3.1.4 Vibration Test

The vibration test for the ES-3100 package is designed to simulate the environmental effects of the vibration regime that the ES-3100 will experience during use. A Lansmont model 10000-10 vibration table was used to perform the testing. A vibration spectrum simulating the Safe-Secure Trailer/Safeguards Transporter (SST/SGT) was used. The test duration was based on the longest trip that the package is likely to endure, namely one hour per 1000 trip-miles. Hence, the 4-h test duration used was conservative and should encompass any conceivable trip that the ES-3100 might undergo. The vibration controller was programmed to the power spectrum density shown in Table 3.1.

After having undergone the water spray test, free drop, penetration test, and the compression test, TU-4 was securely strapped to the vibration table with a nylon tie-down strap (as specified in the test plan) to begin the 4-hour test (Figure 3.5).

Table 3.1 Vertical Power Spectrum Density (PSD)

Freq (Hz)	G^2/Hz
1.0	4.0e-3
2.0	3.0e-2
4.0	3.0e-2
6.5	2.0e-3
75.0	2.0e-3
110.0	8.0e-5
380.0	8.0e-5
1000.0	5.0e-6

Figure 3.5 Test units staged for vibration testing

After the vibration test there was no apparent damage to the exterior of the package. The package was not opened to inspect the internal condition. However, upon later opening the package, there was an effect observed that was attributed to the vibration test. See Section 5.1, Drum Disassembly Observations.

3.2 Free Drop Test (Test Units 1 through 5)

TU-1 through TU-5 were subjected to the 1.2 m (4 ft) NCT drop test. As shown in Table 3.2, these units were dropped in various orientations. Deformation of each test unit from the NCT drop test is described in this section. Total deformation, cumulative for all impact tests, for each package, is reported in tabular form in Section 4.4. The details of the NCT free drop test, including data on damage, measurements, and damage sketches for each package, are reported in Appendices H-L for test units TU-1 through TU-5, respectively.

The drop tests on TU-1, TU-3, TU-4, and TU-5 were carried out at the NTRC indoor drop pad, located in Room L110. This provided the essentially unyielding surface for the NCT free drop tests (Ref: ORNL/NTRC-001 *Design and Certification of Targets for Drop Testing at the NTRC Package Research Facility*, Rev. 0) Table 3.2 shows the desired package orientation for each drop test and the orientation of each package achieved for the test. TU-2, the chilled unit, was drop tested on the outdoor drop pad just before the HAC drop tests were conducted.

Figure 3.6 shows a typical test set-up being performed. The measuring bar is used to determine the proper drop height and assist in aligning the package to the center of the drop pad. The figure shows TU-1 suspended for the drop test and is also representative of the TU-5 slap-down drop at an angle of 12°. Figure 3.7 shows the chilled TU-2 being dropped on the outdoor drop pad. Figure 3.8 shows how TU-3 was angled so that it would drop on the 0° marking with package CG over the impacting edge. Figure 3.9 shows the damage that occurred to TU-3 after it was dropped. Finally, Figure 3.10 shows the orientation of TU-4 for its top-down drop test.

Table 3.2 Planned vs. measured package orientation for NCT drop tests

Test Unit	Desired Orientation	Measured Orientation
TU-1	Axis of package 12° angle to horizontal; 0° marking should contact drop pad first	Axis of package 12.1° from horizontal
TU-2	Axis of package horizontal; 0° marking should contact drop pad first	Axis of package 0.1° from horizontal
TU-3	Axis of package rotated downward 24.6° from horizontal; 0° marking should contact first	Axis of package 25° from horizontal
TU-4	Axis of package vertical; drum lid should contact drop pad first	Axis of package 0.1° from vertical
TU-5	Axis of package 12° angle to horizontal; 0° marking should contact drop pad first	Axis of package 12.1° from horizontal

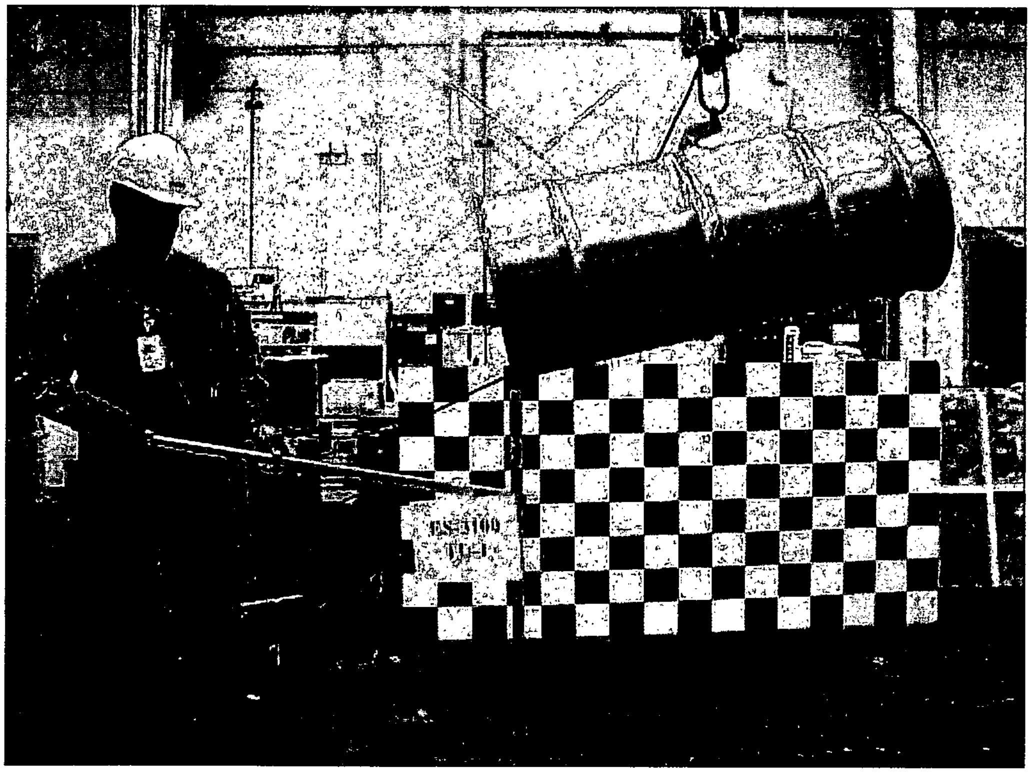


Figure 3.6 TU-1 positioned for the 12.1° NCT side drop test

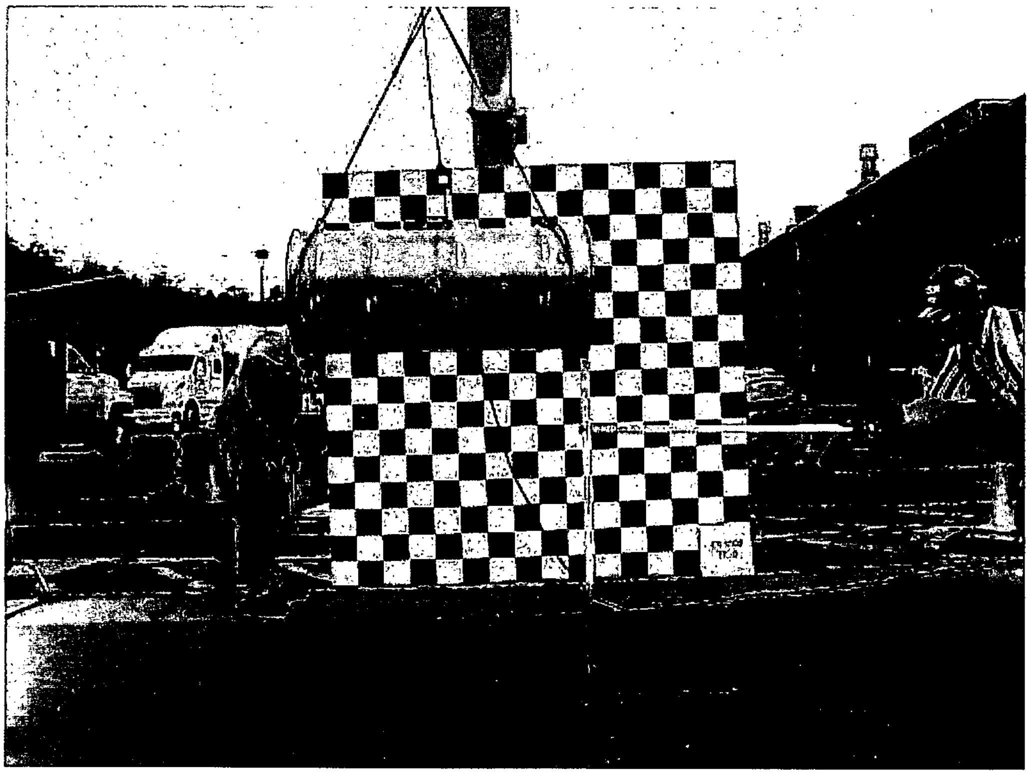


Figure 3.7 TU-2 being dropped horizontally while still cold

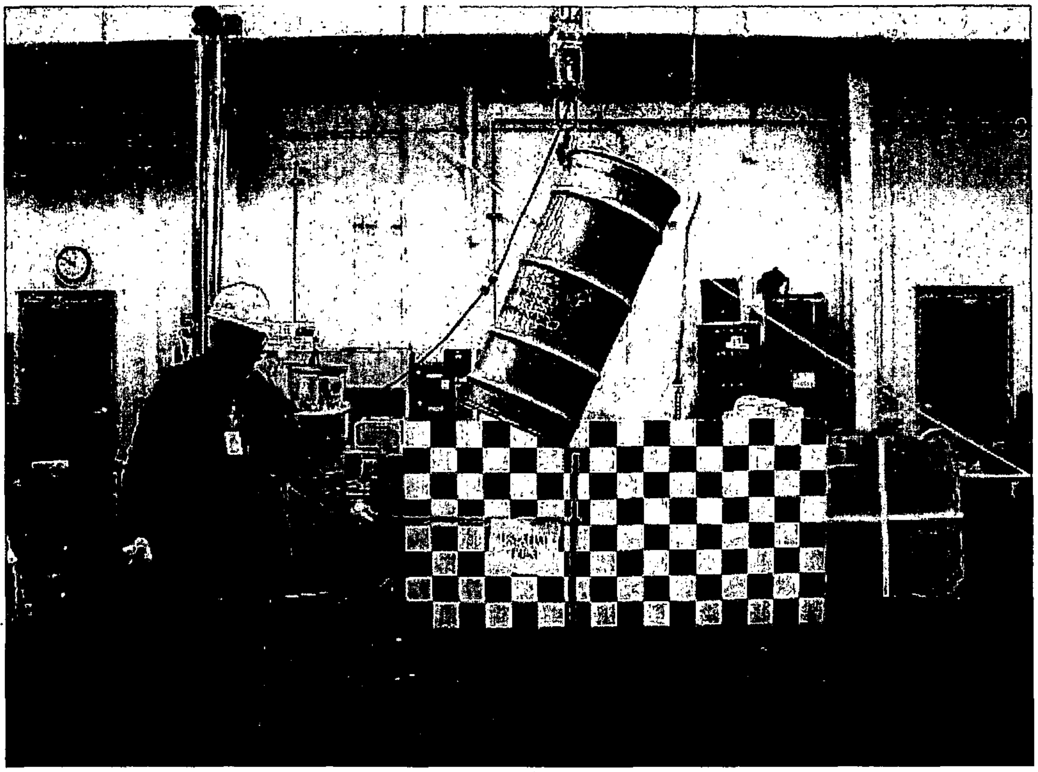


Figure 3.8 TU-3 being angled 24.6° so that 0° corner contacts the drop pad first

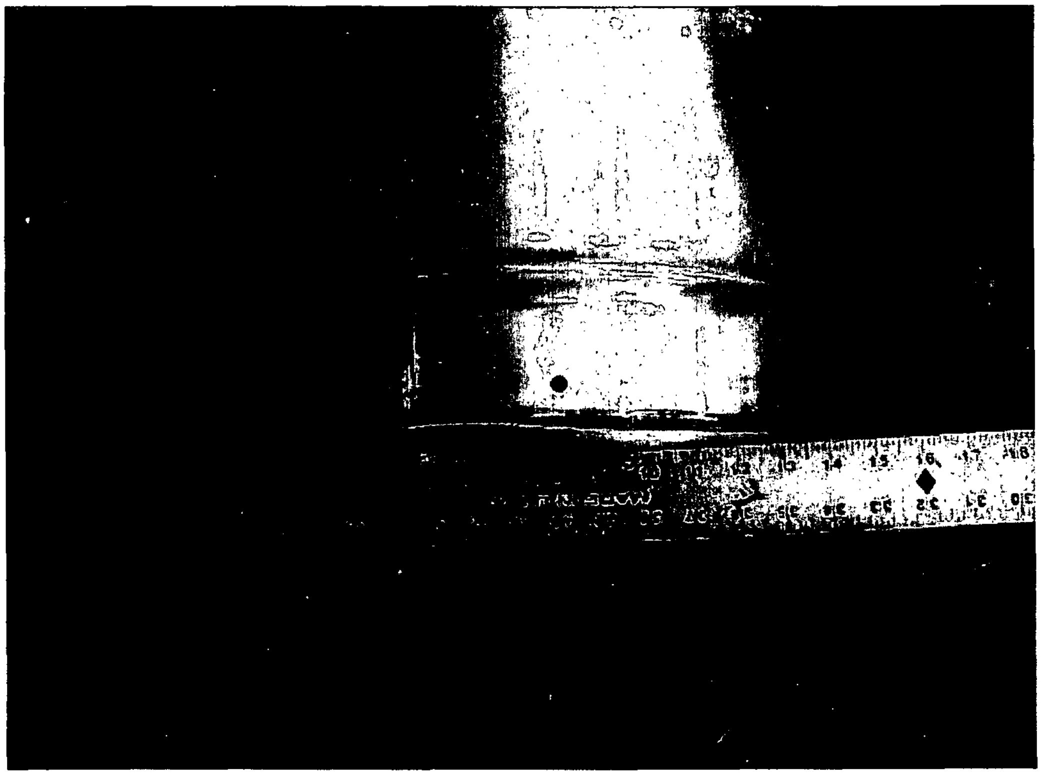


Figure 3.9 Damage to TU-3 after NCT drop

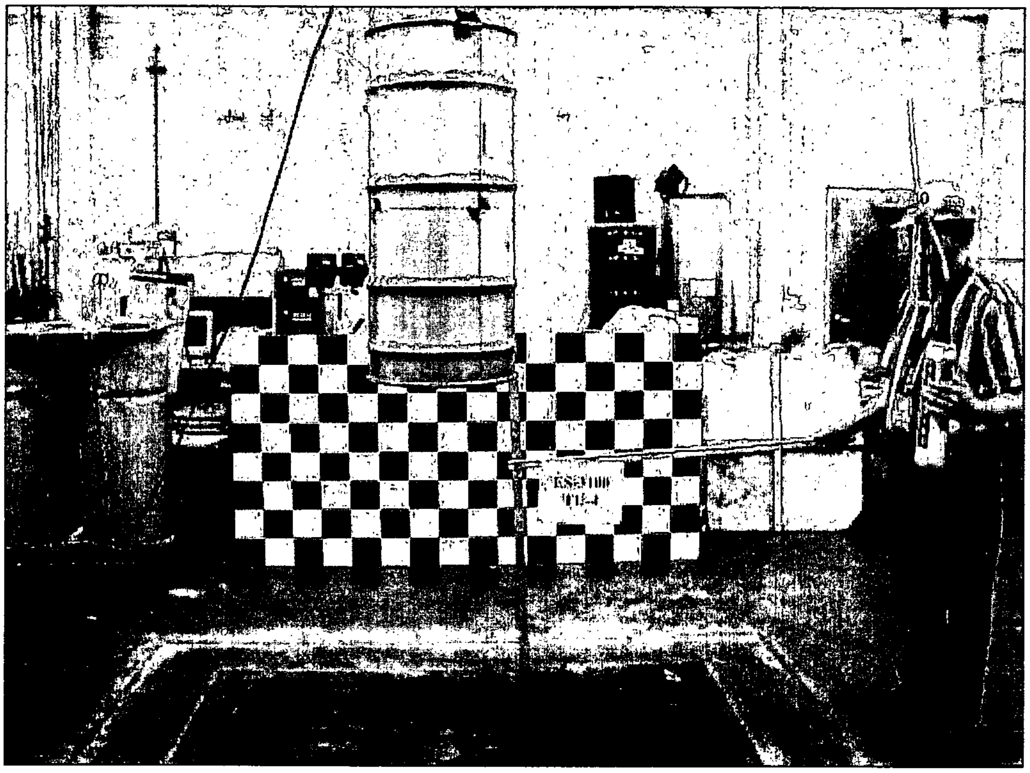


Figure 3.10 TU-4 being positioned head-down for the NCT vertical drop test

TU-1 had a measured angle of 12.1° from horizontal for the NCT drop along its 0° line with the bottom of the package lower. (To view this positioning, refer back to Fig. 3.6.) It experienced slight flattening at the top and bottom false wires and on the hoops along the 0° line. Use of a caliper determined that its diameter from 0° to 180° at both the top and bottom false wires decreased by 1/8 in and 1/4 in, respectively. The top false wire, where the impact occurred, had a flattened region 4-3/8 in long. The bottom false wire also had a flattened region of 4-5/8 in length. The flats of the top and bottom hoop were 4-1/2 in and 4 in, respectively.

TU-2 was dropped horizontally along its 0° line, deviating only 0.1° from the horizontal. It experienced a modest decrease in diameter and showed only slight flattening of its rolling hoops. Its top false wire flattened about 4 in, but the bottom false wire showed only a small dimple.

TU-3 was dropped at a 25° angle (desired was 24.6°) along its 0° line with the lid end impacting first. Because of the sharpness of the angle, the top false wire absorbed most of the damage and bent outward but did not flatten. See Figure 3.9 for an illustration of this damage. The height of the package decreased by 0.5 in along the 0° line but increased along the 180° line by 1/8 in. The diameters of the hoops and false wires remained constant.

TU-4 had a measured angle of 0.1° from vertical (Figure 3.10) and was dropped squarely on its top. In fact, it rested on its top after the drop. There was no visible damage to the top false wire, and it did not have a measurable change in diameter. The drum did show a modest 1/8-in decrease in height at the 180° and 270° lines.

TU-5 deviated only 0.1° from the intended 12° angle to horizontal and was dropped on the 0° line of the package. The top false wire absorbed most of the impact and showed the most damage resulting from 1.2-m NCT drop. Figure 3.11 shows the extent of the flattening that occurred. It lost 0.5 in diameter along the 0° to 180° width and had a flat of 5-3/8 in. Also, the washer at about 270° was movable, though the nut remained more than finger tight. The diameters of the rolling hoops uniformly decreased by 1/8 in, and the diameter of the bottom false wire decreased by 1/4 in. The bottom false wire also had a flat of 5 in.

Figure 3.11 Flattening of top false wire of TU-5.

4 HAC TESTS

The 10 CFR 71.73 *Hypothetical Accident Conditions* (HAC) compliance testing sequence was performed on test units TU-1 through TU-5. TU-2 was chilled to below -40 °C (-40 °F) before the structural tests. TU-1 through TU-5 were subjected to the 9-m (30-ft) free fall drop test followed by the 9-m (30-ft) dynamic crush test. For the 9-m (30-ft) dynamic crush test, the portion of the package damaged in the previous tests was placed in contact with the drop pad and the 1 m × 1 m 500 kg (1102 lb) crush plate was dropped to impact on the opposite (i.e., the undamaged) side. Next, all five test units were subjected to the HAC puncture test. Then all 5 test unit were subjected to the thermal test. Separately, an undamaged CV, TU-6, was subjected to the 15-m (50-ft) immersion test. Following each of the tests on TU-1, TU-3, TU-4, and TU-5, dimensional measurements were made to document the damage and are presented in Appendices H - L. Dimensional measurements were not taken between the tests on TU-2, so that it could remain as cold as possible for the tests. A summary of the cumulative damage measurements are presented in Section 4.4.

4.1 HAC 9-m (30 ft) Drop Test

Following the NCT drops, the test units were subjected to the 9-m (30-ft) HAC drop test. The HAC drop testing was performed at the NTRC outdoor drop pad. This pad provided the essentially unyielding surface required by the regulations. The construction of the drop pad is described in ORNL/NTRC-001 *Design and Certification of Targets for Drop Testing at the NTRC Package Research Facility*, Rev. 0.

The packages were dropped in the orientations shown in Table 4.1. All test units were dropped with the 0° side or edge contacting the drop pad first. Table 4.1 shows the desired package orientation for the HAC 9-m drop tests and the measured package orientations achieved for those tests.

Table 4.1 HAC 9-m drop test desired package orientation vs. measured orientation

Test Unit	Desired Orientation	Measured Orientation
TU-1	Axis of package 12° from horizontal, lid up, 0° side down	Axis of package 12.2° from horizontal
TU-2	Axis of package horizontal, 0° side down	Axis of package 0.1° from horizontal
TU-3	Axis of package 24.6° from vertical, lid down, 0° side down	Axis of package 24.8° from vertical
TU-4	Axis of package vertical, lid down	Axis of package 0.2° from vertical
TU-5	Axis of package 12° from horizontal, lid up, 0° side down	Axis of package 12.5° from horizontal

Following this test, a variety of dimensional measurements were made to document the damage. The measurements taken after this test for each of the test units are presented in Appendices H - L. Figure 4.1 and Figure 4.2 show setup and results, respectively, for the HAC drop test of TU-3. Figure 4.3 through Figure 4.6 diagram the HAC drop test setup for each test unit.

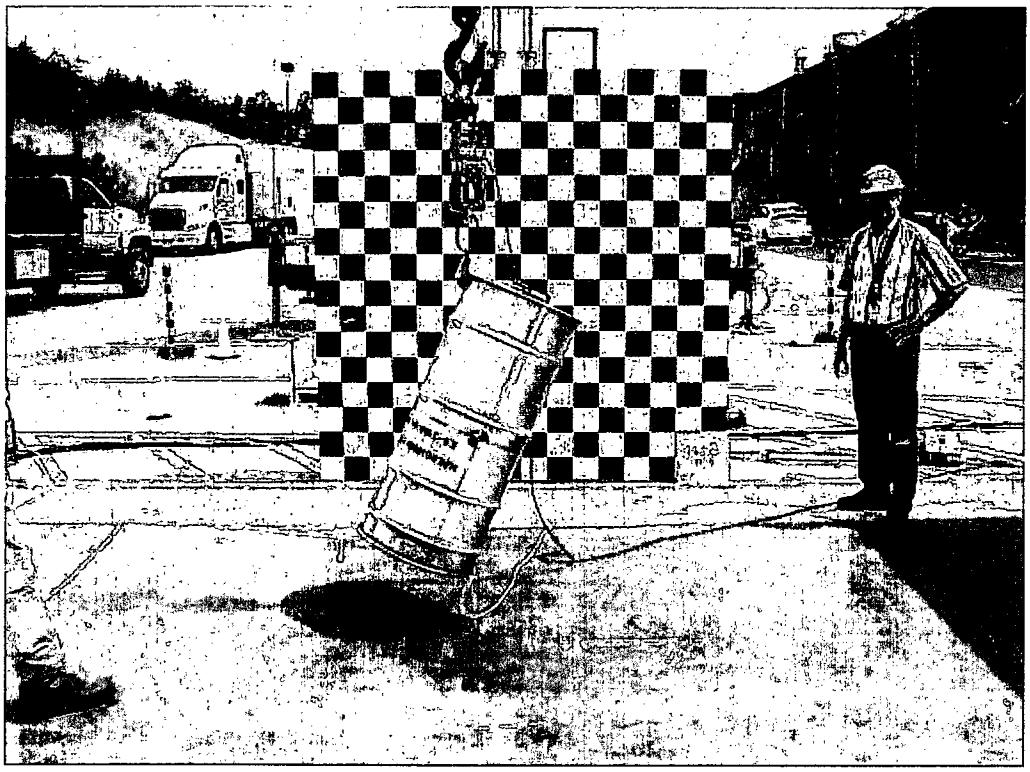


Figure 4.1 Test setup for the HAC 9-m free drop of TU-3

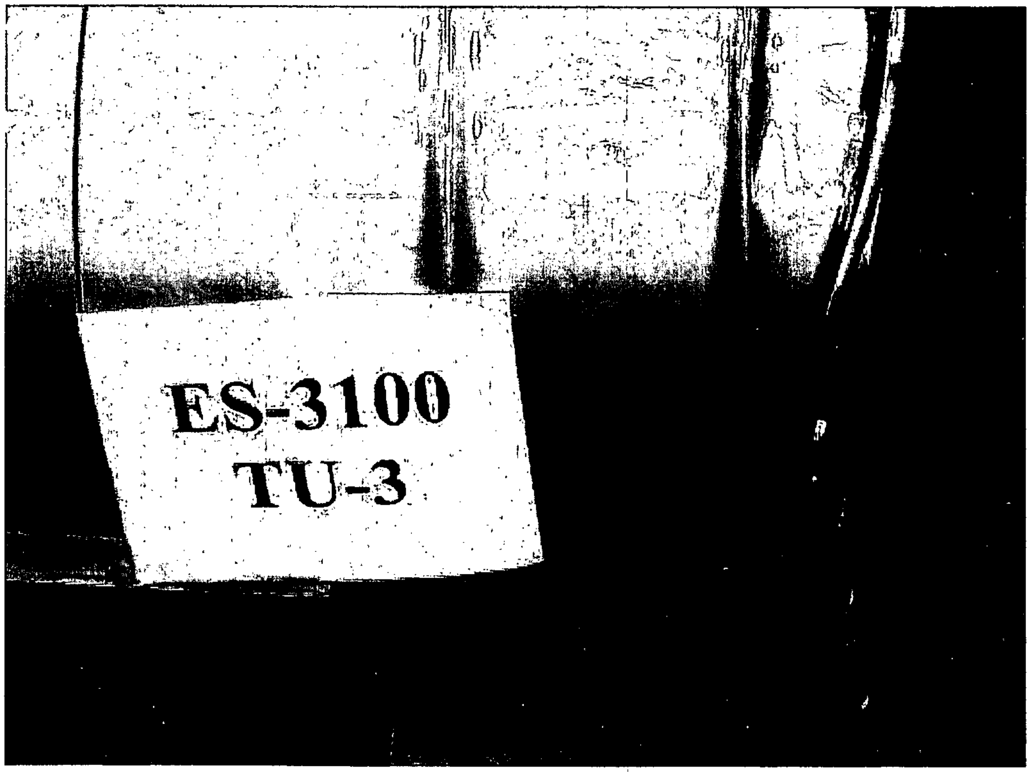


Figure 4.2 Results of the HAC drop of TU-3

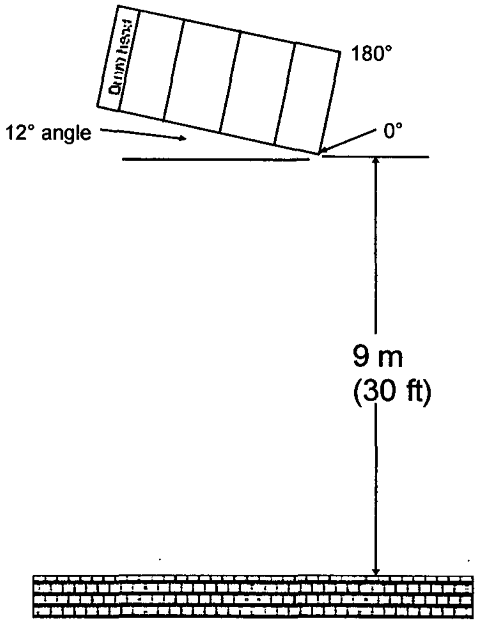


Figure 4.3 TU-1 and TU-5 HAC 9-m drop test setup

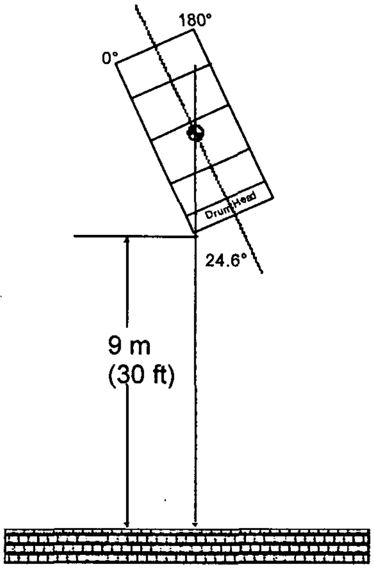


Figure 4.5 TU-3 HAC 9-m drop test setup

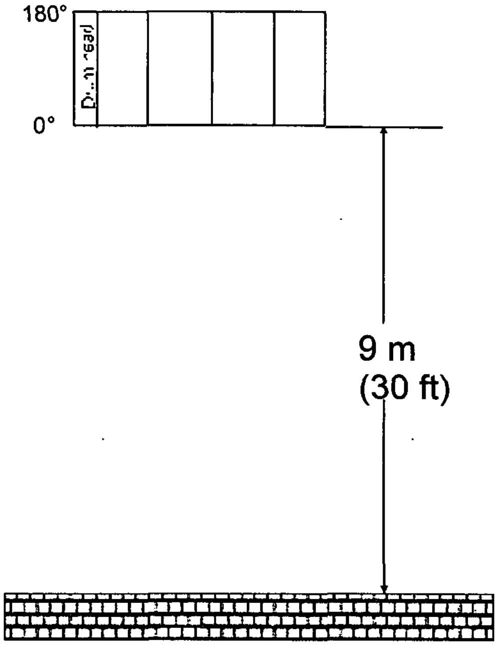


Figure 4.4 TU-2 HAC 9-m drop test setup

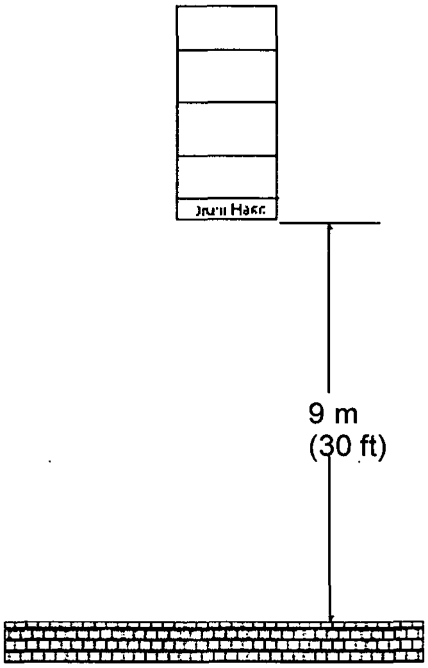


Figure 4.6 TU-4 HAC 9-m drop test setup

TU-1 was dropped with the axis of the package at an angle of 12.2° from horizontal with the lid up, on its 0° side from a distance of 9 m. The drum's side was flattened, generating a flat of 8 inches at the top false wire and 10 inches at the bottom false wire. The diameter of the drum along the direction of impact was reduced by 5/8 inch at the top false wire and by 1-3/16 inch at the bottom false wire. No nuts were loosened. See the datasheet in the Appendix H for more details. See Appendix A for photographs of damage.

TU-2 was dropped with the axis of the package at an angle of 0.4° from horizontal on its 180° side from a distance of 9 m. The package had been cooled to below -40 °C prior to testing. In order to test the package while it was as cold as possible, the NCT drop, HAC drop, HAC crush, and puncture tests were conducted promptly one after the other. Physical measurement of the intermediate damage was not taken. Only the cumulative damage at the end of these tests was taken. The cumulative damage is described in Section 4.3. No nuts were loosened. See the datasheet in the Appendix I for more details. See Appendix B for photographs of damage.

TU-3 was dropped with the CG over the edge of the lid, at an angle of 24.8° from vertical, with its 0° side impacting first from a distance of 9 m. The drum's top false wire was forced down 1-1/8 inches at the point of impact, creating a flat 16 inches long. No nuts were loosened. See the datasheet in the Appendix J for more details. See Appendix C for photographs of damage.

TU-4 was dropped with the lid impacting first from a distance of 9 m at an angle of 0.2° from vertical. The drum's lid was flattened slightly. The overall height of the package was reduced about 3/8 inch on the 90° side to 7/8 inch on the 270° side. No nuts were loosened. See the datasheet in the Appendix K for more details. See Appendix D for photographs of damage.

TU-5 was dropped with the axis of the package at an angle of 12.5° from horizontal with lid up, on its 0° side from a distance of 9 m. The drum's side was flattened, generating a flat of 8-3/8 inches at the top false wire and 9-1/4 inches at the bottom false wire. The diameter of the drum along the direction of impact was reduced by 1/8 inch at the top false wire and 5/8 inch at the bottom false wire. No nuts were loosened. See the datasheet in the Appendix L for more details. See Appendix E for photographs of damage.

4.2 HAC Dynamic Crush Test

When a fissile material, Type B package weighs less than 500 kg and has an overall density less than 1000kg/m^3 (62.4 lb/ft^3) 10 CFR 71.73 stipulates that the dynamic crush test follows the 9-m free drop test. Therefore, the test units were subjected to the dynamic crush test after being subjected to the 9-m free drop test.

Test Units 1 through 5 were subjected to the dynamic crush test. This test consisted of placing the test units on the unyielding impact pad and dropping a 1 m × 1 m square 500 kg (1102 lb) steel plate onto the package from a 9-m (30-ft) drop height. Figure 4.7 shows the results of the dynamic crush test of TU-1.

Figure 4.7 Results of the dynamic crush test of TU-1.

Figure 4.8 shows the test setup for TU-3 after the package had been balanced and prior to the raising of the 500 kg steel plate. Figure 4.9 and Figure 4.10 show the damage resulting from the crush test of TU-3. Figure 4.11 through Figure 4.14 show the setup for each of the crush tests performed.

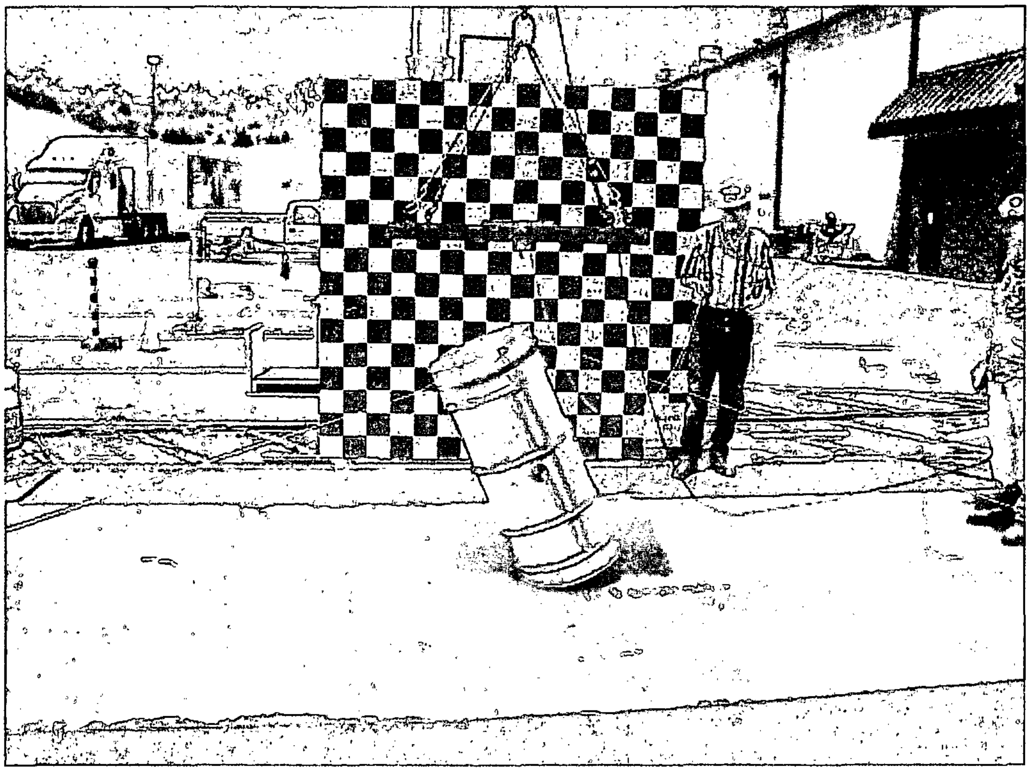


Figure 4.8 TU-3 dynamic crush test set-up, ready to raise crush plate

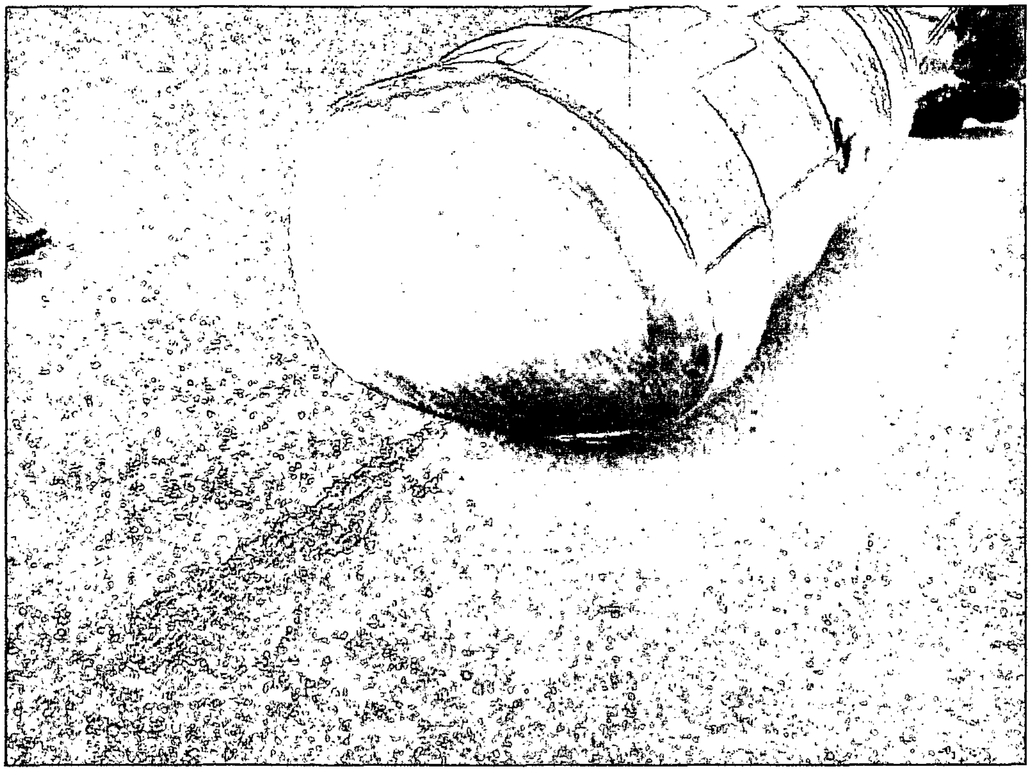


Figure 4.9 Damaged bottom of TU-3 after the dynamic crush test

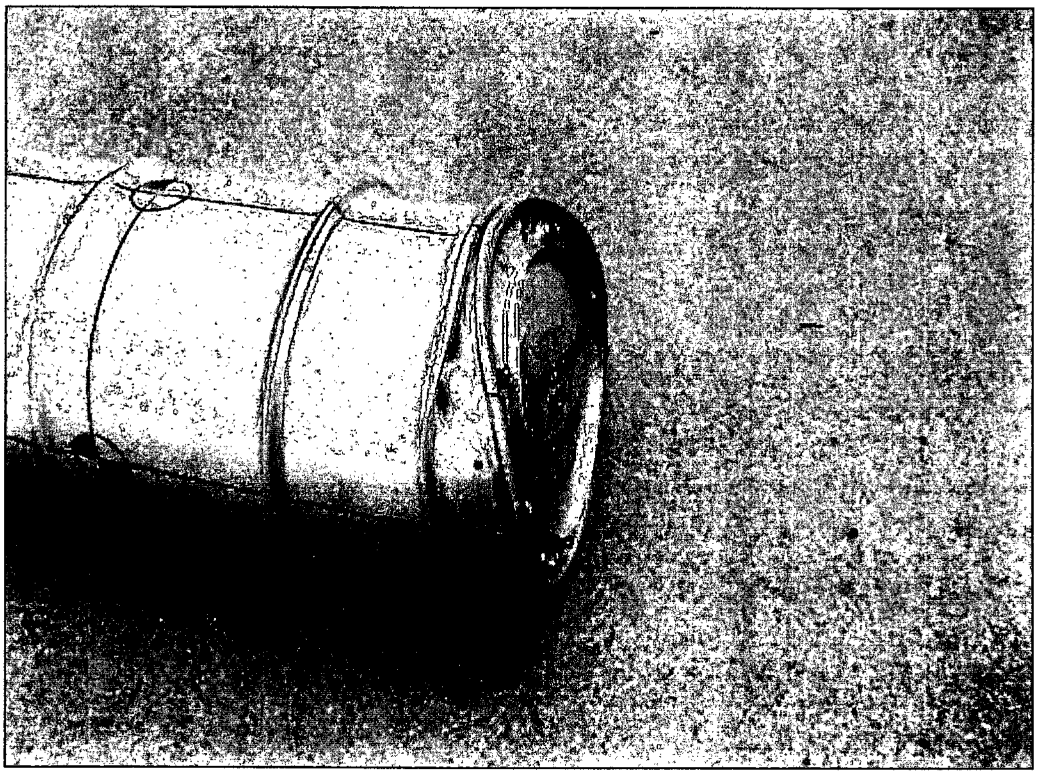


Figure 4.10 Damaged top of TU-3 after the dynamic crush test

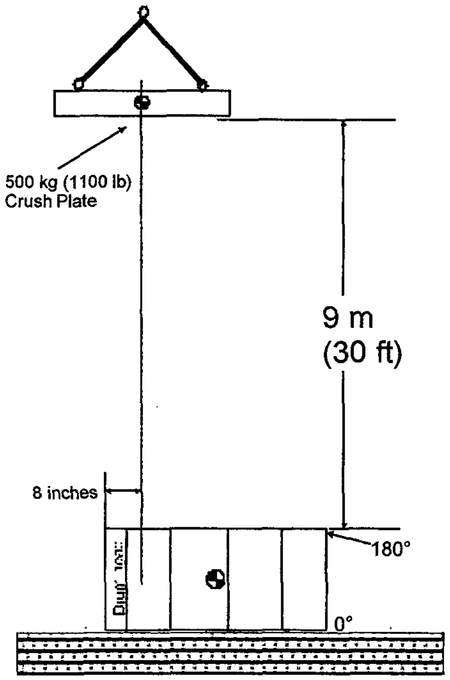


Figure 4.11 HAC crush test setup for TU-1

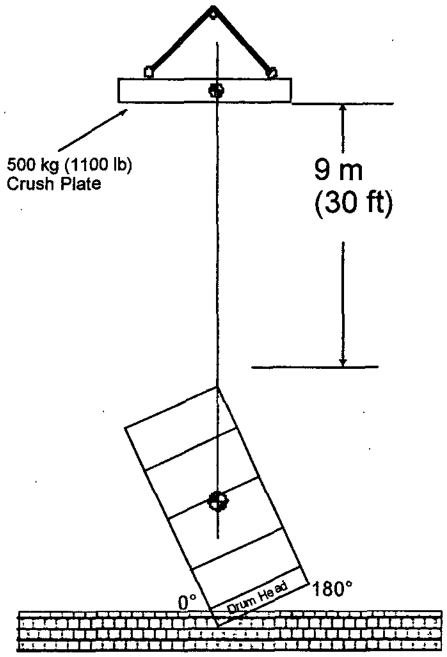


Figure 4.13 HAC crush test setup for TU-3

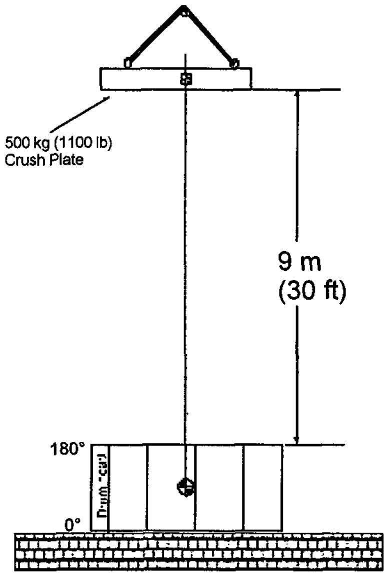


Figure 4.12 HAC crush test setup for TU-2 and TU-5

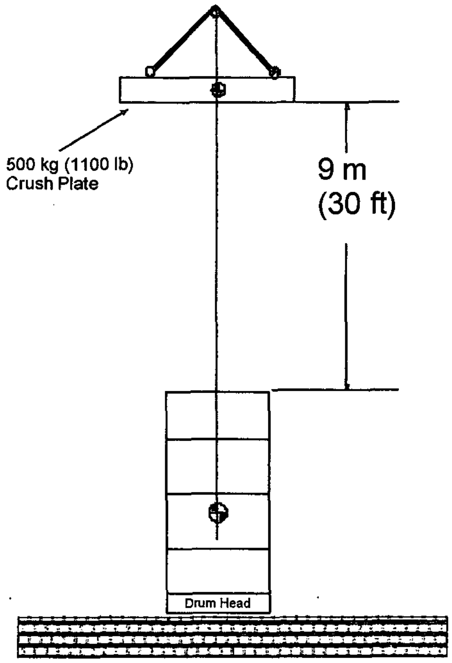


Figure 4.14 HAC crush test setup for TU-4

TU-1 was set horizontally on the impact pad with the previously damaged 0° side down and the crush plate was centered over the approximate location of the CV flange, about 8 inches from the top of the package. The impact flattened the 180° side above the bottom hoop, generating a flat of 8-1/2 inches at the top false wire and 10-5/8 inches just above the bottom hoop. The impact also increased the flattening of the 0° side, generating a flat of 10 inches at the CG hoop to 9 inches at the top false wire. The diameter of the drum along the direction of impact was reduced by 2-7/8 inch at the top false wire and about 2-3/8 inch just above the bottom hoop. No nuts were loosened. See the datasheet in the Appendix H for more details. See Appendix A for photographs of damage.

TU-2, the chilled unit, was set horizontally on the impact pad with the previously damaged 0° side down and the crush plate was centered over the CG of the package. The package's 0° side was flattened, generating a flat of 6-1/4 inches at the top hoop and 14-7/8 inches at the bottom hoop. The diameter of the drum along the direction of impact was reduced by 1-5/8 inch at the top false wire and 3-3/4 inch at the bottom hoop. The package's 180° side was flattened, generating a flat of 8 inches at the top false wire to 10-1/8 inches at the CG + top hoop. The diameter of the drum along the direction of impact was reduced by 1-5/8 inch at the top false wire and 3-3/4 inch at the bottom hoop. No nuts were loosened. See the datasheet in the Appendix I for more details. See Appendix B for photographs of damage.

TU-3 was tested by orienting the package on the impact pad in the same CG-over-corner attitude that was used when it was previously dropped from 9 m. To do this the package had to be balanced with its damaged edge on the impact pad and the bottom of the package in an upward position. To hold the package in position, two thin nylon cords were anchored to the impact pad and attached around the diameter of the package. These cords were adjusted in length to properly balance the package at the desired angle. The bottom false wire of the package on the 180° side was flattened. The bottom false wire was crushed down about 6 inches and the damaged top false wire was crushed down about 5 inches. The stud and its nut nearest the 0° position was sheared off. See the datasheet in the Appendix J for more details. See Appendix C for photographs of damage.

TU-4 was set vertically, top down on the drop pad, and the crush plate was centered over the bottom of the drum. The height of the package was reduced by 3-5/8 at 0° to about 2-1/4 at 180°. No nuts were loosened. See the datasheet in the Appendix K for more details. See Appendix D for photographs of damage.

TU-5 was set horizontally on the drop pad with previously damaged, 0° side down. The crush plate was aligned so that the edge of the crush plate would impact the top hoop rather than over the CG. This was a field change from the Test Plan. The actual impact created a crease about 3 inches from the top and 1 inch from the bottom. The impact flattened the 180° side below the top, generating a flat of 8-5/8 inches at the top crease and 11 inches at the bottom crease. The impact increased the flattening of the 0° side, generating a flat of 8-7/8 inches at the top to 11-3/8 inches at the bottom hoop. The diameter of the drum along the direction of impact was reduced by 1-3/4 inches at the CG + top hoop (3) and 1-7/16 inch at the bottom false wire. No nuts were loosened. See the datasheet in the Appendix L for more details. See Appendix E for photographs of damage.

4.3 HAC Puncture Test

TU-1 through TU-5 were each subjected to at least one HAC puncture test. Each package was raised to a height of 1 m (40 inches) above a 15-cm (6-inch) diameter steel puncture bar that had been bolted to the steel impacting surface of the drop pad. TU-1 was subjected to four puncture tests. In the first test the punch impacted the CG on the 0° line. Then the area of the CV flange on the 180° line was impacted. Afterwards, the third test was designed to impact at 28° from vertical through the CG on the 90° line.

After completion of these first three tests, it was then noticed the drawings in the test plan were not in agreement with the text of the test plan. The angles specified in the text were from horizontal rather than from vertical as shown in the drawings. After conferring with Y-12 personnel, the fourth test was changed to impact at 40° from horizontal on the 270° line instead of 40° from vertical as shown in the drawing. Also, an additional puncture test was conducted on TU-3 at an angle of 28° from horizontal, impacting the 270° side.

Figure 4.15 shows the TU-1 set-up process for the HAC puncture test. The set-up process was essentially the same for each test unit. The 1-m bar was used to both determine the correct drop height and to assist in aligning the impact point with the center of the puncture bar.

The prior damage caused by both the HAC 9-m (30 ft) drop and HAC crush test misaligned the test unit surfaces from the horizontal axis of the package. Therefore, TU-1, TU-2, and TU-5 were rigged to be dropped so that the impacted surface was parallel to the puncture bar face. To accomplish this, prior to lifting, the angle of the upper surface of the package was measured while the package was lying flat on the floor. Once the package was raised, the rigging was adjusted to reproduce the same reading on the level. Table 4.2 shows the desired package orientation and the orientation that was achieved for each puncture test. The orientation readings recorded on the data sheets for each test unit is the difference between the level reading with the test unit on the drop pad and with it suspended and ready to drop. Figure 4.17 through Figure 4.25 diagram the HAC puncture test set-up for each of the test units.

Table 4.2 Package orientations for HAC puncture test

Test Unit	Desired Orientation	Measured Orientation
TU-1	Axis of package horizontal	Axis of package 0.0° from horizontal
TU-1	Axis of package horizontal	Axis of package 0.0° from horizontal
TU-1	Axis of package 28° from vertical	Axis of package 27.9° from vertical
TU-1	Axis of package 40° from horizontal	Axis of package 40.1° from horizontal
TU-2	Axis of package horizontal	Axis of package 0.8° from horizontal
TU-3	Axis of package 24.6° from vertical	Axis of package 25.2° from vertical
TU-3	Axis of package 28° from horizontal	Axis of package 28.4° from horizontal
TU-4	Axis of package vertical	Axis of package 0.3° from vertical
TU-5	Axis of package horizontal	Axis of package 0.1° from horizontal

The resulting impacts produced indentations in the surface of the outer drums, but did not puncture the drum surfaces (Figure 4.16). Typically, damage was observed to cover a circular-shaped area approximately 6 inches in diameter or a crescent shaped dent. The dent depths ranged from a slight indentation to 7/8-in deep. The detailed dimensional data for this test was recorded on data sheets in Appendices H- L.

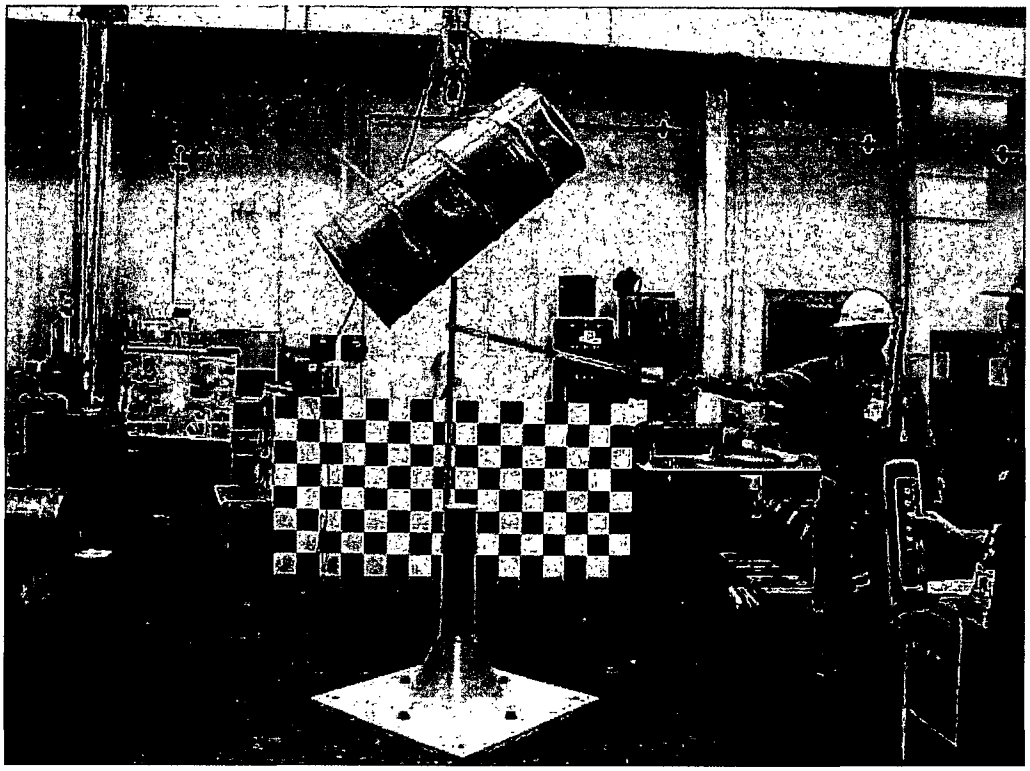


Figure 4.15 Test setup for the puncture test of TU-1

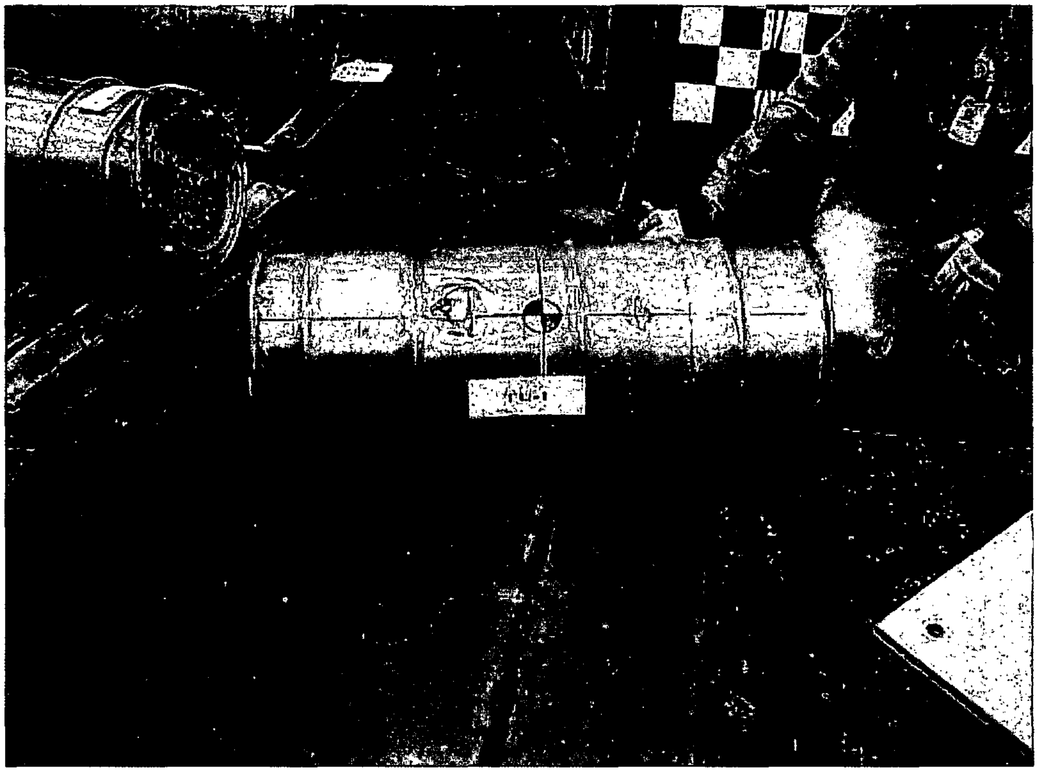


Figure 4.16 Damage from puncture test of TU-1

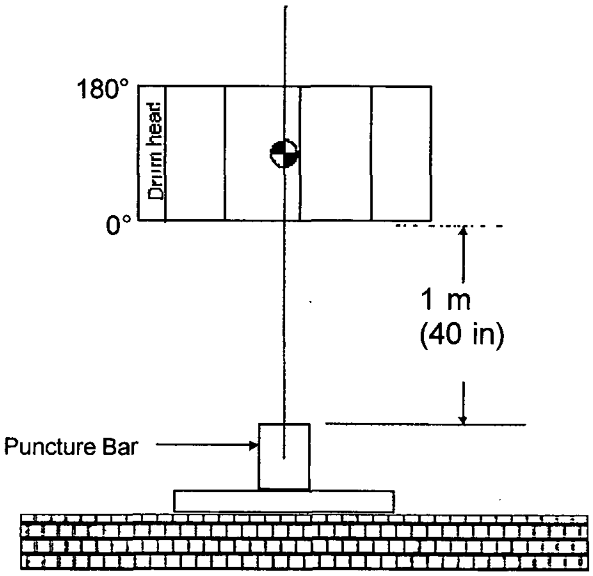


Figure 4.17 Initial TU-1 puncture test setup

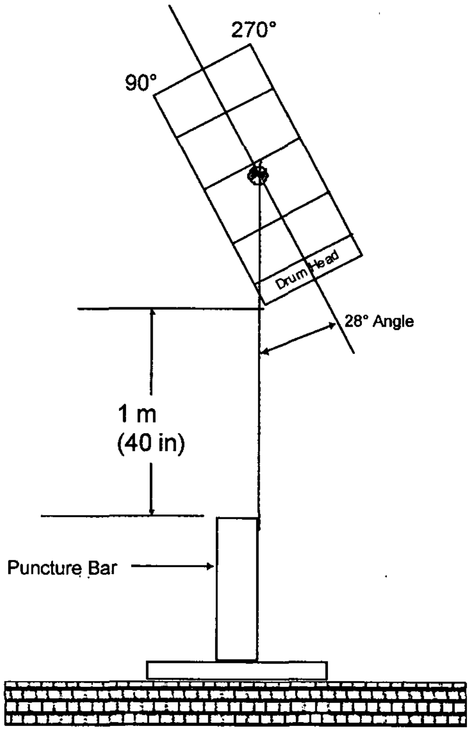


Figure 4.18 Orientation for third TU-1 HAC 1m puncture test

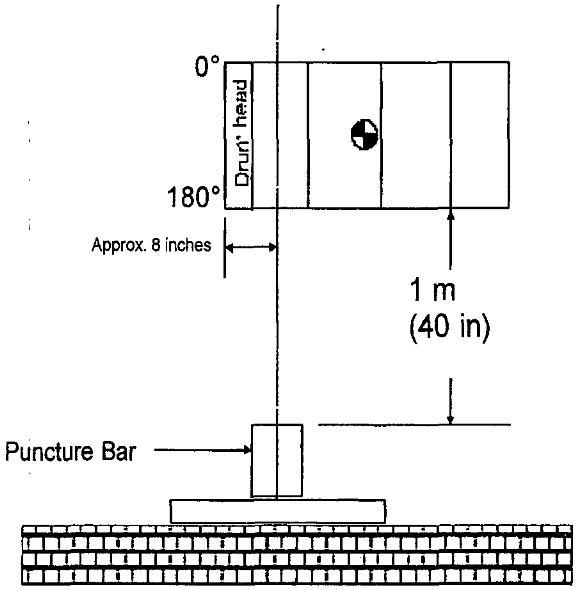


Figure 4.19 Second TU-1 puncture test setup

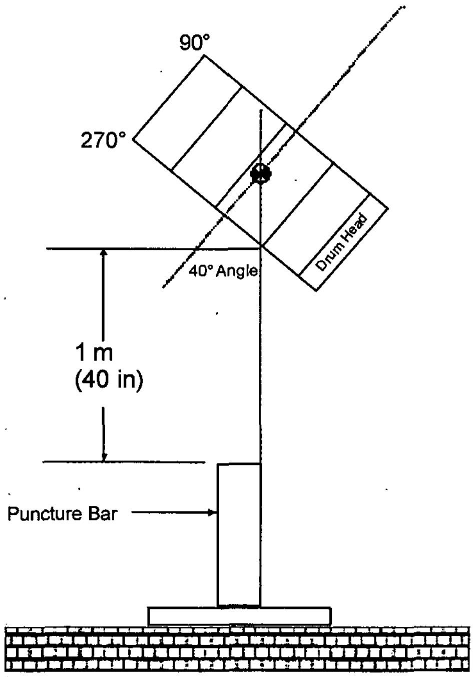


Figure 4.20 Orientation for fourth TU-1 HAC 1m puncture test

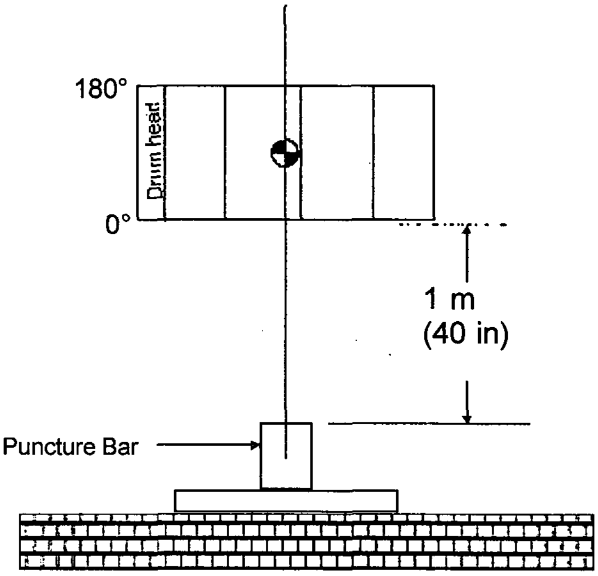


Figure 4.21 TU-2 puncture test setup

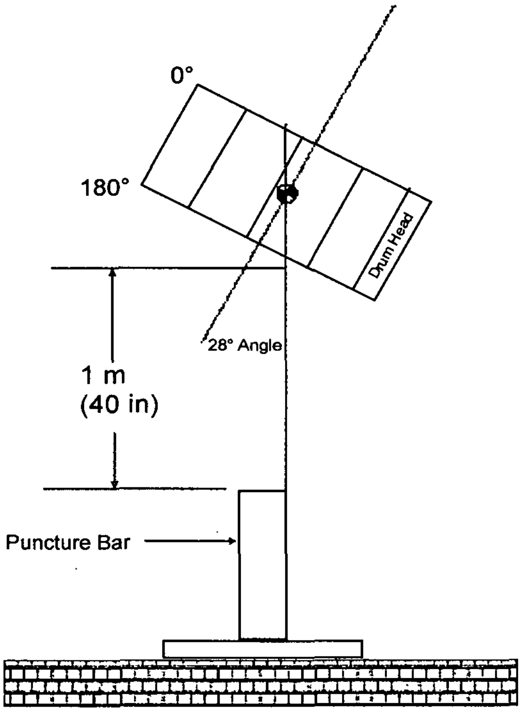


Figure 4.23 TU-3 second puncture test setup

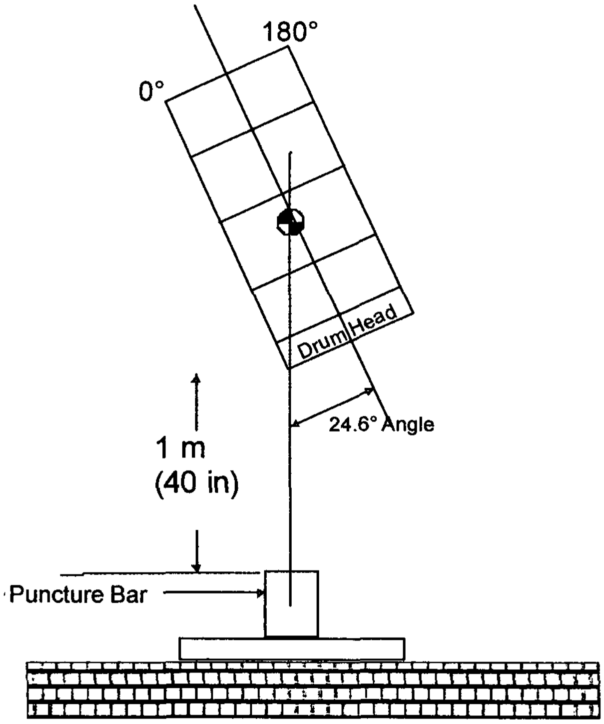


Figure 4.22 TU-3 puncture test setup

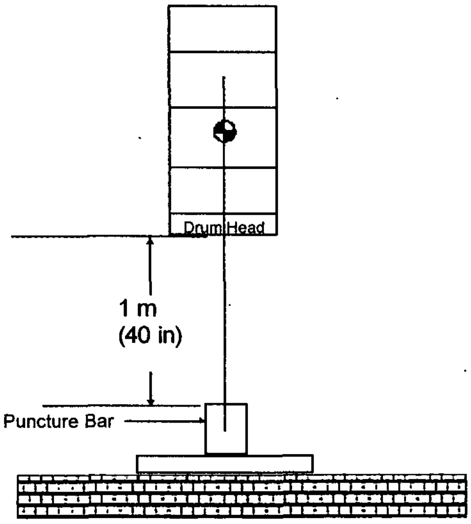


Figure 4.24 TU-4 puncture test setup

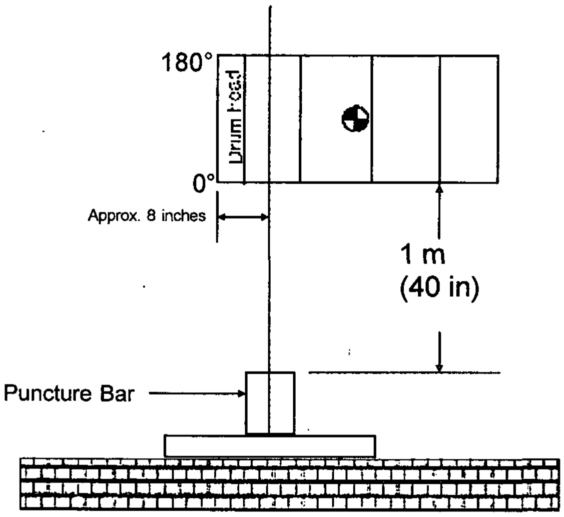


Figure 4.25 TU-5 puncture test setup

TU-1 was puncture tested in four different orientations. TU-1 was dropped with the package horizontal on its 0° side from a distance of 1 m at an angle of 0.0° from horizontal onto the puncture bar which was located under the CG of the package. For the second test, TU-1 was dropped with the package horizontal on its 180° side from a distance of 1 m at an angle of 0.0° from horizontal onto the puncture bar which was located under the CV flange, about 8 inches from the top of the drum. These impacts produced circular dents with a depth of about 5/8 and 3/8 of an inch. TU-1 was dropped a third time with the lower side of the package on its 90° side from a distance of 1 m at an angle of 27.9° from vertical. The puncture bar was located under the CG of the drum. The impact produced crescent shaped dents along the side of the package with the deepest dent having a depth of about 5/8 of an inch. TU-1 was dropped a fourth time with the lower side of the package on its 270° side from a distance of 1 m at an angle of 40.1 ° from horizontal. The puncture bar was located under the CG of the drum. The impact produced crescent shaped dents along the side of the package with the deepest dent having a depth of about 3/4 of an inch. No nuts were loosened. See the datasheet in the Appendix H for more details. See Appendix A for photographs of damage.

TU-2 was puncture tested with the lower side of the package horizontal on its 0° side from a distance of 1 m at an angle of 0.8° from horizontal. The puncture bar was located under the CG of the package. The impact produced a circular dent with a depth of about 1/8 of an inch. No nuts were loosened. See the datasheet in the Appendix I for more details. See Appendix B for photographs of damage.

TU-3 was puncture tested in the CG over edge orientation from a distance of 1 m with the axis of the package at 25.2° from vertical. The puncture bar was position to impact the damaged 0° edge of the lid. The impact produced a shallow crescent-shaped dent in the reinforcing rim with a depth of about 1/16 of an inch. TU-3 was dropped a second time with the lower side of the package on its 270° side from a distance of 1 m at an angle of 28.4° from horizontal. The puncture bar was located under the CG of the drum. The impact produced a crescent-shaped dent in the side of the drum with a depth of about 7/8 of an inch. No nuts were loosened. See the datasheet in the Appendix J for more details. See Appendix C for photographs of damage.

TU-4 was puncture tested with the axis of the package vertical onto its top from a distance of 1 m at an angle of 0.3° from vertical. The puncture bar was located under the center of the top of the drum. The impact produced a circular dent with a depth of about 1/8 of an inch. The package stood balanced on top of the puncture bar after the test. No nuts were loosened. See the datasheet in the Appendix K for more details. See Appendix D for photographs of damage.

TU-5 was puncture tested with the lower side of the package horizontal on its 0° side from a distance of 1 m at an angle of 0.1° from horizontal. The puncture bar was located under the CV flange, about 8 inches from the top of the drum. The impact produced a circular dent with a depth of about 1/8 of an inch. No nuts were loosened. See the datasheet in the Appendix L for more details. See Appendix E for photographs of damage.

4.4 Summary of Cumulative Damage from Impact Tests

To quantify the damage from the drop testing, the diameters of the outer drums were measured across the 0° – 180° plane and the 90° – 270° plane at six locations on each test unit. Figure 4.26 shows the six locations along the side of each test unit where deformation measurements were taken. The height of each test unit was measured at the 0°, 90°, 180°, and 270° locations. The width of flattening from impact and crush was measured at six locations along the package on the impacted sides for the cumulative drop and crush damage. Total damage from all drop tests is summarized in Table 4.3 through Table 4.5 .

Some measurements were taken on some test units and not the others because damage was not incurred on some test units due to the various orientations the packages were tested in. For instance, side flattening did not exist for TU-4 as the test unit was subjected exclusively to end impacts. The damage produced on TU-3 by the CG over corner impacts is difficult to summarize; the reader is referred to the data sheets in Appendix J to understand both the shape and dimensions of the damage resulting from this testing.

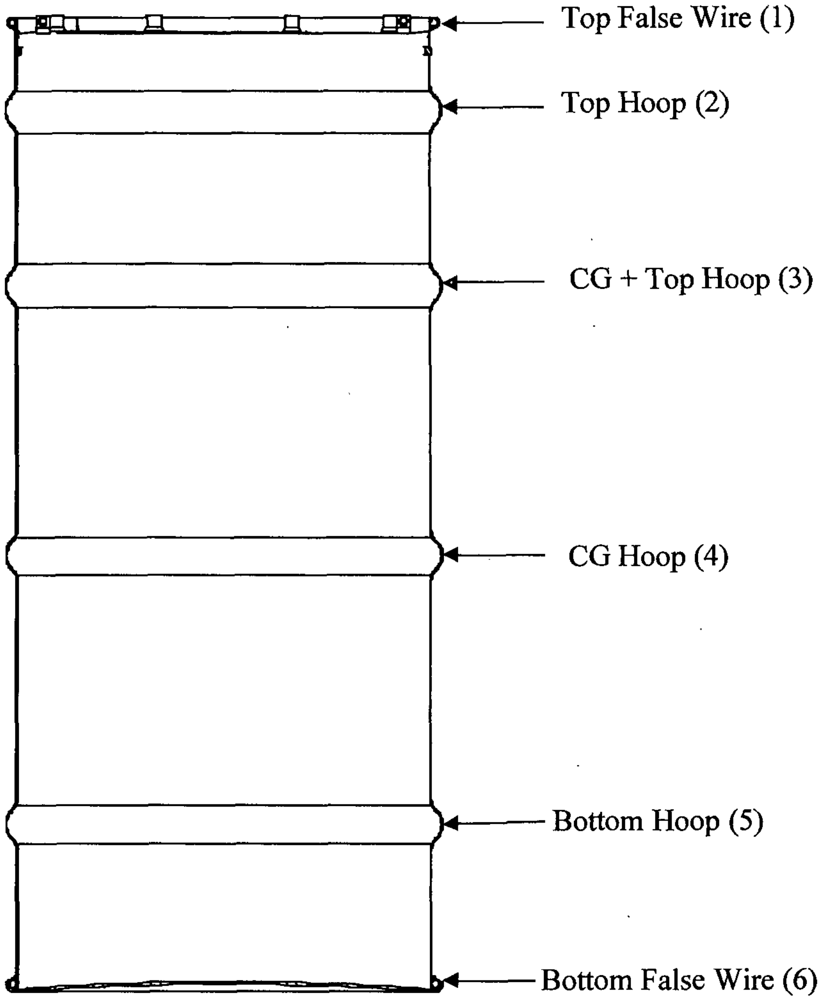


Figure 4.26 Locations where measurements were made on test unit exteriors

Table 4.3 Summary of total height change of each test unit after all impact testing (units = inches)

Test Unit	Initial Height 0°	Final Height 0°	Change in Height 0°	Initial Height 90°	Final Height 90°	Change in Height 90°	Initial Height 180°	Final Height 180°	Change in Height 180°	Initial Height 270°	Final Height 270°	Change in Height 270°
TU-1	43 1/2	44 7/8	+ 1 3/8	43 1/2	43 3/8	- 1/8	43 1/2	44	+ 1/2	43 1/2	43 5/8	+ 1/8
TU-2	43 1/2	44 3/4	+ 1 1/4	43 1/2	43 3/4	+ 1/4	43 1/2	42 3/4	- 3/4	43 1/2	43 5/8	+ 1/8
TU-3	43 1/2	39 3/8	- 1 1/8	43 1/2	42 7/16	- 1/16	43 1/2	39 1/8	- 4 3/8	43 1/2	42 1/2	- 1
TU-4	43 1/2	39 3/8	- 1 1/8	43 1/2	40 3/8	- 3 1/8	43 5/8	40 5/8	- 3	43 5/8	39 3/4	- 3 7/8
TU-5	43 1/2	45	+ 1 1/2	43 1/2	43 1/2	0	43 1/2	43 3/4	+ 1/4	43 1/2	43 7/8	+ 3/8

Table 4.4 Measurement of the width of "flats" after HAC crush test for side impact units (TU-1, TU-2 and TU-5) (units = inches)

Test Unit	Top false wire (1) 0°	Top hoop (2) 0°	CG + Top Hoop (3) 0°	CG Hoop(4) 0°	Bottom hoop (5) 0°	Bottom false wire (6) 0°	Top false wire (1) 180°	Top hoop (2) 180°	CG + Top Hoop (3) 180°	CG Hoop(4) 180°	Bottom hoop (5) 180°	Bottom false wire (6) 180°
TU-1	8 7/8	8 1/2	8	8 3/4	10 1/4	11 3/8	0	12 1/2	12	11 3/8	11 3/8	10 1/2
TU-2	6 1/4	8 7/8	9 5/8	12	14 7/8	0	8	9	10 1/8	9 7/8	9 7/8	9 3/8
TU-5	8 7/8	8 1/2	8	8 3/4	10 1/4	11 3/8	0	12 1/2	12	11 3/8	11 3/8	10 1/2

Table 4.5 Changes in diameter after all impact testing (units = inches)

Test Unit		Top false wire (1)	Top hoop (2)	CG + Top Hoop (3)	CG Hoop (4)	Bottom hoop (5)	Bottom false wire (6)
TU-1	**Initial Diameter 0° - 180°**	19 1/4	19 1/4	19 1/4	19 1/4	19 1/4	19 1/4
	Final Diameter 0° - 180°	15 5/8	16	16 1/4	16 1/2	18 1/4	17 13/16
	Change in Diameter 0° - 180°	- 3 5/8	- 3 1/4	- 3	- 2 3/4	- 1	- 1 9/16
	Initial Diameter 90° - 270°	19 1/4	19 1/4	19 1/4	19 1/4	19 1/4	19 1/4
	Final Diameter 90° - 270°	20 5/8	20 7/16	19 7/8	19 1/2	19 1/4	20 1/4
	Change in Diameter 90° - 270°	+ 1 3/8	+ 1 3/16	+ 5/8	+ 1/4	0	+ 1
TU-2	**Initial Diameter 0° - 180°**	19 1/4	19 1/4	19 1/4	19 1/4	19 1/4	19 1/4
	Final Diameter 0° - 180°	17 5/8	17 3/8	17	16	15 1/2	18
	Change in Diameter 0° - 180°	- 1 5/8	- 1 7/8	- 2 1/4	- 3 1/4	- 3 3/4	- 1 1/4
	Initial Diameter 90° - 270°	19 1/4	19 1/4	19 1/4	19 1/4	19 1/4	19 1/4
	Final Diameter 90° - 270°	19 13/16	19 3/4	20	20 1/4	20 1/8	19 3/8
	Change in Diameter 90° - 270°	+ 9/16	+ 1/2	+ 3/4	+ 1	+ 7/8	+ 1/8
TU-3	**Initial Diameter 0° - 180°**	19 1/4	19 1/8	19 1/8	19 1/8	19 1/8	19 1/8
	Final Diameter 0° - 180°	19 1/4	19 3/4	19 1/4	19 1/8	19 1/8	18
	Change in Diameter 0° - 180°	0	+ 5/8	+ 1/8	0	0	- 1 1/8
	Initial Diameter 90° - 270°	19 1/8	19 1/8	19 1/8	19 1/8	19 1/8	19 1/8
	Final Diameter 90° - 270°	19 1/16	20 1/4	19 3/4	19 1/4	19 3/4	19 3/8
	Change in Diameter 90° - 270°	- 1/16	+ 1 1/8	+ 5/8	+ 1/8	+ 5/8	+ 1/4
TU-4	**Initial Diameter 0° - 180°**	19 1/4	19 1/4	19 1/4	19 1/4	19 1/4	19 3/8
	Final Diameter 0° - 180°	19 1/4	20	20	19 7/16	19 15/16	19 1/4
	Change in Diameter 0° - 180°	0	+ 3/4	+ 3/4	+ 3/16	+ 11/16	- 1/8
	Initial Diameter 90° - 270°	19 3/8	19 1/4	19 1/4	19 1/4	19 1/4	19 1/4
	Final Diameter 90° - 270°	19 3/8	20 1/8	20 1/16	19 1/2	20	19 1/4
	Change in Diameter 90° - 270°	0	+ 7/8	+ 11/16	+ 1/4	+ 3/4	0
TU-5	**Initial Diameter 0° - 180°**	19 3/8	19 1/4	19 1/4	19 1/4	19 1/4	19 1/4
	Final Diameter 0° - 180°	19 3/8	19 3/8	19 3/8	19 1/4	19 1/4	19 5/16
	Change in Diameter 0° - 180°	0	+ 1/8	+ 1/8	0	0	+ 1/16
	Initial Diameter 90° - 270°	19 3/8	19 1/4	19 1/4	19 1/4	19 1/4	19 1/4
	Final Diameter 90° - 270°	19 3/8	19 5/8	20	20	19 3/4	19 3/8
	Change in Diameter 90° - 270°	0	+ 3/8	+ 3/4	+ 3/4	+ 1/2	+1/8

4.5 HAC Thermal Test

The HAC thermal test requirements are given in 10 CFR 71.73(c)(4). For the ES-3100 test units, a furnace located at the Timken Precision Forging Facility in Latrobe, PA was used for the HAC thermal testing. The test method used was based upon and closely followed ASTM E2230 *Standard Practice for Thermal Qualification of Type B Packages for Radioactive Material.*

4.5.1 Furnace Description

The thermal testing of the ES-3100 test units was performed in the gas-fired Furnace #3 in the Precision Forging Facility at Timken Steel Company in Latrobe, PA. Timken Steel maintains and operates this furnace as an AMS2750 certified Class 1A furnace. The furnace is an open-fired natural gas fueled box furnace with a 20 ft x 12 ft x 8 ft work zone and a guillotine door. The furnace has been in service since the mid 1980s. The furnace is normally used as a billet reheat furnace for the forging of billets and round bars. The estimated heating design load is 10 tons within a range of 1400°F to 2100°F.

The heating system consists of six North American high-velocity pulse-fired burners with a total heating capacity 10M to 12M BTU. Pulse-fired burners operate with air being blown through them continuously with natural gas being pulsed into the burners when the control system calls for additional heat. The burners are crown mounted with two zone controls. A single flue is located 24 inches above the hearth line in the center of the back wall. The flue is rear-chambered for a power damper (disconnected) with an external vented stack. The furnace insulation consists of a cast hearth floor refractory brick curb 12-in w x 24-in high on the wall with the remaining height of the walls and the ceiling lined with ceramic fiber pyro-block. Figure 4.27 shows the interior of Furnace #3.

The control system consists of a Honeywell UDC3300 controller, DOR2500 multipoint recorder, Vista Interface software, and UDC3300 over-temperature controller. Control and over-temperature thermocouples are type S 20ga. The control thermocouple junctions are mounted flush at the wall. The thermocouples are located 12 inches to the left and down of burner #1 for zone 1 and 12 inches to the left and down of burner #6. The over-temperature thermocouples are mounted in the roof at the center of each zone. The over-temperature thermocouple junctions are 4 inches below the ceiling.

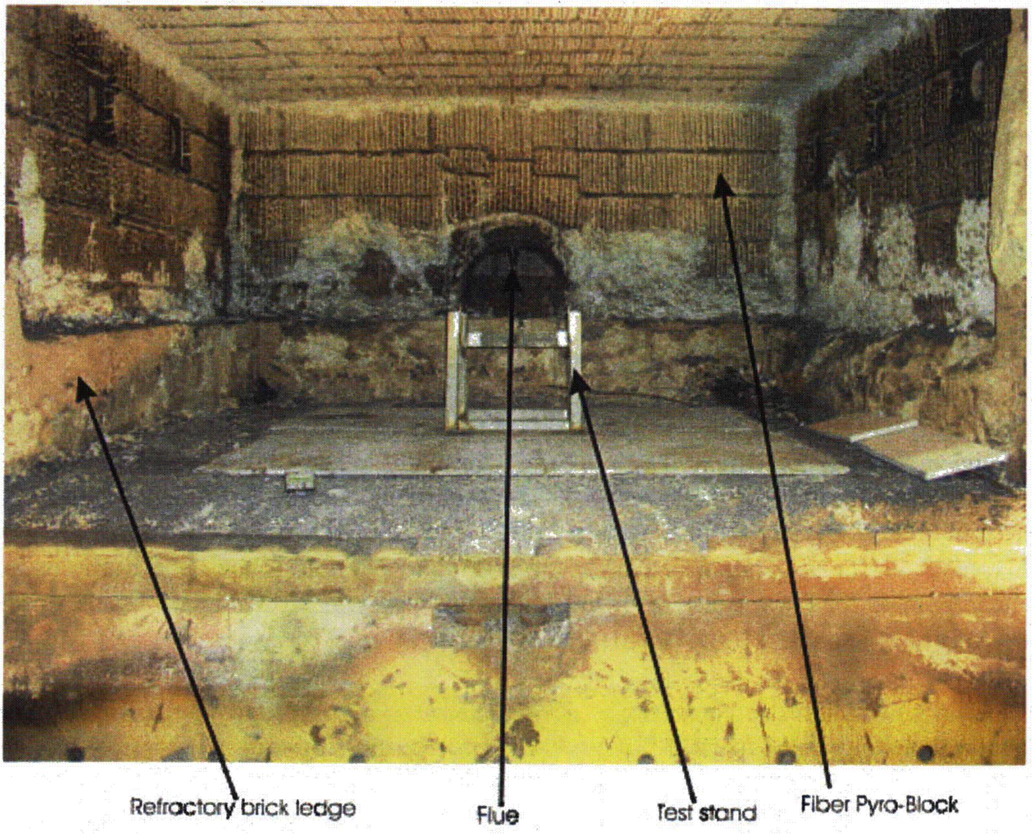


Figure 4.27 Interior of furnace #3

4.5.2 Furnace Setup

Furnaces used for performing the HAC thermal testing are required to operate in very tight temperature ranges with relatively light loads. In addition, a thorough understanding of the thermal environment surrounding the test unit is required. Commercial furnaces, like the Timken furnace #3, usually require that the operating parameters of the furnace be changed considerably from the normal settings to meet the desired thermal regime for HAC testing. In addition, considerable additional instrumentation must be installed for monitoring during testing. Furnace #3 was no exception, and in order to perform the ES-3100 testing several temporary additions and modifications were made to Furnace #3.

In the area of physical modifications, two 4 ft x 8 ft x 1 in thick plates of steel were placed on the floor to provide a secure and flat surface to which the test stand was mounted. The test stand was centered in the furnace then tack-welded to the steel plates.

A computer-based thermal monitoring system, developed by ORNL, was used to monitor the furnace environment and the test units during these tests. This system provides 72 data channels that are continuously logged to a data file. During the test runs the system was set to log data every 15 seconds from each data channel. The thermocouples used for the ES-3100 thermal testing were calibrated .063-inch and .037-inch diameter Type K thermocouples. These lightweight thermocouples provide a very rapid response to changes in temperature which provides a very accurate picture of the furnace and test unit thermal behavior.

In order to monitor the furnace environment during testing, a total of 18 thermocouples were installed on the furnace surfaces and the test stand. Figure 4.28 diagrams the location of the thermocouples in the left wall, Figure 4.29 diagrams the location of thermocouples on the right wall, and Figure 4.30 diagrams the location of thermocouples on the back wall and front door (locations in the furnace are referenced from a position looking into the furnace from the door). Figure 4.31 through Figure 4.32 show the thermocouples installed on the left, back, and right walls. The wall thermocouples were fastened to the both the refractory brick or pyro-block with 3/8 in x 2 in lag screw anchors and the tip of each thermocouple was covered with refractory cement. Three thermocouples were installed on the steel floor plate. These thermocouples were aligned along the axis of the test unit as it sits on the test stand. Finally, three thermocouples were attached to the test stand — one on the inward facing surface of each side member and the back member. The floor plate and test stand thermocouples were attached with metal clips tack-welded to the surface and the thermocouple tips were covered with refractory cement. See Appendix G for additional photographs of thermal test activities.

Once furnace preparations were completed, several practice loadings were performed on the cold furnace to ensure that the test units could be loaded onto the test stand and rapidly unloaded from the furnace to minimize the cooling of the furnace due to the door being open. After the cold load/unload practice was completed, the furnace was fired. Once fired, the furnace was allowed to heat soak for more than at 24 h before testing was initiated.

A number of changes to the furnace and its control system were made to produce an acceptable thermal regime. To compensate for the furnace over-firing, the fuel supply to burners

#2 and #5 was shut down after TU-3 was tested. Because the air supply for burners #2 and #5 ran continuously, excess oxygen needed to support combustion of material in the test unit was ensured. After these changes were performed, furnace control thermocouple cycles were controlled to +/-15°F of set point of the furnace controller thermocouple. A set point temperature of 1600°F was needed to consistently keep all additional furnace thermocouples above 1475°F.

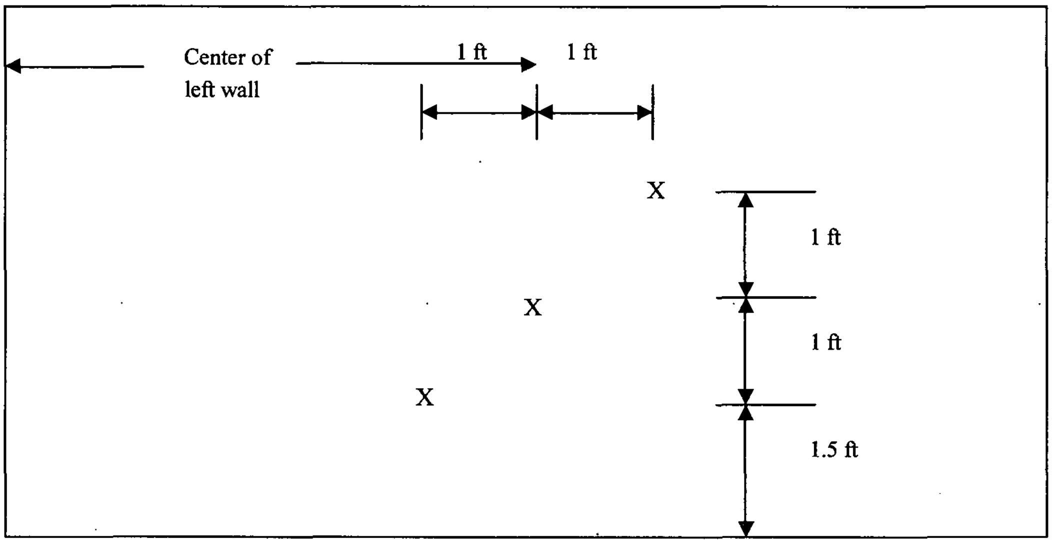


Figure 4.28 Approximate location of 3 thermocouples in left wall of furnace

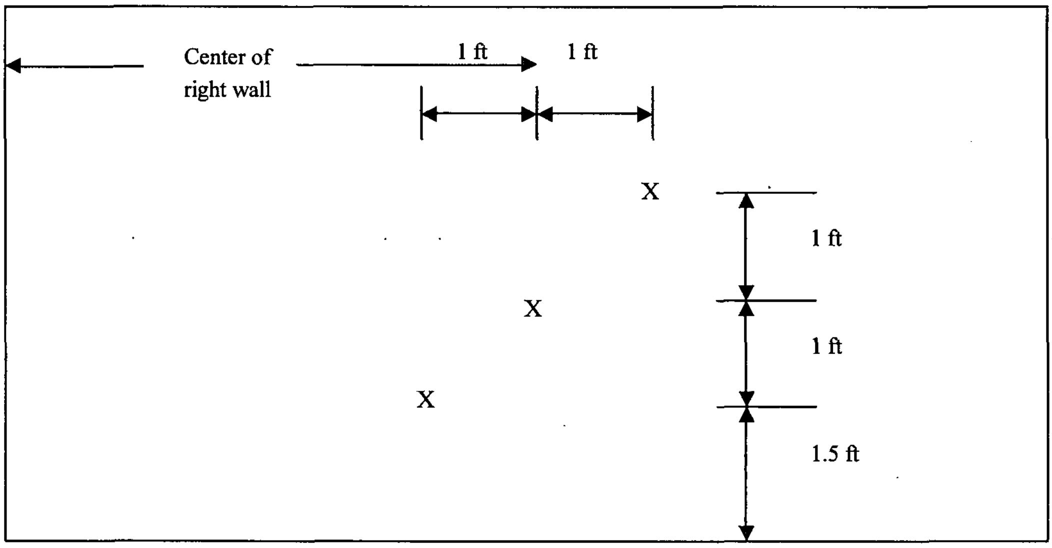


Figure 4.29 Approximate location of 3 thermocouples in right wall of furnace

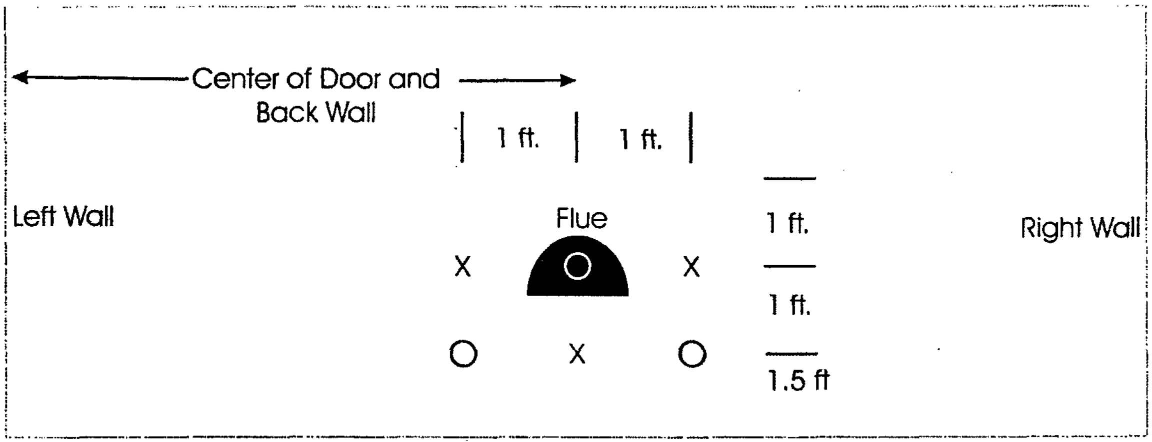


Figure 4.30 Approximate location of thermocouples in door (O) and back wall (X)

Figure 4.31 Furnace #3 left wall thermocouple layout

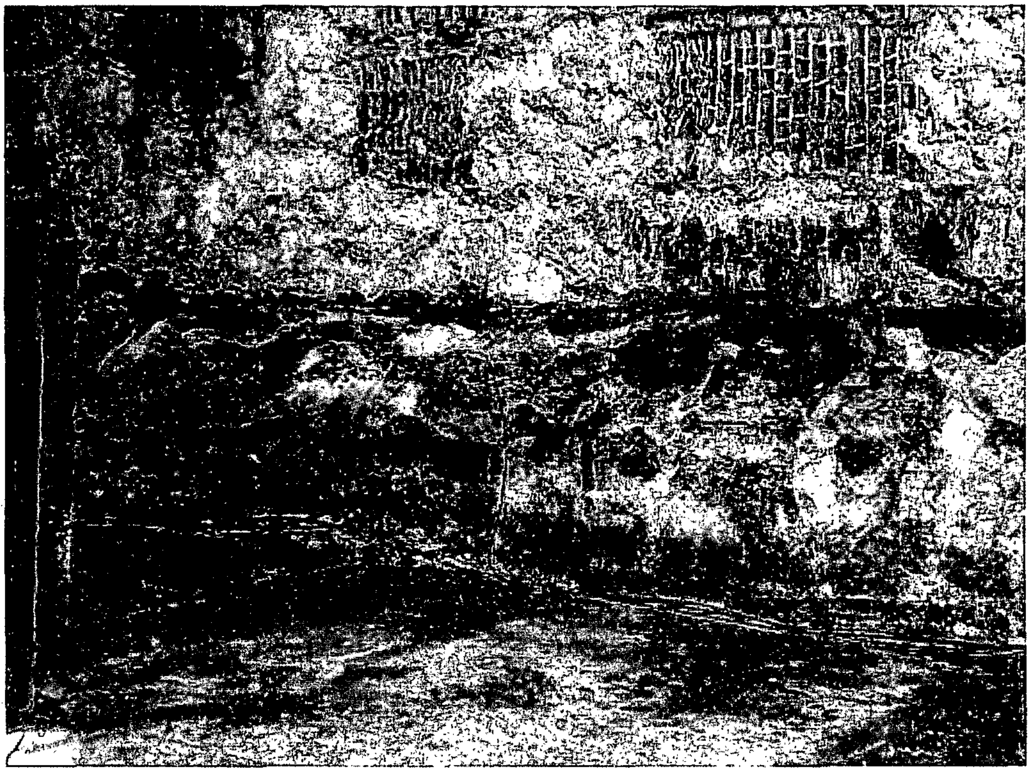


Figure 4.32 Furnace #3 right wall thermocouple layout.

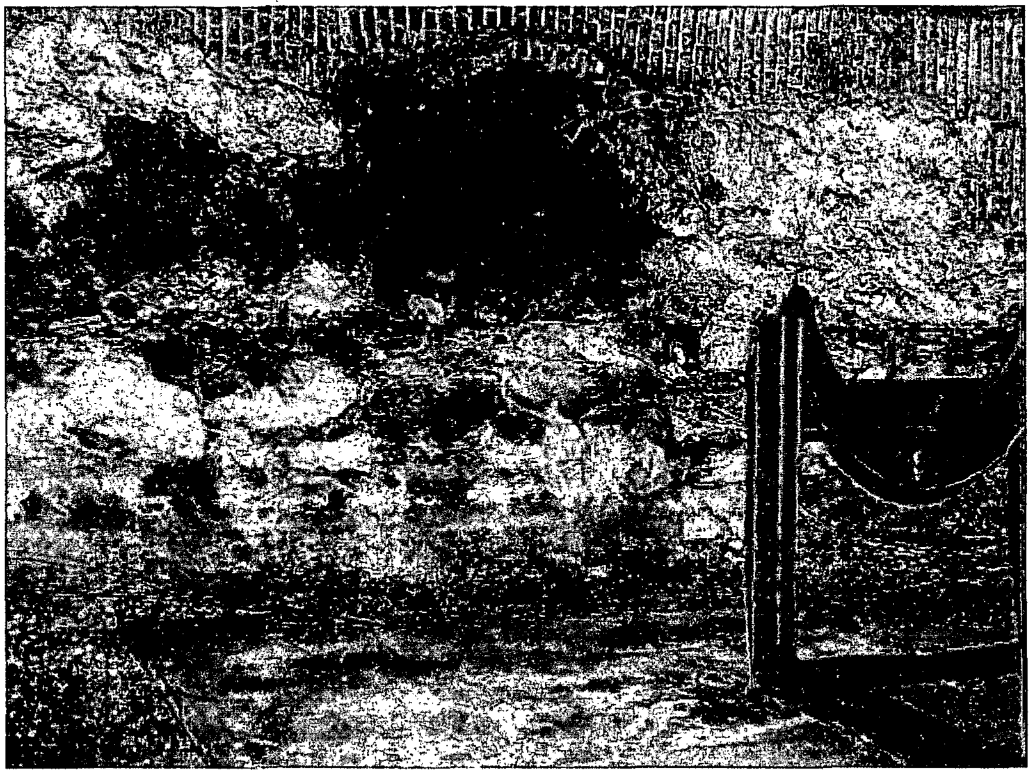


Figure 4.33 Furnace #3 back wall thermocouple layout (Note: flue in center of picture)

4.5.3 Test Unit Setup and Preparation

All of the test units were preheated to raise the internal temperature to above 38°C (100°F) by placing them in a 6 ft x 6 ft x 6 ft environmental chamber. Figure 4.34 shows the preheat chamber with some of the test units loaded. The environment chamber was heated by a torpedo-type kerosene space heater which is controlled by a mechanical bulb thermostat with a control range of 100°F to 200°F. In accord with the stipulations and procedures referenced in the Test Plan for pre-heating, the temperature in the environmental chamber was set at 66 °C (150 °F) at 09:24 on 06/14/2004 for approximately 23 hours and then set to 43°C (110°F) at 08:19 on 06/15/2004 for the next ~24 hours. The Thermal Data Acquisition System was set up and connected to the preheat chamber when the preheat chamber was loaded and turned on. The data channel F-35 is the exhaust temperature from the preheat chamber while channel F-36 is the skin temperature of one of the test units in the preheat chamber. Channel F-34 is the ambient temperature of the room.

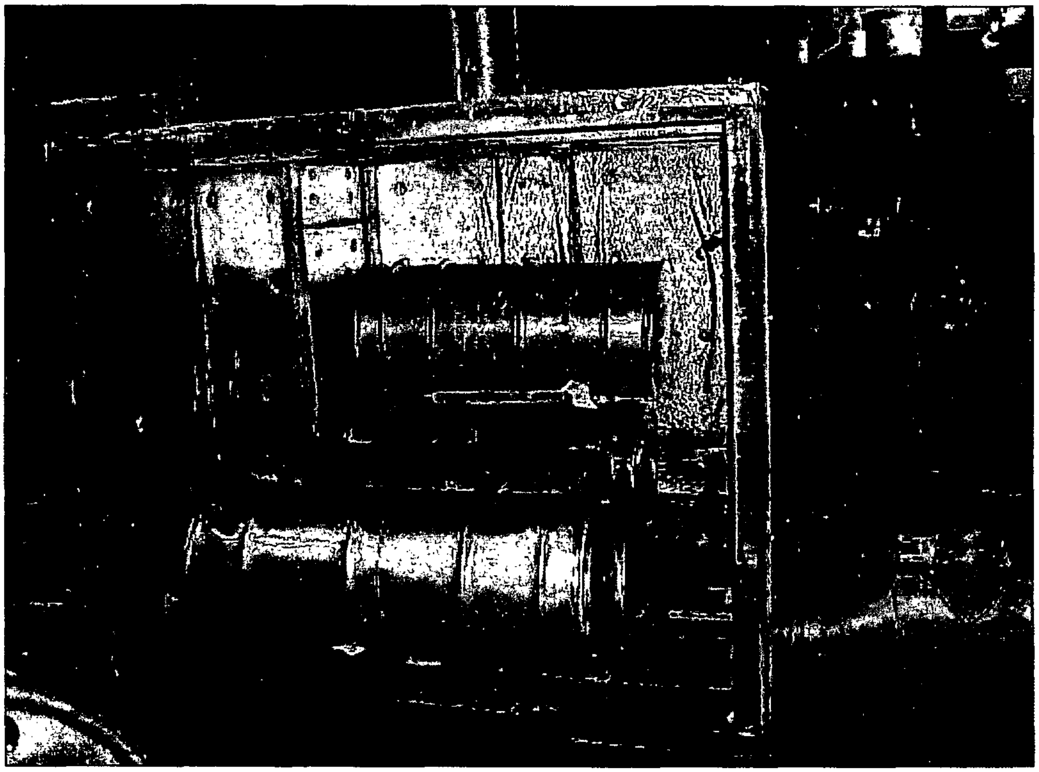


Figure 4.34 Test units in preheat chamber

After preheating and just prior to loading a test unit into the furnace, six .063-inch diameter thermocouples were attached to the exterior surface of each package. Metal retainer clips had previously been tack-welded to the drums to hold the thermocouples in place. The thermocouple tips were inserted underneath the metal clips, and then wrapped around the metal clips. In order to eliminate any radiant viewing factor between the thermocouples and the furnace walls, the tips and metal clips were covered with a ceramic coating. After installation and just prior to insertion of the test unit into the furnace, the functionality of each thermocouple was tested using a propane torch.

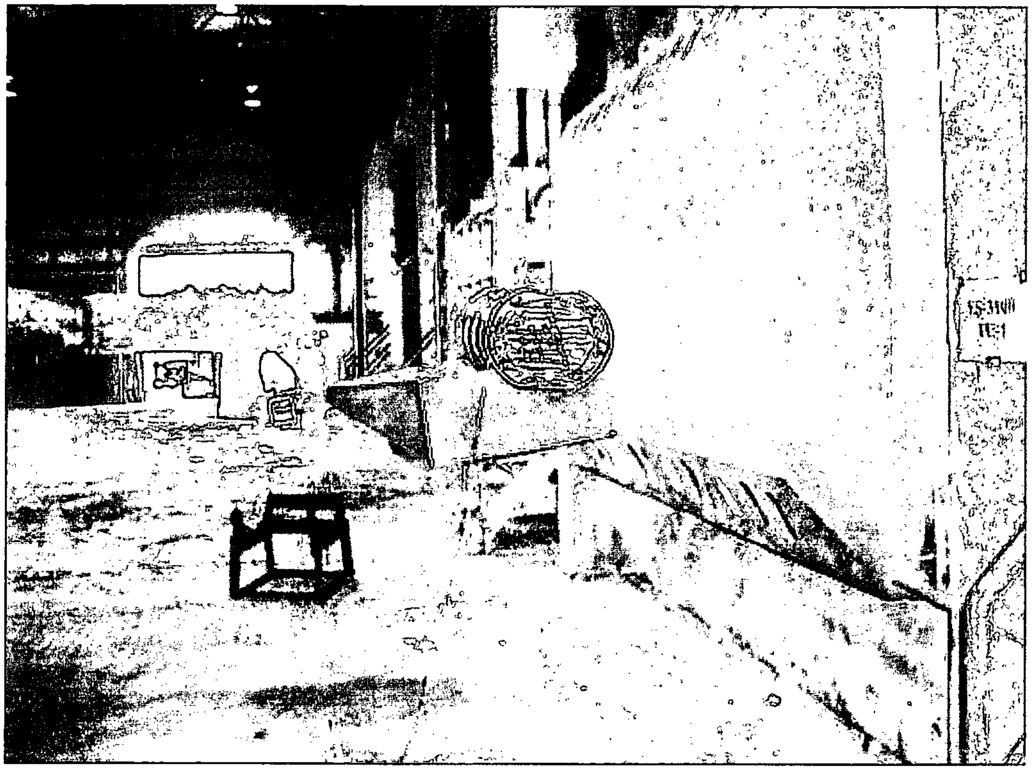


Figure 4.35 TU-1 wired with thermocouples, ready for loading

4.5.4 Thermal Testing

The HAC thermal test requires that the package be exposed to an 800°C (1475°F) or greater thermal source for a minimum of 30 minutes. The recovery time between test runs was reduced from 60 minutes to 45 minutes because the furnace demonstrated that it would become thermally stable in that length of time.

Packages were loaded into the furnace using a fork truck with an extended arm that had a cradle used to stabilize the package at the end of the arm (Figure 4.36). The chronological order of the thermal tests was TU-3, TU-4, TU-1, TU-5, and TU-2.

The 30-minute thermal test for each test unit did not begin until the furnace thermocouples recovered to a temperature above 800 °C (1475 °F) and five of the six external thermocouples on the test unit had reached 800 °C (1475 °F). Thermocouple readings were recorded every 15 seconds. The test units required 7 to 13 minutes to reach the test temperature threshold. This meant that each test unit was actually in the furnace environment for a total of 37 to 43 minutes.

Upon completion of the 30-minute test, each test package was removed from the furnace and placed on a stand where it was permitted to cool naturally. All loading and unloading cycles were videotaped and are available on the DVD or VHS tape of the ES-3100 testing. See the data sheets in Appendices H-L for additional details. See Appendices A-E and G for photographs of the thermal testing.

Figure 4.36 Fork truck and modified fork used for test unit insertion and extraction

4.5.5 Thermal Test Data

TU-1 was preheated to above 100 °F for more than 48 hours. After preheating, the test unit was removed from the preheat chamber and the 6 external thermocouples were installed. The unit was oriented horizontally, top to the right, with 0° down. The unit was loaded into the furnace and door closed in 64 seconds. The 30-minute test began 7 minutes after loading. There was some difficulty removing the test unit from the furnace, causing the test unit to be inside the furnace with the door opened for approximately an additional minute. Upon removal, small flames coming from the TID hole at 0° were noted. The unit was placed on a cooling stand. The flames quit after about 22 minutes, turned to smoke and the package smoked lightly for about one hour.

TU-2 was preheated to above 100 °F for more than 48 hours. After preheating, the test unit was removed from the preheat chamber and the 6 external thermocouples were installed. The unit was oriented horizontally, top to the right, with 0° down. The unit was loaded into the furnace and door closed in 61 seconds. The 30-minute test began 10 minutes after loading. Upon removal, smoke was coming from the TID hole at 180°.. The unit was placed on a cooling stand. The package smoked lightly for about 40 minutes.

TU-3 was preheated to above 100 °F for approximately 47 hours. After preheating, the test unit was removed from the preheat chamber and the 6 external thermocouples were installed. The unit was oriented horizontally, top to the right, with 0° down. The unit was loaded into the furnace and door closed in 59 seconds. The 30-minute test began 13 minutes after loading. Upon removal, smoke coming from the TID holes was noted. The unit was placed on a cooling stand. The package smoked lightly for about 35 minutes. All six burners were on for this test only.

TU-4 was preheated to above 100 °F for more than 48 hours. After preheating, the test unit was removed from the preheat chamber and the 6 external thermocouples were installed. The unit was oriented horizontally, top to the right, with 0° down. The unit was loaded into the furnace and door closed in 50 seconds. The 30-minute test began 9 minutes after loading. Upon removal, small flames coming from the TID hole at 0° were noted. The unit was placed on a cooling stand. The flames quit in less than a minute. The package smoked lightly for about 12 minutes.

TU-5 was preheated to above 100 °F for more than 48 hours. After preheating, the test unit was removed from the preheat chamber and the 6 external thermocouples were installed. The unit was oriented horizontally, top to the right, with 0° down. The unit was loaded into the furnace and door closed in 64 seconds. The 30-minute test began 10 minutes after loading. Upon removal, no flame, only smoke was noted. The unit was placed on a cooling stand. The package smoked lightly for about 1/2 hour.

Data from all of the thermocouples were recorded at 15-second intervals. There are two graphs for each test unit. On each graph there is a horizontal line indicating the 800 °C (1475 °F) minimum temperature of the HAC test criteria. The first graph for each test unit shows the furnace thermocouples from opening the furnace door to inserting the test unit until after the test unit was extracted. For the plots of furnace temperatures, the temperature scale has been limited to 1400 °F to 1700°F to increase the visibility of the details of the plot. The time axis of each plot is relative to the opening of the door for loading. The second graph shows the test unit's external thermocouple readings. For the plots of external package temperatures, the scale has been set to 1400 °F to 1700 °F.

To minimize clutter in the legend of the graphs, the thermal recorder channel designations are used. Table 4.6 shows the thermocouple locations and the channel identification for the furnace thermocouples, and Table 4.7 provides this information for the thermocouples of the test units. The graphs are presented in Figure 4.37 through Figure 4.48.

Table 4.6 Mapping of furnace thermocouple location to thermal recorder channel number

FURNACE THERMOCOUPLE LOCATION	CHANNEL IDENTIFICATION
Left wall upper	F-1
Left wall center	F-2
Left wall lower	F-3
Back wall left	F-4
Back wall center	F-5
Back wall right	F-6
Right wall upper	F-7
Right wall center	F-8
Right wall lower	F-9
Floor plate left	F-10
Floor plate center	F-11
Floor plate right	F-12
Stand left	F-13
Stand center (back)	F-14
Stand right	F-15
Door left	F-16
Door center	F-17
Door right	F-18
Preheat Chamber Exhaust	F-35
Package Surface in Preheat Chamber	F-36
Ambient Temperature	F-34

Table 4.7 Mapping of test unit thermocouple location to thermal recorder channel number

	THERMOCOUPLE LOCATION	CHANNEL IDENTIFICATION
TU-1	TU-1 Lid	P-1-1
	TU-1 0°	P-1-2
	TU-1 90°	P-1-3
	TU-1 180°	P-1-4
	TU-1 270°	P-1-5
	TU-1 Bottom	P-1-6
TU-2	TU-2 Lid	P-2-1
	TU-2 0°	P-2-2
	TU-2 90°	P-2-3
	TU-2 180°	P-2-4
	TU-2 270°	P-2-5
	TU-2 Bottom	P-2-6
TU-3	TU-3 Lid	P-3-1
	TU-3 0°	P-3-2
	TU-3 90°	P-3-3
	TU-3 180°	P-3-4
	TU-3 270°	P-3-5
	TU-3 Bottom	P-3-6
TU-4	TU-4 Lid	P-4-1
	TU-4 0°	P-4-2
	TU-4 90°	P-4-3
	TU-4 180°	P-4-4
	TU-4 270°	P-4-5
	TU-4 Bottom	P-4-6
TU-5	TU-5 Lid	P-4-7
	TU-5 0°	P-4-8
	TU-5 90°	P-4-9
	TU-5 180°	P-4-10
	TU-5 270°	P-4-11
	TU-5 Bottom	P-4-12

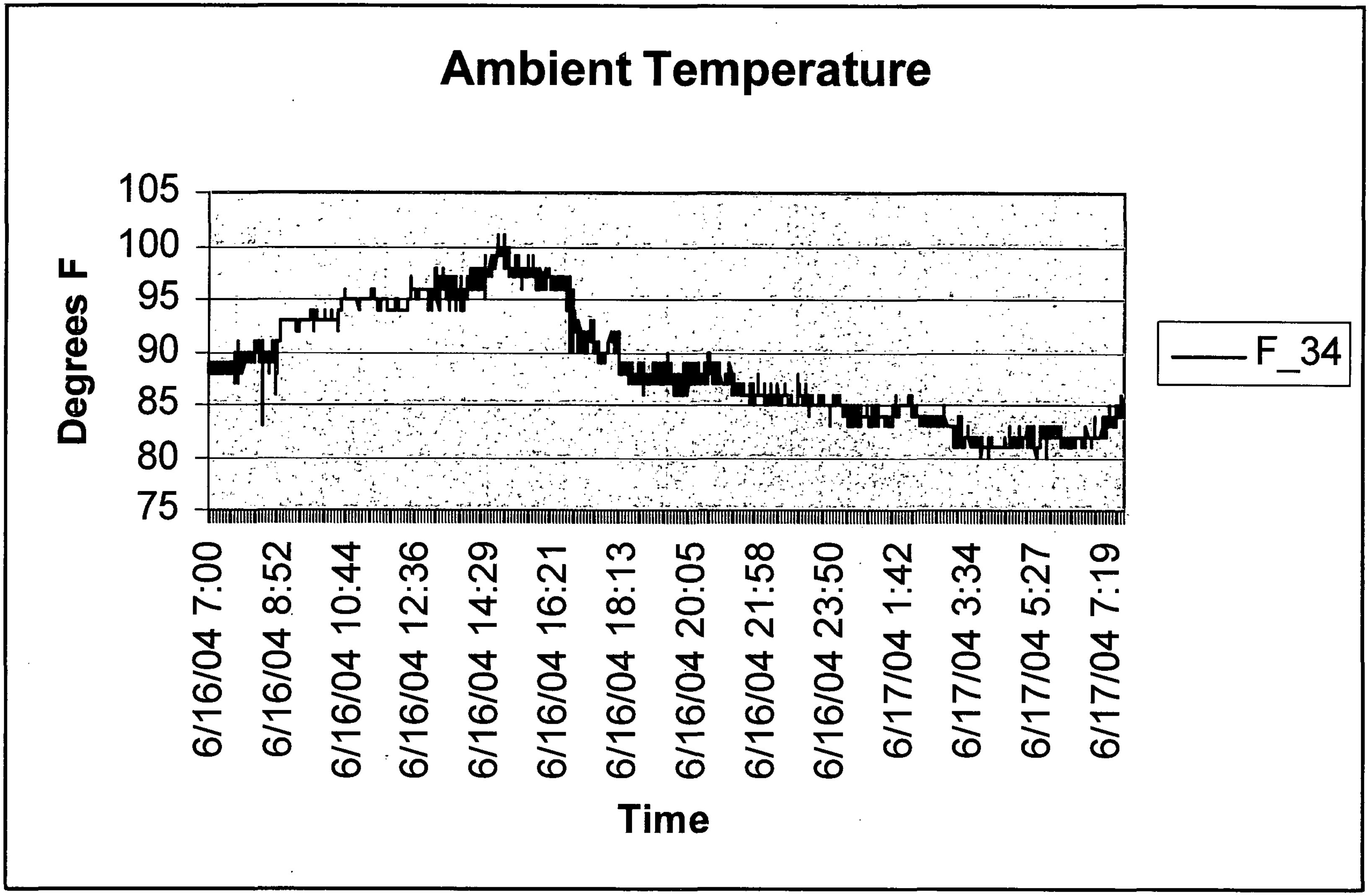


Figure 4.37 Ambient Temperature

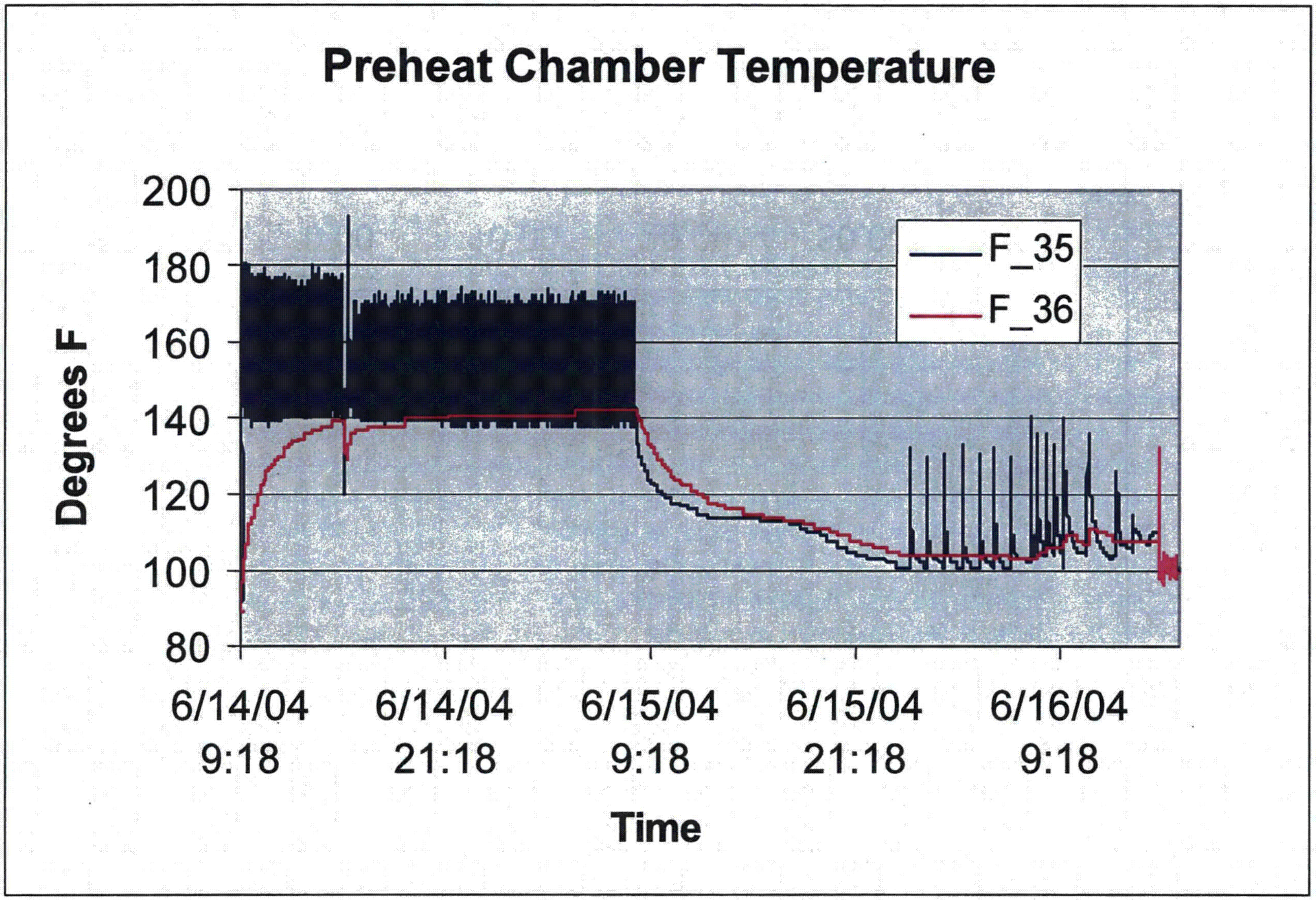


Figure 4.38 Preheat Chamber Temperature

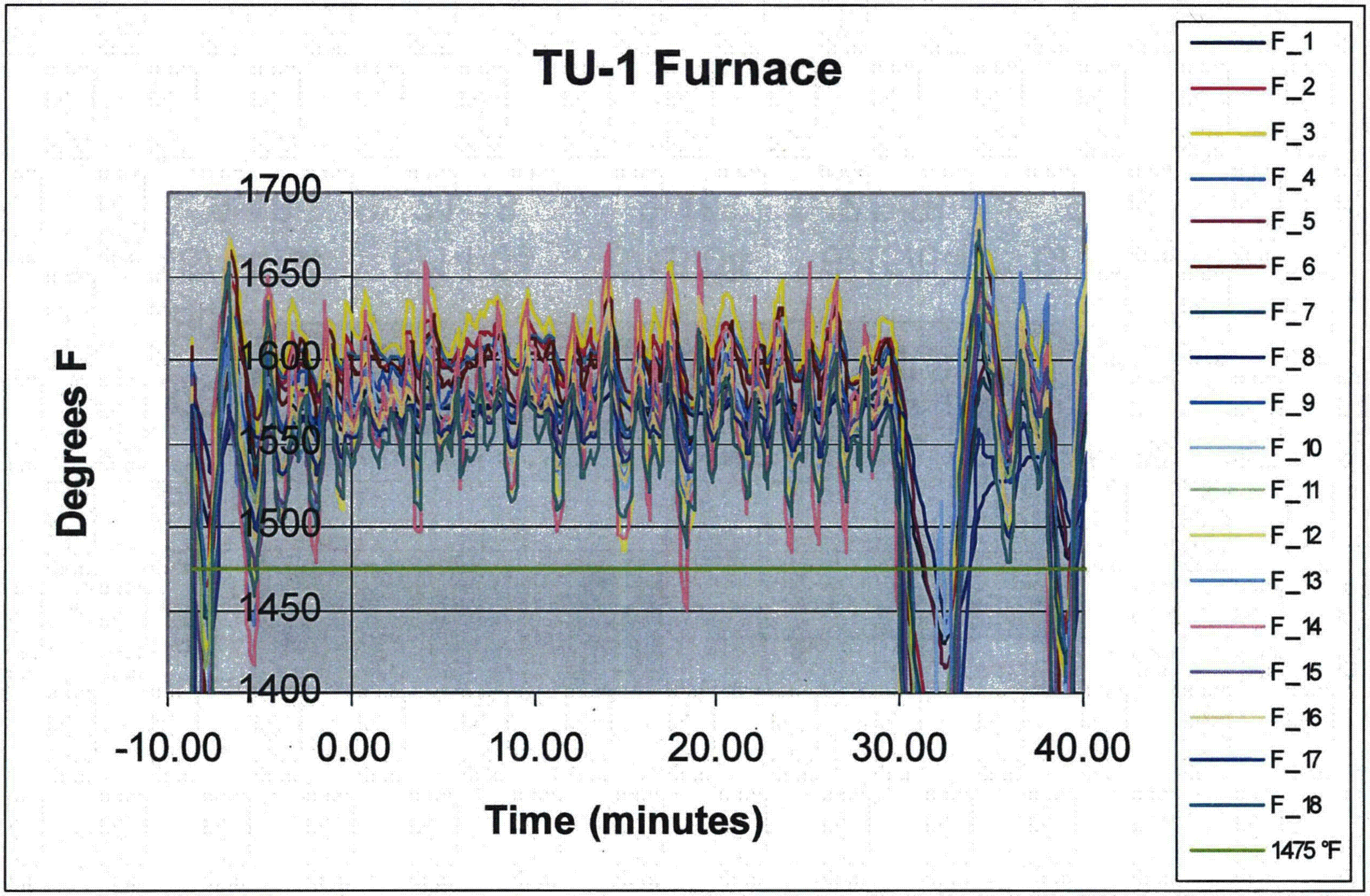


Figure 4.39 TU-1 Thermal test, Furnace thermocouples

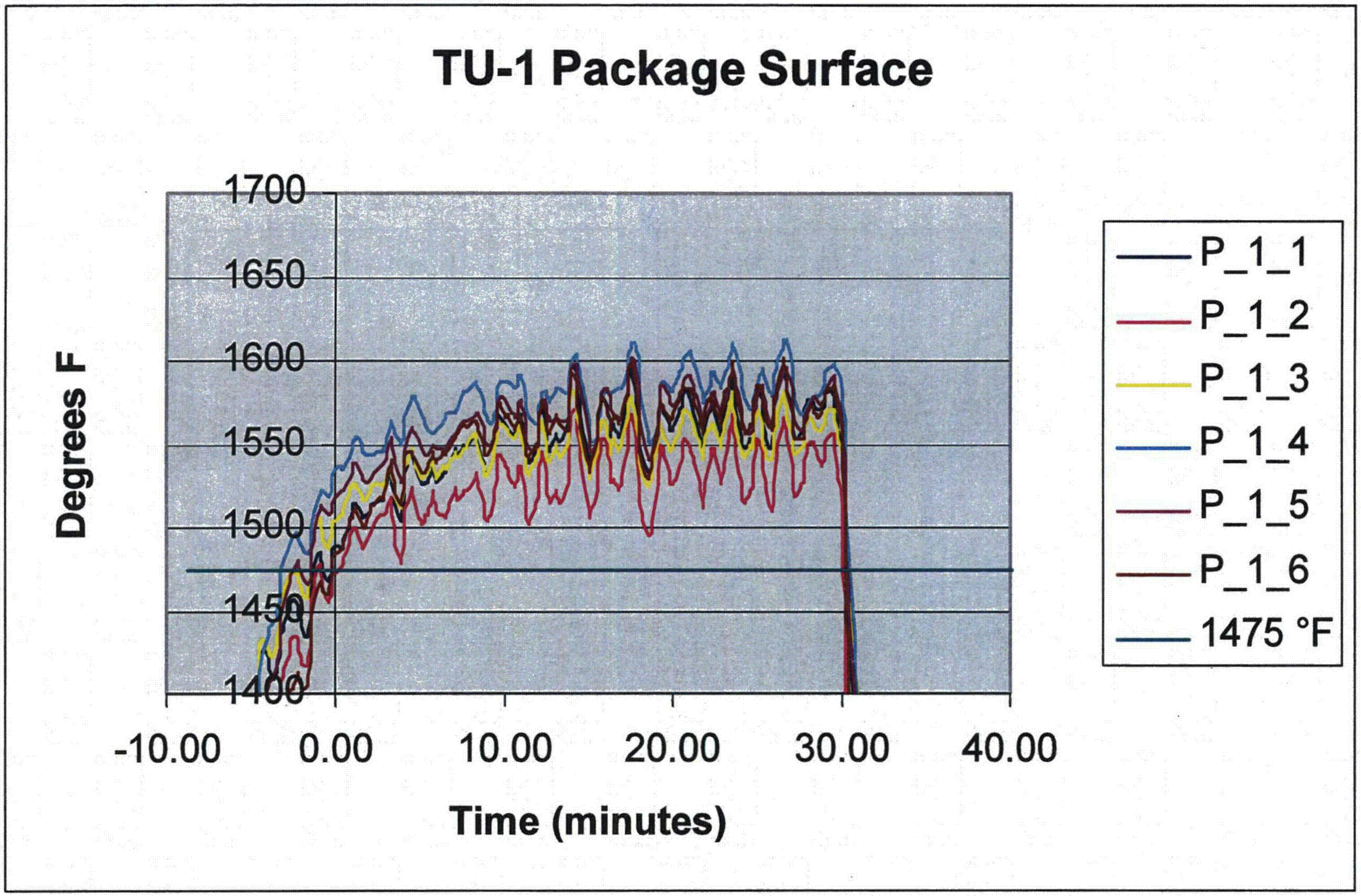


Figure 4.40 TU-1 Thermal test, Package thermocouples

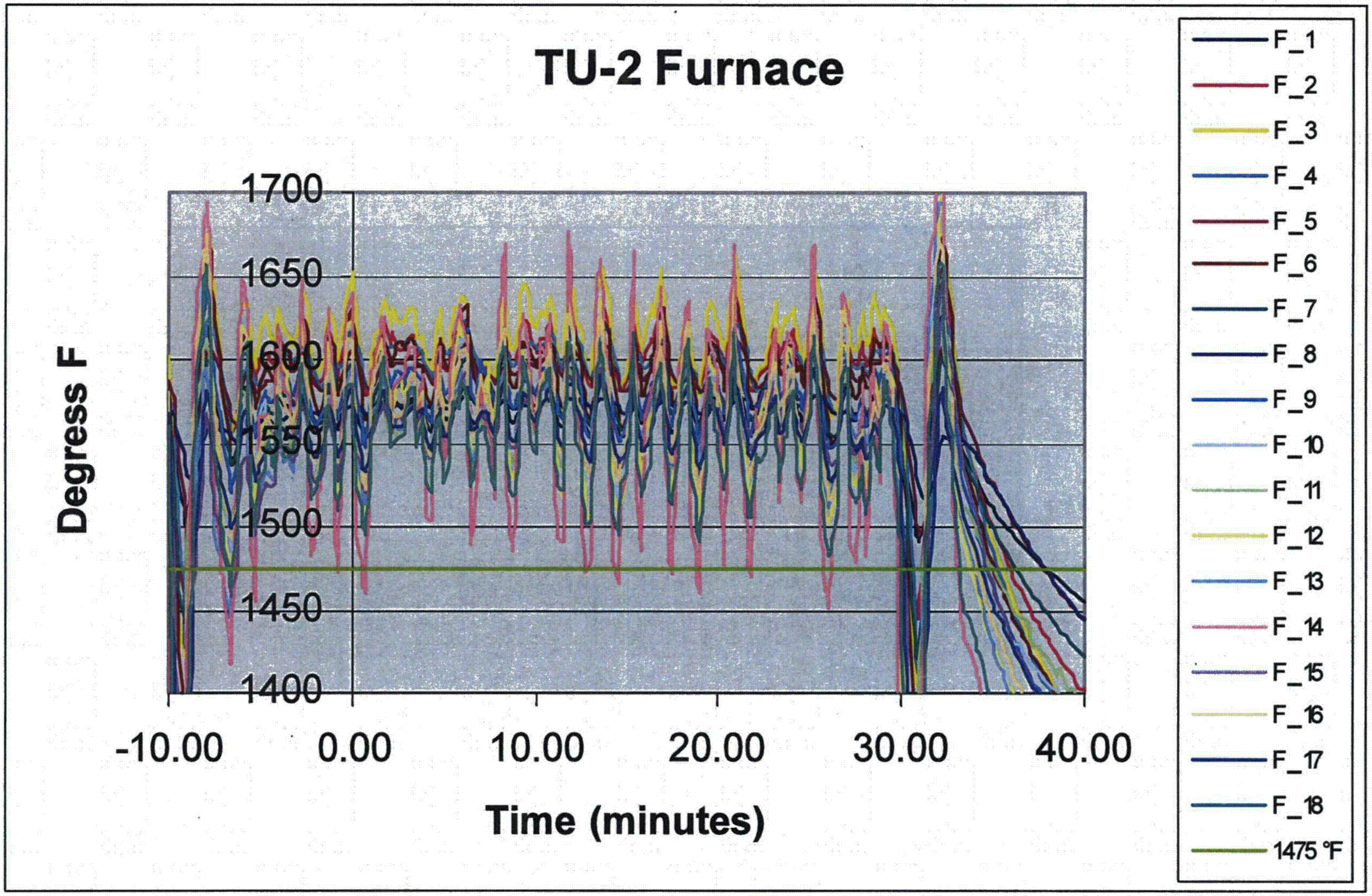


Figure 4.41 TU-2 Thermal test, Furnace thermocouples

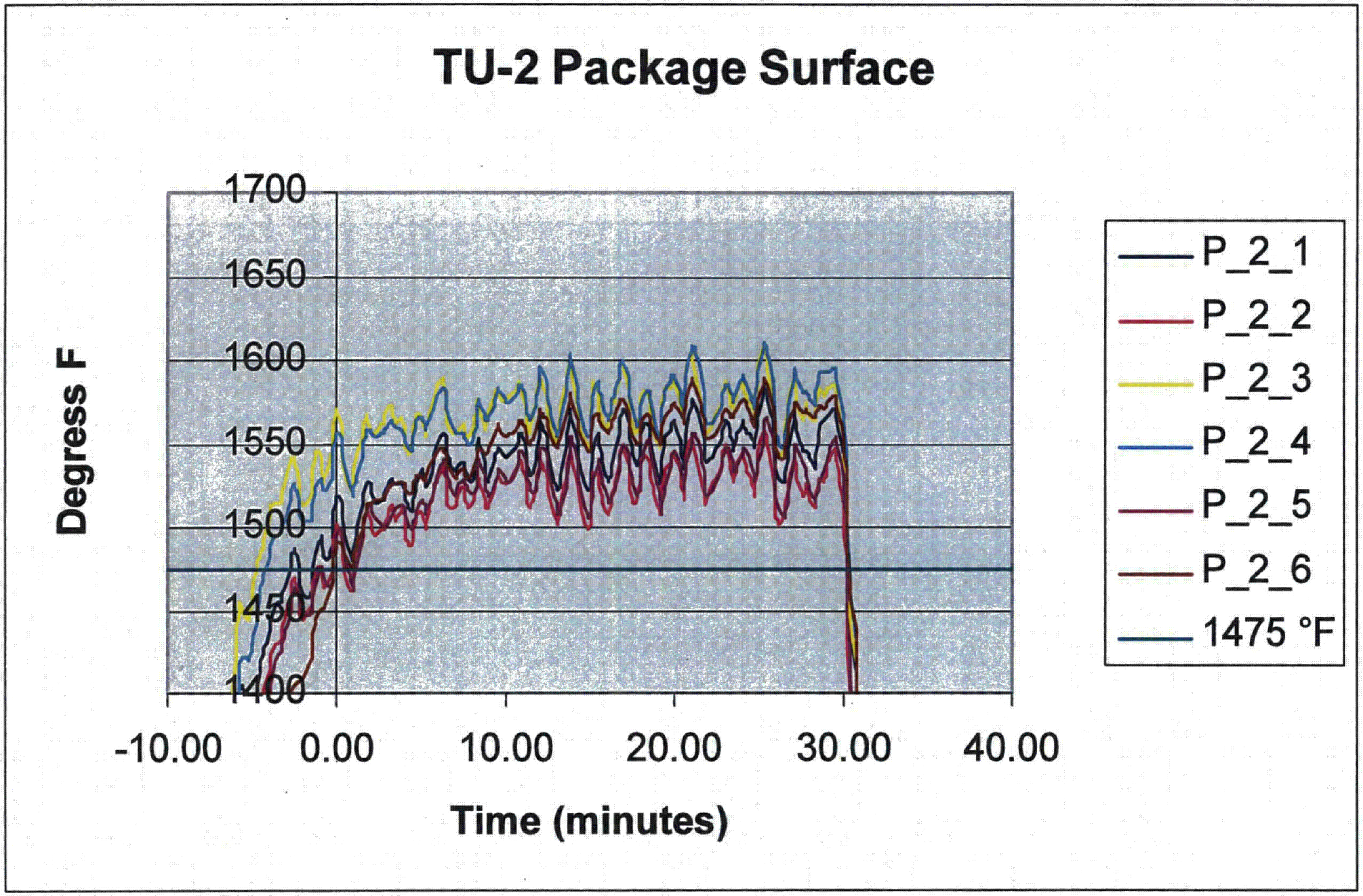


Figure 4.42 TU-2 Thermal test, Package thermocouples

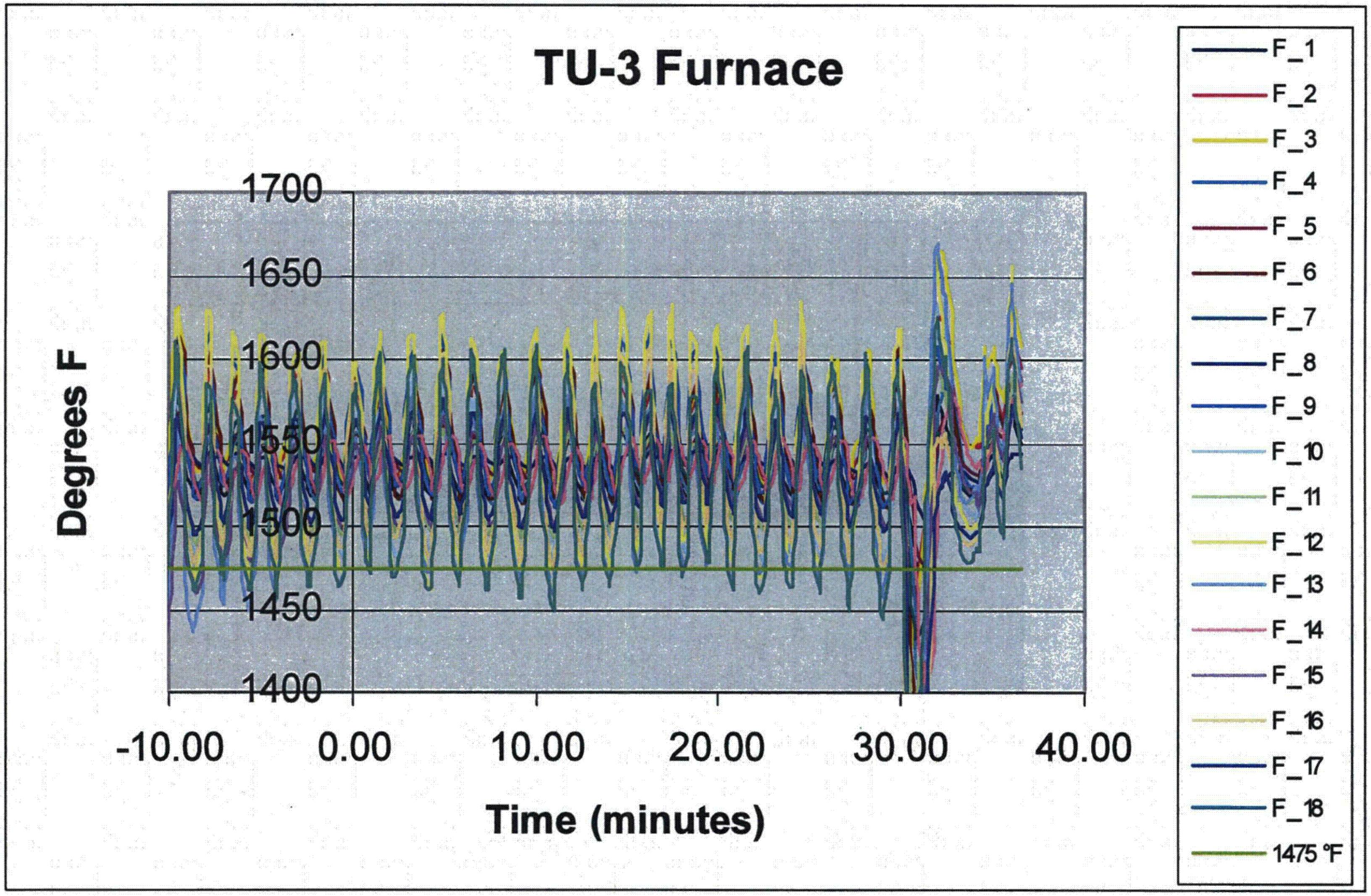


Figure 4.43 TU-3 Thermal test, Furnace thermocouples

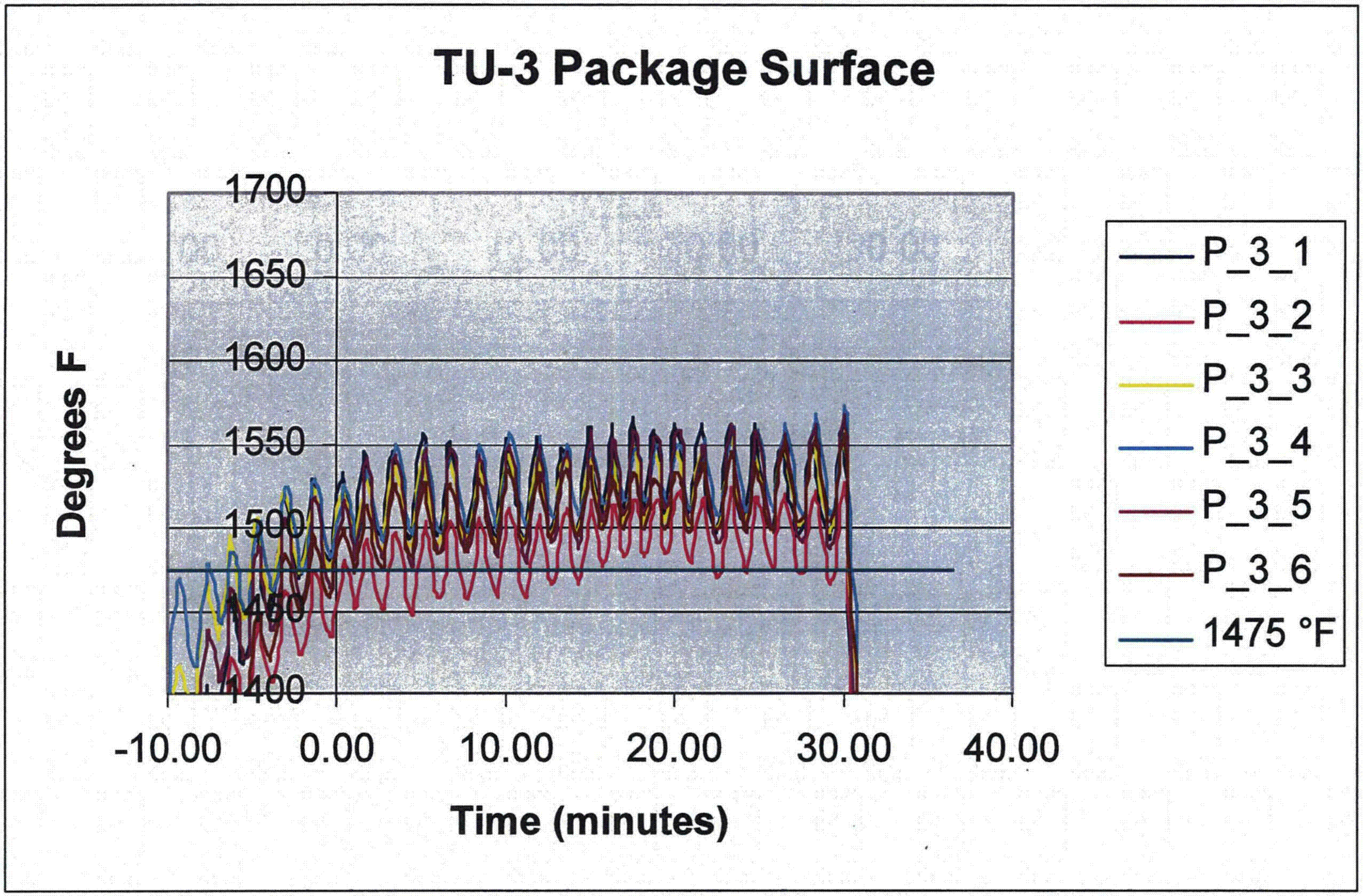


Figure 4.44 TU-3 Thermal test, Package thermocouples

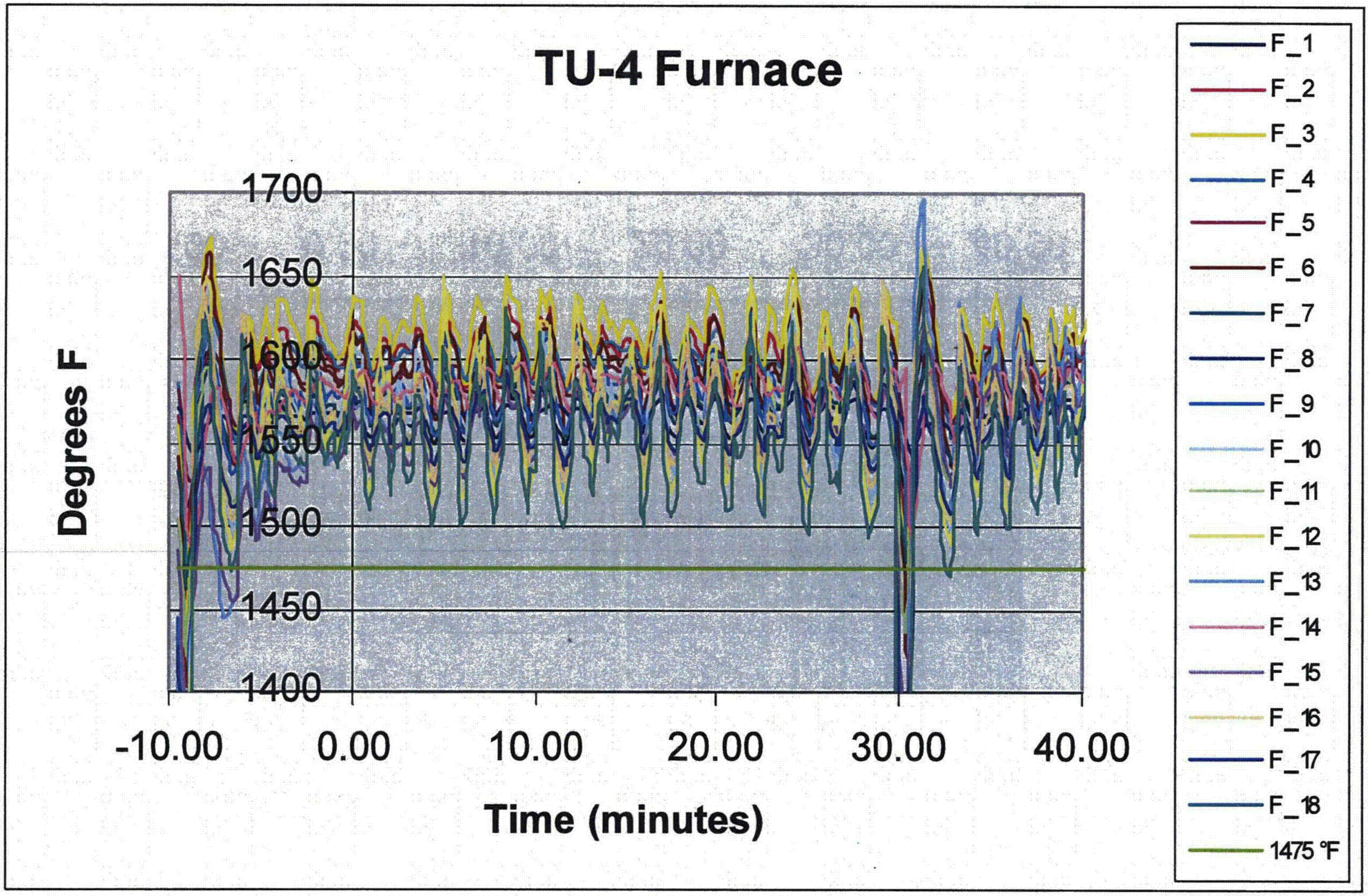


Figure 4.45 TU-4 Thermal test, Furnace thermocouples

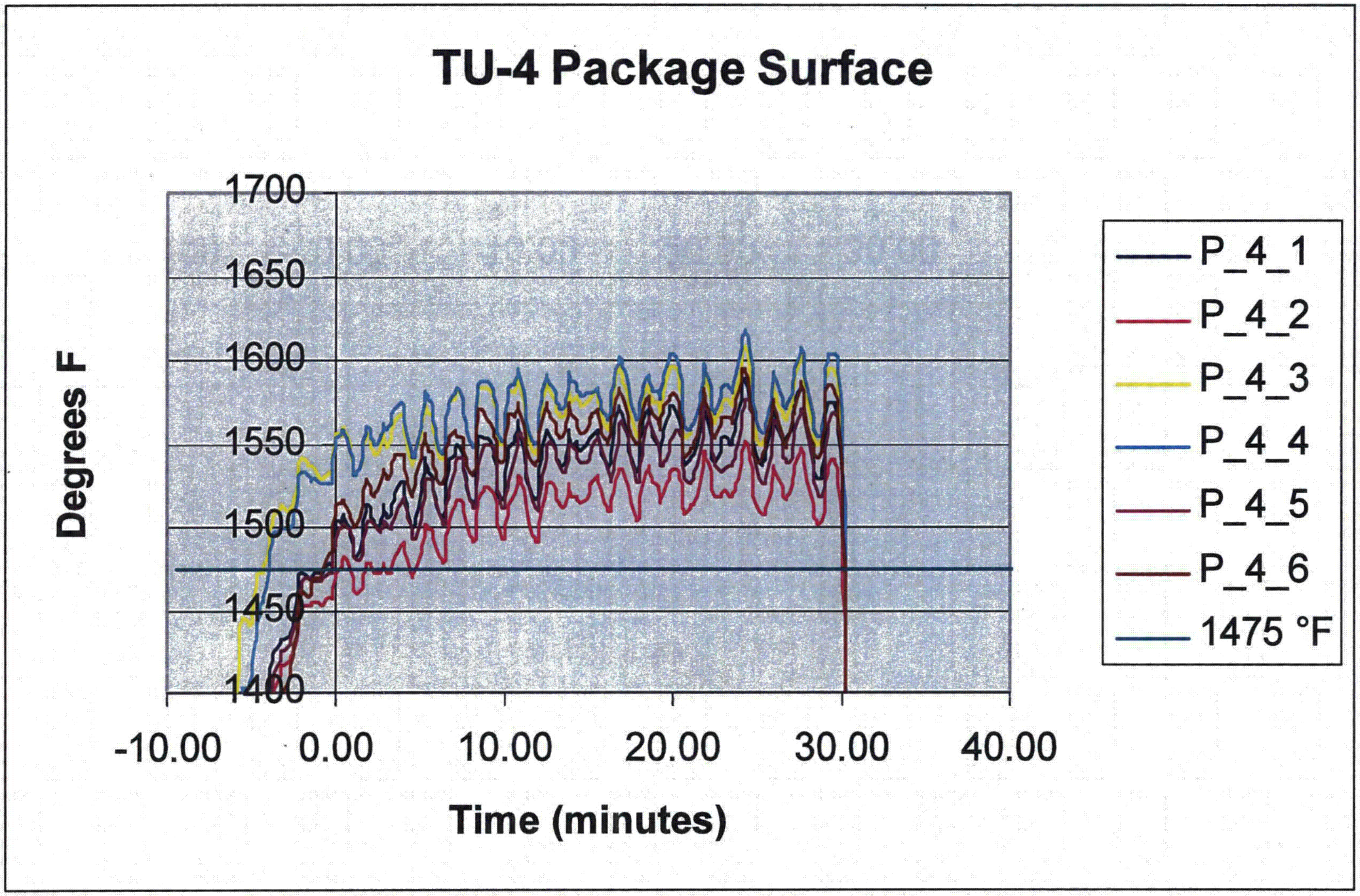


Figure 4.46 TU-4 Thermal test, Package thermocouples

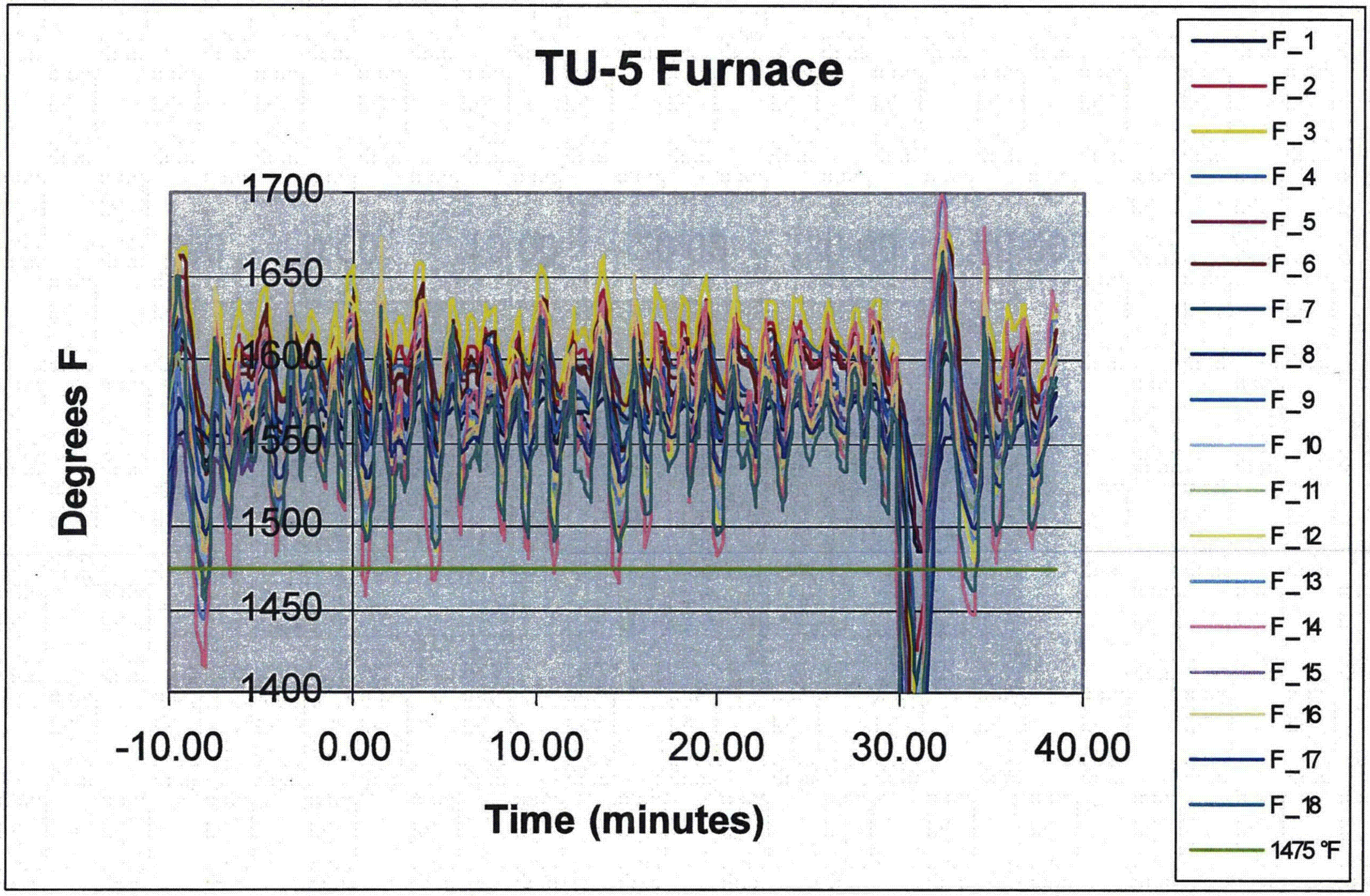


Figure 4.47 TU-5 Thermal test, Furnace thermocouples

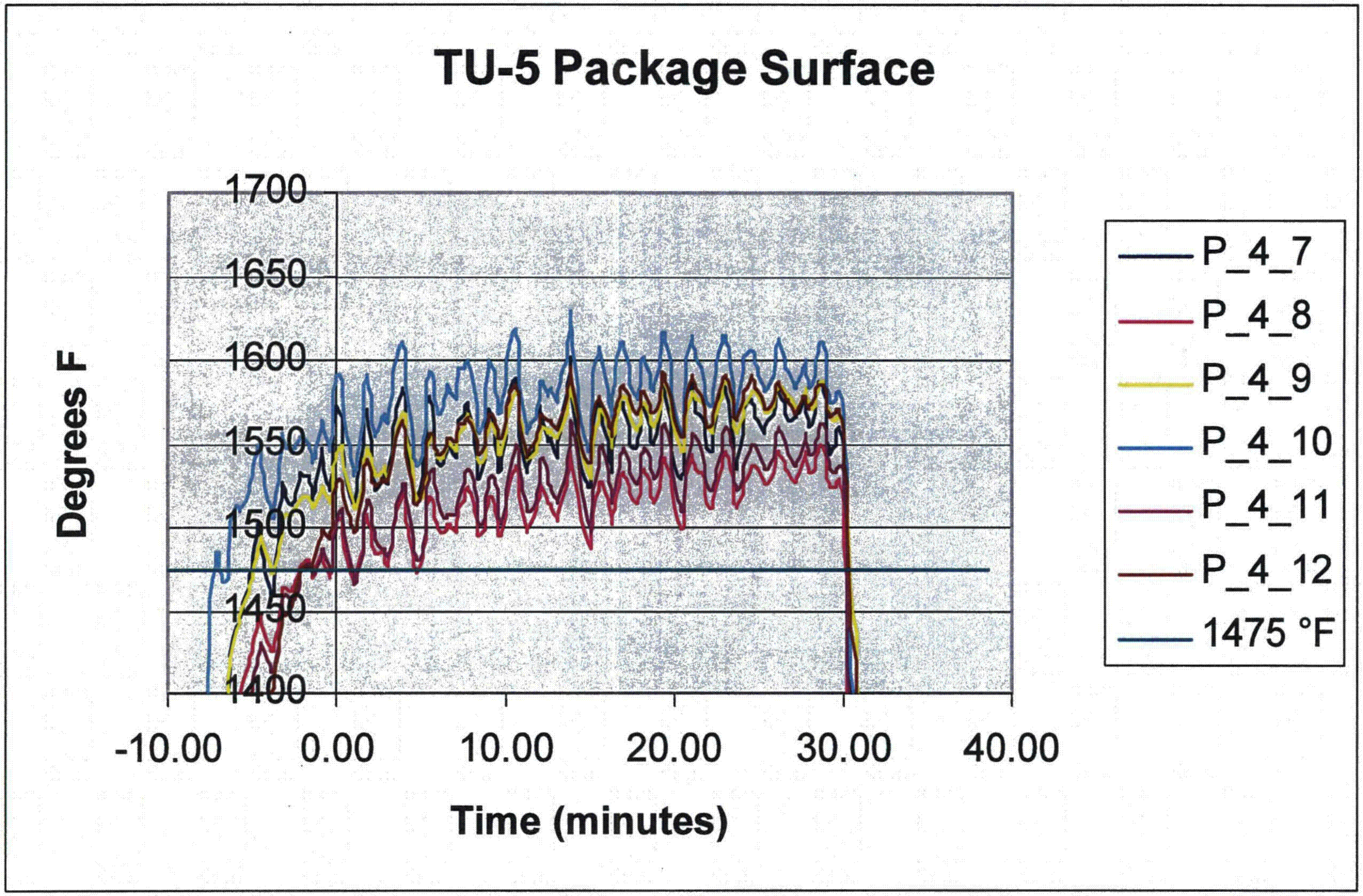


Figure 4.48 TU-5 Thermal test, Package thermocouples

5 POST-HAC DISASSEMBLY AND INSPECTION

After being returned to the NTRC from the thermal test facility, the test units were disassembled and inspected. The post-thermal weights of each test unit, top plug, and containment vessel were recorded on TEST FORM 4. The drums were disassembled and photographic records of the process were taken. Each test unit was visually inspected, and the condition of the package and any observations were recorded on the test forms. Photographs were taken of the disassembly process and any conditions that deserved documenting.

The drum lids, top plugs and CVs from each test unit (TU-1 through TU-5) were removed from the drum. Removal of the lids and top plugs was the most difficult part of the disassembly process. Once the lids and top plugs were removed, all of the CVs were easily removed without the need of any force. Then post-test leak testing and immersion testing was performed on each CV. Next, disassembly of the CVs was performed. This section describes all of the disassembly processes. Subsequently, post-test leak testing and immersion testing of these units are discussed in Sections 5.2 and 5.3, respectively.

5.1 Drum Disassembly Observations

TU-1 had experienced both a 1.2-m drop and a 9-m drop on its 0° side and a crush test along its 180° side. Therefore the package was so pinched that it made the top plug difficult to extract. First, it was necessary to use a crowbar to remove the lid because of the severe pinch on the lid, mainly due to the crush test. Figure 4.7 shows how the lid had crinkled and folded after the tests, and the flattening along the 0° and 180° sides gave warning that the disassembly process would be difficult. The lid came off easily enough once a crowbar was applied to it, but the top plug resisted removal. In order to facilitate disassembly, the compression tester was employed to squeeze the drum and restore some roundness to it before the top plug could be extracted (Figure 5.1). Even after compressing the drum with up to 29,000 lbs of force, the top plug could not be extracted easily. Further compression on alternate sides and levering with a crowbar finally succeeded in freeing the top plug. The CV then slid out easily from the drum.

Figure 5.2 shows how the silicone cushion that fits between the top plug and inner liner had partially disintegrated, but the cushion at the top of the CV had remained intact. The gray char on the floor at the lip of the drum resulted from the dark gray silicone cushion turning whitish upon charring and depositing a residue. Another effect that was attributed to the charring of the silicone cushion was the presence of a few drops of purplish fluid. (See Figure 5.3) This was also seen in other units where the silicone cushion had burned and is likely a by-product of decomposition.

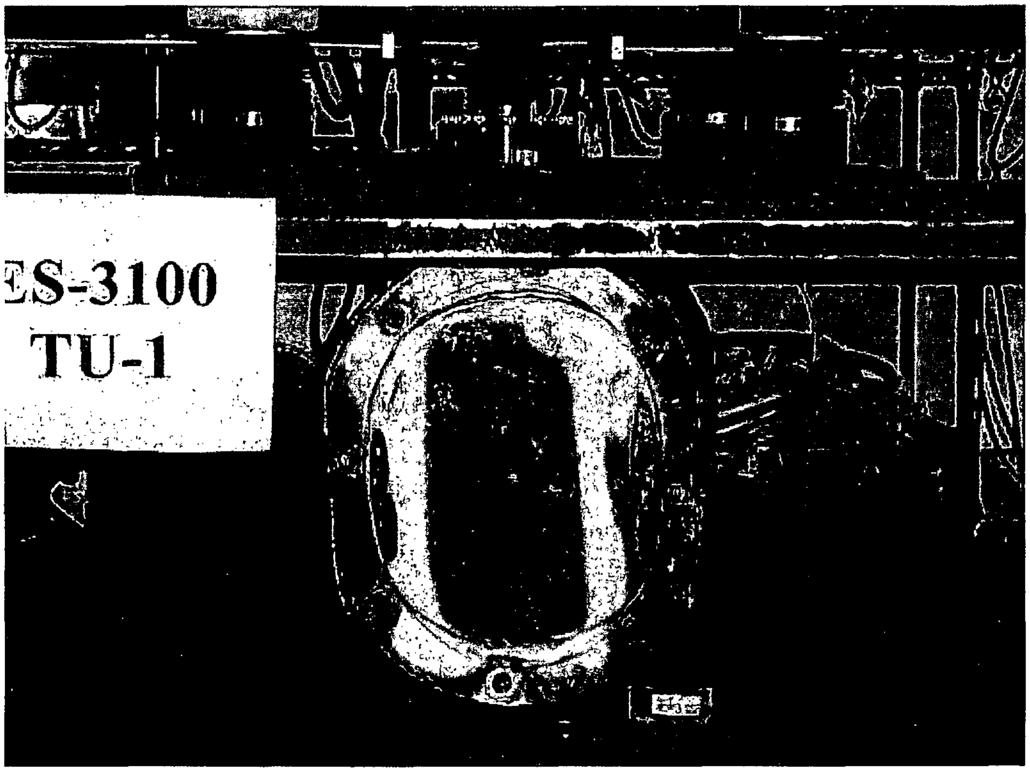


Figure 5.1 The compression table being used to assist with top plug removal

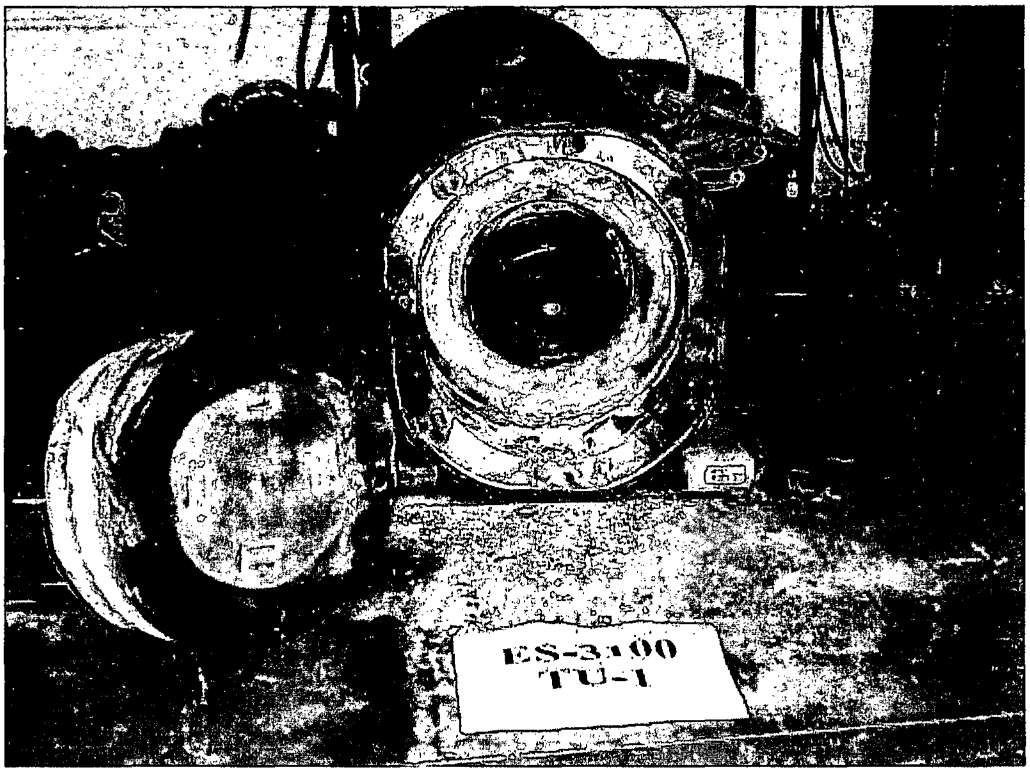


Figure 5.2 TU-1 with top plug removed

Figure 5.3 TU-1 - Purplish liquid from decomposition of cushion

TU-2 had experienced two horizontal drops onto its 0° side and the 1,100 lb crush plate dropping flat onto its 180° side. Therefore, the test unit was somewhat oblong from being flattened on both sides. The compression tester was used to restore some roundness to it, and the top plug was removed without too much difficulty. Figure 5.4 illustrates that the components of TU-2 were in good condition after being disassembled. The white residue on the side of the top plug indicates that part of the silicone cushion was degraded.

Having experienced a drop on the lid edge, CG over corner and the impact of the crush plate on its opposite corner, the drum of TU-3 could not stand upright because the bottom and top of it had been considerably deformed. The lid of TU-3 had to be pried off with considerable effort, and the top plug was extremely difficult to remove. In fact, it was necessary to cut the top plug with a pneumatic cutting shear and remove the exposed Kaolite so that the top plug shell could be collapsed enough to allow it to be removed from the drum (Figure 5.5). After a section of the top of the plug had been removed, the Kaolite was scooped out and the plug was then cut, folded away from the pinch-point of the drum, and removed with a crowbar. The Kaolite was retained in a plastic bag for weighing or material balance. Figure 5.6 shows a view of the top plug after removal. After the top plug was removed, the CV was easily removed.

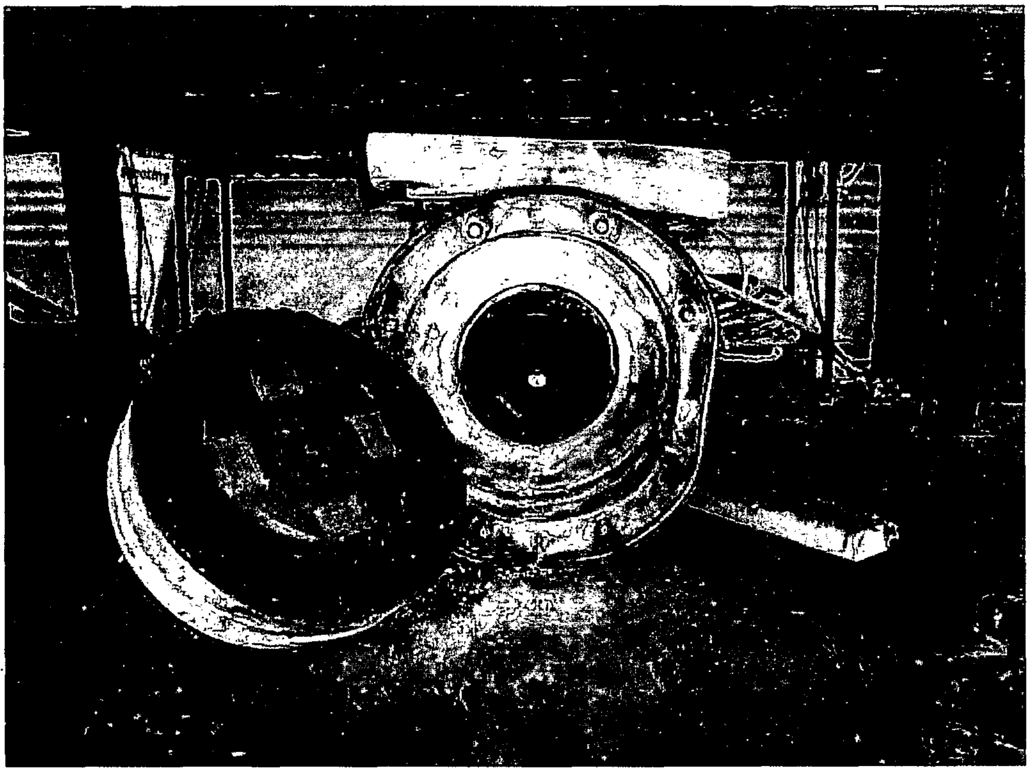


Figure 5.4 TU-2 disassembly using compression

Figure 5.5 The lid of TU-3 being prepared for cutting

Figure 5.6 Top plug and kaolite from TU-3

TU-4 had experienced both a 4 ft and a 30-ft drop onto its drum head and the crush plate had been dropped on its bottom. Thus, most of the apparent damage was to the lid area. The lid and top plug were removed with crowbars. The uppermost vertical section of the inner liner was protruding upward. Figure 5.7 shows how the uppermost vertical section of the inner liner protrudes upward. Figure 5.8 is a top view of this phenomenon.

Another oddity, which was not seen in any of the other test units, was that the lower containment vessel's silicone cushion expanded around the sides of the CV vessel and worked its way upward. Figure 5.9 shows the silicone cushion wrapped around the body of the CV and another undamaged silicone cushion being displayed for comparison. Because no other test units displayed this phenomenon, it is believed to have occurred during the vibration test.

TU-5 was in relatively good shape after the tests and was easily disassembled. Most of the silicone cushion underneath the top plug withstood the thermal test. So not much char was present but the silicone itself was gooey and sticky. Figure 5.10 gives an indication of the degraded state of the silicone cushion.

Figure 5.7 Convex appearance of inner liner of TU-4 drum

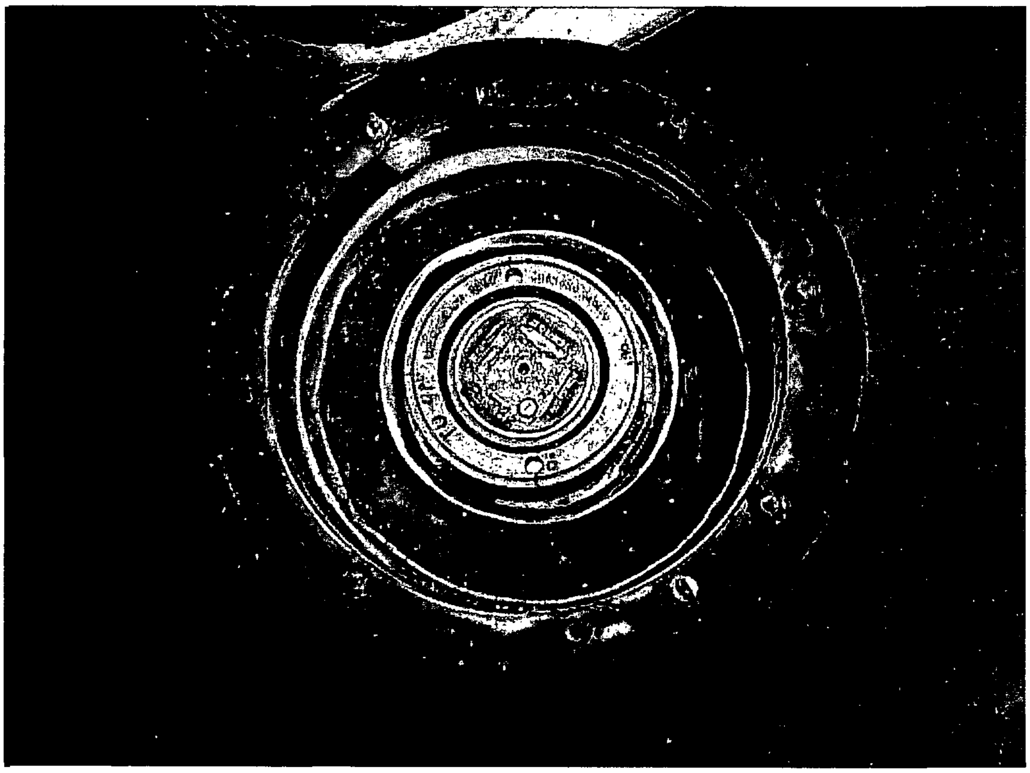


Figure 5.8 Top view of inner liner of TU-4

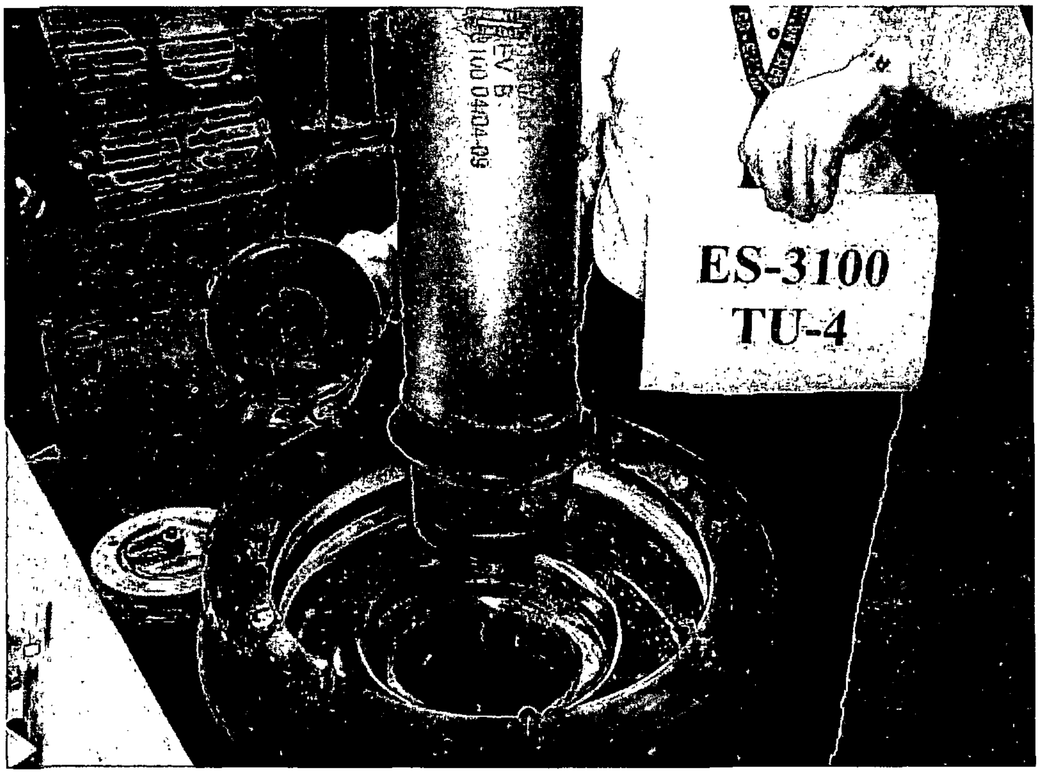


Figure 5.9 Silicone cushion skirting the CV of TU-4

Figure 5.10 Deterioration of TU-5's silicone cushion

5.2 Post-test Leak Tests

After the CVs were removed from TU-1 through TU-5, two different leak tests were performed on each CV:

- an operational leak test of the CV O-rings,
- a full containment boundary leak test with helium

5.2.1 Post-test Operational Leak Test

The O-rings of the CV were leak tested using a CALT5 leak tester. Additional details regarding the CALT5 leak tests can be found in Section 2.4. The sensitivity of the leak check was 5×10^{-5} cc/sec. Using the algorithm referenced in Section 2.4, all of the test units had leak rates less than 1×10^{-4} ref-cc/sec (Table 5.1).

Table 5.1 Post-test leak rate for the test unit CV lids

Drum ID	TU-1	TU-2	TU-3	TU-4	TU-5
Lid Leak Rate, ref-cc/sec	4.1432E-5	3.2361E-5	2.5899E-5	2.4773E-5	2.3829E-5

5.2.2 Post-test Helium Leak Test

The main body of the each CV was leak checked to a sensitivity of 1×10^{-7} cc/sec using the Varian Model 959 helium leak test system and was performed to the TTG Procedure TTG-PRF-02, Rev. 0, dated 1-30-04. Each CV was prepared for the test by drilling a hole in the CV lid and tapping for a ¼-inch NPT tapered pipe thread. A K-flange adapter was screwed into the hole with fast setting epoxy on the threads to seal them. After the epoxy hardened, the mass spectrometer helium leak tester was connected to the adapter. The vacuum pump was then engaged and the volume of the CV was evacuated to < 100 milliTorr. The CV was enclosed in a plastic bag and evacuated with a shop vacuum to reduce the ambient air in the bag. A constant flow of helium gas was introduced into the bag to ensure that the CV would remain bathed in helium during the test. The helium atmosphere was maintained for at least 20 minutes. Figure 5.11 shows one of the test units being subjected to the full containment boundary leak test. Complete data from these tests are given on Appendices H – L. Photos of the various leak tests are shown in Appendices A – E.

Figure 5.11 TU-4 undergoing the containment boundary helium leak test

TU-1 was tested twice. The first test indicated no helium detected at all. It was discovered that the test port plug had not been removed; thus the helium was not against the inner O-ring. The plug was removed and the CV evacuated and leak tested again. The second test indicated no leaks, just typical diffusion through the polymer O-ring. See Figure 5.12 for details of the leak rate curve.

TU-2 remained at 0.0E-9 cc/sec for most of the 20 minute test period but displayed an unusual pulsing. Because of these unusual readings it was re-tested 3 days later. Due to the unusual pulsing of the leak-rate reading the data was taken differently during the second test. The start time, amplitude, and duration of the pulses were recorded rather than the leak-rate readings at regular time intervals. The second test showed pulsing that initiated at roughly 1-minute intervals and had a duration 10 s, 10s, 13, 15, 15, 20, 21.5, 23, 24.3, and 30 seconds respectively. The leak rate pulses ranged from less than 1E-8 to 1.4E-6. The readings between pulses were <1E-9. See Figure 5.13 for details of the leak rate curve. The peak amplitude changed after adding helium in a manner expected for diffusion through the O-rings rather than a rise immediately following the addition of helium that would indicate a leak to the outside of the CV. This indicated that there were no leaks.

TU-3 was leak tested and there were no indicated leaks, just typical diffusion through the polymer O-ring. See Figure 5.14 for details of the leak rate curve.

TU-4 was leak tested and there were no indicated leaks, just typical diffusion through the polymer O-ring. See Figure 5.15 for details of the leak rate curve.

TU-5 was tested 4 times because of unusual pulsing of the leak rate reading. During the first test it was discovered that the brass plug had not been removed. The plug was removed and the test restarted. The first test showed a typical diffusion curve with 5 short duration pulses occurring during the test. These pulses occurred between the readings taken every 2 minutes. See Figure 5.16.

TU-5 had three product cans as the surrogate payload. As the CV was evacuated, the lids of the can popped loose allowing the air inside to escape. It was speculated that the lids remained against the sealing surface and allowed the remaining air in the cans to slowly and intermittently leak out thus giving an indicated leak rate on the leak detector. TU-5 was tested a second time with similar results. The pulses in the leak rate reading occurred even when there was no helium being added to the bag. This indicated that the 'leak' was internally from the cans rather than from the containment boundary. The third test was an attempt to test the inner O-ring. The intent was to connect the leak tester to the leak test port and add helium to the inside of the CV through the hole drilled for the first leak test. This attempt was aborted because a tight seal between the leak tester adapter and the leak test port could not be made. The fourth test, setup as in the normal manner, was allowed to pump down over the weekend. This test showed a typical diffusion curve with only three unusual pulses. The peak amplitude changed after adding helium in a manner expected for diffusion through the O-rings rather than a rise immediately following the addition of helium that would indicate a leak to the outside of the CV. The CV is considered to be leak tight. The fourth test is charted in Figure 5.17.

Although some units had unusual spikes in the leak rate readings, all five test units show leak rate curves typical of diffusion through the O-rings and did not show a typical sustained jump in the leak rate readings. Therefore, all of these test units are considered to be leak-tight.

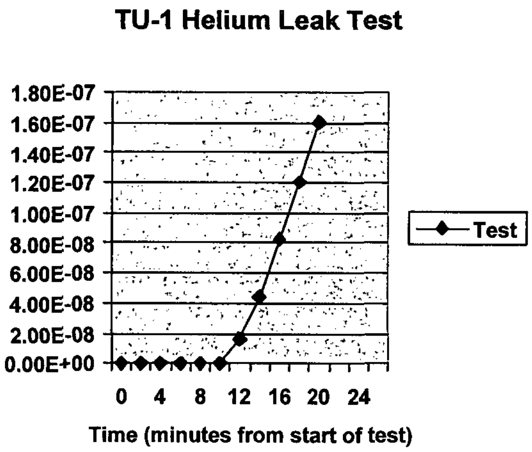


Figure 5.12 TU-1 helium leak (in cc/sec) rate for full boundary leak check

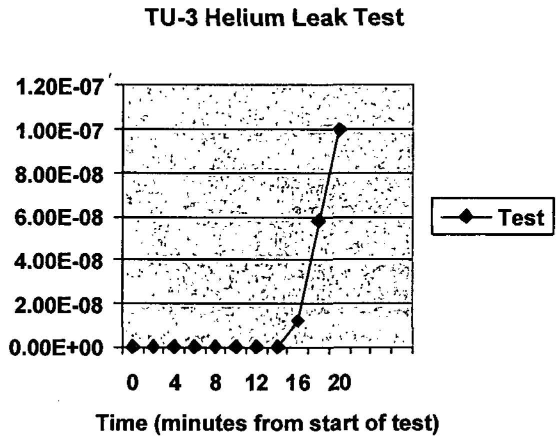


Figure 5.14 TU-3 helium leak rate (in cc/sec) for full boundary leak check

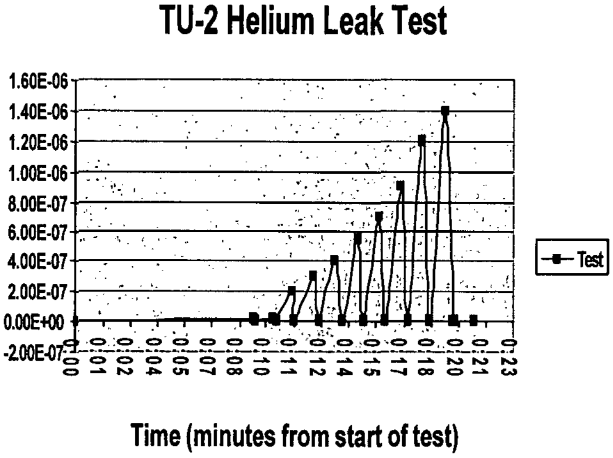


Figure 5.13 TU-2 helium leak rate (in cc/sec) for full boundary leak check

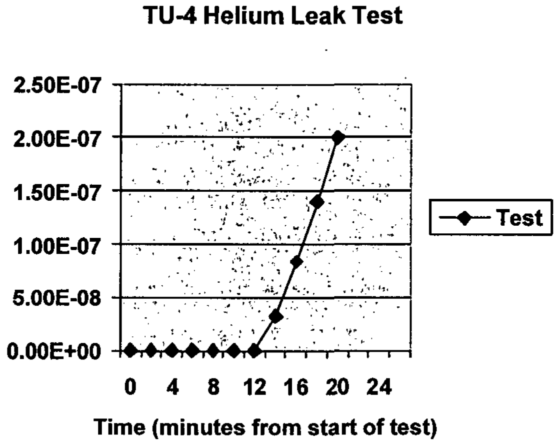


Figure 5.15 TU-4 helium leak rate (in cc/sec) for full boundary leak check

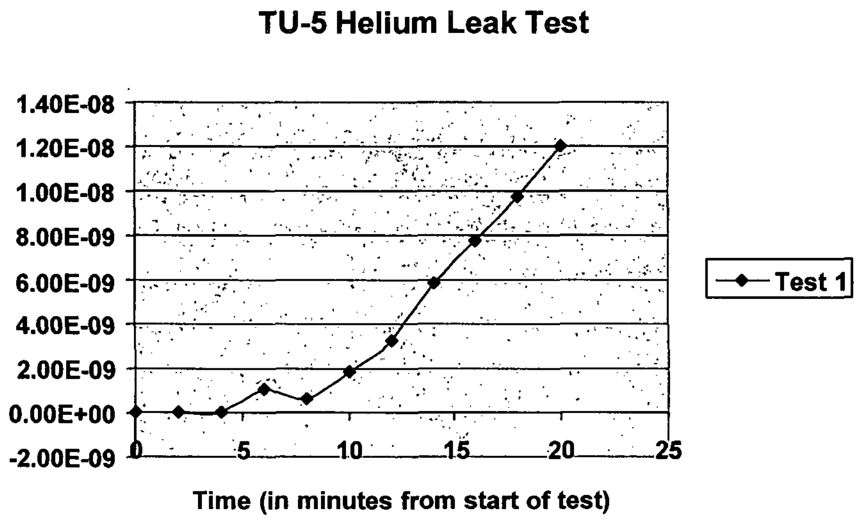


Figure 5.16 Test #1 - TU-5 helium leak rate (in cc/sec) for full boundary leak check

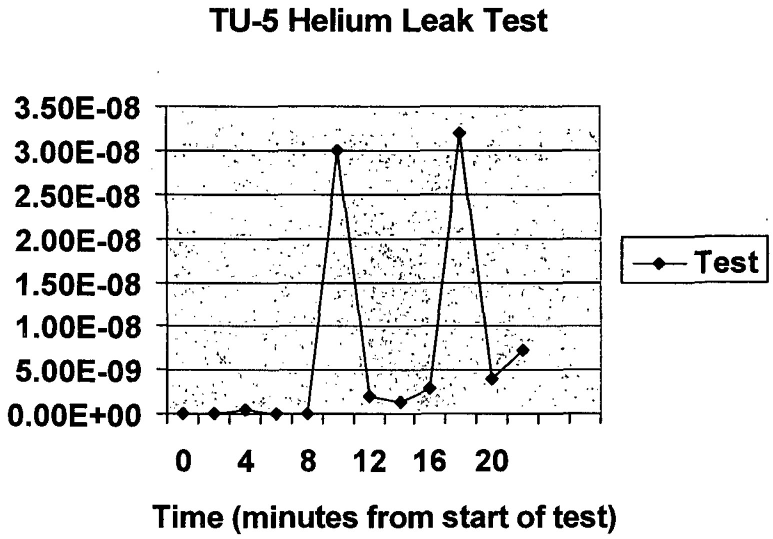


Figure 5.17 Test # 4 - TU-5 helium leak rate (in cc/sec) for full boundary leak check

5.3 0.9-m (3 ft) Immersion Test

After the operational leak tests were performed, the test units were subjected to the required 0.9 m (3 ft) water immersion test. The CVs from TU-1 through TU-5 were immersed under a head of water of at least 0.9 m (3 ft) for over 8 hours. Figure 5.18 shows three of the units undergoing testing and a tape measure being used to assure that the water depth was greater than 0.9 m.

Once the immersion tests had been completed, the CVs were opened to remove the contents, gather available data and look for signs of water in-leakage. No water in-leakage was detected in any of the units.

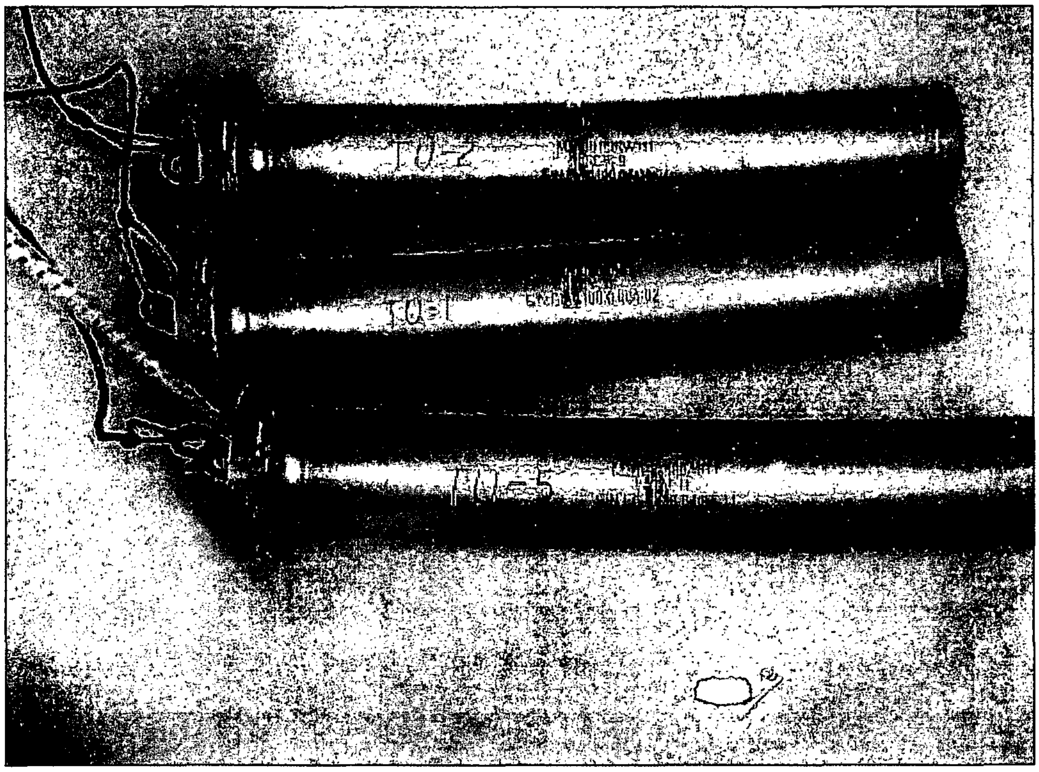


Figure 5.18 TU-1, -2, and -5 inside immersion tank

5.4 15-m (50 ft) Immersion Test on TU-6

10 CFR 71 requires that a "separate undamaged specimen must be subjected to a water pressure equivalent to immersion under a head of water of at least 15 m (50 ft)." The CV from TU-6 was used as the undamaged specimen. This CV was tested in the Y-12 Immersion Test Tank. The test tank is a vertical axis cylinder about 30 inches in diameter and 6 ft in height with a lid on the top secured by bolts.

Because this test was conducted at the hydro-testing facility in the secure area of Y-12, no photographs could be taken. The tank was filled with water and TU-6 was placed in it so that it sat upright on the bottom of the tank. The lid was then installed onto the tank. The tank was pressurized to 21.7 psig [the equivalent of 15.26 m (50.05 ft.) of water] and held at that pressure for 8 hours. At the end of the test run, TU-6 was removed from the tank and allowed to drip dry. Data forms from this test can be found in Appendix M.

The CV was opened and inspected for water in-leakage and physical damage to the test unit. There was no sign of water in-leakage or physical damage. Some small drops of water were noticed on the outside of the O-rings when the top of the CV was removed. Water on the outside of the O-ring is a normal occurrence.

5.5 CV Disassembly Observations

Once the top plug was removed from the units, the CVs were easily removed from the drums. During the disassembly of the CVs the torque required to remove the lid was measured and recorded. (The nuts of the lid were initially torqued to 115 ± 5 ft-lbs.) Table 5.2 shows the torque required to loosen the CV lid nut. The surrogate payloads of TU-1, TU-2, TU-3, and TU-4 had rust on their surface, which is likely a result of oils and moisture transferred from fingerprints during handling. Often the cable lanyards of the lower two sections of the surrogate load were flattened because the cable had been squeezed between the test weights and the CV wall. The Borobond4 spacers functioned well and withstood the tests with little visible damage, whereas the silicone vibration absorbing pad on the top of each surrogate test weight often showed signs of shredding if not outright disintegration. Because the temperature labels can be blemished by impact or abrasion, some of the labels inside the units were unreadable.

Table 5.2 CV Lid removal torque

	TU-1	TU-2	TU-3	TU-4	TU-5	TU-6
Torque (ft-lbs)	105	45	60	30	60	100

More specific details of the disassembly of the test units are presented below, and temperatures of the temperature-indicating labels attached to both the inside and outside of the units can be found in Section 5.6.

Inside the CV of TU-1, the spacer cushion on the top surrogate load had partially disintegrated (see Figure 5.19) because of the pounding it experienced, and the temperature labels attached just below the flange were scraped and marred due to movement of the surrogate load. The lifting cables attached to the loads were flattened, and the loads had rust spots that were believed to have been caused by handprints from assembling the CV and the leak check procedure pulling moisture from the Borobond4 spacers. (See Figure 5.20.) The spacer cushions on the lower two surrogate load units survived the testing intact. The protective silicone cushion placed on the CV floor was in very good condition, remaining partially stuck to the bottom of the CV after the surrogate load was removed.

The surrogate payloads of TU-2 were also easily removed from the CV and showed nothing remarkable. The Borobond4 spacers were in excellent condition with the upper one being dented only slightly. The cable lanyards attached to the load showed some damage. Referring to Figure 5.21, the cable attached to the load to the left actually broke, and the cable of the next load showed damage. None of the cables of the other test units broke.

The surrogate payloads of TU-3 displayed more rust than most of the other units. Also, the silicone pads on top of the metallic payloads were beginning to unravel and fray. In Figure 5.22, note particularly how the cushion of the top load (further left in the picture) had stripped. On the other hand, the Borobond4 spacers were in excellent condition. Figure 5.23 is an illustration of how the temperature labels were abraded and marred by the movement of the load inside the CV.

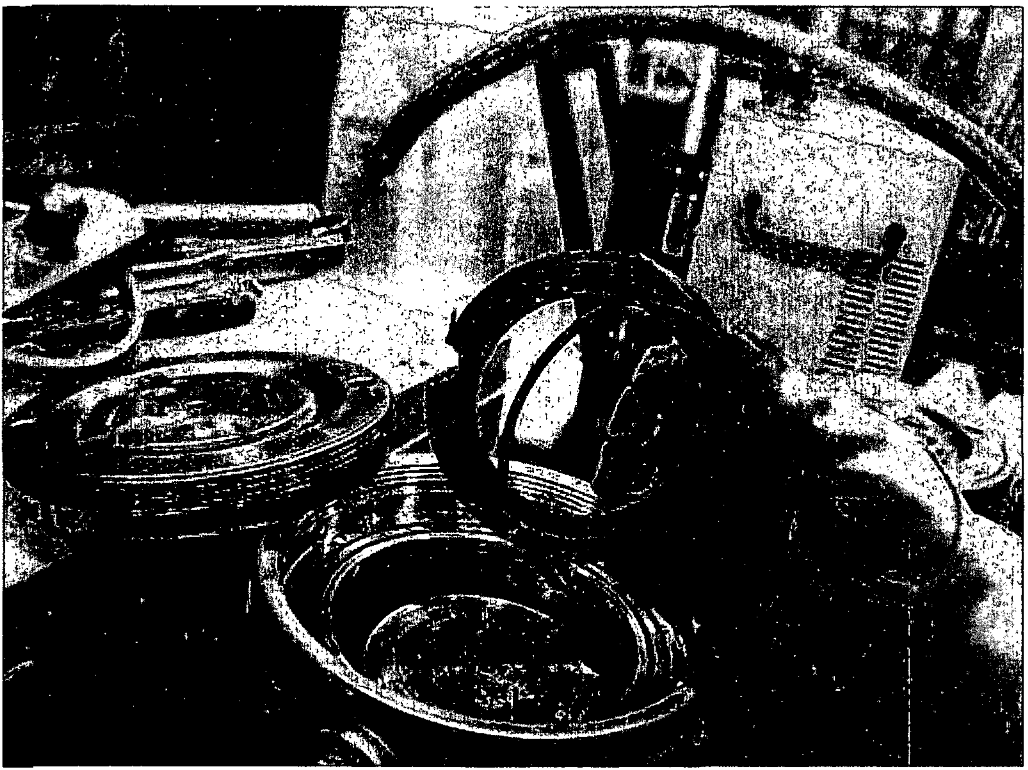


Figure 5.19 Disintegration of spacer cushion of surrogate load

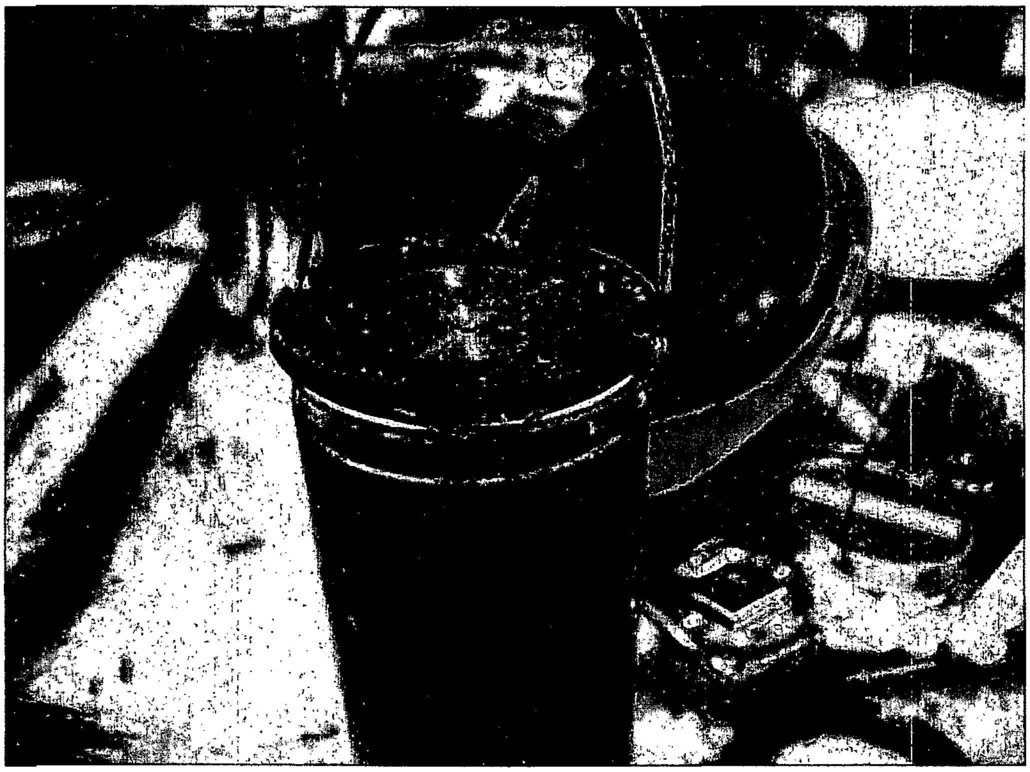


Figure 5.20 TU-1 surrogate load showing rust

Figure 5.21 Broken cable lanyard of TU-2

Figure 5.22 Surrogate payloads of TU-3

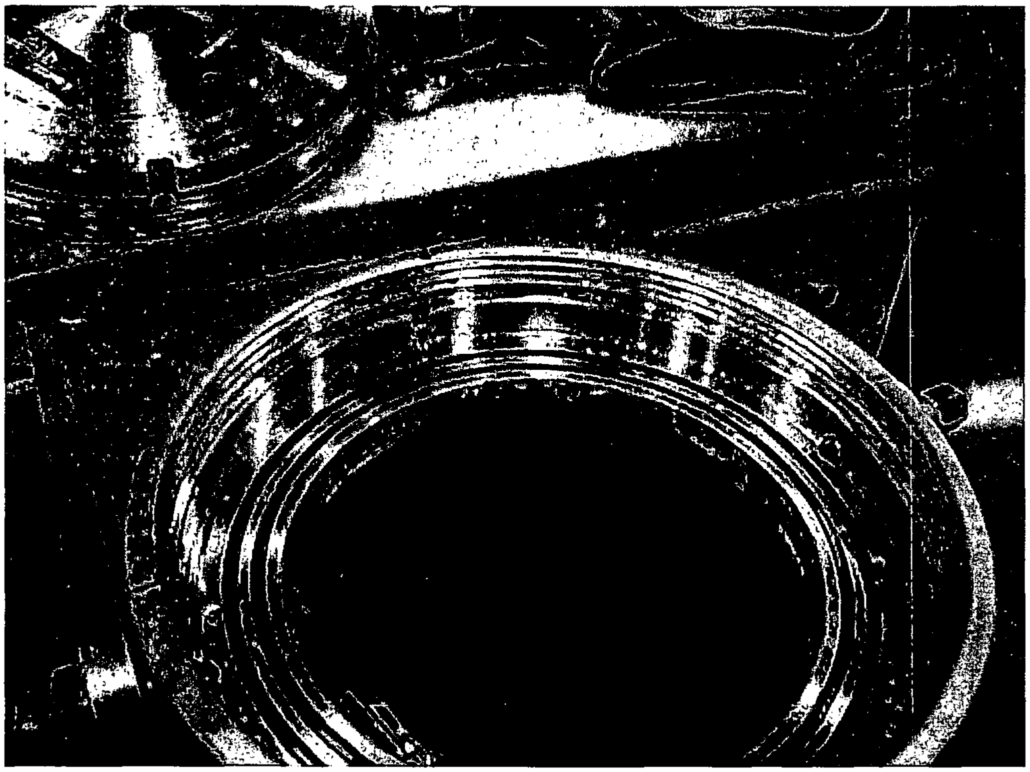


Figure 5.23 Blemishing of temperature labels on flange of CV

TU-4 was disassembled with no difficulties. Some temperature-indicating labels around the flange of TU-4 were blemished by the movement of the surrogate load. In this case, though, the bottom half of the horizontally-placed labels appeared to be more chewed up than blackened. As usual, the silicone pad of the top load showed damage. An oddity that was not seen in any of the other test units was that the lower containment vessel's silicone cushion, which was designed to absorb vibration and shock, expanded around the outside of the CV vessel and worked its way upward. Figure 5.24 shows the silicone cushion wrapped around the body of the CV and another undamaged silicone cushion being displayed for comparison. It is believed that the silicone cushion became "impaled" on the CV during the vibration test, though it may have occurred during either the top-down drop test or top crush test.

TU-5 had lightweight surrogate payloads. The placement of empty cans into the unit to simulate a lightweight load had an unexpected effect. A vacuum was placed on the unit to conduct the post-helium leak test. Later when the vacuum in the CV was being vented, after the initial helium leak check, the lids of the cans were apparently re-sealed and hence collapsed by atmospheric pressure. Figure 5.25 shows how the surrogate payloads were crushed by the pressure of the atmosphere after the cans retained a vacuum. The silicone cushioning was in good condition.

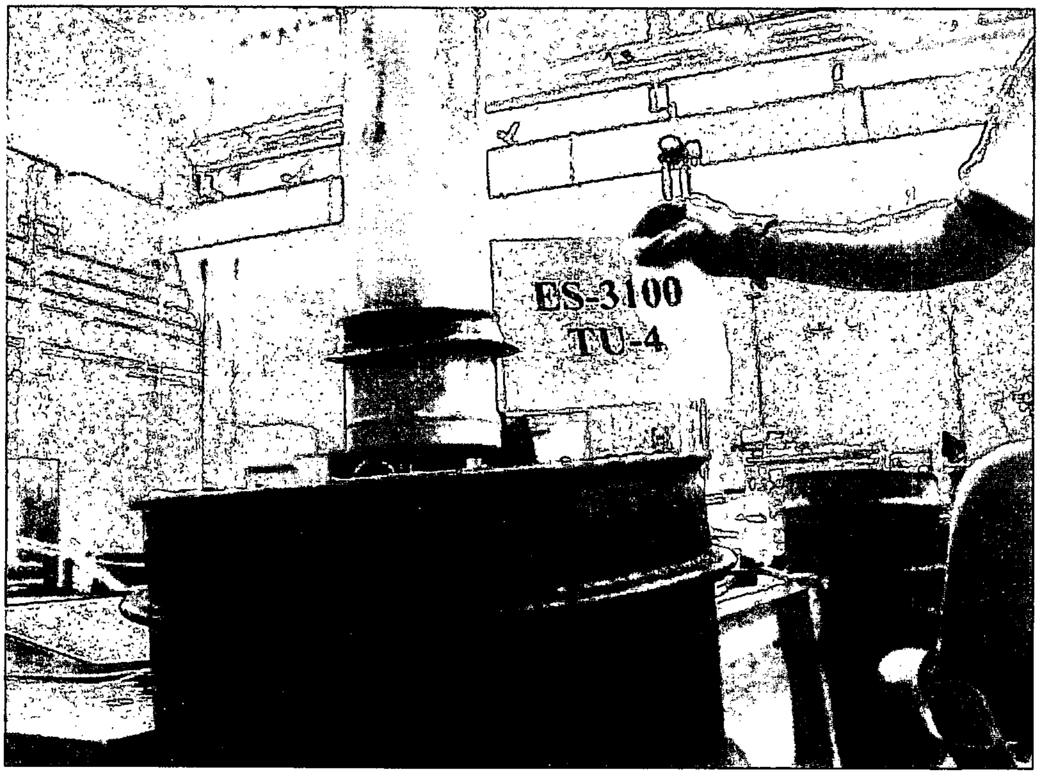


Figure 5.24 Silicone cushion skirting TU-4

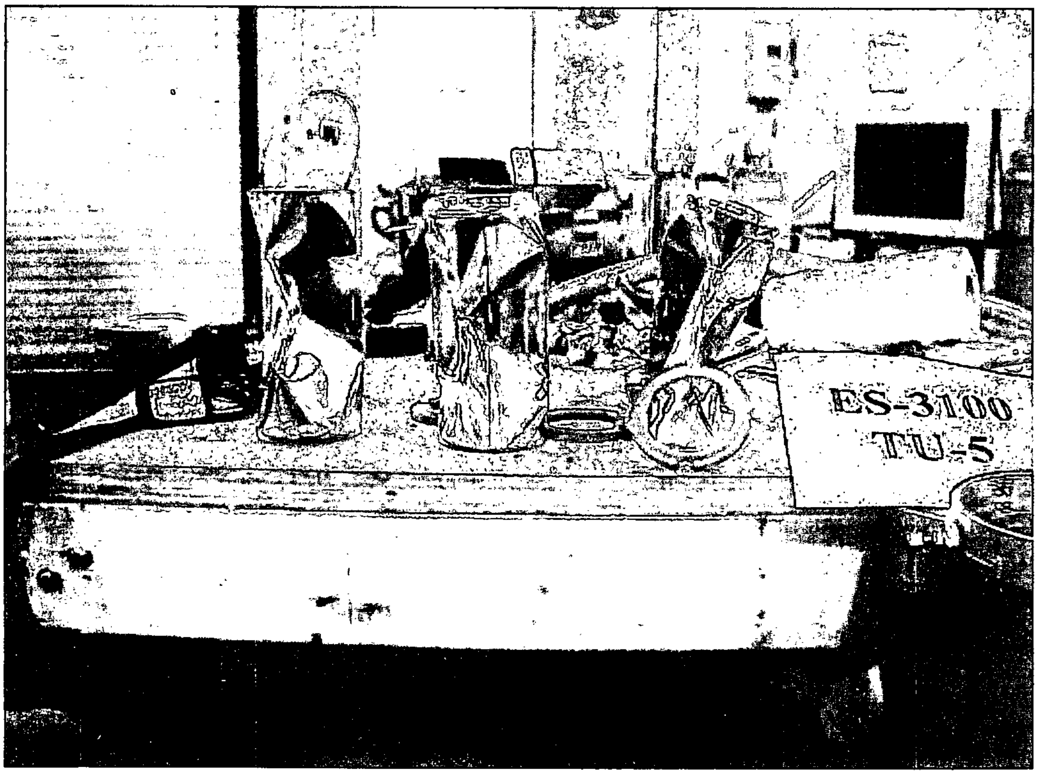


Figure 5.25 Crushed surrogate payloads due to vacuum during helium leak test

5.6 Temperature-indicating Label Results

Each test unit had 48 temperature-indicating label locations installed during the assembly of the test unit. Upon disassembly the temperature-indicating labels were read and the highest indicated temperatures recorded. The locations of the temperature labels are shown in Figure 5.26 through Figure 5.31. When applying the temperature labels to the CV lids the B range labels (171°F-261°F) were mistakenly used in place of the 125°F-300°F label specified in the Test Plan.

In general, none of the labels were burned and the temperatures of the CV flanges were less than 300°F. The labels on the top of the CV and on the Borobond4 step of the outer drum of TU-4 were almost completely black. These temperature labels are impact sensitive as well as temperature sensitive. These labels on TU-4 were directly impacted since this unit was subjected to multiple axial impacts. As noted on the data form, the labels on the top of the Borobond4 liner are inconsistent and are likely blacked-out from the impact of the CV rather than temperature. The same is true for the CV top of TU-4 where the CV impacted the top plug. Impact damage is probable because some temperature-indicating spots show part of the spot black while part is still white. Also several labels were lost due to physical damage especially the ones on the inside of the CV flange. The readings of the temperature labels for each test unit are presented in Table 5.3 through Table 5.7.

M2E801580A027
HEAVY TEST WEIGHT ASSEMBLY WITH BOROBOND SPACERS

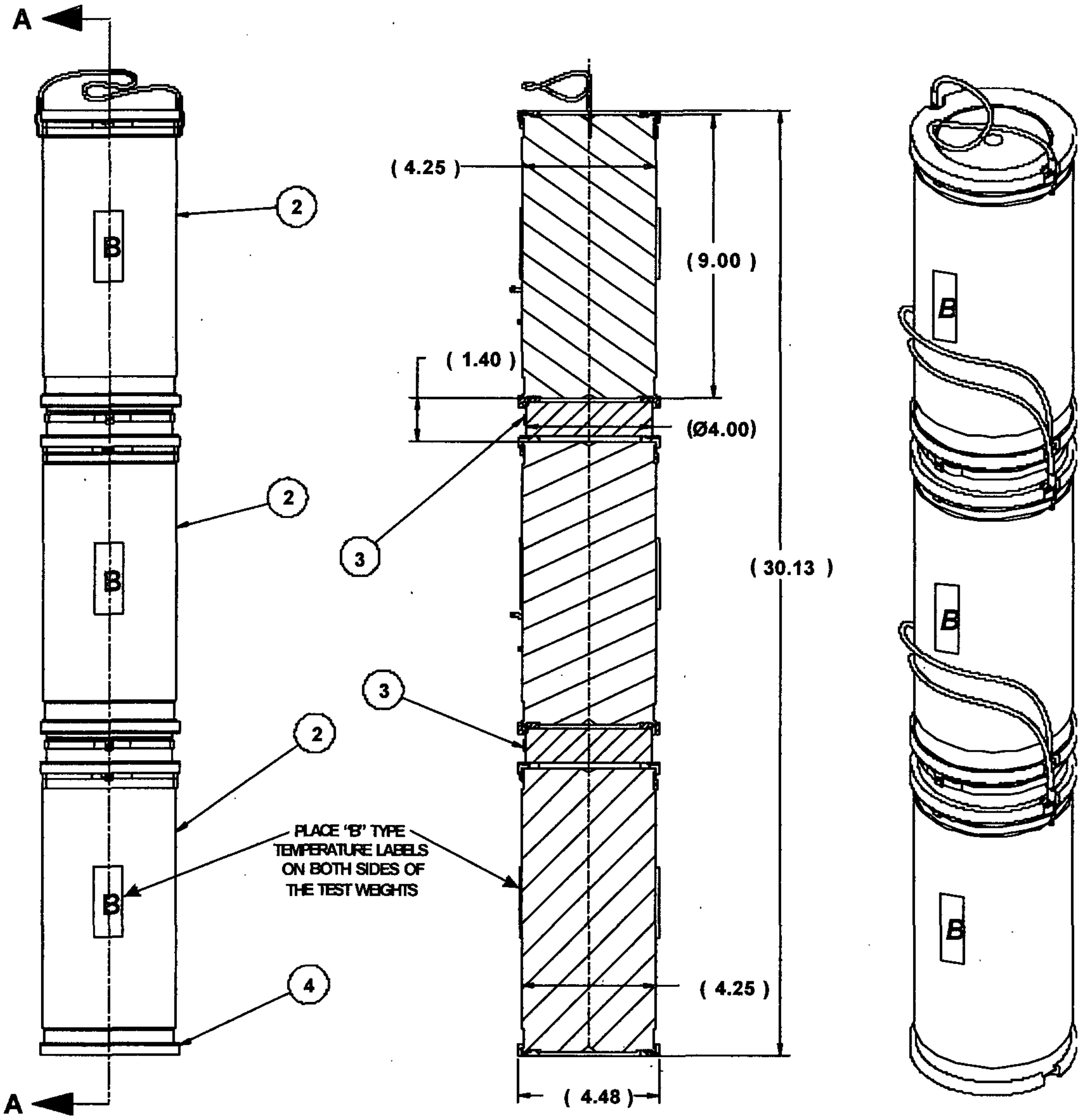


Figure 5.26 Surrogate payload temperature label locations (TU-1, TU-2, TU-3, and TU-4)

M2E801580A029; LIGHT TEST WEIGHT ASSEMBLY (BALLAST FILLED)

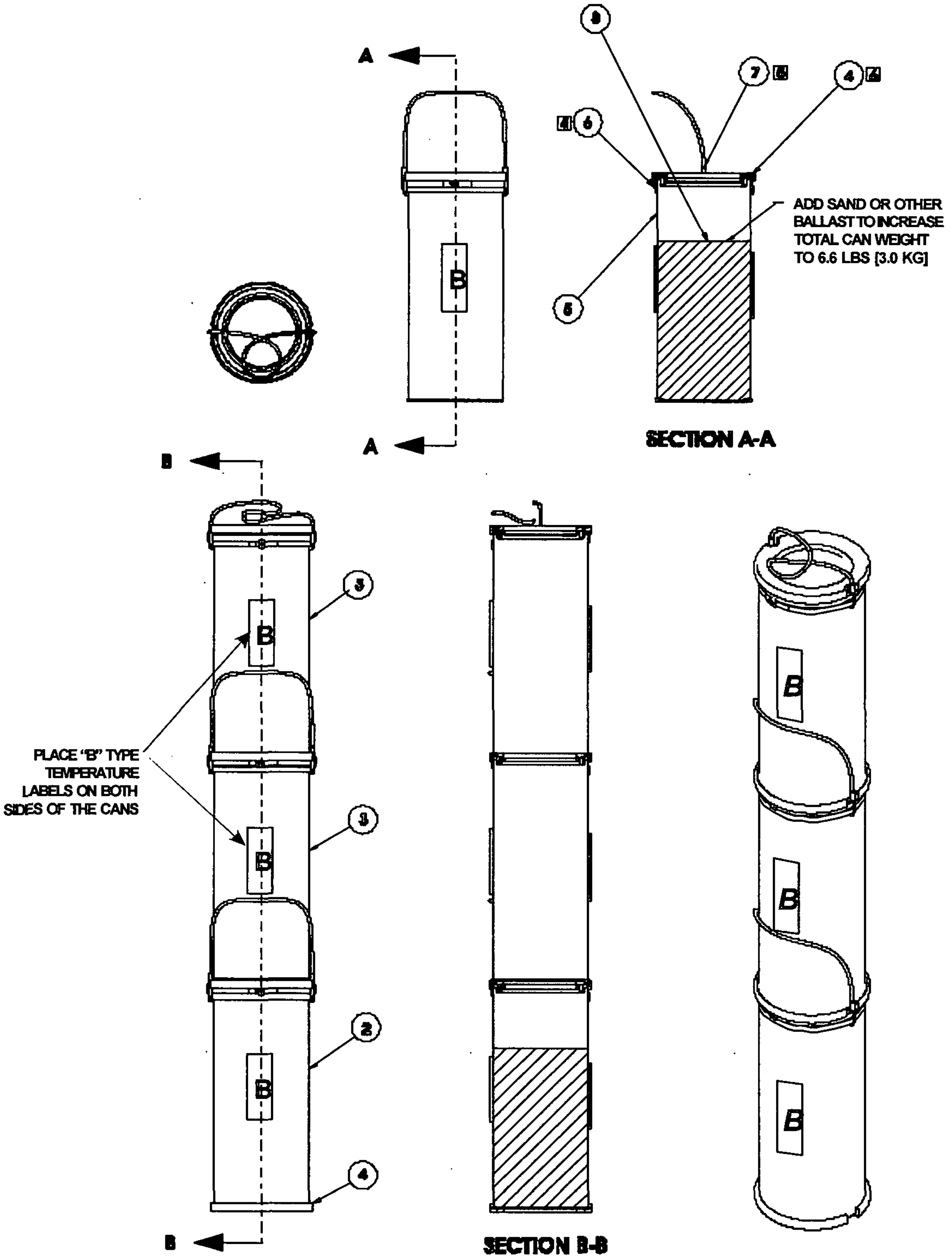


Figure 5.27 Light-weight test assembly temperature-indicating label locations

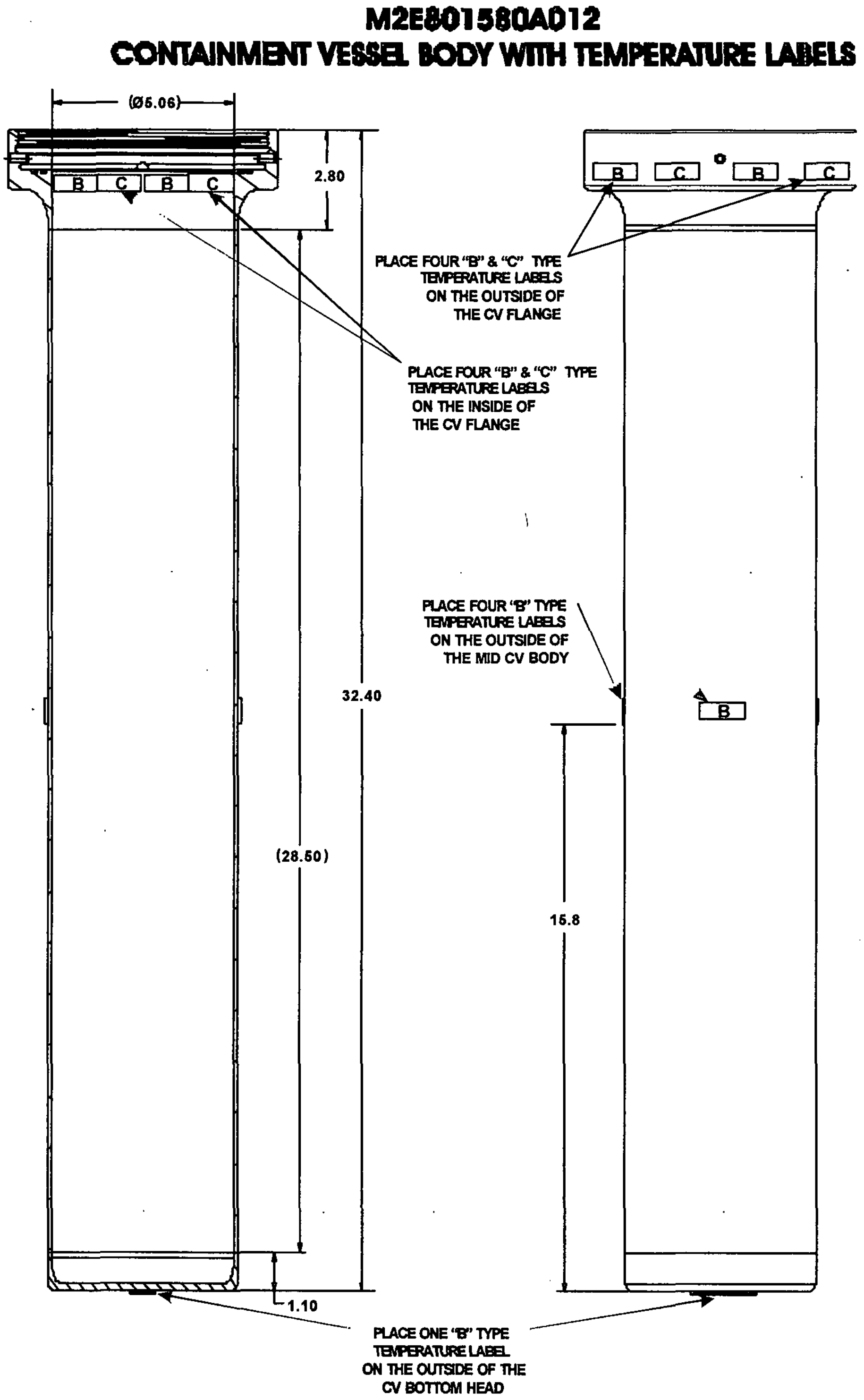


Figure 5.28 CV body temperature-indicating label locations

M2E801580A014
CONTAINMENT VESSEL LID ASSEMBLY

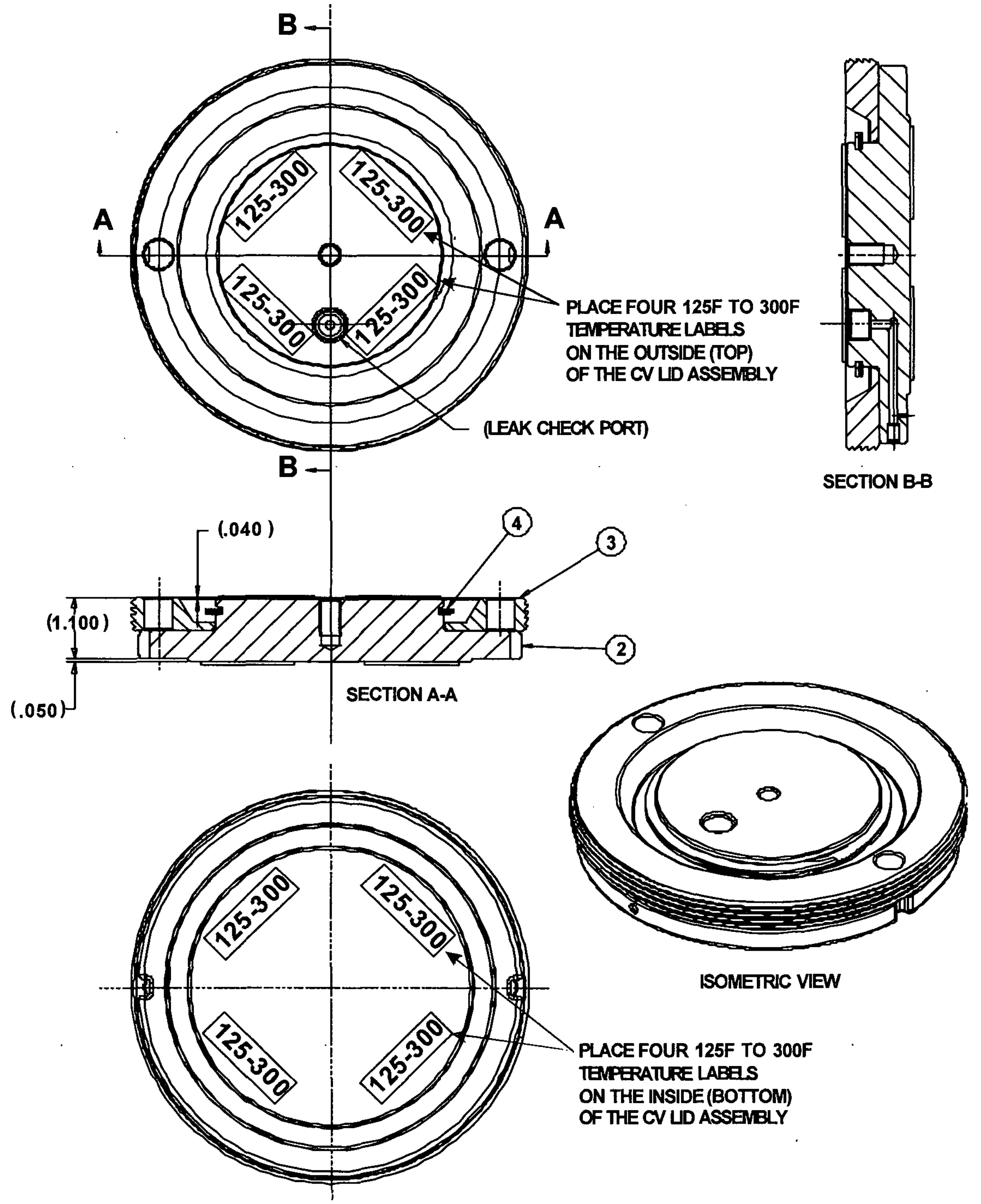


Figure 5.29 CV lid temperature-indicating label locations

(Note: B range labels were mistakenly used on the CV lid instead of the 125-300°F range labels.)

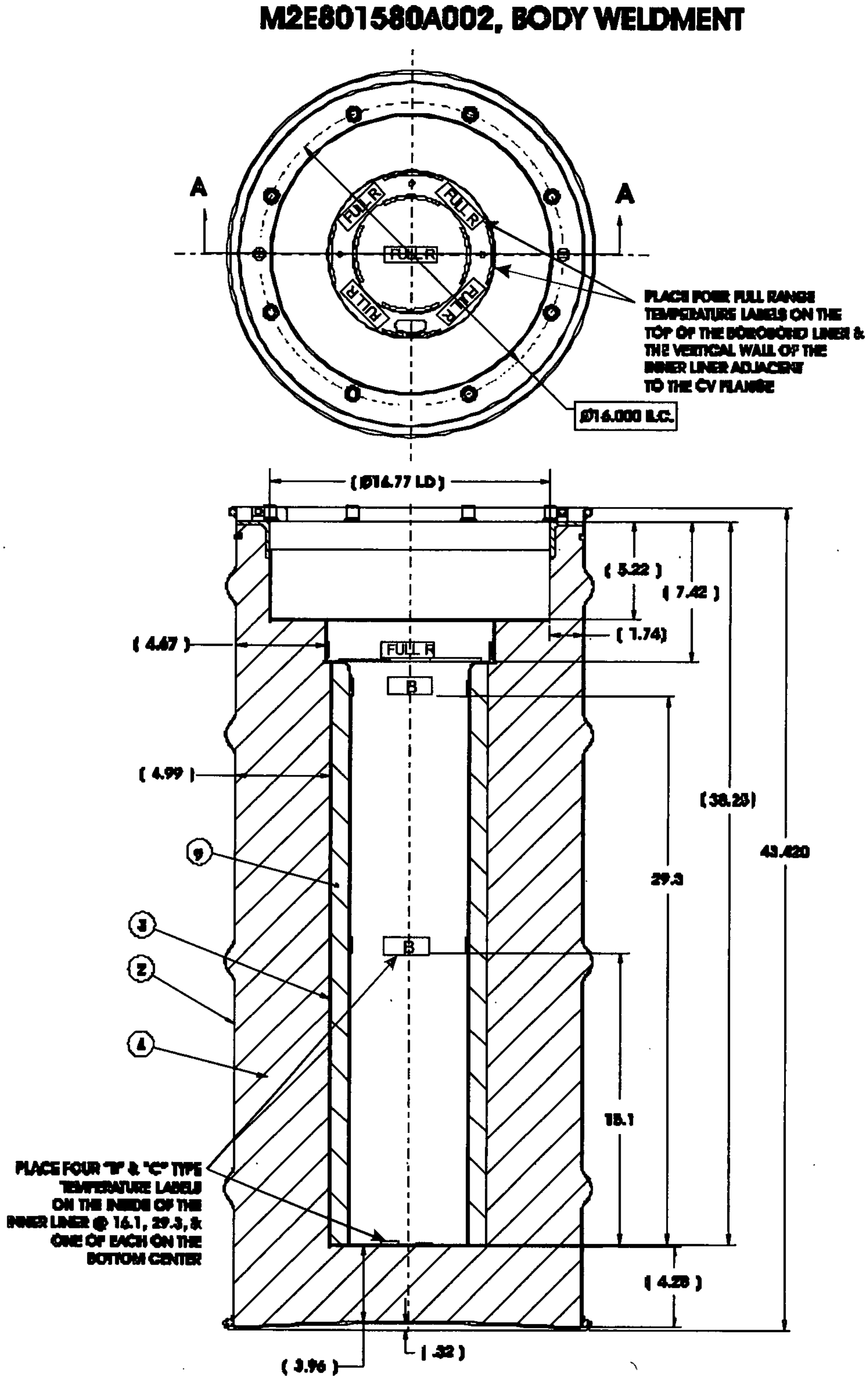
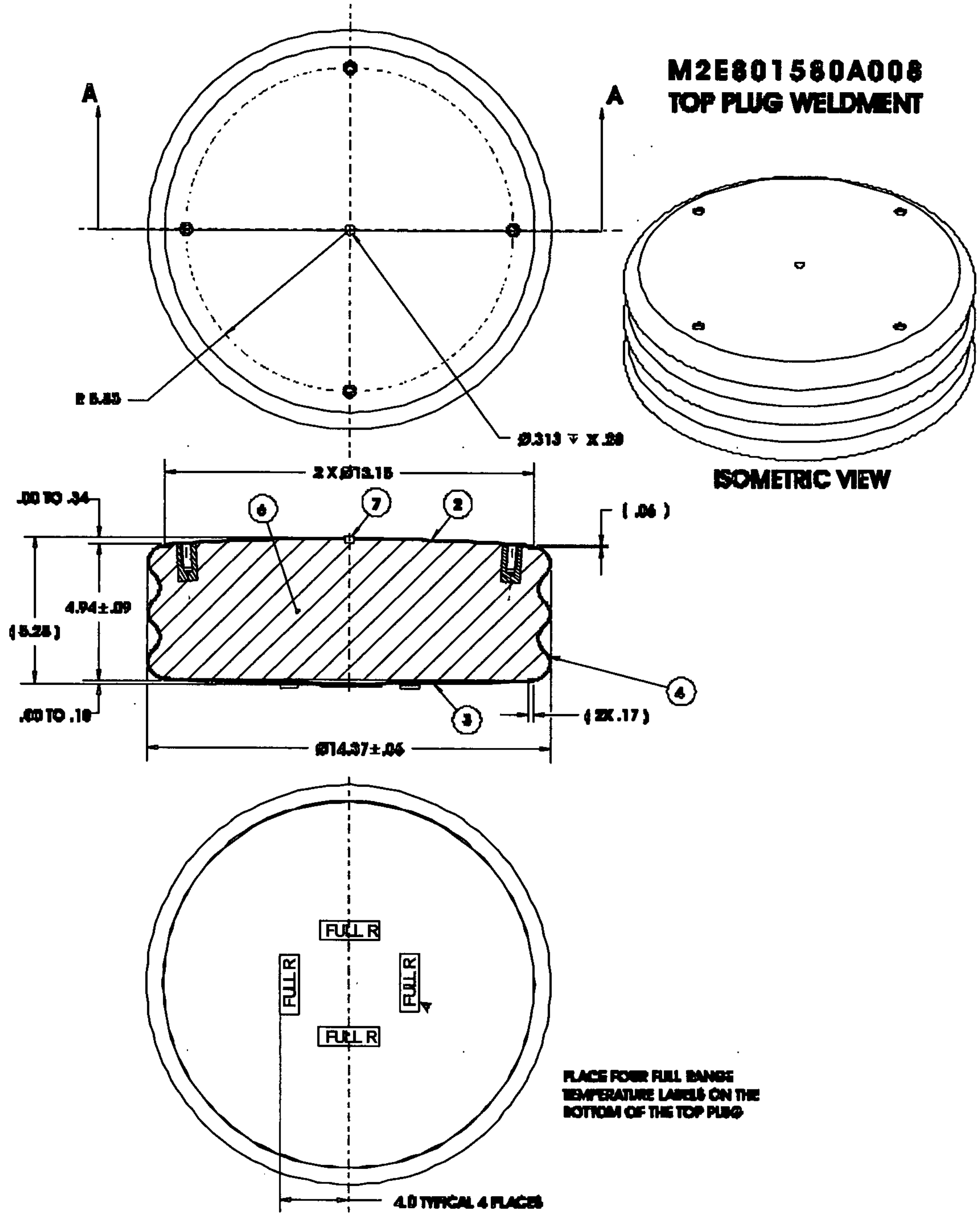


Figure 5.30 Inner liner temperature label indicating locations



PLACE FOUR FULL RANGE
TEMPERATURE LABELS ON THE
BOTTOM OF THE TOP PLUG

Figure 5.31 Top Plug temperature-indicating label locations

Table 5.3 Temperature-indicating Labels reading for TU-1

TEMPERATURE INDICATOR NUMBER LOCATION CHART						
ON THE SURROGATE PAYLOAD						
Location	**0°**			**180°**		
Side Top	1	B 180	°F	4	B 180	°F
Side Middle	2	B 171	°F	5	B 171	°F
Side Bottom	3	B 171	°F	6	B 171	°F

ON THE CV												
Location	**0°**			**90°**			**180°**			**270°**		
CV Lid Top (outside)	7	B 230	°F	8	B 241	°F	9	B 241	°F	10	B 230	°F
CV Lid Bottom (inside)	11	B 210	°F	12	B 210	°F	13	B 210	°F	14	B 219	°F
Flange (outside)	15	B 230 C ----	°F	16	B 230 C ----	°F	17	B 241 C ----	°F	18	B 230 C ----	°F
Flange (inside)	19	B-Destroyed C- Destroyed	°F	20	B 210 C-Damaged	°F	21	B 210 C ----	°F	22	B 219 C ----	°F
Body Mid Height (outside)	23	B 210	°F	24	B 171	°F	25	B 171	°F	26	B 180	°F
CV Base (outside)	27	B 210	°F	Note: Temp label centered on bottom								

ON THE INNER LINER AND TOP PLUG												
Location	**0°**			**90°**			**180°**			**270°**		
Top Plug Bottom	28	300	°F	29	300	°F	30	300	°F	31	300	°F
Flange Step Wall	32	275	°F	33	200	°F	34	250	°F	35	275	°F
BoroBond4 Step	36	225	°F	37	200	°F	38	225	°F	39	225	°F
CV Body Wall High	40	B 210	°F	41	C ----	°F	42	B 210	°F	43	C ----	°F
CV Body Wall Middle	44	B 210	°F	45	C ----	°F	46	B 190	°F	47	C ----	°F
Liner Bottom	48	B 219	°F	Note: Temp label centered on bottom								

Note: B and C indicate range type of label.

Note: ---- indicates no spots were blacked-out.

Table 5.4 Temperature-indicating Labels reading for TU-2

TEMPERATURE INDICATOR NUMBER LOCATION CHART

ON THE SURROGATE PAYLOAD

Location	0°			180°		
Side Top	1	B 171	°F	4	B 171	°F
Side Middle	2	B 171	°F	5	B 171	°F
Side Bottom	3	B 171	°F	6	B 171	°F

ON THE CV

Location	0°			90°			180°			270°		
CV Lid Top (outside)	7	B 230	°F	8	B 230	°F	9	B 230	°F	10	B 230	°F
CV Lid Bottom (inside)	11	B 190	°F	12	B 219	°F	13	B 210	°F	14	B 219	°F
Flange (outside)	15	B 210 C ----	°F	16	B 230 C ----	°F	17	B 230 C ----	°F	18	B 230 C ----	°F
Flange (inside)	19	B-Destroyed C- Destroyed	°F	20	B 210 C ----	°F	21	B-Destroyed C- Destroyed	°F	22	B-Destroyed C- Destroyed	°F
Body Mid Height (outside)	23	B 180	°F	24	B 180	°F	25	B 190	°F	26	B 180	°F
CV Base (outside)	27	B 210	°F	Note: Temp label centered on bottom								

ON THE INNER LINER AND TOP PLUG

Location	0°			90°			180°			270°		
Top Plug Bottom	28	325	°F	29	325	°F	30	300	°F	31	300	°F
Flange Step Wall	32	Destroyed	°F	33	250	°F	34	325	°F	35	275	°F
BoroBond4 Step	36	225	°F	37	225	°F	38	275	°F	39	225	°F
CV Body Wall High	40	B 210	°F	41	C ----	°F	42	B 210	°F	43	C ---	°F
CV Body Wall Middle	44	B 171	°F	45	C ----	°F	46	B 199	°F	47	C ----	°F
Liner Bottom	48	B 210	°F	Note: Temp label centered on bottom								

Note: B and C indicate range type of label.
Note: ---- indicates no spots were blacked-out.

Table 5.5 Temperature-indicating Labels reading for TU-3

<table>
<tr><th colspan="13">TEMPERATURE INDICATOR NUMBER LOCATION CHART</th></tr>
<tr><td colspan="13">ON THE SURROGATE PAYLOAD</td></tr>
<tr><th>Location</th><th colspan="6">0°</th><th colspan="6">180°</th></tr>
<tr><td>Side Top</td><td>1</td><td colspan="4">B 171</td><td>°F</td><td>4</td><td colspan="4">B 171</td><td>°F</td></tr>
<tr><td>Side Middle</td><td>2</td><td colspan="4">B 171</td><td>°F</td><td>5</td><td colspan="4">B 171</td><td>°F</td></tr>
<tr><td>Side Bottom</td><td>3</td><td colspan="4">B 171</td><td>°F</td><td>6</td><td colspan="4">B 171</td><td>°F</td></tr>
<tr><td colspan="13"></td></tr>
<tr><td colspan="13">ON THE CV</td></tr>
<tr><th>Location</th><th colspan="3">0°</th><th colspan="3">90°</th><th colspan="3">180°</th><th colspan="3">270°</th></tr>
<tr><td>CV Lid Top (outside)</td><td>7</td><td>B 230</td><td>°F</td><td>8</td><td>B 230</td><td>°F</td><td>9</td><td>B 241</td><td>°F</td><td>10</td><td>B 241</td><td>°F</td></tr>
<tr><td>CV Lid Bottom (inside)</td><td>11</td><td>B 230</td><td>°F</td><td>12</td><td>B 230</td><td>°F</td><td>13</td><td>B 230</td><td>°F</td><td>14</td><td>B 230</td><td>°F</td></tr>
<tr><td>Flange (outside)</td><td>15</td><td>B 230
C ----</td><td>°F</td><td>16</td><td>B 230
C ----</td><td>°F</td><td>17</td><td>B 230
C ----</td><td>°F</td><td>18</td><td>B 230
C ----</td><td>°F</td></tr>
<tr><td>Flange (inside)</td><td>19</td><td>B 210
C ----</td><td>°F</td><td>20</td><td>B-Destroyed
C- Destroyed</td><td>°F</td><td>21</td><td>B 230
C ----</td><td>°F</td><td>22</td><td>B-Destroyed
C- Destroyed</td><td>°F</td></tr>
<tr><td>Body Mid Height (outside)</td><td>23</td><td>B 210</td><td>°F</td><td>24</td><td>B 180</td><td>°F</td><td>25</td><td>B 180</td><td>°F</td><td>26</td><td>B 171</td><td>°F</td></tr>
<tr><td>CV Base (outside)</td><td>27</td><td>B 190</td><td>°F</td><td colspan="9">Note: Temp label centered on bottom</td></tr>
<tr><td colspan="13"></td></tr>
<tr><td colspan="13">ON THE INNER LINER AND TOP PLUG</td></tr>
<tr><th>Location</th><th colspan="3">0°</th><th colspan="3">90°</th><th colspan="3">180°</th><th colspan="3">270°</th></tr>
<tr><td>Top Plug Bottom</td><td>28</td><td>275</td><td>°F</td><td>29</td><td>300</td><td>°F</td><td>30</td><td>350</td><td>°F</td><td>31</td><td>300</td><td>°F</td></tr>
<tr><td>Flange Step Wall</td><td>32</td><td>225</td><td>°F</td><td>33</td><td>275</td><td>°F</td><td>34</td><td>275</td><td>°F</td><td>35</td><td>275</td><td>°F</td></tr>
<tr><td>BoroBond4 Step</td><td>36</td><td>200</td><td>°F</td><td>37</td><td>225</td><td>°F</td><td>38</td><td>225</td><td>°F</td><td>39</td><td>225</td><td>°F</td></tr>
<tr><td>CV Body Wall High</td><td>40</td><td>B 210</td><td>°F</td><td>41</td><td>C ----</td><td>°F</td><td>42</td><td>B 210</td><td>°F</td><td>43</td><td>C ----</td><td>°F</td></tr>
<tr><td>CV Body Wall Middle</td><td>44</td><td>B 241</td><td>°F</td><td>45</td><td>C ----</td><td>°F</td><td>46</td><td>B 199</td><td>°F</td><td>47</td><td>C ----</td><td>°F</td></tr>
<tr><td>Liner Bottom</td><td>48</td><td>B 210</td><td>°F</td><td colspan="9">Note: Temp label centered on bottom</td></tr>
</table>

Note: B and C indicate range type of label.

Note: ---- indicates no spots were blacked-out.

Table 5.6 Temperature-indicating Labels reading for TU-4

<table>
<tr><th colspan="13">TEMPERATURE INDICATOR NUMBER LOCATION CHART</th></tr>
<tr><th colspan="13">ON THE SURROGATE PAYLOAD</th></tr>
<tr><th>Location</th><th colspan="6">0°</th><th colspan="6">180°</th></tr>
<tr><td>Side Top</td><td>1</td><td colspan="4">B 171</td><td>°F</td><td>4</td><td colspan="4">B 171</td><td>°F</td></tr>
<tr><td>Side Middle</td><td>2</td><td colspan="4">B 171</td><td>°F</td><td>5</td><td colspan="4">B 171</td><td>°F</td></tr>
<tr><td>Side Bottom</td><td>3</td><td colspan="4">B 171</td><td>°F</td><td>6</td><td colspan="4">B 171</td><td>°F</td></tr>
<tr><td colspan="13"></td></tr>
<tr><th colspan="13">ON THE CV</th></tr>
<tr><th>Location</th><th colspan="3">0°</th><th colspan="3">90°</th><th colspan="3">180°</th><th colspan="3">270°</th></tr>
<tr><td>CV Lid Top (outside)</td><td>7</td><td>B 261</td><td>°F</td><td>8</td><td>B 261</td><td>°F</td><td>9</td><td>B 261</td><td>°F</td><td>10</td><td>B 261</td><td>°F</td></tr>
<tr><td>CV Lid Bottom (inside)</td><td>11</td><td>B 230</td><td>°F</td><td>12</td><td>B 230</td><td>°F</td><td>13</td><td>B 230</td><td>°F</td><td>14</td><td>B 230</td><td>°F</td></tr>
<tr><td>Flange (outside)</td><td>15</td><td>B 241
C ----</td><td>°F</td><td>16</td><td>B 241
C ----</td><td>°F</td><td>17</td><td>B 241
C ----</td><td>°F</td><td>18</td><td>B 241
C ----</td><td>°F</td></tr>
<tr><td>Flange (inside)</td><td>19</td><td>B 219
C ----</td><td>°F</td><td>20</td><td>B-Destroyed
C- Destroyed</td><td>°F</td><td>21</td><td>B-Destroyed
C- Destroyed</td><td>°F</td><td>22</td><td>B 219
C ----</td><td>°F</td></tr>
<tr><td>Body Mid Height (outside)</td><td>23</td><td>B 180</td><td>°F</td><td>24</td><td>B 180</td><td>°F</td><td>25</td><td>B 180</td><td>°F</td><td>26</td><td>B 180</td><td>°F</td></tr>
<tr><td>CV Base (outside)</td><td>27</td><td>B 230</td><td>°F</td><td colspan="10">Note: Temp label centered on bottom</td></tr>
<tr><td colspan="13"></td></tr>
<tr><th colspan="13">ON THE INNER LINER AND TOP PLUG</th></tr>
<tr><th>Location</th><th colspan="3">0°</th><th colspan="3">90°</th><th colspan="3">180°</th><th colspan="3">270°</th></tr>
<tr><td>Top Plug Bottom</td><td>28</td><td>350</td><td>°F</td><td>29</td><td>350</td><td>°F</td><td>30</td><td>350</td><td>°F</td><td>31</td><td>350</td><td>°F</td></tr>
<tr><td>Flange Step Wall</td><td>32</td><td>275</td><td>°F</td><td>33</td><td>275</td><td>°F</td><td>34</td><td>275</td><td>°F</td><td>35</td><td>275</td><td>°F</td></tr>
<tr><td>BoroBond4 Step</td><td>36</td><td>350</td><td>°F</td><td>37</td><td>350</td><td>°F</td><td>38</td><td>300</td><td>°F</td><td>39</td><td>350</td><td>°F</td></tr>
<tr><td>CV Body Wall High</td><td>40</td><td>B 210</td><td>°F</td><td>41</td><td>C ----</td><td>°F</td><td>42</td><td>B 210</td><td>°F</td><td>43</td><td>C ----</td><td>°F</td></tr>
<tr><td>CV Body Wall Middle</td><td>44</td><td>B 190</td><td>°F</td><td>45</td><td>C ----</td><td>°F</td><td>46</td><td>B 199</td><td>°F</td><td>47</td><td>C ----</td><td>°F</td></tr>
<tr><td>Liner Bottom</td><td>48</td><td>B 261</td><td>°F</td><td colspan="10">Note: Temp label centered on bottom</td></tr>
</table>

Note: B and C indicate range type of label.

Note: ---- indicates no spots were blacked-out.

Table 5.7 Temperature-indicating Labels reading for TU-5

TEMPERATURE INDICATOR NUMBER LOCATION CHART

ON THE SURROGATE PAYLOAD

Location	**0°**			**180°**		
Side Top	1	B 210	°F	4	B 210	°F
Side Middle	2	B 199	°F	5	B 199	°F
Side Bottom	3	B 190	°F	6	B 190	°F

ON THE CV

Location	**0°**			**90°**			**180°**			**270°**		
CV Lid Top (outside)	7	B 250	°F	8	B 261	°F	9	B 261	°F	10	B 250	°F
CV Lid Bottom (inside)	11	B 241	°F	12	B 241	°F	13	B 241	°F	14	B 241	°F
Flange (outside)	15	B 250 C ----	°F	16	B 241 C ----	°F	17	B 250 C ----	°F	18	B 241 C ----	°F
Flange (inside)	19	B 230 C ----	°F	20	B 241 C ----	°F	21	B 241 C ----	°F	22	B 230 C ----	°F
Body Mid Height (outside)	23	B 199	°F	24	B 199	°F	25	B 199	°F	26	B 199	°F
CV Base (outside)	27	B 210	°F	Note: Temp label centered on bottom								

ON THE INNER LINER AND TOP PLUG

Location	**0°**			**90°**			**180°**			**270°**		
Top Plug Bottom	28	325	°F	29	300	°F	30	325	°F	31	350	°F
Flange Step Wall	32	250	°F	33	250	°F	34	275	°F	35	275	°F
BoroBond4 Step	36	225	°F	37	225	°F	38	250	°F	39	250	°F
CV Body Wall High	40	B 210	°F	41	C ----	°F	42	B 219	°F	43	C ----	°F
CV Body Wall Middle	44	B 210	°F	45	C ----	°F	46	B 210	°F	47	C ----	°F
Liner Bottom	48	B 230	°F	Note: Temp label centered on bottom								

Note: B and C indicate range type of label.

Note: ---- indicates no spots were blacked-out.

Appendix 2.10.8

THE ES-3100 TEST REPORT; VOL. 3, APPENDIX K - TU-4 DATA SHEETS

Appendix K – TU-4 Data Sheets

TEST FORM 1 - COMPONENT WEIGHTS

Test Plan ES-3100

Test Unit 4

PRE-DROP TEST WEIGHTS			POST THERMAL TEST WEIGHTS		
PART NAME	**WEIGHT**	**UNITS**	**PART NAME**	**WEIGHT**	**UNITS**
CV (lid assem. & body)	32	lbs.			lbs.
CV surrogate payload,	110	lbs.			lbs.
CV assembly	143	lbs.	CV assembly	143	lbs.
Drum Silicone inserts	1	lbs.	Drum Silicone inserts	2	lbs.
Drum Top Plug	19	lbs.	Drum Top Plug	18	lbs.
Drum Body Assy	282	lbs.	Drum Body Assy	281	lbs.
Test package Assy	445	lbs.	Test package Assy	444	lbs.

EQUIPMENT

Scale: X-502322 Expiration Date: 10-28-04

Accuracy: ± 1 lb

Comments: Drum plug was weighed twice to verify its lighter weight (2 lbs less than other units')

I certify that the above tasks have been performed and that the observations and comments are correct.

Leonard Dickerson 5-19-04 5-19-04

Testing Technician Date Witness Date

*All photographs/movies will be uniquely identified with test unit, date and time to ensure that the proper sequence can be reconstructed

TEST FORM 2 - ASSEMBLY OF THE CV

Test Plan ES-3100

Test Unit 4

VERIFIED	TASK
✓	CV test unit serial number: ES-3100 04/04-09
✓	All containment vessel (CV) components have been visually inspected to ensure they are present and in good condition.
✓	Temperature indicators have been affixed to the surface of the CV and on Surrogate payload as indicated on Figure 5.1 through Figure 5.6.
✓	None of the temperature indicators indicate exposure to a temperature in the measured range.
✓	The container and lid have been clearly marked as "TU- 4".
✓	The CV O-rings and sealing surfaces have been inspected for defects and found acceptable.
✓	Clean all surfaces with isopropyl alcohol and air dry.
N/A	The CV O-rings have been lubricated and installed. Use new O-rings.
✓	The surrogate payload # N/A , weighing 110 pounds was aligned and installed in the CV.
✓	The nut ring has been lubricated with Krytox grease per Y-12 Drawing M2E801580A011.
✓	The lid has been installed on the container and the previously applied markings align. This lid has had a torque of 115±5 ft-lb applied. Ambient temperature at closure is 21 °C (72 °F). Torque wrench # Z0020040628A2 Calibration Expiration Date 5/14/05
✓	Mark the top of the CV lid with 0°, 90°, 180° and 270° locations with a permanent marker. 0° is on the centerline of the leak test port and the axis of the package
✓	The CV assembly has been weighed and the weight has been recorded on TEST FORM 1 .
✓	The CV assembly has been leak tested with the CALT5 per the Manufacturer's Instructions Manual.
✓	Install modified VCO plug (Y-12 will supply) in leak test port and hex plug in lifting ring hole. *
✓	Photographs of the assembly have been taken*.

Comments: * approved the hexplug to be left out

certify that the above tasks have been performed and that the observations and comments are correct.

Testing Technician

Date 5-19-04

Witness Leonard Dickerson

Date 5-19-04

*All photographs/movies will be uniquely identified with test unit, date and time to ensure that the proper sequence can be reconstructed

TEST FORM 3 - ASSEMBLY OF TEST PACKAGE

Test Plan ES-3100

Test Unit 4

VERIFIED	TASK
✓	Verify operational leak test is complete and form completed and modified VCO plug is installed.
✓	The exterior of the drum has been clearly marked "TU-4".
✓	Record the drum serial number: ES-3100 04/04-09
✓	The center-of-gravity markings have been applied to the drum.
✓	Mark the 0°, 90°, 180°, 270° locations on the Drum Lid, Top Plug, and the inner and outside walls of the drum with a permanent marker. The 0° location is the vertical, outside-wall seam of the drum.
✓	The silicone CV Bottom Pad has been installed at the bottom of the inner liner.
✓	The silicone Plug Pad has been installed on the horizontal portion of the top plug step of the inner liner.
✓	The CV assembly has been loaded into the drum with the 0° rotated and aligned with the 0° location on the drum.
✓	The silicone CV Flange Pad has been installed over the CV lid.
✓	The Drum Top Plug was weighed and the weight has been recorded on TEST FORM 1
✓	The Drum Top Plug has been loaded into the drum with the 0° rotated and aligned with the 0° location on the drum.
✓	The Drum Lid has been installed with the 0° mark aligned with the 0° mark on the drum.
✓	The drum lid washers are placed over the lugs and the drum lid nuts were initially installed and a torque of 30 ± 1 ft.-lb applied. The nuts were then tightened a second time with a torque of 30 ± 1 ft-lbs again applied No torque sequence is required to be followed.
	Torque wrench #4010282626 Calibration Expiration Date 10-27-04
✓	The test package assembly has been weighed and the weight recorded on TEST FORM
✓	Photographs of the assembly have been taken*.

Comments:

I certify that the above tasks have been performed and that the observations and comments are correct.

Leonard Dickerson
Testing Technician

5-19-04
Date

Witness

5-19-04
Date

*All photographs/movies will be uniquely identified with test unit, date and time to ensure that the proper sequence can be reconstructed

ORNL TRANSPORTATION TECHNOLOGY GROUP OAK RIDGE NATIONAL LABORATORY OAK RIDGE, TENNESSEE 37831	Operating Procedure for Operational Leak Test - Testing of Radioactive Material Packages.	Test Procedure: TTG-PRF- 01	
		Page 3 / 3	Rev. 0
		Issue Date: 1-30-04	Review Date: 1-30-05

Procedure Checklist

Test Plan: ORNL/TTG-NTRC-011 ES-3100

Test Unit: TU-4

VERIFIED	TASK
✓	Have a photographer's clapboard with package name and test unit number.
✓	A photograph of the leak tester connections has been taken.
✓	Both CALT5 Leak Tester and CVs have been in the same ambient conditions for 24 hours.
✓	Determine the interstitial volume of the test unit. Print out results.
✓	Determine the length of test from CALT5 Instruction Manual Table according to volume and accuracy needed.
✓	Program the info into the CALT5 tester.
✓	Run the CALT5 leak test. Print out results.
✓	Enter the data from CALT5 printout onto Data Sheet.
✓	Calculate the leak rate and enter on Data Sheet.

Comments:

I certify that the above tasks have been performed and that the observations and comments are correct.

Testing Technician

5/19/04
Date

5-19-04
Date

5. Data Sheet

Test Plan: ORNL/NTRC-011 ES-3100

Test Unit: 4

VERIFIED **TASK**

✓ Assembly Leak Test Post Testing Leak Test

✓

✓ A leak test in accordance with the CALT5 Manufacturer's Instructions Manual was performed on the CV assembly. Both CALT5 Leak Tester and CVs have been in the same ambient conditions for 24 hours.

Leak Tester Cert. # M287134 Expiration Date: 3/3/2005

✓ Ambient temperature: 21 °C (___ °F)

Measuring device TTG Fluke

Attach CALT5 Printout Here

$$Lr = \frac{3.84\ cm3 * 4.96667}{9\ \text{min}} \left(\frac{\frac{1969.06\ mBar}{1013.25\ mBar/atm}}{(21\ °C + 273)°K} - \frac{\frac{1964.89\ mBar}{1013.25\ mBar/atm}}{(21\ °C + 273)°K} \right) ref - cc/\text{sec}$$

$$Lr = \frac{3.84\ cm3 * 4.96667}{9\ \text{min}} \left(\frac{\_\_\_\ atm}{294\ °K} - \frac{\_\_\_\ atm}{294\ °K} \right) ref - cc/\text{sec}$$

$$Lr = 2.1191 * 1.39982 \times 10^{-5} = 2.96638 \times 10^{-5}\ ref - cc/\text{sec}$$

Comments:

I certify that the above tasks have been performed and that the observations and comments are correct.

Testing Technician

Date 5/19/04

Checked by

Date 5-19-04

```
System Date WED 19 MAY 2004 00:51:29
CALT No: 0052 Transducer No: 835279
Days since last calibration: 8
_____________________________________
                ORNL
         CALT5 - Version U1.43

  ****MEASURE  VOLUME****
_____________________________________

   Reference Volume: 2 cc
Reference Volume No: ISN026
  Test Reference No: TTGPRF01
  Design/Serial Nos: ES-3100/TU-4
 Number of Readings: 2
            Comment: cv lid
_____________________________________
        Pressure mbar         Volume
Atmos    Start    Final        (cc)
_____________________________________
977.74   1915.88  1588.91     3.84
977.96   1981.90  1632.77     3.84

     Average Volume: 3.84 cc


Sig:________________ Date: 5/19/04
(Tested by)


Sig:________________ Date: 5-19-04
(Supervisor)
=====================================
```

```
System Date WED 19 MAY 2004 00:56:18
CALT No: 0052 Transducer No: 835279
Days since last calibration: 8
_____________________________________
                ORNL
         CALT5 - Version U1.43

          Pressure  Drop
   **  LEAKAGE  TEST  **
_____________________________________

Test Reference No: TTGPRF01
Design/Serial Nos: ES-3100/TU-4
          Comment: cv lid
Interspace Volume: 3.84 cc
    Settling Time: 3 mins
    Test Duration: 9 mins
      Temperature: 21°C
Temperature ratio: 1.014
```

```
Sig: ____
(Tested by)


Sig: ____________ Date: 5-19-04
(Supervisor)
==========================================


System Date WED 19 MAY 2004 00:56:18
CALT No: 0052 Transducer No: 835279
Days since last calibration: 8
-----------------------------------------
                ORNL
         CALT5 - Version U1.43

            Pressure Drop
     ** LEAKAGE TEST **
-----------------------------------------

Test Reference No: TTGPRF01
Design/Serial Nos: ES-3100/TU-4
          Comment: cv lid
Interspace Volume: 3.84 cc
    Settling Time: 3 mins
    Test Duration: 9 mins
      Temperature: 21°C
Temperature ratio: 1.014
          μ ratio: 0.991
  Pass Rate (SLR): 1.0E-04 bar cc/sec
    Allowable δP : -40 mbar
-----------------------------------------
  **** RESULTS ****
       Pressure mbar     Date/Time
-----------------------------------------
Atmos: 977.85
Start: 1969.06 19 MAY 2004 01:01:46
Final: 1964.89 19 MAY 2004 01:10:45
-----------------------------------------
Leakage Rate: 1.0E-05 bar cc/sec

PASS

Standard conditions:
             Temperature: 25°C
      Up stream pressure: 1013 mbar
    Down stream pressure: 0 mbar


Sig: ____________ Date: 5/19/04
(Tested by)


Sig: ____________ Date: 5-19-04
```

[redacted] [redacted] [redacted]

5. Procedure Checklist

Test Plan: ES-3100

Test Unit: 4

VERIFIED **TASK**

✓ Water Spray apparatus has been assembled (§4.2).

✓ Photographer's clapboard with package name and test unit number recorded (§4.2).

✓ Test Unit placed properly in the water spray zone and spray function verified (§4.3).

✓ Photograph of the test arrangement taken, documenting test unit identification (§4.3).

✓ Place the rain gauge upright on the ground adjacent to the test specimen (§4.4).

✓ Water spray has been started is spraying on the top and 4 sides, with a minimum rate of 2 in/hr (5 cm/hr) (§4.5). 9:10 a.m. → 1 p.m.

✓ Water spray has been stopped after 1 hour, ✓ rain gauge reading has been recorded ✓ and any damage noted (§4.5).

✓ Photographs of the resulting damage (if any) were taken (§4.5).

Comments. rain gage used to measure flowrate; four readings of 10 to 15 min duration were taken from different sides to give an average 15 in/h (nominally 0.16 in/min)

I certify that the above tasks have been performed and that the observations and comments are correct.

Leonard Dickerson — Testing Technician — 5-20-04 Date

Checked by — 5-20-04 Date

6. Data Sheet

Test Plan: ES-3100

Test Unit: 4

VERIFIED	TASK	
✓	Start Date and Time of Water Spray Test: 5-20-04 9:10 a.m.	(§4.5)
✓	End Date and Time of Water Spray Test: 5-20-04 13:00	(§4.6)
✓	Rain Gauge Reading: 15 in/h	(§4.6)
✓	Ambient temperature: °C (64 °F) Measuring device: Fluke 52 K/J Thermometer	

Testing Damage Observations:

Comments: after test, unit was lowered to its side and inverted by crane to drain water

I certify that the above tasks have been performed and that the observations and comments are correct.

Leonard Dickerson
Testing Technician

5-20-04
Date

Checked by

5-20-04
Date

5. Procedure Checklist

Test Plan: ES-3100

Test Unit: 4

VERIFIED	TASK
✓	Water Spray Test (TTG-PRF-05) has been completed within 2 hours before Drop Test. (§4.3)
✓	Have a photographer's clapboard with package name and test unit number. (§4.4)
✓	Attitude of the rigged and raised test unit is set. (§4.5)
✓	Photograph of the rigging arrangements has been taken. (§4.5)
✓	Photograph of the measured drop angle has been taken. (§4.5)
✓	The test unit has been raised designated drop height. (§4.6)
✓	Photograph of the height measurement has been taken. (§4.6)
✓	Video camera(s) are setup and running to take video of the drop. (§4.7)
✓	The release mechanism has been plugged into power outlet. (§4.7)
✓	Countdown, Release the test unit, unplug release mechanism. (§4.7)
✓	Videos camera stopped. (§4.8)
✓	Photographs of the resulting damage were taken. (§4.9)
✓	Ambient temperature recorded. (§4.10)
✓	Date and time of test recorded. (§4.10)

Comments:

I certify that the above tasks have been performed and that the observations and comments are correct.

Testing Technician

5-20-04
Date

Leonard Dickerson
Checked by

5-20-04
Date

ORNL TRANSPORTATION TECHNOLOGIES GROUP OAK RIDGE NATIONAL LABORATORY OAK RIDGE, TENNESSEE 37831	Operating Procedures for NCT Drop Test - Testing of Radioactive Material Packages	Test Instruction: TTG-PRF-08	
		Page 6 / 6	Rev. 0
		Issue Date: 1-30-04	Review Date: 1-30-05

6. Data Sheet

Test Plan: ES-3100

Test Unit: 4

VERIFIED **TASK**

✓ Water Spray Test (TTG-PRF-05) Time completed: 13:00 (§4.3)

✓ Intended attitude and angle of the test unit 0. Tolerance ± 2. (§4.2)

✓ Attitude Description: Head down (§4.2)

✓ Measured attitude and angle of the test unit 0.1 degrees. (§4.2)

✓ Level number 311-024-501 Calibration Exp. Date 6-04 (§4.2)

✓ Height above the drop pad 4 ft Measuring device TTG Rod (§4.6)

✓ Date and Time of Drop Test: 14:10 (§4.10)

✓ Ambient temperature: 22.4°C (72.4°F) Measuring device Fluke 52 (§4.10)

Testing Damage Observations: ______

Comments: ______

I certify that the above tasks have been performed and that the observations and comments are correct

	5-20-04	Leonard Dickerson	5-20-04
Testing Technician	Date	Checked by	Date

TEST FORM 1 – **Post 1.2m (4 ft) FREE FALL DROP TEST** Test Plan - ES-3100

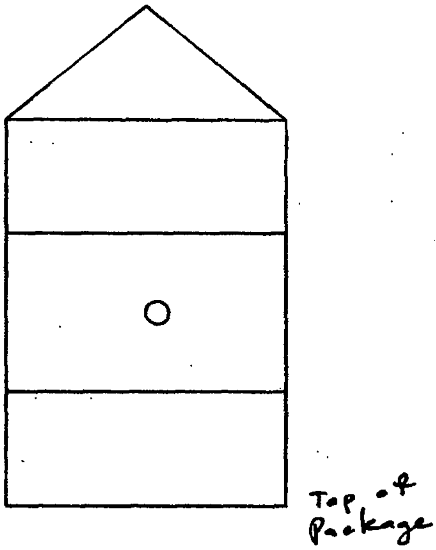
DAMAGE MEASUREMENTS

Test Unit TU 4

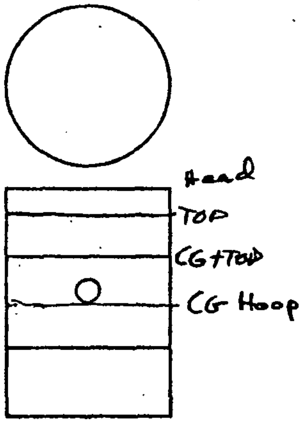
Height	0	90	180	270
Pre	43 1/2	43 1/2	43 4/8	43 4/8
Post	43 1/2	43 1/2	43 1/2	43 1/2

DIAMETER	0 to 180		90 to 270	
	Pre	Post	Pre	Post
Top Chime	19 1/4	19 1/4	19 3/8	19 3/8
Top Hoop	19 1/4	19 1/4	19 1/4	19 1/4
CG Hoop	19 1/8	19 1/8	19 1/4	19 1/4
Bottom Hoop	19 1/8	19 1/8	19 1/4	19 1/4
Bottom Chime	19 3/8	19 3/8	19 1/4	19 1/4
CG+Top Hoop	19 1/4	19 1/4	19 1/4	19 1/4

Sketch Drop Setup Here



Sketch Package Damage Here



Comments:

I certify that the above tasks have been performed and that the observations and comments are correct.

	5-20-04	Leonard Dickerson	5-20-04
Testing Technician	Date	Verified By	Date

ORNL TRANSPORTATION TECHNOLOGIES GROUP OAK RIDGE NATIONAL LABORATORY OAK RIDGE, TENNESSEE 37831	Operating Procedures for NCT Penetration Test - Testing of Radioactive Material Packages	Test Instruction: TTG-PRF-09	
		Page 4 / 5	Rev. 0
		Issue Date: 1-30-04	Review Date: 1-30-05

5. Procedure Checklist

Test Plan: ES-3100

Test Unit: 4

VERIFIED	TASK
✓	Water Spray Test (TIN-03) has been completed within 2 hours before Drop Test. (§4.2)
✓	Have a photographer's clapboard with package name and test unit number. (§4.3)
✓	Penetration Bar Serial Number: NTRC - 001
✓	The package has been placed on the drop pad and blocked to keep from moving during test. (§4.4)
✓	The penetration bar has been suspended above and aligned to the target point on the package. (§4.5)
✓	Photograph of the target alignment has been taken. (§4.5)
✓	The penetration bar has been raised to the specified drop height above the target point. (§4.5)
✓	Photograph of the height measurement has been taken. (§4.5)
✓	Video camera(s) are setup and running to take video of the drop. (§4.6)
✓	The release mechanism has been plugged into power outlet. (§4.6)
✓	Countdown; release the test unit; unplug release mechanism. (§4.6)
✓	The penetration bar has impacted the package at the target point. (§4.6)
✓	Videos camera stopped. (§4.7)
✓	Date and Time of test recorded. (§4.8)
✓	Ambient temperature recorded. (§4.9)
✓	Photographs of the resulting damage were taken. (§4.10)

Comments:

I certify that the above tasks have been performed and that the observations and comments are correct.

	5-20-04	Leonard Dickerson	5-20-04
Testing Technician	Date	Checked by	Date

ORNL TRANSPORTATION TECHNOLOGIES GROUP OAK RIDGE NATIONAL LABORATORY OAK RIDGE, TENNESSEE 37831	Operating Procedures for NCT Penetration Test - Testing of Radioactive Material Packages	Test Instruction: TTG-PRF-09	
		Page 5 / 5	Rev. 0
		Issue Date: 1-30-04	Review Date: 1-30-05

6. Data Sheet

Test Plan: ES-3100

Test Unit: 4

VERIFIED **TASK**

✓ Water Spray Test (TTG-PRF-05) Time completed: 13:00 (§4.2)

✓ Description of the target point: 7½ from top on 0° line (§4.5)

✓ Height above the package: 1 m Measuring device: 1 m Stick (§4.5)

✓ Date and Time of Penetration Test: 14:30 (§4.8)

✓ Ambient temperature: 21.6 °C (____ °F) Measuring device TTG Fluke (§4.9)

Testing Damage Observations: ____________________

Comments: ____________________

I certify that the above tasks have been performed and that the observations and comments are correct.

Testing Technician: ____________ Date: 5-20-04

Checked by: Leonard Dickerson Date: 5-20-04

5. Procedure Checklist

Test Plan: ES-3100

Test Unit: 4

VERIFIED	TASK
✓	Determine load to be applied. (§4)
✓	Water Spray Test (TTG-PRF-05) completed within 2 hours prior to Compression Test. (§4.3)
✓	Excess water from the Water Spray Test permitted to drain from test specimen. (§4.3)
✓	Photographer's clapboard with package name and test unit number prepared. (§4.4)
✓	Package placed in the center of the compression tester base and upper platen lowered onto package top. Alternatively, package placed on sturdy horizontal surface for stacking test, and initial dead weight placed on top. (§4.5)
✓	Photograph of the test specimen test setup taken. (§4.6)
✓	Record height measurement of the package prior to loading. (§4.6)
✓	Photograph of the height measurement taken. (§4.6)
	Program the compression tester to apply the required force and duration per Procedure TTG-PRF-17 and start the test. Alternatively, stack the remaining required dead weight onto the package top, completing the stack. (§4.7)
✓	Compression tester has successfully completed per program. Alternatively, carefully remove the dead weight from the test specimen. (§4.8)
✓	Record final height measurement of the test specimen (post-test). (§4.8)
✓	Photograph of the post test height measurement taken. (§4.8)
✓	Photographs of any other resulting damage taken. (§4.9)

Comments:

I certify that the above tasks have been performed and that the observations and comments are correct.

Testing Technician

5-21-04
Date

5/21/04
Date

6. Data Sheet

Test Plan: ES-3100

Test Unit: 4

VERIFIED **TASK**

✓ Calculate and record the greater of 5 times the weight of the package OR 1.9 psi times the projected vertical area of the package. (§4)

5 × 450 = 2,250 lbs => 2,300 lbs applied

1.9 psi × projected vertical area N/A = ______ lbs.

✓ Load to be applied to package 2,300 lbs. (§4)

✓ Water Spray Test (TIN-03) Time completed: 1 P.M. (§4.3)

✓ Height Measurements: 0°: 43.5 in; 90°: 43.5 in; 270°: 43 5/8; 43 5/8 (§4.6)

✓ Start Date and Time: May 20, 2004 ; 2:55 p.m. (§4.7)

✓ Finish Date and Time: 5-21-04,18:00 (§4.8)

Height Measurements: 0° → 43.5, 90° → 43.5, ~~280°~~ 180° → 43 5/8, 270° 43 5/8 (§4.8)

✓ Ambient temperature: 21.4 °C (706 °F) Measuring device: Fluke 52 (§4.9)

Testing Damage Observations: No observable damage

Comments:

I certify that the above tasks have been performed and that the observations and comments are correct.

Testing Technician   Date 5-21-04   Checked by   Date 5/21/04

ORNL TRANSPORTATION TECHNOLOGIES GROUP OAK RIDGE NATIONAL LABORATORY OAK RIDGE, TENNESSEE 37831	Operating Procedures for NCT Vibration Test - Testing of Radioactive Material Packages	Test Instruction: TTG-PRF-06	
		Page 3 / 4	Rev. 0
		Issue Date: 1-30-04	Review Date: 1-30-05

Procedure Checklist

Test Plan: ES-3100

Test Unit: 4

VERIFIED	TASK
✓	Prepare photographer's clapboard with package name and test unit number (§4.2).
✓	Package has been placed in the center of the vibration table (§4.3).
✓	Package has been secured to the vibration table, if required (§4.3).
✓	Photograph of the package in place has been taken (§4.4).
✓	Vibration table controller has been programmed for applied vibration and duration per Procedure TTG-PRF-16, using specifications outlined in the Test Plan (§4.5).
✓	Vibration test initiated per program (§4.6).
✓	Record vibration test information on Data Sheet (§4.7).
✓	Vibration test successfully completed per program, results printed (§4.8).
✓	Test specimen removed from vibration table and examined for damage (§4.9).
✓	Photographs of any observed damage completed, and recorded on Data Sheet (§4.9).

Comments: No observable damage externally. Not disassembled

I certify that the above tasks have been performed and that the observations and comments are correct.

	5-28-04	Leonard Dickerson	6-2-04
Testing Technician	Date	Checked by	Date

ORNL TRANSPORTATION TECHNOLOGIES GROUP OAK RIDGE NATIONAL LABORATORY OAK RIDGE, TENNESSEE 37831	Operating Procedures for NCT Vibration Test - Testing of Radioactive Material Packages	Test Instruction: TTG-PRF-06	
		Page 4 / 4	Rev. 0
		Issue Date: 1-30-04	Review Date: 1-30-05

Data Sheet

Test Plan: ES-3100

Test Unit: TU-4

VERIFIED	TASK
✓	Ambient temperature: 20.6°C (___°F) (§4.6)
✓	Start Date and Time: 5-22-04 08:15 (§4.6)
N/A	The DOT Bounce test has been performed for one hour. (§4.8)
OR	
✓	The random vibration test has been performed for 4 hour(s). (§4.8) The PSD for this test was as follows:
✓	End Date and Time: 5-22-04 | 12:20 (§4.8)
	Vibration controller test printout attached: Y/N (§4.8)

Testing Damage Observations: None Not disassembled

Comments:

I certify that the above tasks have been performed and that the observations and comments are correct.

	5-28-04	Leonard Dickason	6-2-04
Testing Technician	Date	Checked by	Date

5. Procedure Checklist

Test Plan: ORNL-NTRL-011

Test Unit: 4

VERIFIED	TASK
✓	Have a photographer's clapboard with package name and test unit number. (§4.3)
✓	The ambient temperature has been recorded. (§4.4)
✓	Attitude of the rigged test unit is set. (§4.5)
✓	Photograph of the rigging arrangements has been taken. (§4.5)
✓	Photograph of the measured drop angle has been taken. (§4.5)
✓	The test unit has been raised to the designated drop height. (§4.7)
✓	Photograph of the height measurement has been taken. (§4.7)
✓	Video camera(s) are setup and running to take video of the drop. (§4.8)
✓	The release mechanism has been plugged into power outlet. (§4.8)
✓	Countdown, Release the test unit, unplug release mechanism. (§4.8)
✓	Videos camera stopped. (§4.9)
✓	Date and time of test were recorded. (§4.10)
✓	Photographs of the resulting damage were taken. (§4.11)
✓	Remove plumbob from Test piece
✓	Hold release mechanism in hand and ensure it is in hand until after drop is completed.

wlf
5/25/04

Comments:

I certify that the above tasks have been performed and that the observations and comments are correct.

Testing Technician

5-25-04
Date

Leonard Dickerson
Checked by

5-25-04
Date

ORNL TRANSPORTATION TECHNOLOGIES GROUP OAK RIDGE NATIONAL LABORATORY OAK RIDGE, TENNESSEE 37831	Operating Procedures for HAC Drop Test - Testing of Radioactive Material Packages	Test Instruction: TTG-PRF-10	
		Page 5 / 5	Rev. 0
		Issue Date: 1-30-04	Review Date: 1-30-05

6. Data Sheet

Test Plan: ORNL/NTRC-011

Test Unit: 4

VERIFIED	TASK
✓	Intended attitude of the test unit 0°. Tolerance ± 2 (§4.2)
✓	Measured attitude of the test unit 0.2° degrees. (§4.5)
✓	Level number 311-006-501 Calibration Exp. Date 6/04 (§4.5)
✓	Height above the drop pad 9 m Measuring device TTG string (§4.7)
✓	Date and Time of Drop Test: 5/25/04 11:54 (§4.10)
✓	Ambient temperature: 27.3 °C (____ °F) Measuring device TTG Fluke (§4.4)

Testing Damage Observations: ______________________

Comments. ______________________

I certify that the above tasks have been performed and that the observations and comments are correct.

	5-25-04	Leonard Dickerson	5-25-04
Testing Technician	Date	Checked by	Date

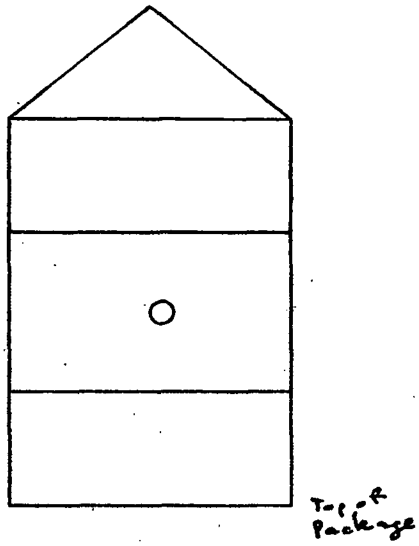
TEST FORM 2 – **Post 9m (30 ft) FREE FALL DROP TEST** Test Plan - ES-3100

DAMAGE MEASUREMENTS ES 3100 Test Unit 4

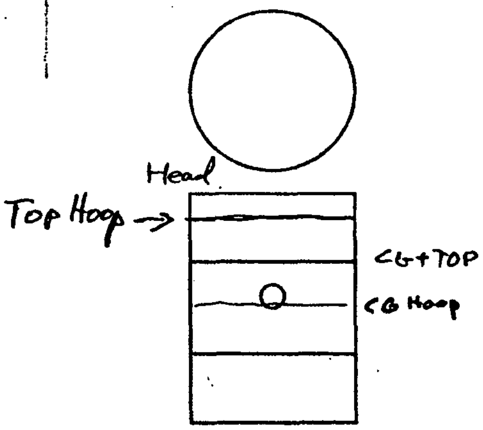
Height	0	90	180	270
Pre	43 ½	43 ½	43 ½	43 ½
Post	43	43 1/8	42 7/8	42 5/8

DIAMETER	0 to 180		90 to 270	
	Pre	Post	Pre	Post
Top Chime	19 1/4	19 1/4	19 1/8	19 3/8
Top Hoop	19 1/4	19 1/8	19 1/4	19 7/8
CG Hoop	19 1/8	19 1/8	19 1/4	19 1/4
Bottom Hoop	19 1/8	19 1/4	19 1/4	19 1/4
Bottom Chime	19 3/8	19 1/4	19 1/4	19 1/4
CG+Top Hoop	19 1/4	19 13/16	19 1/4	19 3/8

Sketch Drop Setup Here



Sketch Package Damage Here



Comments: No Flats noted.

Concavity on bottom evenly distributed from edge. maximum depth is 3/8 inch.

Top Hoop narrowed – no value recorded.

I certify that the above tasks have been performed and that the observations and comments are correct.

Leonard Dickerson 5-25-04 5-25-04

Testing Technician Date Verified By Date

5. Procedure Checklist

Test Plan: ES-3100

Test Unit: 4

VERIFIED	TASK
✓	Have a photographer's clapboard with package name and test unit number. (§4.3)
✓	The ambient temperature has been recorded. (§4.4)
✓	Attitude of the test unit is set. (§4.5)
✓	Photograph of the attitude has been taken. (§4.5)
N/A	Photograph of the measured angle has been taken. (§4.5)
✓	The crush plate has been raised to the designated drop height and located over the target point. (§4.7)
✓	Photograph of the set position has been taken. (§4.7)
✓	Video camera(s) are setup and running to take video of the drop. (§4.8)
✓	The release mechanism has been plugged into power outlet. (§4.8)
✓	Countdown, Release the crush plate, unplug release mechanism. (§4.8)
✓	Videos camera stopped. (§4.9)
✓	Date and time of test recorded. (§4.10)
✓	Photographs of the resulting damage were taken. (§4.11)
✓	Remove plumbob from crush ~~Task~~ ~~piece~~ plate.
✓	Hold release mechanism in hand and ensure it is in hand until after drop is completed

mff 5/25/04

Comments:

I certify that the above tasks have been performed and that the observations and comments are correct.

	5-25-04	Leonard Dickerson	5-25-04
Testing Technician	Date	Checked by	Date

6. Data Sheet

Test Plan: ES-3100

Test Unit: 4

VERIFIED — TASK

✓ Intended attitude of the test unit ~~[illegible]~~ Vert. Tolerance ±_____ (§4.5)

N/A Measured attitude of the test unit _____ degrees. (§4.5)

N/A Level number __________ Calibration Exp. Date ________ (§4.5)

✓ Height above the target: 30 feet Measuring device TTG String (§4.7)

✓ Date and Time of Crush Test: 5/25/04 2:18p (§4.10)

✓ Ambient temperature: 29.8 °C (___°F) Measuring device TTG Fluke (§4.11)

Testing Damage Observations: ____________________

Comments: ____________________

I certify that the above tasks have been performed and that the observations and comments are correct.

____________ 5-25-04 Leonard Dickerson 5-25-04

Testing Technician — Date — Checked by — Date

TEST FORM 3 – Post 9m (30 ft) DYNAMIC CRUSH TEST

Test Plan - ES-3100

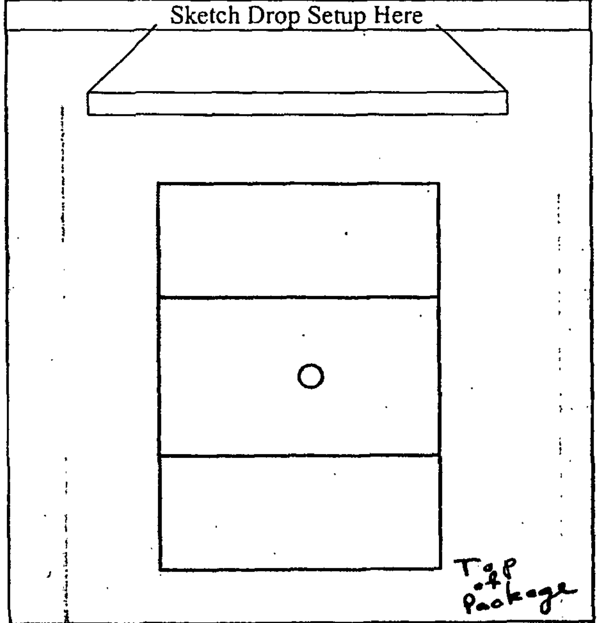
DAMAGE MEASUREMENTS

Test Unit 4

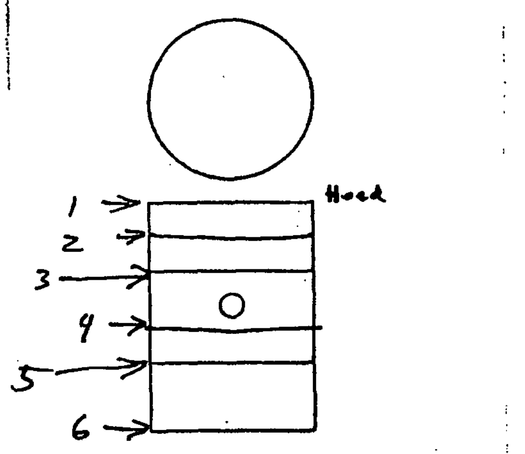
Height	0	90	180	270
Pre	43	43 1/8	42 7/8	42 5/8
Post	39 3/8	40 7/8	40 5/8	39 3/4

	DIAMETER	0 to 180		90 to 270	
		Pre	Post	Pre	Post
1	~~Top Chime~~	19 1/4	19 1/4	19 3/8	19 3/8
2	~~Top Hoop~~	19 1/8	20	19 3/8	20 1/8
3	~~CG~~	19 1/16	20	19 3/8	20 1/16
4	~~Bottom~~ Hoop	19 1/8	19 7/16	19 1/4	19 1/2
5	Bottom ~~Chime~~	19 1/4	19 15/16	19 1/4	20
6		19 1/4	19 1/4	19 1/4	19 1/4

Sketch Drop Setup Here



Sketch Package Damage Here



Comments:

I certify that the above tasks have been performed and that the observations and comments are correct.

Testing Technician
Date 5-26-04

Leonard Dickerson
Verified By
Date 5-26-04

5. Procedure Checklist

Test Plan: ES-3100

Test Unit: 4

VERIFIED	TASK
✓	Have a photographer's clapboard with package name and test unit number. (§4.3)
✓	Attitude of the rigged test unit is set. (§4.4)
✓	Photograph of the rigging arrangements has been taken. (§4.4)
✓	Photograph of the measured drop angle has been taken. (§4.4)
✓	The test unit has been raised to the designated drop height. (§4.5)
✓	Photograph of the height measurement has been taken. (§4.5)
✓	Video camera(s) are setup and running to take video of the drop. (§4.6)
✓	The release mechanism has been plugged into power outlet. (§4.6)
✓	Countdown, Release the test unit, unplug release mechanism. (§4.6)
✓	Videos camera stopped. (§4.7)
✓	The ambient temperature has been recorded. (§4.8)
✓	Date and time of test recorded. (§4.9)
✓	Photographs of the resulting damage were taken. (§4.10)

Comments:

I certify that the above tasks have been performed and that the observations and comments are correct.

Testing Technician

5-27-04
Date

Leonard Dickerson
Checked by

5-27-04
Date

6. Data Sheet

Test Plan: ES-3100

Test Unit: 4

VERIFIED	TASK
✓	Intended attitude of the test unit 90° Vertical head down. Tolerance ± 2 (§4.4)
✓	Measured attitude of the test unit 89.7 degrees. (§4.4)
✓	Level number 381-006-501 Calibration Exp. Date 6-04 (§4.4)
✓	Height above the punch 1m Measuring device TTG 1m Rod (§4.5)
✓	Date and Time of Drop Test: 5-27-04 1315 (§4.8)
✓	Ambient temperature: 22 °C (71.4°F) Measuring device TTG Fluke (§4.9)

Testing Damage Observations:

Comments: Package stood on punch after impact.

I certify that the above tasks have been performed and that the observations and comments are correct.

Technician

5-27-04
Date

Leonard Dickerson
Checked by

5-27-04
Date

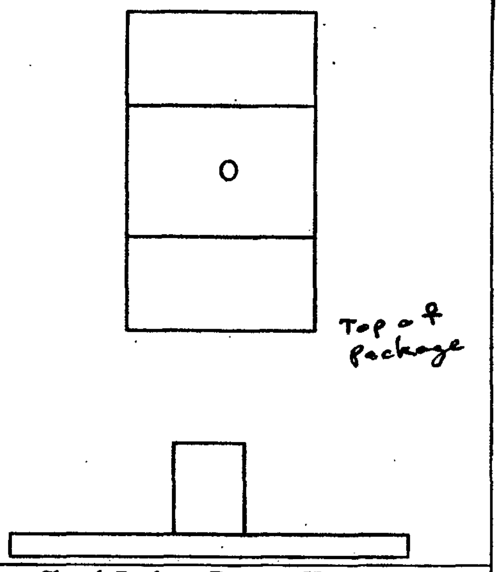
TEST FORM 4 – Post 1 m (40 in) PUNCTURE DROP TEST

Test Plan - ES-3100

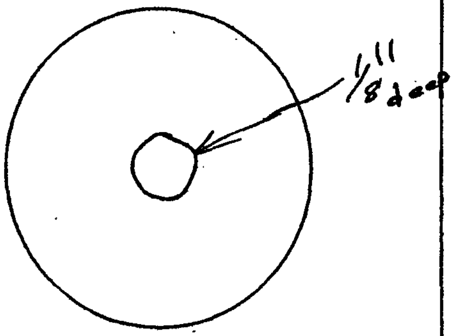
DAMAGE MEASUREMENTS

Test Unit 4

Sketch Drop Setup Here



Sketch Package Damage Here



Comments: Slight indent ≈ 1/8" deep

I certify that the above tasks have been performed and that the observations and comments are correct.

Testing Technician

6-2-04
Date

Verified By

6/2/04
Date

5. Procedure Checklist

Test Plan: ES-3100 ORNL/NTRC-011

Test Unit: TU-4

VERIFIED	TASK
✓	All thermocouples channels on the data acquisition system have been tested. (§4.2a)
✓	All thermocouples have been installed in the furnace, connected to Data Acquisition System (DAS), labeled and tested. (§4.3c)
✓	The test unit has been preheated to over 38 °C (100 °F). (§4.2b)
✓	Furnace has reached the minimum soak point temperature of 800 °C (1475 °F), and has soaked at this temperature for a minimum of 24 hours. (§4.3c)
✓	The thermal data acquisition system is set to read every 30 seconds or less. (§4.3c) 15 s
✓	All thermocouples have been installed on the exterior of drum, in accordance with the Test Plan, attached to DAS , labeled and tested. (§4.2c)
✓	Photographs and/or video of the test setup have been taken. (§4.3c)
✓	The unit has been placed in the furnace, on the support stand, with the 0° point down or as specified in the test plan. (§4.4c)
✓	The 30 minute timed test begins when 5 out of 6 test unit thermocouples and 15 of 18 furnace thermocouples reached the test temperature of 800 °C (1475 °F), as specified in this procedure. (§4.4d)
✓	Immediately following the timed test (minimum of 30 minutes at 800 °C) the test unit was taken out of the furnace and allowed to cool naturally. (§4.4e)
✓	Notes regarding smoke and/or flames emanating from the test specimen are recorded. (§4.4e)

Comments:

I certify that the above tasks have been performed and that the observations and comments are correct.

	6/16/04	Leonard Dickerson	6-16-04
Testing Technician	Date	Checked by	Date

6. Data Sheet

Test Plan: ES-3100 ORNL/NTRC-011

Test Unit: TU-4

VERIFIED	TASK
✓	The test unit has been preheated to over 38 °C (100 °F). Measuring device: TTG DATA Acq. Calibration expiration date: N/A (§4.2b)
✓	The furnace has reached the minimum soak point temperature of 800 °C (1475 °F), and has soaked at this temperature for a minimum of 8 hours. The furnace set point temperature has been adjusted to ______ °C (1600 °F) at least ~~one hour~~ 45 min prior to each test. (§4.3c) MRF CAB Date: 6/16 Time: 8:55 [✓ am]/pm
✓	The test unit has been placed in the furnace, on the support stand, at: (§4.4c) Time: 9:53 [✓ am]/pm Open furnace door time: 50 seconds
✓	The 30 minute timed test began when 5 out of 6 test unit thermocouples and 15 of 18 furnace thermocouples reached the test temperature of 800 °C (1475 °F): (§4.4d) Time: 10:02 [✓ am]/pm
✓	The test unit was removed from the furnace and allowed to cool naturally. (§4.4e) Time: 10:32 [✓ am]/pm Ambient Temperature ______ °C (95 °F)
✓	The unit stopped outgassing (flames) at ______; outgassing/burnout elapsed time was ______ minutes. (§4.4e)

Testing Damage Observations: Flaming from TID when removed Flaming ceased in less than 1 minute. Smoking continued. Outgassing (smoking) stopped at 10:44 (42 min ~~into~~ after run).

Comments:

I certify that the above ormed and that the observations and comments are correct.

Testing Technician

6/16/04
Date

Leonard Dickerson
Checked by

6/16/04
Date

ORNL TRANSPORTATION TECHNOLOGY GROUP OAK RIDGE NATIONAL LABORATORY OAK RIDGE, TENNESSEE 37831	Operating Procedure for Operational Leak Test - Testing of Radioactive Material Packages.	Test Procedure: TTG-PRF- 01	
		Page 3 / 3	Rev. 0
		Issue Date: 1-30-04	Review Date: 1-30-05

Procedure Checklist

Test Plan: ES-3100

Test Unit: 4

VERIFIED	TASK
✓	Have a photographer's clapboard with package name and test unit number.
✓	A photograph of the leak tester connections has been taken.
✓	Both CALT5 Leak Tester and CVs have been in the same ambient conditions for 24 hours.
✓	Determine the interstitial volume of the test unit. Print out results.
✓	Determine the length of test from CALT5 Instruction Manual Table according to volume and accuracy needed.
✓	Program the info into the CALT5 tester.
✓	Run the CALT5 leak test. Print out results.
✓	Enter the data from CALT5 printout onto Data Sheet.
✓	Calculate the leak rate and enter on Data Sheet.

Comments:

I certify that the above tasks have been performed and that the observations and comments are correct.

Testing Technician

6-30-04
Date

Leonard Dickerson
Checked by

6-30-04
Date

ORNL TRANSPORTATION TECHNOLOGY GROUP OAK RIDGE NATIONAL LABORATORY OAK RIDGE, TENNESSEE 37831	Operating Procedure for Operational Leak Test - Testing of Radioactive Material Packages.	Test Procedure: TTG-PRF- 01	
		Page 4 / 4	Rev. 0
		Issue Date: 1-30-04	Review Date: 1-30-05

5. Data Sheet

Test Plan: ES-3100

Test Unit: 4

VERIFIED TASK

✓ Assembly Leak Test Post Testing Leak Test X

✓ Length of test from CALT5 Instruction Manual Table according to volume and accuracy needed. Test Time: 9 min.

✓ A leak test in accordance with the CALT5 Manufacturer's Instructions Manual was performed on the CV assembly. Both CALT5 Leak Tester and CVs have been in the same ambient conditions for 24 hours.

Leak Tester Cert. # M287139 Expiration Date: 3/3/05

✓ Ambient temperature: 21.1 °C (°F)

Measuring device TTG Fluke

Attach CALT5 Printout Here

$$Lr = \frac{3.772\ cm3 * 4.96667}{9\ min}\left(\frac{\frac{2131.16\ mBar}{1013.25\ mBar/atm}}{(21.1\ °C + 273)°K} - \frac{\frac{2127.63\ mBar}{1013.25\ mBar/atm}}{(21.1\ °C + 273)°K}\right) ref - cc/sec$$

$$Lr = \frac{3.772\ cm3 * 4.96667}{9\ min}\left(\frac{2.1033\ atm}{294.1\ °K} - \frac{2.0998\ atm}{294.1\ °K}\right) ref - cc/sec$$

$$Lr = 2.0816 * .00001190 = 2.4773 \times 10^{-5}\ ref - cc/sec$$

Comments:

I certify that the above tasks have been performed and that the observations and comments are correct.

Testing Technician Date 6-30-04

Leonard Dickerson 6-30-04

Checked by Date

```
System Date WED 30 JUN 2004 04:29:44
CALT No: 0052 Transducer No: 835279
Days since last calibration: 50
------------------------------------------
                 ORNL
         CALT5 - Version U1.43

***MEASURE  VOLUME***
------------------------------------------

   Reference Volume: 2 cc
Reference Volume No: ISN026
  Test Reference No: TTGPRF01
  Design/Serial Nos: ES-3100/TU-4
 Number of Readings: 2
            Comment: cv lid
------------------------------------------
         Pressure mbar           Volume
Atmos      Start     Final        (cc)
------------------------------------------
977.00   2107.94   1709.49      3.76
976.57   2121.53   1719.55      3.78

     Average Volume: 3.772 cc


Sig: ______________ Date: 6-30-04
(Tested by)


Sig: Leonard Dickerson Date: 6-30-04
(Supervisor)
==========================================
```

```
System Date WED 30 JUN 2004 04:34:23
CALT No: 0052 Transducer No: 835279
Days since last calibration: 50
------------------------------------------
                 ORNL
         CALT5 - Version U1.43

           Pressure  Drop
    **  LEAKAGE  TEST  **
------------------------------------------

   Test Reference No: TTGPRF01
   Design/Serial Nos: ES-3100/TU-4
             Comment: cv lid
  Interspace Volume: 3.772 cc
       Settling Time: 3 mins
       Test Duration: 9 mins
         Temperature: 21.1°C
   Temperature ratio: 1.013
             μ ratio: 0.992
    Pass Rate (SLR): 1.0E-04 bar cc/sec
      Allowable δP : -50 mbar
------------------------------------------
  ***  RESULTS  ***
       Pressure mbar      Date/Time
------------------------------------------
Atmos: 976.46
Start: 2131.16 30 JUN 2004 04:38:38
Final: 2127.63 30 JUN 2004 04:47:38
------------------------------------------
Leakage Rate: 7.1E-06 bar cc/sec

PASS

Standard conditions:
             Temperature: 25°C
     Up stream pressure: 1013 mbar
   Down stream pressure: 0 mbar


Sig: ______________ Date: 6-30-04
(Tested by)


Sig: Leonard Dickerson Date: 6-30-04
(Supervisor)
==========================================
```

5. Procedure Checklist

a. Prepare Test Unit

Test Plan: ES-3100

Test Unit: 4

VERIFIED	TASK
✓	Area around where the package will be penetrated cleared of any tape, paint, loose labels, etc. (§4a.1)
✓	¼ in NPT threaded hole drilled and tapped. (§4a.2)
✓	Test weight bag penetrated (if necessary). (§4a.3)
✓	Threaded hole and surrounding surface cleaned with a wiping cloth or tissue soaked in isopropyl alcohol or a wet Vacu-Solve swab. (§4a.4)
✓	Solvent has evaporated. (§4a.5)
✓	Epoxy mixed and applied to the thread of a ¼ in NPT to K-Flange adaptor taking care to not obstruct the hole in the adaptor with epoxy. (§4a.6)
✓	Adapter threaded into the ¼ in NPT hole in the package ensuring that there is a continuous filet of epoxy between the adaptor stem and the surface of the Test Unit (if necessary, add epoxy to create a filet). (§4a.7)
✓	Epoxy has hardened at least 4 hours. (§4a.8)
✓	Mixing tools properly disposed of. (§4a.9)

Comments:

I certify that the above tasks have been performed and that the observations and comments are correct.

Testing Technician
7-21-04
Date

Leonard Dickerson
Checked by
7-30-04
Date

b. Check List for Test Unit Pump-out

Test Plan: ES-3100

Test Unit: 4

VERIFIED	TASK
✓	Test unit placed on a plastic bag that is large enough to envelop the test unit. (§4b.1)
✓	Varian 959 Turbo Leak Detector positioned so that it can be attached to the test unit without further movement. (§4b.2)
✓	Varian 959 Turbo Leak Detector started. (CAUTION: Once the leak detector is started DO NOT move the leak detector until it is fully shutdown and the internal turbo-pump has come to a complete stop. Movement of the leak detector with a spinning turbo-pump will damage or destroy the pump.) (§4b.3)
✓	Varian 959 Turbo Leak Detector calibrated and zeroed per the calibration procedure provided in the leak detector manual. (§4b.4)
✓	Calibration leak rate, serial number, and calibration expiration date recorded. (§4b.5)
✓	Leak detector attached to the test unit. (§4b.6)
✓	Test unit pump-out initiated (record date and time). (§4b.7)
N/A	¼ in. flexible plastic tubing used for vent attached hear the bottom of the test unit. (§4b.8)
✓	¼ in. flexible plastic tubing used for He fill attached at the top of the test unit. (§4b.9)
✓	Test unit enveloped in the plastic bag and bag secured with a reasonably tight seal. Note: Do not envelop the K-Flange adaptor or the point where the adaptor enters the test unit. (§4b.10)
✓	Slit for evacuating bag cut into bag. (§4b.11)
✓	He regulator attached to the He cylinder and the ¼ in. plastic tubing that is attached to the top of the test unit. (§4b.12)
✓	Picture taken of test unit connected to leak check system, including photo clapboard. (§4b.13)

Comments.

I certify that the above tasks have been performed and that the observations and comments are correct.

Testing Technician

7-23-04
Date

Leonard L Dickerson
Checked by

7-30-04
Date

ORNL TRANSPORTATION TECHNOLOGIES GROUP OAK RIDGE NATIONAL LABORATORY OAK RIDGE, TENNESSEE 37831	Standard Full Boundary Leak Test Method – Helium Leak Testing	Test Instruction: TTG-PRF-02	
		Page 8 / 10	Rev. 0
		Issue Date: 1-30-04	Review Date: 1-30-05

c. Check List for Leak Check of Test Unit

Test Plan: ES-3100

Test Unit: 4

VERIFIED	TASK
✓	Vacuum in test unit less than 100 milliTorr (preferably less than 50 milliTorr). Record date and time. (§4c.1)
✓	Leak detector range switch set to the 10^{-9} position. (§4c.2)
✓	Plastic bag surrounding test unit evacuated using shop-vac. (§4c.3)
✓	Inflate bag with He. Record the time (hour:minute:second ± 5 sec) and leak rate reading from the leak detector display. (§4c.4)
✓	He leak rate recorded every 2 minutes (±5 sec) and the time that the range switch is changed to the next higher decade (e.g. from 10^{-9} to the 10^{-8} range). (§4c.5)
✓	Final reading taken at 20 minutes (± 5 sec) elapsed time and He supply turned off. (§4c.7)
✓	Leak detector placed in Vent mode. (§4c.8)
✓	Plastic bag and tubes removed from the test unit. (§4c.9)
✓	Leak Detector detached from test unit. (§4c.10)
✓	Close out test unit data sheet with signatures and date. (§4c.11)
NA	IF another test unit is to be leak checked THEN bring the next test unit into position for checking. (CAUTION: Once the leak detector is started DO NOT move the leak detector until it is fully shutdown and the internal turbo-pump has come to a complete stop. Movement of the leak detector with a spinning turbo-pump will damage or destroy the pump.) (§4c.12)
✓	IF this is the last test unit THEN completely shutdown the leak detector. Allow all components to come to a full stop prior to moving the leak detector. (§4c.13)

I certify that the above tasks have been performed and that the observations and comments are correct.

Testing Technician

7-23-04
Date

Leonard Dickerson
Checked by

7-30-04
Date

6. Data Sheet

Test Plan: ES-3100

Test Unit: 4

VERIFIED **TASK**

✓ He calibration leak identification: Leak rate He cc/sec 7.2 *10 - 8 (§4b.5)
Calibration expiration date mm 8 /dd 29 /yyyy 2004

✓ Test unit pump-out started
Date and time mm 7 /dd 21 /yyyy 2004 hh 16 :mm 35 (§4b.7)

✓ Test unit vacuum at or below 100 milliTorr. Pressure in milliTorr 60 (§4c.4)
Date and time mm 7 /dd 23 /yyyy 2004 hh 11 :mm 04

✓ He Leak Rate Table (§4c.4 - 6)

Clock Time hr:min:sec	He Leak Rate
11:04	0 x10⁻⁹
11:06	0 x10⁻⁹
11:08	0 x10⁻⁹
11:10	0 x10⁻⁹
11:12	0 x 10⁻⁹
11:14	0 x 10⁻⁹
11:16	0 x 10⁻⁹
11:18	3.2 x10⁻⁸
11:20	8.4 x10⁻⁸
11:22	1.4 x10⁻⁷
11:24	2.0 x10⁻⁷

✓ Ambient temperature during test: 21.8°C Measuring device TTG Fluke
(§4c.7)

Comments:

I certify that the above tasks have been performed and that the observations and comments are correct.

Testing Technician

7-23-04
Date

Leonard Dickerson
Checked by

7-30-04
Date

TEST FORM 4 - POST-THERMAL TESTING INSPECTION

Test Plan ES-3100

Test Unit 4

VERIFIED	TASK
✓	Following the thermal test and after cooling, the test package was weighed, and the weight recorded on TEST FORM 1 .
✓	The drum, lid, nuts, and studs have been visually examined to determine the extent of the testing damage. Observations:
✓	The camera(s) are set up to take photographs* and/or videotape of the damage due to testing.
✓	The drum lid has been removed and the condition of the exposed parts have been visually examined for damage and the condition has been recorded. Observations:
✓	The Top Plug Assembly has been removed and visually inspected to determine the extent of impact and thermal damage. Record the exposed temperature indicator blackout reading on TEST FORM 5 . Observations:
✓	The CV assembly has been removed and visually examined for damage. Record the exposed temperature indicator blackout readings on TEST FORM 5 . Observations:
✓	The CV assembly has been weighed and the weight recorded on TEST FORM 1
✓	Use TTG-PRF-01 for the CV post-test operational leak check, TTG-PRF-02 for the full containment boundary leak check and TTG-PRF-14 for the 3 ft. immersion test.
✓	Disassemble the CV. Record torque value needed to loosen CV lid. 30 ft-lb.
✓	Read the temperature indicators from the surrogate payload. Record the temperature indicators' blackout readings on TEST FORM 5 .
✓	All loose parts will be placed in separate polyethylene bags, marked with test unit identification, tape closed, and prepared for storage with the test package.
✓	Mark and reassemble the test package to the extent possible for shipment.
✓	*Photographs and/or video of the damage resulting from the testing have been taken.

Comments: Borobond cans intact

I certify that the above tasks have been performed and that the observations and comments are correct.

Testing Technician
7-27-04
Date
Leonard Dickerson
Witness
7-30-04
Date

5. Procedure Checklist

Test Plan: ES-3100

Test Unit: 4

VERIFIED	TASK
✓	Have a photographer's clapboard with package name and test unit number. (§4.2)
✓	The test unit has been lowered to the bottom of the tank in designated orientation. (§4.5)
✓	The depth to the highest point of the test unit has been measured and is at least 0.9m (3 ft.). (§4.5)
✓	Photograph of the depth measurement has been taken. (§4.5)
✓	Start date and time has been noted. (§4.6)
✓	Test time has expired. (§4.7)
✓	Test unit has been removed from the tank. (§4.7)
✓	End date and time has been noted. (§4.7)
✓	Open the test unit and record breaking torque values during removal, if required. (§4.8)
✓	Inspect for water in-leakage or structural damage. (§4.8)
✓	Photographs of any resulting damage or lack thereof were taken. (§4.8)

Comments:

I certify that the above tasks have been performed and that the observations and comments are correct.

	7-26-04	Leonard Dickerson	7-30-04
Testing Technician	Date	Checked by	Date

ORNL TRANSPORTATION TECHNOLOGIES GROUP OAK RIDGE NATIONAL LABORATORY OAK RIDGE, TENNESSEE 37831	Operating Procedures for HAC 0.9 Meter Immersion Test - Testing of Radioactive Material Packages	Test Instruction: TTG-PRF-14	
		Page 4 / 4	Rev. 0
		Issue Date: 1-30-04	Review Date: 1-30-05

6. Data Sheet

Test Plan: ES-3100

Test Unit: 4

VERIFIED	TASK
✓	Intended attitude of the test unit in tank (e.g. on side) on side (§4.3)
✓	Depth of water above the test unit 39" Measuring device Tape Measure (§4.5)
✓	Start Date and Time of Immersion Test: 7-26-04 10:40 (§4.6)
✓	Water temperature: 22.1 °C (°F) Measuring device TTG Fluke (§4.6)
✓	End Date and Time of Immersion Test: 7-27-04 08:30 (§4.7)
✓	Water temperature: 21.1 °C (69.8 °F) Measuring device TTG Fluke (§4.7)
✓	Detected in-leakage of water: (YES/[✓ NO]) (§4.7)
✓	Detected structural damage: (YES/[✓ NO]) (§4.7)

Testing Damage Observations:

Comments:

I certify that the above tasks have been performed and that the observations and comments are correct.

Testing Technician

7-26-04
Date

Leonard Dickerson
Checked by

7-~~26~~30-04
Date

TEST FORM 5 - TEMPERATURE INDICATOR READINGS

Test Plan ES-3100

Test Unit 4

A visual inspection of each temperature indicator on the package consisting of those indicators inside the CV, outside the CV, and on the drum liner will be made. The values of the blackouts that occurred will be recorded below.

RECORD BLACKOUT TEMPERATURES AT THESE LOCATIONS:

TEMPERATURE INDICATOR NUMBER LOCATION CHART				
ON THE SURROGATE PAYLOAD				
Location	**0°**		**180°**	
Side Top	1 B 171 °F		2 B 171 °F	
Side Middle	3 B 171 °F		4 B 171 °F	
Side Bottom	5 B 171 °F		6 B 171 °F	
ON THE CV				
Location	**0°**	**90°**	**180°**	**270°**
CV Lid Top (outside)	7 B 261 °F	8 B 261 °F	9 B 261 °F	10 B 261 °F
CV Lid Bottom (inside)	11 B 230 °F	12 B 230 °F	13 B 230 °F	14 B 230 °F
Flange (outside)	15 B 241 °F	16 B 241 °F	17 B 241 °F	18 B 241 °F
Flange (inside)	19 B 219 °F	20 B Destroyed	21 B Destroyed °F	22 B 219 °F
Body Mid Height (outside)	23 B 180 °F	24 B 180 °F	25 B 180 °F	26 B 180 °F
CV Base (outside)	27 B 230 °F	Note: Temp label centered on bottom		
ON THE INNER LINER AND TOP PLUG				
Location	**0°**	**90°**	**180°**	**270°**
Top Plug Bottom	28 350 °F	29 350 °F	30 350 °F	31 350 °F
Flange Step Wall	32 275 °F	33 275 °F	34 275 °F	35 275 °F
BoroBond4 Step	36 350 °F	37 350 °F	38 300 °F	39 350 °F
CV Body Wall High	40 B 210 °F	41 C — °F	42 B 210 °F	43 C — °F
CV Body Wall Middle	44 B 190 °F	45 C — °F	46 B 199 °F	47 C — °F
Liner Bottom	48 B 261 °F	Note: Temp label centered on bottom Impact damage on Liner Bottom Label		

Comments: Borobond4 Step temperature are higher than Flange Step wall, these labels may be blacked from impact damage. Labels on CV lid maxed out - inconsistent - may be black from impact damage.

I certify that the above tasks have been performed and that the observations and comments are correct.

	7-27-04	Leonard Dickerson	7-30-04
Testing Technician	Date	Witness	Date

*All photographs/movies will be uniquely identified with test unit, date and time to ensure that the proper sequence can be reconstructed

Appendix 2.10.9

PACKAGING MATERIALS OUTGASSING STUDY FINAL REPORT

BWXT Y-12
Protecting America's Future

Y-12
NATIONAL
SECURITY
COMPLEX

MANAGED BY
BWXT Y-12, L.L.C.
FOR THE UNITED STATES
DEPARTMENT OF ENERGY

UCN-13672 (11-03)

Y/DZ-2720

Packaging Materials Outgassing Study Final Report

R. A. Smith
Compatibility and Surveillance
Technology Development

Issue Date: September 26, 2006

Prepared by the
Y-12 National Security Complex
Oak Ridge, TN 37831
Managed by
BWXT Y-12, L.L.C.
for the
U. S. DEPARTMENT OF ENERGY
under contract DE-AC05-00OR22800

Y/DZ-2720

PACKAGING MATERIALS OUTGASSING STUDY FINAL REPORT

R. A. Smith
Compatibility and Surveillance
Technology Development
Building 9202, MS 8097, 576-0615

Issue Date: September 26, 2006

Prepared by the
Y-12 National Security Complex
Oak Ridge, TN 37831
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ABBREVIATIONS, ACRONYMS, AND INITIALISMS

PE	polyethylene
PTFE	polytetrafluoroethylene
HAC	Hypothetical Accident Conditions
HDPE	high-density polyethylene
NCS	Normal Condition for Storage
PU	polyurethane
DSC	differential scanning calorimetry
TGA	thermogravimetric analysis
ppm	parts per million
STP	standard temperature and pressure
NRC	Nuclear Regulatory Commission

ABSTRACT

An outgassing study was conducted on two polyurethane packaging foams, two polymer bottles (polytetrafluoroethylene and polyethylene), and two polymer lids. The purpose was to measure the volume of gases that diffuse from these packaging materials at a maximum of 400°F when stored in ambient air within sealed containers. A specific heating profile was used to measure the offgassing quantities in a set of accelerated aging tests. This set of experiments was designed to duplicate an earlier study conducted in 1991. Thermogravimetric analysis and differential scanning calorimetry tests were conducted to obtain basic information about the polyurethane foams. The polyurethane foams demonstrated the largest degree of outgassing per mass; specifically, the white foam outgassed 50% less than the red foam. The polytetrafluoroethylene and polyethylene materials provided relatively small amounts of outgassing. The polyethylene materials appeared to react further upon cooling, leading to negative outgassing values due to consumption of gas in the container.

INTRODUCTION

Various materials are required for safely packaging items for transport or storage. Polymeric foams are a common means of protecting items from impact damage. The use of the foams in this study has the added requirement of minimal outgassing such that the closed container is not breeched if exposed to fire. The experiments completed here provide measurements of the gases per polymer mass that would be released at elevated temperatures. It is assumed that the major constituent of such gases is water, as polymers have a tendency to adsorb water, particularly if a filler is compounded into the polymeric matrix. Fillers, processing aids, colorants, stabilizers, and other additives are typically added to polymers for mechanical property enhancement (Fried). Little information is available about the composition of the materials in this study.

Another packaging application for polymers includes plastic bottles, used to contain liquids and solid powders. The current study measures outgassing from a Teflon (polytetrafluoroethylene or PTFE) and a polyethylene (PE) bottle, as well as their respective lids. The latter are unknown polymer types, although one is assumed to be high-density polyethylene by its manufacturer's stamp. Table 1 lists some characteristic average values for the polymer resins under study. The polyurethane (PU) foam, also listed in this table, has a significantly low moisture absorption level due to its probable closed cell configuration (MatWeb). PU resin properties vary widely according to the formulation and processing.

Table 1. Characteristic values for polymer resins and PU foam in this study (Fried, Gibson, and MatWeb

Polymer	T_g (°C)	T_m (°C)	Density (g/cm^3)	Water absorption (%)
Polytetrafluoroethylene	−73 (−99°F)	327 (621°F)	2.1	0.01
Polyethylene	−120 (−184°F)	98–135 (208–275°F)	1.0	0.03
Polyurethane	−70 (−94°F)	177 (350°F)	1.2	1.0–38.0
Polyurethane foam	−70 (−94°F)	177 (350°F)	0.45	1.0–5.0

The objective of this project is to heat plastic materials in ramped stages up to 400°F (204°C) and measure outgassing quantities within sealed containers. The goal is to reproduce test results from similar tests done in 1991, as reported in a letter authored by earlier researchers (Tinnel). Data from that document were used in safety documentation submitted in 1991 as characterization for the scenarios called Hypothetical Accident Conditions (HAC) and Normal Condition for Storage (NCS). Starting with the assumption that an item being shipped is contained in a polyethylene bag, it is then cushioned in PU foam. The foam is sealed in a can that is insulated by a lightweight concrete. The concrete is packaged in an outer steel drum that is vented. According to standards set forth by the U. S. Nuclear Regulatory Commission,

- In the HAC scenario, the drum is assumed to burn in a fire for 30 min, and the foam reaches a 300°F (149°C) temperature.
- In the NCS situation, a drum is assumed to sit out in the sun for several days and nights, which means that it is subject to continual temperature excursions between cool and 180°F (82°C).

In both cases, the PU foam will outgas over a short or long time, and it is required not to exceed a pressure that will damage the shipping container and cause the container to be breeched. It is assumed that moisture is the major offgassed constituent from this polymer structure, which only degrades beyond temperatures higher than 250°C (Hobbs).

PU foams are typically formulated from a polyol and an isocyanate component, adding a gas or blowing agent to one of these components to achieve the cellular structure. As stated earlier, additional constituents may be among the starting materials, as required in various applications. The original PU foam is a reddish-orange polyurethane formulated from Dow Chemicals components and was used for shipping protection until Dow decided to no longer manufacture this material. A white PU foam is now being considered to replace the earlier type and has components produced by BJB Enterprises, Inc. Both PU foams are tough and rigid and feature a nonporous skin where the foam apparently contacted the mold walls. There was random variability between the ratio of foam to skin in the specimens cut initially; smaller samples tended to have a larger fraction of skin. Care was taken to cut specimens from the mass of the foam, as the skin can demonstrate different properties; these foams are essentially composite materials (Broos). The density of the red foam specimens ranged from 0.45 to 0.50 g/cm^3 in the experiments discussed here. The density of the white foam material ranged from 0.27 to 0.49 g/cm^3. The polyethylene bottle is an opaque white material and has a density typically similar to water (1.0 g/cm^3). Teflon material typically has a density of 2.1 g/cm^3; this bottle has a smooth waxy texture.

Preliminary examination of the two foams was done using differential scanning calorimetry (DSC) and thermogravimetric analysis (TGA) in order to characterize some thermal properties. Figures 2 through 5 present the data. Figures 6 through 13 provide the outgassing data in this study. Figures 14, 15, and 16 comprise the basic molecular structures of these polymers.

DIFFERENTIAL SCANNING CALORIMETRY

DSC is an analytical method that measures the quantity of heat flow required to maintain a reference and sample at a particular temperature. The specific heat of the sample is then determined over a temperature range, giving information about phase transitions, kinetic processes, and other thermal attributes (Kämpf). The PU foams undergo some type of transition, cell softening or a glass transition, near 200°F (93°C); however, the presence of additives such as flame retardants, catalysts, or antioxidants could also have an effect on the DSC output. The red foams and white foams begin melting at 480°F and 560°F, respectively (250°C and 293°C).

THERMOGRAVIMETRIC ANALYSIS

TGA was run on each polymer, and weight loss was tracked as a function of temperature. The structure of PUs typically begins degradation between 250 and 350°C (480–660°F). The red PU demonstrates three regions of decomposition at 480°F, 553°F, and 696°F. The white PU only gives evidence of two decomposition processes, at 562°F and 689°F. The 550–560°F temperature is where polymer bridges begin to break and re-form into a secondary polymer structure; over 600°F, the secondary polymer structure breaks down as well. In the case of the red PU, the early decomposition is possibly loss of some additive. In both cases, the initial 1–2% weight loss corresponds well with the loss of moisture.

OUTGASSING STUDIES

During the outgassing study, samples of polymeric packaging materials were placed in vacuum-sealed stainless steel containers (retorts). Each retort was then attached to a capacitance manometer or "baratron" for direct measurement of the internal container pressure as the temperature was increased. This method allows tracking of the volatiles emitted from the materials, which are thought to mainly comprise moisture but also decomposition products at sufficiently high temperatures. While absorbed moisture is not immediately apparent under ambient conditions, the water contained in packaging is available to diffuse out over long time frames, such as years. Controlled heating provides a method to ascertain the maximum amount of outgassing from a material mass. This study provides information about the outgassing of volatiles in the situation combining elevated temperatures with the presence of air.

After the polymer specimens were loaded into retorts, the open or "free" volume within the containers was calculated. This study was initiated in the presence of atmospheric moisture and air pressure with a single absolute pressure gauge established to monitor the pressure as the temperature was ramped to a 204°C (400°F) maximum. Outgassing pressures are the sum of those gases emitted from the polymer specimen and retort, in addition to the air trapped inside the retort. The pressure gauge used has a maximum measurement range of 10,000 torr and was located outside the oven. The actual measurement volume included the retort headspace and the 24-in. flexible stainless steel hose used to connect the sample retort in the oven to the measurement device. An additional 1000-torr baratron was used as a reference to provide a measurement of the ambient pressure in the laboratory.

EXPERIMENTAL

Materials

The Packaging Engineering group provided the following test items for this study:

1. orange/dark red polyurethane foam in blocks (111.58 g)—this material had been formulated using components from Dow Chemical;
2. off-white polyurethane foam in blocks (168.8 g)—this material was formulated with components known as BJB280;
3. a clear/translucent Teflon (polytetrafluoroethylene) bottle capped with a white plastic lid labeled "Nalgene," possibly made of high-density polyethylene; and
4. an opaque polyethylene bottle capped with a black plastic lid, probably polyethylene.

Samples of random sizes and weights were cut using a blade or large scissors. Care was taken to exclude the skin from the foam materials being tested. Specimens were cut and weighed immediately before being sealed into a vacuum container. The total weight of pieces placed into a particular container was recorded in grams.

Equipment and Procedure

Standard vacuum hardware was used to seal randomly sized specimens of each material (weighing from 8 to 12 g) in air after these were weighed on a calibrated scale. (For the two PU foams, the experiment had been repeated with smaller masses.) Additionally a "blank" container was tested over the temperature range. This blank served to provide a baseline outgassing level for the container. The oven was programmed to heat to specific temperature plateaus and hold for a specified time period before ramping linearly to the next temperature. The temperature profile, named "Profile 5," is described in Table 2. Despite the programming of the oven to cool to 50°F, its minimum temperature after heating was about 110°F; to cool the oven to room temperature the oven door was opened, which allowed free circulation of air into the heating zone.

Table 2. Heating and cooling profile (Profile 5) for outgassing tests

Temperature setting		Duration of ramp or hold
77–150°F	25–65°C	1-h ramp
150°F	65°C	2-h hold
150–200°F	65–93°C	1-h ramp
200°F	93°C	2-h hold
200–250°F	93–121°C	1-h ramp
250°F	121°C	2-h hold
250–300°F	121–149°C	1-h ramp
300°F	149°C	4-h hold
300–350°F	149–177°C	1-h ramp
350°F	177°C	4-h hold
350–400°F	177–204°C	1-h ramp
400°F	204°C	4-h hold
400–111°F	204–44°C	2-h ramp
111°F	44°C	Lower oven limit
77°F	25°C	Oven opened to lab

It should be noted that during the test period the test laboratory experienced continual temperature swings between 56 and 80°F (13–27°C). This range is typical for this laboratory and can cause random noise in the data under collection. For example, according to its specifications, the Despatch oven control stability is ±0.5°C per 5°C change in ambient temperature. The signal conditioner and display have linearity and accuracies in the parts per million (ppm) range per degree °C, but the combination of these small variations provides a visible noise level at extremely small outgassing levels.

The containers were constructed of stainless steel and bolted with the use of a copper gasket between 2.75-in. conflat flanges (Fig. 1). The assembly was completed with ¼-in. VCR® fittings and Swagelok or Nupro valves, using silver-plated nickel gaskets to seal interfaces.

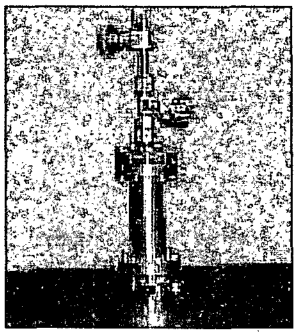

Fig. 1. Stainless steel vacuum container or *retort*.

Pressure measurements were conducted using an MKS Instruments Type 690A14TRB 10,000-torr baratron providing output to an MKS 670 signal conditioner electronics unit. The baratron had an accuracy of 0.12% of reading and operates with a 59–104°F (15–40°C) ambient temperature span. The signal outputs were processed using a program called "Generic Application for Reading Pressure Gages for Import into Excel," and data were collected using LabView software on a laboratory computer. Data were downloaded from this computer for storage and analysis on an office personal computer.

The heating procedure displayed in Table 2 was conducted in a Despatch LAC 1-67-6 programmable laboratory oven that uses a Protocol Plus microprocessor control. A thermocouple was used to separately track and write the oven temperature to the aforementioned LabView program.

Experimental Steps

- Clean stainless steel retorts using isopropanol and wipe dry. Allow to air dry for 24 h.
- Cut and weigh polymer samples in atmosphere.
- Document material type, sample name, and weight.
- Place polymer pieces in stainless steel retort; label retort with sample name.
- Bolt container to conflat flange using a copper gasket and six bolts.
- Store retorts near Despatch oven until testing could be conducted.
- Select random retort for test; use nickel gasket to connect container to flexible tubing inside oven.
- Record pressures from baratrons measuring ambient and experimental pressures; these should be equivalent before test.
- Open National Instruments program and establish data collection mode and sampling rate (in data points per minute).
- Check data readout from signal conditioner and thermocouple.
- Check data download to personal computer via Labview program using Excel.
- Open sample retort valve.
- Turn oven on and load Profile 5; select Run.
- Periodically check system to ensure that data are being collected as planned.
- At end of test, record pressures according to both ambient and experimental baratrons; note oven temperature.
- Turn off oven and open oven door.
- Allow pressure to reach a new "ambient" equilibrium, and again record pressures.
- Close sample retort valve.
- Unbolt sample retort, and reserve for possible headspace gas analysis.
- Download data immediately in Excel *.csv format.
- Stop data collection program.

DATA AND RESULTS

The data were collected, then downloaded and analyzed using Microsoft Excel. The raw data were recorded as pressure in units torr as a function of time; temperature in degrees centigrade was also tracked as a function of time. For all materials, charts were later calculated to provide outgassing volume in cm^3(STP)/g and temperature in degrees Fahrenheit from ambient to 400°F, as a function of elapsed time (duration in hours). Blank data were used to calculate the moles of outgassed species contributed by the sample container and other system components. Appendix 1, *Data Analysis*, provides additional detail on data processing.

BLANK OUTGASSING RESULTS

Two empty containers (blanks 1 and 3) were subjected to the same temperature profile in separate tests. Outgassing patterns shown in Figs. 6 and 7 provide a guide to the variation in (a) oven runs at different times and (b) blank outgassing under identical temperature profiles. The oven temperature was observed to vary as much as 5% at the same temperature setting. In concert with this, the blank outgassing pressures varied from each other by −0.25 to 4.2% in these tests. An analysis shows a 0.58 correlation of pressure to temperature variation between these two experiments. The other significant variable that can cause variation in outgassing between the two seemingly identical blanks is dimensional variations. The container volume difference (observed to be <2%) will lead to pressure discrepancies for identical gas quantities. In the current tests, molar quantities were calculated using container data developed through successive gas expansions to measure their volumes.

FOAM OUTGASSING RESULTS

The results from two red foam specimens are averaged in Fig. 8, where the specific volume of outgassing from each specimen is plotted with the temperature in degrees Fahrenheit. This normalized value is cited as specific volume at standard temperature and pressure (STP), providing the volume per specimen mass at standard temperature (273 K) and pressure (1 atm); the specific volume = $V/g = (nRT/p)g^{-1}$. It can be noted that the magnitude of outgassing is comparable to the 1991 data, but perhaps slightly less due to the material outgassing over time in storage. The experiment described here increases the temperature range and time of outgassing, so larger ultimate values than those of 1991 are observed. As well, the ramping and hold times were longer in the current experiment. The white foam outgassing quantities are shown in Fig. 7, and while on the same order of magnitude as the red PU, this material appears to produce only half the overall quantity of outgassed species. Both materials had continually increasing outgassing of volatiles at the highest test temperature, indicating that decomposition has started rather than outgassing has been seen at lower temperatures. The molecular structure of polyurethane includes an ester linkage that is subject to hydrolysis. Although some PU has a large moisture content, rigid foams typically have no more than 5% moisture. In this study, the red PU demonstrates about 1.2 wt % and the white foam 0.5 wt % moisture.

TEFLON AND POLYETHYLENE OUTGASSING RESULTS

The polytetrafluoroethylene and polyethylene materials outgassed relatively little, making it difficult to detect outgassing due to the heated container and that arising from the polymer alone. In other words, the final plots (Figs. 11–13) show a great deal of noise. It could be concluded that these materials would not present a large consideration for their outgassing potential in a heated situation. Their polyolefin structure does not attract moisture to the degree of the ester group in the PU structure. An interesting feature of the polyethylene materials is observable as the test vessel is cooled to room temperature. These experiments actually went into a negative pressure status, indicating that a reaction was taking place that consumed the gas phase inside the container. It is recognized that polyolefins degrade in air by oxidative reactions (Boenig). A mechanism for pressure decrease occurs if oxygen present in the original headspace reacts with the polymer and suppresses outgassing, even during the heating cycle. Polymers also degrade by fragmentation, producing free radicals, which can then continue to react with one another (cross-linking). During a cooling of this system, these moieties would have reduced mobility, thereby increasing the probability of reaction with the gas phase. An analysis of the headspace would provide a means to study the remaining constituents.

OUTGASSING COMPARISONS

Figure 14 sets forth a straightforward comparison of outgassing quantities. The maximum and minimum amounts of gas are calculated for various samples after the background quantities are subtracted. These were weighted by the specimen mass and plotted on a bar chart as moles per gram of polymer specimen. The PUs demonstratedly have a larger outgassing of volatile species per mass, in comparison to PE and PTFE. Again, it is interesting to note the negative outgassing values in the case of PE minimums.

CONCLUSIONS

The next experimental procedure would be to conduct a gas analysis of the headspace on each container. The Y-12 National Security Complex Plant Laboratory is the best resource to complete this task. This would pinpoint the identity of outgassed species and provide a guide to ascertaining chemical reactions taking place in the solid–gas interface. This certainly would verify that reactions between the oxygen and polymer fragments have occurred.

Another stage would be to clearly identify the identity and manufacturer of each material, including the age, ingredients, and processing steps. Processing information for each polymer would assist in explaining the DSC and TGA output, if such an effort is desired. The response of a polymer to its environment involves its constituents, processing history, and treatment in storage. The large range of polymer properties, including outgassing, is due to these variables.

It can be concluded that PU foams absorb and outgas moisture to a larger extent than the polyolefins, as expected according to their respective molecular structures. This is also reflected in the literature absorption values. The white PU outgassing is no more likely to cause a shipping container breech than the red PU outgassing in the Nuclear Regulatory Commission (NRC) scenarios. The red PU outgassed a specific volume per mass similar to that quantity derived in the 1991 study.

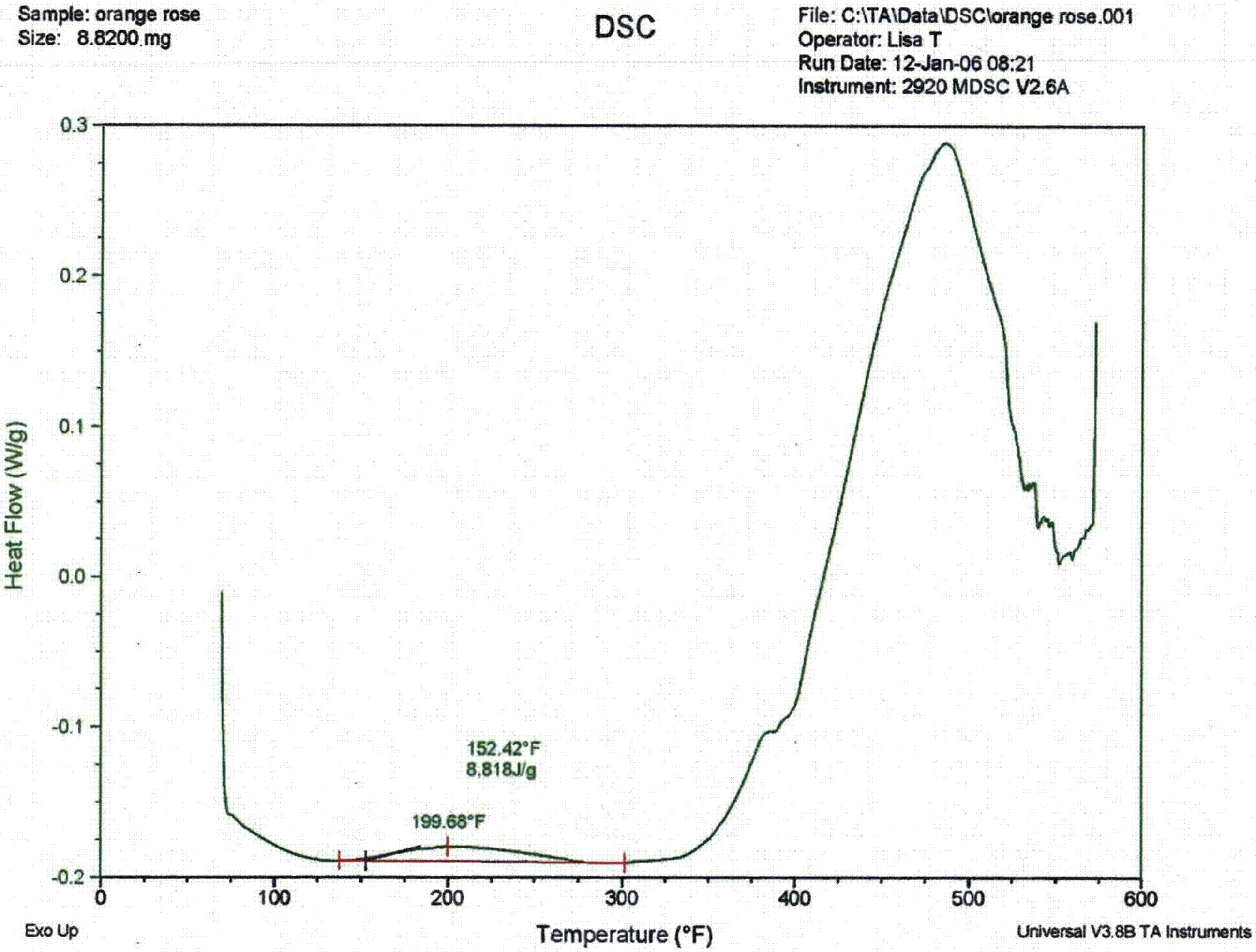

Fig. 2. Red PU thermogram showing thermal transitions at 200°C and 490°C.

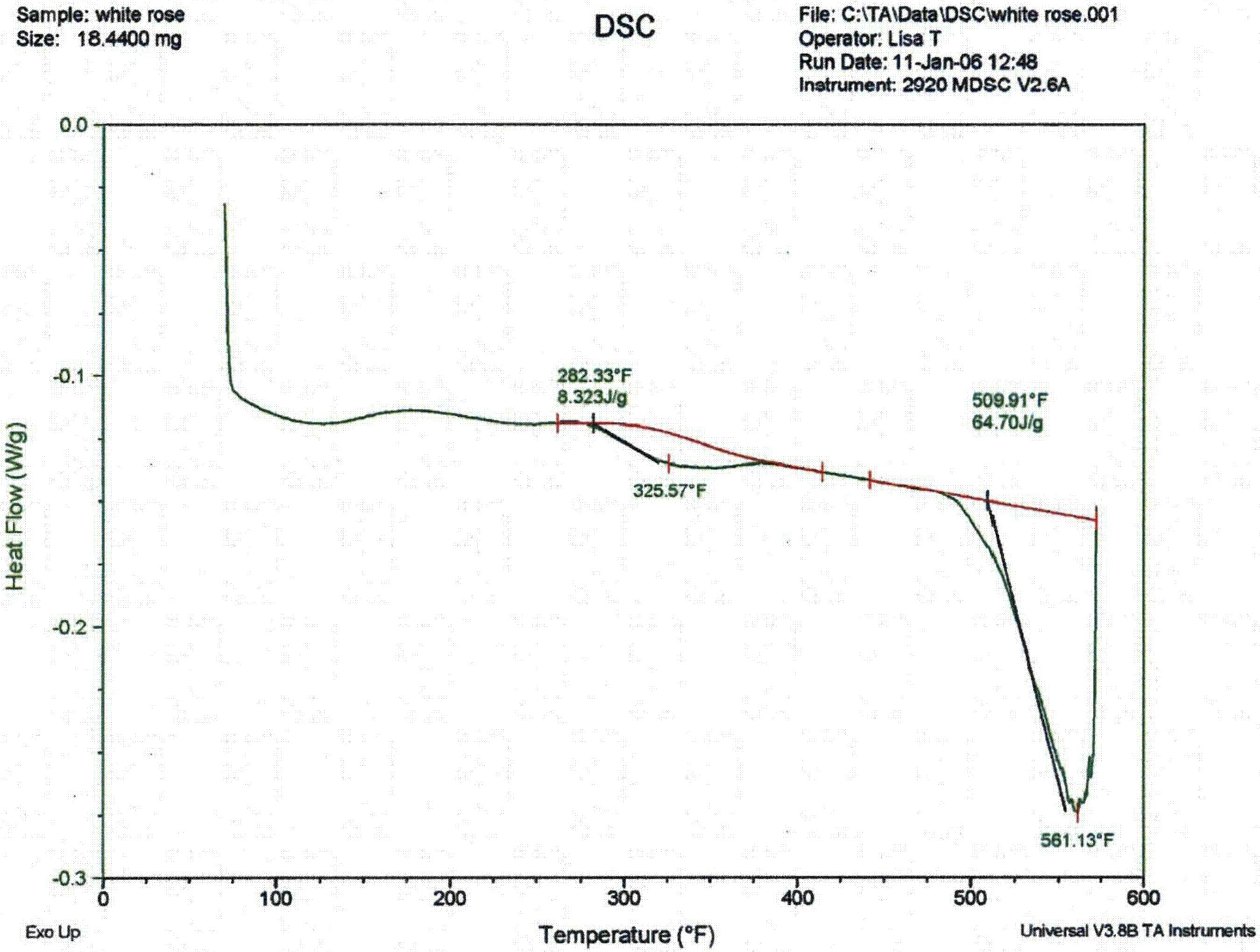

Fig. 3. White PU thermogram showing thermal transitions at 325°C and 560°C.

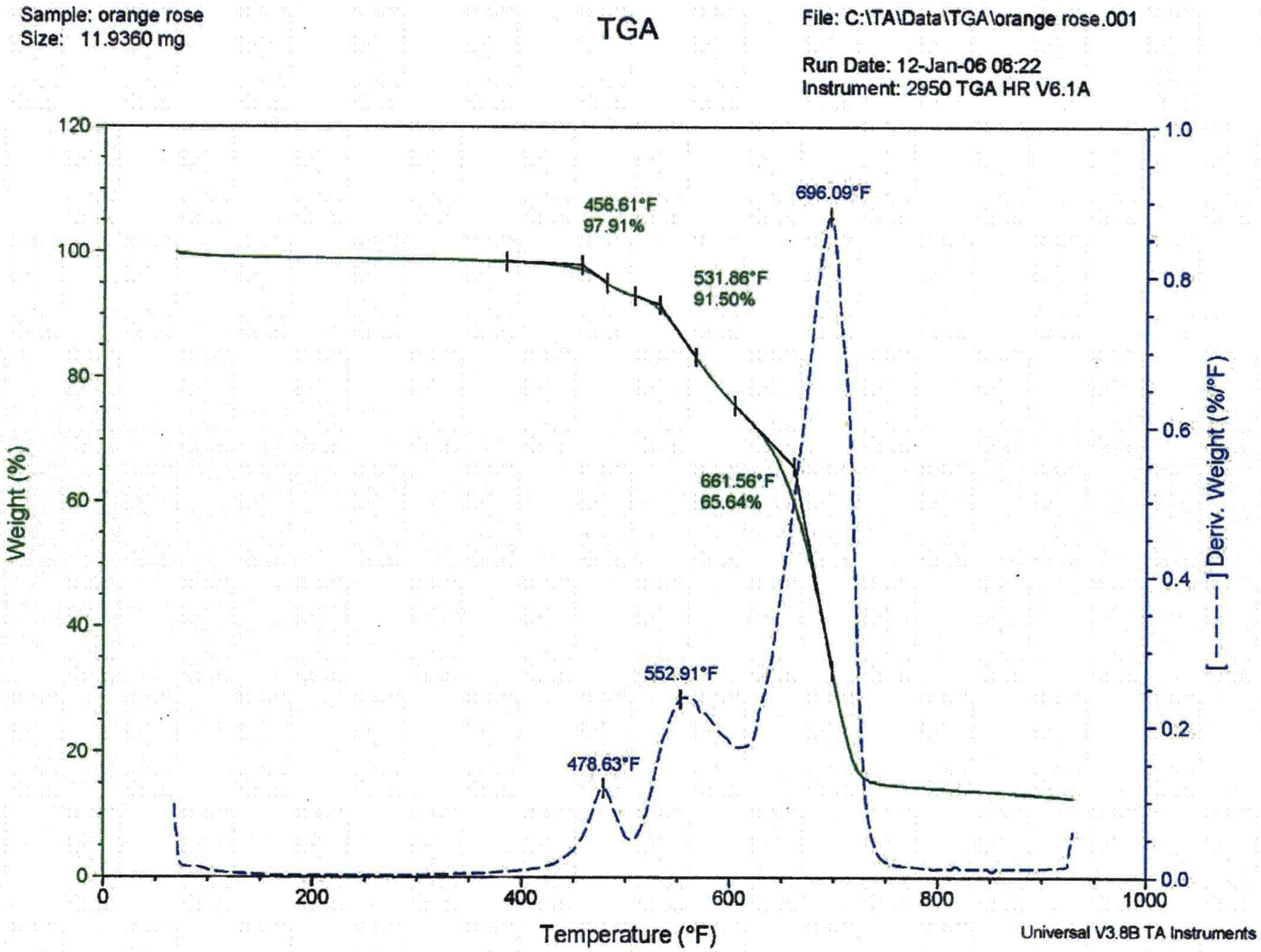

Fig. 4. Red PU foam showing three regions of thermal decomposition.

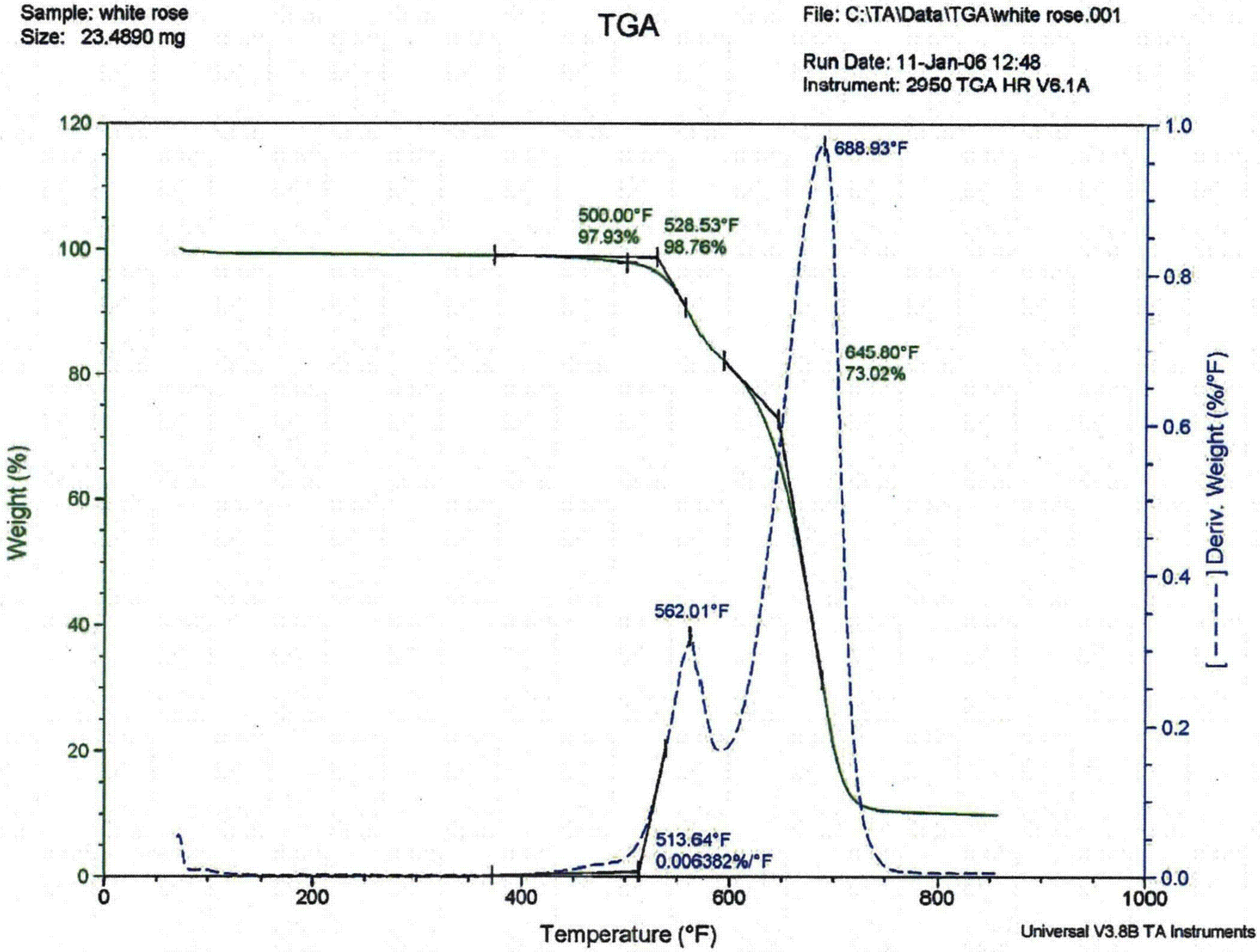

Fig. 5. White PU foam showing two regions of decomposition.

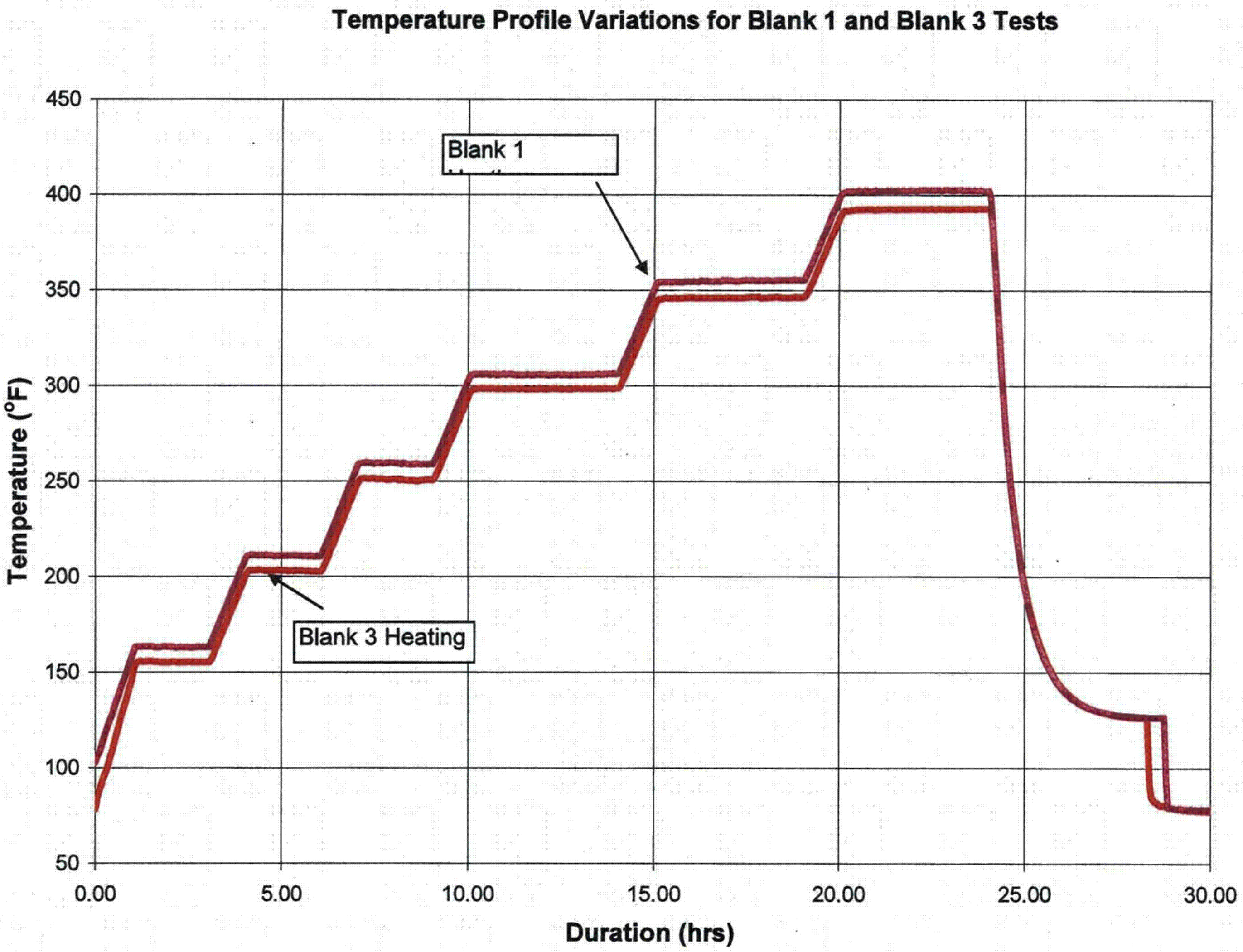

Fig 6. Variation in heating profile from oven may lead to variation in outgassing results.

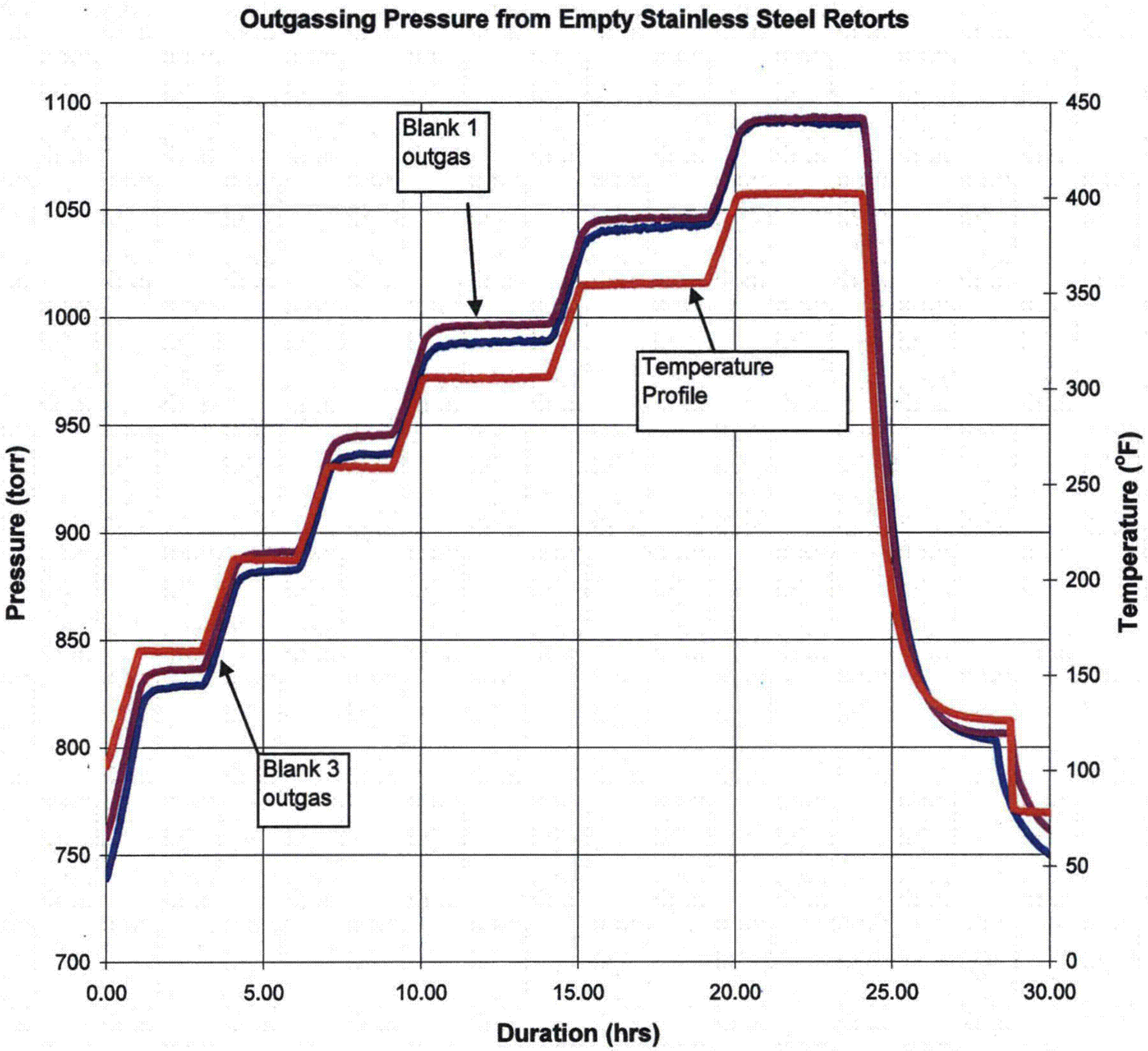

Fig. 7. Outgassing pressures from two stainless steel retorts.

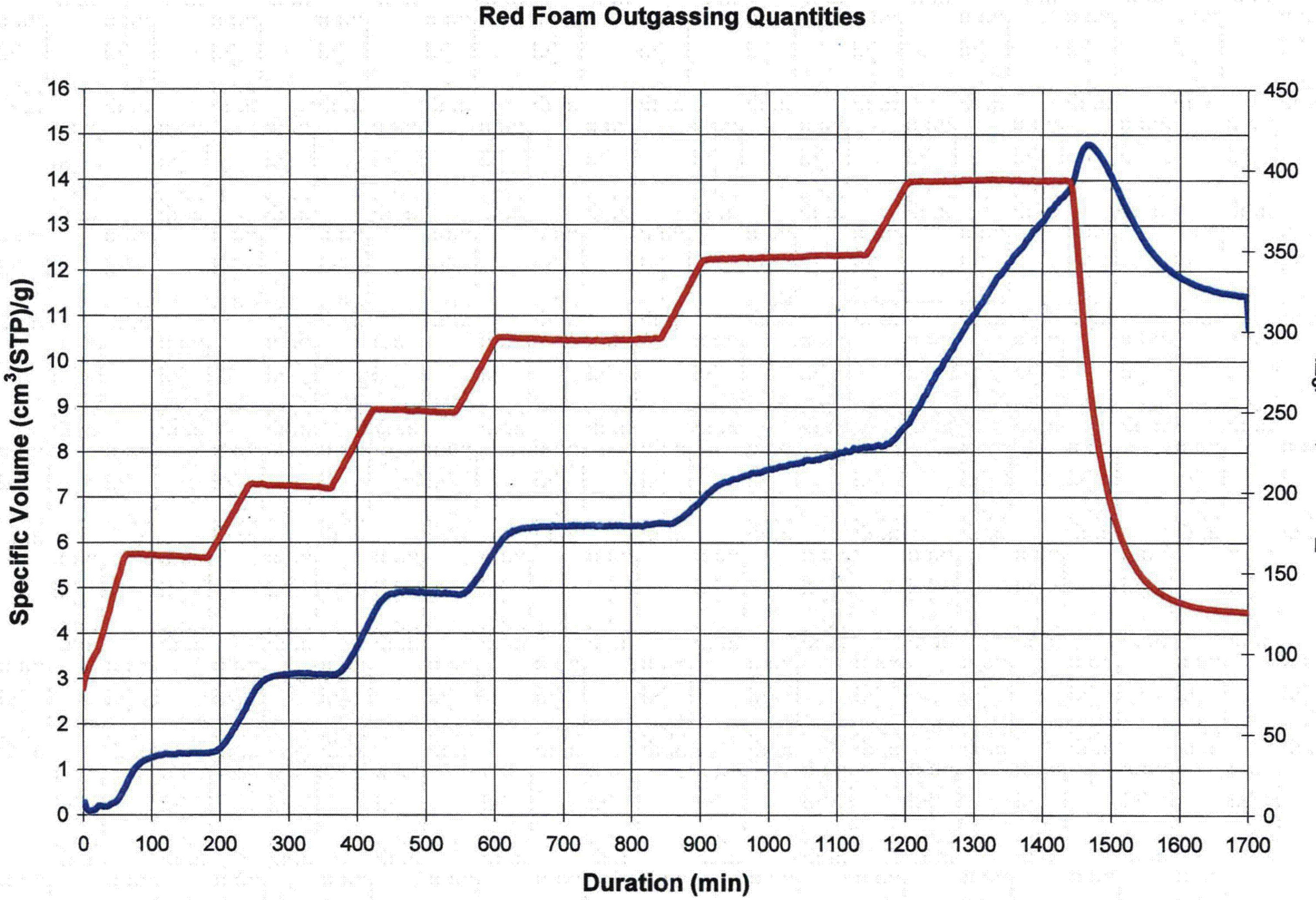

Fig. 8. Outgassing of two red PU foam specimens (8.88 g and 2.98 g).

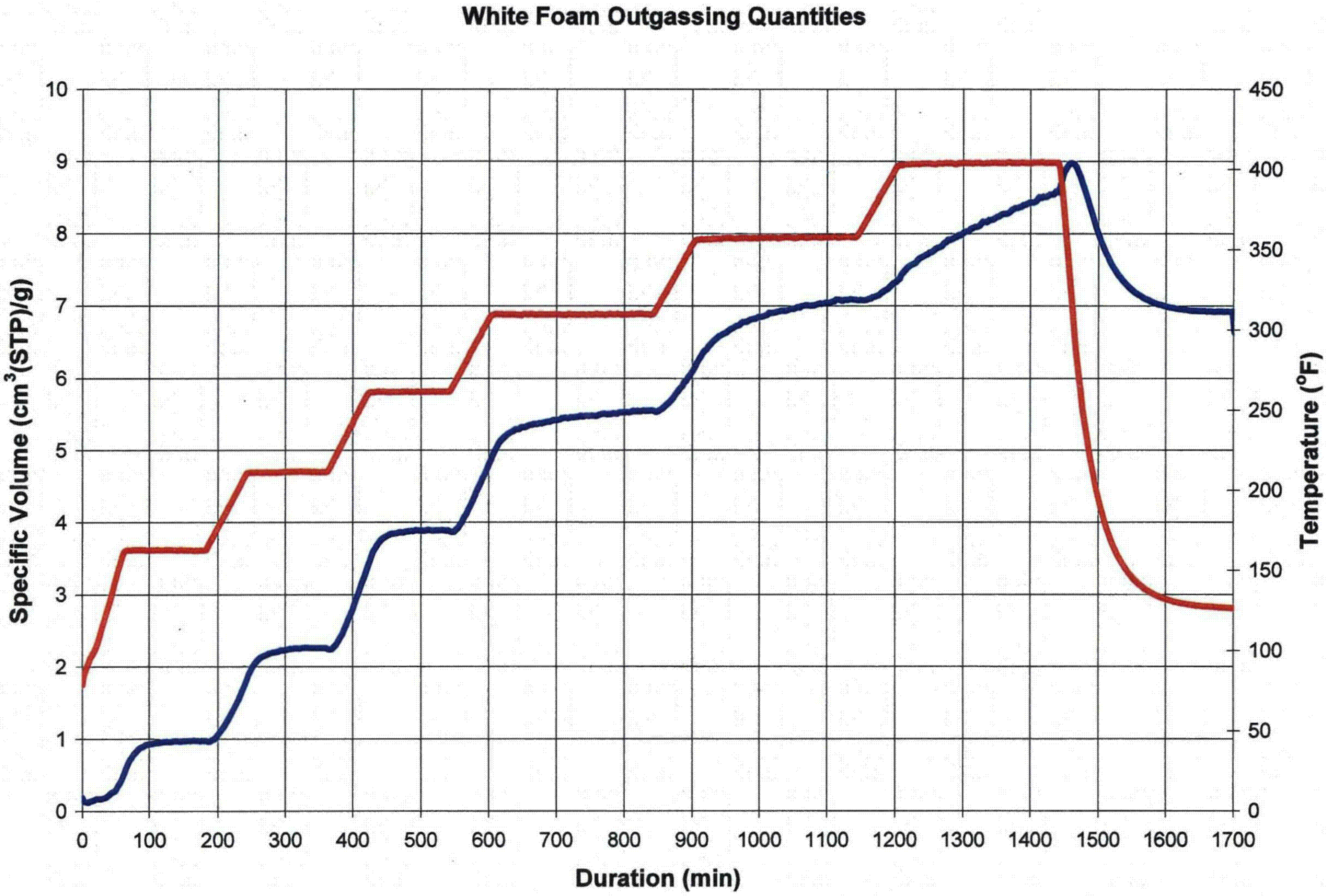

Fig. 9. Outgassing of an 11.06-g specimen of white PU foam.

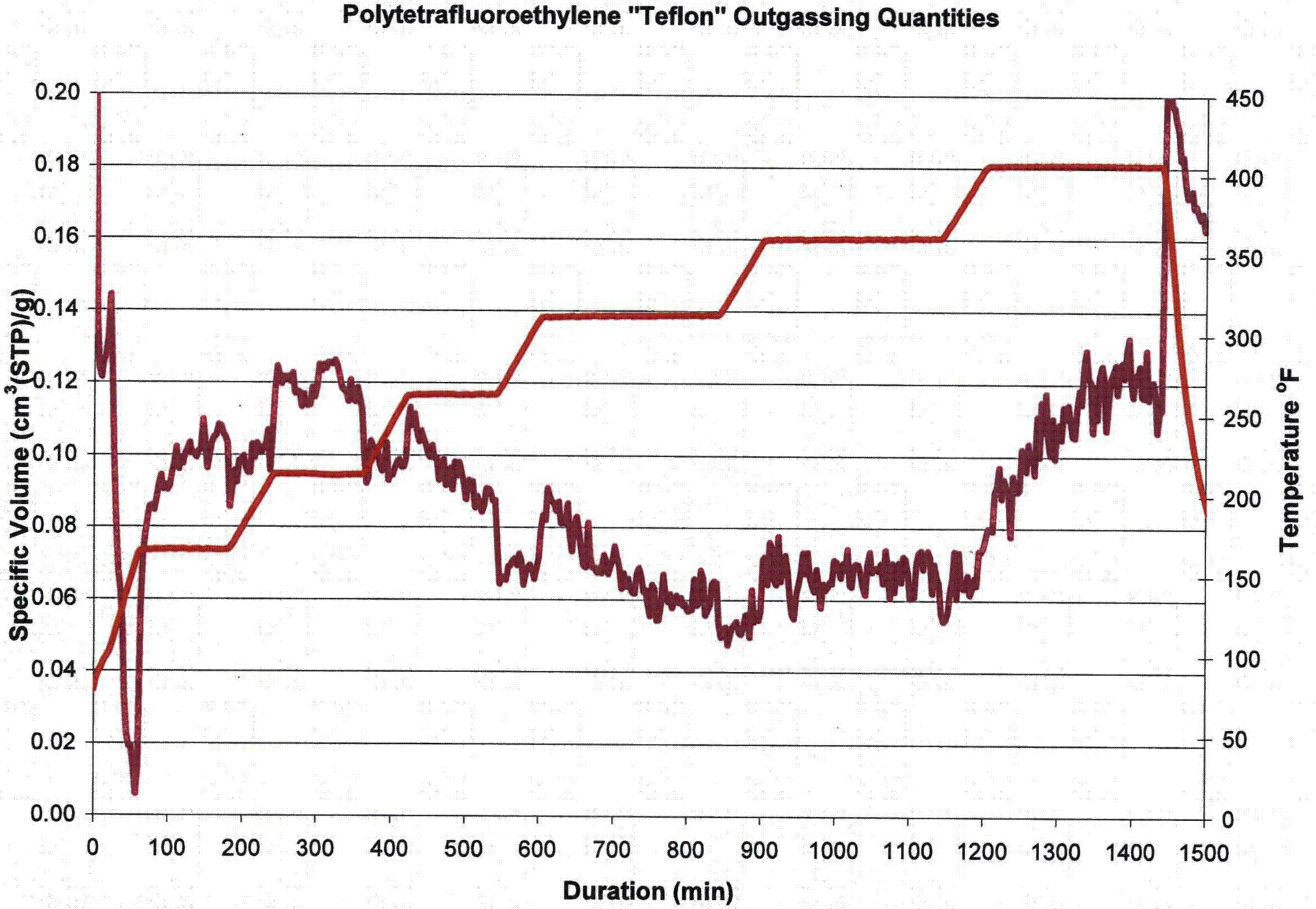

Fig 10. Outgassing of two polytetrafluoroethylene (Teflon) specimens (8.14 g and 12.41 g) competes with measurement noise.

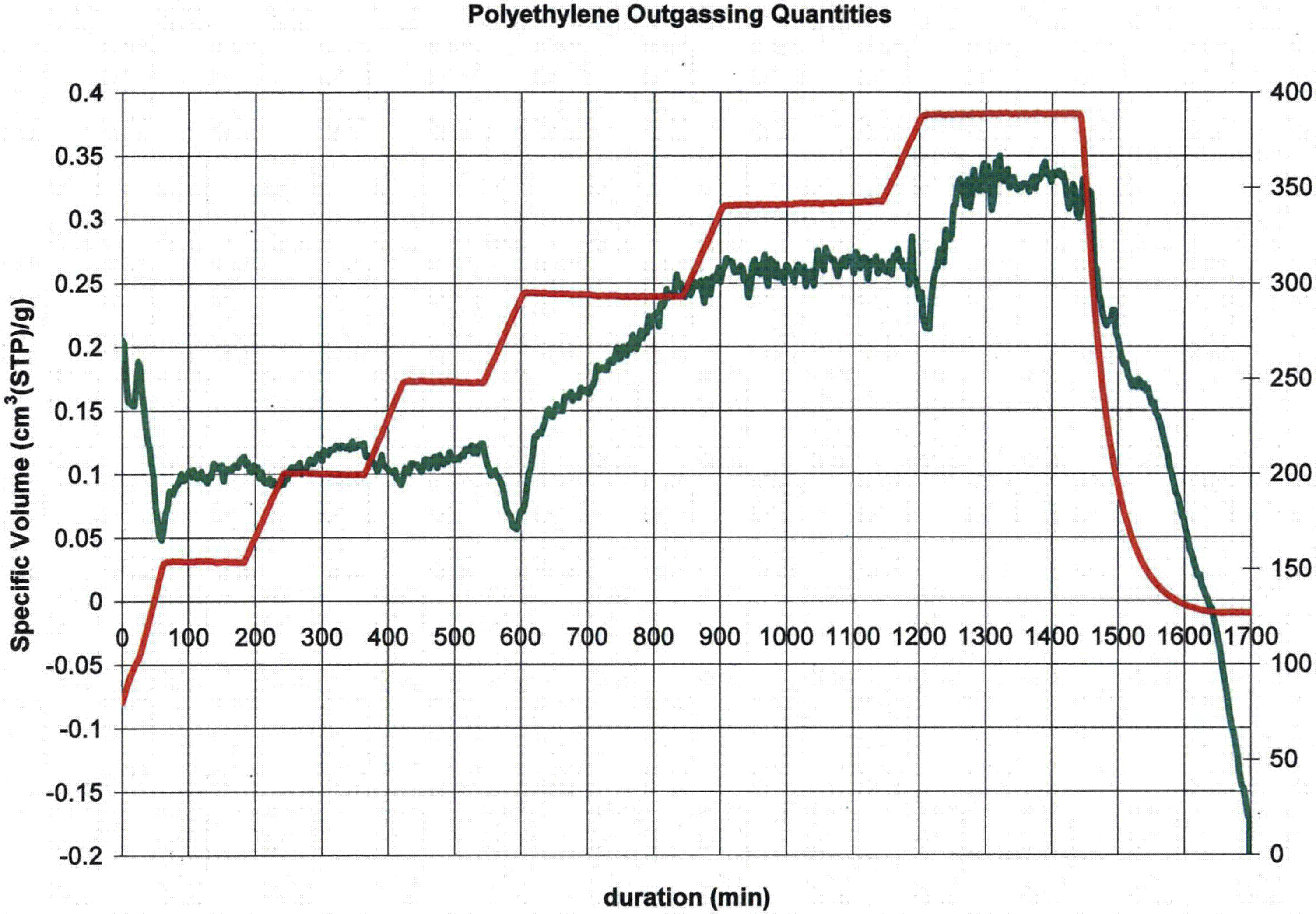

Fig. 11. Outgassing of an 8.18-g specimen of polyethylene bottle is at noise level and decreases rapidly upon cooling.

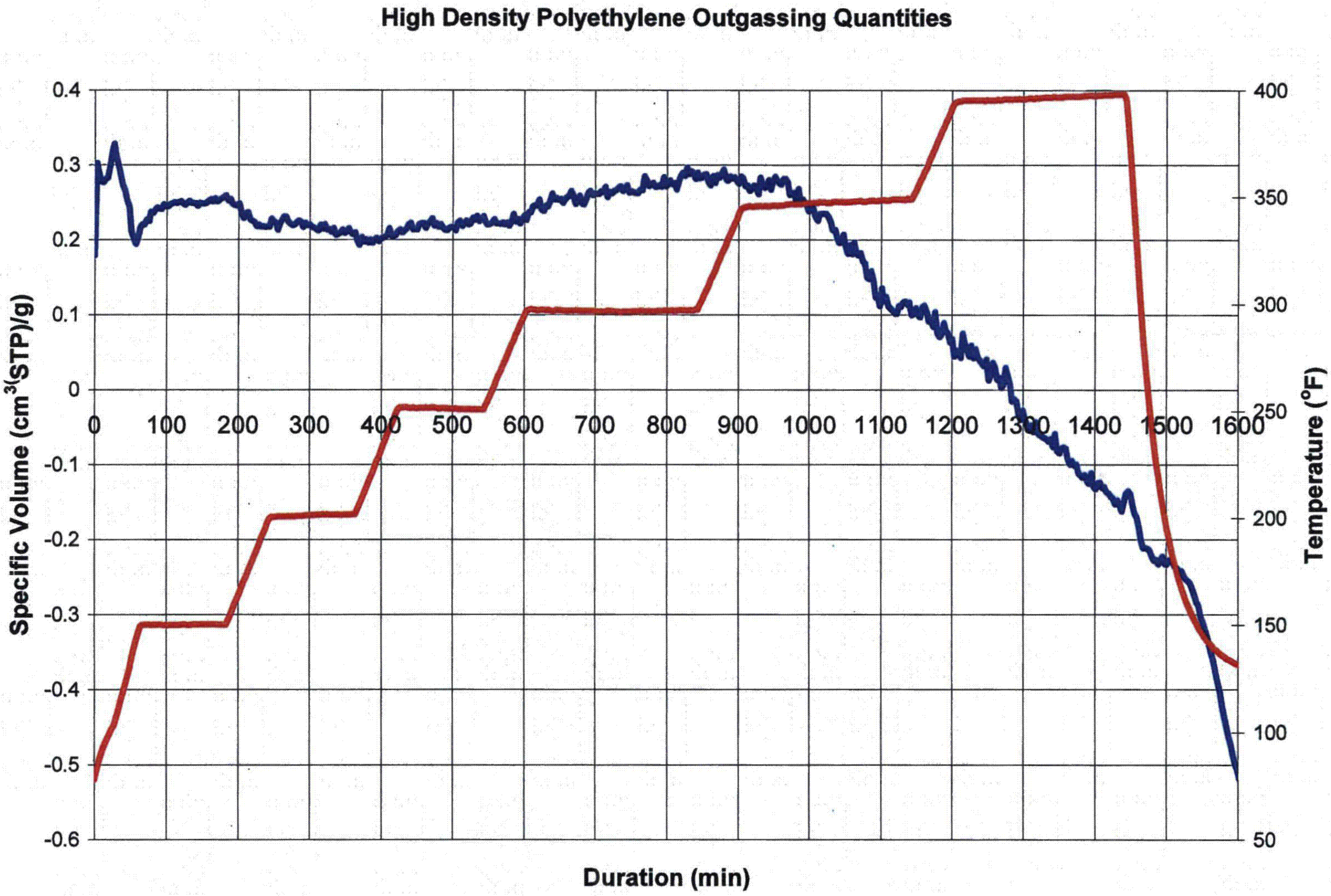

Fig. 12. Outgassing of an 8.3-g specimen of an HDPE bottle lid.

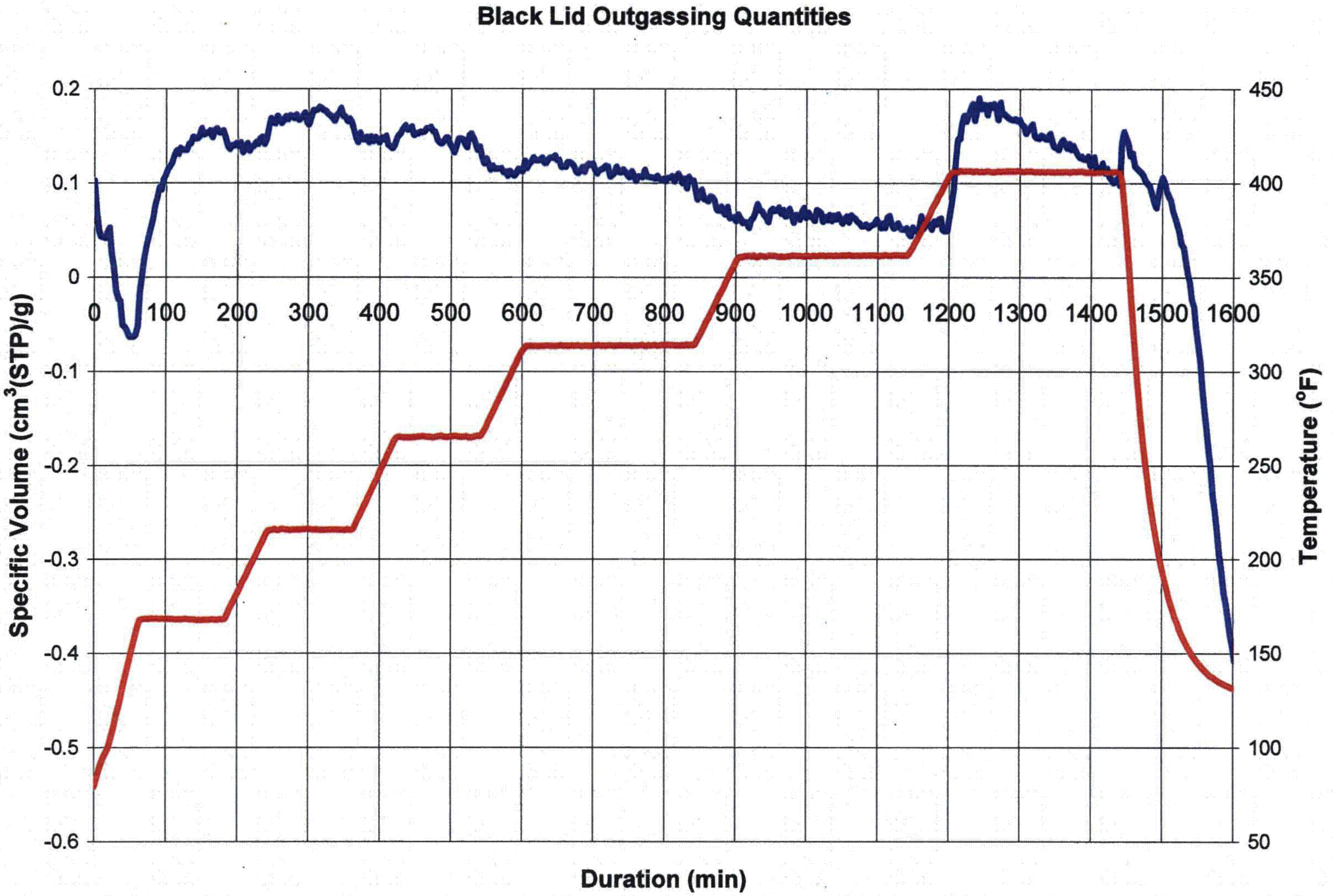

Fig. 13. Outgassing of an 8.90-g specimen of a black plastic bottle lid, possibly polyethylene.

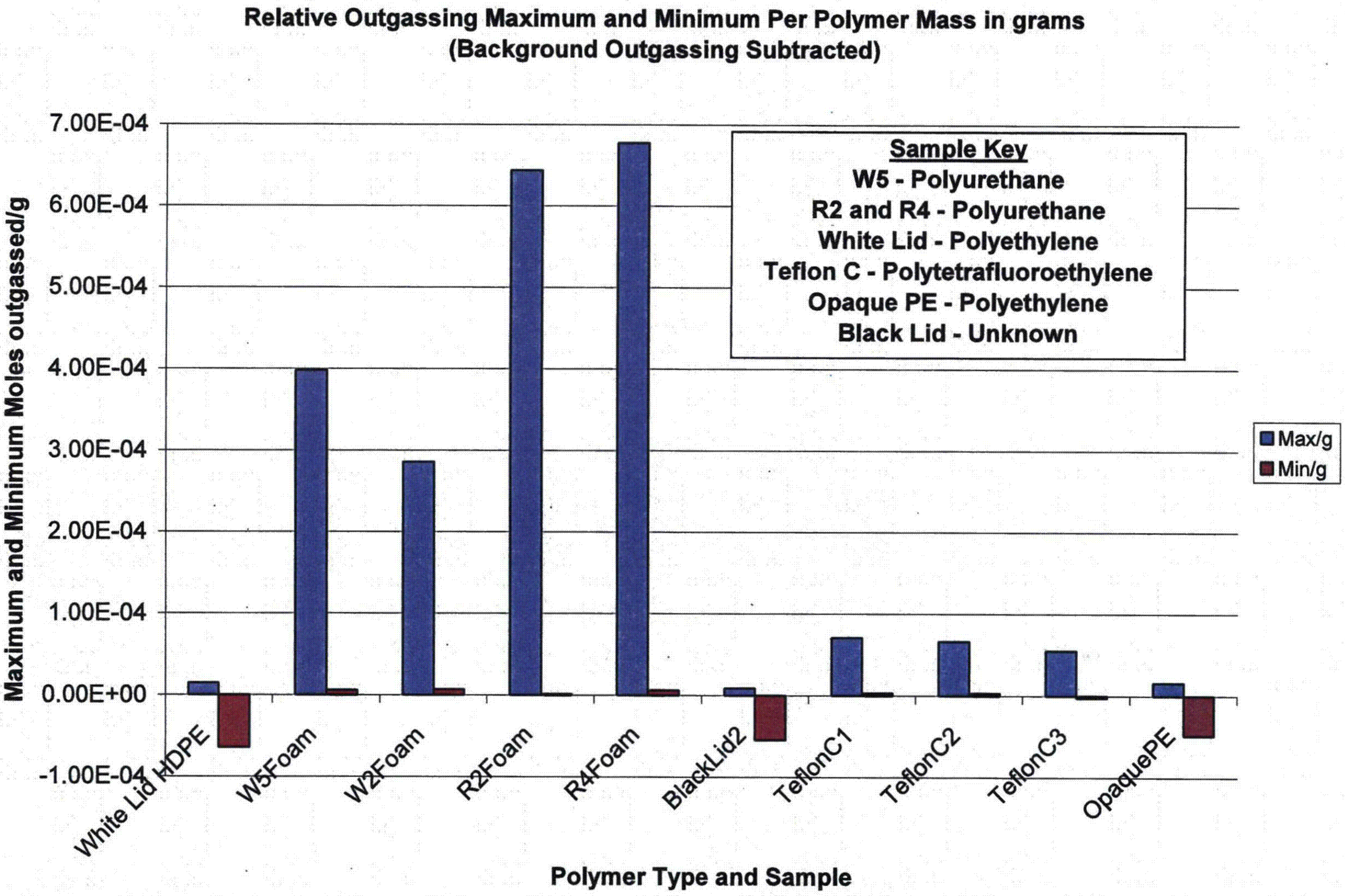

Fig. 14. Relative outgassing by polymer types examined.

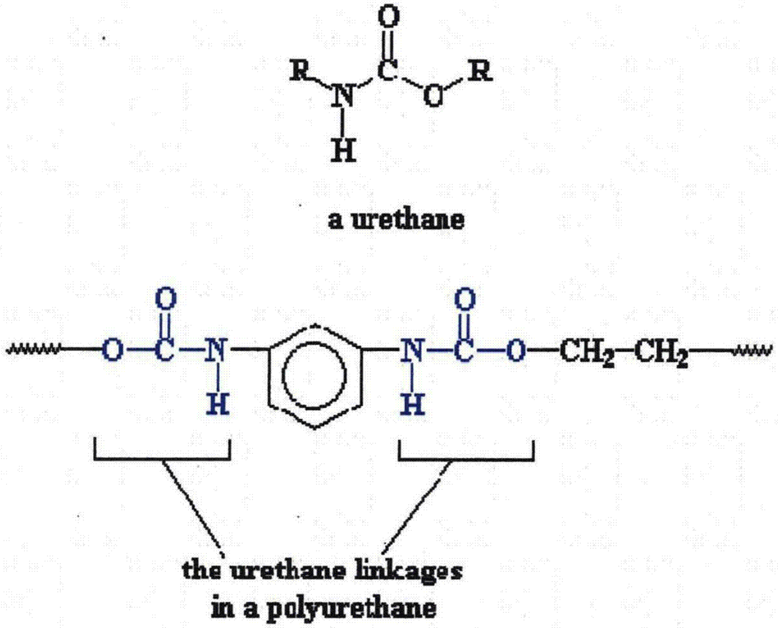

Fig. 15. Polyurethane molecular structure.

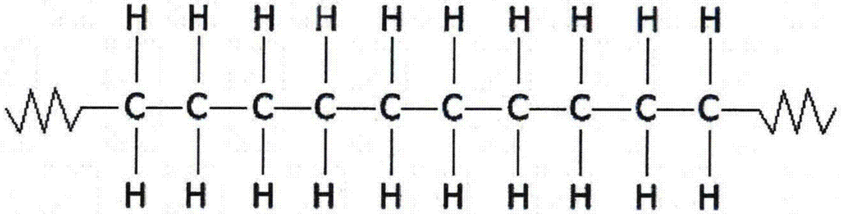

Fig. 16. Polyethylene molecular structure.

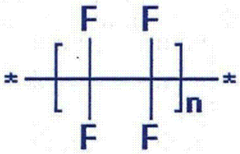

Fig. 17. Polytetrafluoroethylene (Teflon) molecular structure.

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APPENDIX 1: DATA ANALYSIS

This is a description of steps taken in Excel software to process data downloaded in the form of *.csv spreadsheets from National Instruments software. In general, new columns are set up for each calculation.

1. Open file
2. Data columns appear including Date and Time, Temperature, Pressure (torr)
3. Input sample name and weight (in grams) above pressure column
4. Insert column for duration—units can include days, hours, or minutes
5. Use CONVERT function to establish column of Fahrenheit temperatures
6. Input values for *R* (gas constant) and *V* (volume of container and flex hose) into cells on top of spreadsheet
7. Set up column to calculate the number of moles according to the Ideal Gas Law:
    a. $N = \{p(\text{torr})V(\text{cm}^3)/[R\ (82.057\ \text{atm-cm}^3/\text{K-mol})*T\ (T°C + 273)\text{K}]\} * (1\ \text{atm}/760\ \text{torr})$ using cell addresses for *p*, *V*, *R*, and *T* values
8. Paste column of blank outgassed moles
9. Subtract column of blank moles outgassed from specimen moles outgassed; this eliminates initial air and system outgassing
10. Calculate the volume of outgassed species at standard temperature and pressure (273 K and 1 atm) or by assuming an ideal gas that will have a volume of 22.4 liters per mole
11. Divide V_{STP} by specimen weight in grams; this column is Specific Volume
12. Plot T (°F) and Specific Volume vs Time (min), created separate axes for temperature and volume variables
13. Apply appropriate titles and formatting.

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