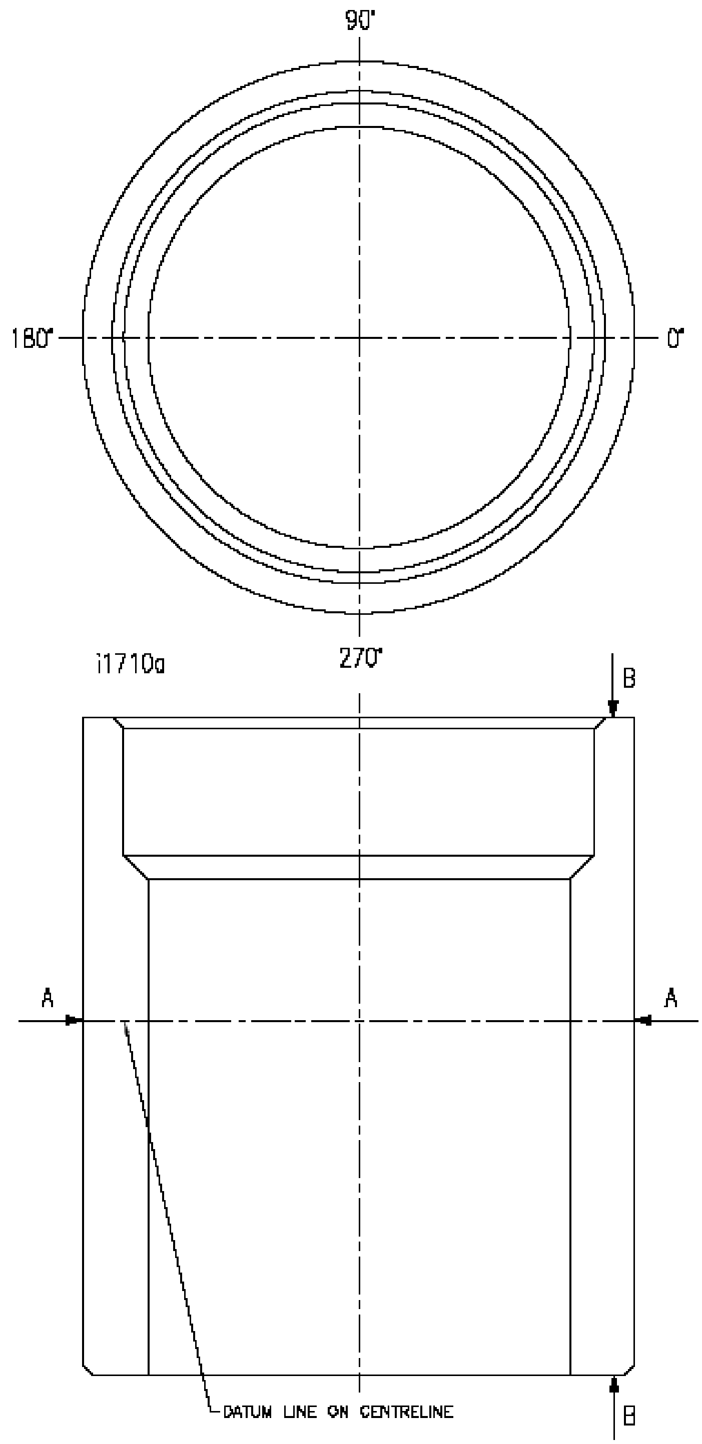


Figure 3 - Datum Lines - Inner Cork

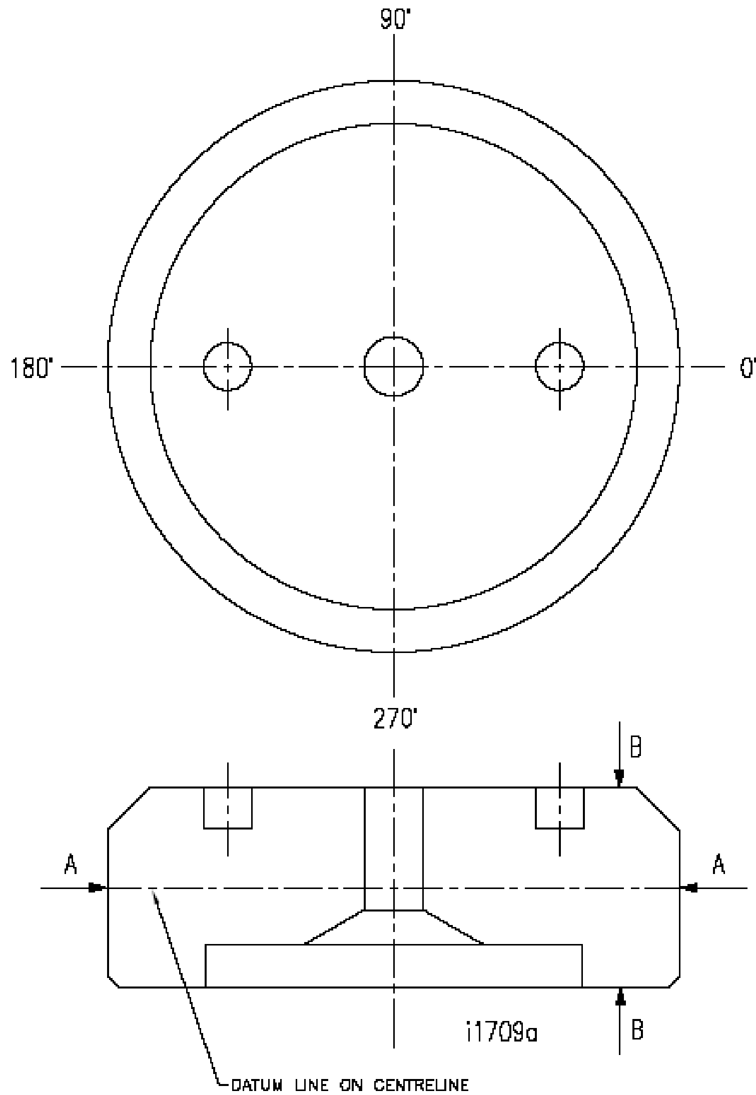


Figure 4 - Datum Lines - Top Cork

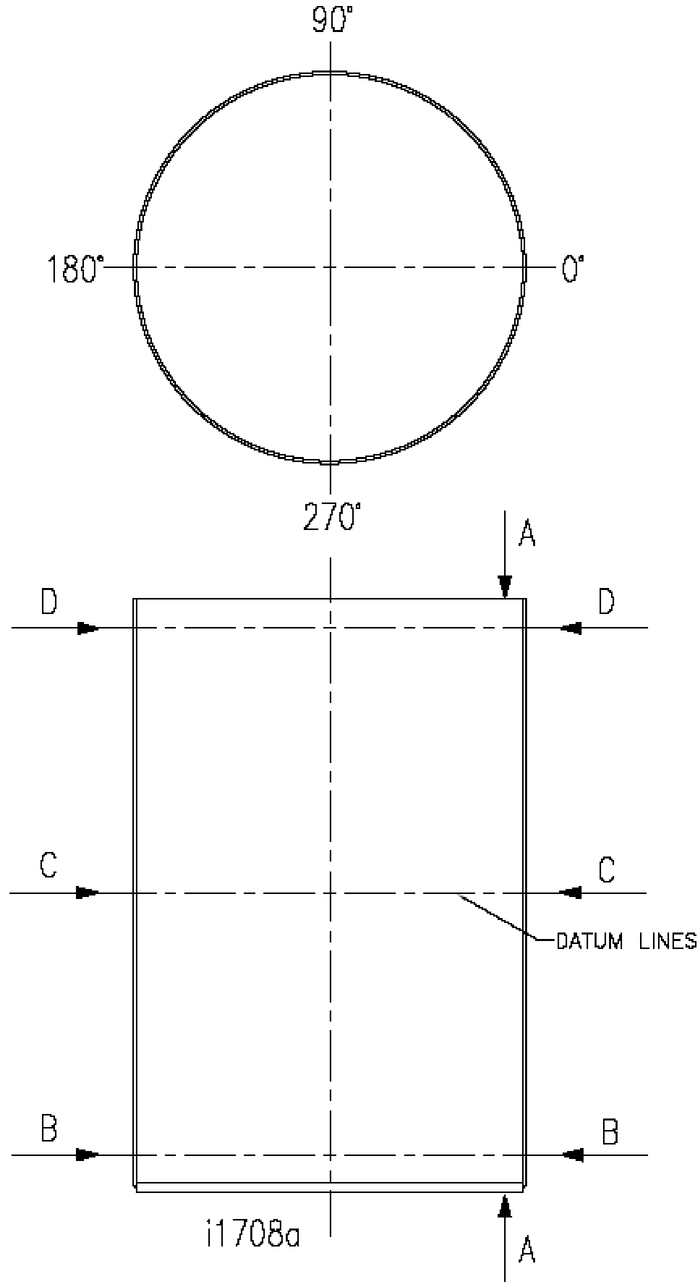


Figure 5 - Datum Lines - Cavity Liner

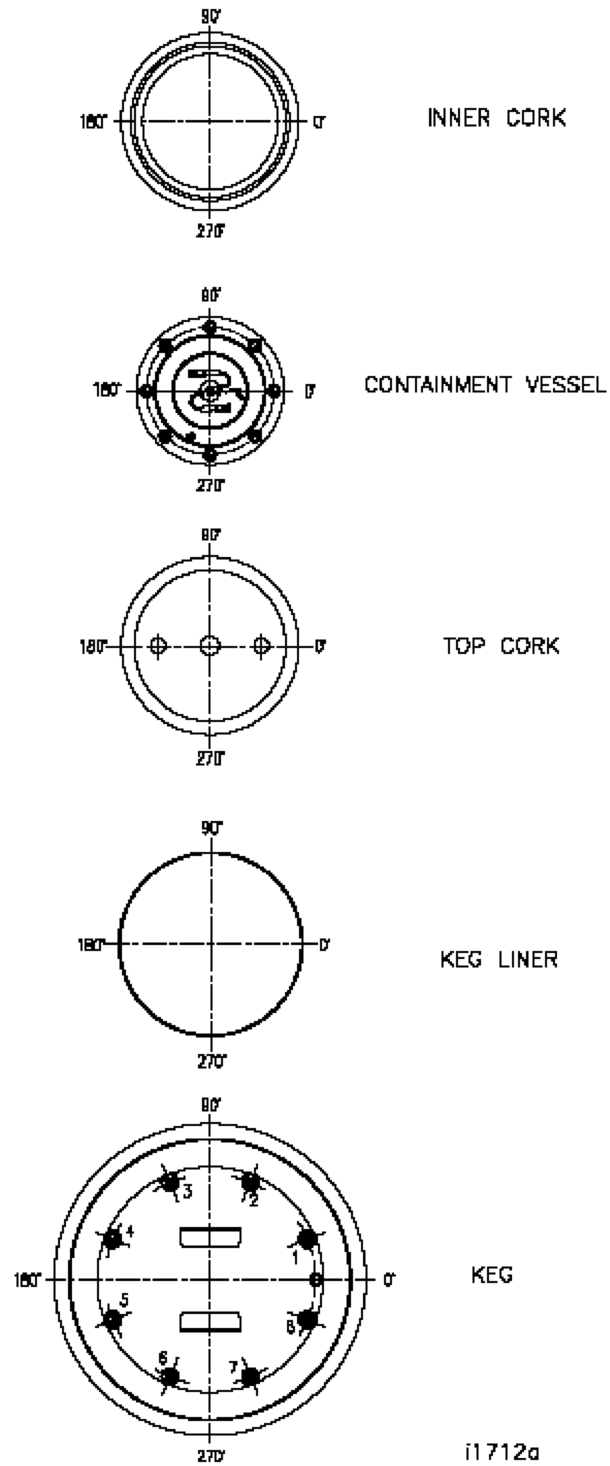


Figure 6 - Orientation of Package Components

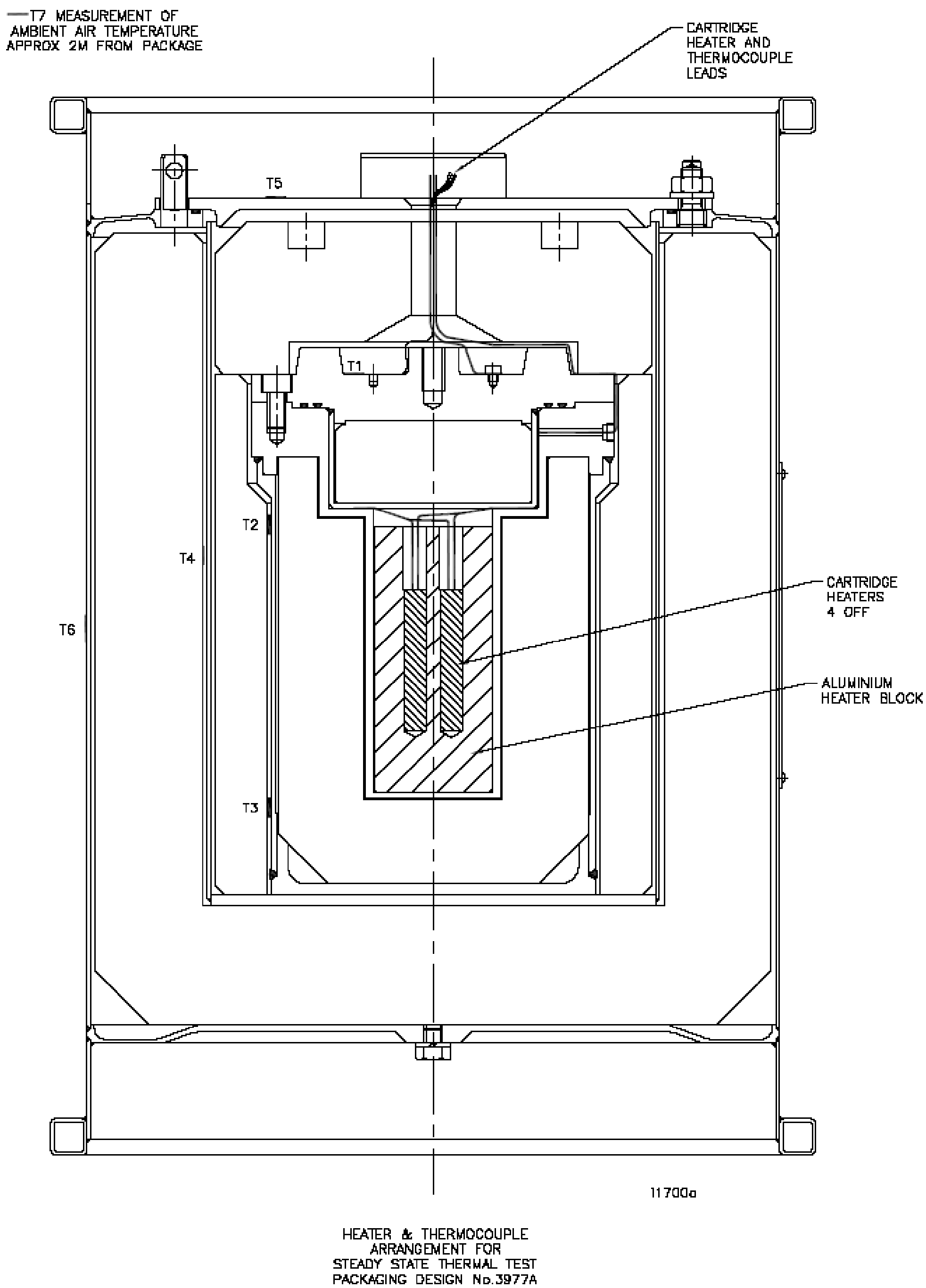


Figure 7 - Steady State Thermal Test

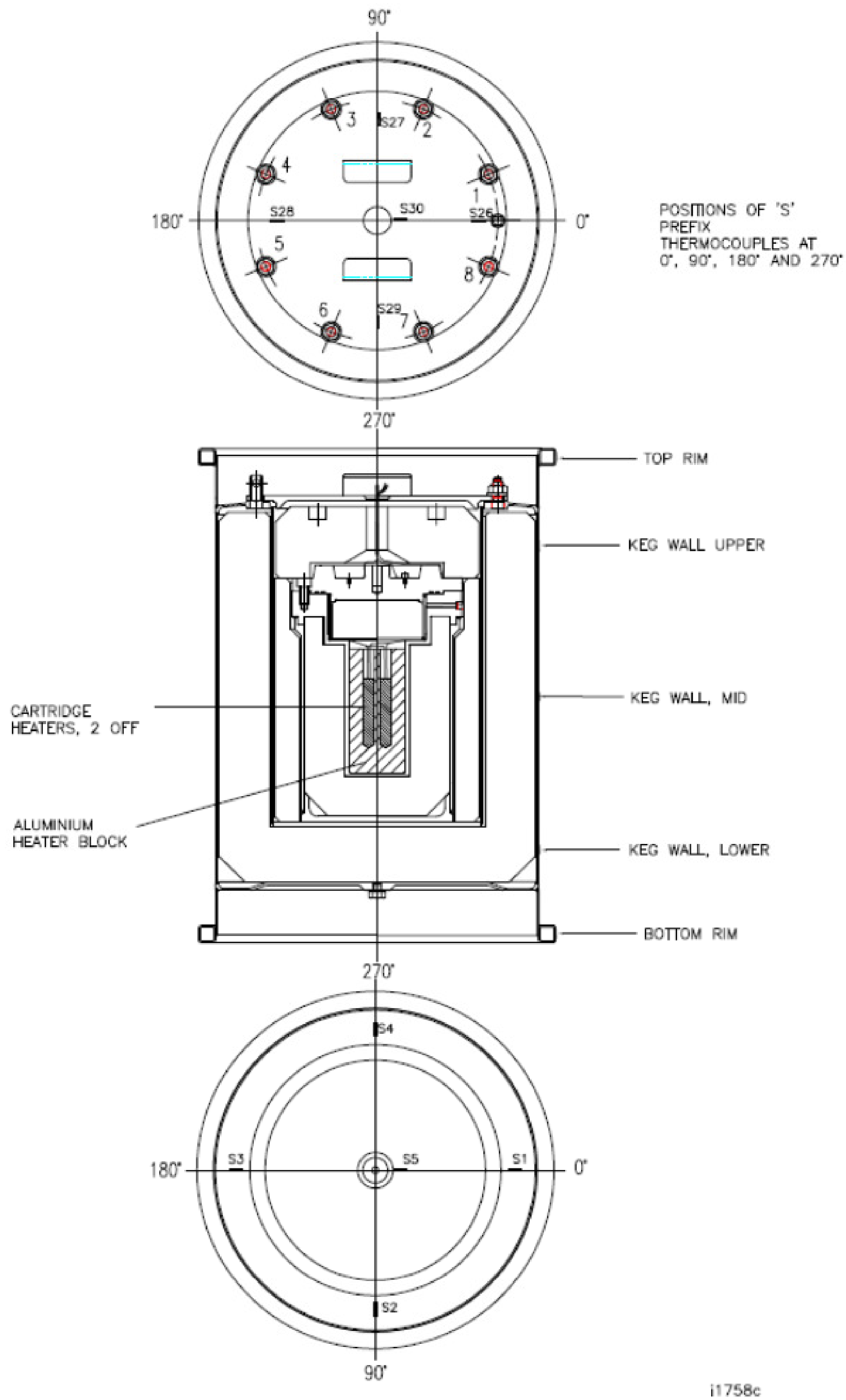


Figure 8 - Surface Thermocouples

The package was positioned in the vertical upright position on a 16 mm thick piece of chipboard covered in aluminum foil as shown in photograph 1. The heater was set to 30 W. The package remained in the vertical position until thermal equilibrium was reached. When the package reached equilibrium the surface temperature of the keg was mapped and the keg orientation changed to a horizontal position as shown in photograph 2. The test was repeated with the keg in the horizontal position until thermal equilibrium was reached and then the surface temperature of the keg was mapped again.

Photograph 1 - Vertical Steady State Thermal Test

Photograph 2 - Horizontal Steady State Thermal Test

5.1.2 Test Results

The temperatures logged during the test are given in Figure 9.

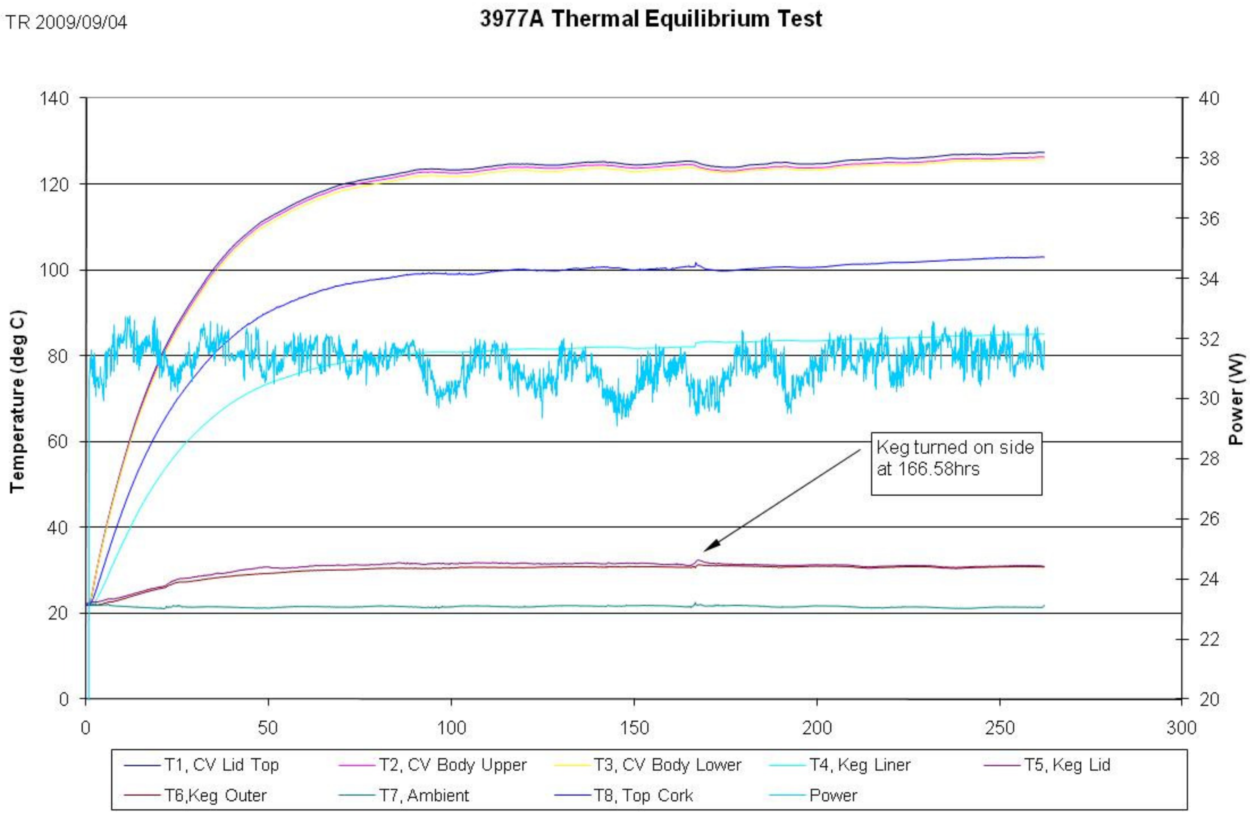


Figure 9 - Temperatures logged during thermal test

The thermocouples within the package indicated that the package had reached thermal equilibrium in vertical orientation after 165 hours. Once equilibrium was reached the package was turned onto the horizontal position resting on the 270° axis. The package reached equilibrium in the horizontal position after a further 96.33 hrs (261.33 hrs total). From the graph it can be seen that the power supplied by the heater varied throughout the steady state test. This is due to the normal fluctuation of the mains voltage. Once the keg reached equilibrium in both the vertical and horizontal position the surface temperature of the keg was mapped. The results are given in Tables 4 and 5 respectively.

Table 7 - Surface Temperature of the Keg in the Vertical Position

Surface temperature identification	Location (As in vertical position)	Reference Position	Measurement (°C)
S1	Underside of keg	0°	29.0
S2	Underside of keg	90°	29.1
S3	Underside of keg	180°	28.9
S4	Underside of keg	270°	29.3
S5	Underside of keg	Centre	34.1

Surface temperature identification	Location (As in vertical position)	Reference Position	Measurement (^{o}C)
S6	Keg wall, bottom rim	0°	25.3
S7	Keg wall, lower	0°	28.5
S8	Keg wall, mid	0°	30.6
S9	Keg wall, upper	0°	29.2
S10	Keg wall, top rim	0°	26.8
S11	Keg wall, bottom rim	90°	25.2
S12	Keg wall, lower	90°	28.4
S13	Keg wall, mid	90°	30.8
S14	Keg wall, upper	90°	29.5
S15	Keg wall, top rim	90°	26.7
S16	Keg wall, bottom rim	180°	25.4
S17	Keg wall, lower	180°	28.6
S18	Keg wall, mid	180°	31.0
S19	Keg wall, upper	180°	29.5
S20	Keg wall, top rim	180°	26.7
S21	Keg wall, bottom rim	270°	25.2
S22	Keg wall, lower	270°	28.7
S23	Keg wall, mid	270°	31.1
S24	Keg wall, upper	270°	29.4
S25	Keg wall, top rim	270°	26.9
S26	Top of keg	0°	31.1
S27	Top of keg	90°	31.5
S28	Top of keg	180°	31.3
S29	Top of keg	270°	31.2
S30	Top of keg	Centre	31.6

Table 8 - Surface Temperature of the Keg in the Horizontal Position

Surface temperature identification	Location (As in vertical position)	Reference Position	Measurement (^{o}C)
S1	Underside of keg	0°	27.0
S2	Underside of keg	90°	27.9
S3	Underside of keg	180°	26.8
S4	Underside of keg	270°	27.0
S5	Underside of keg	Centre	30.0
S6	Keg wall, bottom rim	0°	24.2
S7	Keg wall, lower	0°	27.7
S8	Keg wall, mid	0°	30.6
S9	Keg wall, upper	0°	28.1
S10	Keg wall, top rim	0°	24.5
S11	Keg wall, bottom rim	90°	25.6
S12	Keg wall, lower	90°	28.6
S13	Keg wall, mid	90°	30.9
S14	Keg wall, upper	90°	29.2
S15	Keg wall, top rim	90°	26.3
S16	Keg wall, bottom rim	180°	24.5
S17	Keg wall, lower	180°	27.9
S18	Keg wall, mid	180°	31.1
S19	Keg wall, upper	180°	28.3
S20	Keg wall, top rim	180°	24.7

Surface temperature identification	Location (As in vertical position)	Reference Position	Measurement (°C)
S21	Keg wall, bottom rim	270°	23.7
S22	Keg wall, lower	270°	27.8
S23	Keg wall, mid	270°	32.3
S24	Keg wall, upper	270°	28.5
S25	Keg wall, top rim	270°	23.6
S26	Top of keg	0°	30.2
S27	Top of keg	90°	31.5
S28	Top of keg	180°	30.2
S29	Top of keg	270°	30.4
S30	Top of keg	Centre	31.1

5.2 Test 2 - Compression Test [Ref 15]

5.2.1 Test Method

The empty test keg was used for the compression test. The keg was weighed and the height and diameter of the keg measured using the marked datum points shown in Figure 1. A test load of 914 kg was placed on top of the keg and left for 24 hours as shown in Photograph 3. This load was well in excess of the required load of 803.3 kg which is 5 x maximum weight of the complete package. On completion of the test the keg was weighed and measured using the marked datum points.

Photograph 3 - Compression Test

5.2.2 Test Results

The measurements taken before and after the compression test are given in Table 9. The measurements recorded after the test matched those taken before the test, taking into account measurement errors that would arise. A visual inspection of the keg identified no obvious signs of distortion.

Table 9 - Compression Test Results

Component	Ref Position (Figure 1)	Free Standing before Test	Free Standing after Test
Keg weight		38.635kg	38.640kg
Keg height	A-A @ 0^o	582.19mm	582.18mm
Keg height	A-A @ 90^o	581.92mm	581.88mm
Keg height	A-A @ 180^o	581.78mm	581.83mm
Keg height	A-A @ 270^o	580.75mm	580.76mm
Keg rim diameter	B-B@ 0^o-180^o	419.44mm	419.38mm
Keg rim diameter	B-B@ 90^o-270^o	419.32mm	418.92mm
Keg rim diameter	D-D@ 0^o-180^o	420.40mm	420.38mm
Keg rim diameter	D-D@ 90^o-270^o	419.78mm	419.74mm
Keg body diameter	C-C@ 0^o-180^o	382.30mm	382.31mm
Keg body diameter	C-C@ 90^o-270^o	382.11mm	382.11mm

5.3 Penetration, Drop and Puncture Tests

5.3.1 Assembly of the Package Prior to Testing

The HS 12x95 tungsten insert was filled with 68 g lead shot. It was placed into the containment vessel according to Figure 6. The containment lid was fitted in the orientation shown in Figure 2 and the screws tightened to 10 ± 0.5 Nm. A helium leak test was carried out on the containment vessel as described in section 5.5.

Five thermocouples to monitor the temperature of the package during the drop test were attached at various locations in the package. A thermocouple was attached to the CV lid and one on the body. Another was attached to the underside of the top cork. One was attached to the keg liner and lastly one was attached to the keg body. Two accelerometers were fitted to the top of the containment vessel in the location and orientation shown in Figure 10. The package was then assembled according to Figure 6. The keg nuts were fitted and tightened to 23±1 Nm.

Once assembled the package was not opened until the completion of the testing program. A single package was used for all the tests.

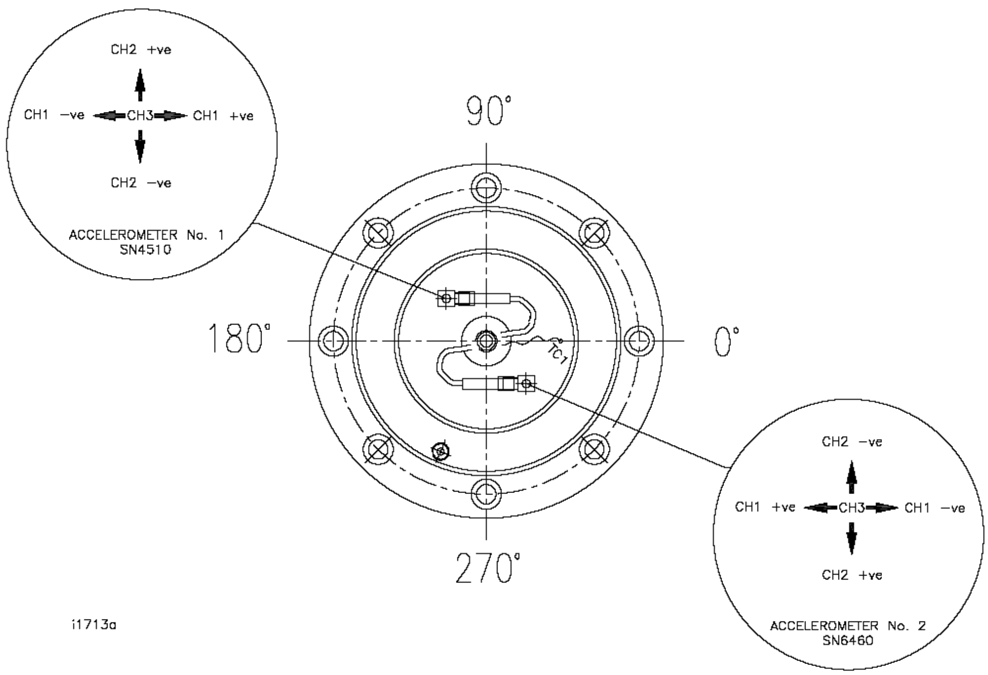


Figure 10 - Accelerometer Orientation

5.3.2 Test 3 – Penetration Test [Ref 16]

5.3.2.1 Test Method

A 6 kg steel bar of diameter of 3.2 cm was dropped 1.7 meters perpendicularly to the package onto the mid section of the long axis of the keg at reference point 0^o, as shown in Photograph 4. The keg was stood on a flat horizontal surface and a guide tube was used to ensure the steel bar impacted the keg at the correct point.

Photograph 4 - Penetration Test

5.3.2.2 Test Results

The penetration bar caused a dent of 8.06 mm in depth and of 290 mm width on impact with the package. No rips or tears in the keg skin were observed as shown in Photograph 5.

Photograph 5 - Penetration Test Damage

5.3.3 Test 4 – 1.2m drop test 1 at ambient, C of G over side [Ref 18]

5.3.3.1 Test Method

On conclusion of the penetration test the keg underwent the first in the series of 1.2 m drop tests. The first test orientation was a free drop onto the side of the keg. The test package was slung from lifting gear horizontally above the test pad as shown in Photograph 6 it was then released to free fall onto the test pad.

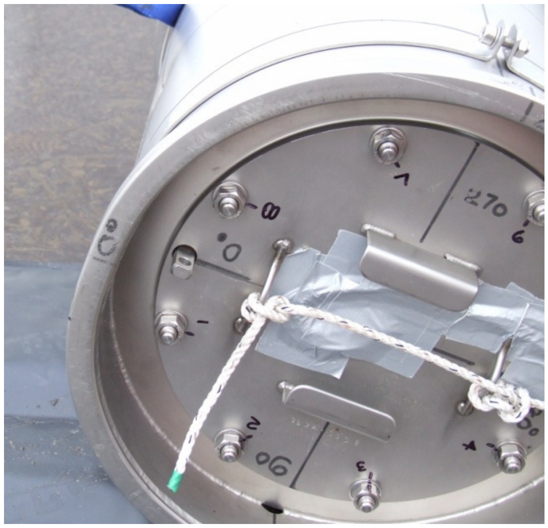
Photograph 6 - 1.2m Drop on Side

5.3.3.2 Test Results

The package impacted the target on the 0° axis it then bounced and landed on the top rim and came to rest on its side as shown in Photograph 7.

Photograph 7 - Rest position after 1.2m side drop

Minimal damage was caused on the top and bottom rims on the 0° axis as shown in Photograph 8. The bottom rim had similar damage.



Photograph 8 - Top Rim Damage

5.3.4 Test 5 – 1.2m drop test 2 at ambient, C of G over top rim [Ref 19]

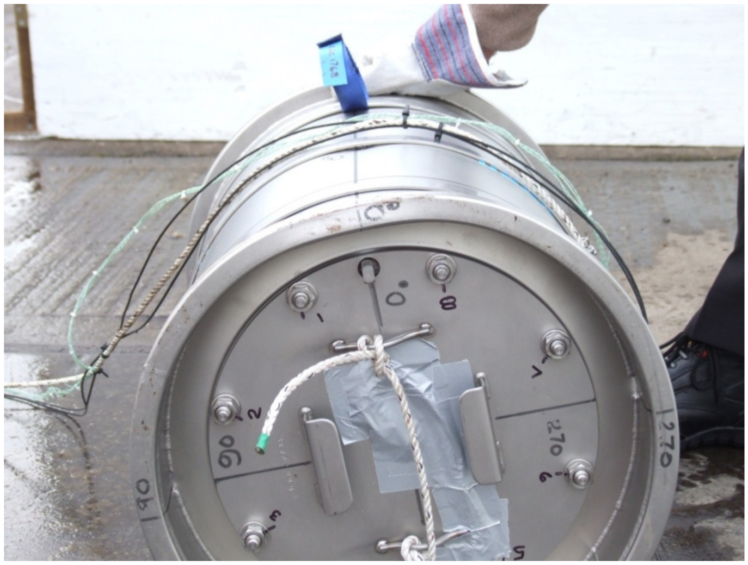
5.3.4.1 Test Method

On completion of the first 1.2m drop test a second was then carried out. The test orientation was a free drop onto the top rim of the keg. The test package was slung from lifting gear above the test pad as shown in Photograph 9; it was then released to free fall onto the test pad.

Photograph 9 - 1.2 m drop over top rim

5.3.4.2 Test Results

The package impacted the target on the top rim on the 0° axis. It bounced landed again on the top rim and came to rest on its side. The drop caused minimal damaged to the package as shown in Photograph 10.



Photograph 10 - Impact Damage from 1.2m Drop on top rim

5.3.5 Test 6 – 1.2 m drop test 3 at ambient, C of G over top [Ref 20]

5.3.5.1 Test Method

On completion of the second 1.2m drop test a third was then carried out. The test orientation was a free drop onto the top of the keg. The test package was slung from lifting gear so that the top of the keg was above the test pad as shown in Photograph 11. The package was then released to free fall onto the test pad.

Photograph 11 - 1.2 m Drop C of G over Top

5.3.5.2 Test Results

The package impacted the target over the top; it bounced and then came to rest on its top. The drop caused minimal damage to the package as shown in Photograph 12.

Photograph 12 - Damage to the keg from the 1.2 m drop over top

5.3.6 Test 7 – 10.2 m drop test at -40°C, C of G over side [Ref 21]

5.3.6.1 Test Method

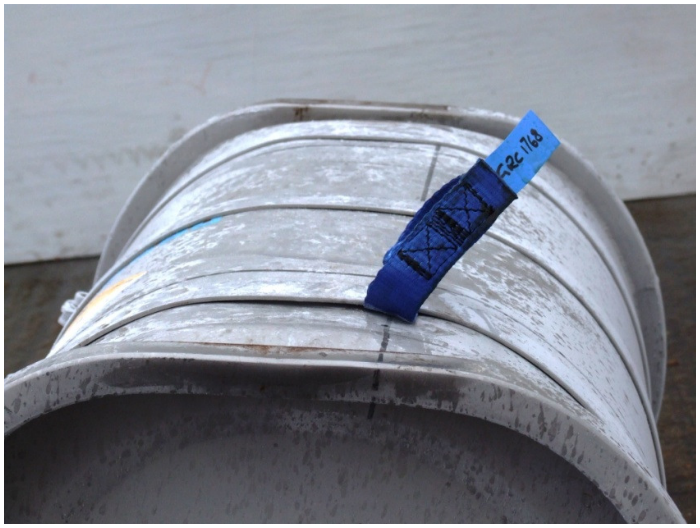
On completion of the 1.2 drop tests the first 10.2 m drop test was carried out at the Croft test facilities. The first test orientation was a free drop onto the side of the keg.

The package was cooled to -40°C and the temperature of the package was recorded prior to the drop using the thermocouples affixed in and on the package during assembly. The test package was horizontally slung from the crane 10.2 m above the test pad as shown in Photograph 13. It was released to free fall onto the test pad which had been placed on the target.

Photograph 13 - 10.2 m drop test over side

5.3.6.2 Test Results

Once released the package landed on its side, bounced landed on the bottom rim and came to rest on its side. The impact caused uniform damage on the top and bottom rims as shown in Photograph 14. The package was at -40°C prior to the test and all items aside from the keg itself remained at -40°C. The keg temperature was measured at -13.2°C.



Photograph 14 - 10.2 m side drop package damage

5.3.7 Test 8 – 10.2 m drop test at -40℃, C of G over top rim [Ref 22]

5.3.7.1 Test Method

On completion of the first 10.2 m drop test the second 10.2 m drop test was carried out at the Croft test facilities. The second test orientation was a free drop onto the top rim of the keg. The package was cooled to -40°C and the temperature was recorded prior to the drop using the thermocouples affixed in and on the package during assembly. The test package was then slung with the C of G over the top rim from a crane 10.2 m above the test pad as shown in Photograph 15 it was released to free fall onto the test pad which had been placed on the target.

Photograph 15 - 10.2m Drop test on top rim

5.3.7.2 Test Results

The package landed on the top rim causing crumpling of the skirt as shown in Photograph 16. The packaged then bounced and rotated and landed on its side. The package temperature was less than -40^{o}C before the test and all components remained at 40^{o}C after the test, the only exception was the keg which was -7.9^{o}C at the end of the test.

Photograph 16 - Damage to package caused by 10.2m drop on top rim

5.3.8 Test 9 – 10.2 m drop test 2 at -40°C, on top end [Ref 23]

5.3.8.1 Test Method

The third 10.2m test orientation was a free drop onto the top end of the keg. Prior to the test the package was cooled to -40^{o}C, the temperature of the package was recorded using the thermocouples affixed in and on the package during its assembly.

The test package was then slung from a crane, vertically top down, 10.2 m above the test pad as shown in Photograph 17. It was then released to free fall onto the test pad which had been placed on the target.

Photograph 17 - 10.2m Drop on Top

5.3.8.2 Test Results

Once released the package landed on the top, bounced and came to rest on its side. The impact caused crumpling of the top skirt and the lid lifting handles to flatten as shown in Photograph 18. The package was at -40^{o}C before the drop test. The drop test itself caused the shearing of the cable which was attached to the logging computer therefore the only temperature measurement available was of the keg which was -16.2^{o}C.

Photograph 18 - Damage caused to keg from 10.2m drop on top

5.3.9 Acceleration Data

The acceleration data was recording during each 1.2 and 10.2 m drop test. The highest g values measured have been summarised in Table 10. A filter has been used on the raw acceleration data to eliminate noise unrelated to the drop. Its use is recommended by the IAEA advisory material [Ref 12].

A low pass digital 4th order Iowpass Butterworth filter with a cut-off frequency of 500 Hz was applied to the raw data.

Test			4 Drop on side	5 Drop on top rim	6 Drop on top	7 Drop on side	8 Drop on top rim	9 Drop on top
Drop Height			1.2	1.2	1.2	10.2	10.2	10.2
Peak Acceleration	Axial (g)	Accelerometer 1	267	377	424	99	338	No Data
		Accelerometer 2	178	374	433	106	No Data	No Data
	Radial (g)	Accelerometer 1	214	521	520	435	228	No Data
		Accelerometer 2	293	590	750	457	No Data	No Data

Table 10 – Acceleration data from drop tests

During the 10.2 m drop test on the rim the cable from accelerometer 2 to the computer was sheared which mean readings were only available from accelerometer 1. The cable to accelerometer 1 then sheared during the 10.2m drop test onto the top. Therefore no accelerometer data was recorded for the 10.2m drop onto the top of the package.

5.3.1 Test 10 – 1 m puncture test on side impact point [Ref 24]

5.3.1.1 Test Method

On completion of the drop test series the first puncture test was carried out. The first puncture test was a free drop from 1 m onto the top end of a steel punch which had a diameter of 150 mm and length of 200 mm. The test orientation was so that the package dropped onto the side of the keg.

As shown in Photograph 19 the test package was slung from the lifting gear so that it was perpendicular to the punch. The height was checked to ensure the lowest point of the package was 1 m above the punch. The package was then released to free fall onto the punch.

Photograph 19 - 1m Puncture Test on Side

5.3.1.2 Test Results

Once released the package impacted the punch on its side and landed on its top. The punch left an impact mark on the package as shown in Photograph 20.

Photograph 20 - Damage from 1 m Puncture Test

5.3.1 Test 12 – 1 m puncture test on top rim edge [Ref 25]

5.3.1.1 Test Method

On completion of the first puncture test the second was carried out. This test was a free drop from 1 m over the top rim onto the steel punch.

As shown in photograph 17 the test package was slung from the lifting gear so that the top rim of the package was positioned over the punch. The height was checked to ensure the lowest point of the package was 1 m above the punch. The package was then released to free fall onto the punch.

Photograph 21 - 1 m Puncture Test onto top rim

5.3.1.2 Test Results

The package landed on the top rim on the punch. The package was already damaged at the point of impact as shown in Photograph 22 and the puncture test caused minimal further damage as shown in Photograph 23.

Photograph 22 - Damage prior to 1m puncture test on top rim

Photograph 23 - Damage caused by 1m puncture test on top rim

5.3.2 Test 11 – 1 m puncture test over the top of the package [Ref 26]

5.3.2.1 Test Method

The final puncture test to be carried out was a drop onto the top of the package. The test orientation was so that the top of the package dropped onto the punch.

As shown in Photograph 24 the test package was slung from the lifting gear so that the bottom of the package was positioned over the punch. The height was checked to ensure the lowest point of the package was 1 m above the punch. The package was then released to free fall onto the punch.

Photograph 24 - 1m Puncture test onto top of package

5.3.2.2 Test Results

The package landed on its top on the punch. The package was already damaged from previous tests as shown in Photograph 25. The punch test caused minimal further damage to the package as shown in Photograph 26.

Photograph 25 - Damage to keg prior to 1m puncture test on top of package

Photograph 26 - Damage caused to package by 1m puncture test on the top of package

5.4 Inspection Details Before and After NCT and HAC Testing [Ref 14]

The keg was measured and weighed before and after the NCT and HAC drop tests. The package was measured using the datum lines shown in figures 1 to 5. These measurements help determine the scope of damage to the package. The results of the dimensional inspection before and after testing are given in Table 11 with the weights presented in Table 12. Photographs 27 to 35 show the post test condition of the package and the individual components.

The outer surface of the keg suffered deformation from the drop and puncture tests with the majority of damage caused to the rims and skirts. Table 11 and Photograph 27 show that the keg height was reduced particularly at 0^o due to the denting sustained during the 10.2 m drop tests. This denting has also caused the rim diameter to reduce on the 0^o to 180^o reference point and increase on the 90^o to 270^o reference point. The puncture test did produce minor damage to the keg body causing the keg diameter to reduce 11 mm in the centre of the keg on the 0 to 180^o reference point. There was however no puncture or tear on the keg surface.

On assembly the keg nuts were tightened to 23±1 Nm. On completion of the test the kegs nuts had loosened as shown by the angular displacement data in Table 11 for the keg nuts. All nuts however were present and the keg lid was still in place.

Dimensional measurement of the containment vessel and insert has shown no change to either item on completion of the test series. The containment vessel screws were tightened to 10 ± 0.5 Nm prior to testing. The torque required to remove the screws after testing was between 7.5 and 9.25 Nm as shown in Table 13. Photograph 33 shows that the insert has not caused any damage inside the containment vessel. The insert had loosened very minimally as demonstrated in Photograph 34.

The weight measurements demonstrate that the insert remains the same weight. The containment vessel increased in weight by 5 g however this is attributable to the cork adhering to the containment vessel body during the drop tests. The change in the keg and liner weight is due to the damage to the cork sustained during the 10.2m drop tests.

Table 11 - Results of Dimensional Inspection

Component	Ref Position	Pre-test Dimension (mm)	Post-test Dimension (mm)	Diff
Insert Assembly				
Check lid closure				
Insert height	A-A	152.57	152.59	0.02
Body lower dia.	B-B @ 0°-180°	64.86	64.88	0.02
Body lower dia.	B-B @ 90°-270°	64.86	64.87	0.01
Body mid dia	C-C @ 0°-180°	64.86	64.87	0.01
Body mid dia	C-C @ 90°-270°	64.85	64.87	0.02
Lid dia	D-D @ 0°-180°	64.86	64.88	0.02
Lid dia	D-D @ 90°-270°	64.86	64.88	0.02
Containment Vessel (Figure 2)				
CV height	A-A @ 0°	287.87	287.87	0
CV height	A-A @ 90°	287.98	287.93	-0.05
CV height	A-A @ 180°	288.09	288.09	0
CV height	A-A @ 270°	287.97	287.96	-0.01
CV lower diameter	B-B @ 0°-180°	179.41	179.39	-0.02
CV lower diameter	B-B @ 90°-270°	179.59	179.60	0.01
CV mid diameter	C-C @ 0°-180°	179.48	179.36	-0.12
CV mid diameter	C-C @ 90°-270°	179.48	179.73	0.25
CV upper diameter	D-D @ 0°-180°	195.05	195.04	-0.01
CV upper diameter	D-D @ 90°-270°	195.07	195.05	-0.02
CV lid diameter	E-E @ 0°-180°	199.89	199.93	0.04
CV lid diameter	E-E @ 90°-270°	199.87	199.93	0.06
CV lid inner O-ring grove	F-F @ 0°-180°	124.99	125.00	0.01
CV lid inner O-ring grove	F-F @ 90°-270°	125.00	125.00	0
Inner Cork (Figure 3)				
Inner Cork diameter	A-A @ 0°-180°	239.37	Not possible to measure because the cork did not remain complete	
Inner Cork diameter	A-A @ 90°-270°	239.38		
Inner Cork height	B-B @ 0°	282.66		
Inner Cork height	B-B @ 90°	283.67		
Inner Cork height	B-B @ 180°	284.30		
Inner Cork height	B-B @ 270°	283.23		
Top Cork (Figure 4)				
Top cork diameter	A-A @ 0°-180°	239.82	Not possible to measure because the cork did not remain complete	
Top cork diameter	A-A @ 90°-270°	239.54		
Top cork height	B-B @ 0°	84.67		
Top cork height	B-B @ 90°	84.81		
Top cork height	B-B @ 180°	85.70		
Top cork height	B-B @ 270°	90.31		
Keg Liner (Figure 5)				
Liner height	A-A @ 0°	376.42	376.00	-0.42
Liner height	A-A @ 90°	376.11	375.84	-0.27
Liner height	A-A @ 180°	376.39	376.11	-0.28
Liner height	A-A @ 270°	377.35	377.00	-0.35
Liner lower dia.	B-B @ 0°-180°	249.19	249.16	-0.03

Component	Ref Position	Pre-test Dimension (mm)	Post-test Dimension (mm)	Diff
Liner lower dia.	B-B @ 90°-270°	250.64	250.62	-0.02
Liner mid dia.	C-C @ 0°-180°	249.42	249.48	0.06
Liner mid dia.	C-C @ 90°-270°	251.11	251.09	-0.02
Liner top dia.	D-D @ 0°-180°	249.26	249.23	-0.03
Liner top dia.	D-D @ 90°-270°	250.57	250.48	-0.09
Keg Assembly (Figure 1)				
Keg height	A-A @ 0°	582.19	551	-31.19
Keg height	A-A @ 90°	581.92	566	-15.92
Keg height	A-A @ 180°	581.78	570	-11.78
Keg height	A-A @ 270°	580.75	567	-13.75
Keg rim diameter	B-B @ 0°-180°	419.44	403	-16.44
Keg rim diameter	B-B @ 90°-270°	419.32	421	1.68
Keg rim diameter	D-D @ 0°-180°	420.40	385	-35.4
Keg rim diameter	D-D @ 90°-270°	419.78	434	14.22
Keg outside diameter	C-C @ 0°-180°	382.30	371.30	-11
Keg outside diameter	C-C @ 90°-270°	382.11	381.87	-0.24
Stud & Nut 1 closed	Angle from perpendicular	0.7°	7.7°	7
Stud & Nut 2 closed	Angle from perpendicular	0.3°	6.7°	6.4
Stud & Nut 3 closed	Angle from perpendicular	0.3°	5.3°	5
Stud & Nut 4 closed	Angle from perpendicular	0.3°	6.2°	5.9
Stud & Nut 5 closed	Angle from perpendicular	0.4°	6.5°	6.1
Stud & Nut 6 closed	Angle from perpendicular	0.3°	7.1°	6.8
Stud & Nut 7 closed	Angle from perpendicular	0.6°	7.8°	7.2
Stud & Nut 8 closed	Angle from perpendicular	0.5°	11.4°	10.9

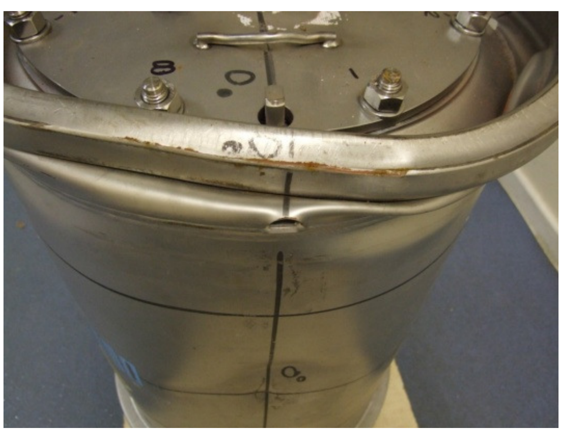
Table 12 - Package weights before and after testing

Component Items	Pre-Test Weight (g)	Post-Test Weight (g)
Keg body, liner, lid, O-ring, nuts and washers	38636.4	38571.4
Top Cork	875	Not retrievable as complete
Inner Cork Body	1270	Not retrievable as complete
Containment Vessel	104336.7	104341.7
Insert	8696.3	8696.3
Dummy Contents	68	68
Total Package weight	153882.4	-

Table 13 - Containment vessel screw torques after testing

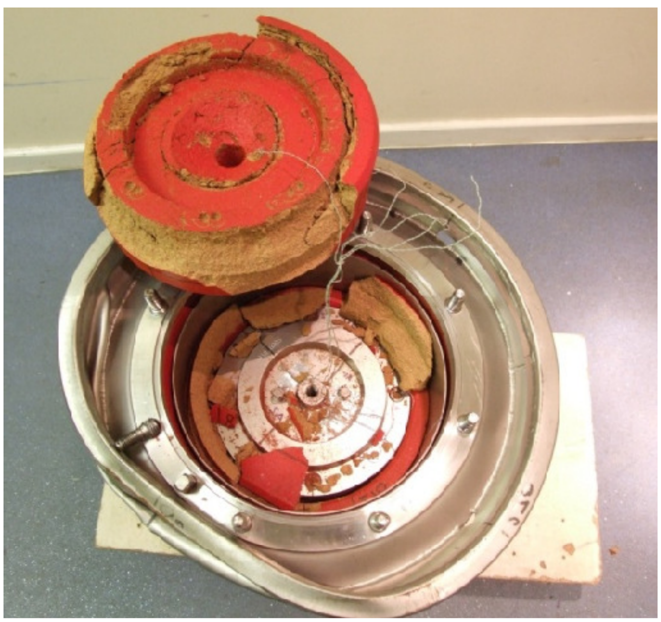
Screw ref	Torque Nm
1	9.25
2	7.50
3	7.00
4	8.25
5	7.50
6	7.00
7	7.50
8	7.50

Photograph 27 - Damaged package after testing



Photograph 28 - Keg damage at main impact point

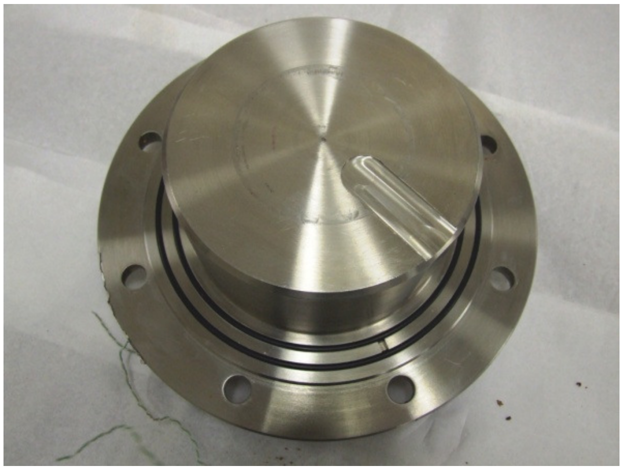
Photograph 29 - Damage to top of package



Photograph 30 - Lid removed from keg

Photograph 31 - Deformation to keg liner

Photograph 32 - Containment vessel after testing



Photograph 33 - Underside of containment vessel lid

Photograph 34 - Insert after testing

Photograph 35 - Opened insert after testing

5.5 Helium Leak Test Before and After NCT and HAC Testing [Ref 27]

5.5.1 Test Method

The containment vessel seal was leak tested before and after the drop, penetration and puncture tests. The test method used was the evacuated envelope (gas detector) method in accordance with ANSI N14.5-1997. The leakage testing of the containment vessel is shown in Figure 11. The test gas used was helium with a purity of equal or greater than 99.99% (Purity 4).

The helium detector (MSLD) was used to evacuate the air from the seal interspace. The air within the containment vessel was then evacuated using the additional cavity test port. The same port was then used to pressurise the cavity with helium. The pass rate set for the test was 2 x 10^{-7} cm^3/s with a sensitivity of 5 x 10^{-8} cm^3/s helium at an upstream pressure of 1 atmosphere absolute and a downstream pressure of 0.01 atm or less.

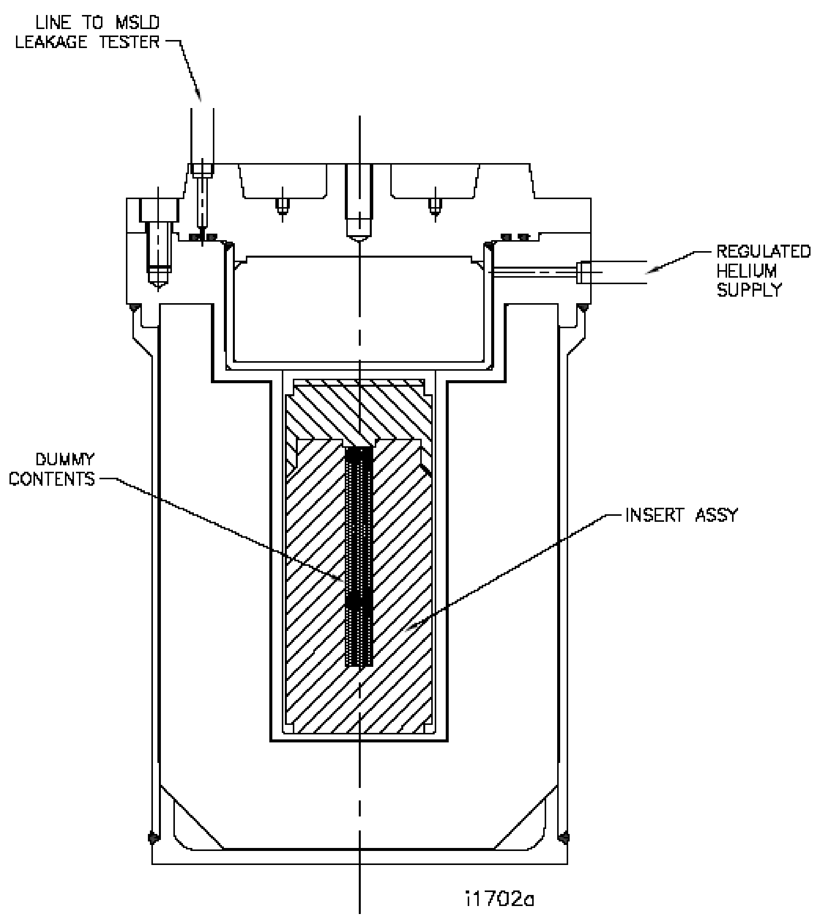


Figure 11 - Helium leakage testing of containment vessel

5.5.2 Test Results

The helium leak test carried out prior to the NCT and HAC tests is detailed in Reference 17. The tested leak rate was 1.21 x 10^{-9} cm^3/sec which meets the acceptance criteria of 2 x10^{-7} cm^3/sec.

The helium leak test carried out after the NCT and HAC tests is detailed in Reference 27. The tested leak rate was 4.61 x 10^{-10} cm^3/sec which meets the acceptance criteria of 2 x10^{-7} cm^3/sec.

The results of the leak tests demonstrate that the containment vessel remained leak tight before and after the NCT and HAC tests. This indicates that the tests did not affect the containment vessel and its sealing system.

6 CONCLUSIONS

On examination of the packaging components on disassembly after the test series the following can be concluded:

- The containment vessel remained leaktight.
- The dimension and the weights of the containment vessel did not alter.
- The keg remained intact with the keg lid in place.
- The keg skin suffered from denting however it was not penetrated and the welds were not torn.
- The majority of the damage was caused to the skirts and rims of the keg during the 10.2 m drop tests with minor damage caused to the body by the puncture test. .

7 REFERENCES

1. Croft Associates Ltd, DL-0C-5900, Drawing List for the SAFKEG HS Packaging Design No 3977A, Issue B
2. Croft Associates Ltd, DL-0C-5987, Drawing List for Alterations to Design No 3977A Serial No 0002 for Testing Purposes, Issue A
3. Croft Associates Ltd, Certificate of Conformity number QAC 1382
4. James Walker, EP18/H/75, Material Data Sheet, Polymer Type EPM, Revision 2, 03/10/2005.
5. James Walker Certificate of Conformity, Certificate Number 960279137.
6. Croft Associates Ltd, Certificate of Conformity number QAC 1457
7. Title 10, Code of Federal Regulations, Part 71 (10 CFR 71), Packaging and Transportation of Radioactive Material. 23 Feb 2009
8. Croft Associates Ltd, Drawing 0C-5942, Keg Design No 3977

9. Croft Associates Ltd, Drawing 0C-5943, Cork Set for Safkeg HS

10. Croft Associates Ltd, Drawing 1C-5946 Containment Vessel Body

11. Croft Associates Ltd, Drawing 1C-5945 Containment Vessel Lid

12. International Atomic Energy Authority, Advisory Material for the IAEA Regulations for the Safe Transport of Radioactive Material, Safety Guide No TS-G-1.1 (Rev 1)

13. Croft Associates Ltd Document No TR 09/09/02, Steady State Thermal Test, Issue A

14. Croft Associates Ltd Document No TR 09/09/06, Inspection Details Before and after NCT and HAC testing, Issue A

15. Croft Associates Ltd Document No TR 09/09/07, Compression test of keg at ambient temperature, Issue A

16. Croft Associates Ltd Document No TR 09/09/09, Penetration Test at Ambient Temperature, Issue A

17. Croft Associates Ltd Document No TR 09/09/08, Helium Leakage Test Prior to Regulatory Test Series, Issue A

18. Croft Associates Ltd Document No TR 09/09/10, 1.2 m Drop Test 1 C of G over Side at Ambient Temperature, Issue A

19. Croft Associates Ltd Document No TR 09/09/11, 1.2m drop test 2 C of G over top rim edge at ambient temperature, Issue A

20. Croft Associates Ltd Document No TR09/09/12, 1.2m drop test 3 C of G over top end at ambient temperature, Issue A

21. Croft Associates Ltd Document No TR 09/09/13, 10.2 m drop test 1, C of G over side at -40°C temperature, Issue A

22. Croft Associates Ltd Document No TR 09/09/14, 10.2m drop test 2, C of G over top rim edge at -40°C temperature, Issue A

23. Croft Associates Ltd Document No TR 09/09/15, 10.2m drop test 3, C of G over top end at -40°C temperature, Issue A

24. Croft Associates Ltd Document No TR 09/09/16, 1m puncture test 1, C of G over side at -40°C temperature, Issue A

25. Croft Associates Ltd Document No TR 09/09/17, 1m puncture test 2, C of G over top rim at -40°C temperature, Issue A

26. Croft Associates Ltd Document No TR 09/09/18, 1m puncture test 3, C of G over top end at -40°C temperature, Issue A

27. Croft Associates Ltd Document No TR 09/09/19, Helium leakage test carried out after test series, Issue A