7.0 Analysis Results

The figures presented in Section 7 may show the punch, however, no punch impacts were made on the HABC model as discussed in Section 6.1.

7.1 HABC-run1hl - Lower Bounding Side

HABC-run1hl are the runs with the lower bounding material properties for the kaolite and the HABC materials. The 4-foot impact occurs from time = 0.0 to 0.01 seconds; the 30-foot impact occurs from 0.01 to 0.02 seconds; and the crush impact occurs from 0.02 to 0.04 seconds.

The initial configuration for HABC-run1hl is shown in Figure 7.1.1. The configuration after the 4-foot impact is shown in Figure 7.1.2. Enlargement of the lid and bottom regions after the 4-foot impact is shown in Figure 7.1.3.

The effective plastic strain in the CV body after the 4-foot impact is shown in Figure 7.1.4. The maximum is 0.0185 in/in and occurs near the bottom head of the CV body. The plastic strain in other components for the 4-foot impact are given in Table 7.1.1.

Table 7.1.1 - HABC-run1hl, 4-Foot Impact, Effective Plastic Strain Levels in Some Components

Component	Effective Plastic Strain, in/in
CV Lid	0.0001
CV Nut Ring	0.0000
Angle	0.0055
Drum	0.1599
Drum Bottom Head	0.1033
Liner	0.1045
Lid	0.1393
Lid Stiffener	0.0004
Lid Studs	0.0000
Lid Stud Nuts	0.0000
Lid Stud Washers	0.0194
Plug Liner	0.0022

Figure 7.1.5 shows the final configuration for the HABC-run1hl 30-foot impact. Figure 7.1.6 shows the lid and bottom regions after the 30-foot impact.

The maximum effective plastic strain due to the 30-foot impact in the CV body is 0.0195 in/in as shown in Figure 7.1.7. The maximum effective plastic strain in the drum lid is shown to be 0.5790 in/in in Figure 7.1.8. The maximum lid strain is a surface strain at the stud hole nearest the rigid surface. The membrane effective plastic strain component is 0.4416 in/in in the localized region near the stud hole. Effective plastic strain levels in other components for the 30-foot impact are given in Table 7.1.2.

Table 7.1.2 - HABC-run1hl, 30-Foot Impact, Effective Plastic Strain Levels in Some Components

Component	Effective Plastic Strain, in/in
CV Lid	0.0002
CV Nut Ring	0.0000
Angle	0.0780
Drum	0.2251
Drum Bottom Head	0.2126
Liner	0.1078
Lid Stiffener	0.0093
Lid Studs	0.1140
Lid Stud Nuts	0.0000
Lid Stud Washers	0.0194
Plug Liner	0.0958

The final configuration for the crush impact is shown in Figure 7.1.9. Figure 7.1.10 shows the configuration at the bottom and lid regions after the crush impact.

Figure 7.1.11 shows the effective plastic strains in the CV body. The maximum is shown to be 0.0206 in/in and occurs below the flange region due to the upper internal weight.

The maximum effective plastic strain in the drum for the crush impact is 0.5139 in/in (surface strain) as shown in Figure 7.1.12. The maximum in the drum occurs near the angle on the crush plate side of the drum. The maximum membrane effective plastic strain at this location is 0.3551 in/in.

Figure 7.1.13 shows that the maximum effective plastic strain in the lid is 1.2580 in/in (surface strain) and occurs just below the upper stud hole (hole nearest the crush plate, 180°). The maximum membrane effective plastic strain in this region of the lid is 0.7746 in/in. A time line investigation during the crush impact shows that the lid exceeds 0.57 in/in strain in bending at about 0.0248 seconds at the 180° stud hole. The crush impact started at about 0.0200 seconds, so the lid reaches failure level near the start of the crush impact. The membrane levels in the lid reach 0.57 in/in at about 0.0264 seconds. The elevated effective plastic strain levels in the lid are localized in the region just inboard of the upper stud.

Figure 7.1.14 shows that the effective plastic strain in the drum studs is 0.5121 in/in and occurs in the upper stud at the bearing of the lid onto the stud. The elevated strains in the stud are localized on the inner surface (bearing of the lid on the stud). Effective plastic strain levels throughout the thickness of the stud are generally 0.25 in/in or less. At time 0.0264 sec, the lid has reached 0.57 in/in strain in membrane, and the maximum strain in the drum studs is about 0.2870 in/in.

Considering the strain levels in the lid and the studs, some tearing at the 180° stud hole would be expected. But the tearing would be localized to the stud hole due to the extent of the strain patterns. Failure of the stud to restrain the lid due to this tearing is not expected. The lid stiffener would limit any tearing from the stud at 180° and the large washer would be expected to restrain the lid. The effective plastic strain in other components due to the crush impact are listed in Table 7.1.3.

Table 7.1.3 - HABC-run1hl, Crush Impact, Effective Plastic Strain Levels in Some Components

Component	Effective Plastic Strain, in/in
CV Lid	0.0002
CV Nut Ring	0.0000
Angle	0.1142
Drum Bottom Head	0.3562
Liner	0.1593
Lid Stiffener	0.0515
Lid Stud Nuts	0.0005
Lid Stud Washers	0.0693
Plug Liner	0.1220

The lid separation time history is shown in Figure 7.1.15. The nodes used in Figure 7.1.15 are shown in Figure 3.1.30. From the time history plot it can be seen that a lid separation of 0.005 in or less would be expected.

Figure 7.1.16 shows kaolite nodes used to find the kaolite thickness time history. Figure 7.1.17 shows the remaining thickness time histories for the nodal pairs shown.

Figure 7.1.18 and 7.1.19 show the diameter and radial time histories for the drum. The nodes are defined in Figure 3.1.34.

Figure 7.1.20 shows the diameter time history for nodal pairs along the length of the liner. Figure 3.1.37 shows the nodes and Table 3.1.3 gives the location of the nodes.

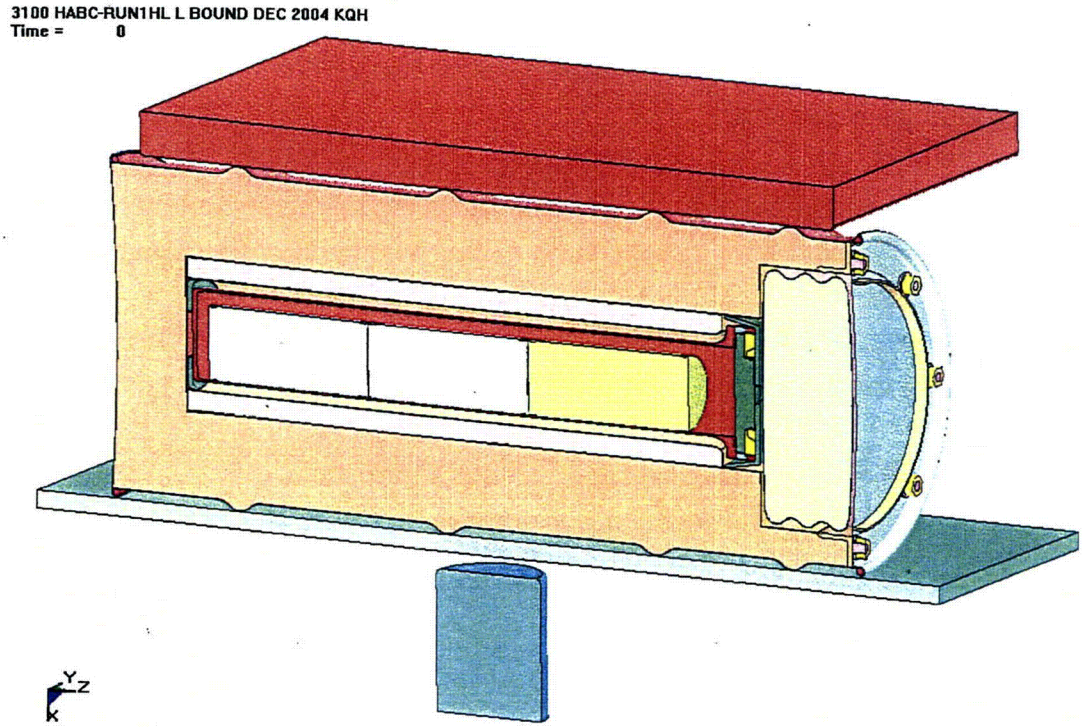


Figure 7.1.1 - HABC-run1hl, Initial Configuration

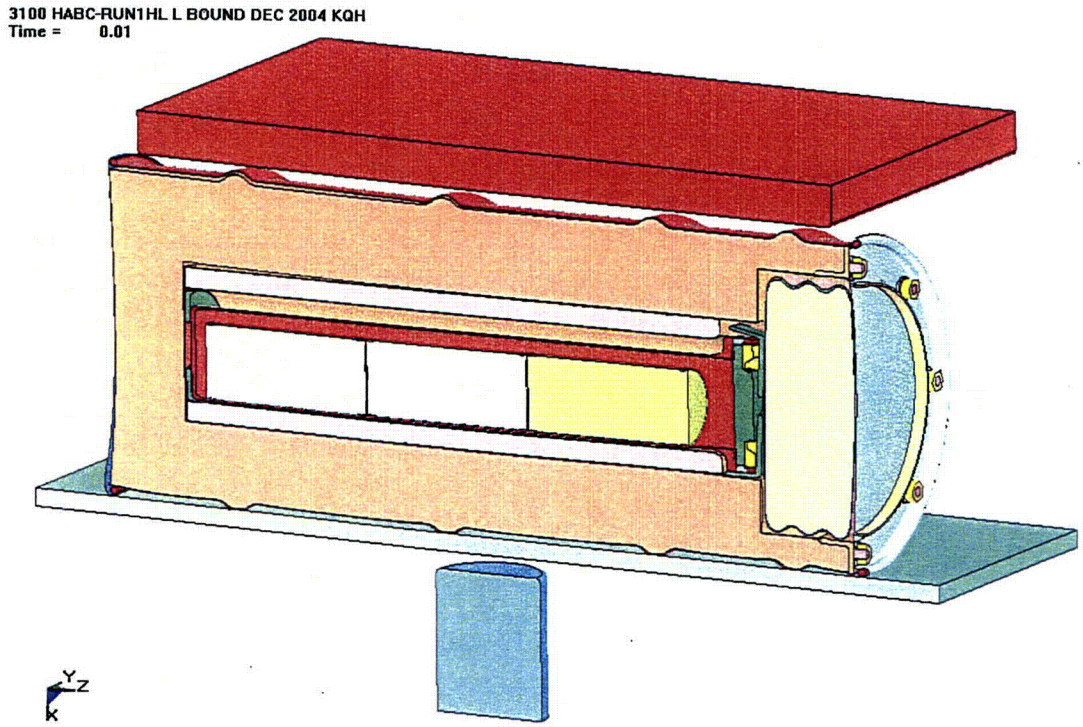


Figure 7.1.2 - HABC-run1hl, Configuration After the 4-Foot Impact

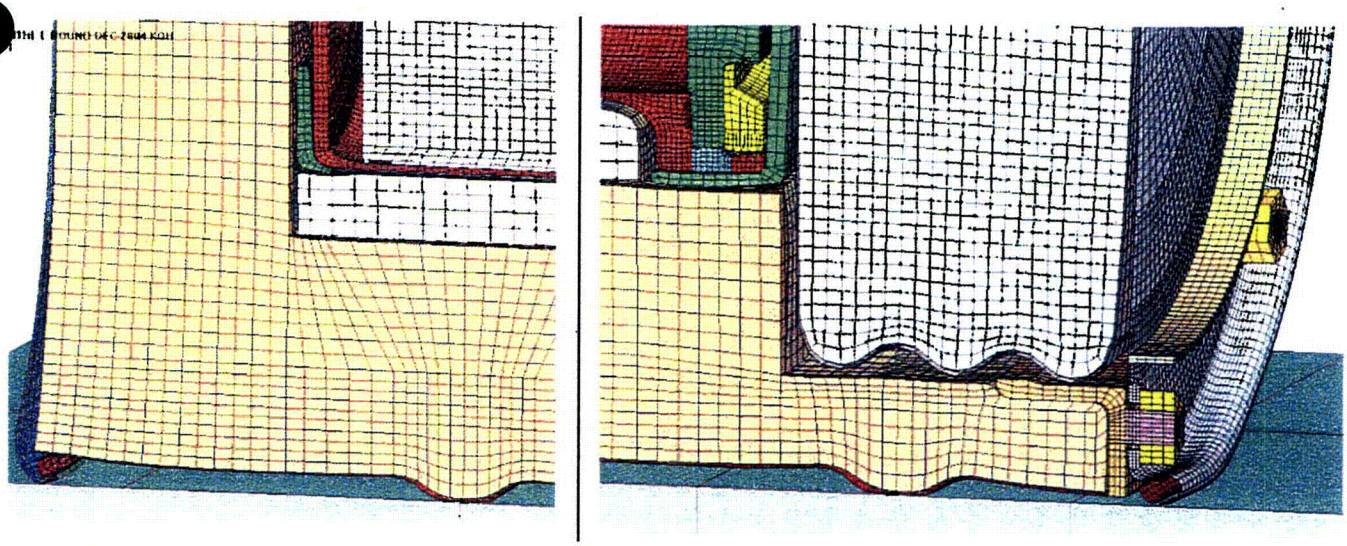


Figure 7.1.3 - HABC-run1hl, 4-Foot Impact, Configuration in the Lid and Bottom

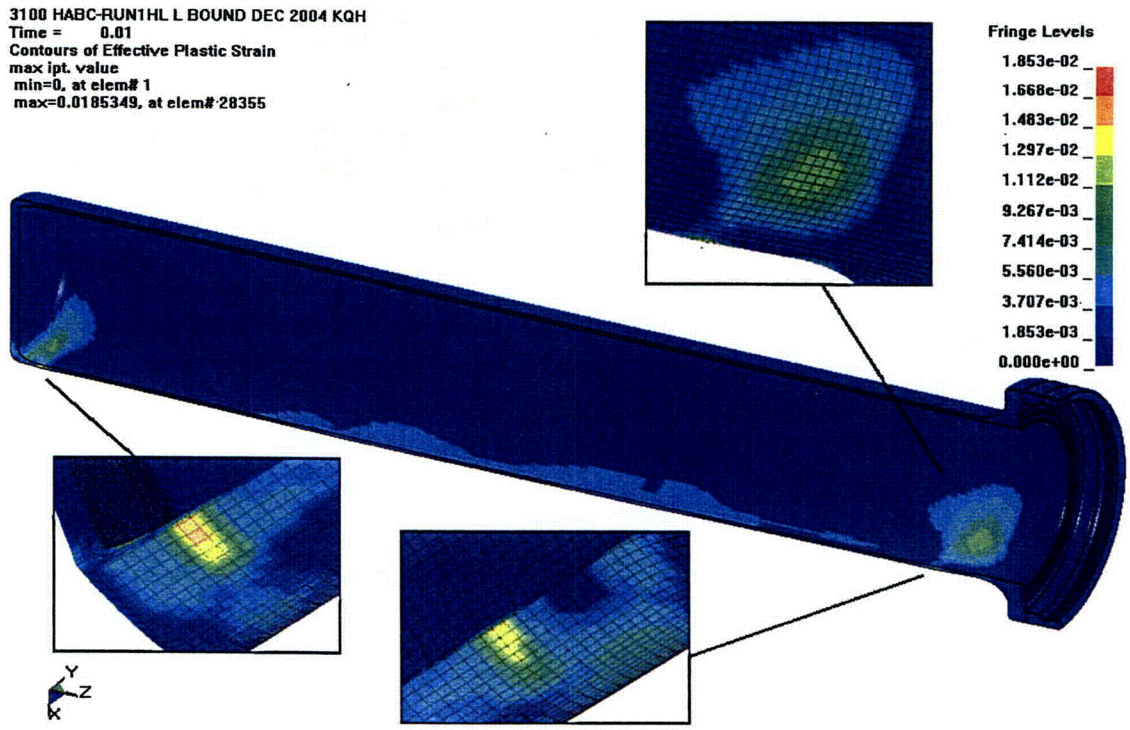


Figure 7.1.4 - HABC-run1hl, 4-Foot Impact, Effective Plastic Strain in the CV Body

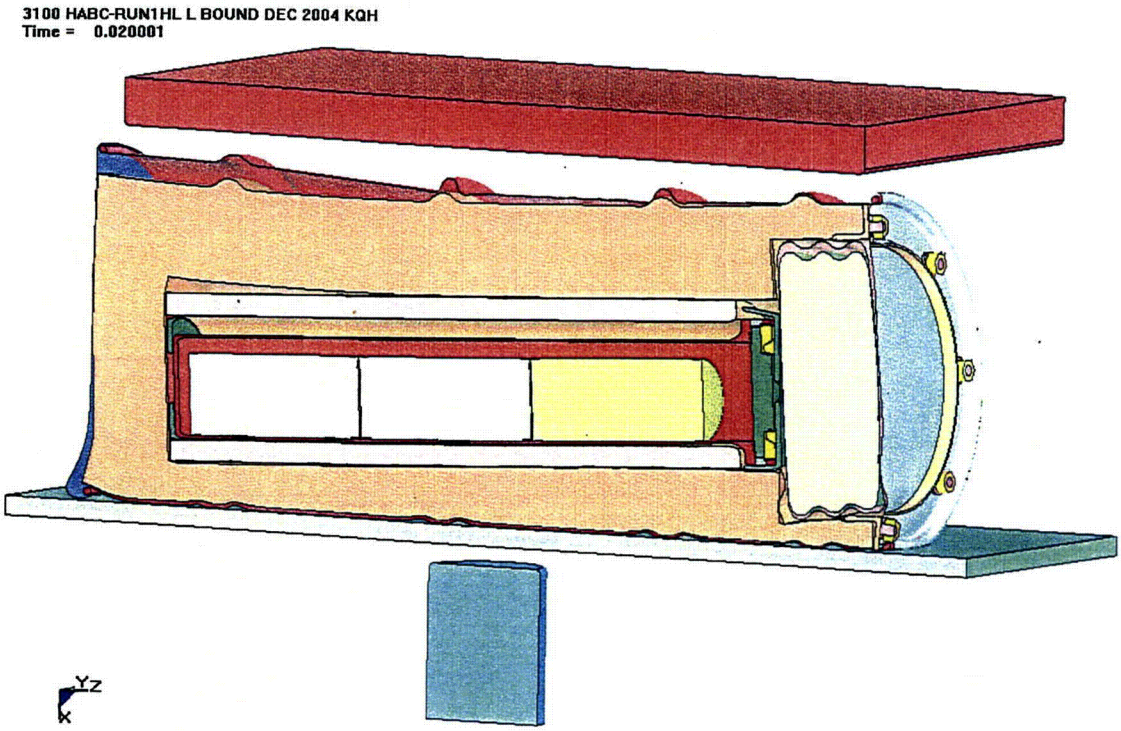


Figure 7.1.5 - HABC-run1hl, 30-Foot Impact, Final Configuration

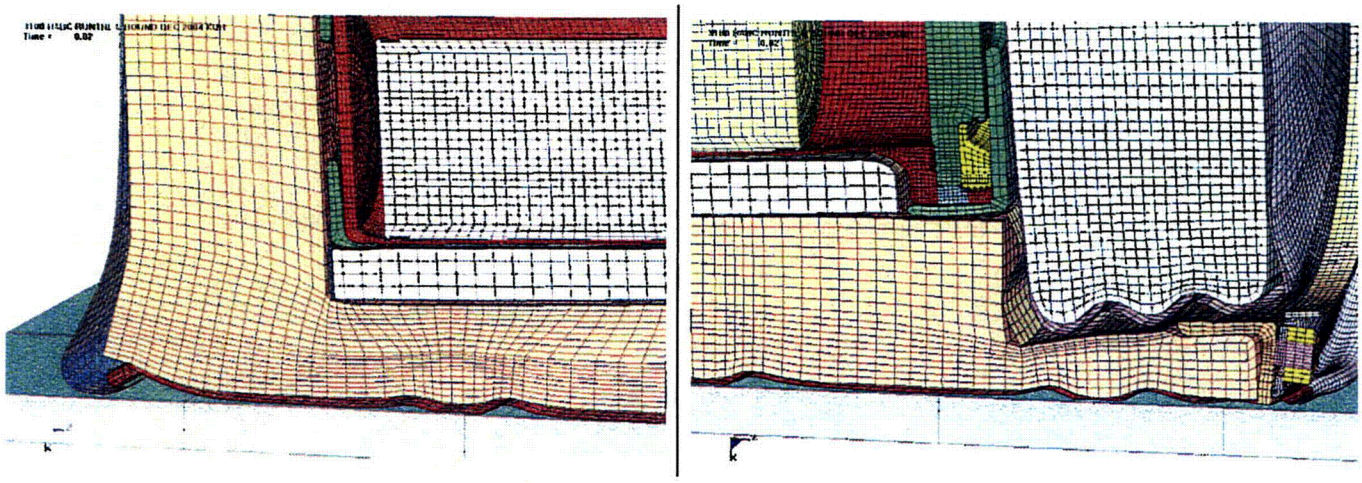


Figure 7.1.6 - HABC-run1hl, 30-Foot Impact, Configuration of the Lid and Bottom

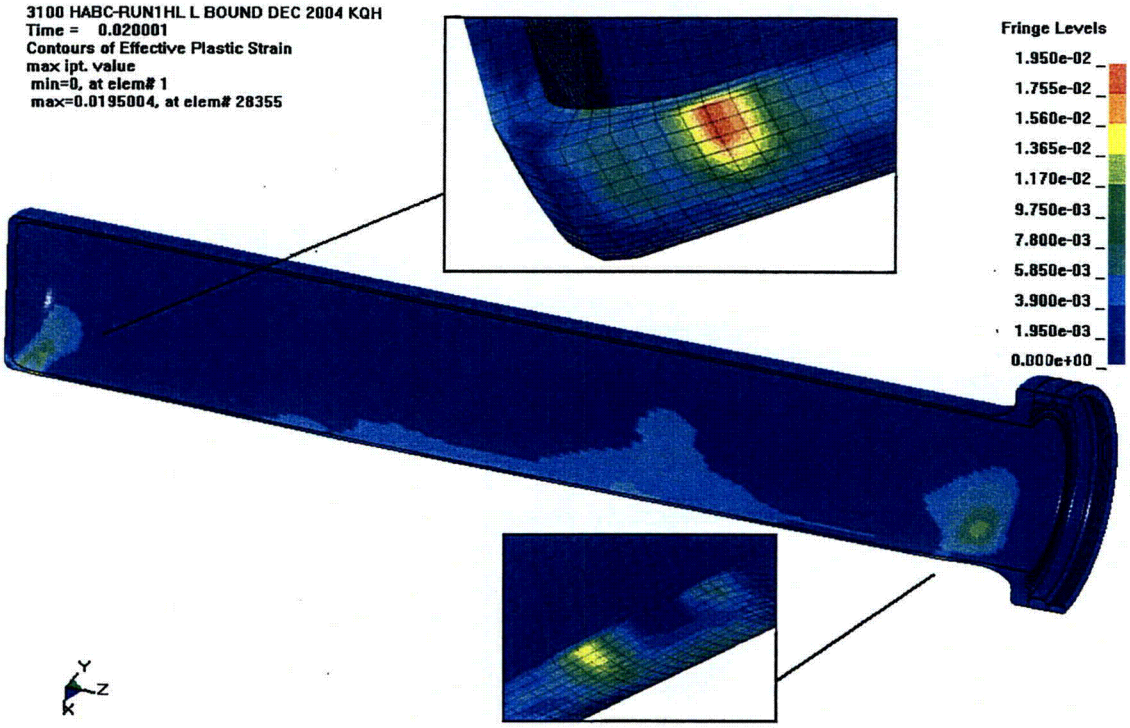


Figure 7.1.7 - HABC-run1hl, 30-Foot Impact, Effective Plastic Strain in the CV Body

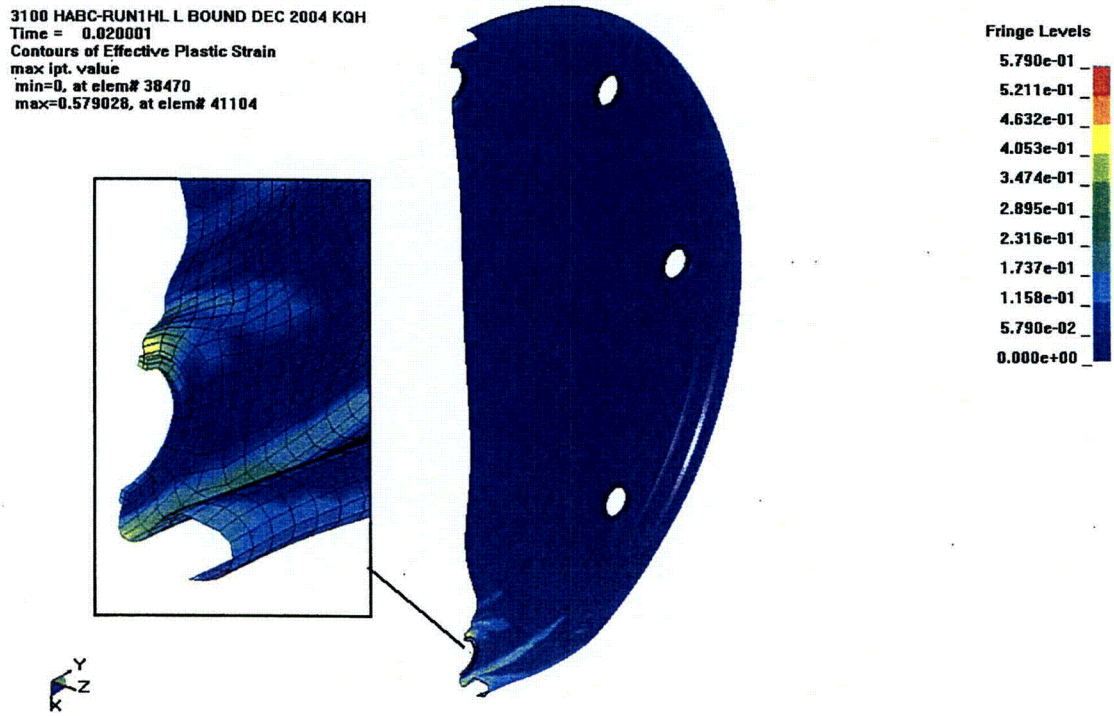


Figure 7.1.8 - HABC-run1hl, 30-Foot Impact, Effective Plastic Strain in the Lid

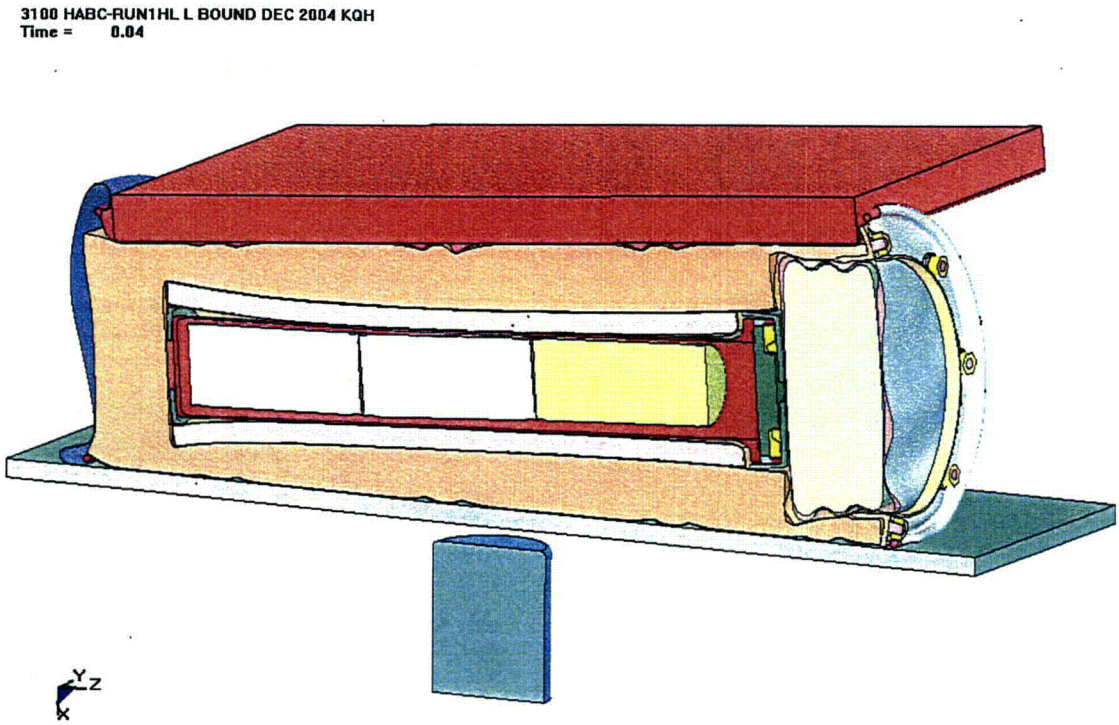


Figure 7.1.9 - HABC-run1hl, Crush Impact, Final Configuration

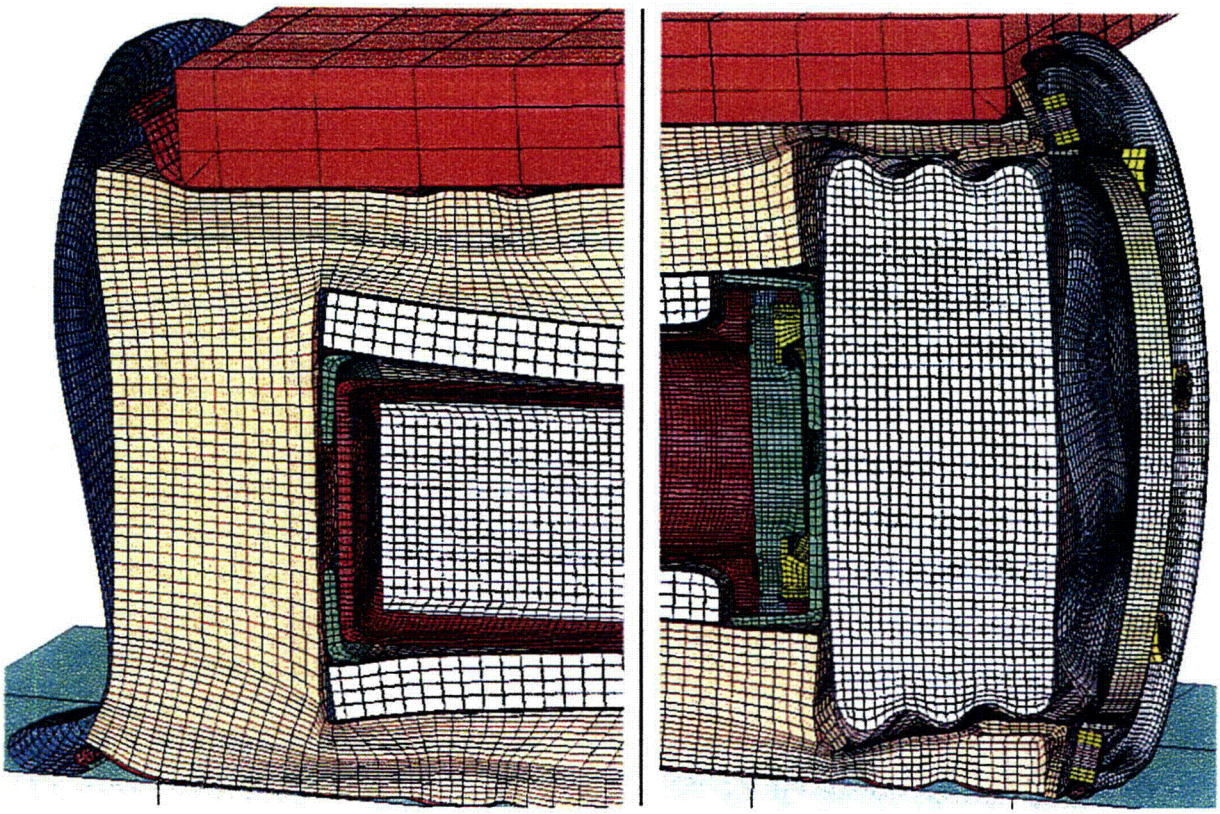


Figure 7.1.10 - HABC-run1hl, Crush Impact, Configuration of the Lid and Bottom

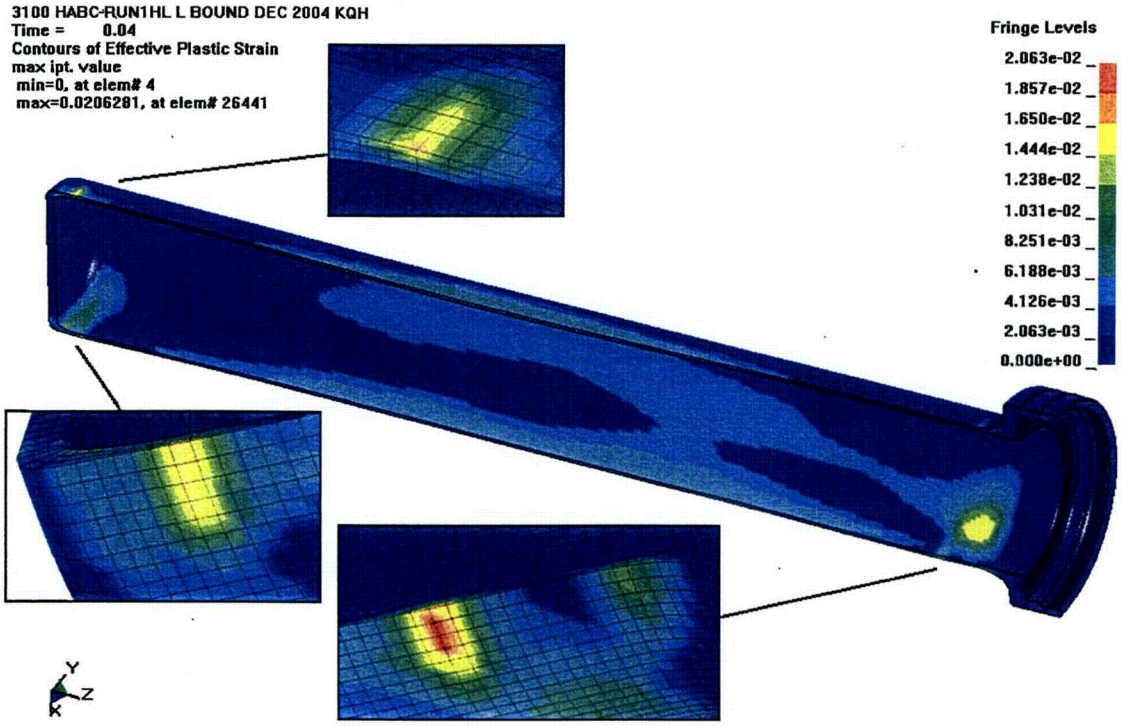


Figure 7.1.11 - HABC-run1hl, Crush Impact, Effective Plastic Strain in the CV Body

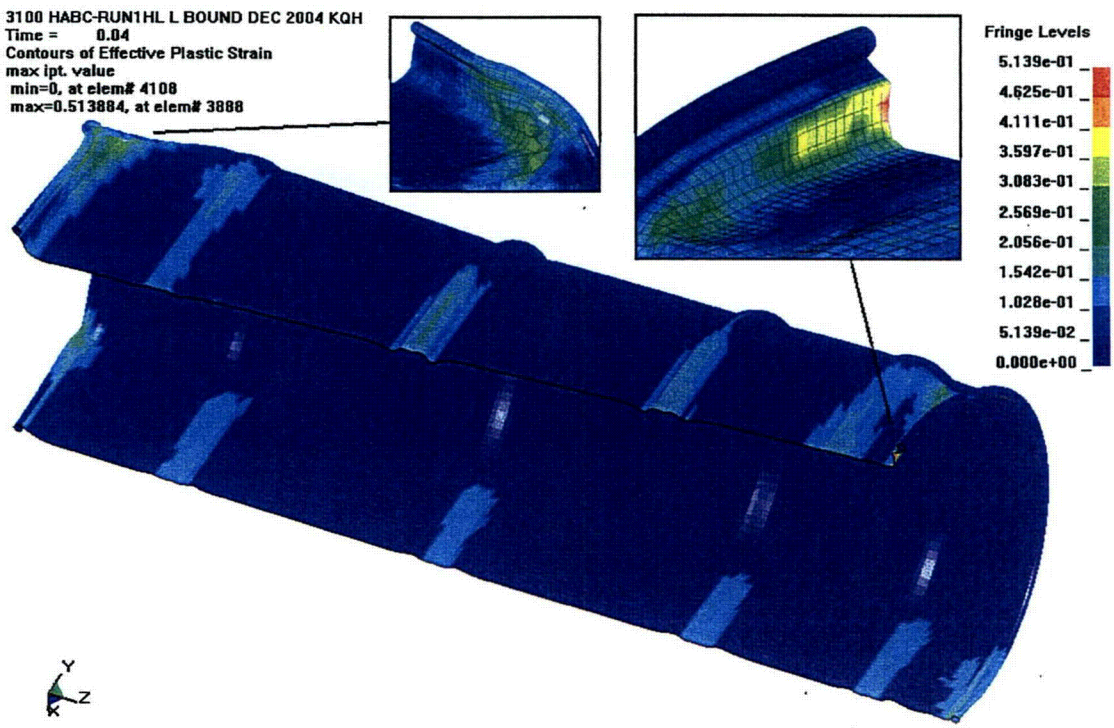


Figure 7.1.12 - HABC-run1hl, Crush Impact, Effective Plastic Strain in the Drum

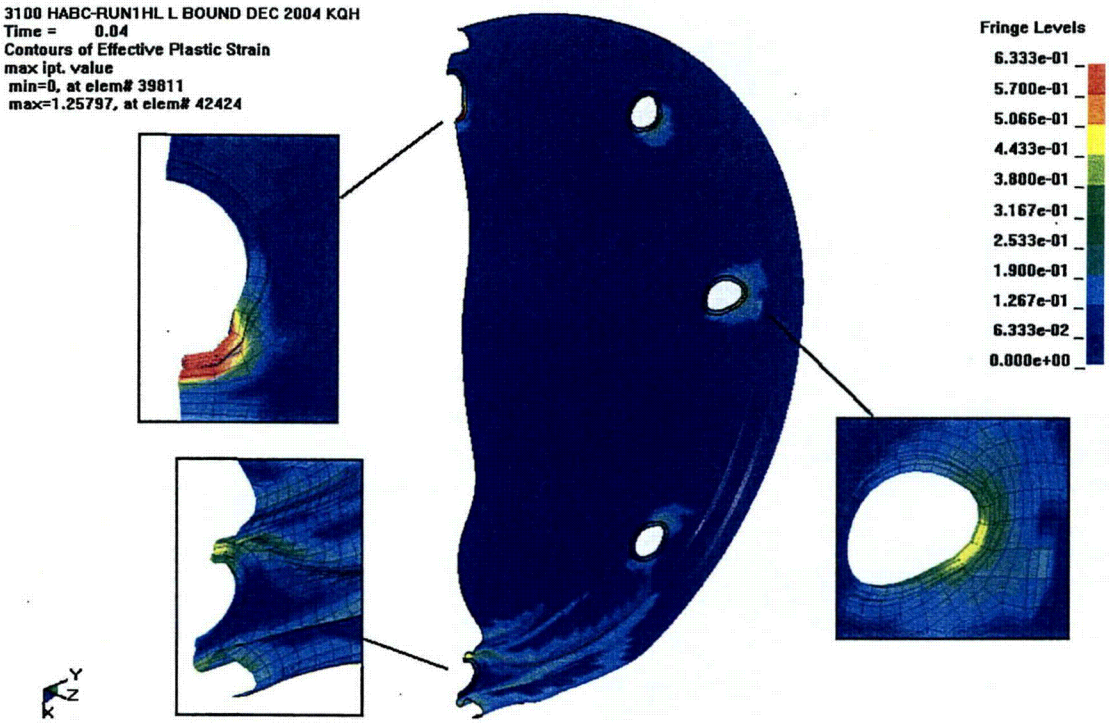


Figure 7.1.13 - HABC-run1hl, Crush Impact, Effective Plastic Strain in the Lid

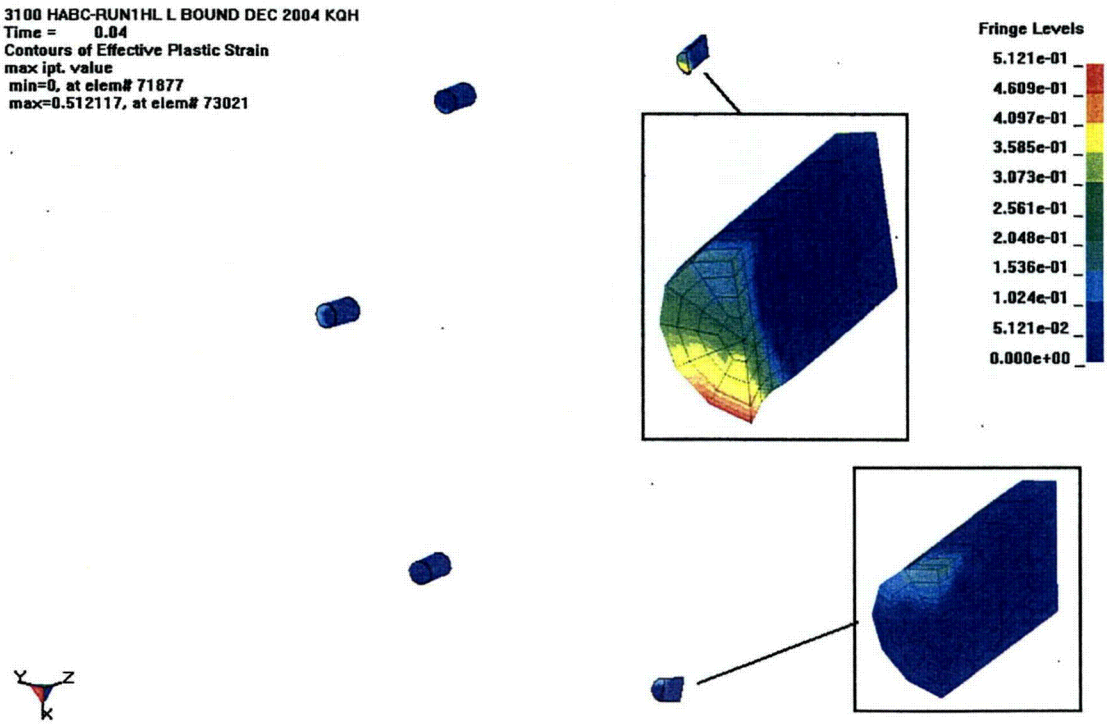


Figure 7.1.14 - HABC-run1hl, Crush Impact, Effective Plastic Strain in the Studs

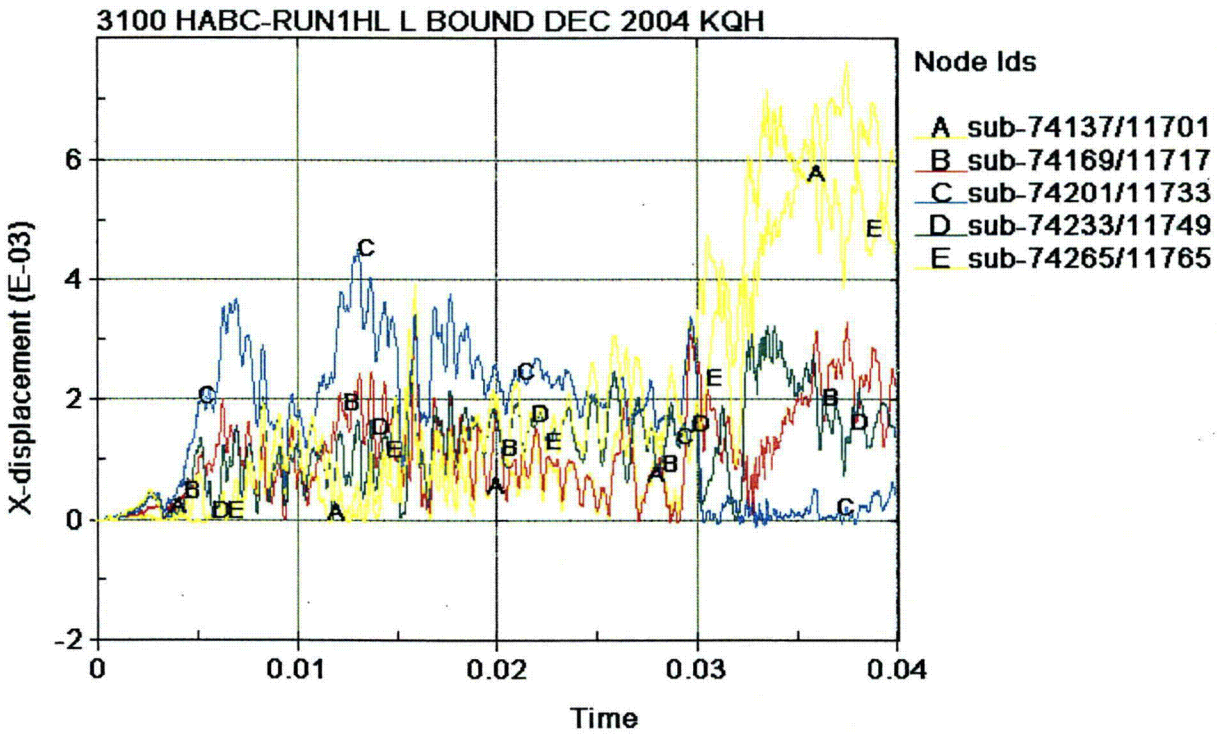


Figure 7.1.15 - HABC-run1hl, CV Lid Separation Time History

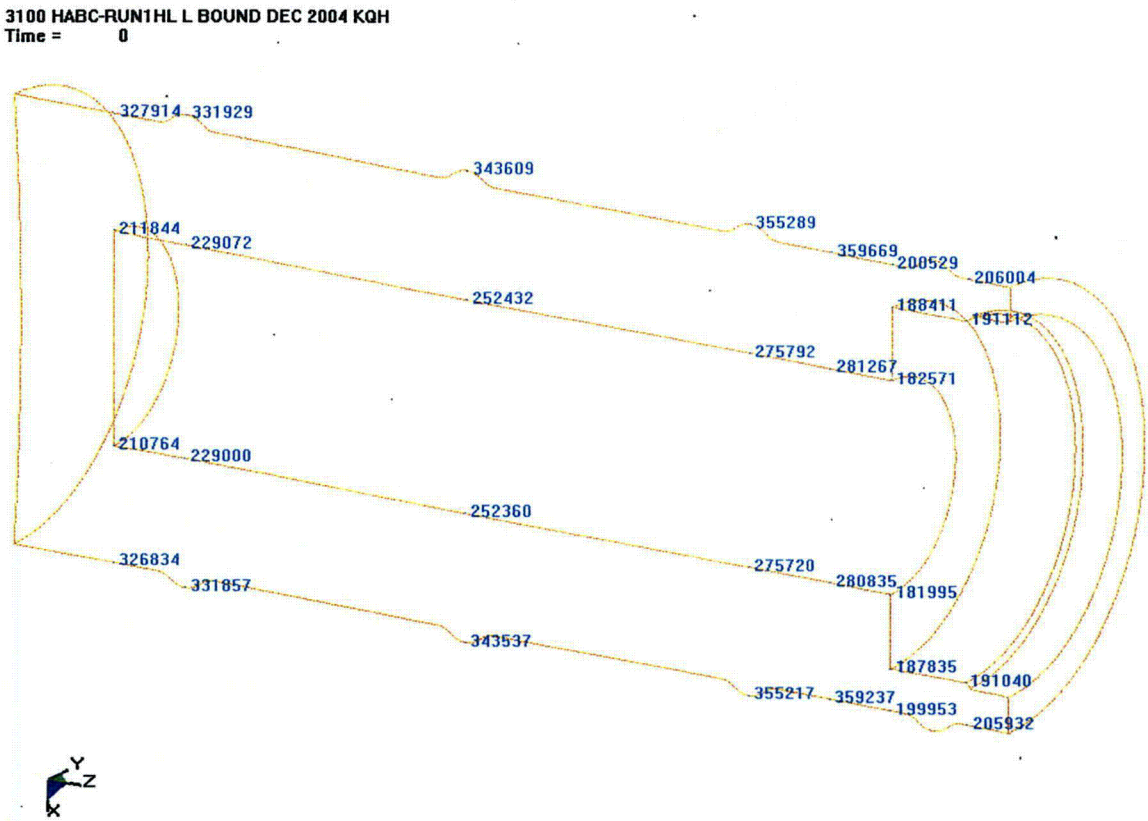


Figure 7.1.16 - HABC-run1hl, Kaolite Nodes

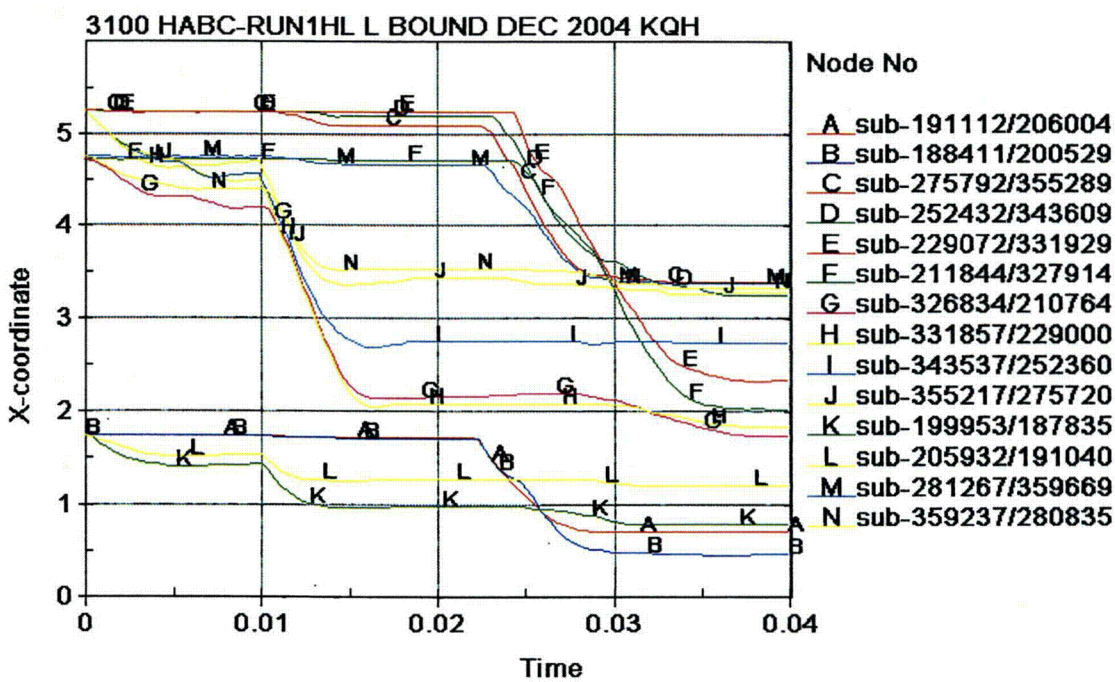


Figure 7.1.17 - HABC-run1hl, Kaolite Thickness Time History

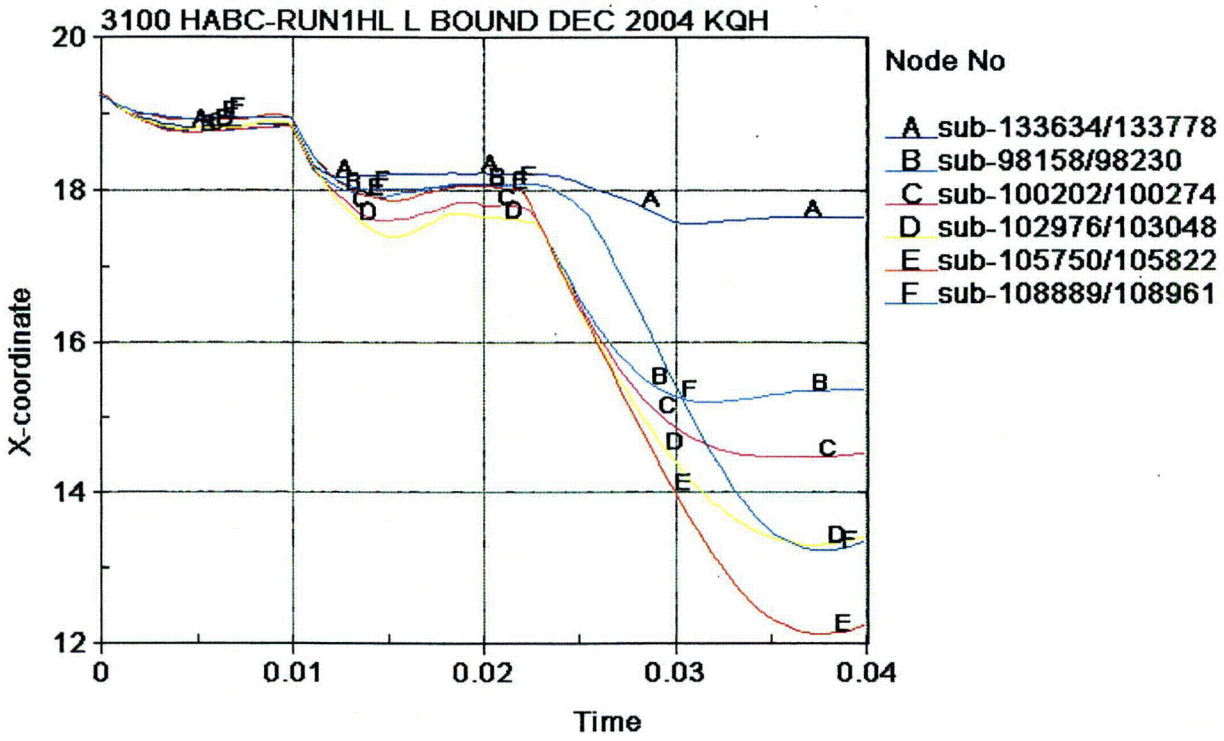


Figure 7.1.18 - HABC-run1hl, Drum Diameter Time History in the X Direction

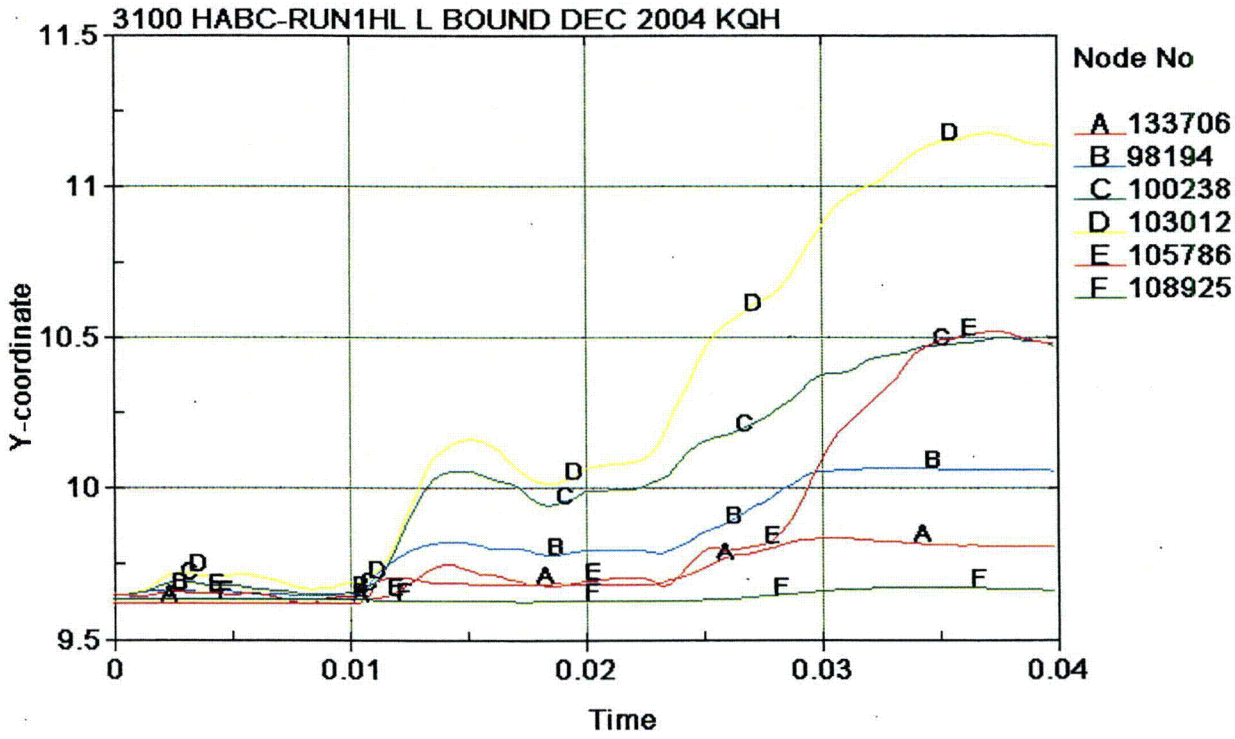


Figure 7.1.19 - HABC-run1hl, Drum Diameter Time History in the Y Direction

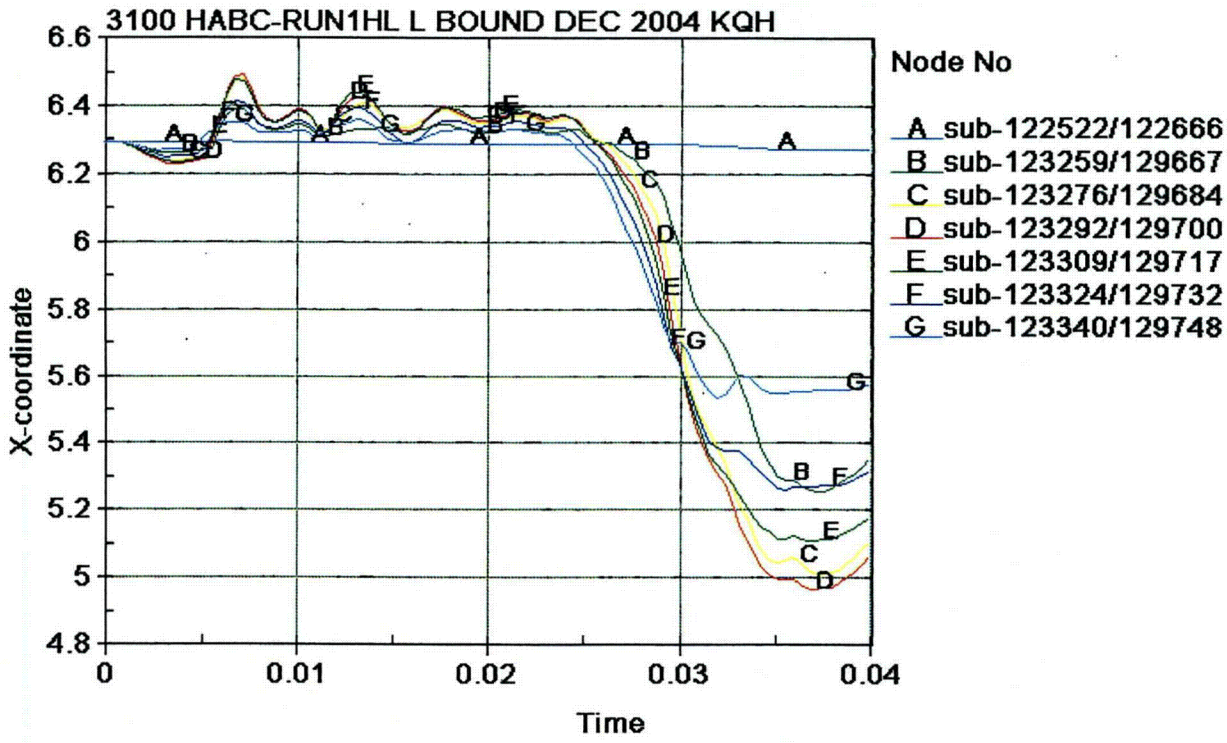


Figure 7.1.20 - HABC-run1hl, Diameter Changes in the Inner Liner

7.2 HABC-run1hh - Upper Bounding Side

HABC-run1hh are the runs with the lower bounding material properties for the kaolite and the HABC materials. The 4-foot impact occurs from time = 0.0 to 0.01 seconds; the 30-foot impact occurs from 0.01 to 0.0188 seconds; and the crush impact occurs from 0.0188 to 0.04 seconds.

The final configuration for the 4-foot impact is shown in Figure 7.2.1. The configuration at the ends of the package are shown in Figure 7.2.2. The effective plastic strain in the CV body for the 4-foot impact is shown in Figure 7.2.3 to be a maximum of 0.0238 in/in. The effective plastic strains in other package components for the 4-foot impact are listed in Table 7.2.1.

Table 7.2.1 - Run1hh, 4-Foot Impact, Effective Plastic Strain Levels in Some Components

Component	Effective Plastic Strain, in/in
CV Lid	0.0000
CV Nut Ring	0.0000
Angle	0.0061
Drum	0.1207
Drum Bottom Head	0.1252
Liner	0.0991
Lid	0.1604
Lid Stiffener	0.0006
Lid Studs	0.0000
Lid Stud Nuts	0.0000
Lid Stud Washers	0.0411
Plug Liner	0.0045

The final configuration for the 30-foot impact is shown in Figure 7.2.4. The configuration at the ends of the package are shown in Figure 7.2.5. The maximum effective plastic strain for the 30-foot impact in the CV Body is 0.0347 in/in near the bottom head (Figure 7.2.6). The maximum effective plastic strain in the drum lid is 0.4063 in/in at the stud near the rigid plane as shown in Figure 7.2.7. The effective plastic strain in other components for the 30-foot impact are given in Table 7.2.2.

Table 7.2.2 - HABC-run1hh, 30-Foot Impact, Effective Plastic Strain Levels in Some Components	
Component	Effective Plastic Strain, in/in
CV Lid	0.0001
CV Nut Ring	0.0000
Angle	0.0632
Drum	0.2296
Drum Bottom Head	0.2517
Liner	0.1184
Lid Stiffener	0.0076
Lid Studs	0.1306
Lid Stud Nuts	0.0004
Lid Stud Washers	0.0424
Plug Liner	0.1072

The configuration after the crush impact is shown in Figure 7.2.8. The configuration at the ends of the package are shown in Figure 7.2.9. The maximum effective plastic strain for the crush impact in the CV body is 0.0525 in/in, on the crush plate side near the lid end of the top inner weight (Figure 7.2.10). The maximum effective plastic strain in the drum is 0.2814 in/in near the angle and the rigid plane (Figure 7.2.11). The maximum effective plastic strain in the drum lid is 0.6413 in/in (surface strain) a shown in Figure 7.2.12. The maximum occurs at the lid hole for the stud closest to the crush plate (180°). The membrane effective plastic strain is 0.4907 in/in at this location in the lid. Figure 7.2.13 shows that the maximum effective plastic strain in the studs is 0.2364 in/in. The effective plastic strain in other components are listed in Table 7.2.3 for the crush impact.

Table 7.2.3 - Run1hh, Crush Impact, Effective Plastic Strain Levels in Some Components	
Component	Effective Plastic Strain, in/in
CV Lid	0.0004
CV Nut Ring	0.0005
Angle	0.0845
Drum Bottom Head	0.2827
Liner	0.2022
Lid Stiffener	0.0171
Lid Stud Nuts	0.0018
Lid Stud Washers	0.0439
Plug Liner	0.1286

The lid separation time history is shown in Figure 7.2.14. The nodes are shown in Figure 3.1.30. The response is oscillatory with peak gap separation on the order of 0.010 in. At the end of the impact, the peaks are on the order of 0.006 in with an average gap on the order of 0.003 in or less.

The kaolite thickness time history is shown in Figure 7.2.15. The nodal pairs are shown in Figure 7.1.16.

Figure 7.2.16 and 7.2.17 show the drum diameter and radial time histories. The nodes are defined in Figure 3.1.34.

Figure 7.2.18 shows the diameter response of the liner. Figure 3.1.37 and Table 3.1.3 define the liner nodes used in Figure 7.2.18.

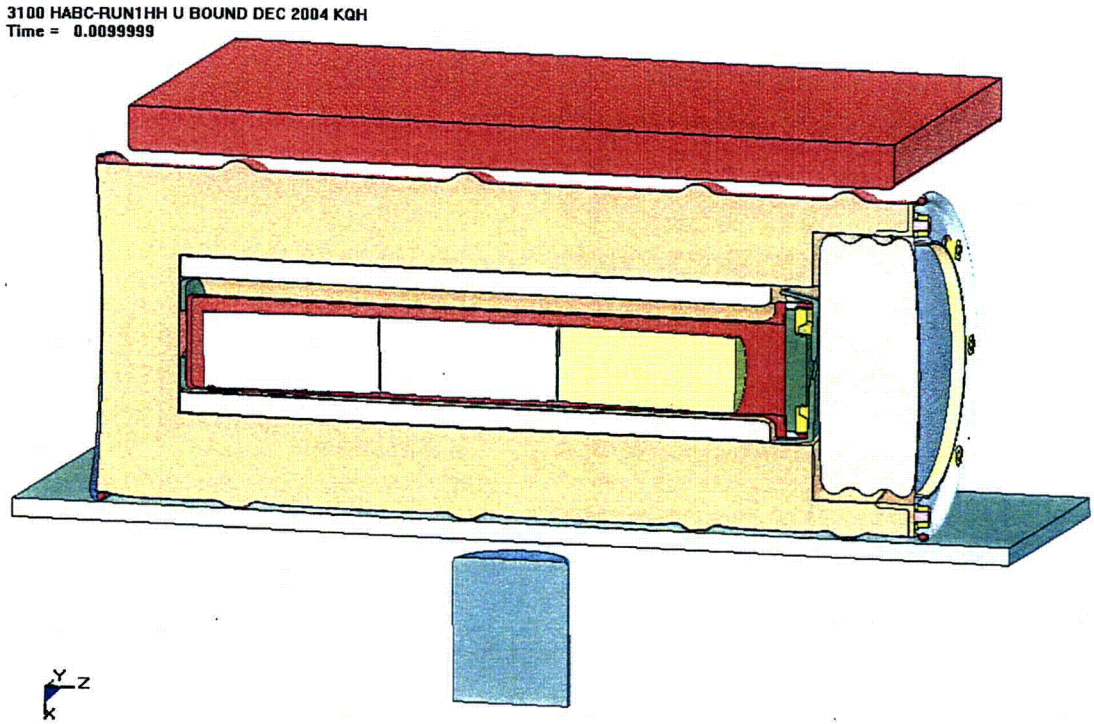


Figure 7.2.1 - HABC-run1hh, Configuration After the 4-Foot Impact

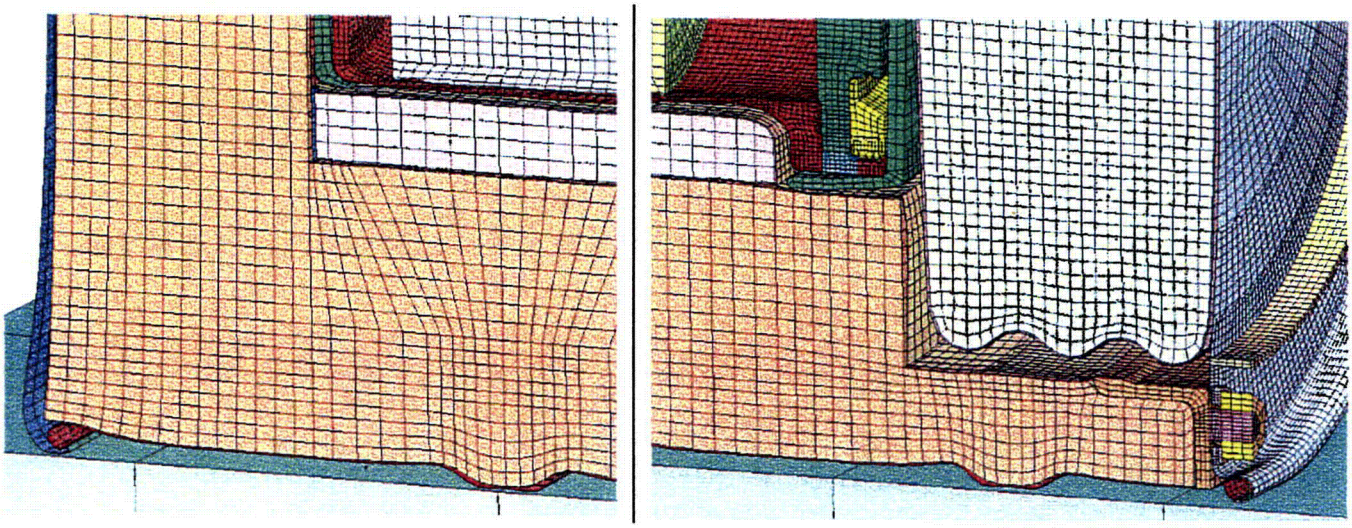


Figure 7.2.2 - HABC-run1hh, 4-Foot Impact, Configuration of the Lid and Bottom

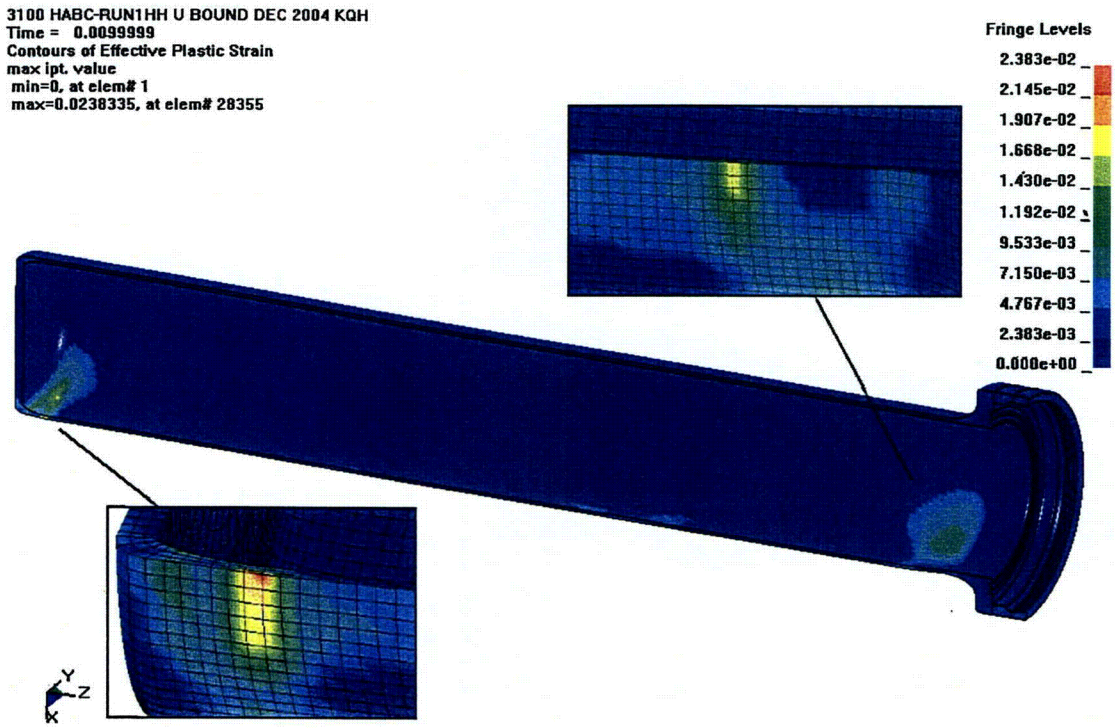


Figure 7.2.3 - HABC-run1hh, 4-Foot Impact, Effective Plastic Strain in the CV Body

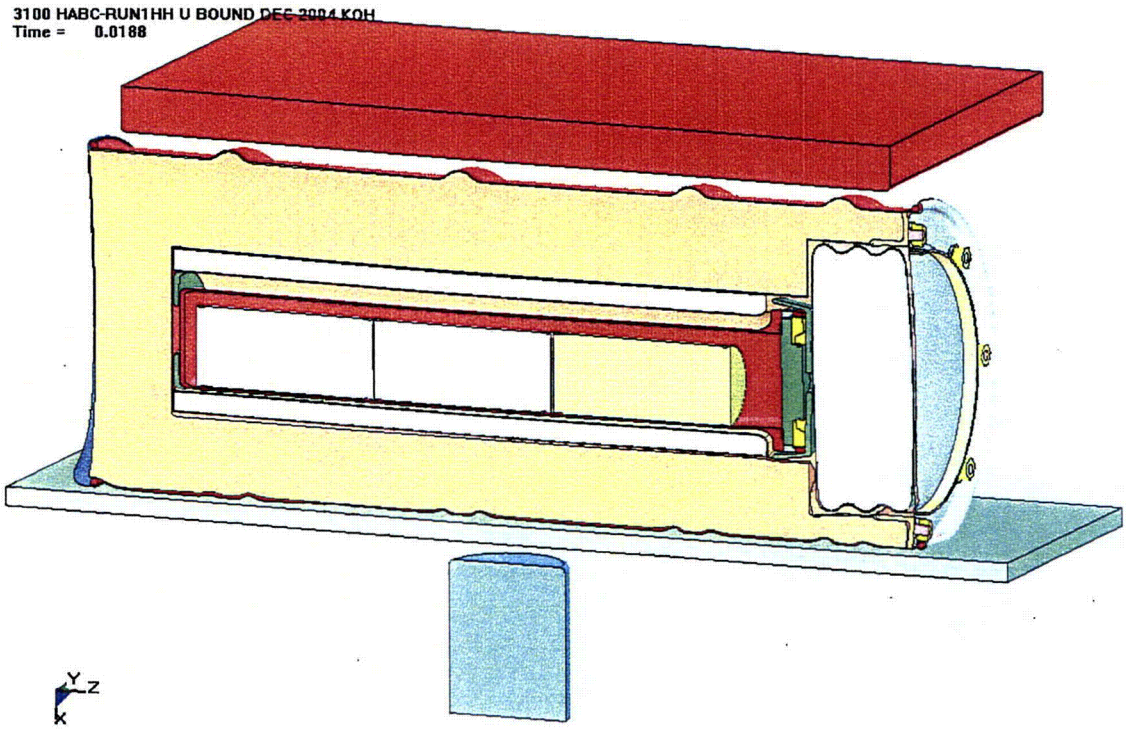


Figure 7.2.4 - HABC-run1hh, Configuration After the 30-Foot Impact

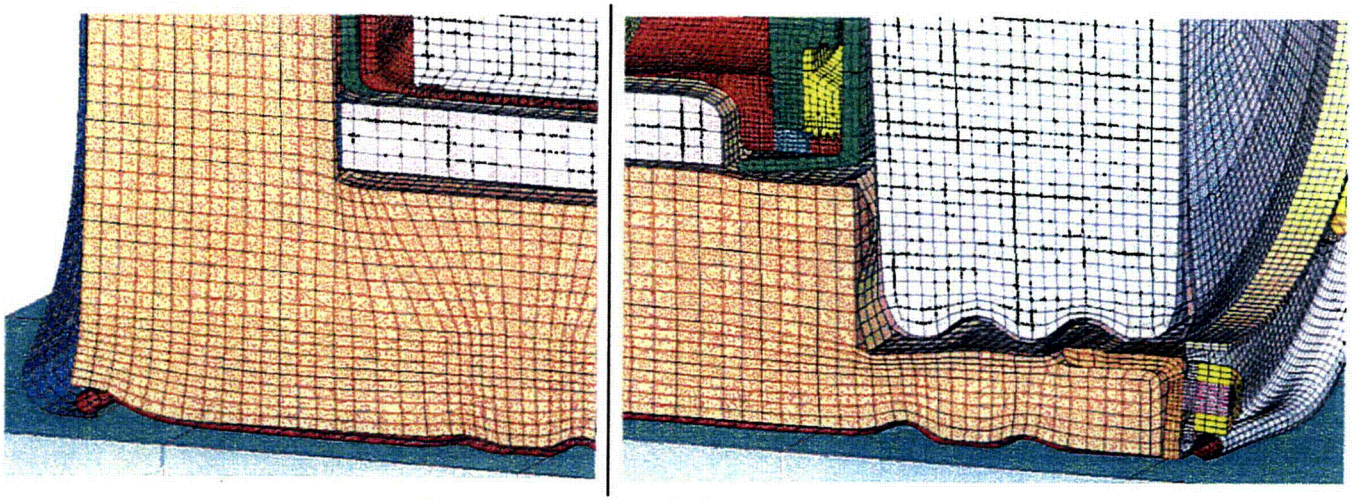


Figure 7.2.5 - HABC-run1hh, 30-Foot Impact, Configuration of the Lid and Bottom

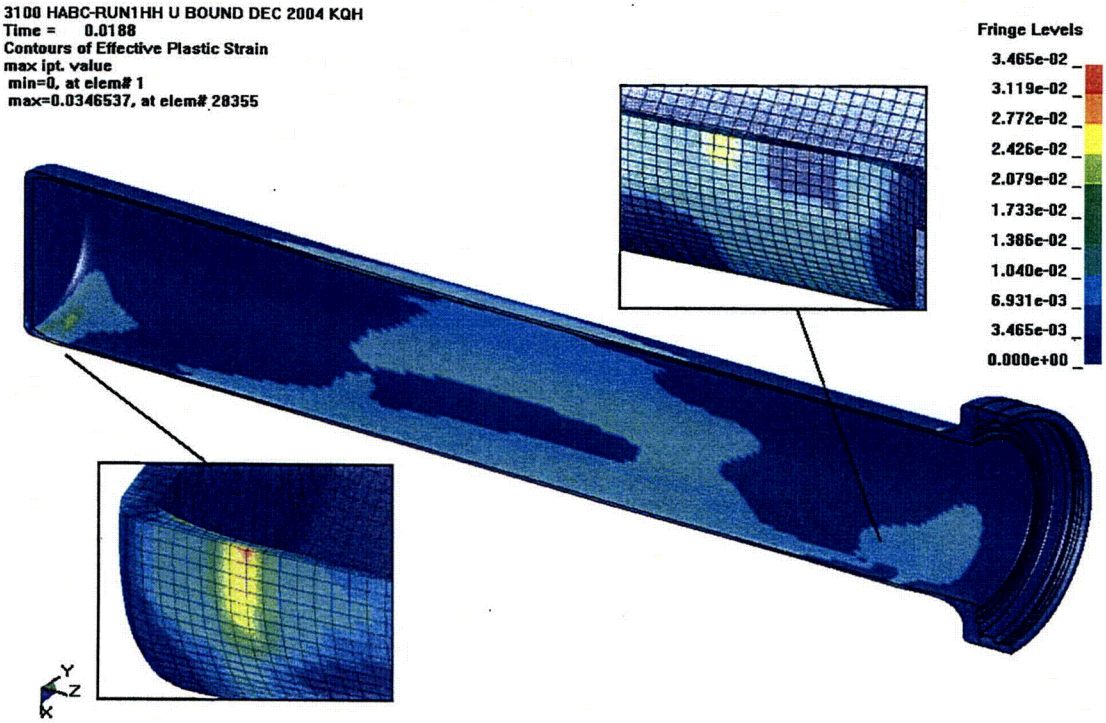


Figure 7.2.6 - HABC-run1hh,30-Foot Impact, Effective Plastic Strain in the CV Body

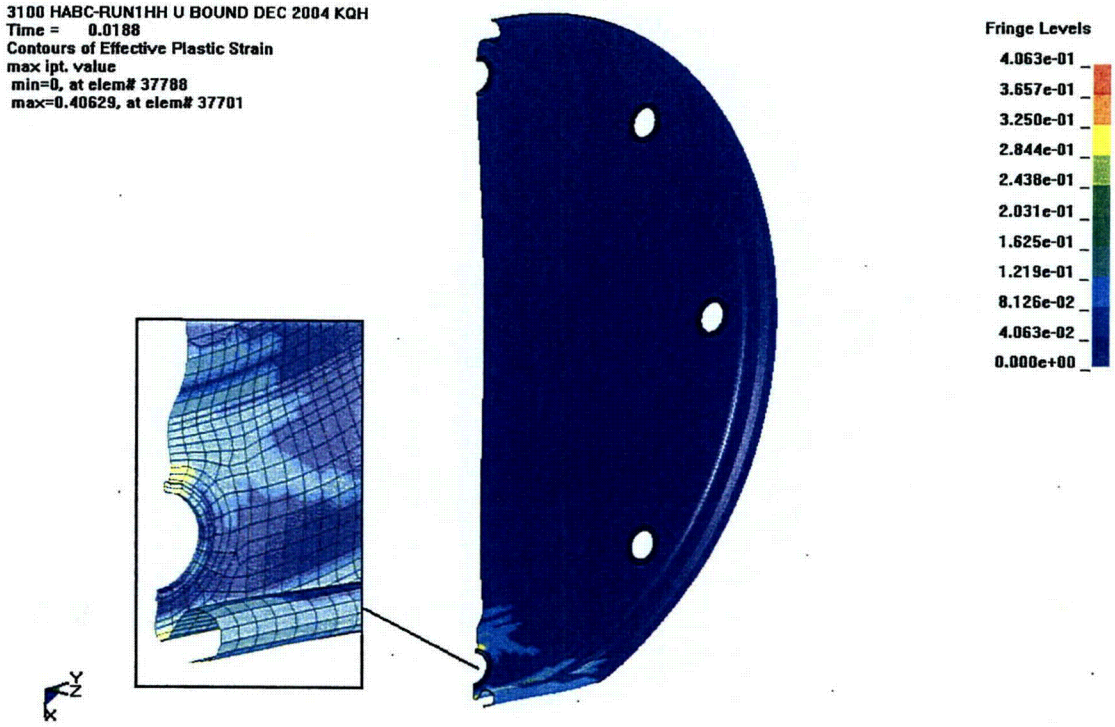


Figure 7.2.7 - HABC-run1hh, 30-Foot Impact, Effective Plastic Strain in the Lid

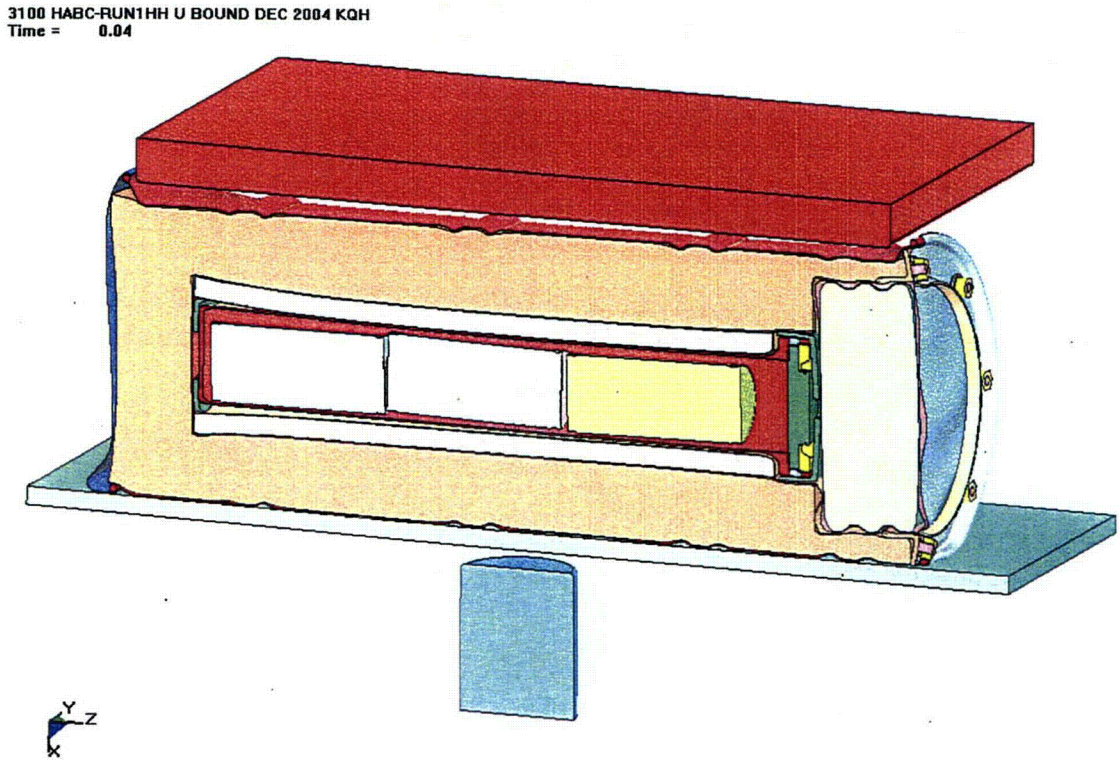


Figure 7.2.8 - HABC-run1hh, Configuration After the Crush Impact

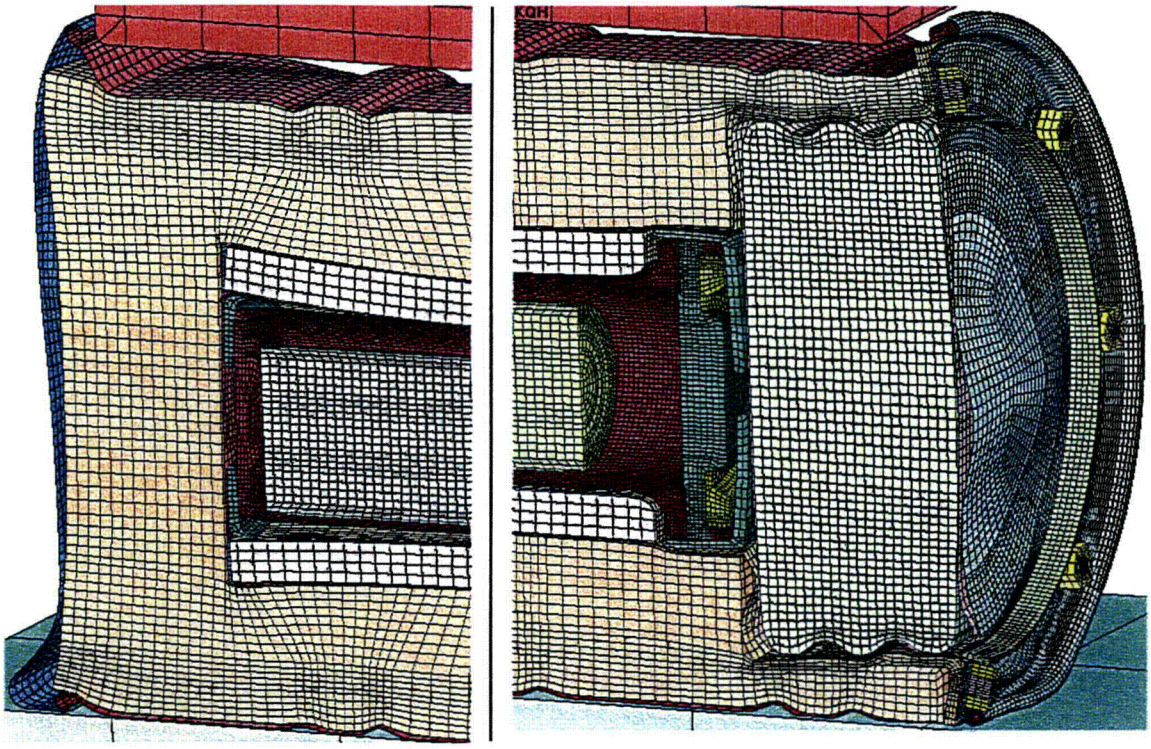


Figure 7.2.9 - HABC-run1hh, Crush Impact, Configuration of the Lid and Bottom

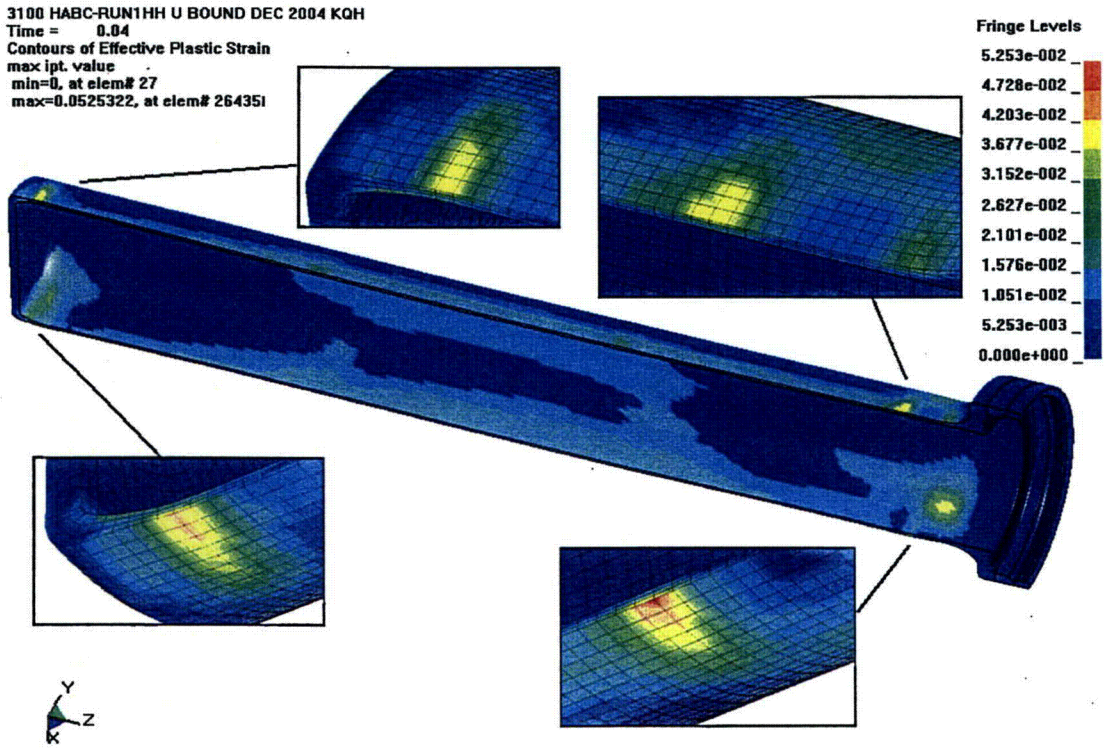


Figure 7.2.10 - HABC-run1hh, Crush Impact, Effective Plastic Strain in the CV Body

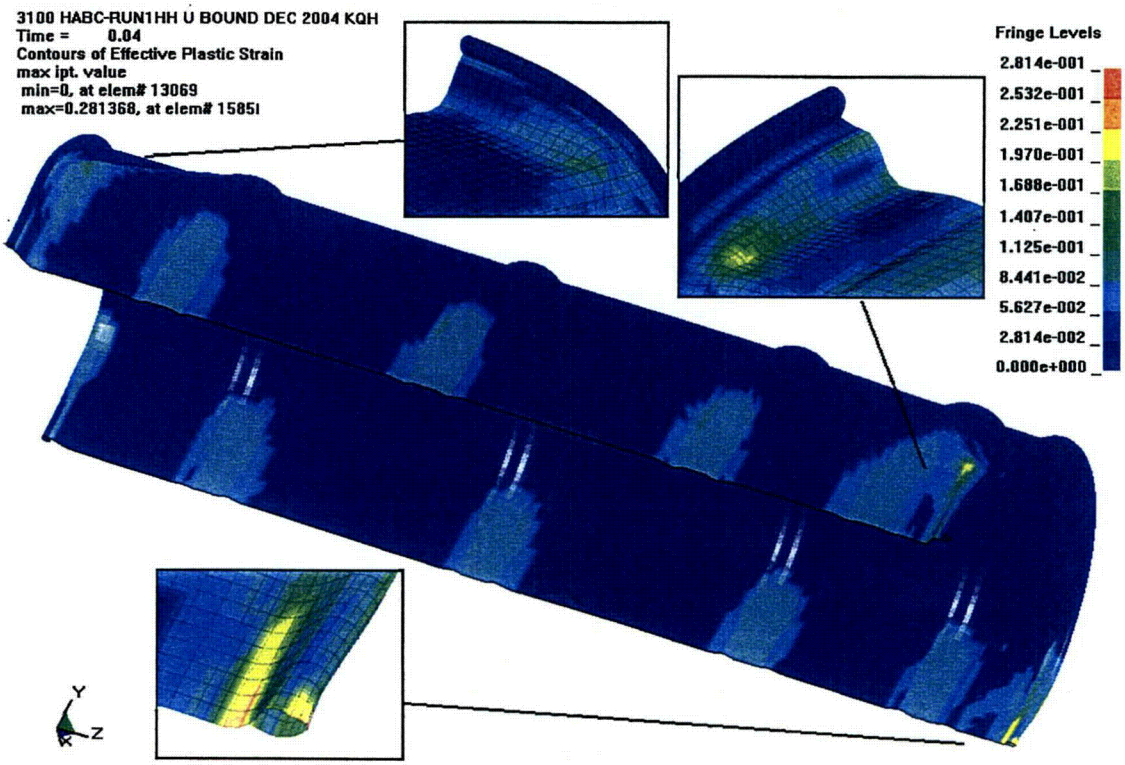


Figure 7.2.11 - HABC-run1hh, Crush Impact, Effective Plastic Strain in the Drum

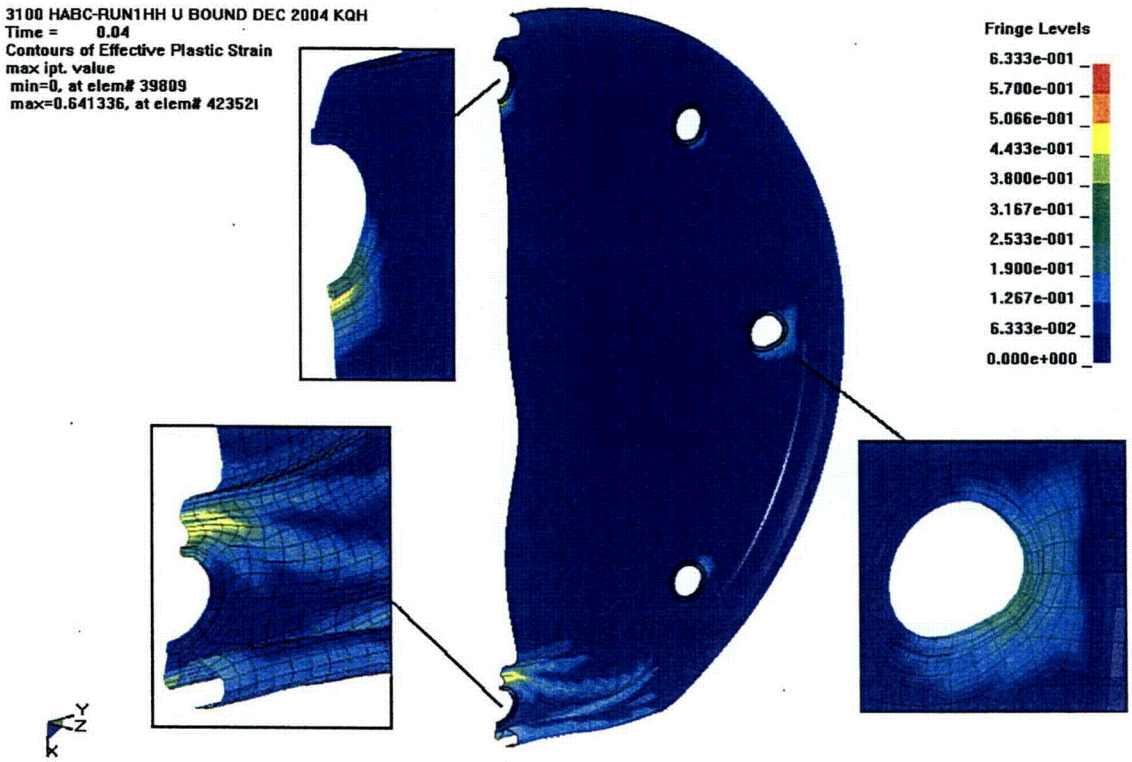


Figure 7.2.12 - HABC-run1hh, Crush Impact, Effective Plastic Strain in the Lid

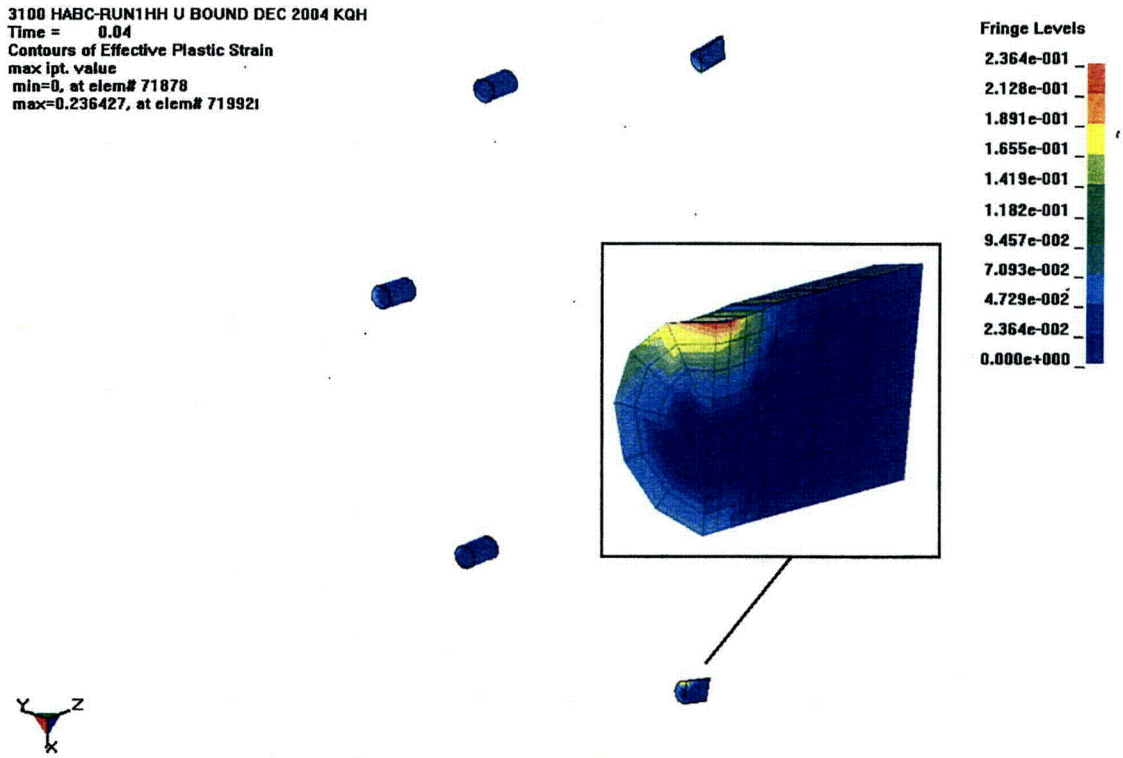


Figure 7.2.13 - HABC-run1hh, Crush Impact, Effective Plastic Strain in the Studs

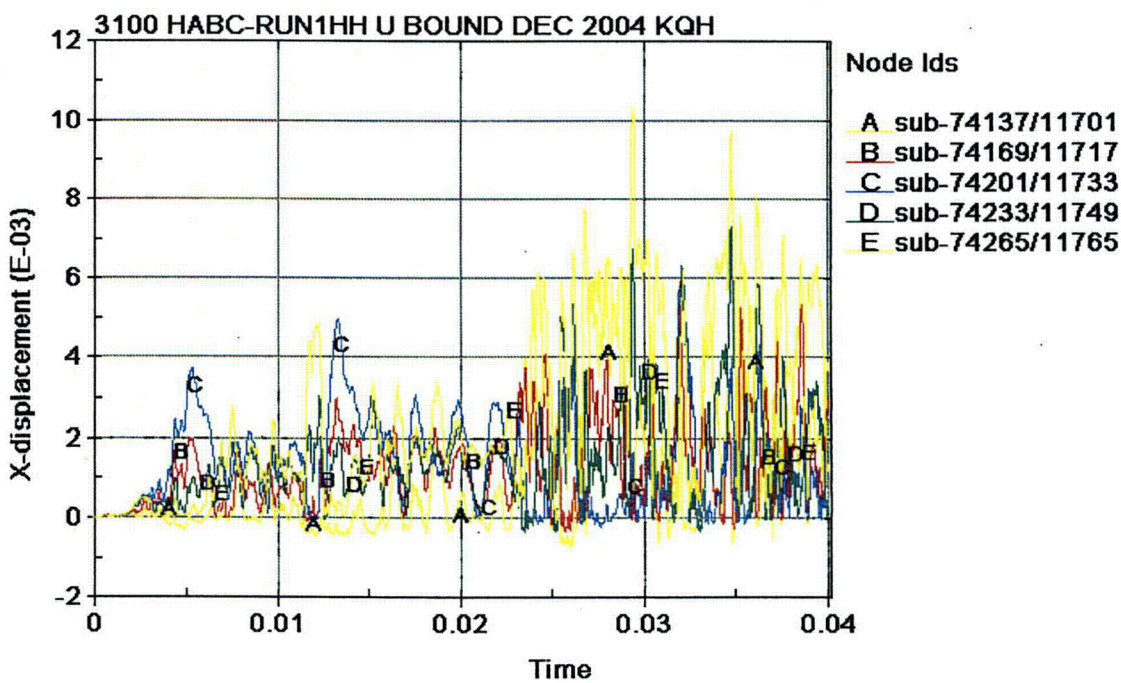


Figure 7.2.14 - HABC-run1hh, CV Lid Separation Time History

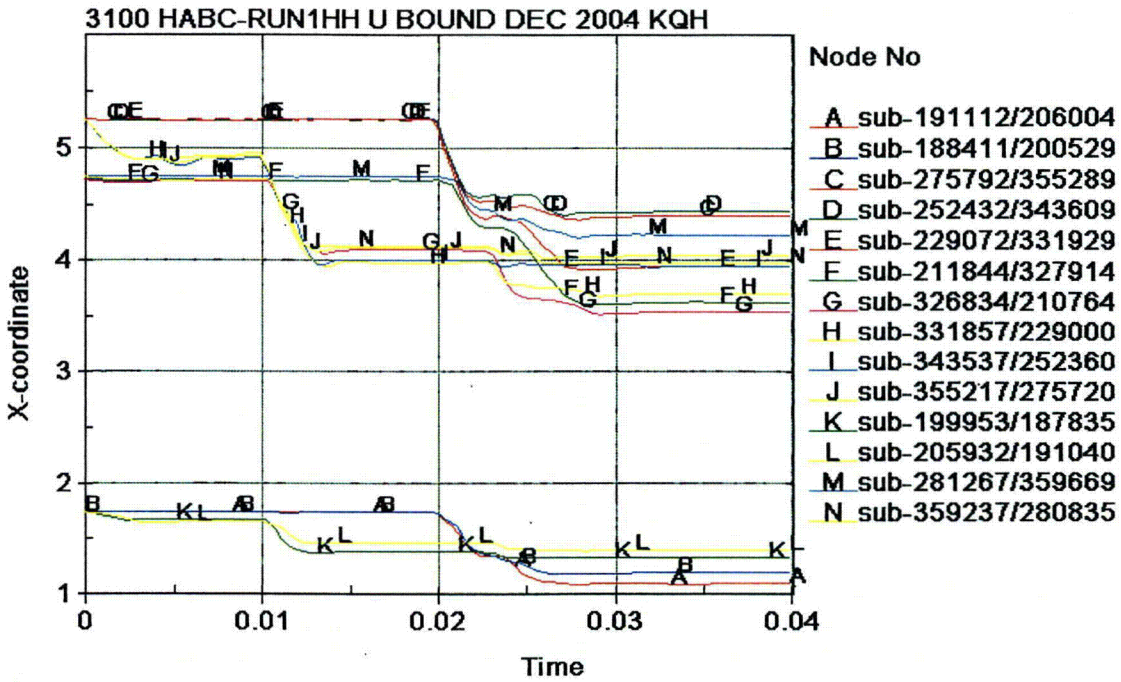


Figure 7.2.15 - HABC-run1hh, Kaolite Thickness Time History

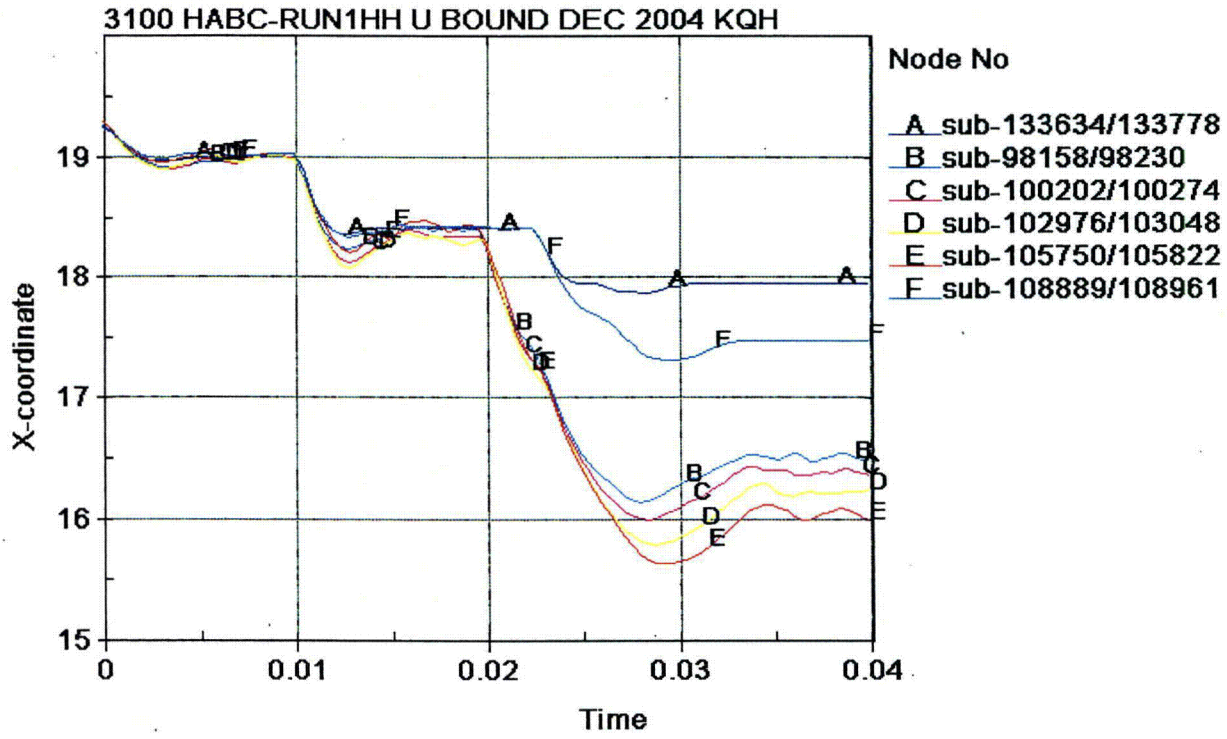


Figure 7.2.16 - HABC-run1hh, Drum Diameter Time History in the X Direction

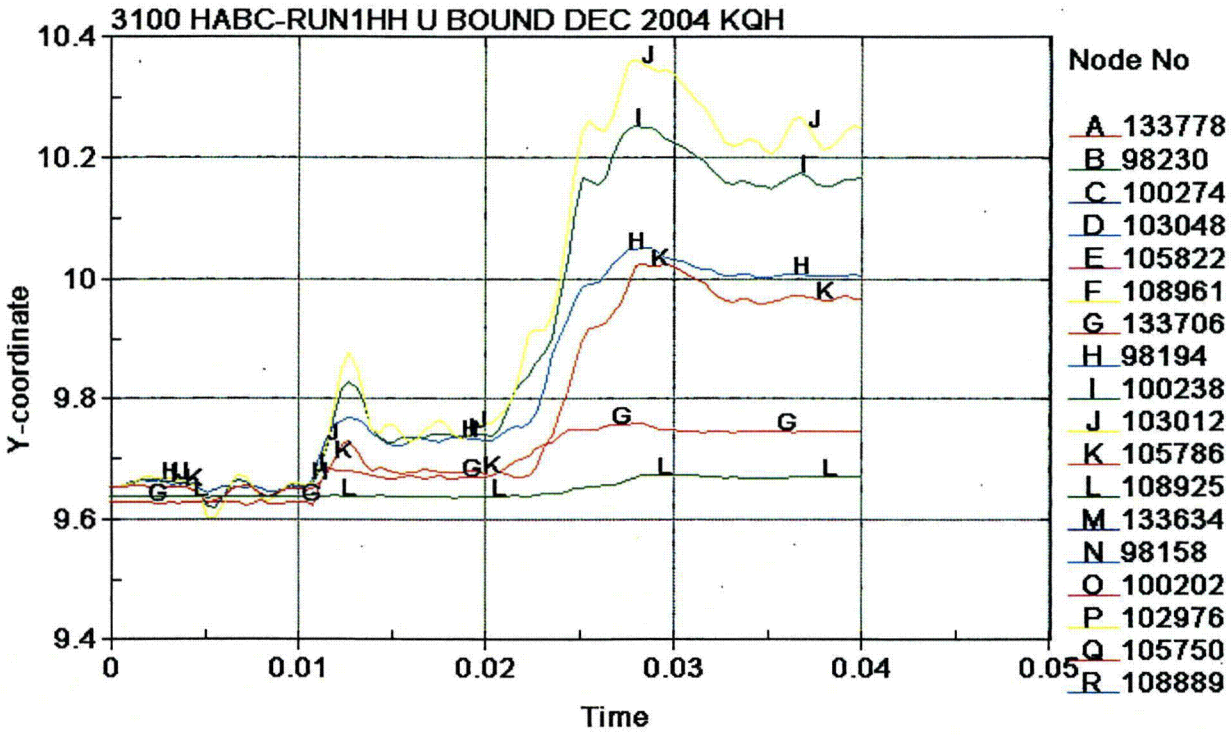


Figure 7.2.17 - HABC-run1hh, Drum Diameter Time History in the Y Direction

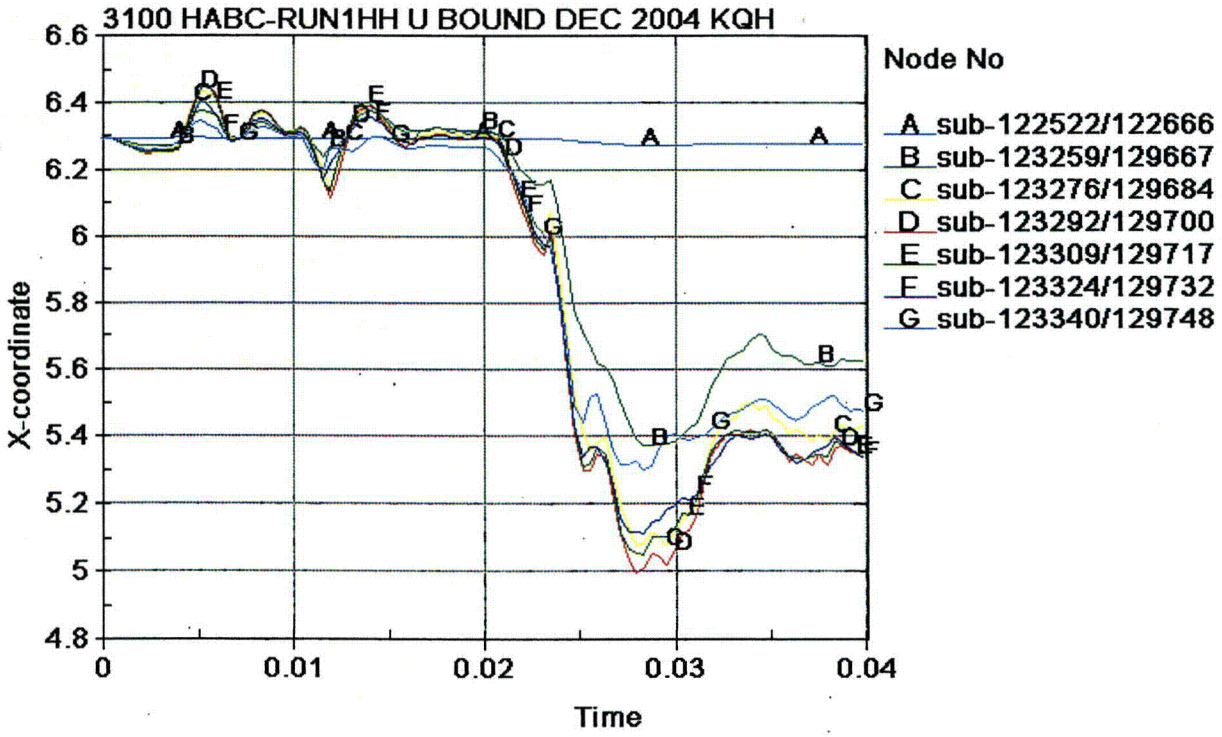


Figure 7.2.18 - HABC-run1hh, Diameter Changes in the Inner Liner

7.3 HABC-run2e - Corner

HABC-run2e is a package CG over corner impact with a 30-foot impact (time = 0 to 0.015 seconds) followed by a crush impact (0.015 to 0.05 seconds).

The configuration after the 30-foot impact is shown in Figure 7.3.1. The maximum effective plastic strain in the CV body is 0.0371 in/in as shown in Figure 7.3.2. Figure 7.3.3 shows that the maximum effective plastic strain in the CV lid is 0.0051 in/in near the outer radius of the center boss.

The maximum effective plastic strain in the lid studs is in the stud at the impact with the rigid plane (0° position) and is 0.5233 in/in. It can be seen from the insert in Figure 7.3.4, that strains near the maximum exist across the thickness of the stud. Therefore, it should be noted that slight differences between the modeled length and actual length of the stud could be significant relative to possible failure of the stud. Other differences such as friction and local flexibility in the test pad armored plate could also significantly effect this stud and cause failure. The maximum effective plastic strains of other components for this impact are listed in Table 7.3.1.

Table 7.3.1 - HABC-run2e, 30-Foot Impact, Effective Plastic Strain Levels in Some Components

Component	Effective Plastic Strain, in/in
CV Nut Ring	0.0002
Angle	0.0394
Drum	0.3247
Drum Bottom Head	0.0000
Liner	0.3983
Lid	0.2791
Lid Stiffener	0.0272
Lid Stud Nuts	0.2260
Lid Stud Washers	0.1528
Plug Liner	0.1152

Figure 7.3.5 shows the final configuration for the crush impact. Figure 7.3.6 shows that the maximum effective plastic strain in the CV body due to the crush impact is 0.0371 in/in.

Figure 7.3.7 shows the effective plastic strain in the CV lid maximum to be 0.0051 in/in. The maximum occurs near the outer radius of the center boss, nearest the impact.

The maximum effective plastic strain in the drum studs is shown to be 0.5598 in/in in Figure 7.3.8. The elevated values of plastic strain occur through out the cross section of the stud. As explained in the 30-foot impact results, slight variances in the length/configuration in this vicinity could prove detrimental for the stud in the test due to the relatively high level of strain through the thickness of the stud.

The maximum effective plastic strain in the liner is 0.5254 in/in as shown in Figure 7.3.9. The maximum is a surface strain and occurs in the folding at about the 80° position at the attachment of the liner to the angle. Investigation shows that the membrane maximum strain is 0.2205 in/in and occurs at the same location.

Table 7.3.2 - HABC-run2e, Crush Impact, Effective Plastic Strain Levels in Some Components

Component	Effective Plastic Strain, in/in
CV Nut Ring	0.0002
Angle	0.0462
Drum	0.3830
Drum Bottom Head	0.0761
Liner	0.5254
Lid	0.3622
Lid Stiffener	0.0272
Lid Stud Nuts	0.2266
Lid Stud Washers	0.1528
Plug Liner	0.1166

The CV lid separation time histories for the nodes shown in Figure 3.1.30 are given in Figure 7.3.10 for the HABC-run2e. Spike separation occurs (about 0.013 in) during the 30-foot impact with the general separation of about 0.008 in. The general separation lasts about 0.01 seconds, then settles to 0.003 in or less. The general separation due to the crush impact is 0.005 in or less, with some spiking to about 0.010 in noted. Nominal separation of 0.003 in or less would be expected.

Figure 7.3.11 shows the location of the nodes used to obtain the minimum kaolite thickness in the plug. Figure 7.3.12 shows the minimum plug thickness time history. A minimum

thickness of about 3.5 inches is reached in the 30-foot impact, and about 3.0 inches is reached in the successive crush impact.

Figure 7.3.13 shows the location of the nodes used to obtain the minimum koalite thickness in the package bottom. The time history thickness is shown in Figure 7.3.14 for the bottom kaolite. A minimum thickness of about 1.75 inches is shown.

Figure 7.3.15 shows the nodes used to obtain overall drum heights for the impacts. The final lengths from the bottom head to the lid are used to describe the deformations. Curve A in Figure 7.3.16 gives the length response of the 30-foot impacted lid corner to the drum bottom. The length after the 30-foot lid impact is about 40.5 in and goes to about 39 in after the crush impact. The Curve B in Figure 7.3.16 shows that the length from the crushed corner of the bottom to the lid reaches about 38 in in length.

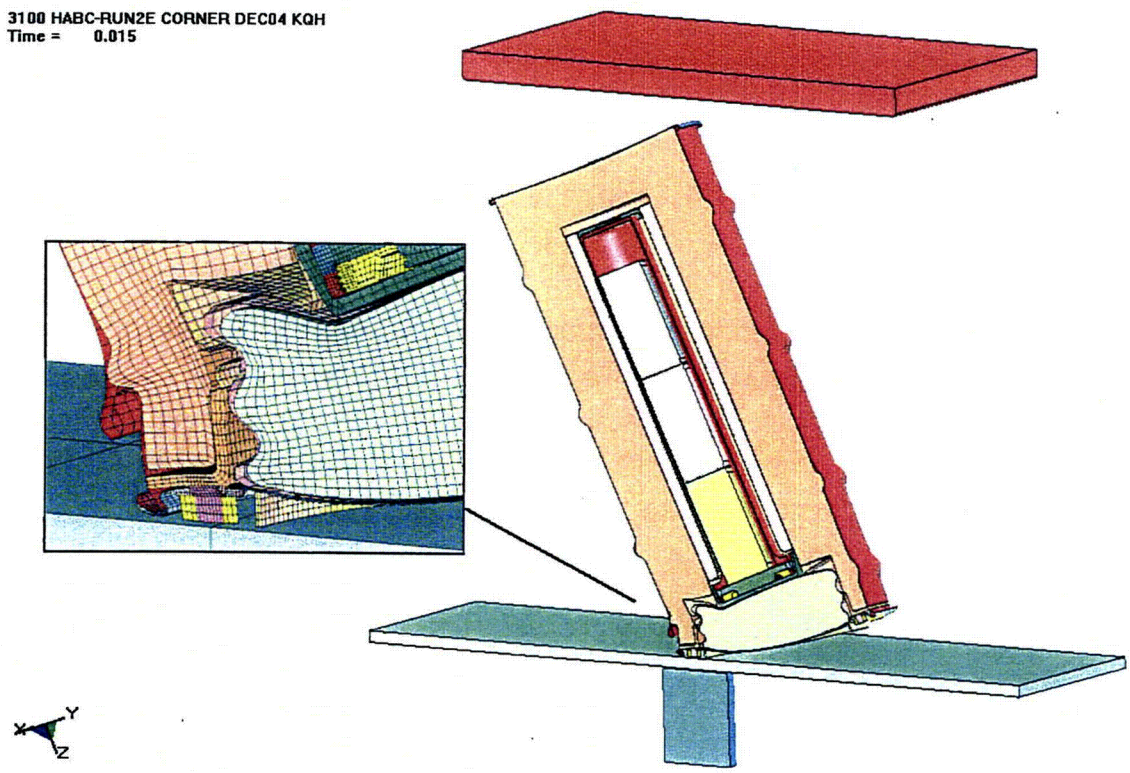


Figure 7.3.1 - HABC-run2e, Configuration of the ES-3100 After the 30-Foot Impact

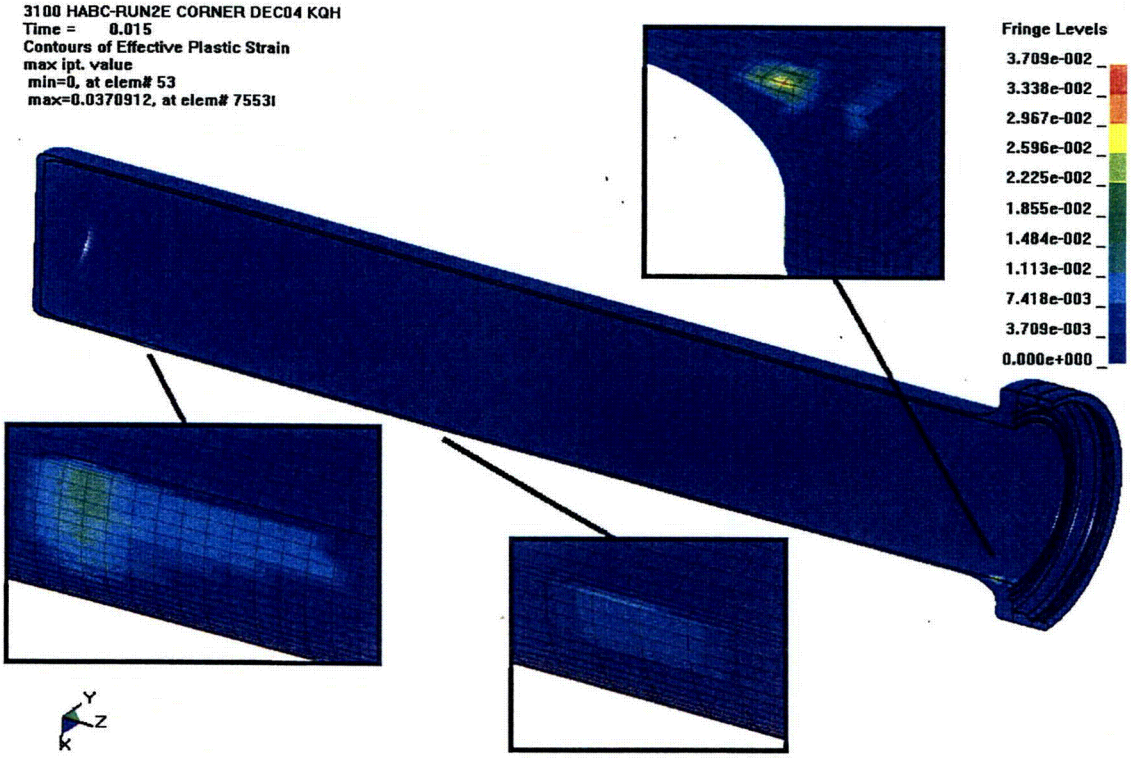


Figure 7.3.2 - HABC-run2e, 30-Foot Impact, Effective Plastic Strains in the CV Body

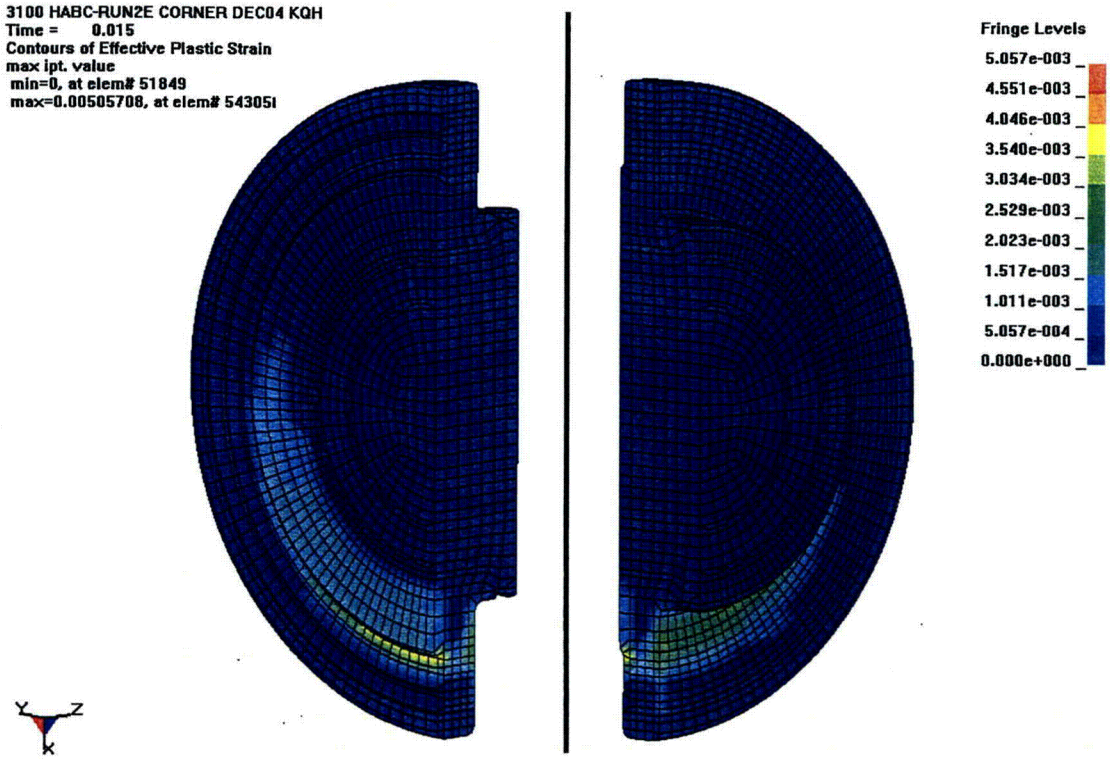


Figure 7.3.3 - HABC-run2e, 30-Foot Impact, Effective Plastic Strain in the CV Body

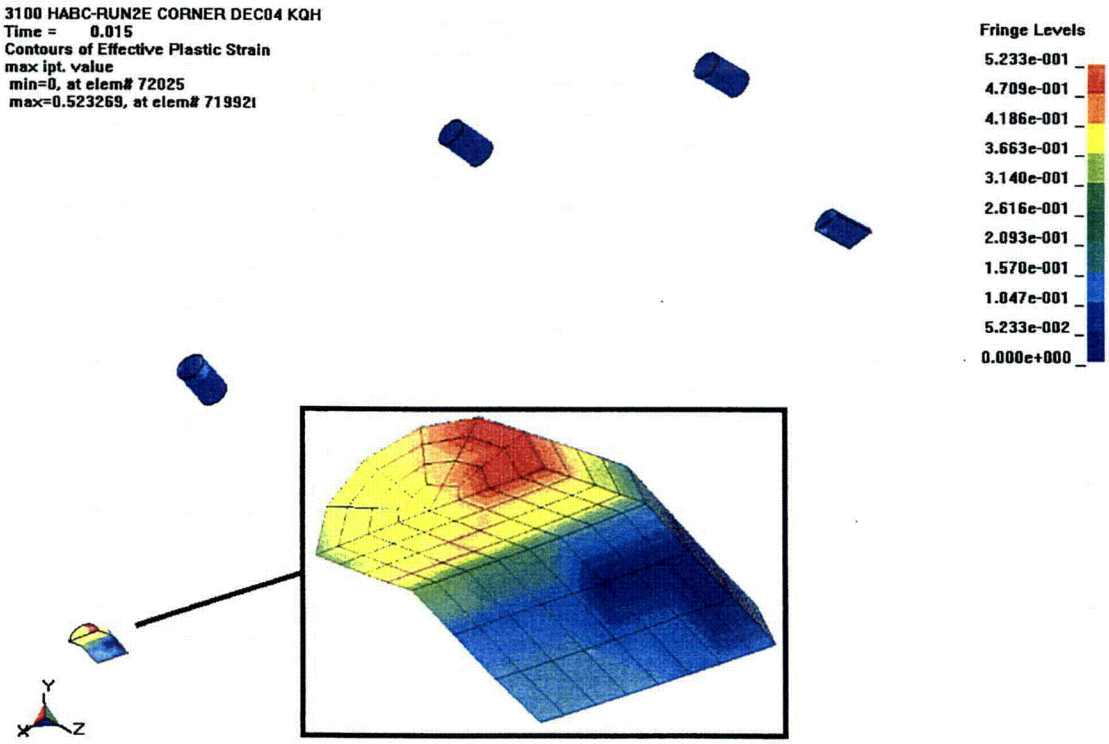
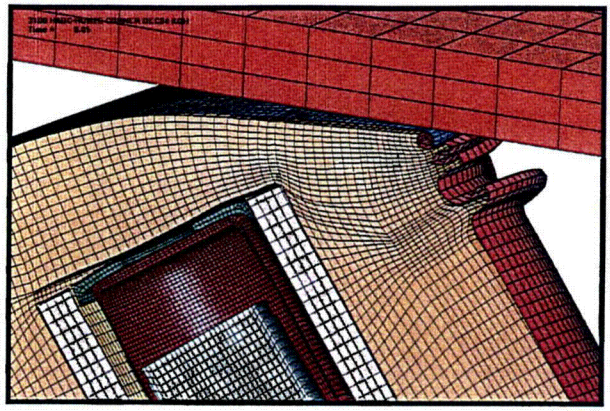
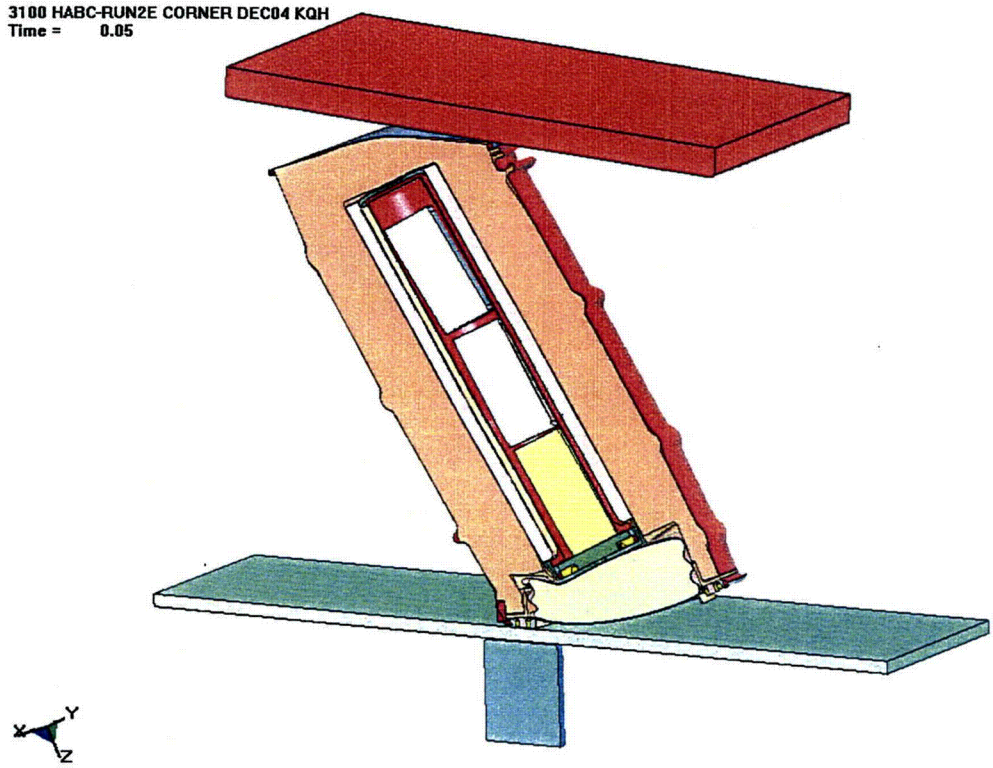


Figure 7.3.4 - HABC-run2e, 30-Foot Impact, Effective Plastic Strain in the Studs





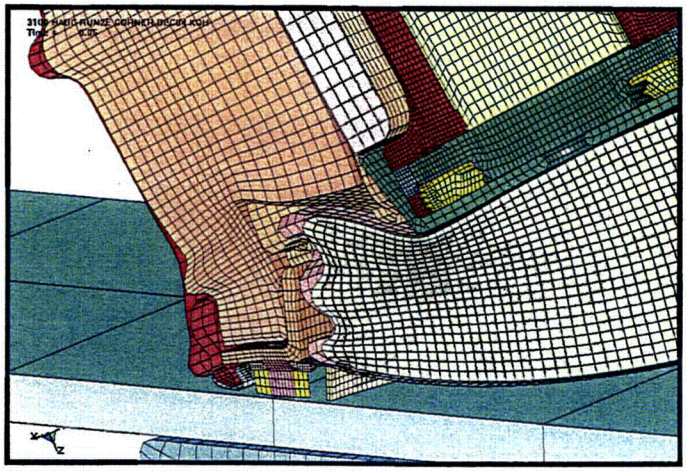


Figure 7.3.5 - HABC-run2e, Configuration After the Crush Impact

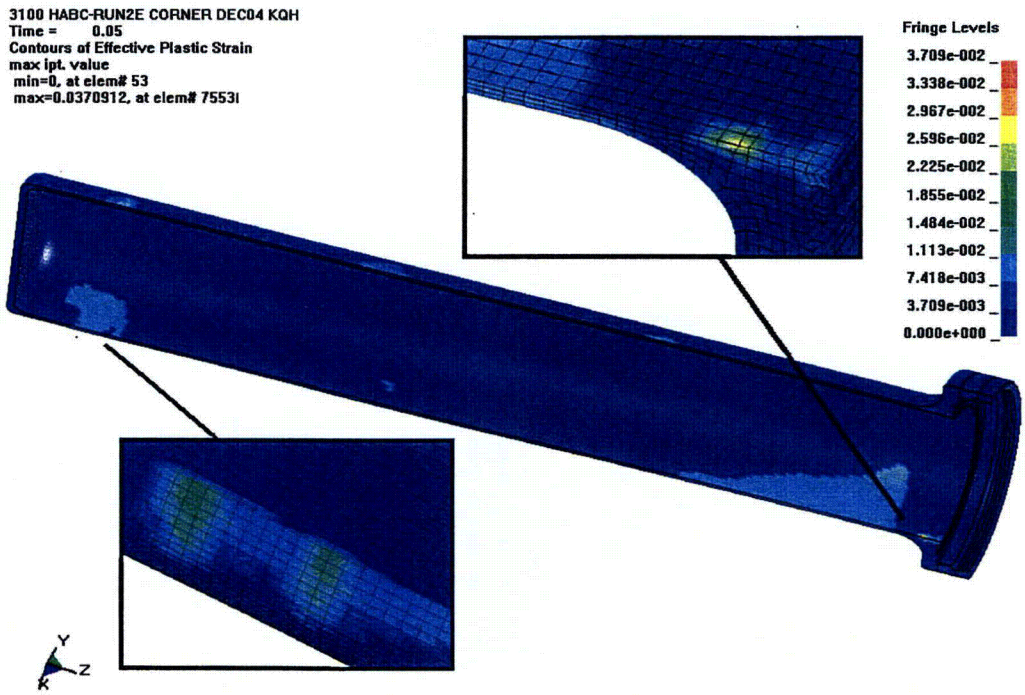


Figure 7.3.6 - HABC-run2e, Crush Impact, Effective Plastic Strain in the CV Body

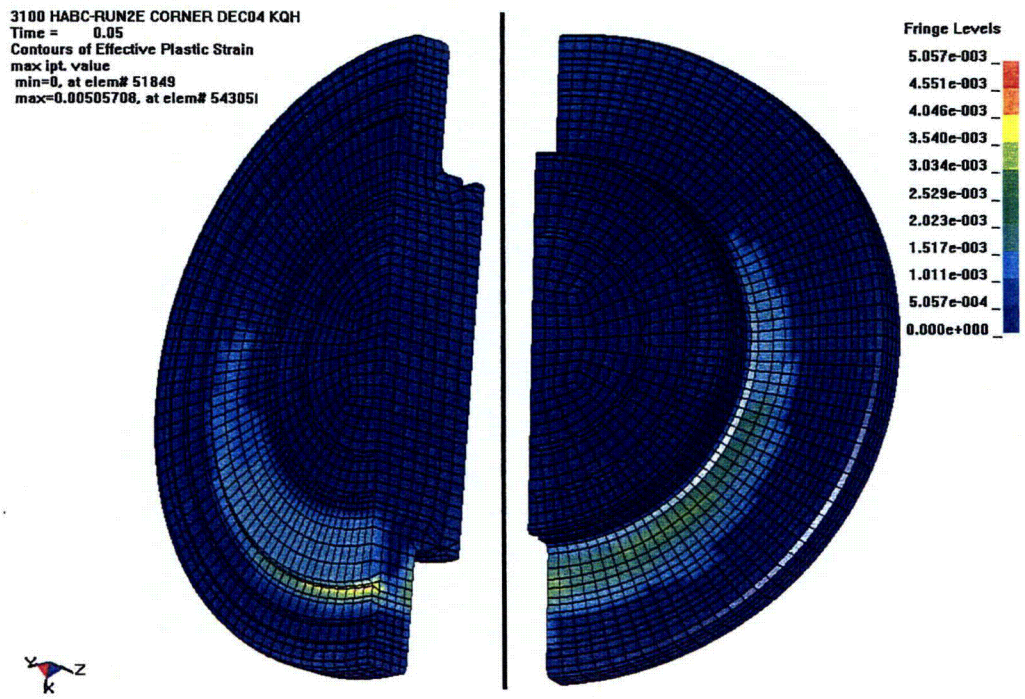


Figure 7.3.7 - HABC-run2e, Crush Impact, Effective Plastic Strain in the CV Lid

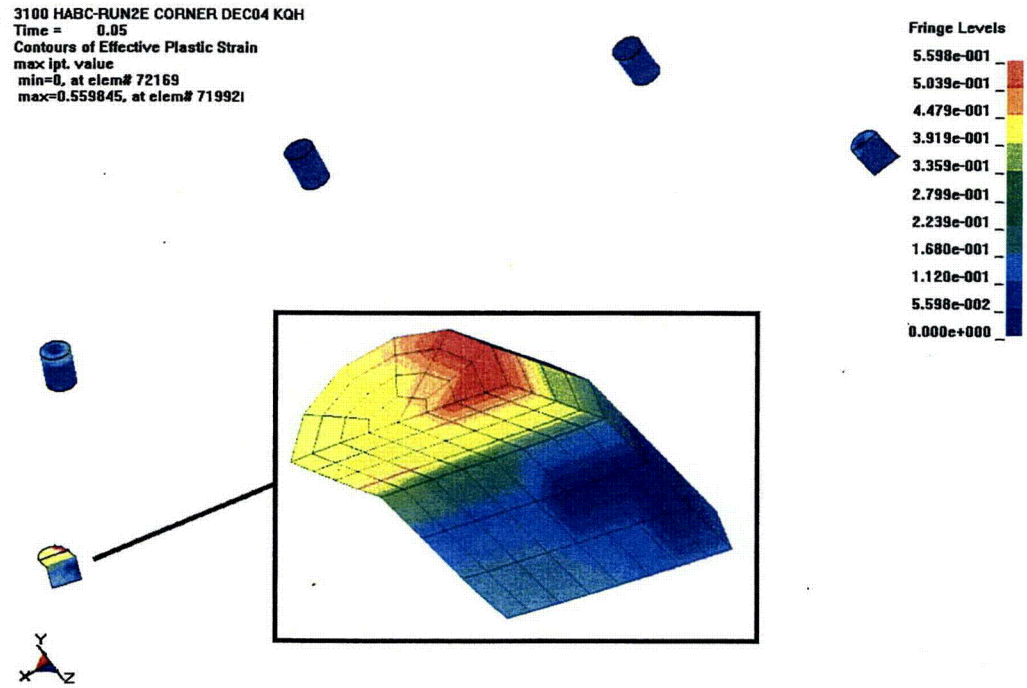


Figure 7.3.8 - HABC-run2e, Crush Impact, Effective Plastic Strain in the Studs

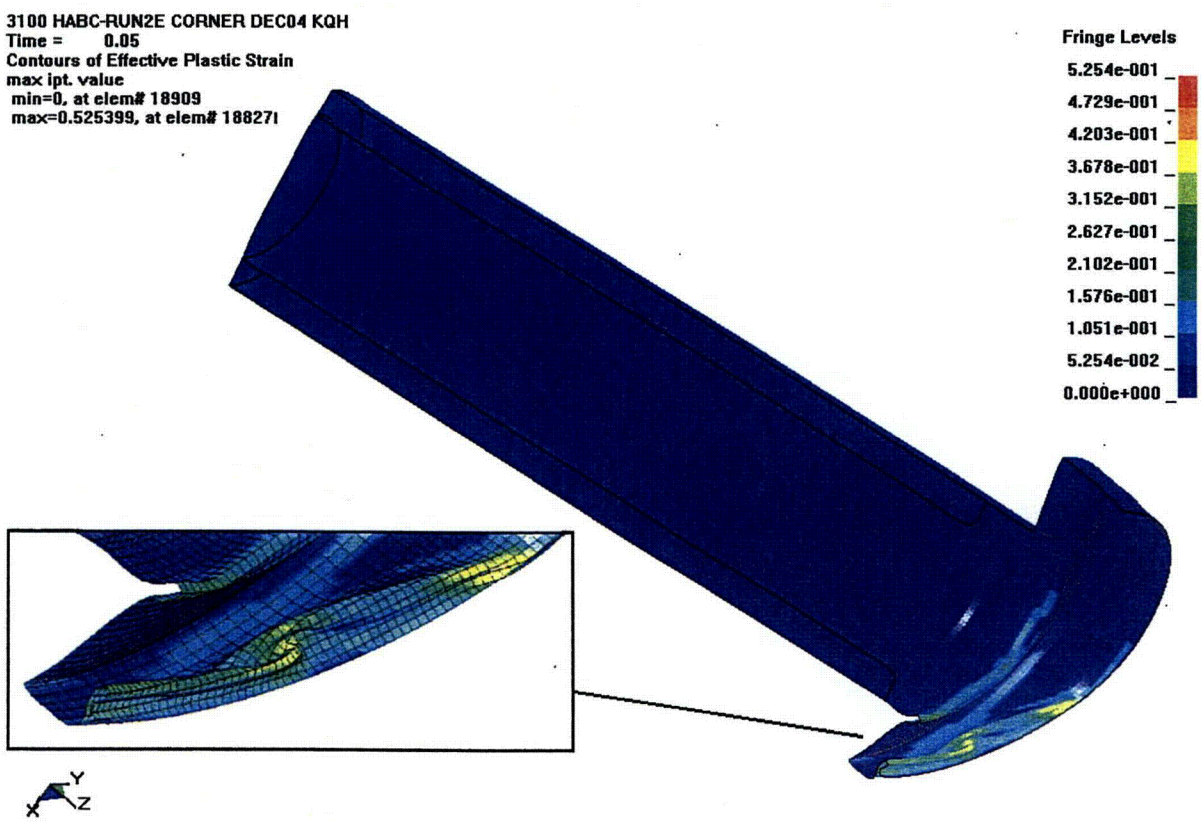


Figure 7.3.9 - HABC-run2e, Crush Impact, Effective Plastic Strain in the Liner

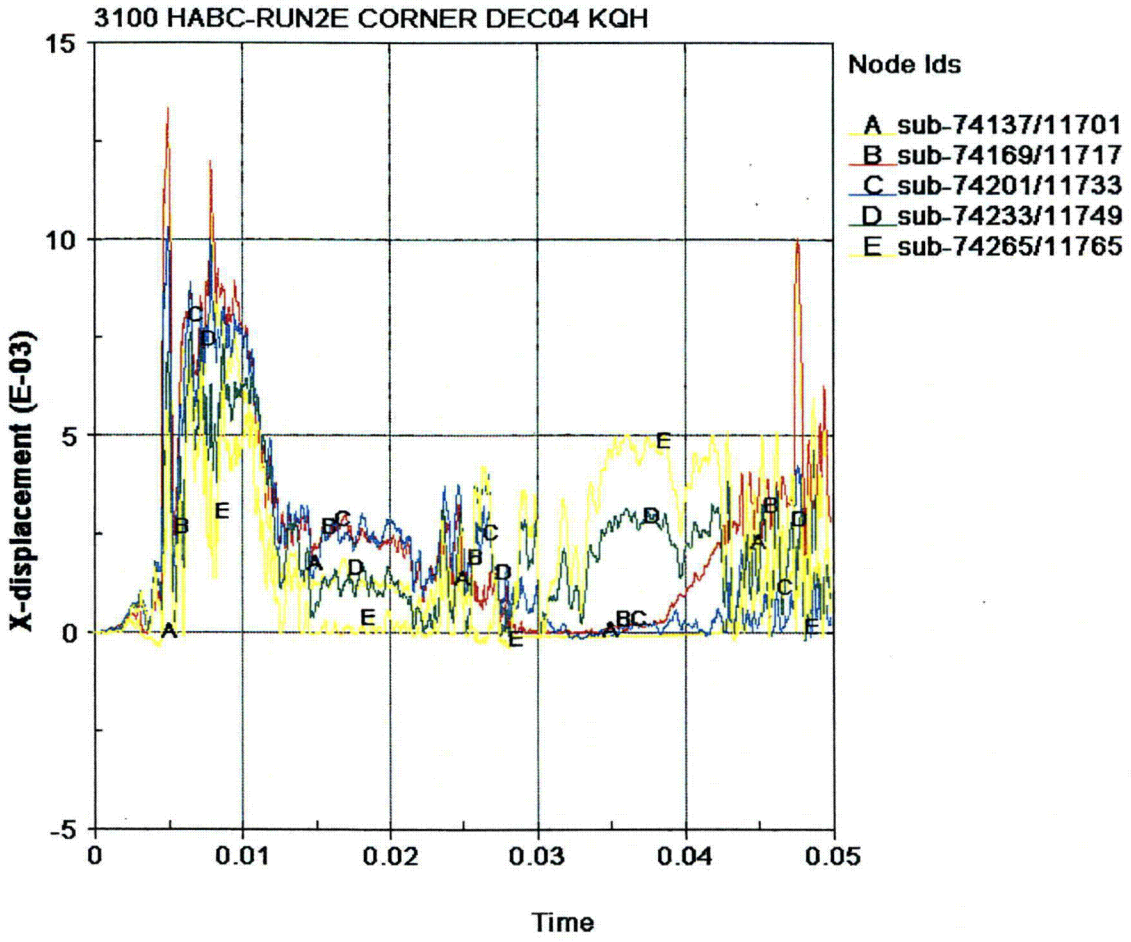


Figure 7.3.10 - HABC-run2e, Crush Impact, CV Lid/Body Separation Time History

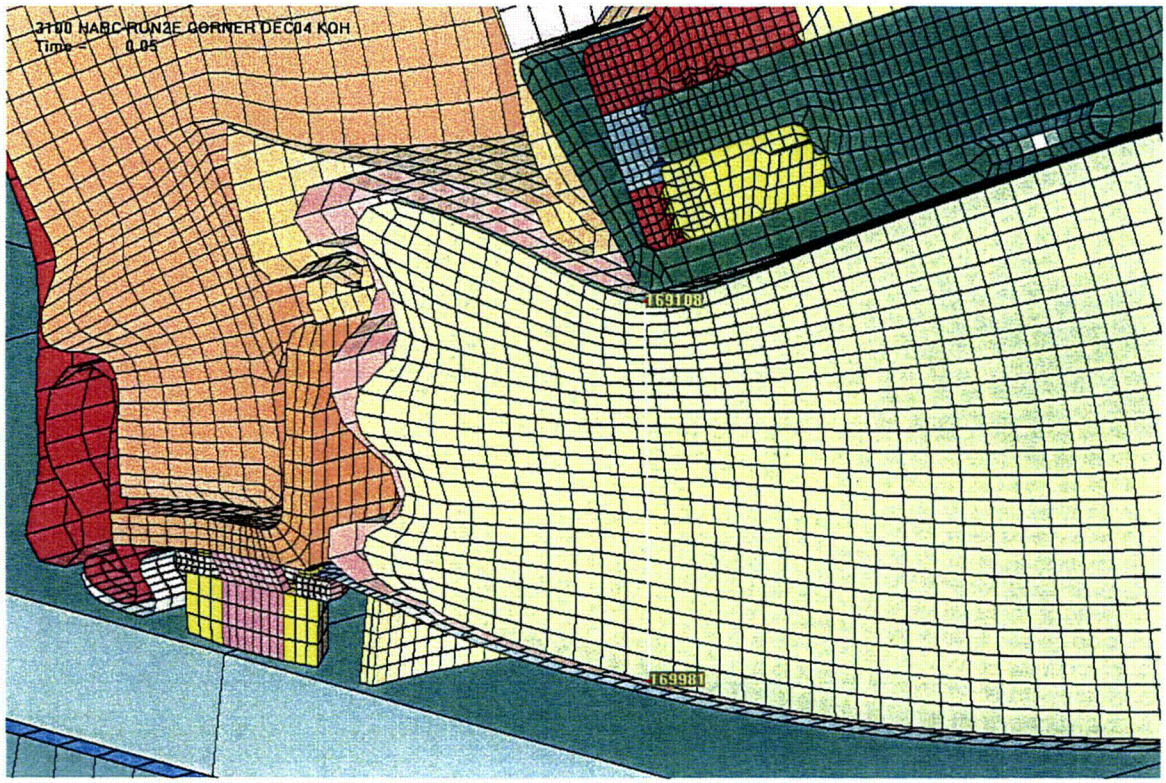


Figure 7.3.11 - HABC-run2e, Plug Thickness After the Crush Impact

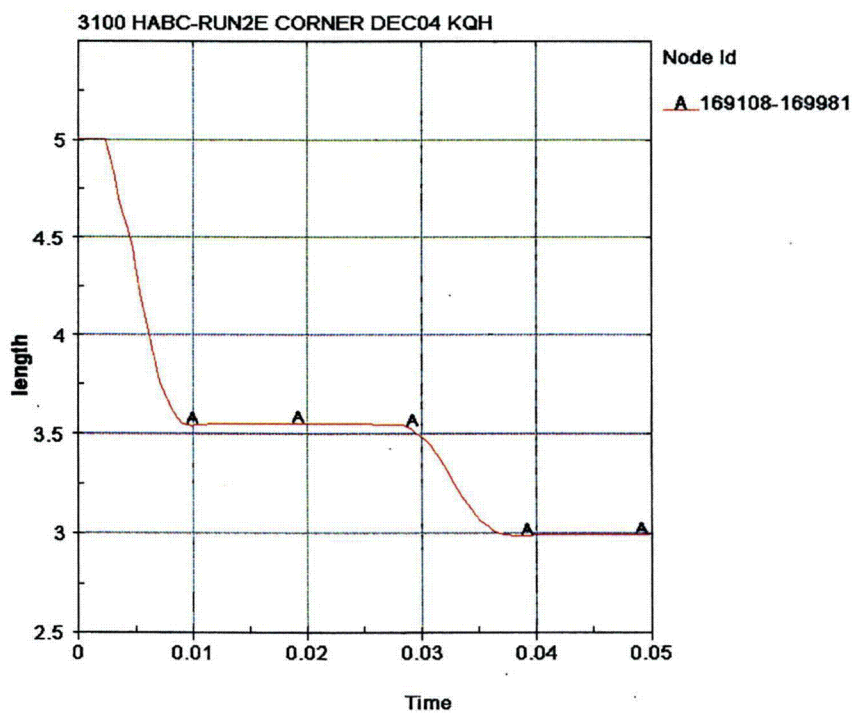


Figure 7.3.12 - HABC-run2e, Plug Thickness Time History

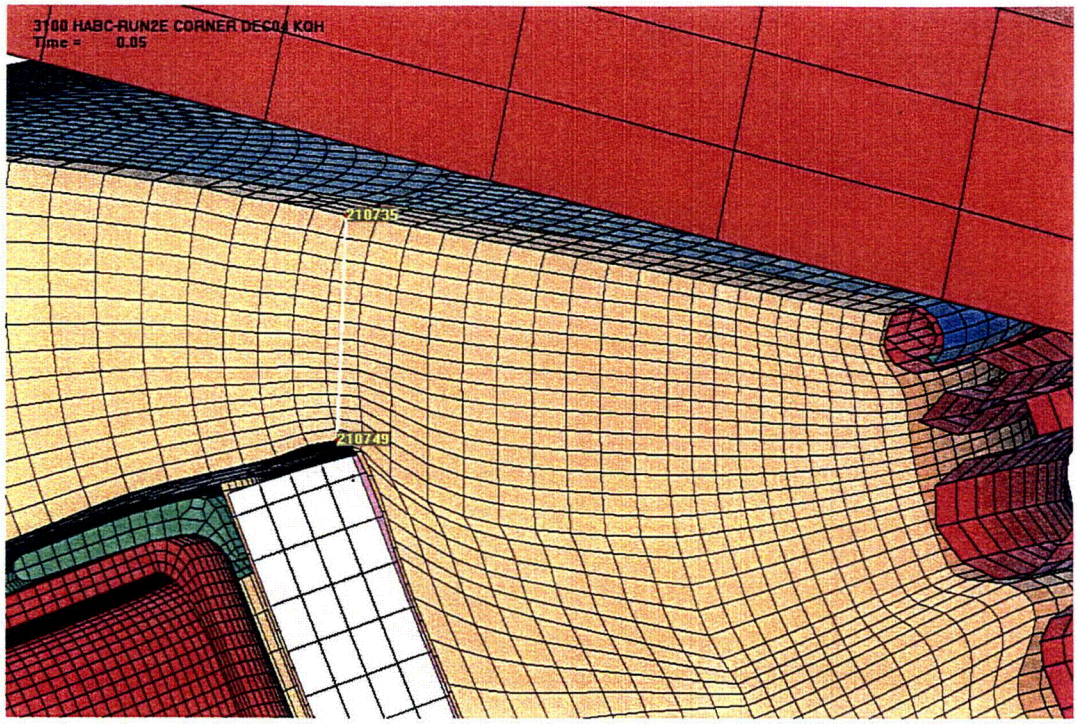


Figure 7.3.13 - HABC-run2e, Bottom Kaolite Thickness After the Crush Impact

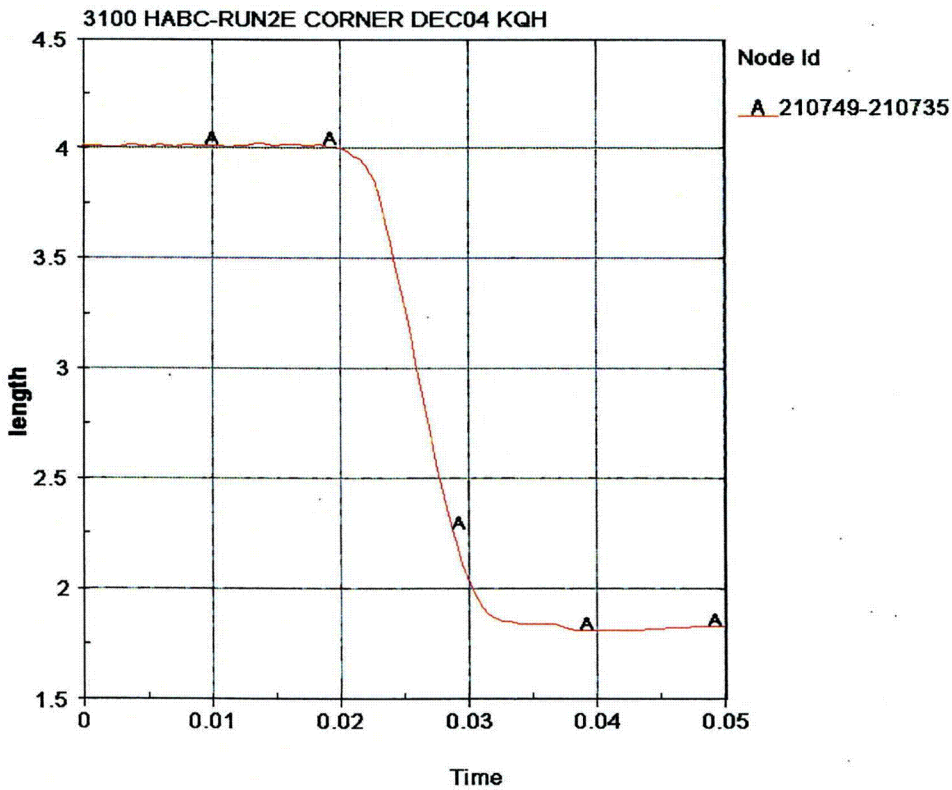


Figure 7.3.14 - HABC-run2e, Bottom Kaolite Thickness Time History

Figure 7.3.15 - HABC-run2e, Length Dimensions in the Drum

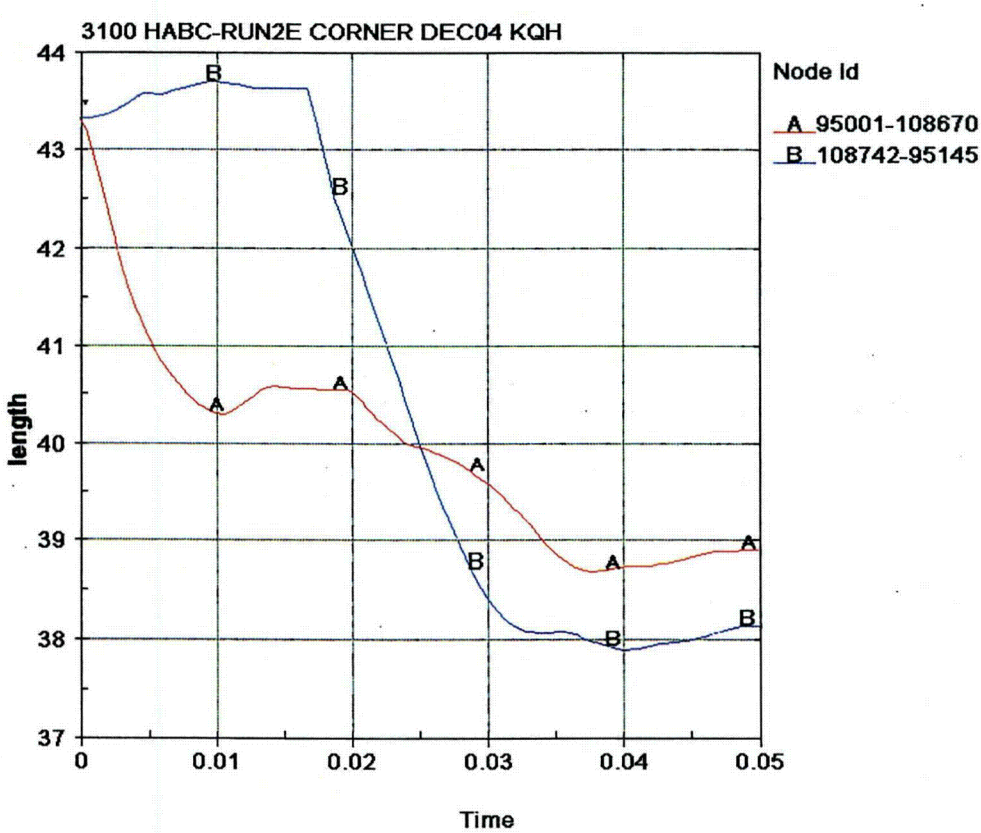


Figure 7.3.16 - HABC-run2e, Drum Length Time History

7.4 HABC-run3b - End

HABC-run3b is a 30-foot lid end impact (time = 0 to 0.010 seconds) followed by a crush impact onto the package bottom (0.010 to 0.028 seconds). Figure 7.4.1 shows the configuration of the container at the end of the 30-foot impact. Figure 7.4.2 shows that the maximum effective plastic strain in the CV body is 0.0028 in/in. The maximum plastic strain occurs in the bottom head. Figure 7.4.3 shows the CV lid. The maximum effective plastic strain is found to be 0.0072 in/in and occurs just outboard of the center boss on the outer surface.

The maximum effective plastic strain in the nut ring is shown to be 0.0011 in/in in Figure 7.4.4. It is believed this plastic strain is an anomaly with the contact surface because: 1) the fringes of plastic strain are not symmetrical, 2) the maximum value of plastic strain occurs at single nodes on an edge of the component and 3) the nut ring bares on the relatively soft silicone pad. Table 7.4.1 summarizes the maximum effective plastic strains in the other package components.

Table 7.4.1 - HABC-run3b, 30-Foot Impact, Effective Plastic Strain Levels in Some Components

Component	Effective Plastic Strain, in/in
Angle	0.0287
Drum	0.0557
Drum Bottom Head	0.0031
Liner	0.0607
Lid	0.1082
Lid Stiffener	0.0069
Lid Studs	0.0962
Lid Stud Nuts	0.0166
Lid Stud Washers	0.0506
Plug Liner	0.0670

Figure 7.4.5 shows the final configuration for the successive crush impact. Figure 7.4.6 shows that the maximum effective plastic strain in the CV body is 0.0083 in/in. The ring of plastic deformation in the sidewall at the bottom head is due to the bending of the bottom head. The other components are summarized in Table 7.4.2.

Table 7.4.2 - HABCrun3b, Crush Impact, Effective Plastic Strain Levels in Some Components	
Component	Effective Plastic Strain, in/in
CV Lid	0.0072
CV Nut Ring	0.0011
Angle	0.0308
Drum	0.1237
Drum Bottom Head	0.0267
Liner	0.3812
Lid	0.1389
Lid Stiffener	0.0100
Lid Studs	0.1535
Lid Stud Nuts	0.0173
Lid Stud Washers	0.0506
Plug Liner	0.0960

The CV lid separation time history is shown in Figure 7.4.7. The response during the 30-foot impact are separation spikes up to about 0.018 in with a general separation of about 0.012 in. The spikes occur for about 0.001 sec, while the general separation occurs for about 0.005 sec. During the crush impact, the gap response oscillates about values of general separation. The general separation remains below a gap of about 0.005 in.

Figure 7.4.8 shows the nodes chosen to observe the plug and bottom kaolite thicknesses and the overall drum height. Figure 7.4.9 shows the time history of the drum height. After the 30-foot impact and the successive crush impact, the drum height is found to be about 39 inches. Figure 7.4.10 shows the minimum plug thickness time history with Curve B. The minimum plug thickness after the 30-foot impact is about 3.75 in. The minimum plug thickness after the successive crush impact is about 3.4 in. Curve A shows the bottom kaolite minimum thickness is about 2.2 in after the crush impact.

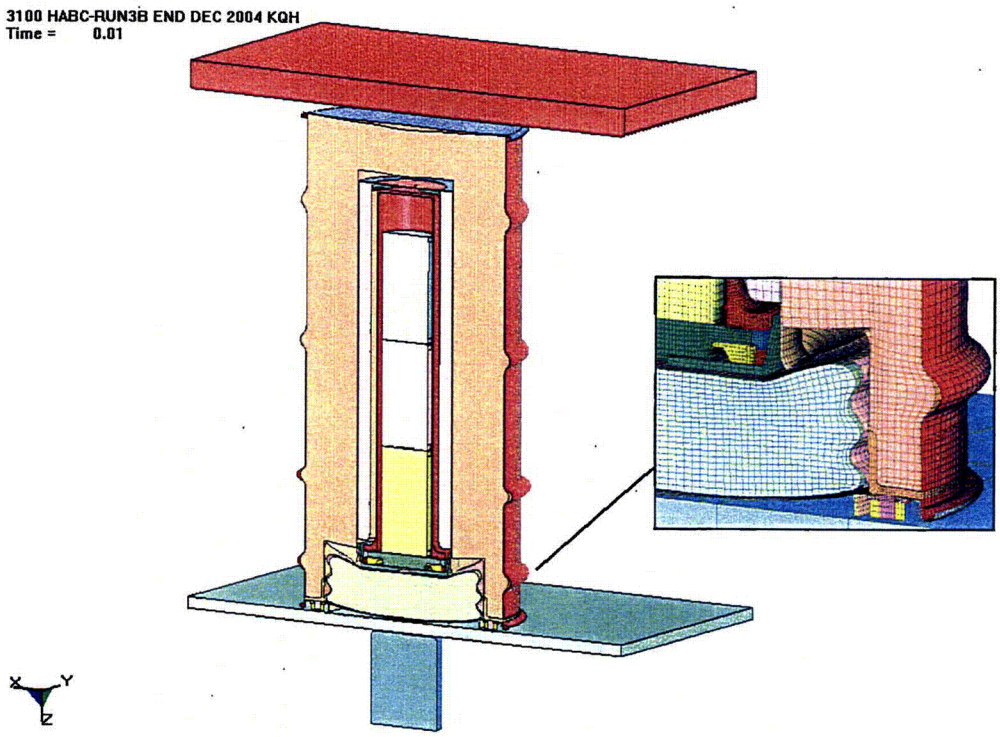


Figure 7.4.1 - HABC-run3b, Configuration After the 30-Foot Impact

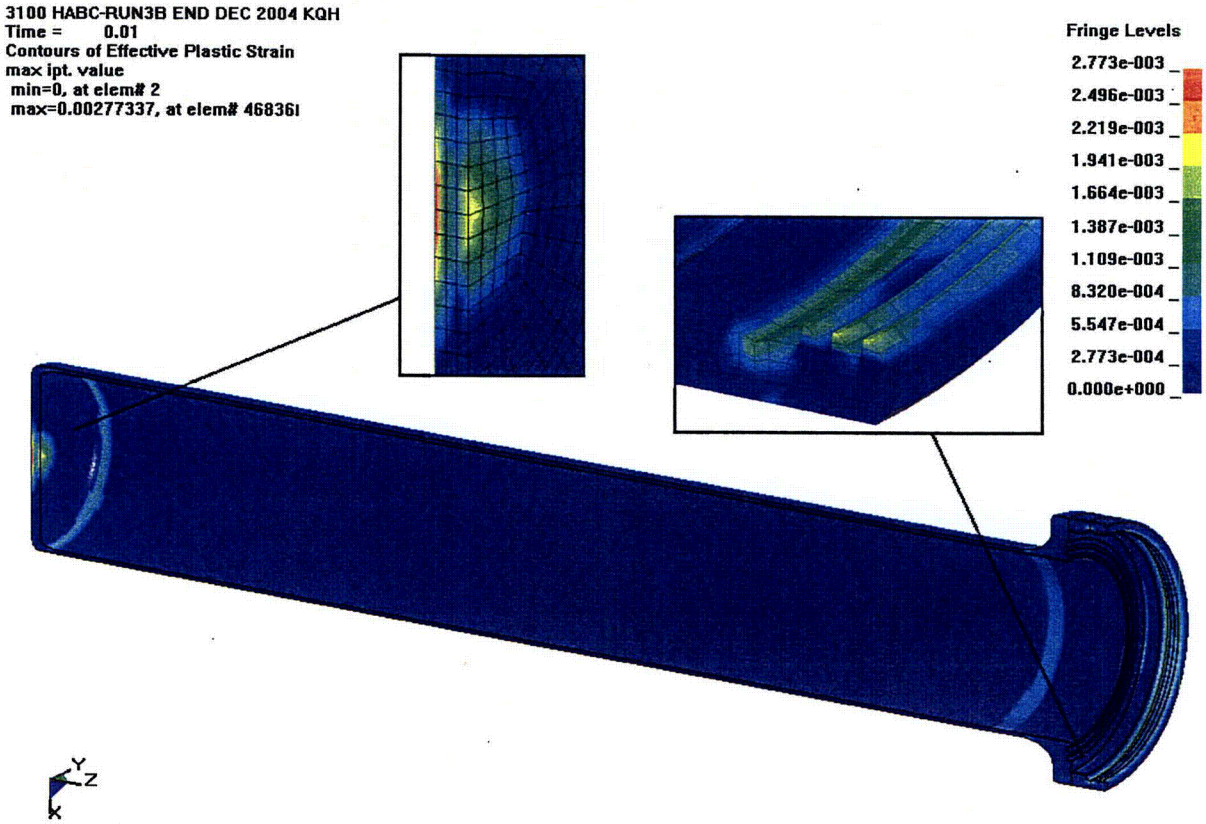


Figure 7.4.2 - HABC-run3b, 30-Foot Impact, Effective Plastic Strain in the CV Body

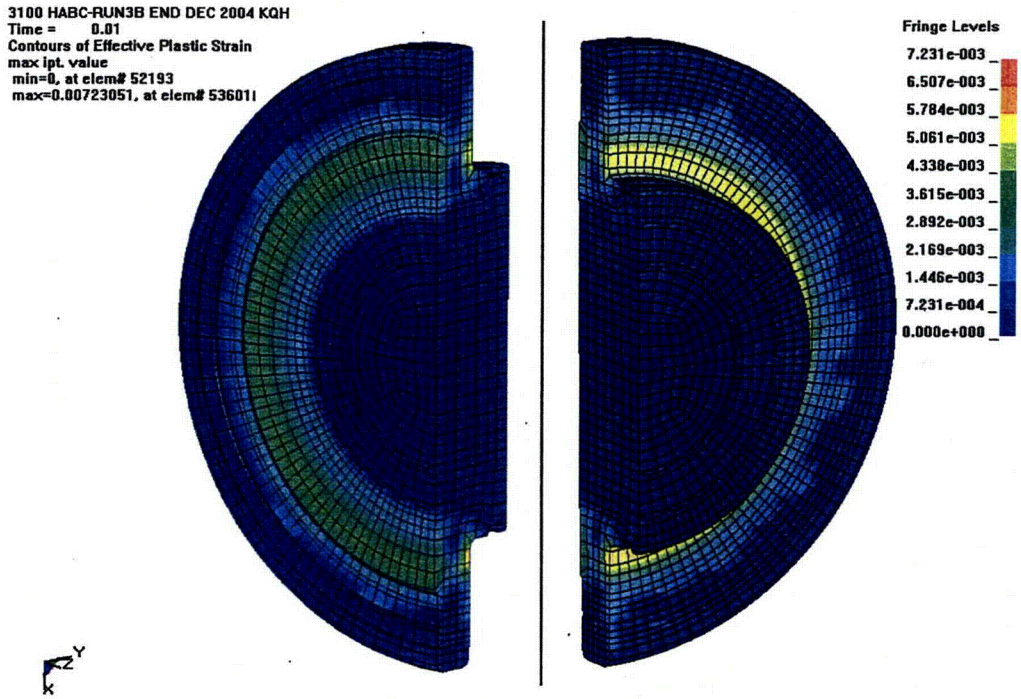


Figure 7.4.3 - HABC-run3b, 30-Foot Impact, Effective Plastic Strain in the CV Lid

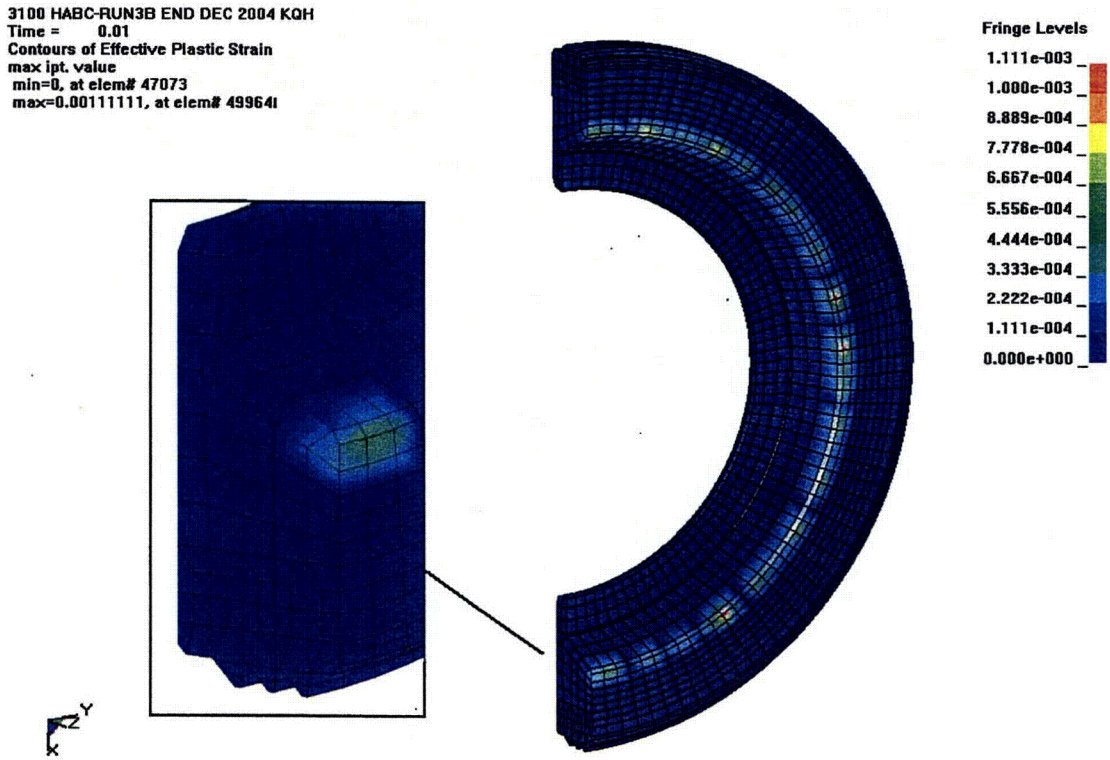


Figure 7.4.4 - HABC-run3b, 30-Foot Impact, Effective Plastic Strain in the CV Nut Ring

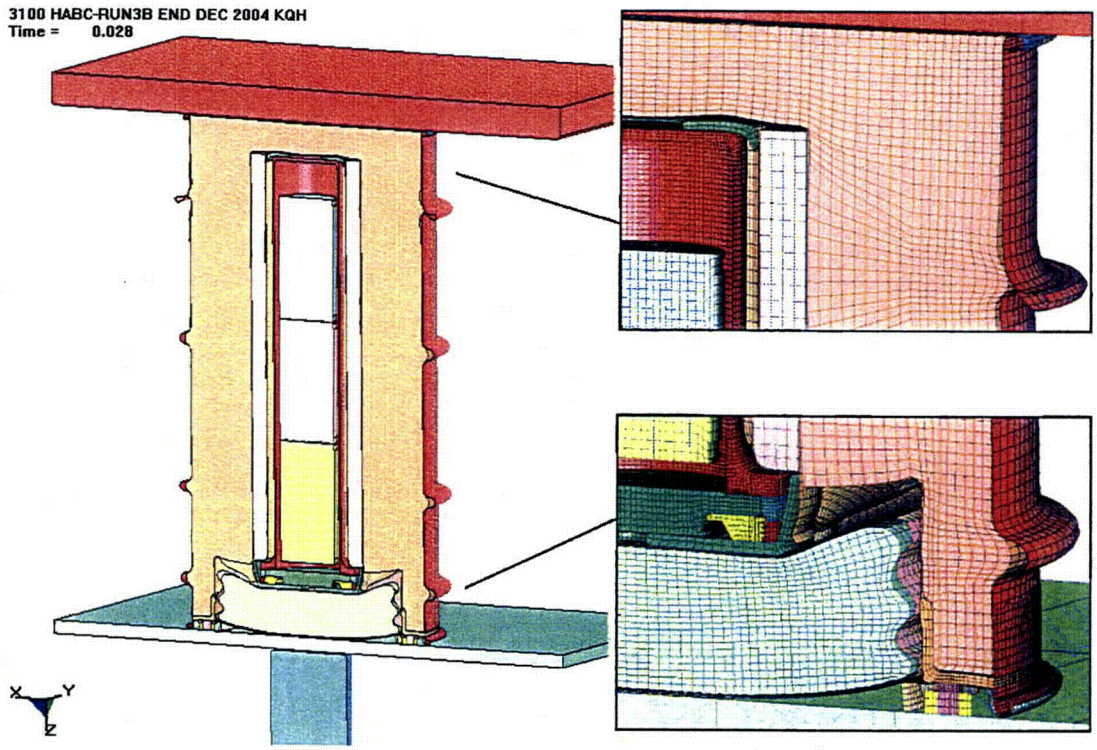


Figure 7.4.5 - HABC-run3b, Configuration After the Crush Impact

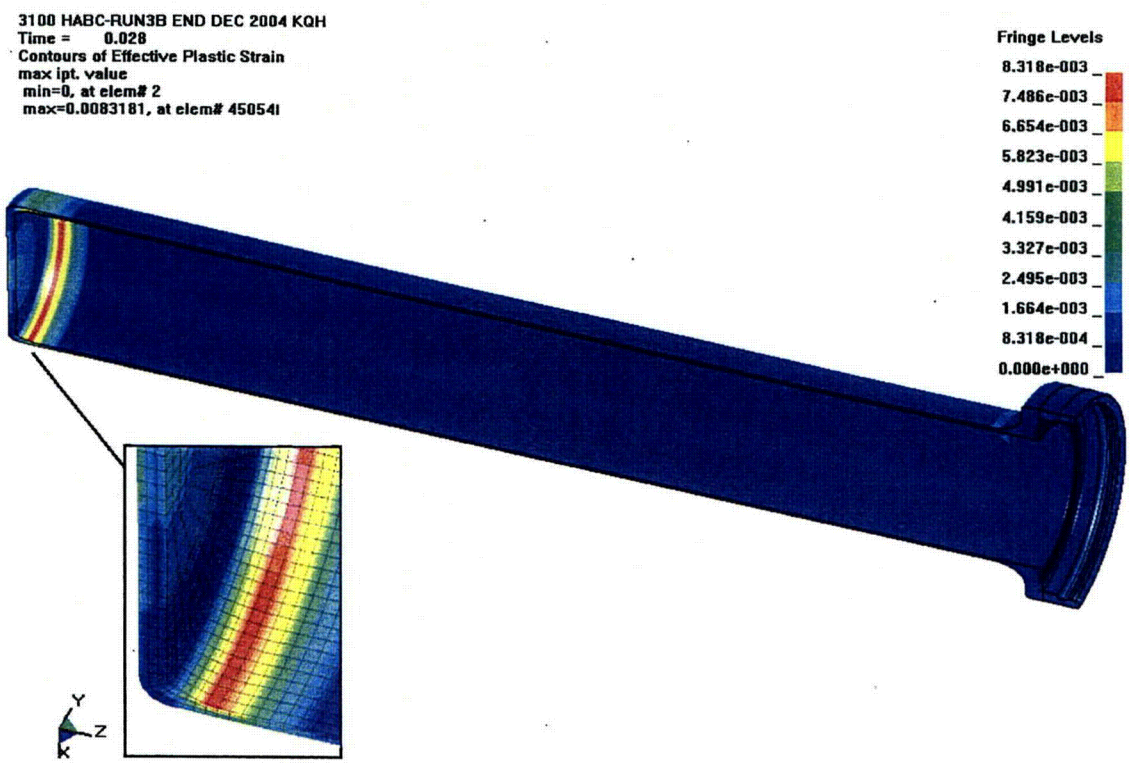


Figure 7.4.6 - HABC-run3b, Crush Impact, Effective Plastic Strain in the CV Body

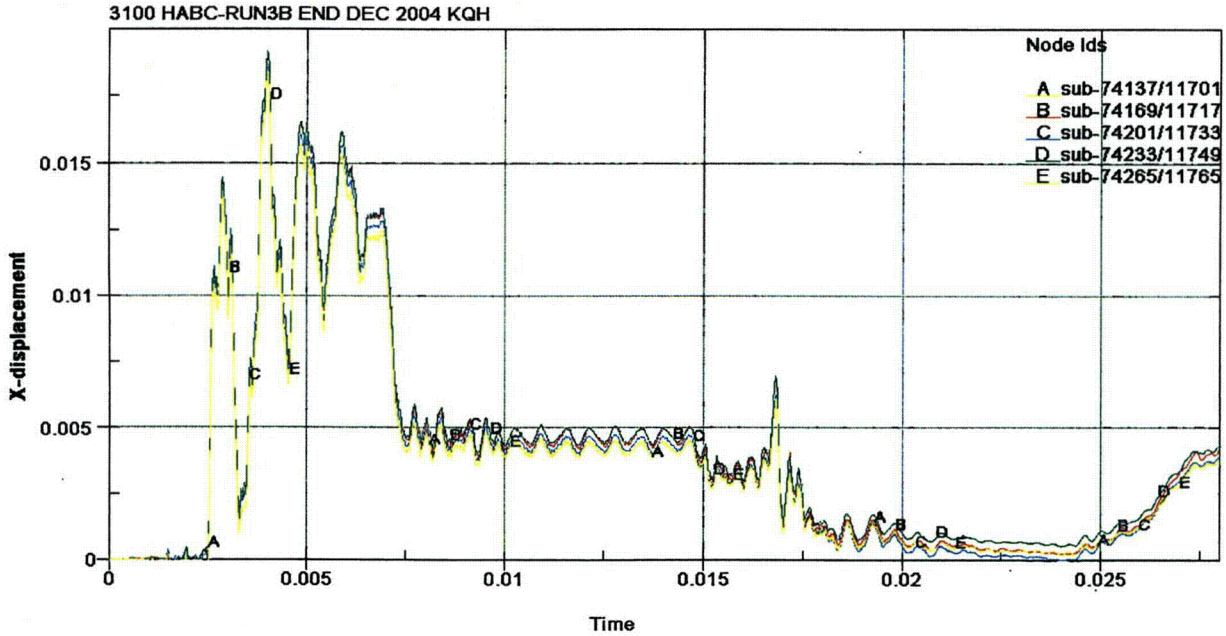


Figure 7.4.7 - HABC-run3b, CV Lid Separation Time History

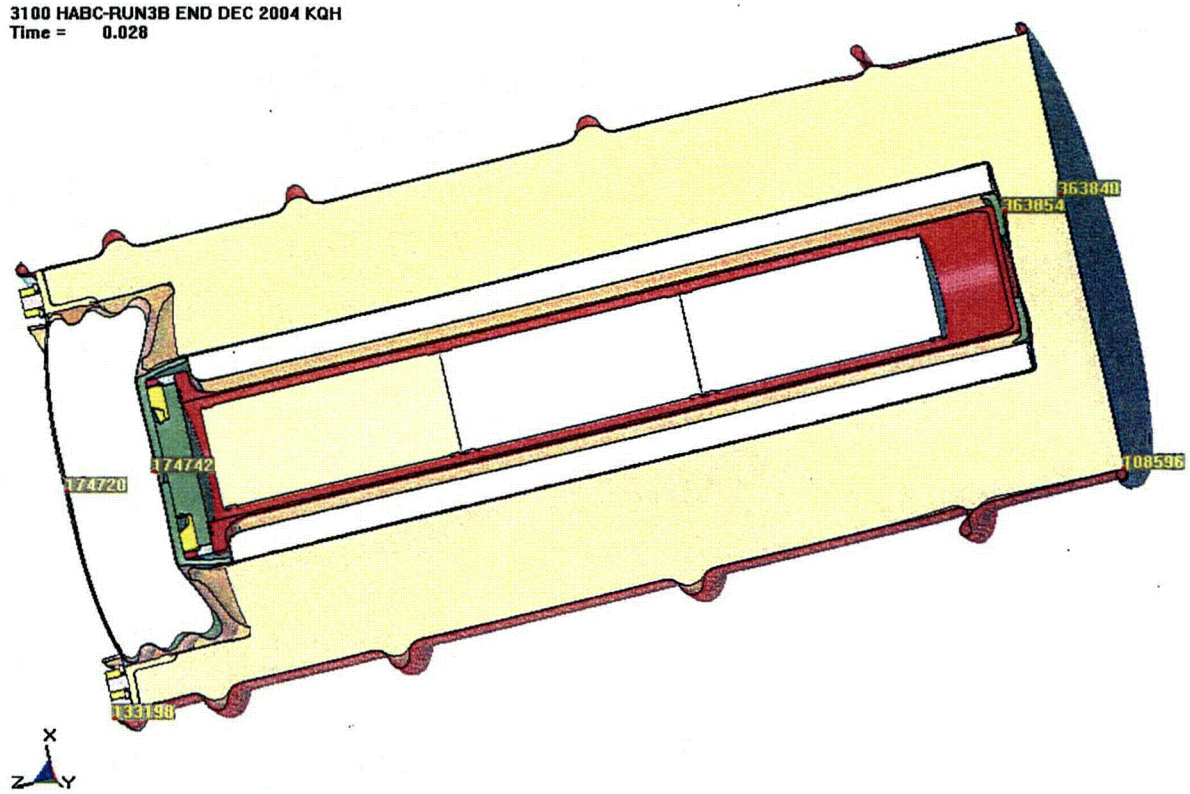


Figure 7.4.8 - HABC-run3b, Nodes to Determine Drum/Kaolite Heights

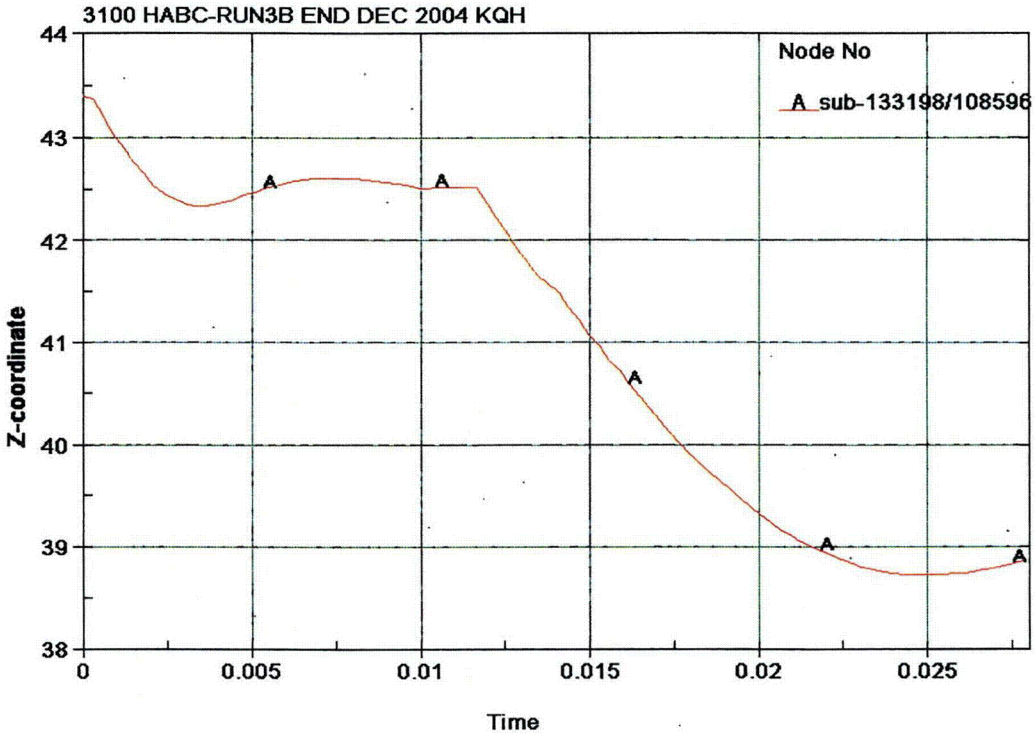


Figure 7.4.9 - HABC-run3b, Drum Height Time History

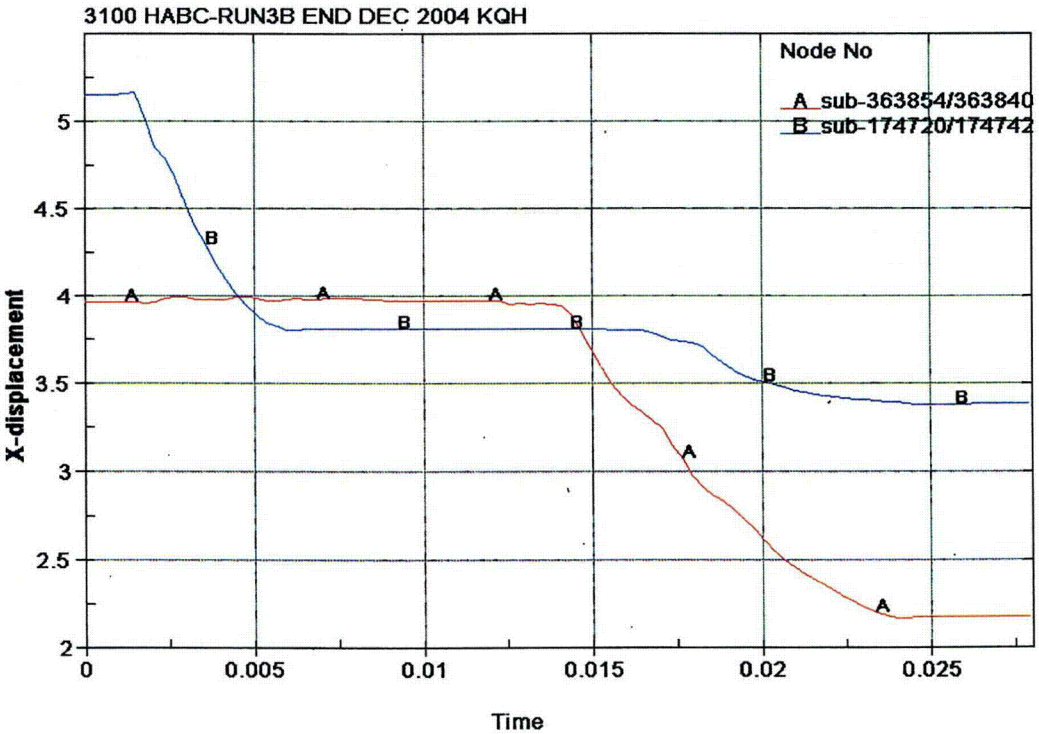


Figure 7.4.10 - HABC-run3b, Kaolite Thickness Time Histories

7.5 HABC-run4g - Slapdown

HABC-run4g is a 12° slapdown, 30-foot impact (time 0 to 0.02 seconds) followed by an offset crush with the crush plate CG over the CV flange (0.0202 to 0.04 seconds). From 0.0200 to 0.0202 sec, the crush plate is moved (via nodal velocities) such that its geometric center is approximately in line with the CV flange.

The initial configuration of the model is shown in Figure 7.5.1. The deflected shape of the package after the 30-foot impact is shown in Figure 7.5.2. Figure 7.5.3 shows enlargements of the corners of the package due to the 30-foot slapdown impact. The maximum effective plastic strain in the CV body for the 30-foot impact is 0.0376 in/in and occurs below the flange and nearest the impacted rigid surface as shown in Figure 7.5.4. Figure 7.5.5 shows that the maximum effective plastic strain in the drum is 0.3018 in/in. The maximum occurs at the bottom drum roll attachment to the drum, as is shown by the element number in the enlargement of the base region of the drum. Figure 7.5.5 does not show this by color fringes due to the nodal averaging of adjacent elements by the plot routine. The maximum strain is a highly localized bending strain in the bottom drum roll. The maximum effective plastic strain in the lid is 0.5278 in/in as shown in Figure 7.5.6. The maximum occurs due to the bearing of the lid onto the stud at the 0° position. The maximum effective plastic strains in other components for the 30-foot impact are listed in Table 7.5.1.

Table 7.5.1 - HABC-run4g, 30-Foot Impact, Effective Plastic Strain Levels in Some Components

Component	Effective Plastic Strain, in/in
CV Lid	0.0004
CV Nut Ring	0.0000
Angle	0.0900
Drum Bottom Head	0.2879
Liner	0.1458
Lid Stiffener	0.0213
Lid Studs	0.1892
Lid Stud Nuts	0.0000
Lid Stud Washers	0.0724
Plug Liner	0.1258

Figure 7.5.7 shows the initial configuration for the offset impact. Figure 3.5.8 shows the final configuration for the crush impact for run4g. Figure 3.5.9 shows enlargements of the package corners after the crush.

The maximum effective plastic strain in the CV body is 0.0564 in/in as shown in Figure 7.5.10. Figure 7.5.11 shows the maximum effective plastic strain in the drum to be 0.3920 in/in, and it occurs on the crush plate side of the drum at the attachment of the angle. Figure 7.5.12 shows the lid after the offset crush impact. The maximum bending effective plastic strain is 0.9689 in/in and occurs at the 90° stud hole. The fringe range in Figure 7.5.12 has been defined to show all values near 0.57 in/in in the color red. The maximum membrane strain is 0.8935 in/in and also occurs at the 90° stud hole. This extremely high level of plastic strain is the lid response to the package trying to ovalize due to the crush impact. Due to the extreme level of effective plastic strain (>0.57 in/in), some localized tearing of the lid would be expected.

Figure 7.5.13 shows the effective plastic strain in the drum studs at the end of the crush impact, 0.4018 in/in. The stud at the 90° position has failed (evident by removed element row at the base of the stud). All of the elements on the cross section at the stud base attachment to the angle reached the prescribed failure strain of 0.57 in/in and were deleted by LS-Dyna. Therefore, the 0.4108 in/in is the plastic strain of the remaining elements. The stud elements reach failure and elements begin to be deleted at about time = 0.0311 seconds. By 0.0319 seconds, all the elements on the stud cross section have been deleted by LS-Dyna.

The lid uses a power law material model, which does not allow material failure in the model. Investigation shows that the lid reaches 0.57 in/in in membrane at about 0.0272 seconds, a time at which the stud strain is about 0.2451 in/in. This demonstrates that the lid reaches failure levels before the stud and at a time which the stud effective plastic strain is relatively low. Therefore, it would be expected that the lid would tear before the stud reaches failure. Due to the extent of the effective plastic strain fringe patterns in the lid plus the conservative modeling of the stud relative to lid shear (Section 2.1 discussion), it is believed that the tearing would be local and that the lid (and by default the plug) would be restrained by the large washers. Table 7.5.2 shows the maximum effective plastic strain in the remainder of the package components for the crush impact.

Table 7.5.2 - HABC-run4g, Crush Impact, Effective Plastic Strain Levels in Some Components	
Component	Effective Plastic Strain, in/in
CV Lid	0.0013
CV Nut Ring	0.0001
Angle	0.1070
Drum	0.3920
Drum Bottom Head	0.2879
Liner	0.2060
Lid Stiffener	0.0894
Lid Stud Nuts	0.0028
Lid Stud Washers	0.0790
Plug Liner	0.2665

Figure 7.5.14 shows the CV lid separation time history. During the 30-foot impact, the maximum spikes reach the 0.0065 in range with a general gap of about 0.005 in reached. During the crush impact, the spikes in gap reach about 0.009 in, while the general separation is about 0.007 in. At the end of the crush impact, the separations appear oscillatory from 0.0 in to about 0.006 in, therefore if a permanent gap were to exist, the maximum separation would be about 0.003 in.

Figure 7.5.15 gives the kaolite thickness time history for chosen kaolite nodes. The nodes are given in Figure 7.1.16.

The nodes on the drum chosen to investigate the diameter/radius changes during the impact are shown in Figure 3.1.34. Figure 7.5.16 shows the drum diameter time histories in the X direction. Figure 7.5.17 shows the drum radial changes in the Y direction.

Figure 7.5.18 shows the diameter time history for the inner liner. The position of the nodes is shown in Figure 3.1.37 and Table 3.1.3.

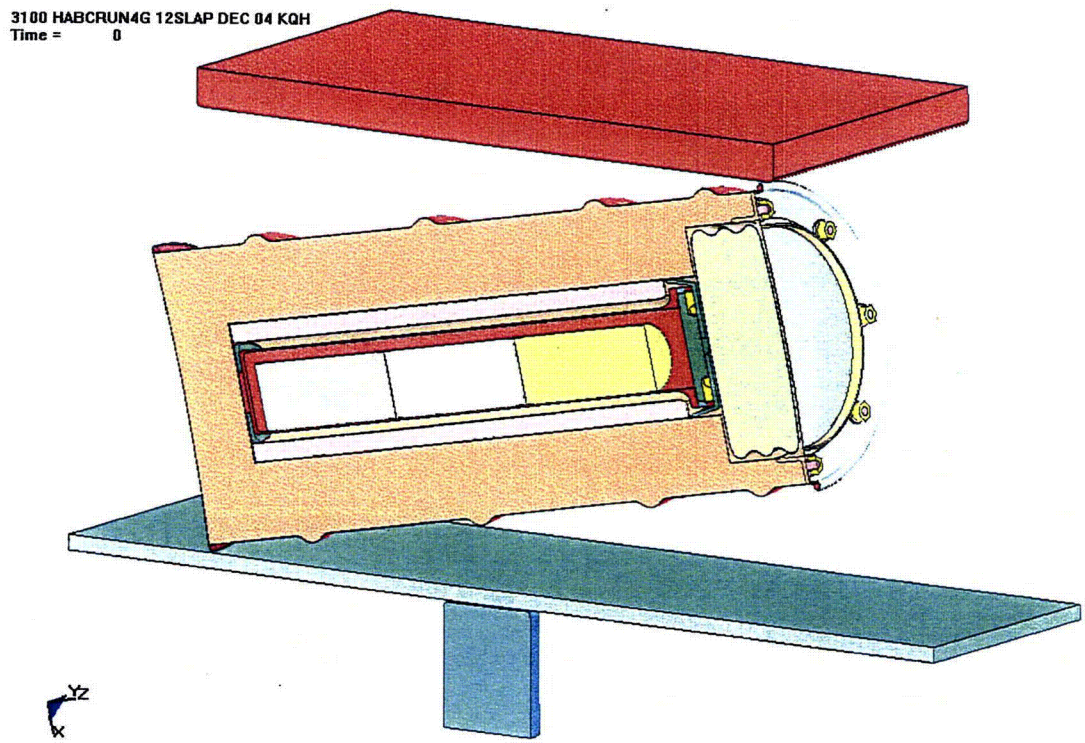
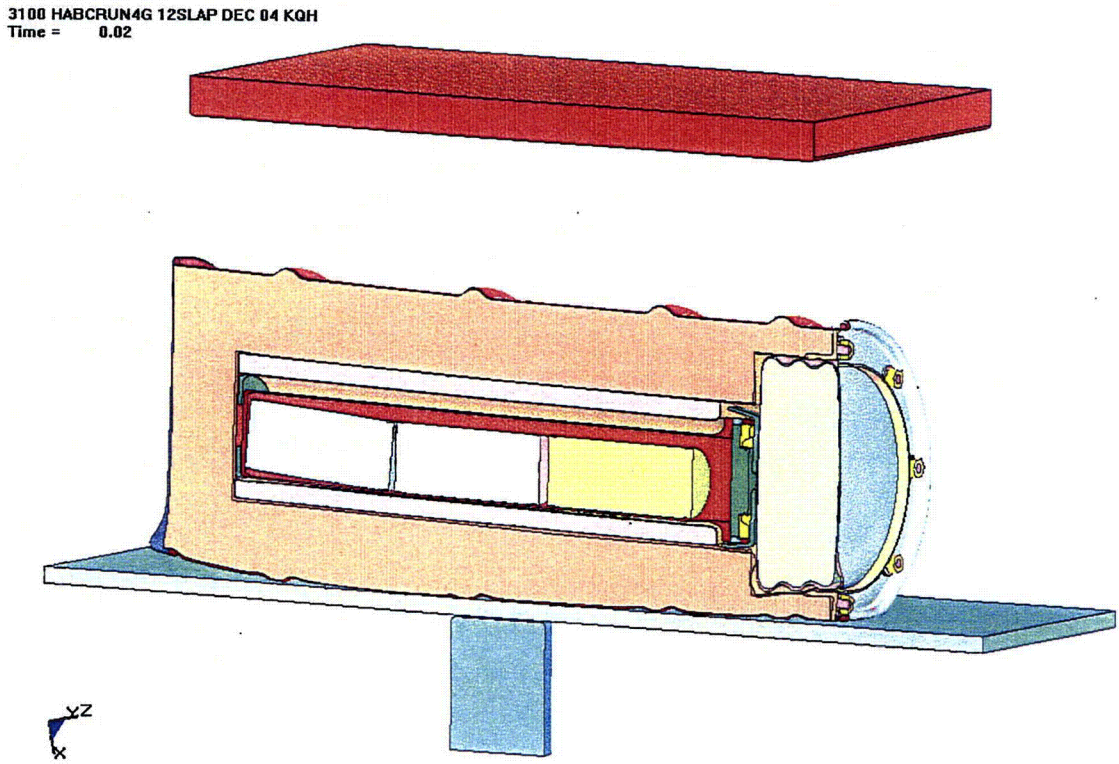


Figure 7.5.1 - HABC-run4g, 12 Degree Slapdown Initial Configuration



7.5.2 - HABC-run4g, Configuration After the 30-Foot Impact

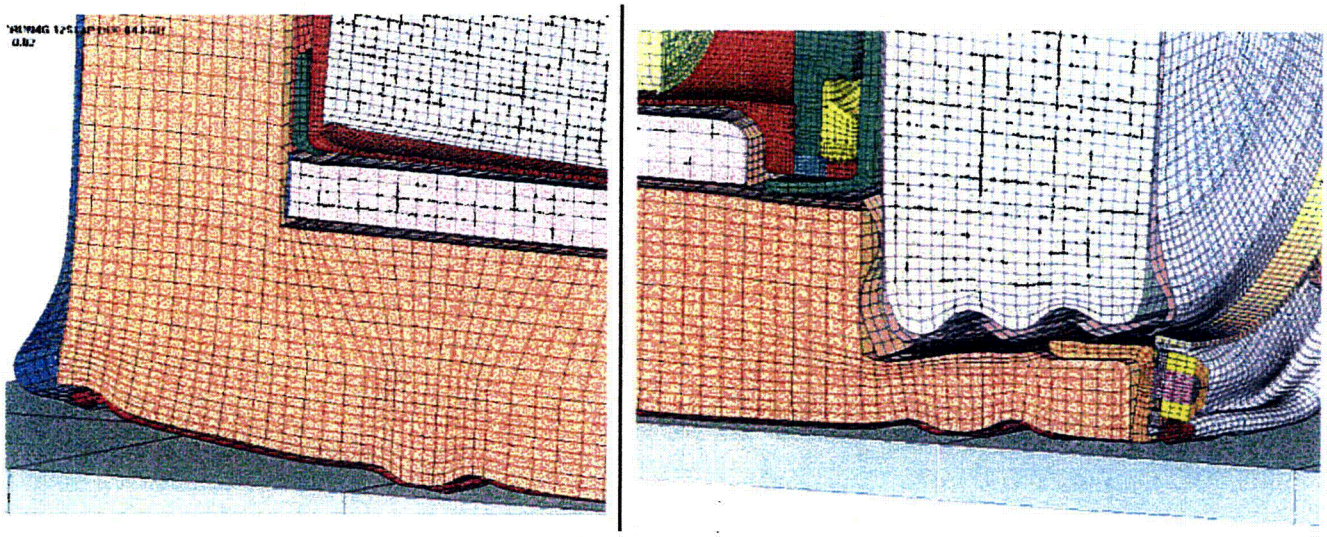


Figure 7.5.3 - HABC-run4g, 30-Foot Impact, Bottom and Lid Configurations

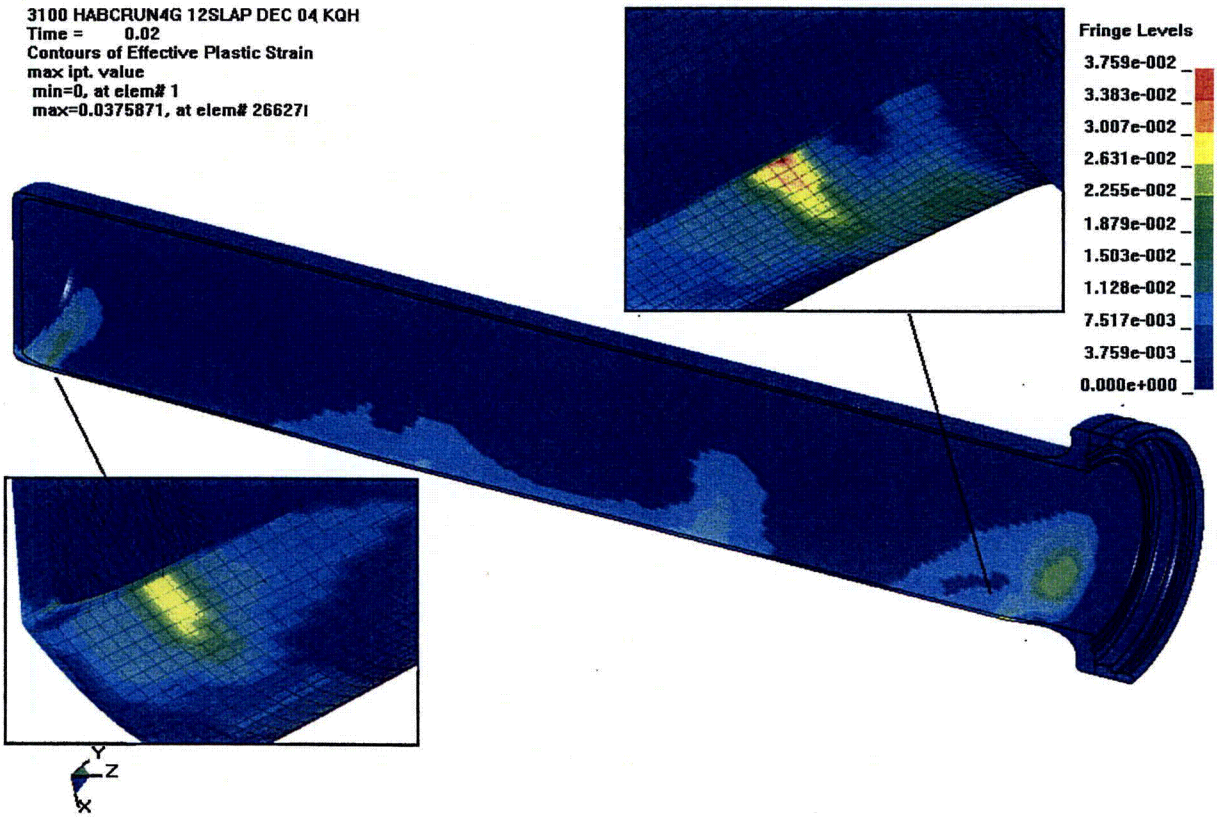


Figure 7.5.4 - HABC-run4g, 30-Foot Impact, Effective Plastic Strain in the CV Body

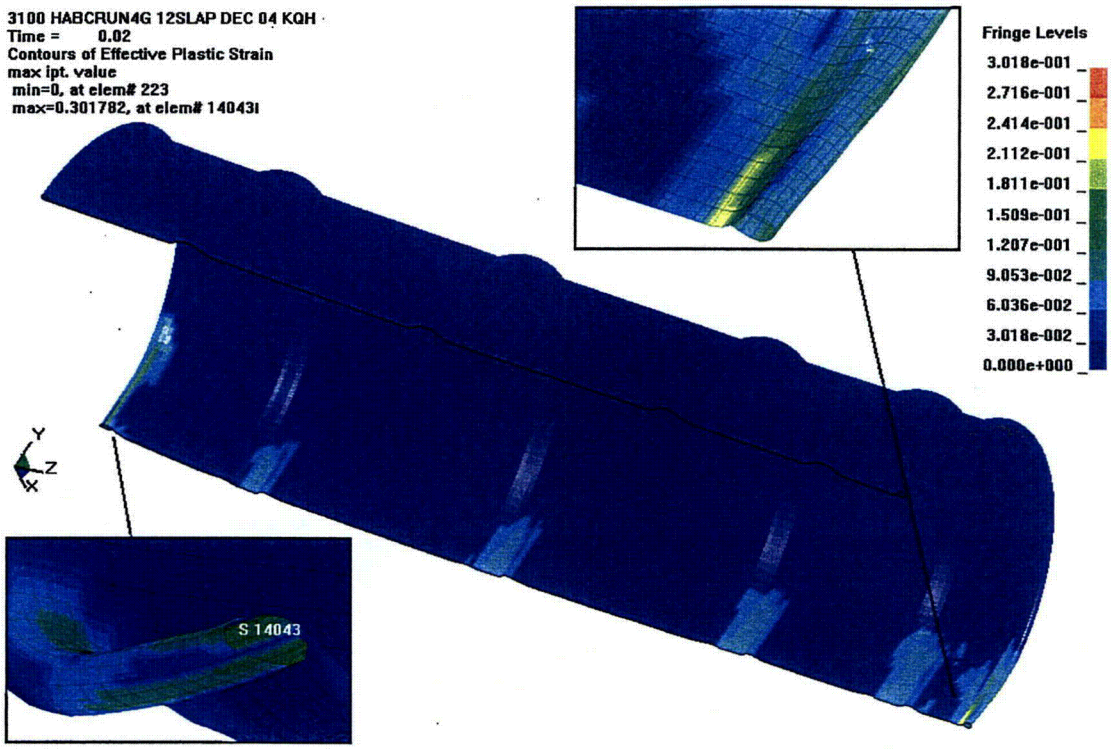


Figure 7.5.5 - HABC-run4g, 30-Foot Impact, Effective Plastic Strain in the Drum

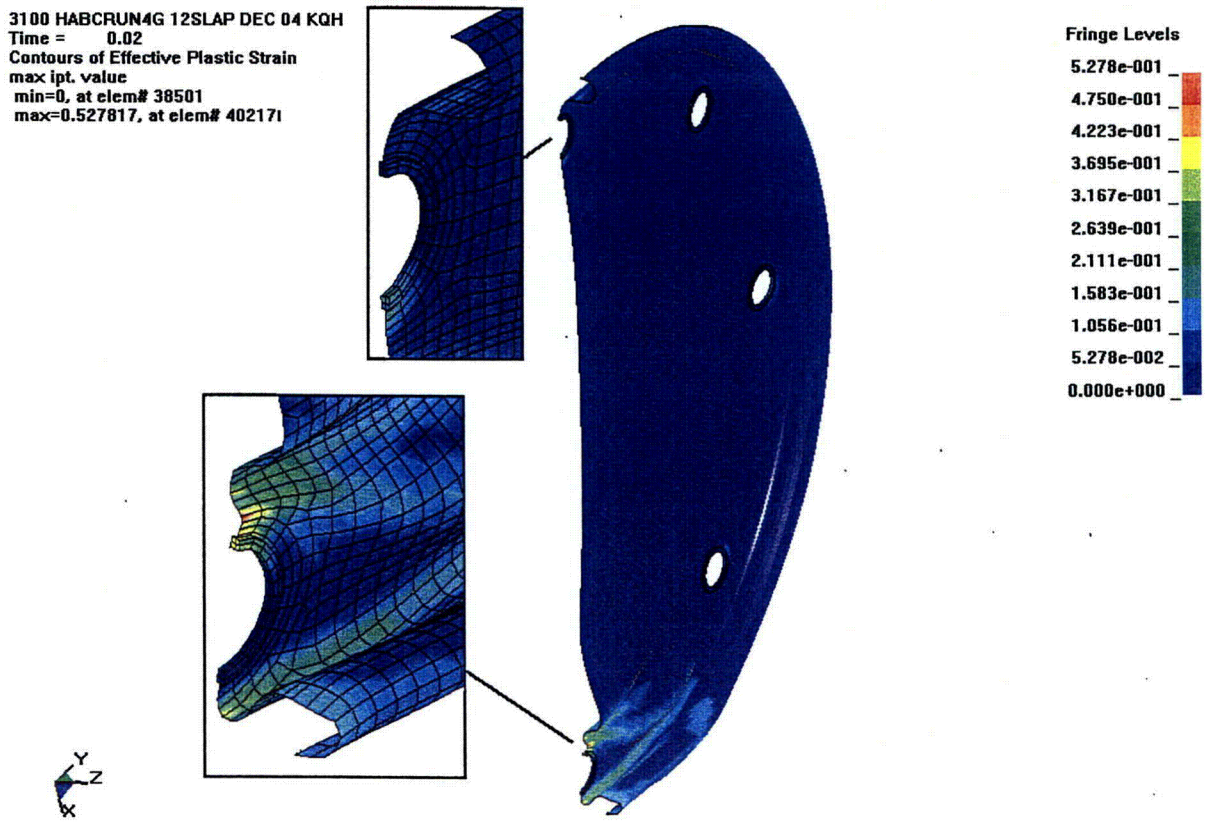


Figure 7.5.6 - HABC-run4g, 30-Foot Impact, Effective Plastic Strain in the Lid

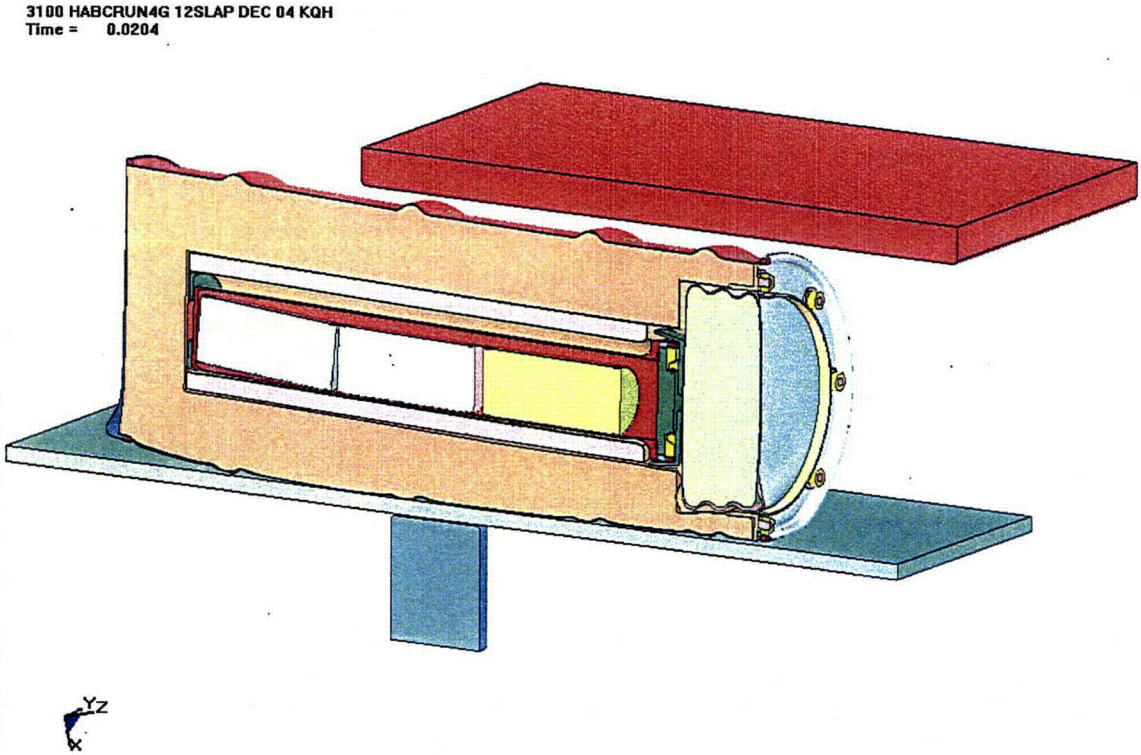


Figure 7.5.7 - HABC-run4g, Initial Configuration of the Offset Crush Impact

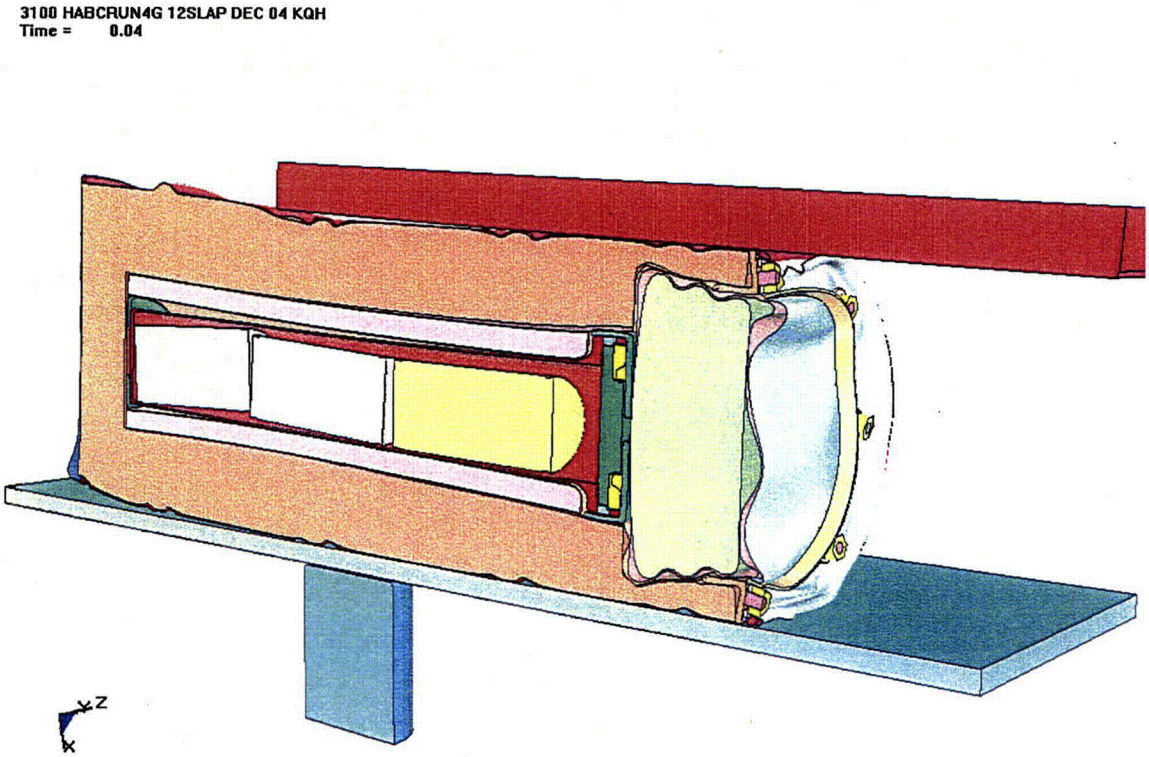


Figure 7.5.8 - HABC-run4g, Final Configuration After the Offset Crush Impact

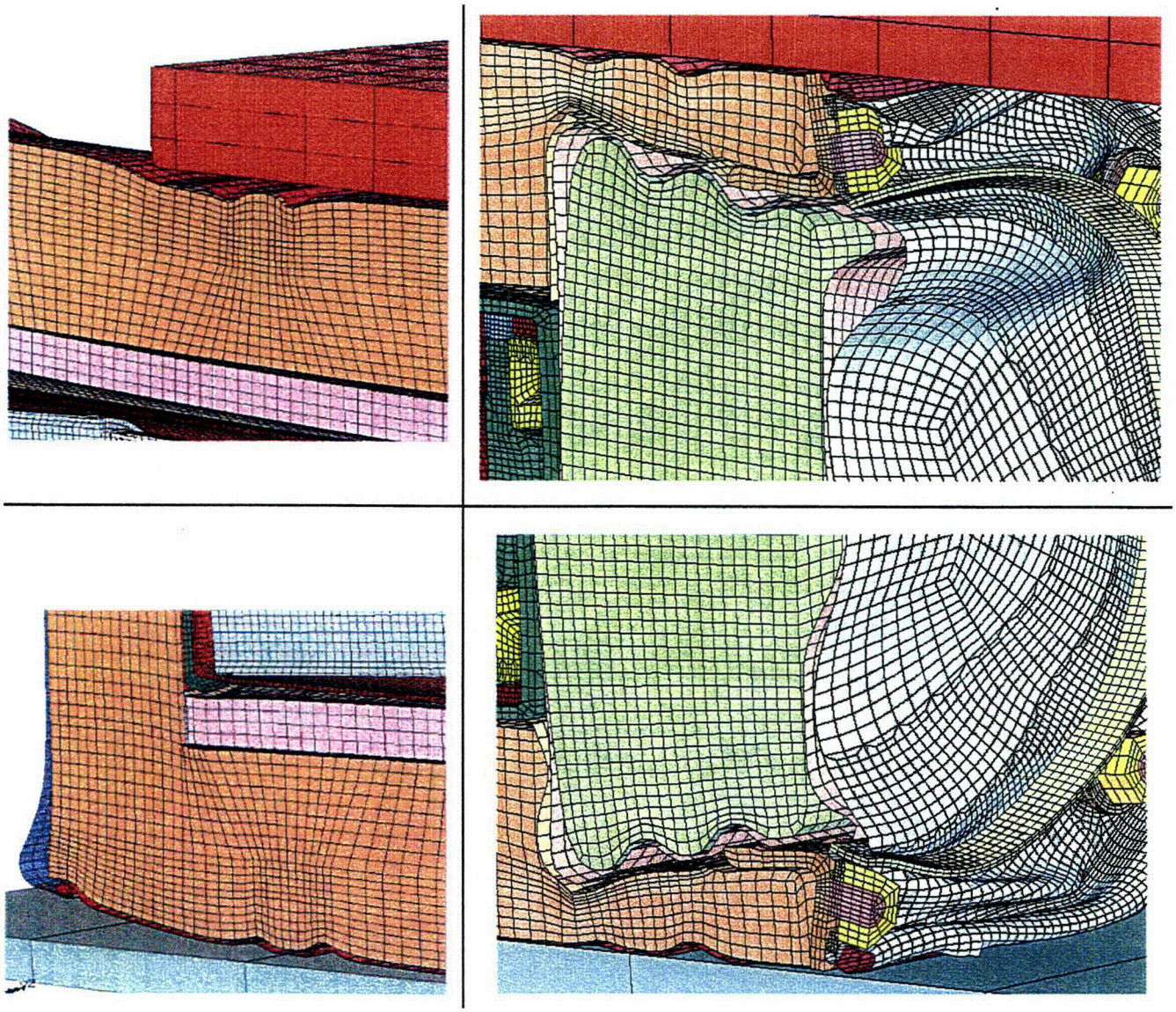


Figure 7.5.9 - HABC-run4g, Crush Impact, Enlarged Views of the Resulting Configuration

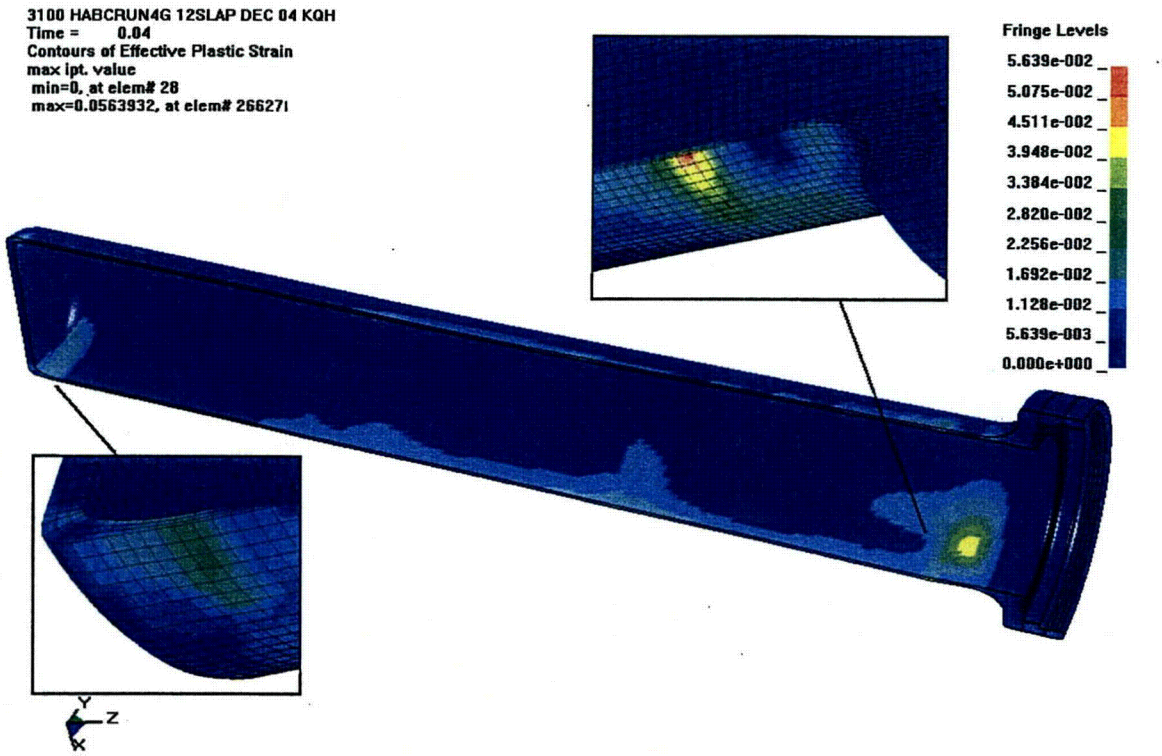


Figure 7.5.10 - HABC-run4g, Crush Impact, Effective Plastic Strain in the CV Body

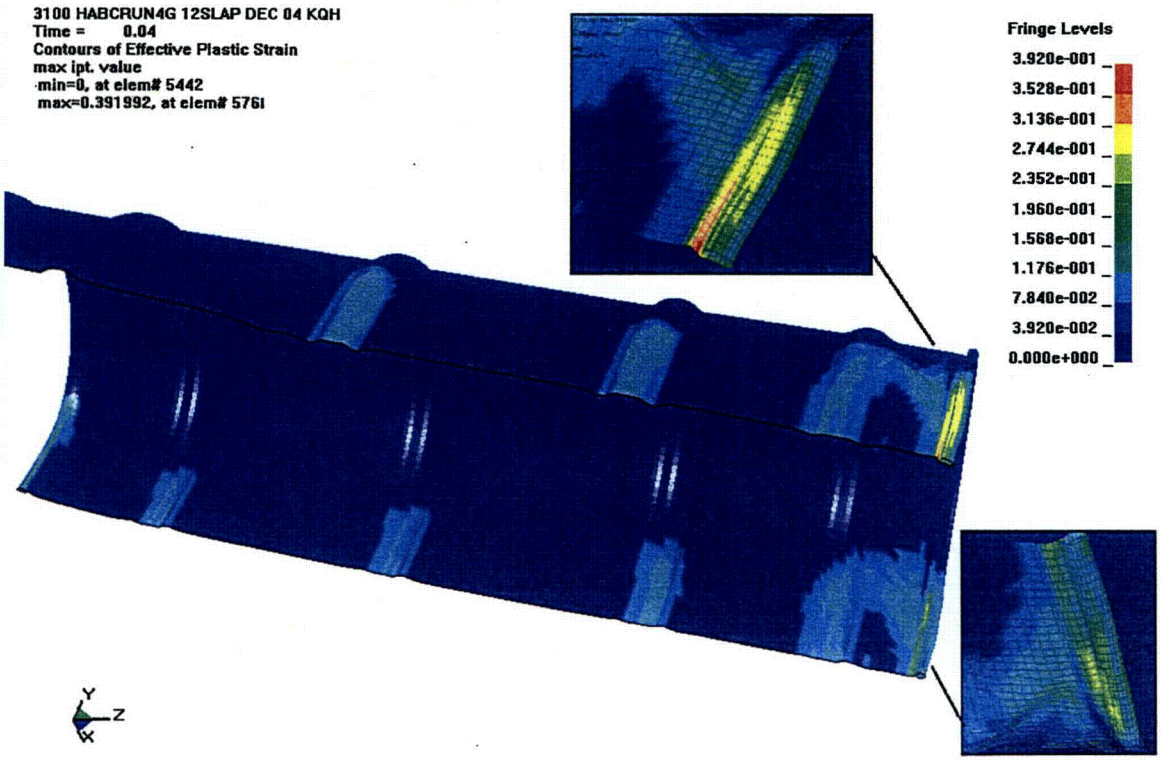


Figure 7.5.11 - HABC-run4g, Crush Impact, Effective Plastic Strain in the Drum

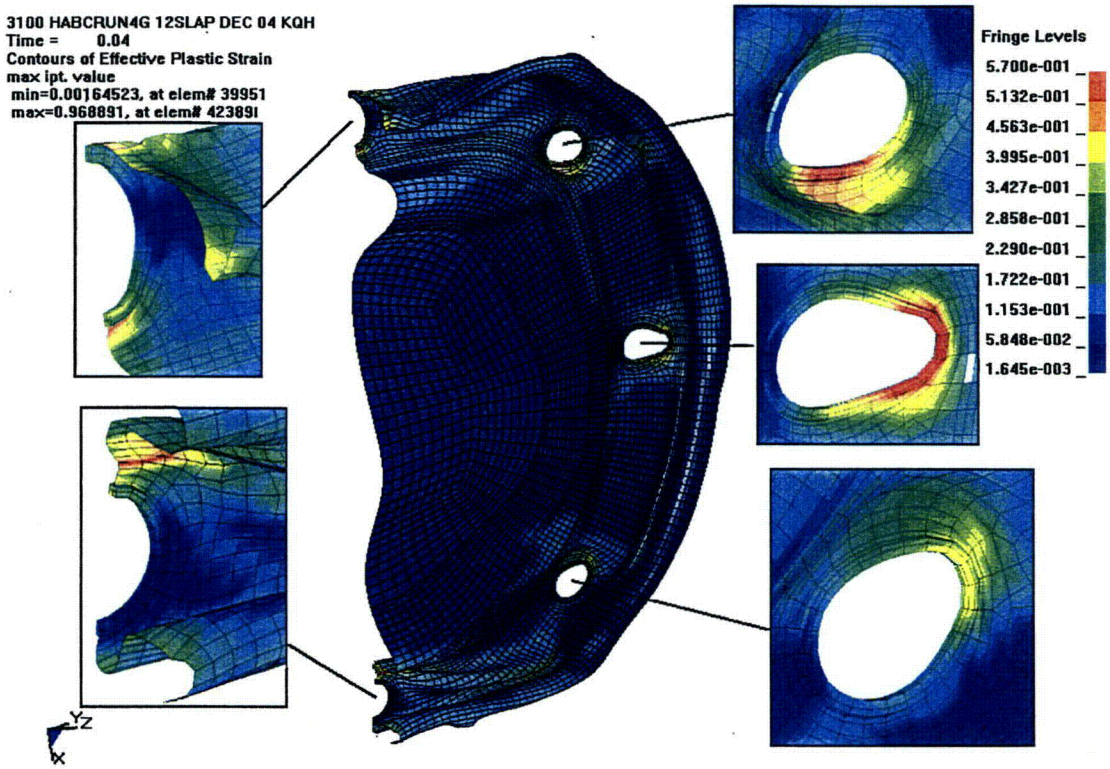


Figure 7.5.12 - HABC-run4g, Crush Impact, Effective Plastic Strain in the Lid

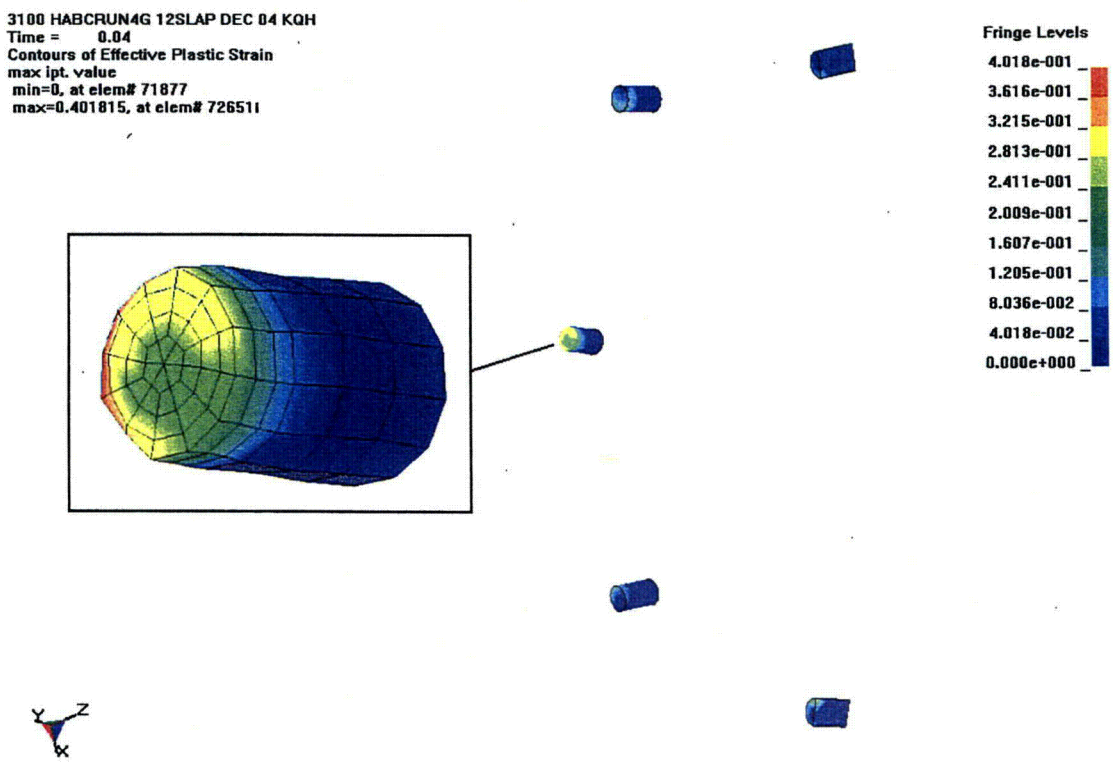


Figure 7.5.13 - HABC-run4g, Crush Impact, Effective Plastic Strain in the Studs

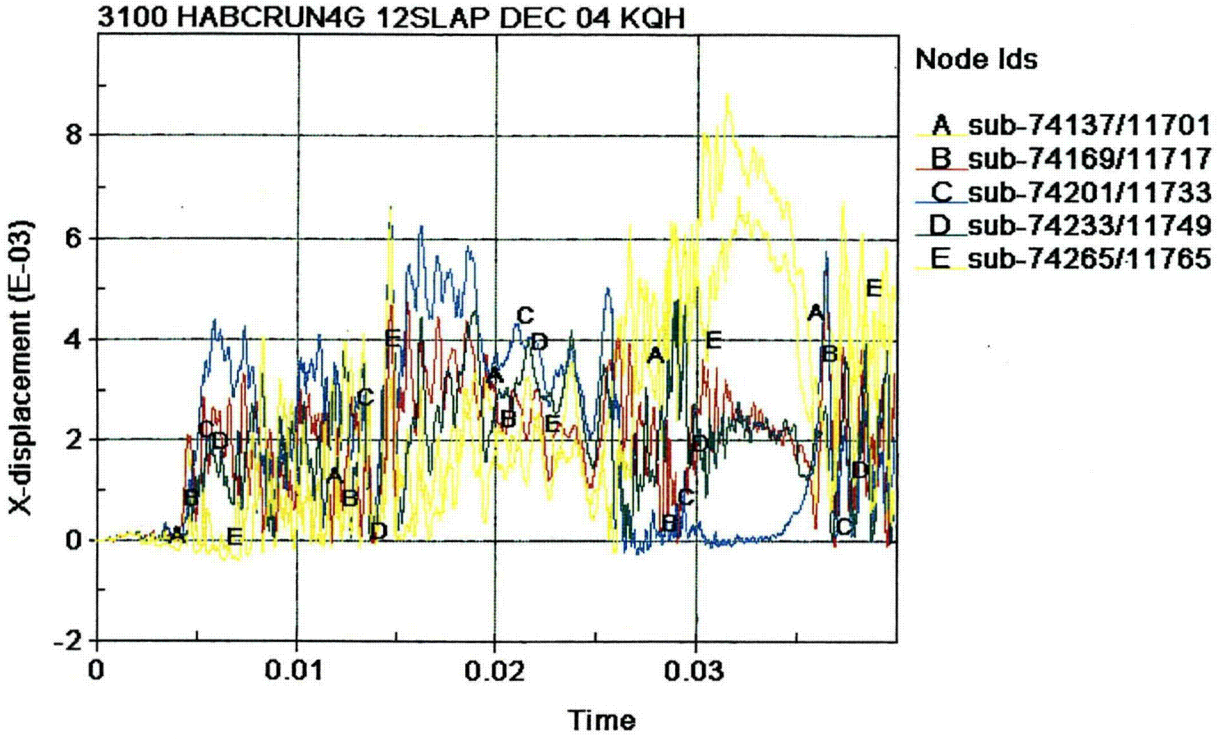


Figure 7.5.14 - HABC-run4g, CV Lid/Body Separation Time History

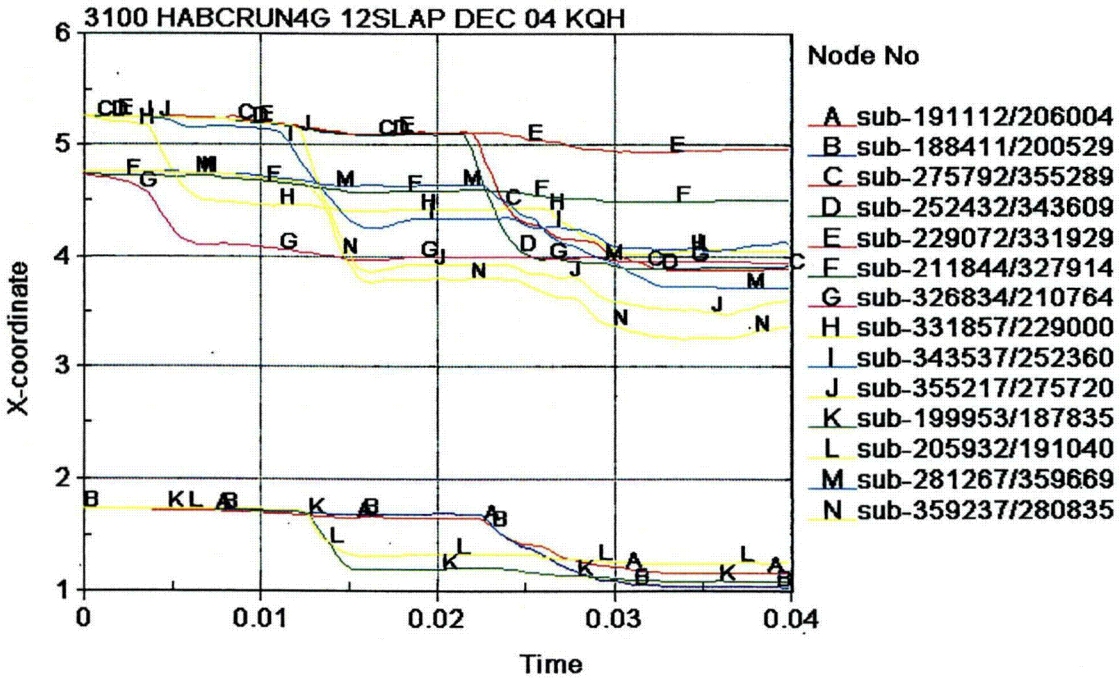


Figure 7.5.15 - HABC-run4g, Kaolite Thickness Time History

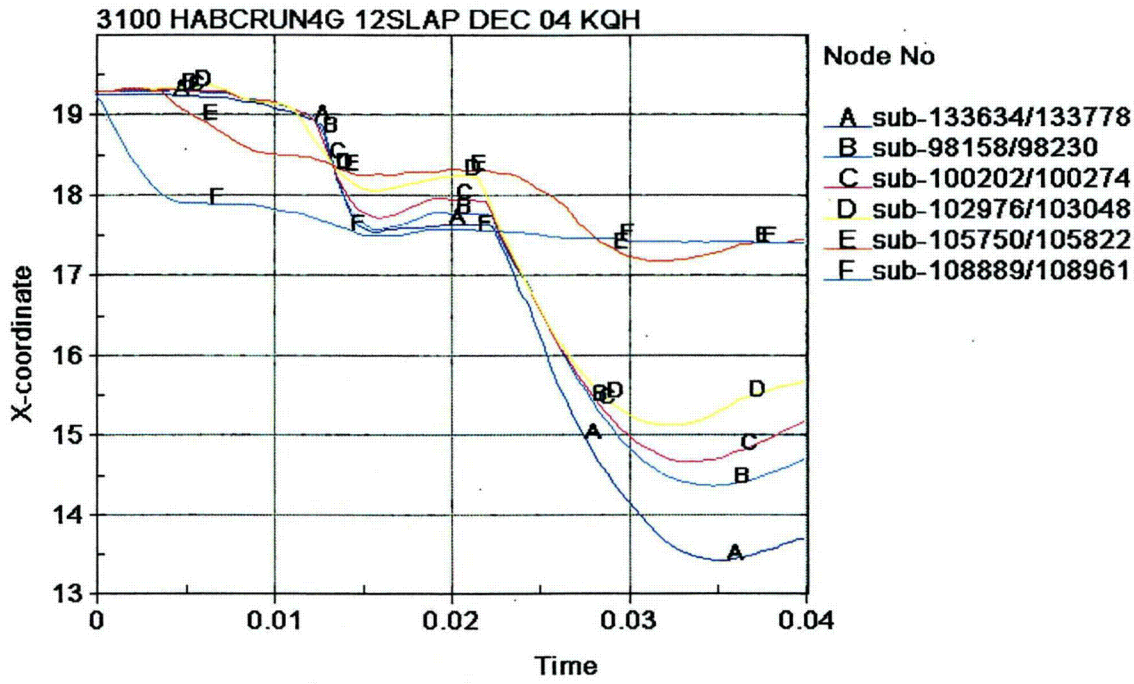


Figure 7.5.16 - HABC-run4g, Diameter Time History for the Drum in the X Direction

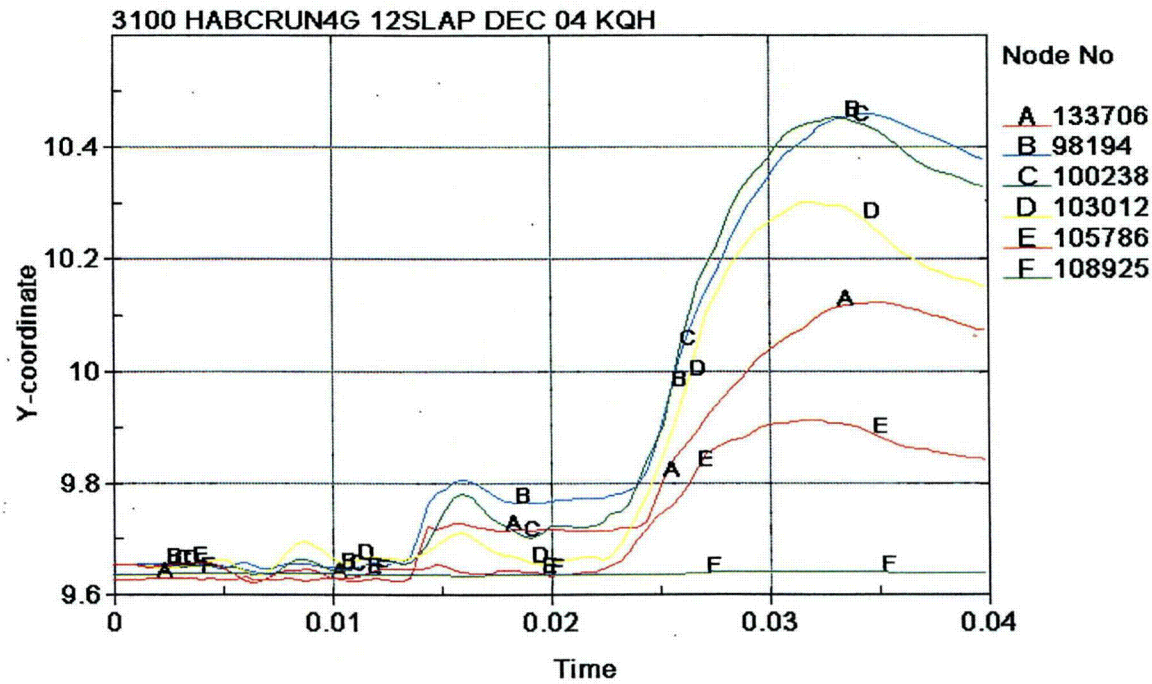


Figure 7.5.17 - HABC-run4g, Radius Time History for the Drum in the Y Direction

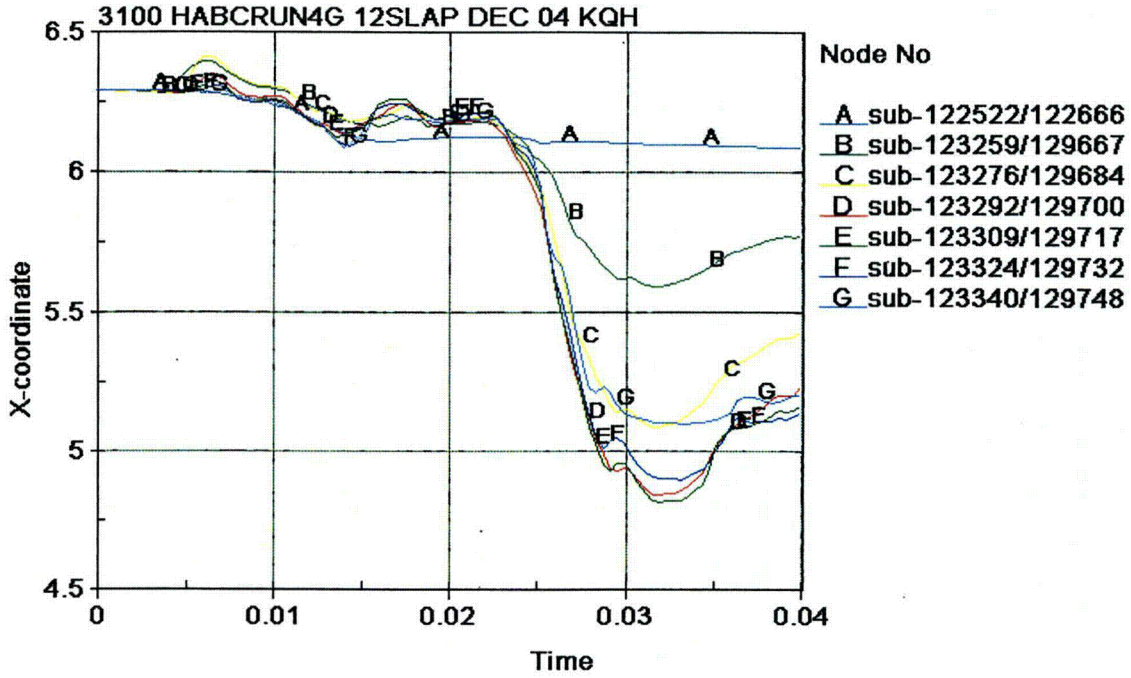


Figure 7.5.18 - HABC-run4g, Diameter Time History for the Inner Liner

7.6 HABC-run4ga - Slapdown

HABC-run4ga is a 30-foot, 12° slapdown impact (time - 0 to 0.02 sec) followed by a crush impact with the crush plate centered on the drum (0.0201 to 0.0400 sec). The HABC-run4g, 30-foot impact is the 30-foot impact for both the HABC-run4g offset crush and this HABC-run4ga centered crush. The difference between the 4g and 4ga impacts is the location to which the crush plate is moved by way of specifying velocities for specific times. In HABC-run4ga, the translation of the crush plate occurs from 0.02 to 0.0201 sec. Therefore, the 30-foot impact results are presented in Section 7.5 and the centered crush results are presented in this section (7.6).

The initial configuration for the start of the centered crush is shown in Figure 7.6.1. The final configuration for the HABC-run4ga crush impact is shown in Figure 7.6.2. Figure 7.6.3 shows the configuration at each end of the package following the centered crush impact.

The maximum effective plastic strain in the CV body is shown to be 0.0643 in/in in Figure 7.6.4. The maximum occurs in the body side wall, on the side nearest the crush plate. Figure 7.6.5 shows the fringes of effective plastic strain in the drum. The maximum strain in the drum is 0.3443 in/in and occurs near the lid in the crimped region shown in the enlarged view. Figure 7.6.6 shows that the maximum effective plastic strain in the lid is 0.5828 in/in. The maximum occurs at the 180° stud hole, and is localized. This value is a surface, or bending strain, the membrane strain is 0.4736 in/in. Therefore, the bending strain is above the failure limit of 0.57 in/in, however the membrane strain is below the limit. Some cracking may occur, but tearing of the lid is not expected. The large washers would provide restraint of the lid.

Table 7.6.1 presents the maximum effective plastic strain in other shipping package components for the run4ga crush impact.

Table 3.6.1 - Run4ga, Crush Impact, Effective Plastic Strain Levels in Some Components	
Component	Effective Plastic Strain, in/in
CV Lid	0.0018
CV Nut Ring	0.0000
Angle	0.0944
Drum Bottom Head	0.3000
Liner	0.2846
Lid Stiffener	0.0288
Lid Studs	0.2390
Lid Stud Nuts	0.0000
Lid Stud Washers	0.0775
Plug Liner	0.1644

The CV lid separation time history is shown in Figure 7.6.7. For the crush impact (0.0201 to 0.0400 sec) the spikes in the gap reach just over 0.01 in. The general gap during the impact reaches about 0.009 in. At the time the impact was halted, the maximum separation was on the order of 0.006 in.

Figure 7.6.8 shows the kaolite thickness time history. The nodes chosen are shown in Figure 7.1.16

Figure 7.6.9 shows the X direction diameter changes in the drum. Figure 7.6.10 shows the Y direction radial changes in the drum. Figure 3.1.34 shows the location of the nodes in the Figure 7.6.9 and 7.6.10 time histories.

Figure 7.6.11 shows the diameter time history for the inner liner. The position of the nodes are shown in Figure 3.1.37 and Table 3.1.3.

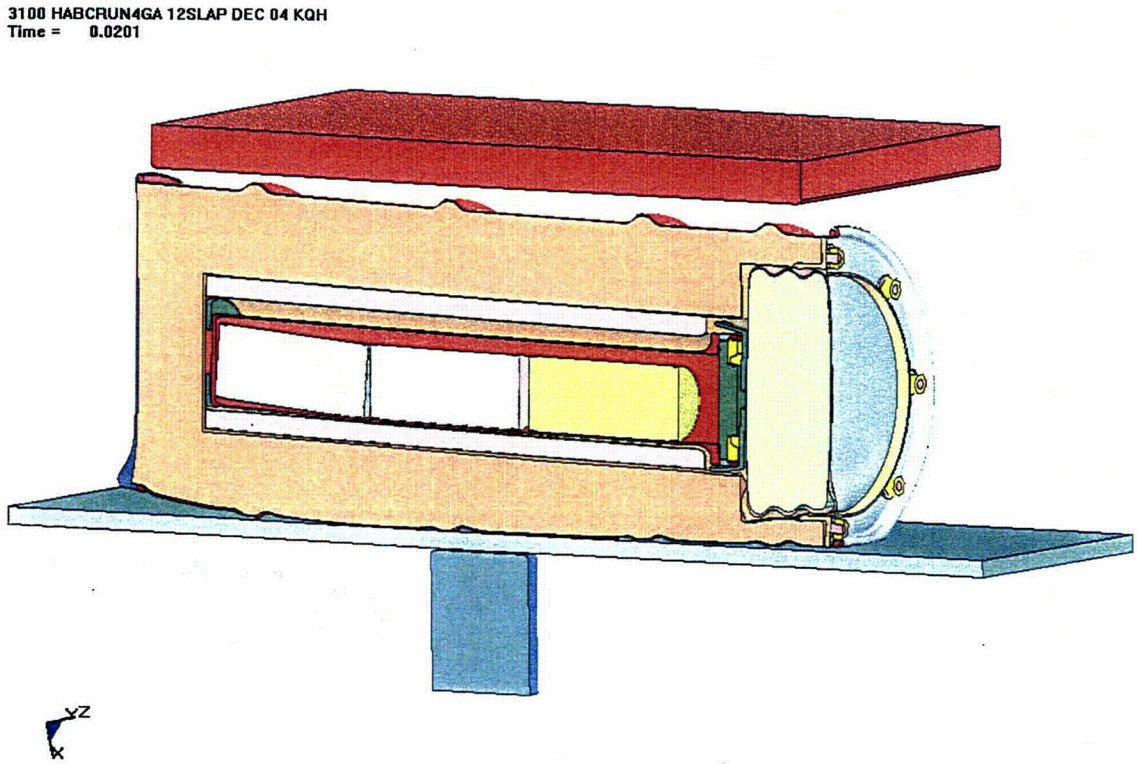


Figure 7.6.1 - HABC-run4ga, Initial Configuration for the Centered Crush Impact

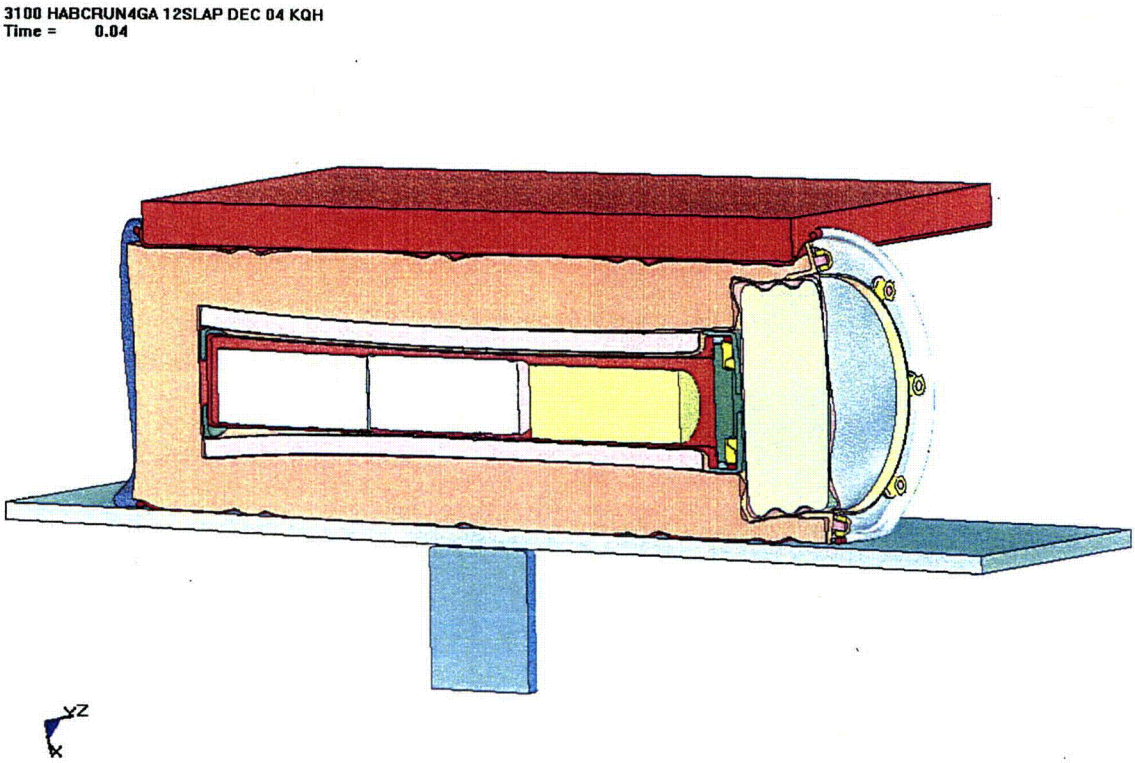


Figure 7.6.2 - HABC-run4ga, Final Configuration of the Centered Crush Impact

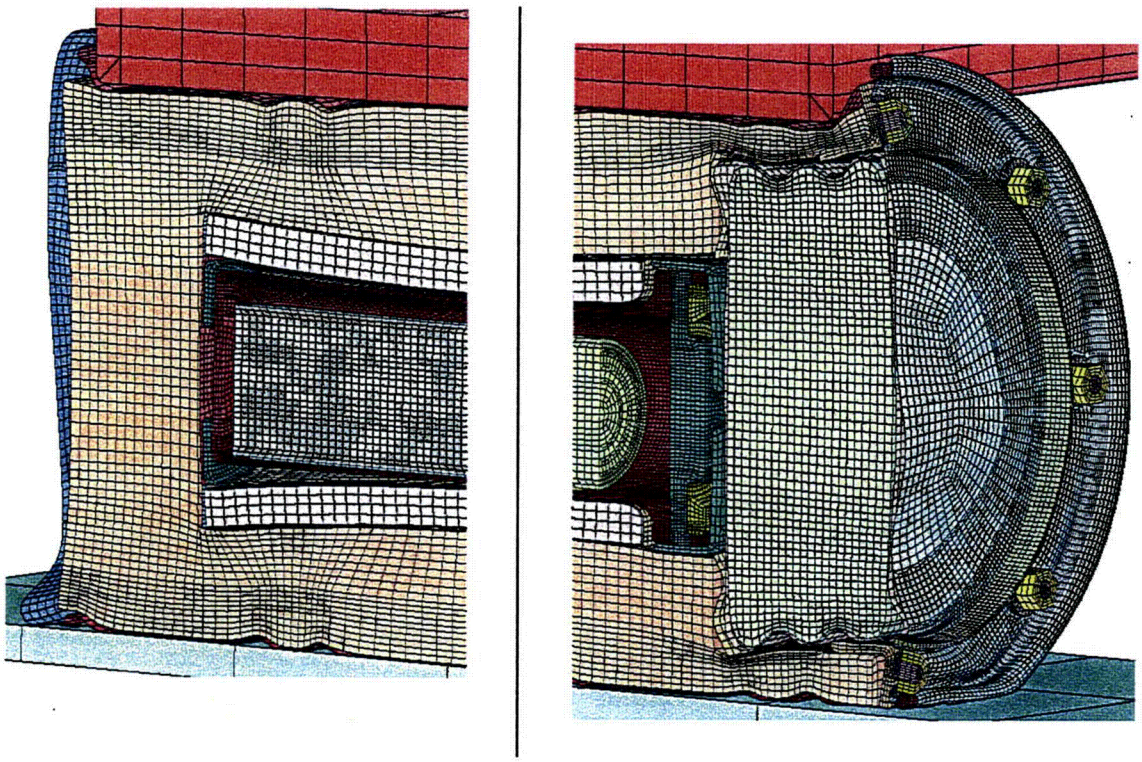


Figure 7.6.3 - HABC-run4ga, Crush Impact, Configurations at the Package Ends

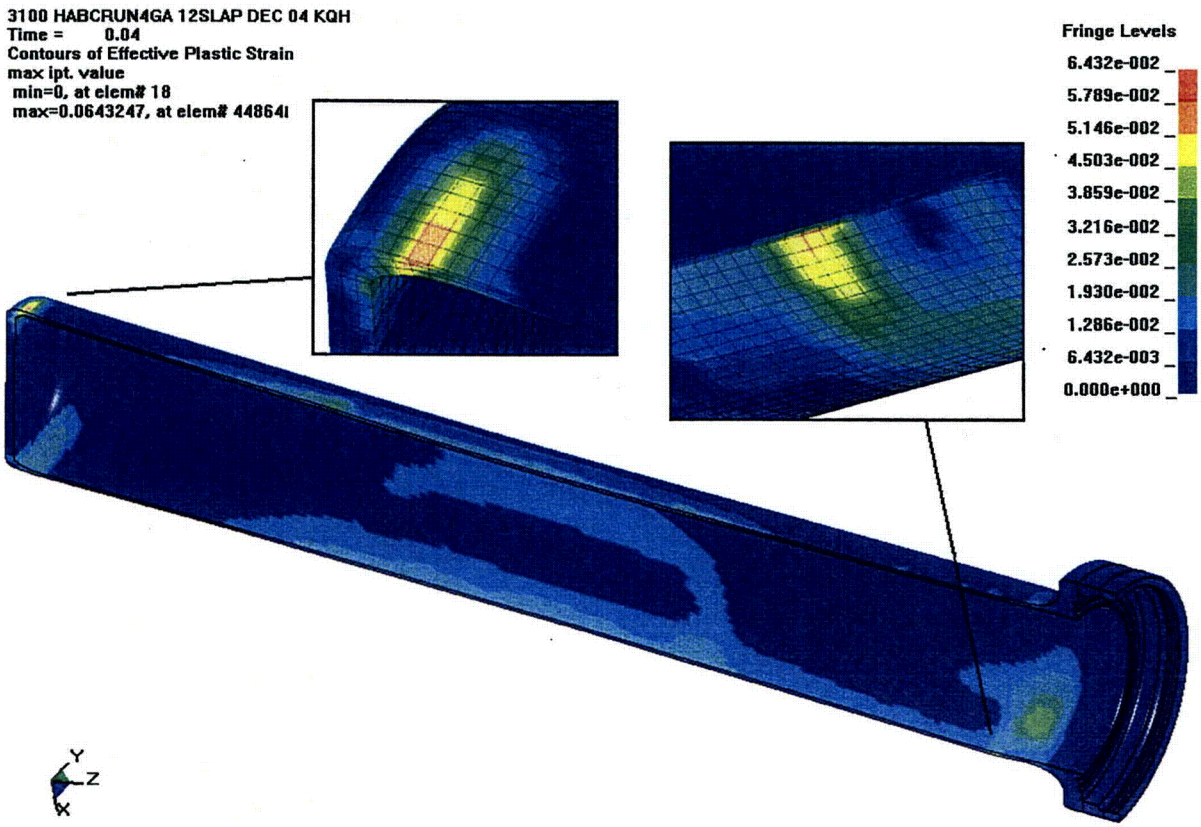


Figure 7.6.4 - HABC-run4ga, Crush Impact, Effective Plastic Strain in the CV Body

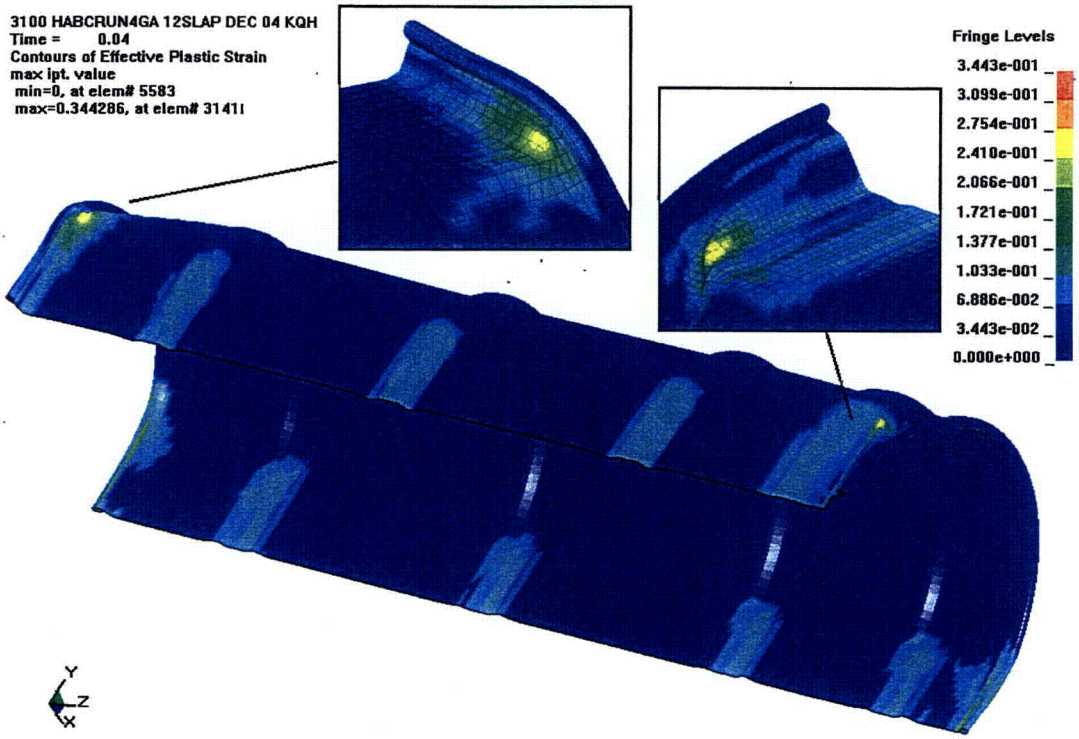


Figure 7.6.5 - HABC-run4ga, Crush Impact, Effective Plastic Strain in the Drum

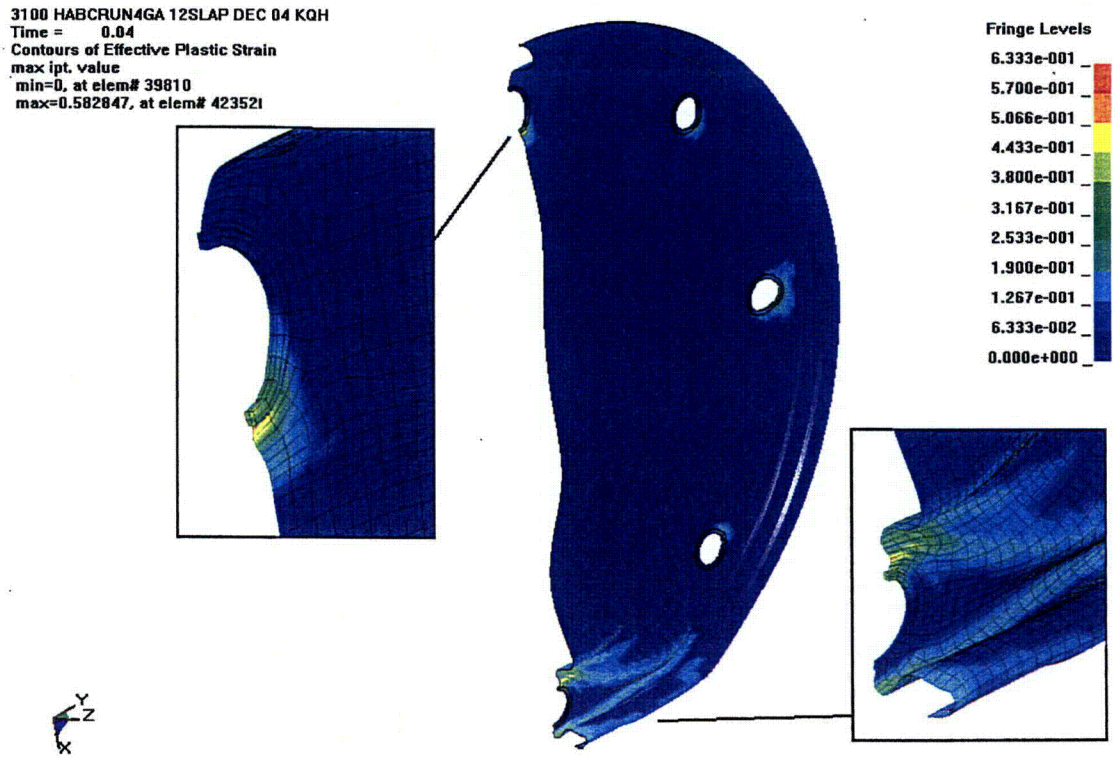


Figure 7.6.6 - HABC-run4ga, Crush Impact, Effective Plastic Strain in the Lid

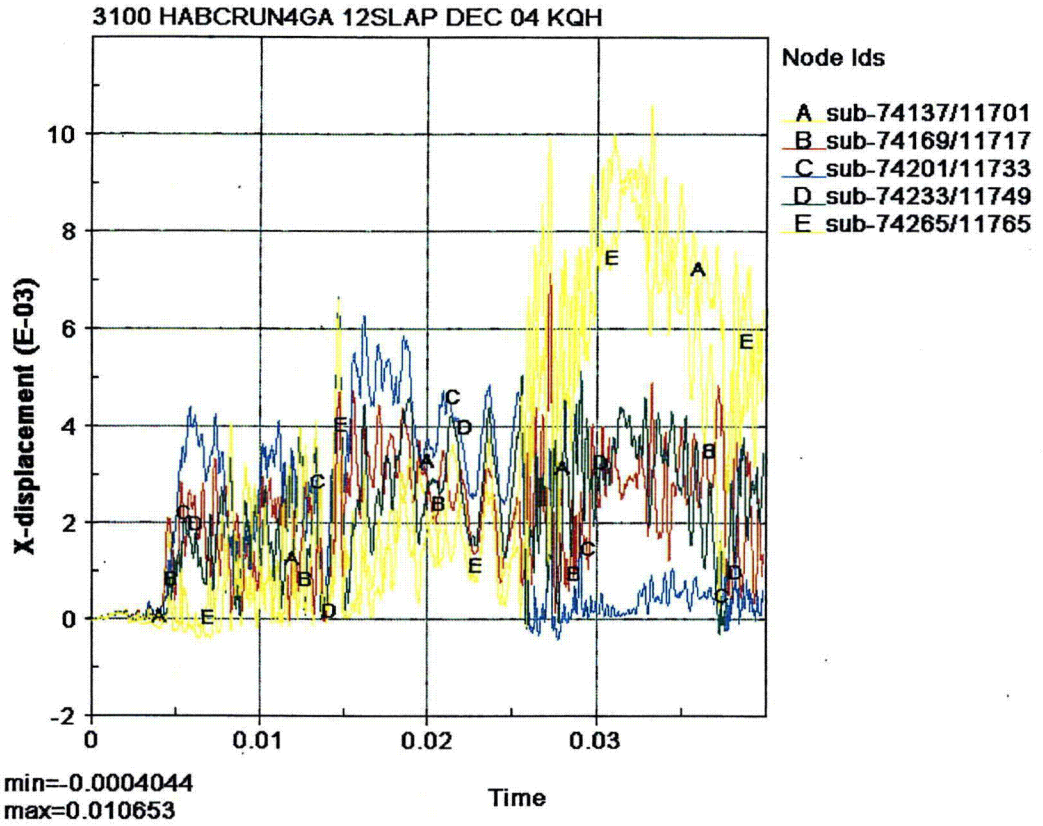


Figure 7.6.7 - HABC-run4ga, CV Lid Separation Time History

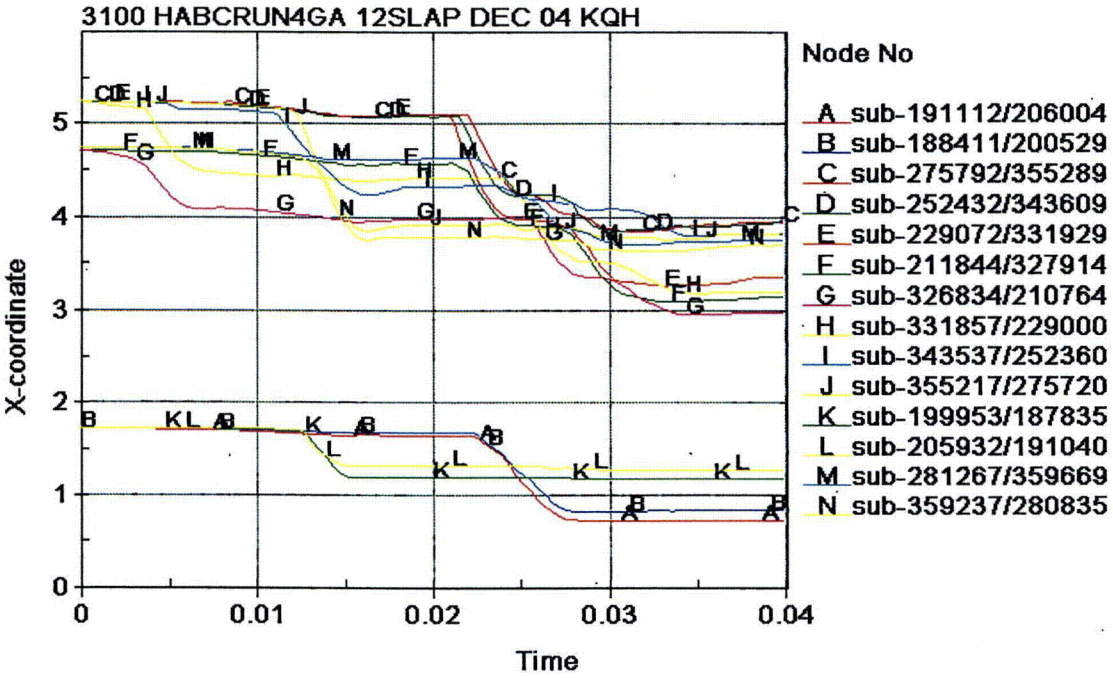


Figure 7.6.8 - HABC-run4ga, Kaolite Thickness Time History

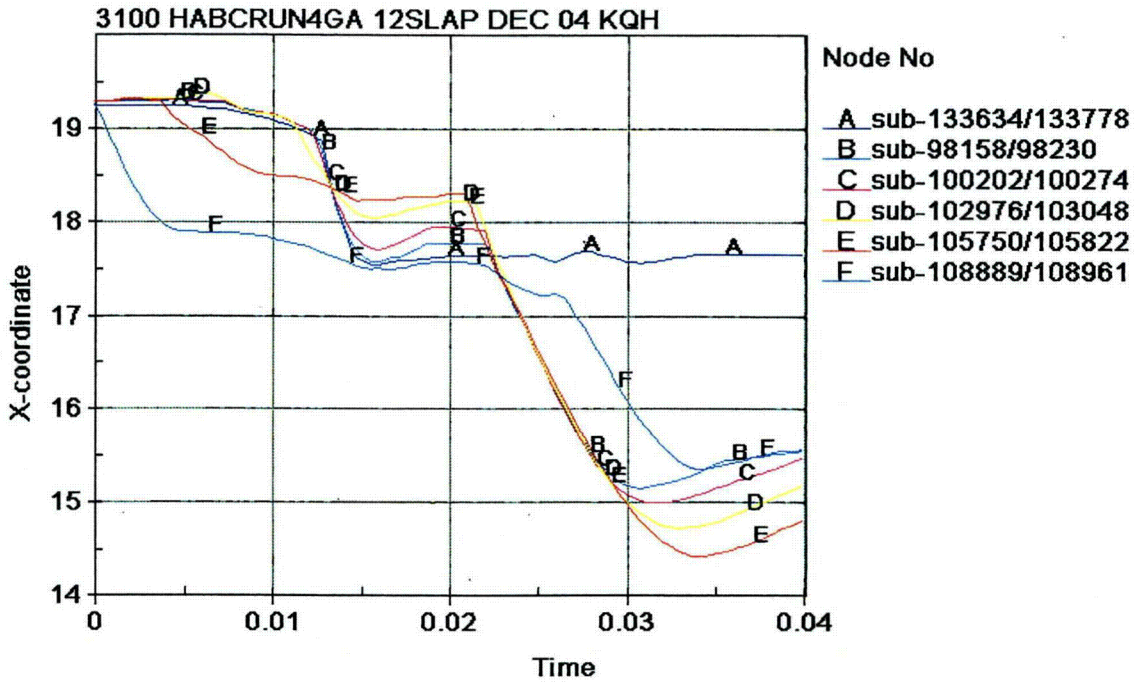


Figure 7.6.9 - HABC-run4ga, Diameter Time History for the Drum in the X Direction

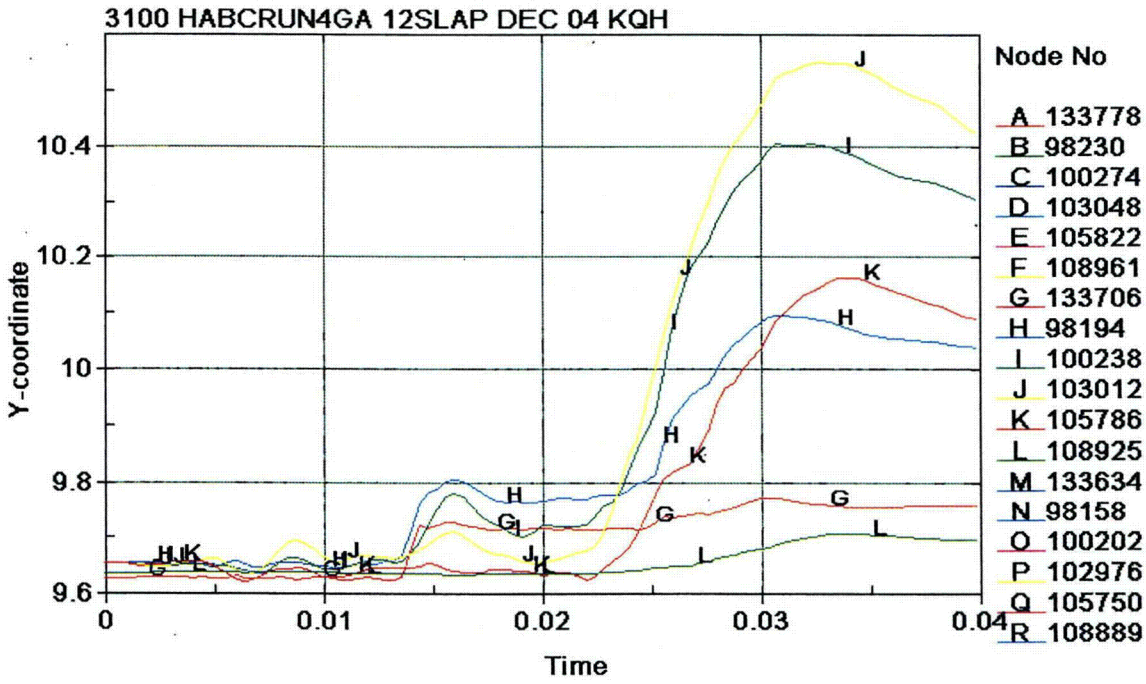


Figure 7.6.10 - HABC-run4ga, Radius Time History for the Drum in the Y Direction

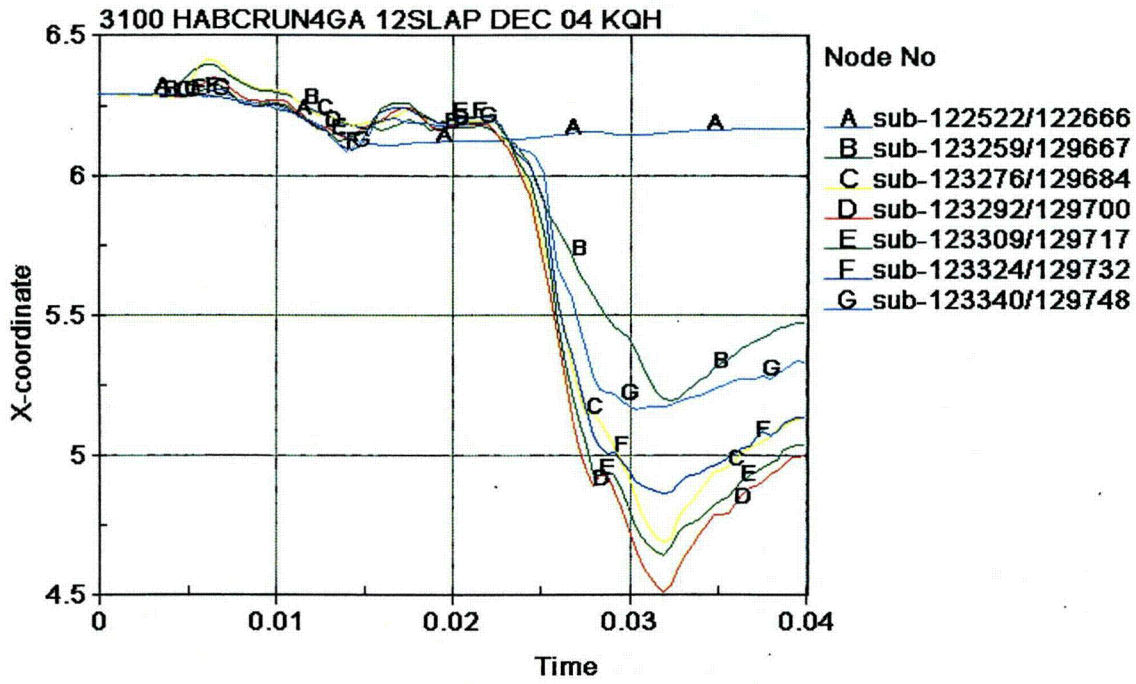


Figure 7.6.11 - HABC-run4ga, Diameter Time History for the Inner Liner

7.7 Comparison of Test vs Analysis

The HABC analysis runs are compared to the test results similar to that performed in Section 3.12 for the initial design using borobond. It should be noted that the testing was with specimen of the borobond neutron absorber design, whereas the analysis models in this section are of the HABC design.

7.7.1 Comparison of HABC Run4g to TU1

The HABC-run4g is a 30-foot, 12° slapdown impact followed by an offset crush (crush plate centered over the CV flange). TU1 is a 12° slapdown with a 4-foot impact, 30-foot impact, offset crush, and punch test specimen. The following Table 7.7.1.1 shows the initial diameter comparisons (pre-impact) using the test data compared to the analysis results.

Table 7.7.1.1 - HABC-run4g vs TU1, Comparison of Initial Diameters (Pre-Impact)

Location	0°- 180°		90°-270°	
	Test	Analysis	Test	Analysis
Top Chime	19.25	19.32	19.25	19.32
Top Hoop	19.25	19.37	19.25	19.37
Top CG Hoop	19.25	19.37	19.25	19.37
CG Hoop	19.25	19.37	19.25	19.37
Bottom Hoop	19.25	19.37	19.25	19.37
Bottom Chime	19.25	19.38	19.25	19.38

The Table 7.7.1.2 shows the results of the 30-foot test and analysis impacts. The test diameters are after the 4 and 30-foot impacts, while the analysis is after the 30-foot impact.

Table 7.7.1.2 - HABC-run4g vs TU1, Diameter Results After the 30-Foot Impact

	0°-180°		90°-270°	
	Test	Analysis	Test	Analysis
Top Chime	18-1/2	18.1	19-3/8	19.5
Top Hoop	18-1/2	18.2	19-3/8	19.6
Top CG Hoop	18-1/2	18.4	19-3/8	19.5
CG Hoop	18-5/8	18.8	19-3/8	19.4
Bottom Hoop	18-5/8	18.9	19-1/4	19.3
Bottom Chime	17-13/16	18.1	19-3/8	19.4

Figure 7.7.1.1 shows the final configuration of the test specimen after the 4-foot and 30-foot impacts. Figure 7.7.1.2 shows the analytical model configuration after the 30-foot impact.

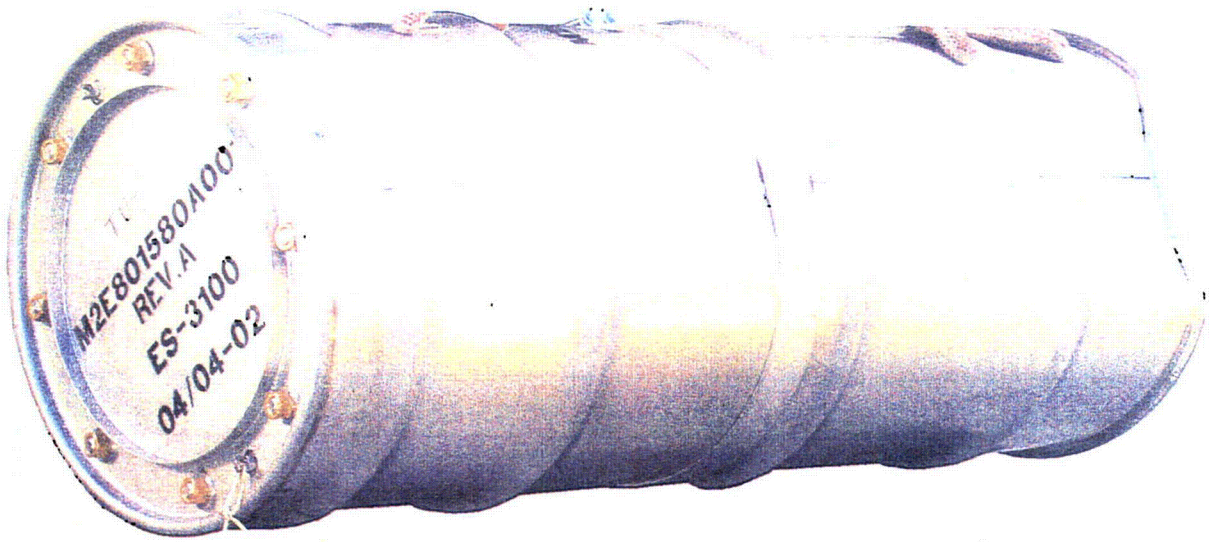


Figure 7.7.1.1 - TU1, Results of 30-Foot Impact

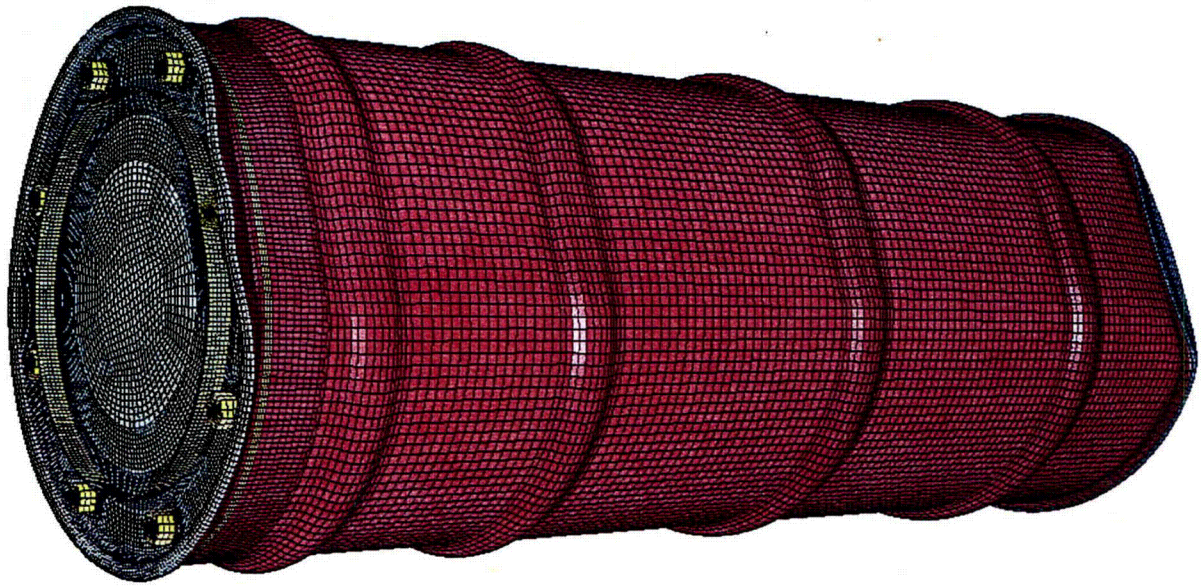


Figure 7.7.1.2 - HABC-run4g, Results of the 30-Foot Impact

Table 7.7.1.3 shows the comparison of the results of the crush impacts. The test data is for the cumulative effects of a 4-foot, 30-foot, and crush impact. The analysis data is for a cumulative 30-foot impact and crush impact.

Table 7.7.1.3 - Run4g vs TU1, Diameter Results After the Crush Impact				
	0°-180°		90°-270°	
	Test	Analysis	Test	Analysis
Top Chime	15-5/8	14.9	20-5/8	20.7
Top Hoop	16	15.1	20-7/16	20.8
Top CG Hoop	16-1/4	15.7	20-1/4	20.7
CG Hoop	16-1/2	16.2	19-7/8	20.4
Bottom Hoop	18-1/4	18.1	19-1/2	19.8
Bottom Chime	17-13/16	18.0	19-1/4	19.4

Figure 7.7.1.3 shows an isometric view of the test specimen with the crush side up. Figure 7.7.1.4 shows a similar view for the analysis results.

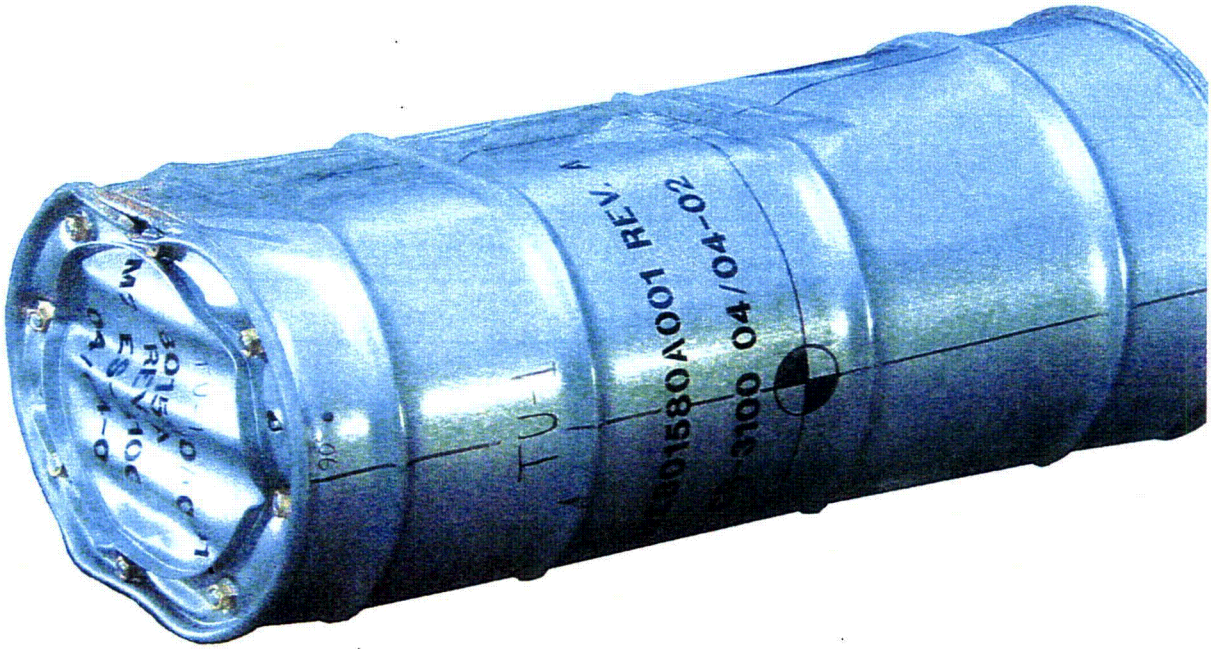


Figure 7.7.1.3 - TU1, View of Crush Damage with the Crush Side Up

Figure 7.7.1.4 - HABC-run4g, View of the Crush Damage, Crush Side Up

Table 7.7.1.4 shows the results of a comparison of the "flats" measurements from the test after the 30-foot impacts and Table 3.12.1.5 compares the crush impact results.

Table 7.7.1.4 - HABC-run4g vs TU1, Comparison of Flats for the 30-Foot Impact		
	Test	Analysis
Top Chime	8	8.8
Top Hoop	7-3/8	8.4
Top CG Hoop	7-1/8	7.6
CG Hoop	6-3/8	5.9
Bottom Hoop	6-3/4	5.9
Bottom Chime	10	10.1

Table 7.7.1.5 - HABC-run4g vs TU1, Comparison of Flats for the Crush Impact				
Location	Rigid Surface Side		Crush Plate Side	
	Test	Analysis	Test	Analysis
Top Chime	9	10.5	8-1/2	10.9
Top Hoop	10	11.0	10	11.0
Top CG Hoop	10	10.1	10-1/8	10.1
CG Hoop	9	8.4	10-5/8	10.1
Bottom Hoop	8-1/4	7.6	- - -	0.0
Bottom Chime	9-7/8	10.1	- - -	0.0

7.7.2 Comparison of HABC Run2e vs TU3

The HABC-run2e is a CG over lid corner 30-foot impact, followed by a bottom corner crush. TU3 is a similar test impact configuration with a 4-foot impact, 30-foot impact on the lid corner, then a crush impact on the bottom corner followed by a punch.

The test results show that there is 1.125 inches between the top chime and the top hoop in the test. Similar measurements in the analysis show that the distance is about 1.7 inches. This would be a somewhat judgmental comparison due to points chosen for measurement on the test specimen might not be the same as those chosen in the analysis. The analysis measurement is from the top of the crimped drum roll to the center of the flattened region in the lid roll, on the plane of symmetry.

Table 7.7.2.1 shows the comparison of the TU3 test unit and the computer run2e drum diameter changes after the 30-foot impact.

Table 7.7.2.1 - Run2e vs TU3, Diameter Results After the 30-Foot Impact

	0°-180°		90°-270°	
	Test	Analysis	Test	Analysis
Top Chime	19-1/4	19.0	19-3/16	19.2
Top Hoop	18-5/8	19.1	19-7/8	20.0
Top CG Hoop	19-1/8	19.3	19-3/8	19.5
CG Hoop	19-1/8	19.4	19-3/8	19.4
Bottom Hoop	19-1/8	19.4	19-1/4	19.4
Bottom Chime	19-1/8	19.4	19-3/8	19.4

Figure 7.7.2.1 is an image of the damage after the 30-foot impact of TU3. The test photo shows the cumulative damage from the 4-foot and 30-foot impacts. Figure 7.7.2.2 shows a similar view after the 30-foot impact in run2e. The analysis image is the damage from only the 30-foot impact.

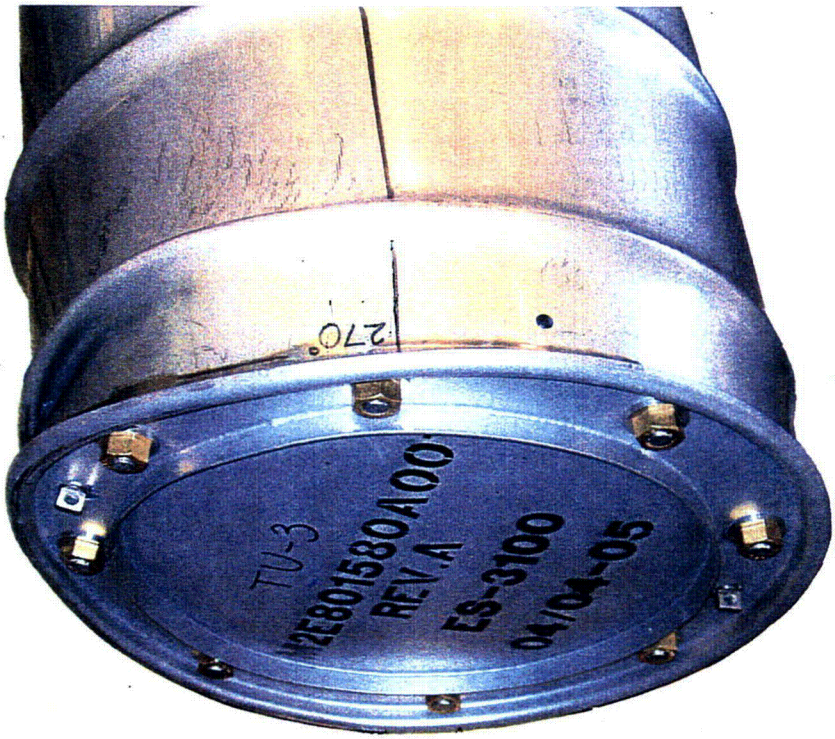


Figure 7.7.2.1 - TU3, Deformed Shape After the 30-Foot Impact

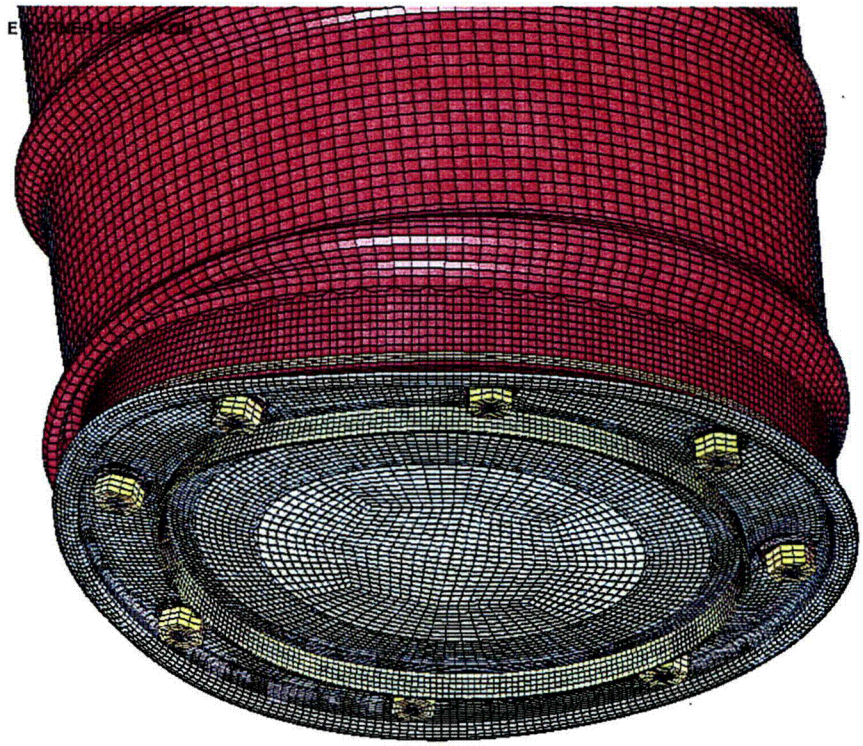


Figure 7.7.2.2 - HABC-run2e, Deformed Shape After the 30-foot Impact

The package drum diameters after the crush impact are compared in Table 7.7.2.2.

Table 7.7.2.2 - Run2e vs TU3, Diameter Results After the Crush Impact				
	0°-180°		90°-270°	
	Test	Analysis	Test	Analysis
Top Chime	19-1/4	19.0	19-1/16	19.0
Top Hoop	18-3/4	18.9	20-1/4	20.6
Top CG Hoop	19-1/4	19.4	19-3/4	19.8
CG Hoop	19-1/8	19.3	19-1/4	19.4
Bottom Hoop	19-1/8	19.3	19-3/4	20.4
Bottom Chime	18	18.6	19-3/8	19.4

The final images after the crush impact are shown for the test and the analysis. Figure 7.7.2.3 shows the final shape of the crushed bottom on the test specimen (4ft + 30ft + crush) and Figure 7.7.2.4 shows a similar view of the analysis (30ft + crush).

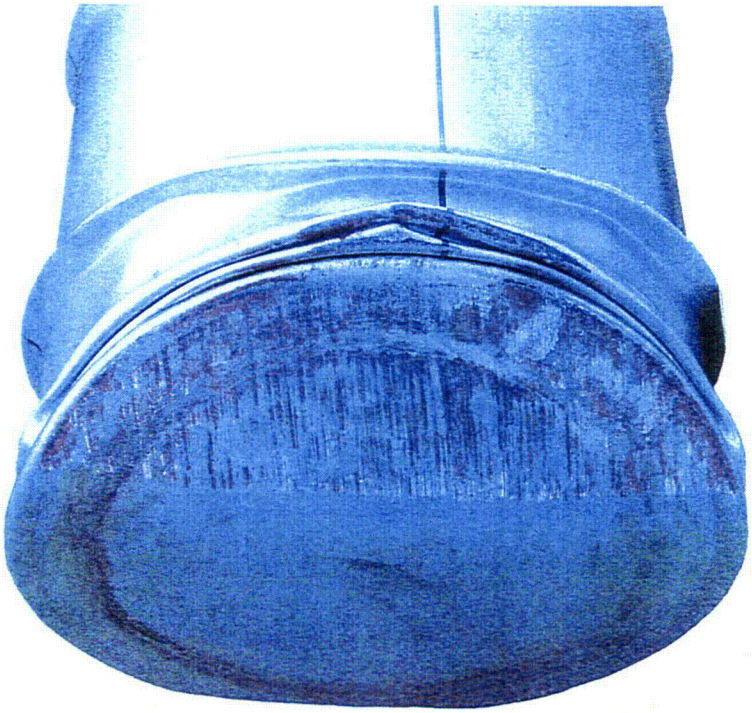


Figure 7.7.2.3 - TU3, Damage to the Bottom Head in the Crush Impact

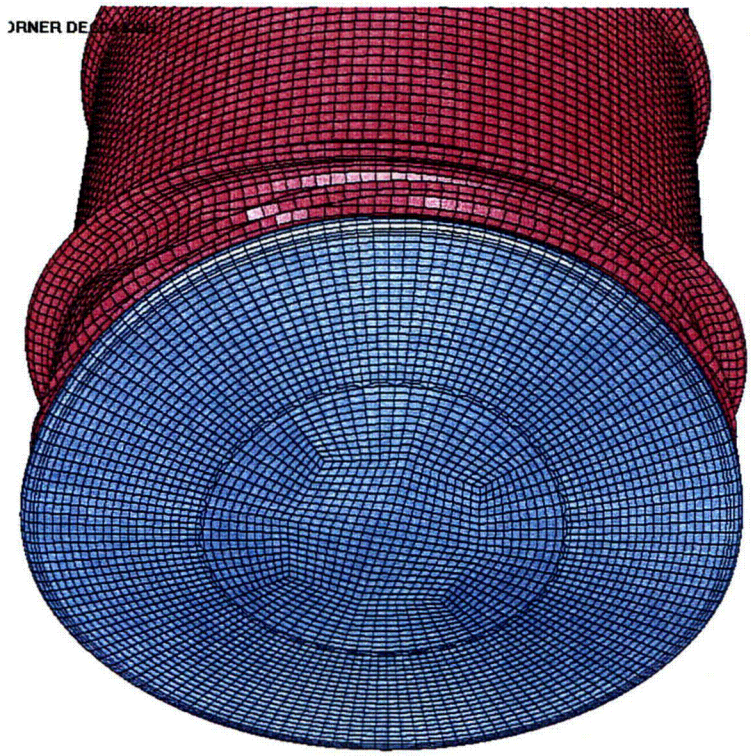


Figure 7.7.2.4 - HABC-run2e, Damage to the Bottom Head in the Crush Impact

The damage to the lid region at the end of the crush impact is shown in Figure 7.7.2.5 for the TU3. The damage to the lid region in the analysis run2e is shown in Figure 7.7.2.6.

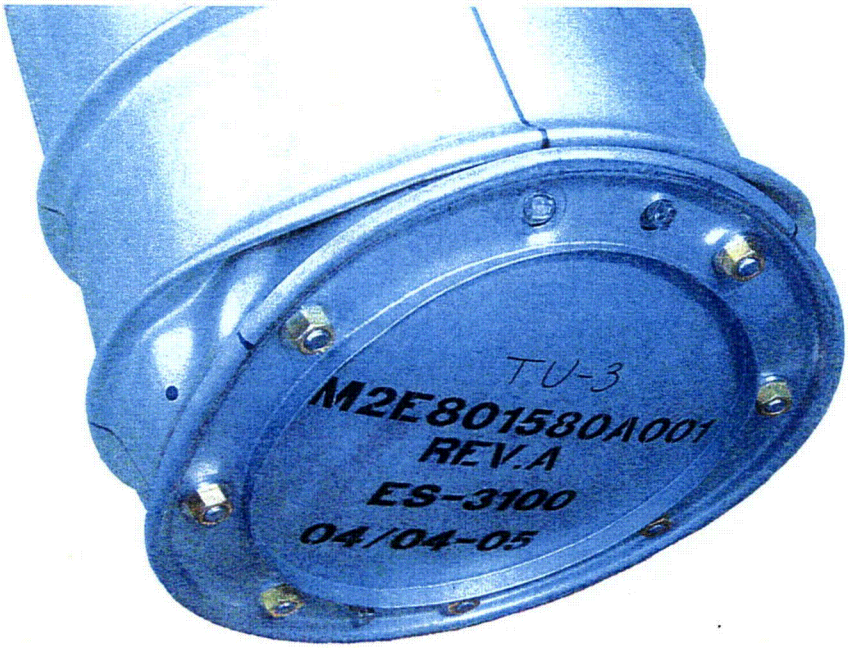


Figure 7.7.2.5 - TU3, Lid Damage from the Crush Impact

Figure 7.7.2.6 - HABC-run2e, Damage to the Bottom Head from the Crush Impact

7.7.3 Comparison of HABC-Run3b vs TU4

The HABC-run3b is a 30-foot lid down impact onto the rigid surface, followed by a crush impact onto the container bottom. The diameter measurements after the 30-foot impact are given in Table 7.7.3.1.

Table 7.7.3.1 - HABC Run3b vs TU4, Diameter Results After the 30-Foot Impact

	0°-180°		90°-270°	
	Test	Analysis	Test	Analysis
Top Chime	19-1/4	19.3	19-3/8	19.3
Top Hoop	19-1/8	19.7	19-7/8	19.7
Top CG Hoop	19-13/16	20.0	19-3/8	20.0
CG Hoop	19-1/8	19.5	19-1/4	19.5
Bottom Hoop	19-1/4	19.4	19-1/4	19.4
Bottom Chime	19-1/4	19.4	19-1/4	19.4

The overall height measurements were compared between the test and the analysis. For the 30-foot impact, the test results vary around the circumference: 43.0 inches at 0°, 43.125 inches at 90°, 42.875 inches at 180° and 42.625 inches at 270°. The analysis is symmetrical, and the height from the top of the lid drum roll to the bottom head surface after the 30-foot impact is about 42.6 inches.

Figure 7.7.3.1 shows the configuration of the TU4 after the 30-foot impact (4ft + 30ft). Figure 7.7.3.2 shows the analysis model configuration after the 30-foot impact in a similar orientation to the test unit.

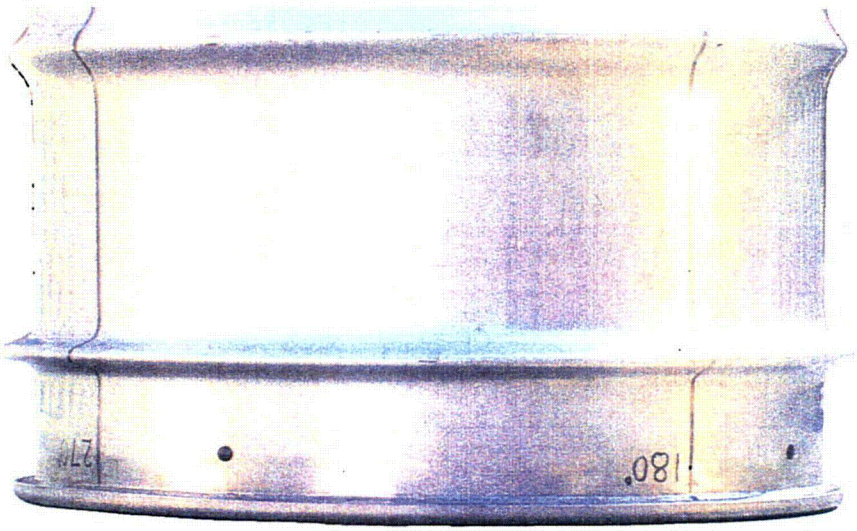


Figure 7.7.3.1 - TU4, 4-Foot + 30-Foot Impact Damage

Figure 7.7.3.2 - HABC-Run3b, 30-Foot Impact Damage

The drum height measurement after the test crush impact is 39-3/8 inches at 0°, 40-3/8 inches at 90°, 40-5/8 inches at 180°, and 39-3/4 inches at-270°. The analytical value for the height is about 39.0 inches.

The drum diameters after the crush impact are compared in Table 7.7.3.2.

Table 7.7.3.2 - HABC Run3b vs TU4, Diameter Results After the Crush Impact

	0°-180°		90°-270°	
	Test	Analysis	Test	Analysis
Top Chime	19-1/4	19.3	19-3/8	19.3
Top Hoop	20	20.1	20-1/8	20.1
Top CG Hoop	20	20.2	20-1/16	20.2
CG Hoop	19-7/16	20.1	19-1/2	20.1
Bottom Hoop	19-15/16	20.5	20	20.5
Bottom Chime	19-1/4	19.4	19-1/4	19.4

Figure 7.7.3.3 shows the TU4 at the end of the crush impact (4ft + 30ft + crush), while Figure 7.7.3.4 shows the configuration of the HABC-run3b model (30ft + crush).

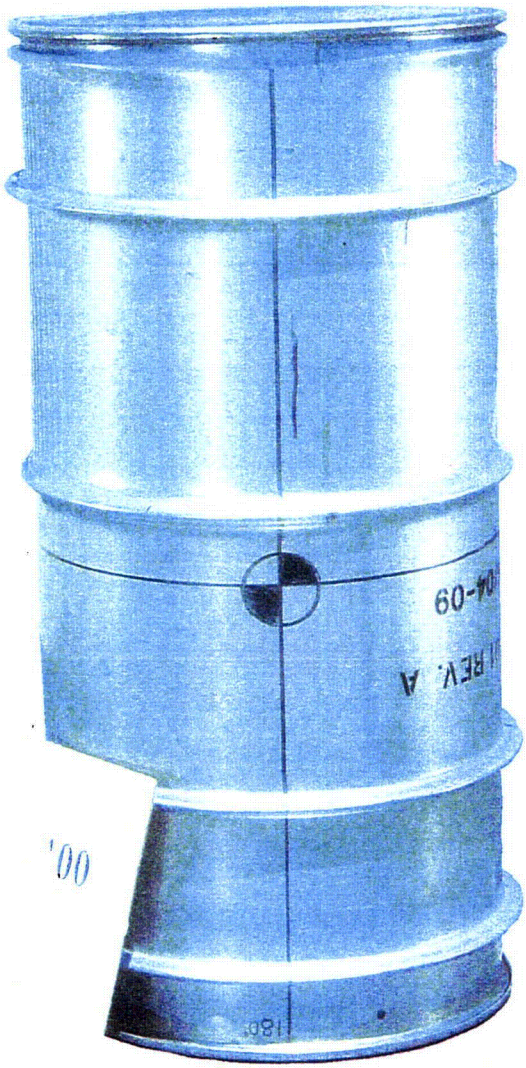


Figure 7.7.3.3 - TU4, Crush Damage

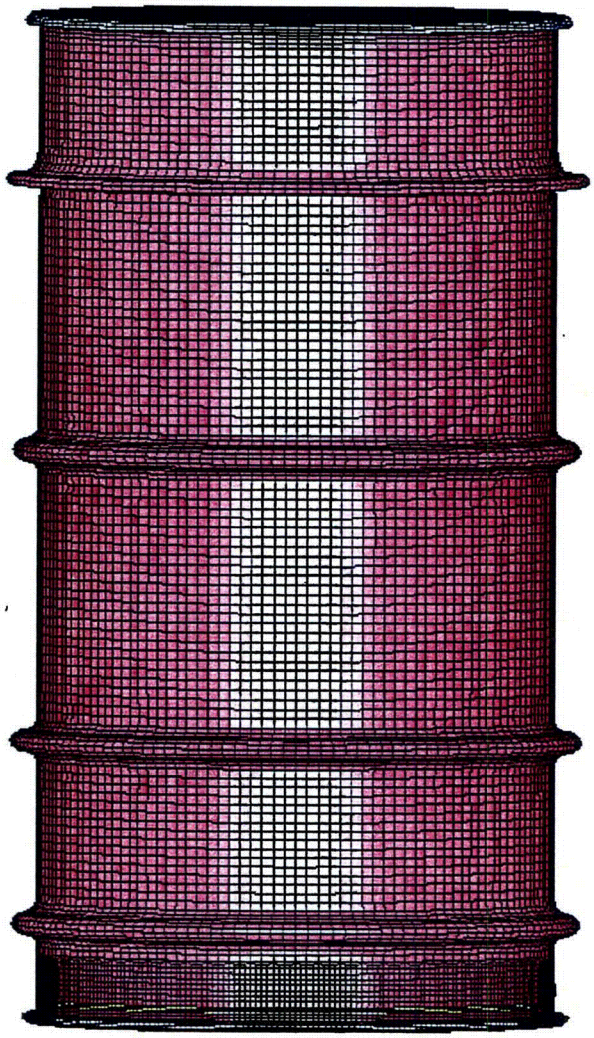


Figure 7.7.3.4 - HABC Run3b, Crush Damage

7.7.4 Comparison of HABC Run1hh vs TU2

HABC-run1hh was the upper bounding kaolite run which included a 4-ft, 30-foot and crush impacts. The test results are for the cumulative damage from the 4-ft, 30ft, crush and punch impacts. The table 7.7.4.1 shows the results for the diameter changes due to all the impacts for the test and the analysis.

Table 7.7.4.1 - Run1hh vs TU2, Cumulative Diameter Results

	0°-180°		90°-270°	
	Test	Analysis	Test	Analysis
Top Chime	17-5/8	18.0	19-13/16	19.6
Top Hoop	17-3/8	16.6	19-3/4	20.1
Top CG Hoop	17	16.5	20	20.4
CG Hoop	16	16.3	20-1/4	20.5
Bottom Hoop	15-1/2	16.1	20-1/8	20.0
Bottom Chime	18	17.6	19-3/8	19.4

Table 7.7.4.2 shows the comparison of the "flats" dimensions for the test and the analysis.

Table 7.7.4.2 - Run1hh vs TU2, Cumulative Flats Results†

	180° - Crush Plate Side		0° - Rigid Surface Side	
	Test‡	Analysis	Test	Analysis
Top Chime	6-1/4	0	8.0	9.2
Top Hoop	8-7/8	10.1	9.0	9.3
Top CG Hoop	9-5/8	9.3	10-1/8	8.4
CG Hoop	12	9.3	9-7/8	9.3
Bottom Hoop	14-7/8	10.1	9-7/8	9.3
Bottom Chime	0	0	9-3/8	10.1

† - Note - The reported test results for the 0 and the 180 sides are reversed in the test report (evidence Figure 7.7.4.3 below).

‡ - Note - The crush plate edge was 4.75 inches from bottom of package.

A visual comparison of the cumulative damage on the rigid surface side after the impacts is shown in Figures 7.7.4.1 (test) and Figure 7.7.4.2 (analysis).

Figure 7.7.4.1 - TU2, Cumulative Damage After the Punch Impact, Rigid Surface Side

Figure 7.7.4.2 - HABC-run1hh, Cumulative Damage, Rigid Surface Side

A visual comparison of the cumulative damage on the crush side after the four impacts is shown in Figures 7.7.4.3 (test) and Figures 7.7.4.4 (analysis).

Figure 7.7.4.3 - TU2, Cumulative Damage After the Punch Impact, Crush Plate Side

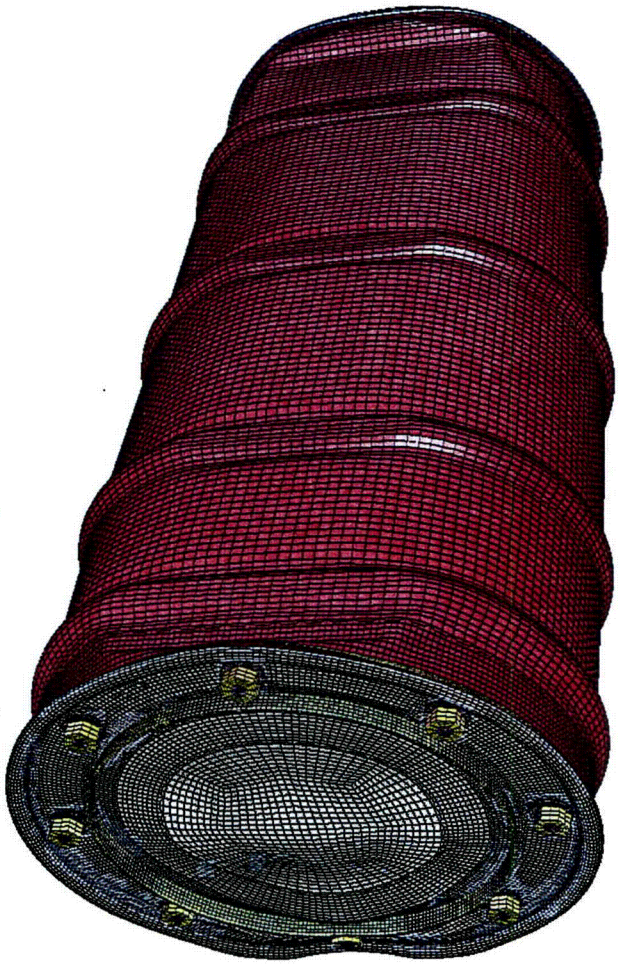


Figure 7.7.4.4 - HABC-run1hh, Cumulative Damage, Crush Plate Side

8.0 Summary

The computer simulation impacts for the HABC re-design of the ES-3100 shipping container are presented in Sections 7.1 to 7.6. The comparison of the HABC re-design container to the physical tests is presented in Section 7.7. The effective plastic strain for the components are summarized in Table 8.0.1. The punch impact is not included in the HABC runs, due to the fact that the drum shell capability is demonstrated in the initial borobond models, and the tested specimen.

Maximum strains in excess of 0.5 in/in are near the 304L strain limit of 0.57 in/in and are highlighted in red in Table 8.0.1. The components which are highlighted included the drum , lid, studs and liner. Evidence from looking at the Table 8.0.1 summary, a high demand is placed on the lid and the studs in the side and slapdown impacts.

In runs HABC-runs1hl, 1hh, 4g and 4ga a high demand is placed on the lid/studs. In runs 1hh, 1hl, 4g and 4ga, the region of plastic strain is very localized at the stud holes. Runs 1hl and 4g also have relatively high demands placed on the studs. In runs1hl and 4g, it is shown that the times at which the lid strains become excessive in membrane, the stud strains are relatively low. Hence, it is predicted that the lid will locally tear, thereby relieving loading on the studs. The tearing associated with the lid is expected to be local due to the localized fringes of extreme strain shown in the Section 7 fringe plots. The large washers provided on the packages would restrain the lid.

In runs HABC-run1hl, 2e and 4g, the studs reach high levels of effective plastic strain. In HABC-run1hl, the lid was shown to tear before the studs reached an elevated level of plastic strain.

HABC-run2e shows that the stud at the impact reaches extreme levels of plastic strain near the 0.57 in/in failure strain in the 30-foot impact and the subsequent crush impact. The level of high strain is throughout the cross section of the stud in HABC-run2e. Due to this high level of strain and the direct load path between the shipping package and the rigid surface, any slight changes in length, friction, localized deformations (stud "digging" into the relatively rigid plate in the test) could cause the stud to fail.

In HABC-run4g, the stud reached its failure strain and the cross section row of elements failed (removed by LS-Dyna). A time study shows that the lid reaches its levels of elevated strain in membrane before the stud. Therefore, the lid is expected to tear before the stud fails, thus relieving loading on the stud. However, the model does show the shipping container response if the lid were not to tear, and the stud were to fail.

The relatively high level of plastic strain in the HABC-run2e liner is a surface strain. Investigation shows that the membrane strain is about 0.2205 in/in, or well below the expected failure level. The deformation/fringe plot shows that the region of high strain is relatively local at the attachment of the liner to the angle. The plot also shows that it is the result of crimping or folding of the liner due to the relatively stiffer angle. Any tearing that might take place would be limited, evidence the local concentration of fringe levels.

Table 8.0.1 - ES-3100 HABC Shipping Package Summary of Component Maximum Effective Plastic Strain (in/in)

Material	Description	HABC-run1hl			HABC-run1hh		
		Side - Lower Bound Kaolite (Section 7.1)			Side - Upper Bound Kaolite (Section 7.2)		
		4-foot	30-foot	Centered Crush	4-foot	30-foot	Centered Crush
1	CV Body	0.0185	0.0195	0.0206	0.0238	0.0347	0.0525
3	CV Lid	0.0001	0.0002	0.0002	0.0000	0.0001	0.0004
4	CV Nut Ring	0.0000	0.0000	0.0000	0.0000	0.0000	0.0005
5	Angle	0.0055	0.0780	0.1142	0.0061	0.0632	0.0845
6	Drum	0.1599	0.2251	0.5139	0.1207	0.2296	0.2814
7	Drum Bottom	0.1033	0.2126	0.3562	0.1252	0.2517	0.2827
10	Liner	0.1045	0.1078	0.1593	0.0991	0.1184	0.2022
12	Lid	0.1393	0.5790	1.2580	0.1604	0.4063	0.6413
15	Lid Stiffener	0.0004	0.0093	0.0515	0.0006	0.0076	0.0171
16	Lid Studs	0.0000	0.1140	0.5121	0.0000	0.1306	0.2364
17	Lid Stud Nuts	0.0000	0.0000	0.0005	0.0000	0.0004	0.0018
18	Lid Stud Washe	0.0194	0.0194	0.0693	0.0411	0.0424	0.0439
19	Plug Liner	0.0022	0.0958	0.1220	0.0045	0.1072	0.1286

Material	Description	HABC-run2e		HABC-run3b		HABC-run4g		HABC-run4ga	
		Corner (Section 7.3)		End (Section 7.4)		Slapdown (Section 7.5)		Slapdown (Section 7.6)	
		Impact	Crush	Impact	Crush	Impact	Offset Crush	Impact	Centered Crush
1	CV Body	0.0371	0.0371	0.0028	0.0083	0.0376	0.0564	Same as HABC-Run4g Impact Results	0.0643
3	CV Lid	0.0051	0.0051	0.0072	0.0072	0.0004	0.0013		0.0018
4	CV Nut Ring	0.0002	0.0002	0.0011	0.0011	0.0000	0.0001		0.0000
5	Angle	0.0394	0.0462	0.0287	0.0308	0.0900	0.1070		0.0944
6	Drum	0.3247	0.3830	0.0557	0.1237	0.3018	0.3920		0.3443
7	Drum Bottom	0.0000	0.0761	0.0031	0.0267	0.2879	0.2879		0.3000
10	Liner	0.3983	0.5254	0.0607	0.3812	0.1458	0.2060		0.2846
12	Lid	0.2791	0.3622	0.1082	0.1389	0.5278	0.9689		0.5828
15	Lid Stiffener	0.0272	0.0272	0.0069	0.0100	0.0213	0.0894		0.0288
16	Lid Studs	0.5233	0.5598	0.0962	0.1535	0.1892	0.4018		0.2390
17	Lid Stud Nuts	0.2260	0.2266	0.0166	0.0173	0.0000	0.0028		0.0000
18	Lid Stud Washe	0.1528	0.1528	0.0506	0.0506	0.0724	0.0790		0.0775
19	Plug Liner	0.1152	0.1166	0.0670	0.0960	0.1258	0.2665		0.1644

9.0 Comparison of Borobond Cylinder and HABC Cylinder Models

Part A of this calculation (Sections 2 through 5) apply to the initial, borobond neutron absorber model. Section 3.12 compared the borobond model results to the physical tested specimen. Part B (Sections 6 through 8) apply to the HABC redesigned neutron absorber model. Section 7.7 compares the HABC model to the physical tested specimen. The HABC model was derived from the initial borobond model, with changes detailed in Section 6. Section 6.1 gives the configuration changes and Section 6.2 gives the material model derivation for the HABC neutron absorber.

The borobond and the HABC materials are similar in nature in that they are castable, cement type materials. The LS-Dyna material model used in both analytical simulations was the *MAT_SOIL_AND_FOAM model. Similar approaches were taken for both the borobond and the HABC to match the material test results to the needed material properties in the analytical model. The approach is shown explicitly for the HABC material model in Section 6.2. The borobond model used in the Part A models, was also used in the Highly Enriched Uranium Materials Facility (HEUMF) storage pallet modeling, testing and qualification.

The CV body cylinder has an outside diameter of about 5.6 in. A minimum liner diameter of about 5.3 inches was found to occur in the borobond slapdown runs (4g, 4ga, 4h and 4ha). This minimum occurred at several locations along the liner length, and also near the CV flange. A somewhat similar response is noted for the HABC models, but with more deflection near the mid-height of the CV cavity. A minimum liner diameter of about 5.2 inches near the CV flange is noted in slapdowns HABC-run4g and 4ga. However, a minimum diameter of about 4.5 in is noted in HABC-run4ga near the mid-height of the CV body. This region of the CV body is remote from the bottom head or the flange and plastic strains in the body are relatively low (compare Figures 3.8.2 and Figure 7.6.4). The region of concern, near the CV flange, experiences about the same deformation (5.3 in vs 5.2 in).

A significant demand is placed on the lid and the studs in both the borobond and the HABC model side and slapdown impacts. This is a precipitate of the design attempt to minimize the number of studs securing the lid. The lid power law material model does not allow for element failure, whereas the model used for the studs (elastic-plastic) did allow element failure to be modeled. The effective plastic strain in bending and membrane reach significantly high levels (about 1.0 strain) in the lid. The regions of elevated plastic strain in the lid are shown to be localized at the stud holes. The studs also reached elevated levels of plastic strain. Investigation into the time history of the demand placed on the lid and the studs reveals that the lid reaches the elevated levels earlier in the impact, and therefore tearing of the lid would be expected. The tearing of the lid is expected to relieve the

loading on the studs, such that the integrity of the studs would be maintained. The large washers will restrain the lid. This fact was verified in the test with some tearing at the 90°and 270° position stud holes and no loss of a stud.

Both models compared favorably with the test results and with each other. This can be seen in the tables in Section 3.12 for the borobond and 7.7 for the HABC material.