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Issued to: Roman V. Kazban

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Project Title: ***Three-Dimensional Models of the Waste Package—Pallet Mechanical Interaction***

Project Staff: Roman V. Kazban, Laura C. Domyancic

This notebook documents the work being done to develop the three-dimensional finite element models of the waste package—pallet mechanical interaction in support of the "Mechanical Disruption of Engineered Barriers" study for the US Nuclear Regulatory Commission. Altair Hypermesh 8.0 is used as pre-processing software ("Altair Hypermesh User's Guide", Version 8.0. Altair Engineering, Inc., Troy, Michigan, 2006), and ABAQUS 6.6 finite element code is used to perform the analysis and as a post-processing software ("ABAQUS User's Manual", Version 6.6. ABAQUS, Inc., Providence, Rhode Island, 2006).

The qualifications required of the staff supporting this work are as follows:

(i) Computational Continuum Mechanics / Finite Element Analysis;
(ii) Mechanical Engineering.

Date: June 12, 2006
Entry by: Roman V. Kazban

Materials and material properties used in the three-dimensional finite element (FE) models
[all data has been obtained from L. Ibarra, et. al. "Drip Shield-Waste Package mechanical Interaction", CNWRA, San Antonio, TX, June 2006]

(1) Alloy 22

At Room Temperature:
Density = 8691.5 kg/m^3 = 8691.5e-9 kg/mm^3;
Modulus of elasticity = 1.799e11 *Pa* = 1.799e5 N/mm^2;
Poisson's ratio = 0.31;

At 150 ^oC:
True Yield Stress = 2.799e8 *Pa* = 2.799e2 N/mm^2;
True Stress = 12.162e8 *Pa* = 12.162e2 N/mm^2;
True Strain = 0.5546.

(2) 316 Stainless Steel (316 S.S.)

At Room Temperature:
Density = 7980 kg/m^3 = 7980e-9 kg/mm^3;
Modulus of elasticity = 1.8616e11 *Pa* = 1.8616e5N/mm^2;
Poisson's ratio = 0.298;

At 150 ^oC:
True Yield Stress = 1.5789e8 *Pa* = 1.5789e2 N/mm^2;
True Stress = 6.6295e8 *Pa* = 6.6295e2 N/mm^2;
True Strain = 0.3039.

Note: Values of the density, the modulus of elasticity, and the Poisson's ratio for Alloy 22, and 316 S.S. at 150 ^oC are not available in the literature. Therefore values of the density, the modulus of elasticity, and the Poisson's ratio at room temperature are used in the finite element models presented here.

Date: June 14, 2006
Entry by: Laura C. Domyancic

Description and geometry of the waste package FE model

The finite element model of the waste package is comprised of the following:

(i) Alloy 22 Outer Shell
(ii) 316 Stainless Steel Inner Vessel

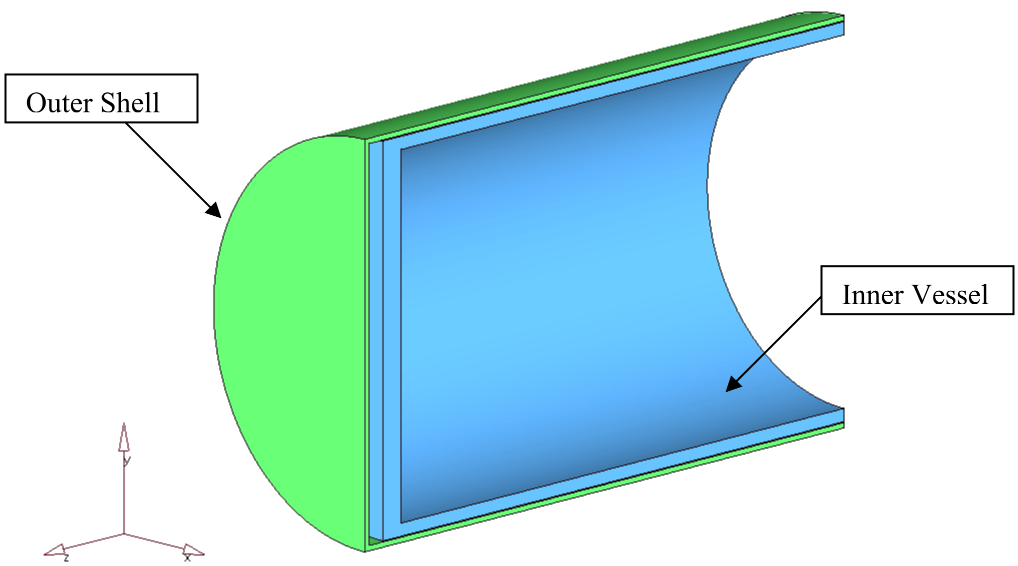


Figure 1: Model of Partial Waste Package

All geometry and dimensions were obtained from "21-PWR Waste Package Configurations for Site Recommendation" (sketch number SK-0175 Rev 02). The FE model corresponds to one quarter of the entire waste package.

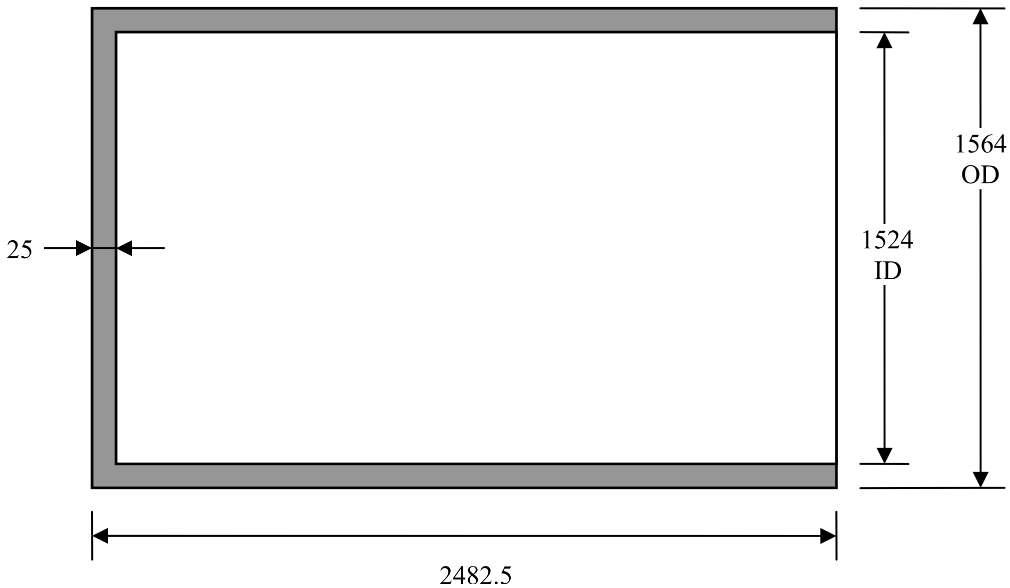


Figure 2: Dimensions of Outer Shell (side view, units of mm)

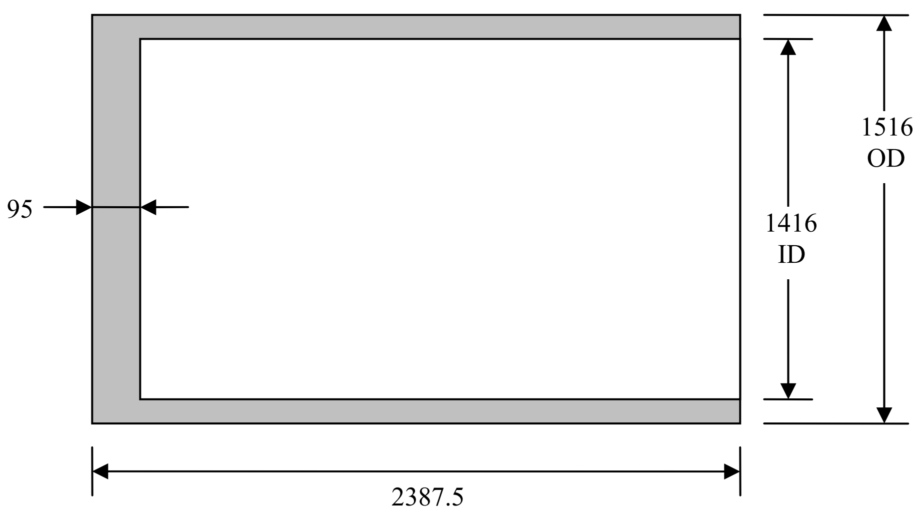


Figure 3: Dimensions of Inner Vessel (side view, units of mm)

The FE model of the waste package is created using solid 8-node linear hexahedral elements (C3D8). Because of the geometry of the lid surfaces, a few 6-node tetrahedral elements (C3D6) are used to complete the mesh. The size of an element in the inner vessel is approximately 20×20×12.5 mm. The average size of an element in the inner vessel lid is 20×22×12.5 mm. The size of an element in the outer shell is approximately 25×30×12.5 mm. The average size of an element in the outer shell lid is 30×30×25 mm. The nodes on the shared surfaces of the shells and their corresponding lids are equivalenced to create a continuous mesh.

Date: June 15, 2006
Entry by: Laura C. Domyancic

Description and geometry of the emplacement pallet FE model

The finite element model of the emplacement pallet is comprised of the following:

(i) Plate #1
(ii) Plate #2
(iii) Plate #3
(iv) Plate #4
(v) Plate #5
(vi) Plate #6
(vii) Plate #7
(viii) Plate #8
(ix) 152.4×152.4×9.53 mm Tubes
(x) 254×76.2×6.35 mm Tubes

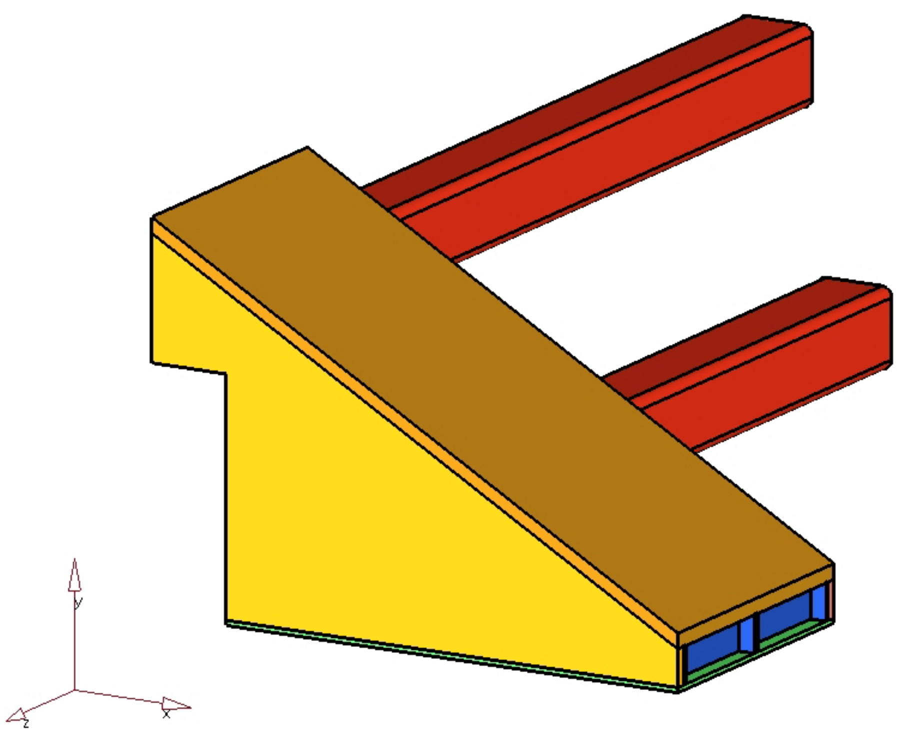


Figure 4: Pallet model with all components

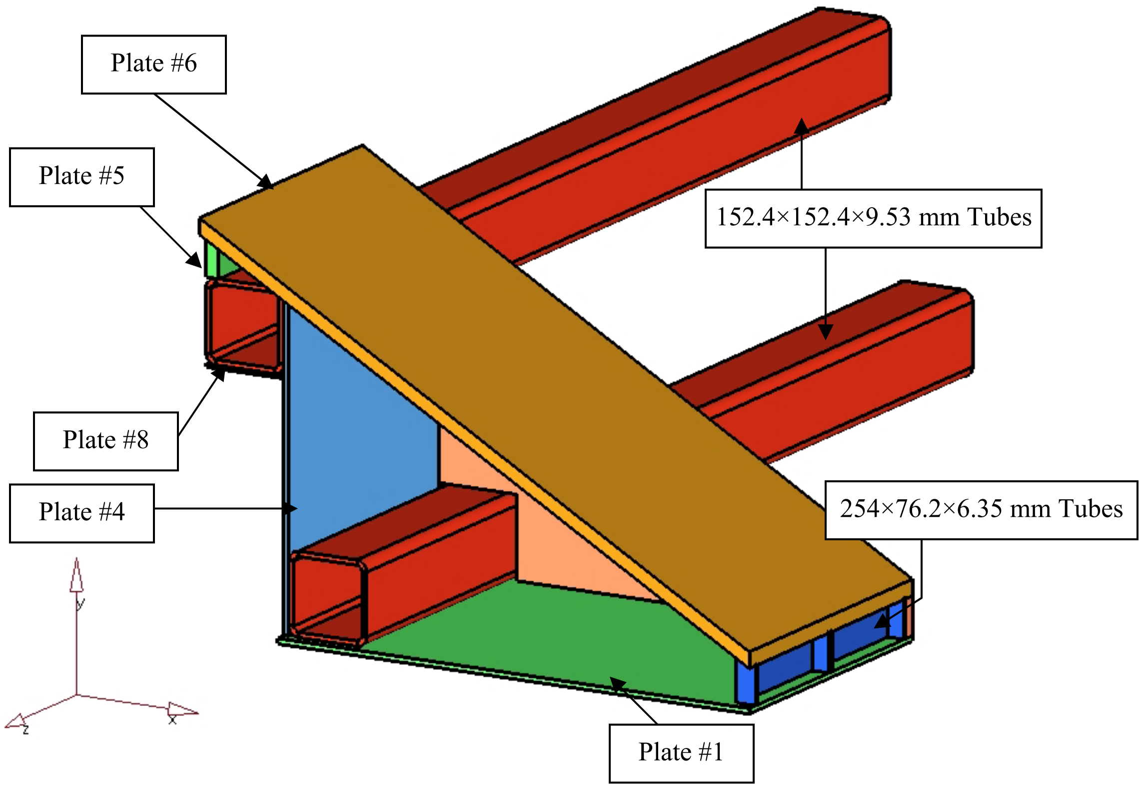


Figure 5: Pallet shown with Plate #2 masked

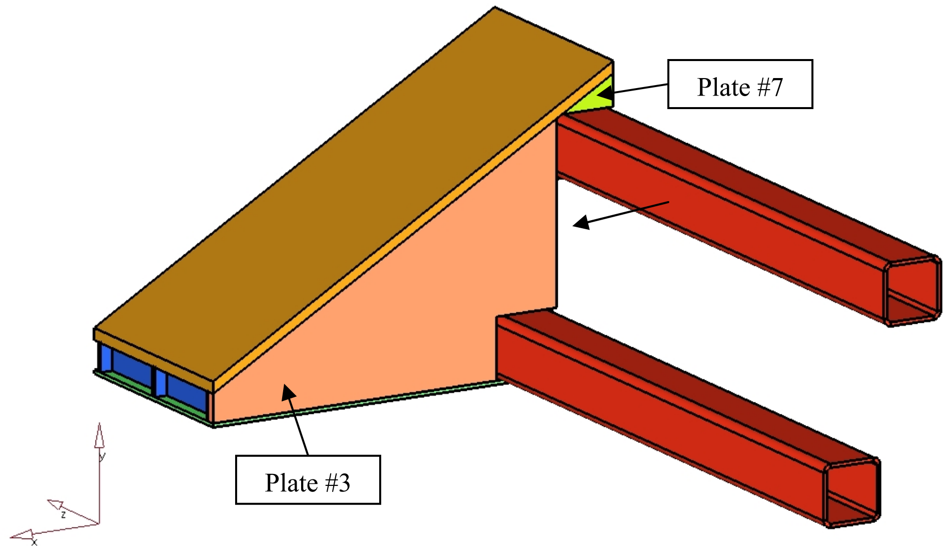


Figure 6: Pallet, rear view

The material for all components is Alloy 22. All geometry and dimensions were obtained from "Emplacement Pallet" (sketch number SK-0144 Rev 01). The FE model corresponds to one quarter of the pallet assembly. In order to create the pallet model, the coordinates of all parts were mapped in the xy-plane (except for the 254×76.2×6.35 mm Tubes, which were mapped in the xz-plane) according to the dimensions given in the drawings.

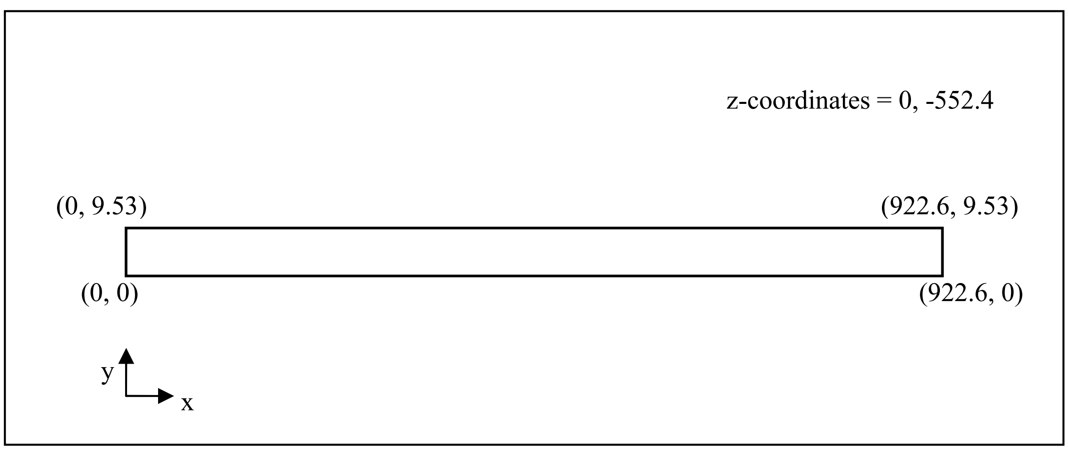


Figure 7: Coordinates of Plate #1 (units of mm)

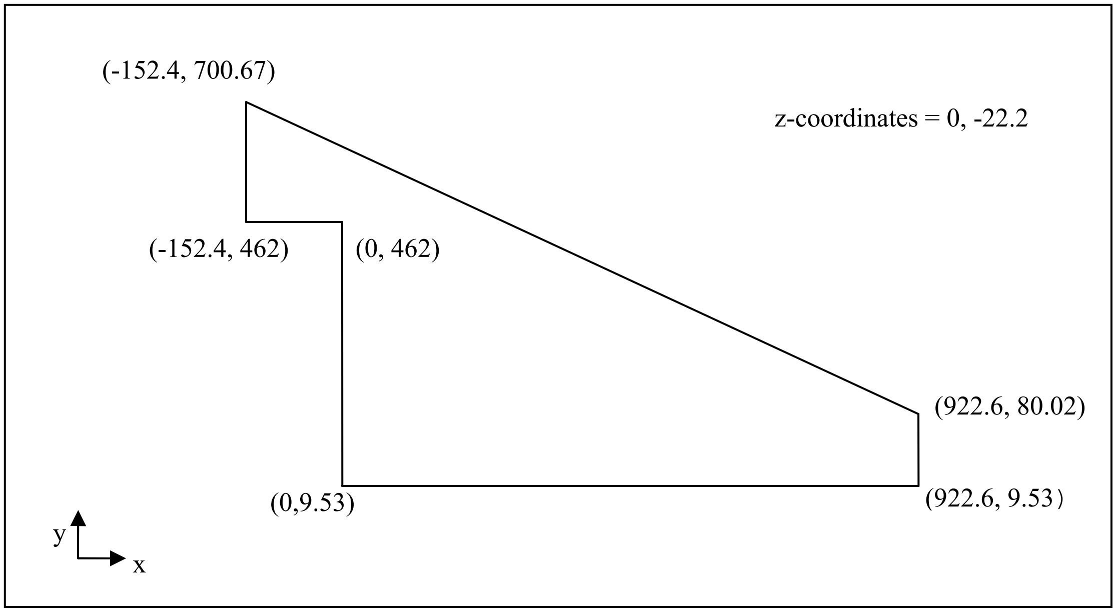


Figure 8: Coordinates of Plate #2 (units of mm)

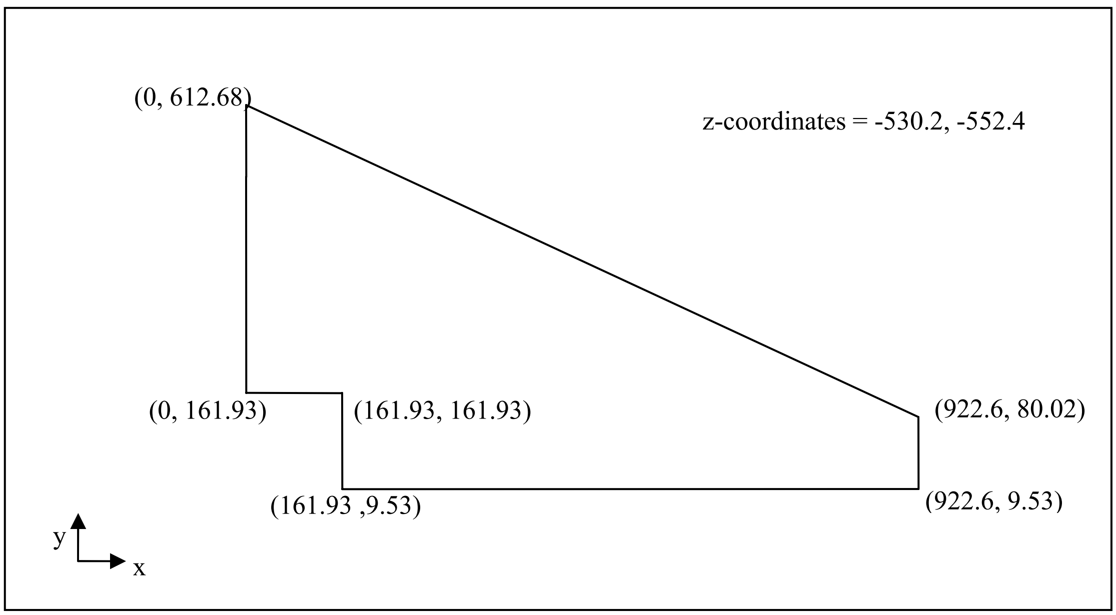


Figure 9: Coordinates of Plate #3 (units of mm)

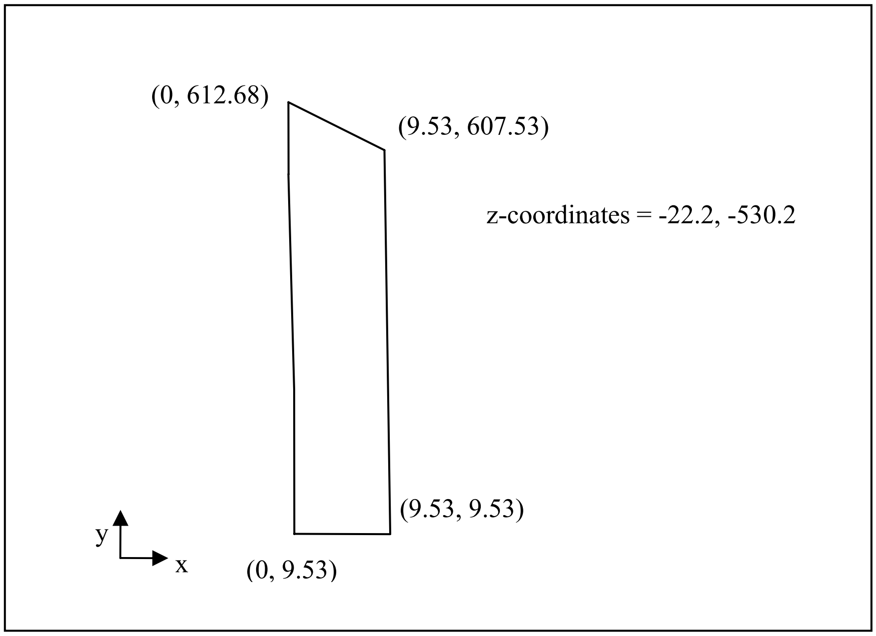


Figure 10: Coordinates of Plate #4 (units of mm)

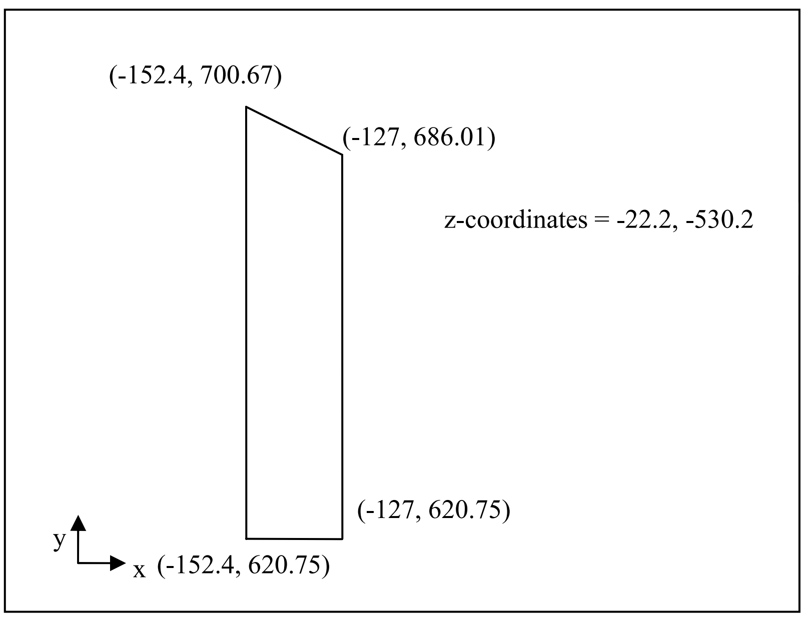


Figure 11: Coordinates of Plate #5 (units of mm)

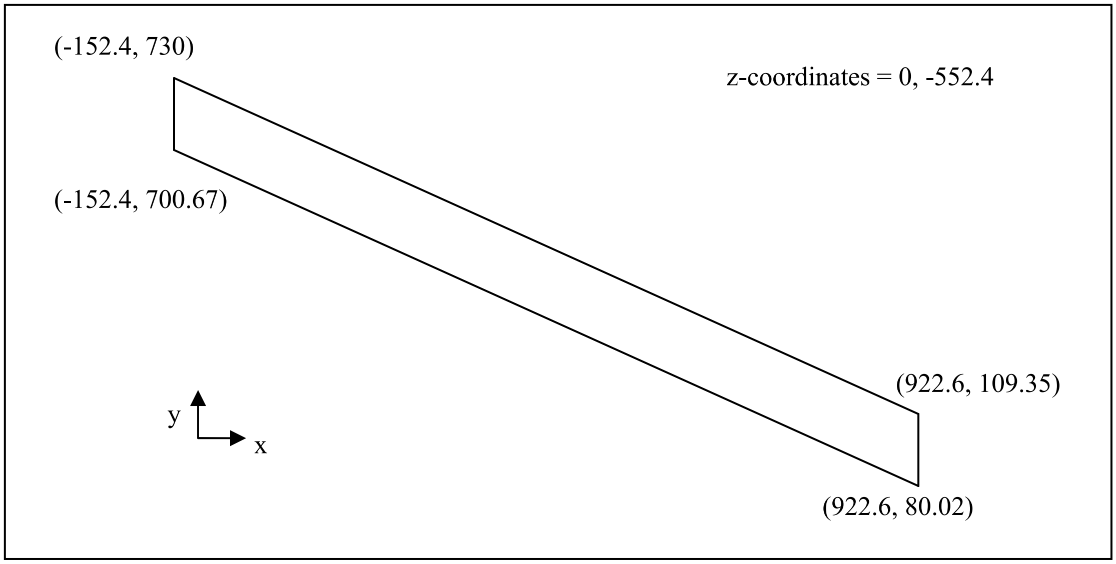


Figure 12: Coordinates of Plate #6 (units of mm)

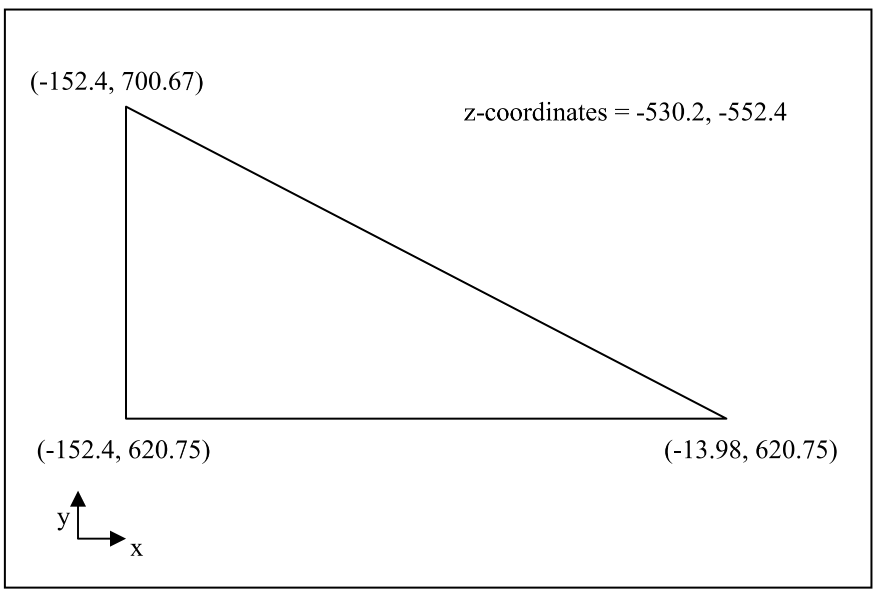


Figure 13: Coordinates of Plate #7 (units of mm)

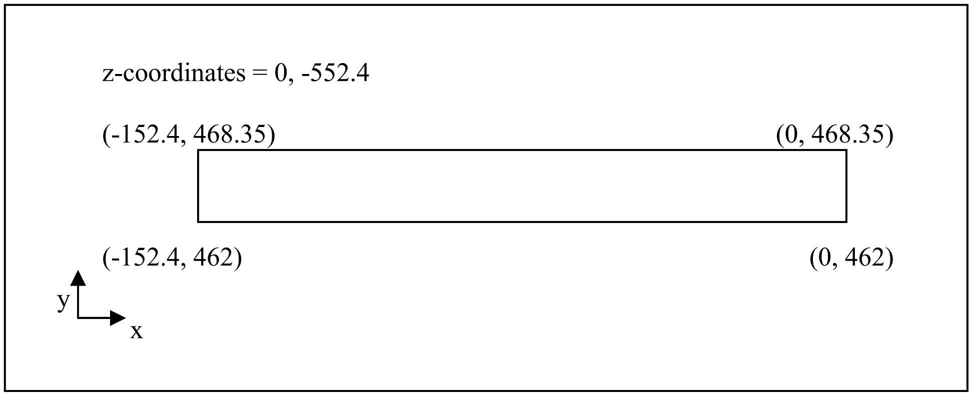


Figure 14: Coordinates of Plate #8 (units of mm)

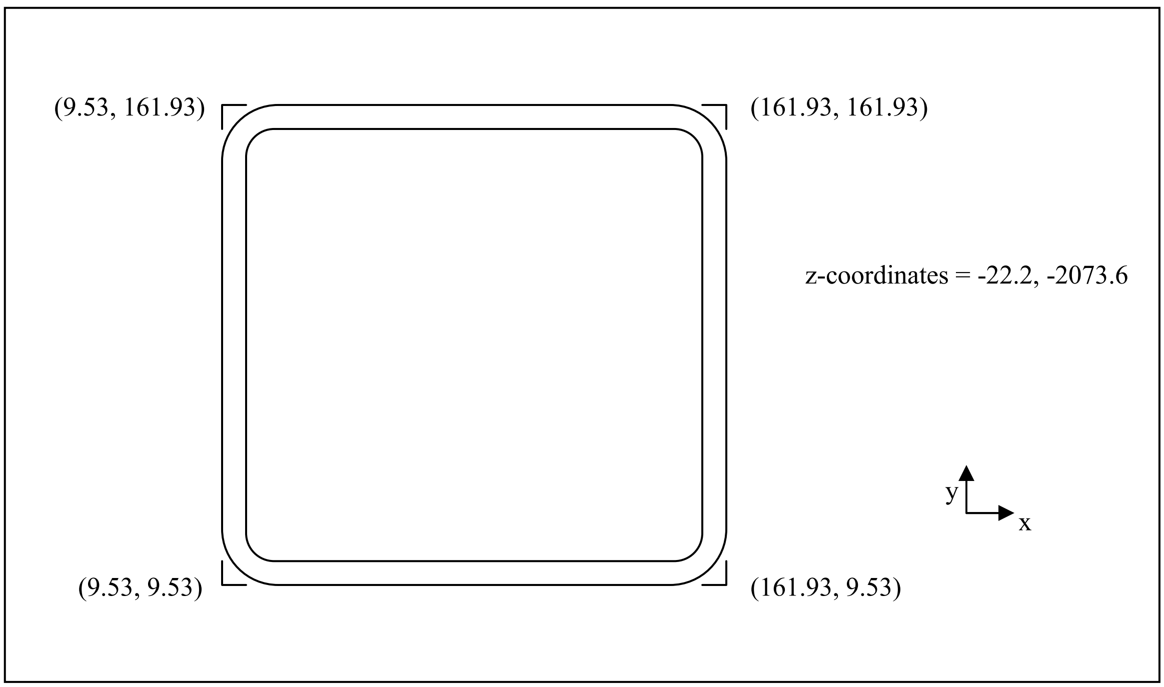


Figure 15: Coordinates of lower 152.4×152.4×9.53 mm Tube (units of mm)

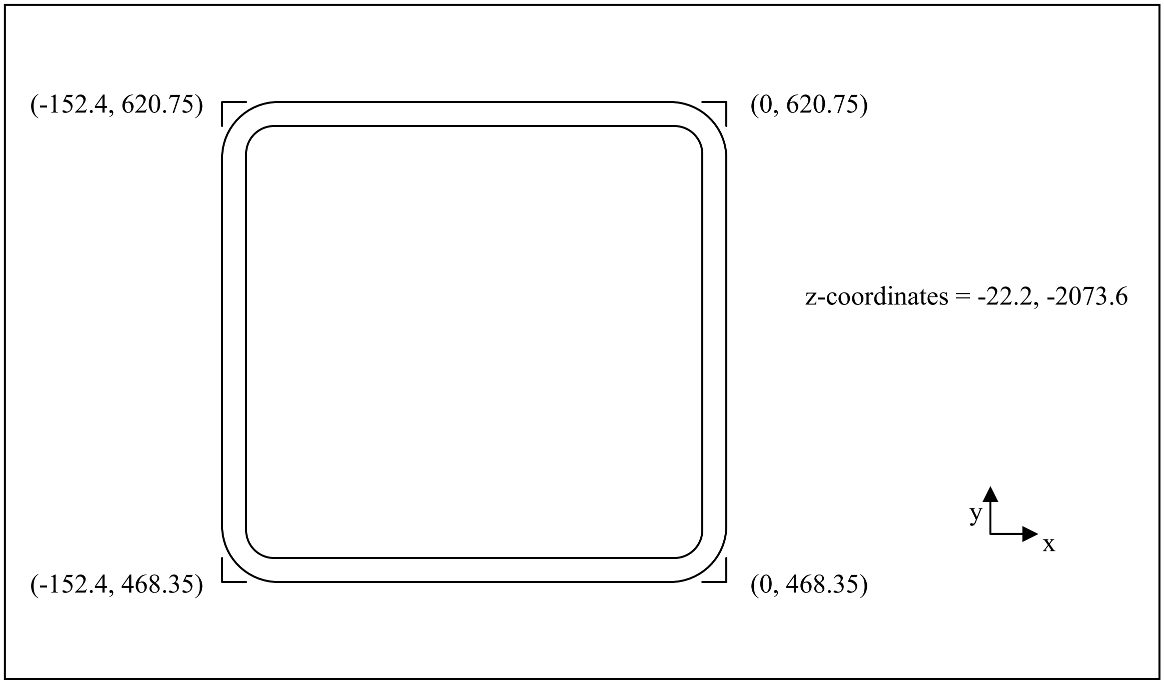


Figure 16: Coordinates of upper 152.4×152.4×9.53 mm Tube (units of mm)

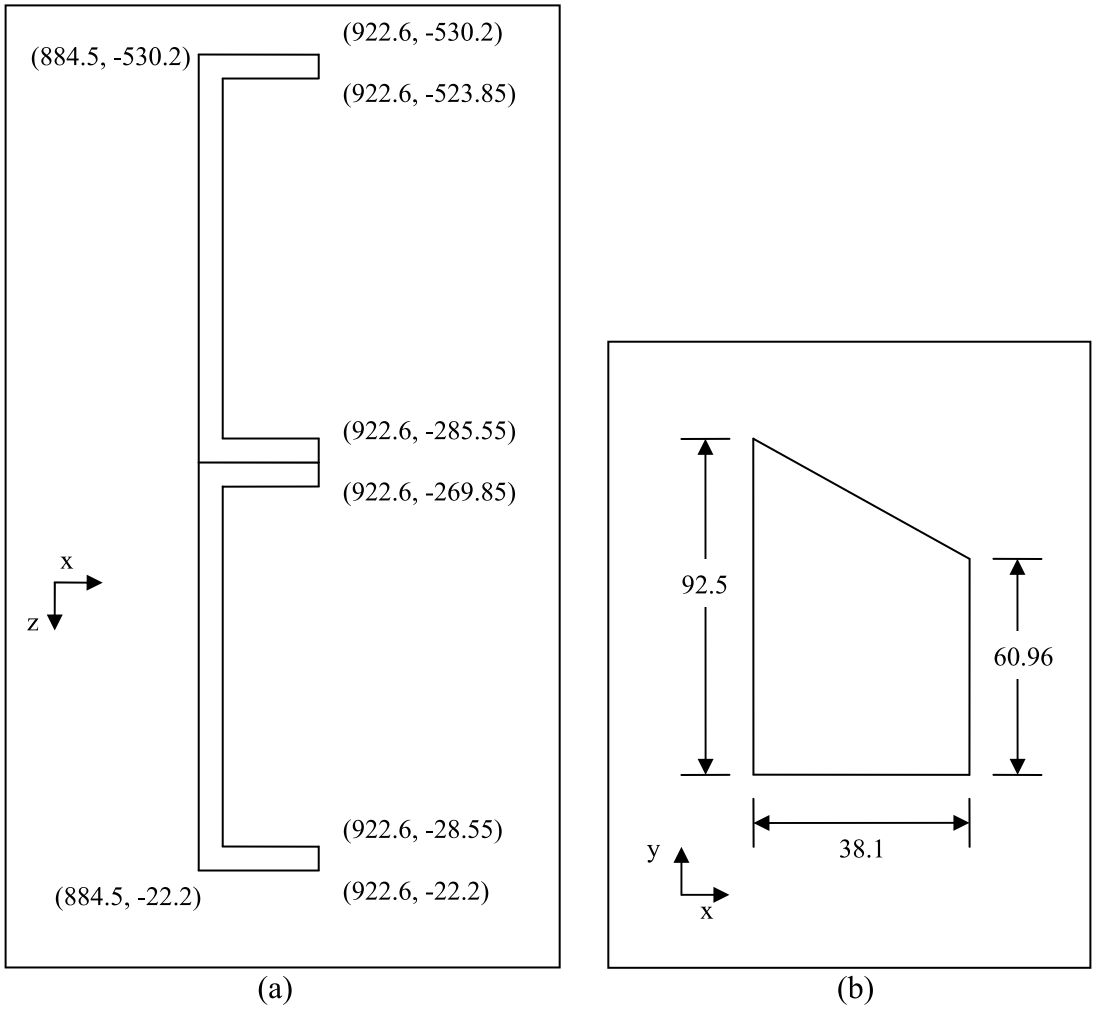


Figure 17: Layout of 254×76.2×6.35 mm Tubes (units of mm), showing (a) coordinates {top view} and (b) dimensions {front view}

Date: June 18, 2007
Entry by: Laura C. Domyancic

The FE model of the pallet is meshed using solid 8-node linear hexahedral elements (C3D8) for Plates #1-7. A few 6-node solid elements (C3D6) are used to complete the mesh for Plate #2, Plate #3, and Plate #7. The size of an element in the contact region of Plate #6 (where the Outer Shell of the waste package will rest) is 10.52×9.77×14.11 mm. The size of an element in the other plates ranges from 5×10×15 mm to 11×12×15 mm. All other components are meshed with a thickness of one element using 8-node continuum shell elements (SC8R). The size of an element in the 254×76.2×6.35 mm Tubes ranges from 6.35×14.8×15.1 mm to 9.1×14×6.35 mm. The average size of an element in the 152.4×152.4×9.53 mm Tubes is 9.53×11.5×14.5 mm. The average size of an element in Plate #8 is 11.4×6.35×14.1 mm. The nodes on the shared surfaces within the pallet are equivalenced to create a continuous mesh.

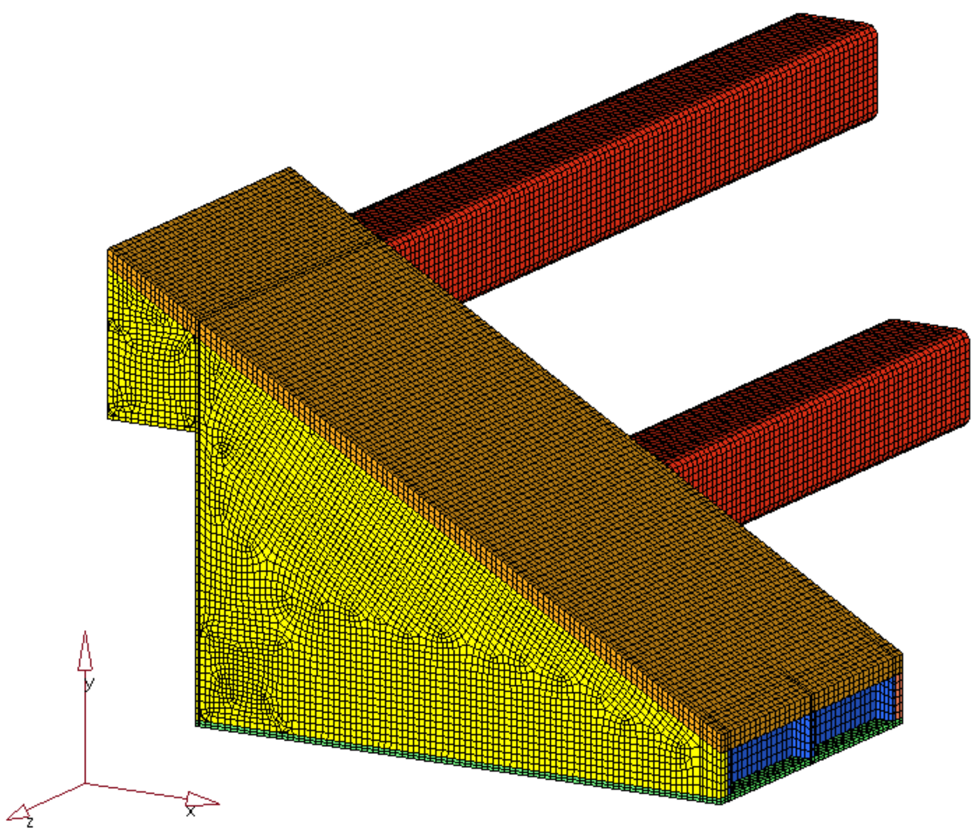


Figure 18: Meshed Pallet

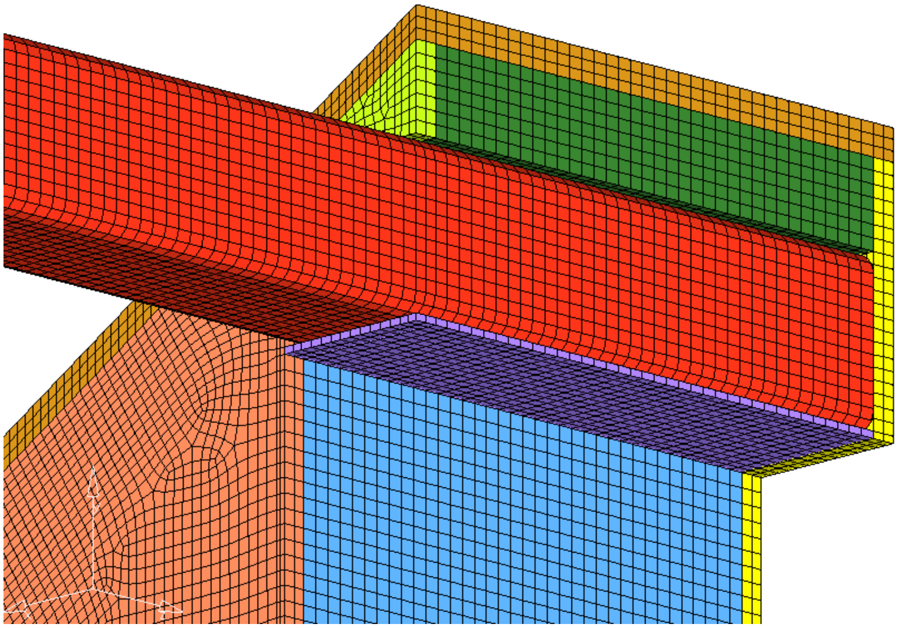


Figure 19: Close-up of upper 152.4×152.4×9.53 mm Tube

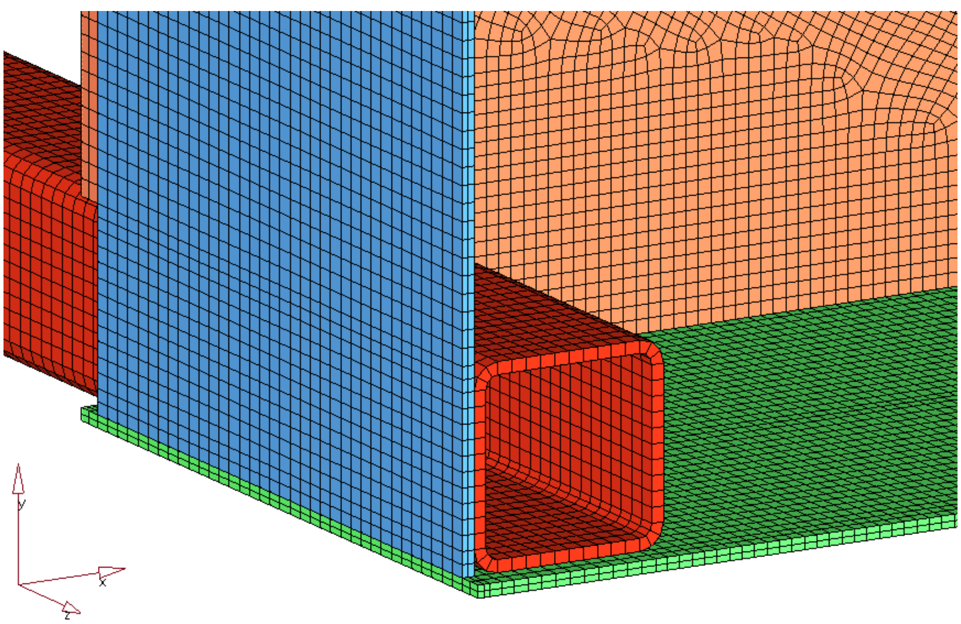


Figure 20: Close-up of lower 152.4×152.4×9.53 mm Tube (with Plate #2 masked)

Date: June 19, 2007
Entry by: Laura Domyancic

The mesh of the Outer Shell of the waste package was refined to create a proper master-slave contact surface. The new size of the elements in contact with Plate #6 of the pallet is 10.1×10×10.9 mm. All other elements range in size from 10×10×28 mm to 10×30×30 mm. The Inner Vessel was also re-meshed to increase the size of the elements. The average size of an element in the Inner Vessel is 45×25×60 mm. Only solid 8-node linear hexahedral elements (C3D8) are used.

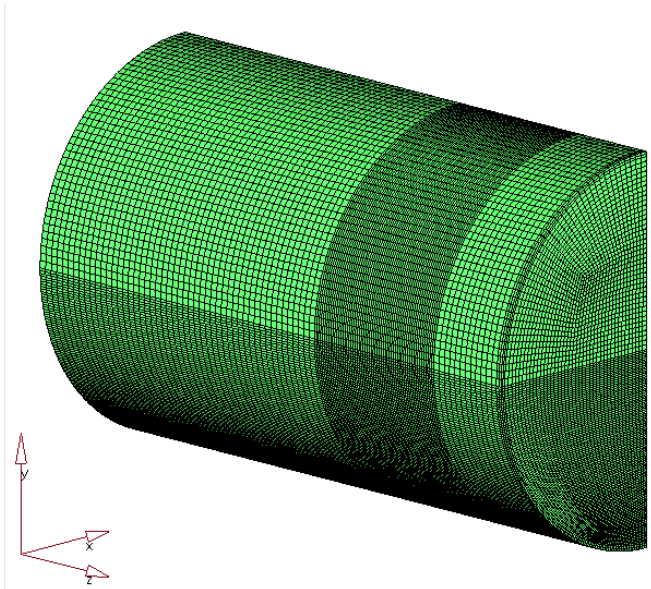


Figure 21: Meshed Outer Shell

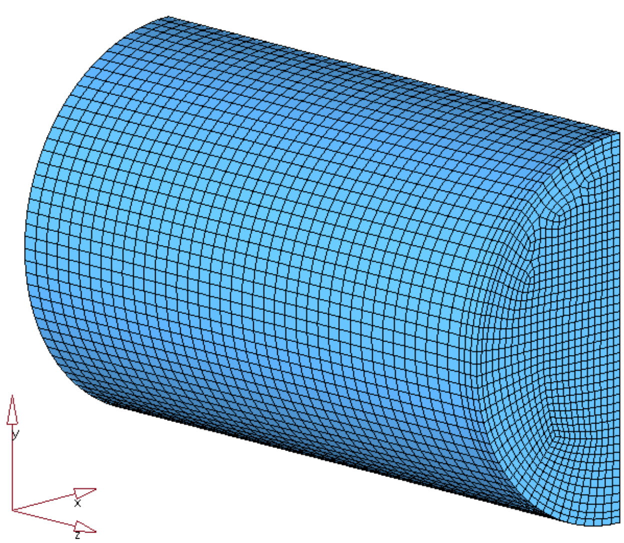


Figure 22: Meshed Inner Vessel

Date: June 20, 2007
Entry by: Laura C. Domyancic

Boundary Conditions for the Waste Package and Pallet (D:\Pallet_WP_assembly)

Kinematic Constraints: The components of the waste package are constrained along the yz-plane of symmetry to prevent displacement in the horizontal direction (x-axis). Displacement in the transverse direction (z-axis) is prevented by constraints along the rear plane of symmetry.

The ends of the 152.4×152.4×9.53 mm Tubes are constrained along the xy-plane of symmetry to prevent displacement in the transverse direction. The pallet is also constrained along the side plane of symmetry to prevent displacement in the horizontal direction. All nodes on the bottom surface of the pallet are constrained from vertical displacement.

A friction coefficient of 0.4 is applied to the Outer Shell/Pallet contact surface and the Outer Shell/Inner Vessel contact surface to properly model friction surface interaction.

The displacement of the waste package in the vertical direction is constrained by two SPRING1 elements of a relatively small stiffness on both the Outer Shell and Inner Vessel to prevent an initial rigid body mode.

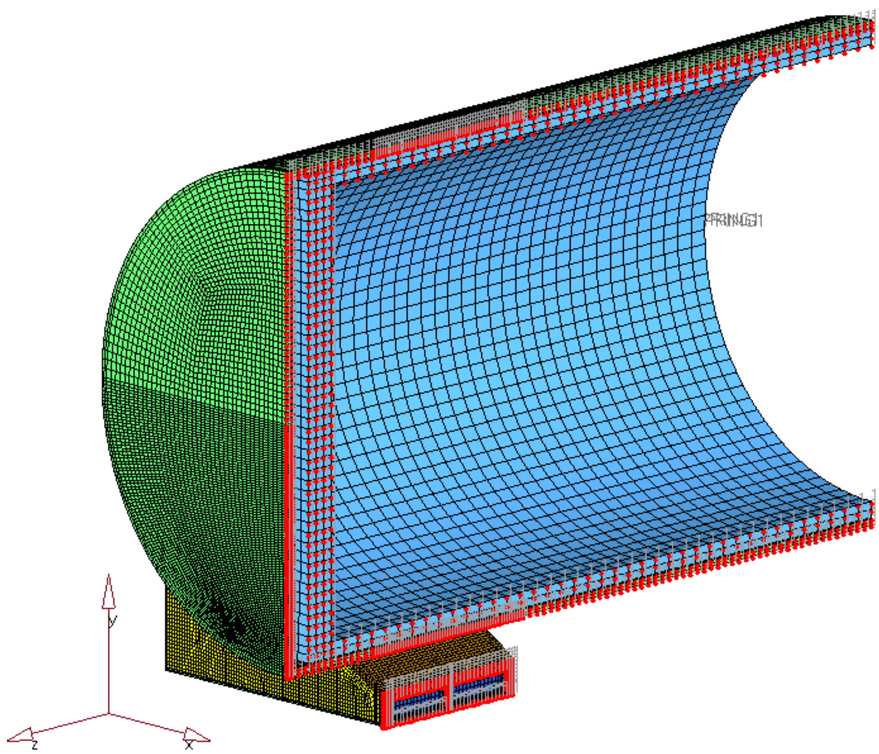


Figure 23: Pallet and Waste Package sides constrained in the x-direction

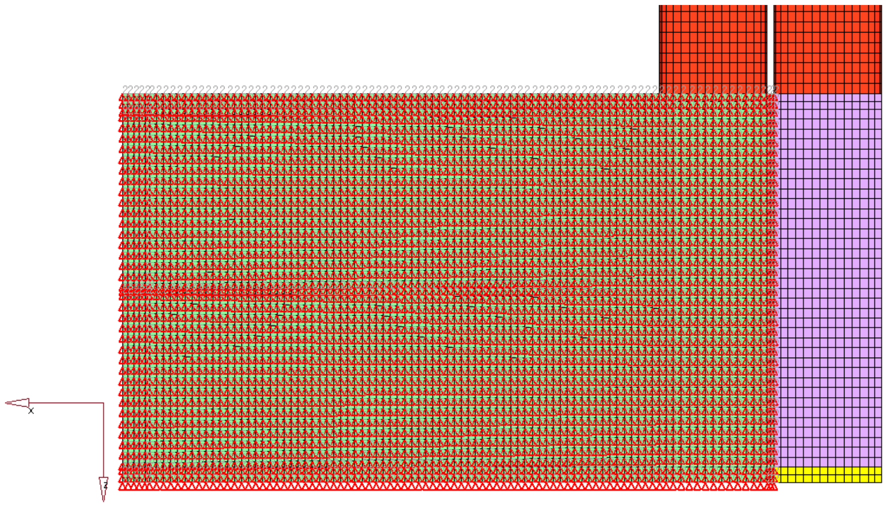


Figure 24: Pallet bottom surface constrained in the y-direction

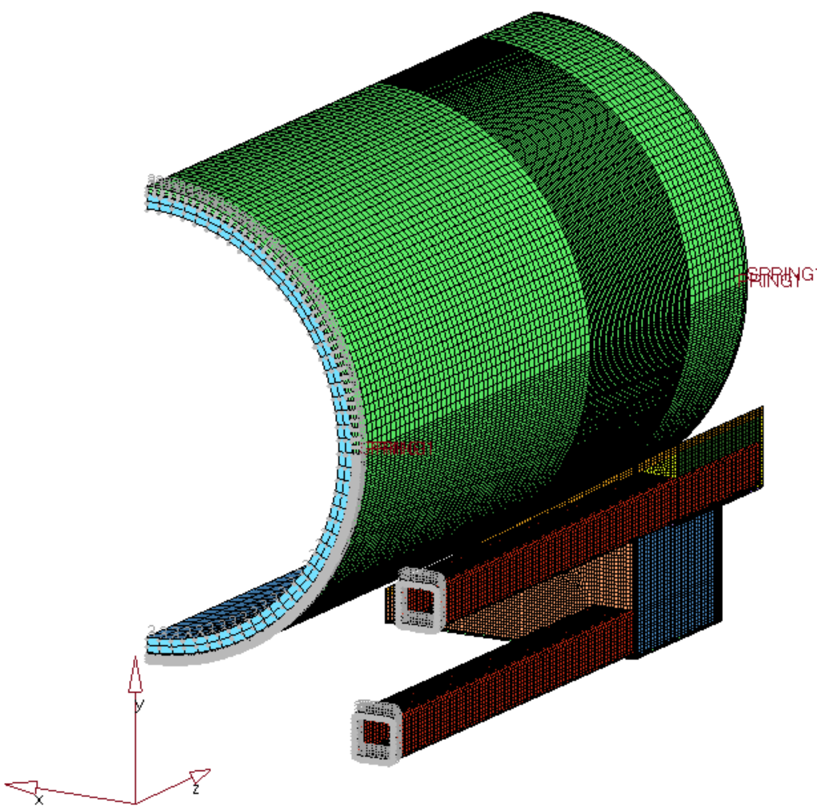


Figure 25: Tube and Waste Package ends constrained in the z-direction and four SPRING1 elements

Date: June 22, 2007
Entry by: Laura C. Domyancic

Loads: The two load sets applied to the model represent the pressure of two bulkheads of the drip shield contacting the Outer Shell of the waste package. The load set representing the pressure of the bulkheads on the waste package is equal to the 300 kPa pressure that is carried by the drip shield crown.

The surface area of the waste package that will be affected by one bulkhead is approximated to be 1000 mm × 150 mm. Because the model corresponds to ¼ of the waste package, the contact area is 500 mm × 150 mm.

On the contact area closest to the Outer Shell lid (Contact Area I), the length and width of one element is 29.24 mm and 10.89 mm, respectively. 238 elements (17 columns × 14 rows) are loaded to reproduce the contact area of 500 mm × 150 mm, which results in an actual area of 497.18 mm × 152.44 mm.

On the contact area of the Outer Shell closest to the xy-plane of symmetry (Contact Area II), the length and width of one element is 29.24 mm and 29.55 mm, respectively. 85 elements (17 columns × 5 rows) are loaded to reproduce the contact area of 500 mm × 150 mm, which results in an actual area of 497.18 mm × 147.75 mm.

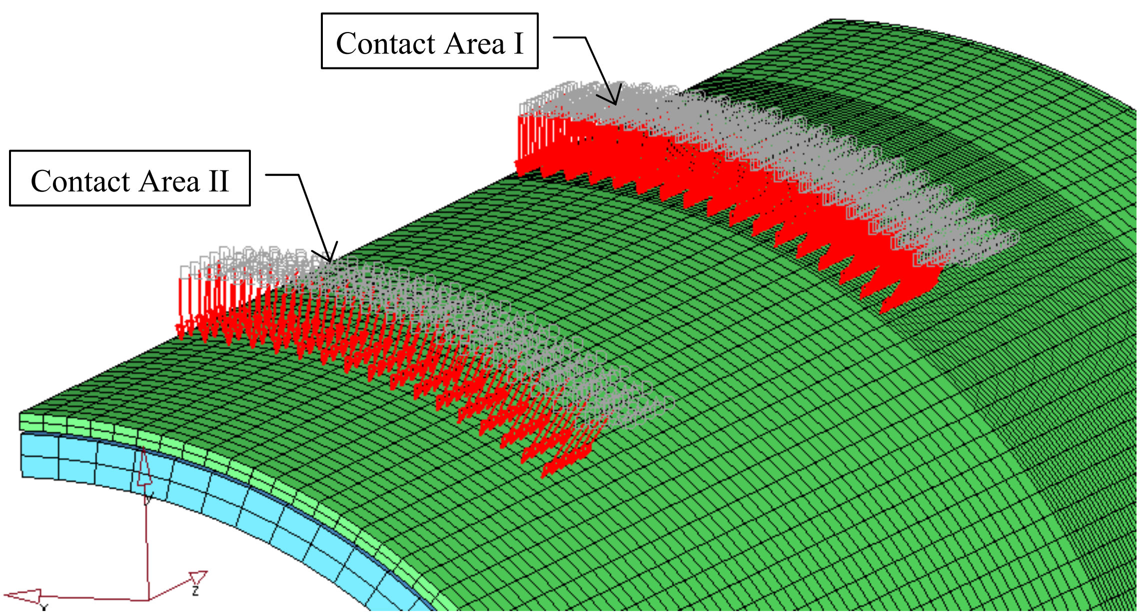


Figure 26: Outer Shell loading

S_{DS} = Surface area of the drip shield crown
L_{DS} = Length of drip shield
C_{DS} = Circumference of one half of the drip shield crown

S_{WP} = Surface contact area
L_{WP} = Length of contact area
C_{WP} = Circumference of contact area

Surface Area calculations:

$$S_{DS} = L_{DS} \cdot C_{DS} = 5805 \cdot 1374.122 = 7976778.2 \ mm^2$$

Contact Area I:

$$S_{WP} = L_{WP} \cdot C_{WP} = 152.44 \cdot 497.18 = 75790.12 \ mm^2$$

Contact Area II:

$$S_{WP} = L_{WP} \cdot C_{WP} = 147.75 \cdot 497.18 = 73458.05 \ mm^2$$

Pressure calculations:

$$P_{DS} \cdot S_{DS} = 4 \cdot P_{WP} \cdot S_{WP}$$

$$P_{DS} = 300 \ kPa = 3.0 \times 10^{-1} \ N/mm^2$$

Contact Area I:

$$P_{WP} = \frac{P_{DS} \cdot S_{DS}}{4 \cdot S_{WP}} = \frac{3.0 \times 10^{-1} \cdot 7976778.2}{4 \cdot 75790.12} = 7.8936 \ N/mm^2$$

Contact Area II:

$$P_{WP} = \frac{P_{DS} \cdot S_{DS}}{4 \cdot S_{WP}} = \frac{3.0 \times 10^{-1} \cdot 7976778.2}{4 \cdot 73458.05} = 8.1442 \ N/mm^2$$

The resulting pressures are 7.8936 N/mm^2 for Contact Area I and 8.1442 N/mm^2 for Contact Area II.

Date: July 2, 2007
Entry by: Laura C. Domyancic

<u>Results for Waste Package and Pallet FEM</u>

The computational analysis of the "Waste Package and Pallet" model was terminated at 31.4% of 3000 kPa. The maximum load applied before structural instabilities occurred was approximately equal to 942 kPa of pressure on the Drip Shield. The first incidence of yielding in the model occurred on the outer surface of the Outer Shell in the area which contacts the Pallet.

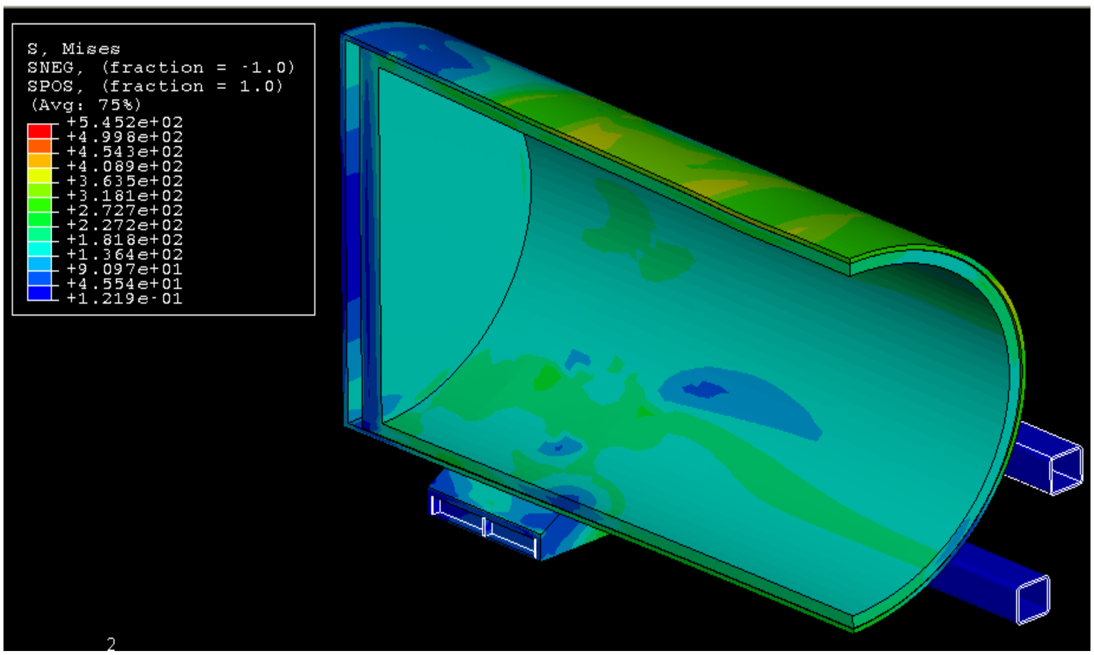


Figure 27: Von Mises Stress distribution at 31.4% of loading
(maximum stress of 545.2 MPa)

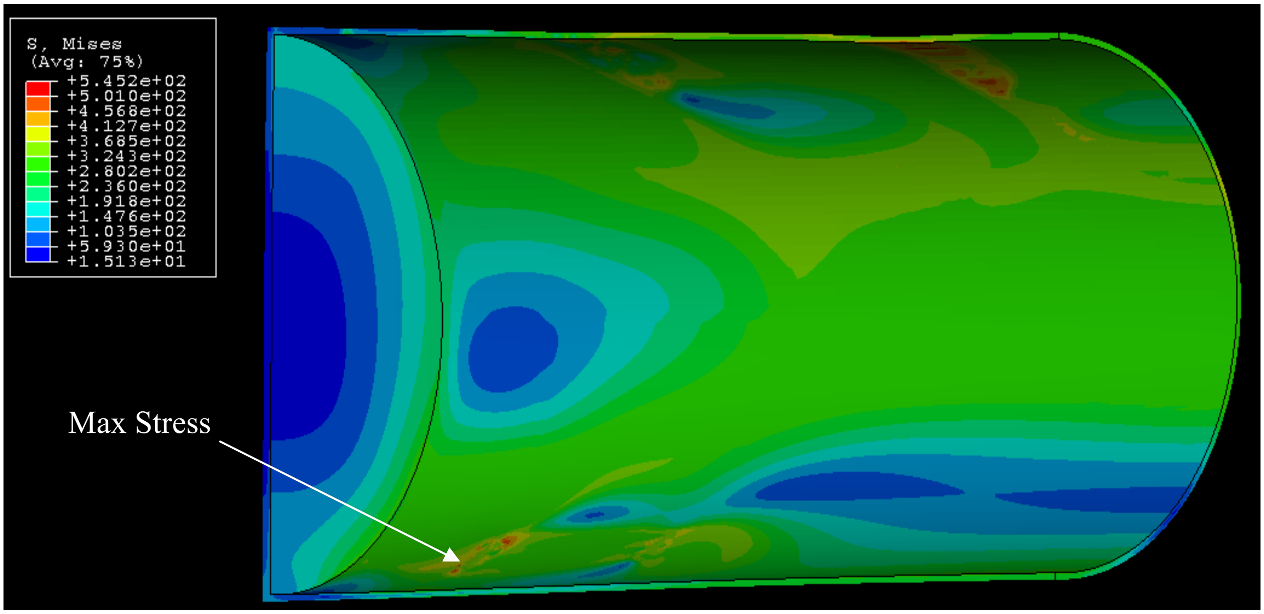


Figure 28: Von Mises Stress distribution on the inside of the Outer Shell at 31.4% of loading (maximum stress of 545.2 MPa)

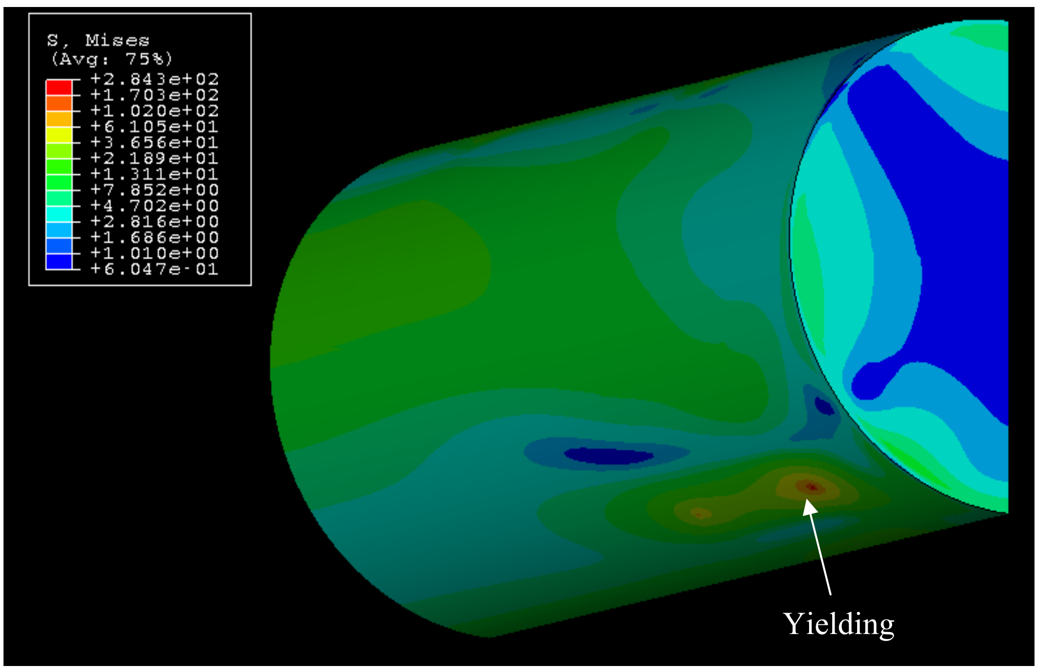
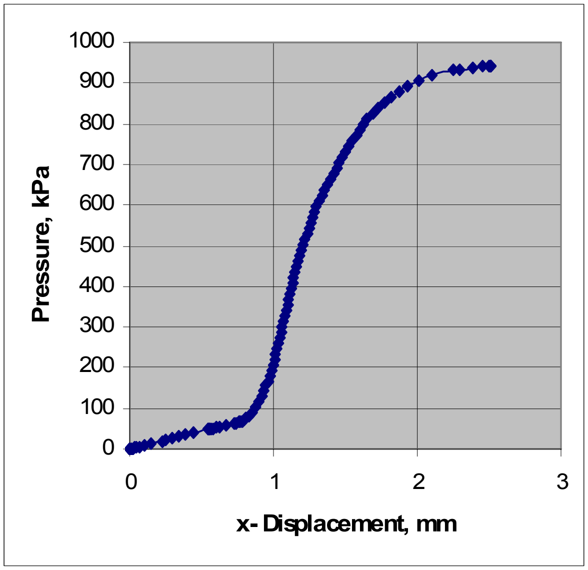
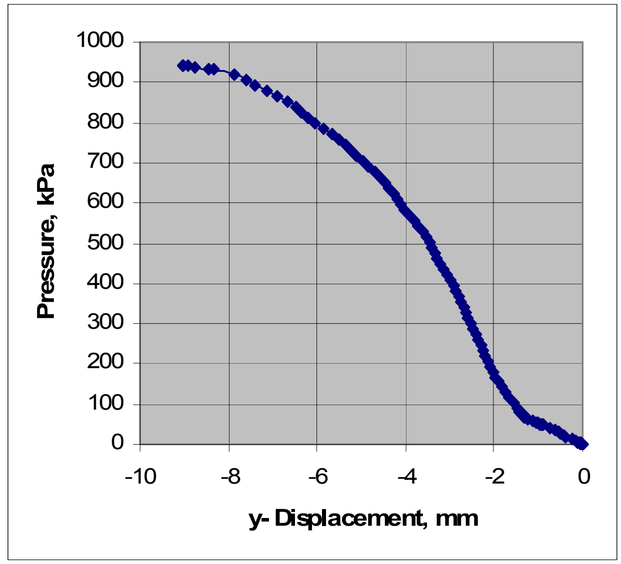


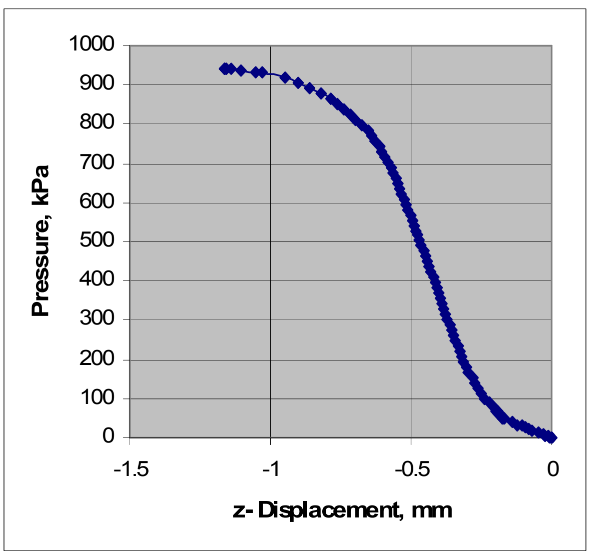
Figure 29: Outer Shell shown at first indication of yielding in the model (yielding @ 13 kPa)



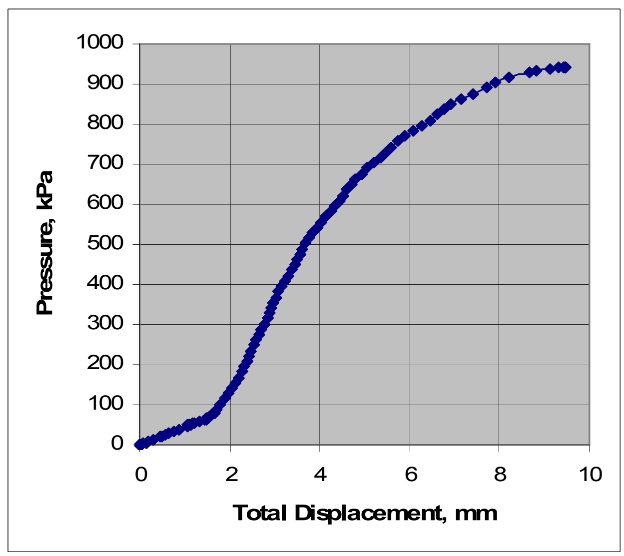
(a)



(b)



(c)



(d)

Figure 30: Displacement of node with maximum stress due to applied pressure

Date: July 3, 2007
Entry by: Laura C. Domyancic

<u>Description and Geometry of the Waste Package and Pallet – Coarse Pallet FEM</u>

The finite element model is composed of the following:

(i) Waste Package
 (a) Alloy 22 Outer Shell
 (b) 316 Stainless Steel Inner Vessel

(ii) Emplacement Pallet with Alloy 22 Plates and Tubes

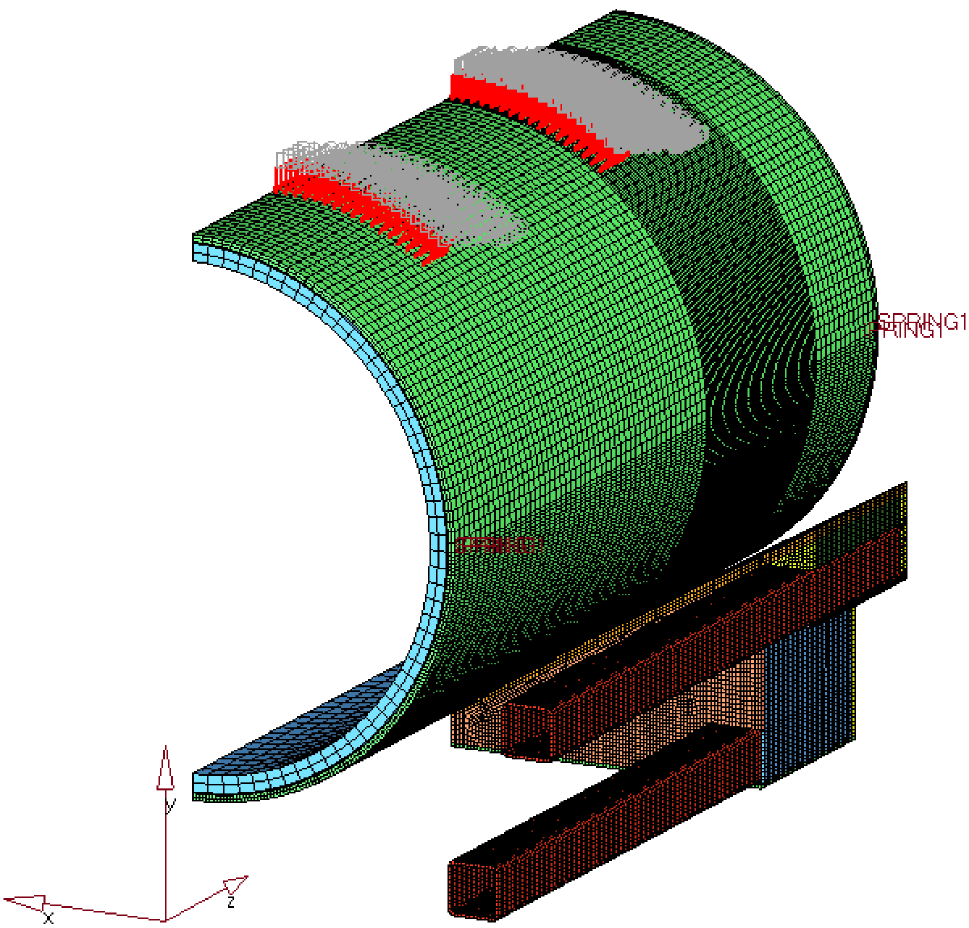


Figure 31

The FE model of the waste package is created using solid 8-node linear hexahedral elements (C3D8). The size of the elements in the Outer Shell that contact Plate #6 of the pallet is 10.1×10×10.9 mm. All other elements range in size from 10×10×28 mm to 10×30×30 mm. The average size of an element in the Inner Vessel is 45×25×60 mm.

The FE model of the pallet is meshed using 8-node continuum shell elements (SC8R) for all parts except Plate #5 and Plate #6. A few 6-node shell elements (SC6R) are used to complete the mesh for Plate #2, Plate #3, and Plate #7. The size of an element in the plates ranges from 5×10×15 mm to 11×13×22 mm. The size of an element in the 254×76.2×6.35 mm Tubes ranges from 6.5×14.8×15 mm to 6.8×14.8×6.4 mm. The average size of an element in the 152.4×152.4×9.53 mm Tubes is 9.5×11.5×14.1 mm. Plate #5 and Plate #6 are meshed using solid 8-node linear hexahedral elements. The average size of an element in Plate #5 is 16×10×14 mm. The average size of an element in Plate #6 is 10.1×9.77×14.1 mm. The nodes on the shared surfaces within the pallet are equivalenced to create a continuous mesh.

Kinematic Constraints: The components of the waste package are constrained along the yz-plane of symmetry to prevent displacement in the horizontal direction (x-axis). Displacement in the transverse direction (z-axis) is prevented by constraints along the rear plane of symmetry.

The ends of the 152.4×152.4×9.53 mm Tubes are constrained along the xy-plane of symmetry to prevent displacement in the transverse direction. The pallet is also constrained along the side plane of symmetry to prevent displacement in the horizontal direction. All nodes on the bottom surface of the pallet are constrained from vertical displacement.

A friction coefficient of 0.4 is applied to the Outer Shell/Pallet contact surface and the Outer Shell/Inner Vessel contact surface to properly model friction surface interaction.

The displacement of the waste package in the vertical direction is constrained by two SPRING1 elements of a relatively small stiffness on both the Outer Shell and Inner Vessel to prevent an initial rigid body mode.

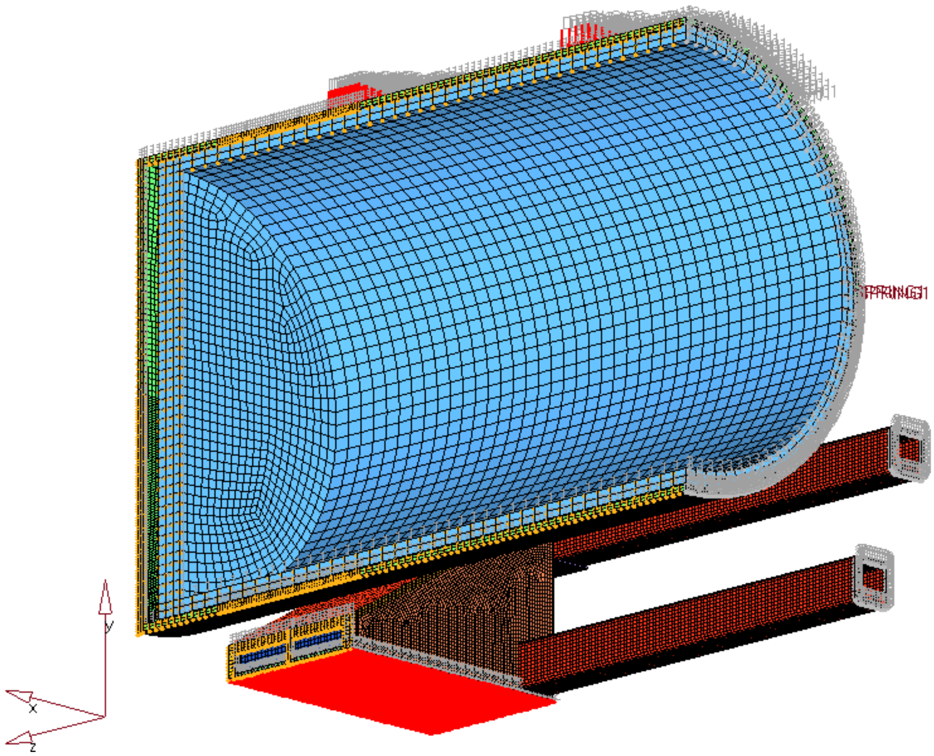


Figure 32: Constrains in the x- (yellow), y- (red), and z- (gray) directions

Loads: The two load sets applied to the model represent the pressure of two bulkheads of the drip shield contacting the Outer Shell of the waste package. The load set representing the pressure of the bulkheads on the waste package is equal to the 300 kPa pressure that is carried by the drip shield crown.

The surface area of the waste package that will be affected by one bulkhead is approximated to be 1000 mm × 150 mm. Because the model corresponds to ¼ of the waste package, the contact area is 500 mm × 150 mm.

On the contact area closest to the Outer Shell lid (Contact Area I), the length and width of one element is 29.24 mm and 10.89 mm, respectively. 238 elements (17 columns × 14 rows) are loaded to reproduce the contact area of 500 mm × 150 mm, which results in an actual area of 497.18 mm × 152.44 mm.

On the contact area of the Outer Shell closest to the xy-plane of symmetry (Contact Area II), the length and width of one element is 29.24 mm and 29.55 mm, respectively. 85 elements (17 columns × 5 rows) are loaded to reproduce the contact area of 500 mm × 150 mm, which results in an actual area of 497.18 mm × 147.75 mm.

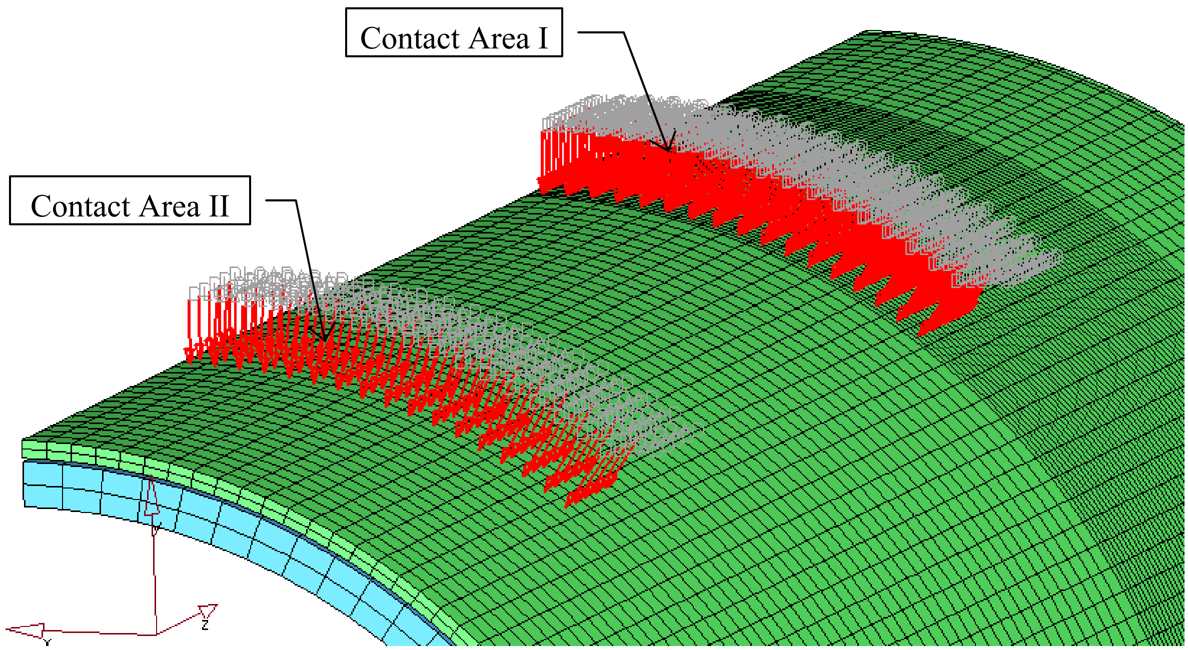


Figure 33: Outer Shell loading

Surface Area calculations:

$$S_{DS} = L_{DS} \cdot C_{DS} = 5805 \cdot 1374.122 = 7976778.2 \ mm^2$$

Contact Area I:

$$S_{WP} = L_{WP} \cdot C_{WP} = 152.44 \cdot 497.18 = 75790.12 \ mm^2$$

Contact Area II:

$$S_{WP} = L_{WP} \cdot C_{WP} = 147.75 \cdot 497.18 = 73458.05 \ mm^2$$

Pressure calculations:

$$P_{DS} \cdot S_{DS} = 4 \cdot P_{WP} \cdot S_{WP}$$

$$P_{DS} = 300 \ kPa = 3.0 \times 10^{-1} \ N/mm^2$$

Contact Area I:

$$P_{WP} = \frac{P_{DS} \cdot S_{DS}}{4 \cdot S_{WP}} = \frac{3.0 \times 10^{-1} \cdot 7976778.2}{4 \cdot 75790.12} = 7.8936 \, {}^{N}\!/_{mm^2}$$

Contact Area II:

$$P_{WP} = \frac{P_{DS} \cdot S_{DS}}{4 \cdot S_{WP}} = \frac{3.0 \times 10^{-1} \cdot 7976778.2}{4 \cdot 73458.05} = 8.1442 \, {}^{N}\!/_{mm^2}$$

The resulting pressures are 7.8936 N/mm^2 for Contact Area I and 8.1442 N/mm^2 for Contact Area II.

Date: July 5, 2007
Entry by: Laura C. Domyancic

Results for Waste Package and Pallet – Coarse Pallet FEM

The computational analysis of the "Waste Package and Pallet – Coarse Mesh" model was terminated at 15.6% of 3000 kPa due to excessively distorted elements. The maximum load applied was approximately equal to 470 kPa on the Drip Shield. The first incidence of yielding in the model occurred on the outer surface of the Outer Shell in the area which contacts the Pallet.

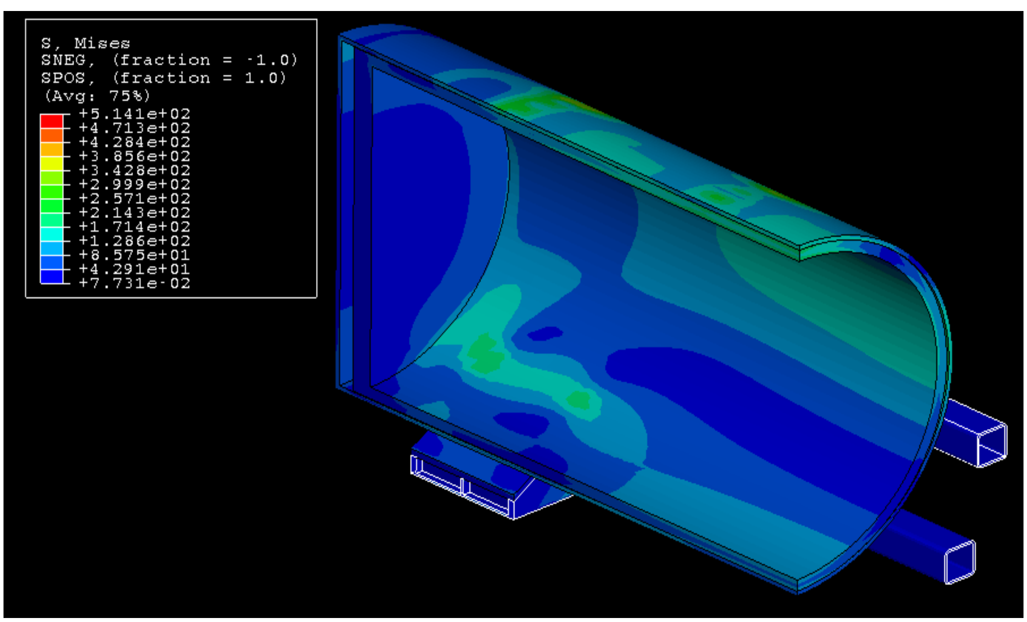


Figure 34: Von Mises Stress distribution at 15.6% of loading (maximum stress of 514.1 MPa)

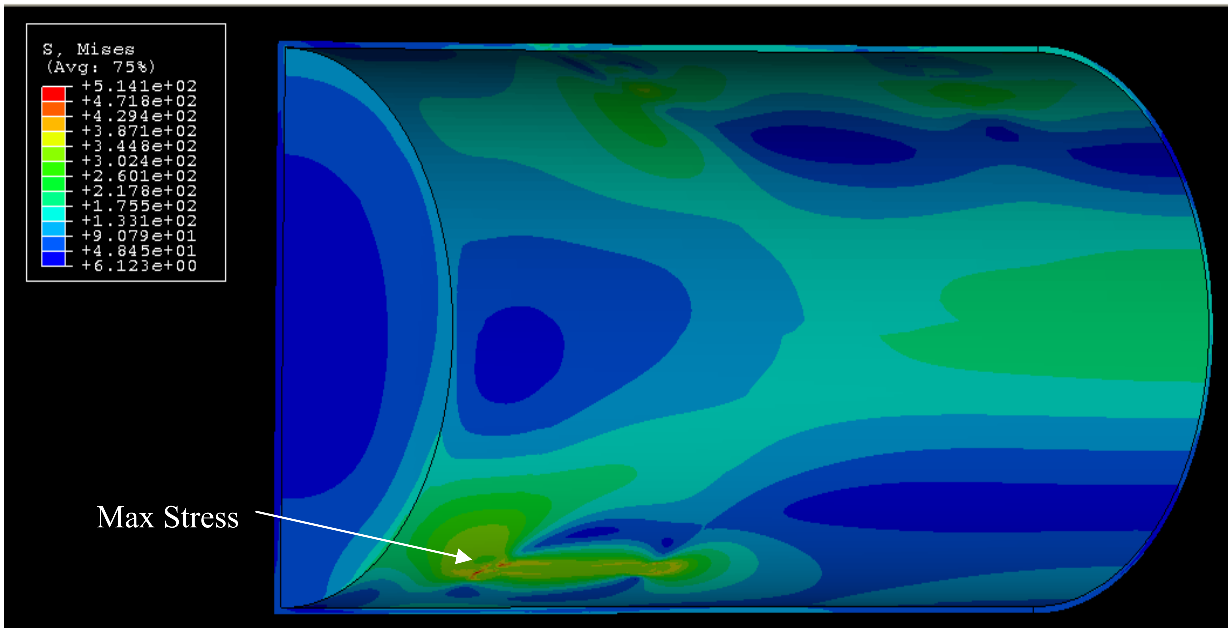


Figure 35: Von Mises Stress distribution on the inside of the Outer Shell at 15.6% of loading (maximum stress of 514.1 MPa)

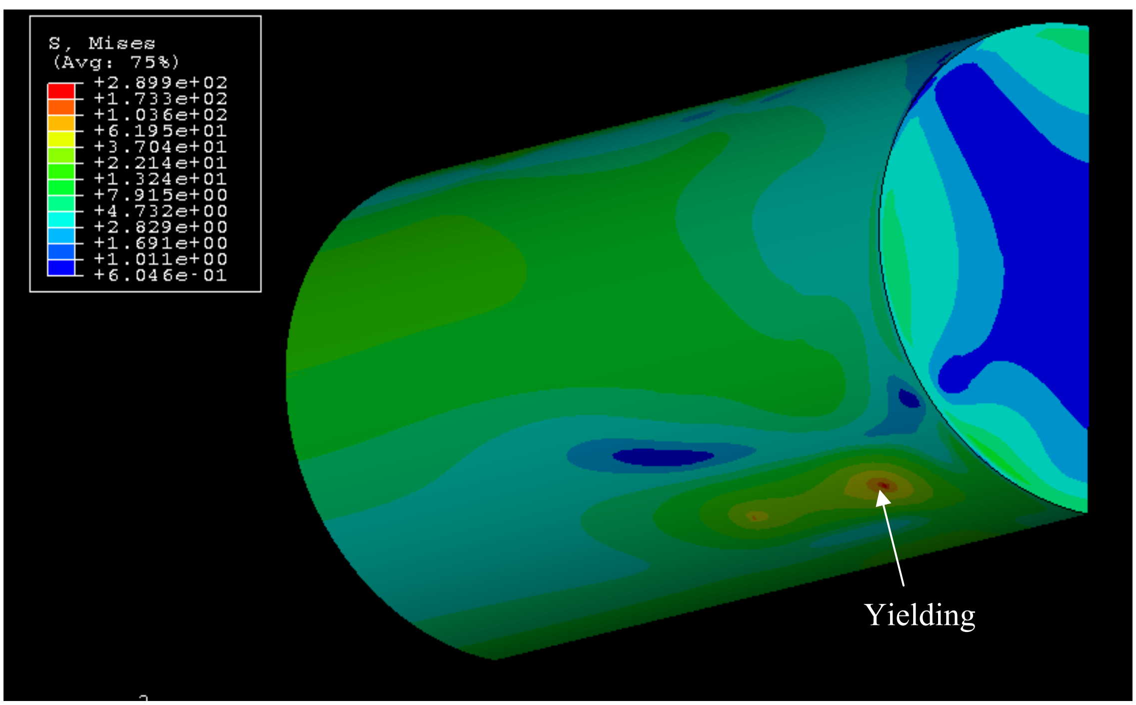


Figure 36: Outer Shell shown at first indication of yielding in the model (yielding @ 13 kPa)

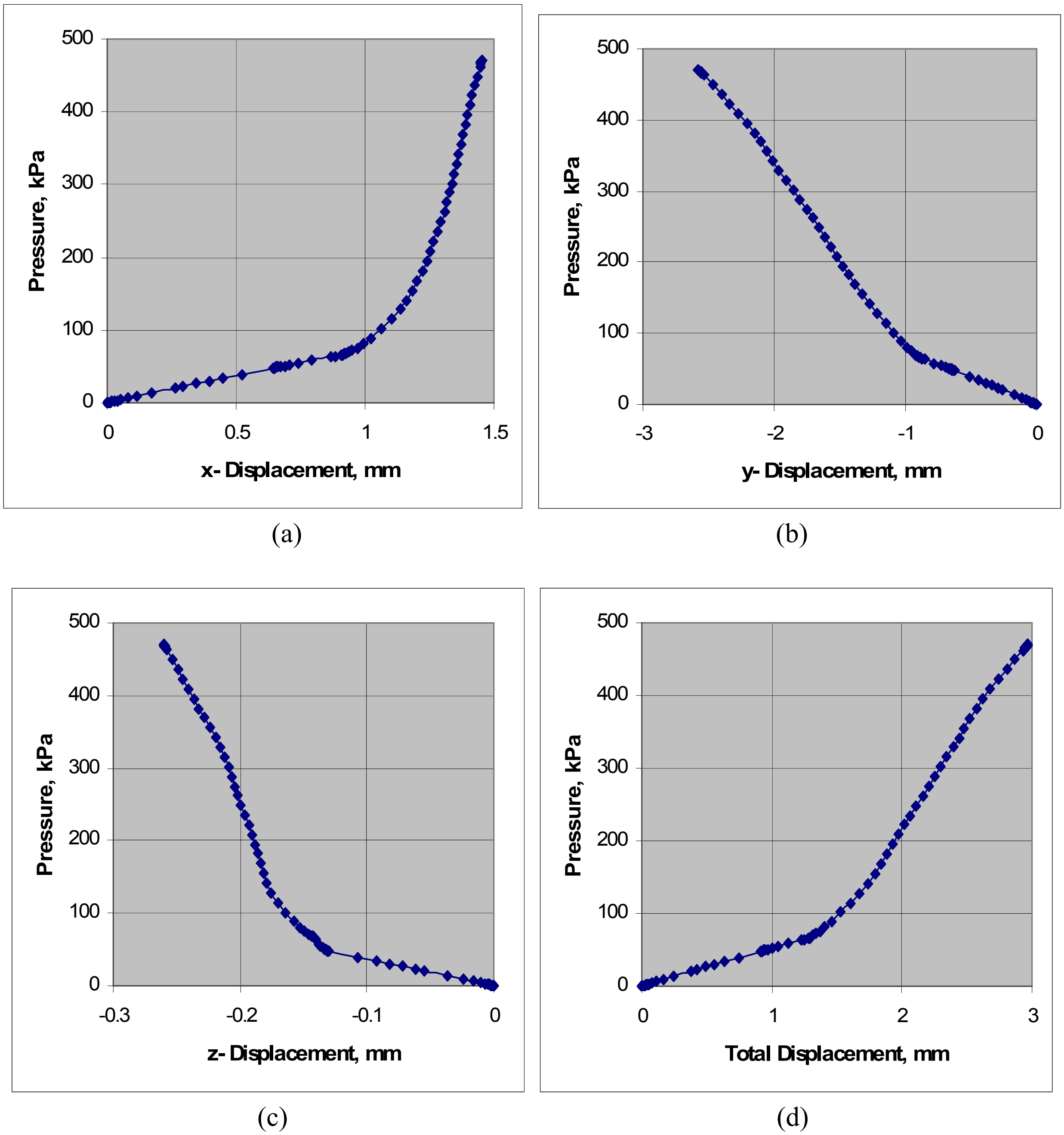


Figure 37: Displacement of node with maximum stress due to applied pressure

Date: July 6, 2007
Entry by: Laura C. Domyancic

Description and Geometry of the Waste Package and Pallet – Refined Pallet FEM
The finite element model is composed of the following:

(i) Waste Package
(a) Alloy 22 Outer Shell
(b) 316 Stainless Steel Inner Vessel

(ii) Emplacement Pallet with Alloy 22 Plates and Tubes

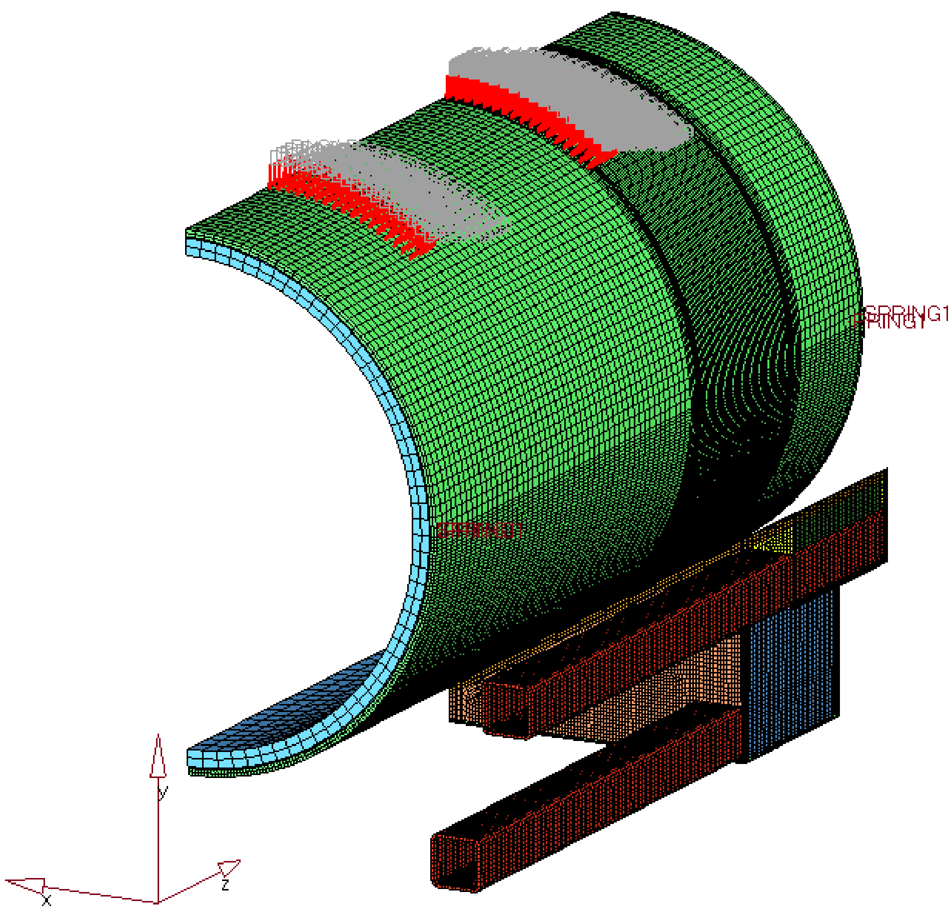


Figure 38

The FE model of the waste package is created using solid 8-node linear hexahedral elements (C3D8). The size of the elements in the Outer Shell that contact Plate #6 of the pallet is 10.1×10×10.9 mm. All other elements range in size from 10×10×28 mm to 10×30×30 mm. The average size of an element in the Inner Vessel is 45×25×60 mm.

The FE model of the pallet is meshed using solid 8-node linear hexahedral elements (C3D8) for Plates#1-7. A few 6-node solid elements (C3D6) are used to complete the mesh for Plate #2, Plate #3, and Plate #7. The average size of an element in the contact region of Plate #6 (where the Outer Shell of the waste package will rest) is 10.1×7.33×14.1 mm. The size of an element in the other plates ranges from 5×5×7.4 mm to 15×15×7.4 mm. All other components are meshed using 8-node continuum shell elements (SC8R). The average size of an element in Plate #8 is 9.52×6.35×14.1 mm. The size of an element in the 254×76.2×6.35 mm Tubes ranges from 6.5×14.8×15 mm to 6.8×14.8×6.4 mm. The average size of an element in the 152.4×152.4×9.53 mm Tubes is 9.52×11.5×14.1 mm. The nodes on the shared surfaces within the pallet are equivalenced to create a continuous mesh.

Kinematic Constraints: The components of the waste package are constrained along the yz-plane of symmetry to prevent displacement in the horizontal direction (x-axis). Displacement in the transverse direction (z-axis) is prevented by constraints along the rear plane of symmetry.

The ends of the 152.4×152.4×9.53 mm Tubes are constrained along the xy-plane of symmetry to prevent displacement in the transverse direction. The pallet is also constrained along the side plane of symmetry to prevent displacement in the horizontal direction. All nodes on the bottom surface of the pallet are constrained from vertical displacement.

A friction coefficient of 0.4 is applied to the Outer Shell/Pallet contact surface and the Outer Shell/Inner Vessel contact surface to properly model friction surface interaction.

The displacement of the waste package in the vertical direction is constrained by two SPRING1 elements of a relatively small stiffness on both the Outer Shell and Inner Vessel to prevent an initial rigid body mode.

Loads: The two load sets applied to the model represent the pressure of two bulkheads of the drip shield contacting the Outer Shell of the waste package. The load set representing the pressure of the bulkheads on the waste package is equal to the 300 kPa pressure that is carried by the drip shield crown.

The surface area of the waste package that will be affected by one bulkhead is approximated to be 1000 mm × 150 mm. Because the model corresponds to ¼ of the waste package, the contact area is 500 mm × 150 mm.

The contact area closest to the Outer Shell lid (Contact Area I) contains 11 rows of elements where the length and width of one element is 29.24 mm and 10.89 mm, respectively, and 5 rows of elements where the length and width of one element is 29.24 mm and 6.53 mm, respectively. 272 elements (17 columns × 16 rows) are loaded to reproduce the contact area of 500 mm × 150 mm, which results in an actual area of 497.18 mm × 152.44 mm.

On the contact area of the Outer Shell closest to the xy-plane of symmetry (Contact Area II), the length and width of one element is 29.24 mm and 29.55 mm, respectively. 85 elements (17 columns × 5 rows) are loaded to reproduce the contact area of 500 mm × 150 mm, which results in an actual area of 497.18 mm × 147.75 mm.

Surface Area calculations:

$$S_{DS} = L_{DS} \cdot C_{DS} = 5805 \cdot 1374.122 = 7976778.2 \ mm^2$$

Contact Area I:

$$S_{WP} = L_{WP} \cdot C_{WP} = 152.44 \cdot 497.18 = 75790.12 \ mm^2$$

Contact Area II:

$$S_{WP} = L_{WP} \cdot C_{WP} = 147.75 \cdot 497.18 = 73458.05 \ mm^2$$

Pressure calculations:

$$P_{DS} \cdot S_{DS} = 4 \cdot P_{WP} \cdot S_{WP}$$

$$P_{DS} = 300 \ kPa = 3.0 \times 10^{-1} \ N/mm^2$$

Contact Area I:

$$P_{WP} = \frac{P_{DS} \cdot S_{DS}}{4 \cdot S_{WP}} = \frac{3.0 \times 10^{-1} \cdot 7976778.2}{4 \cdot 75790.12} = 7.8936 \ N/mm^2$$

Contact Area II:

$$P_{WP} = \frac{P_{DS} \cdot S_{DS}}{4 \cdot S_{WP}} = \frac{3.0 \times 10^{-1} \cdot 7976778.2}{4 \cdot 73458.05} = 8.1442 \ N/mm^2$$

The resulting pressures are 7.8936 N/mm^2 for Contact Area I and 8.1442 N/mm^2 for Contact Area II.

Date: July 9, 2007
Entry by: Laura C. Domyancic

Results of Waste Package and Pallet – Refined Pallet FEM

The computational analysis of the "Waste Package and Pallet – Refined Pallet" model was terminated at 31.43% of 3000 kPa. The maximum load applied before structural instabilities occurred was approximately equal to 943 kPa on the Drip Shield. The first incidence of yielding in the model occurred on the outer surface of the Outer Shell in the area which contacts the Pallet.

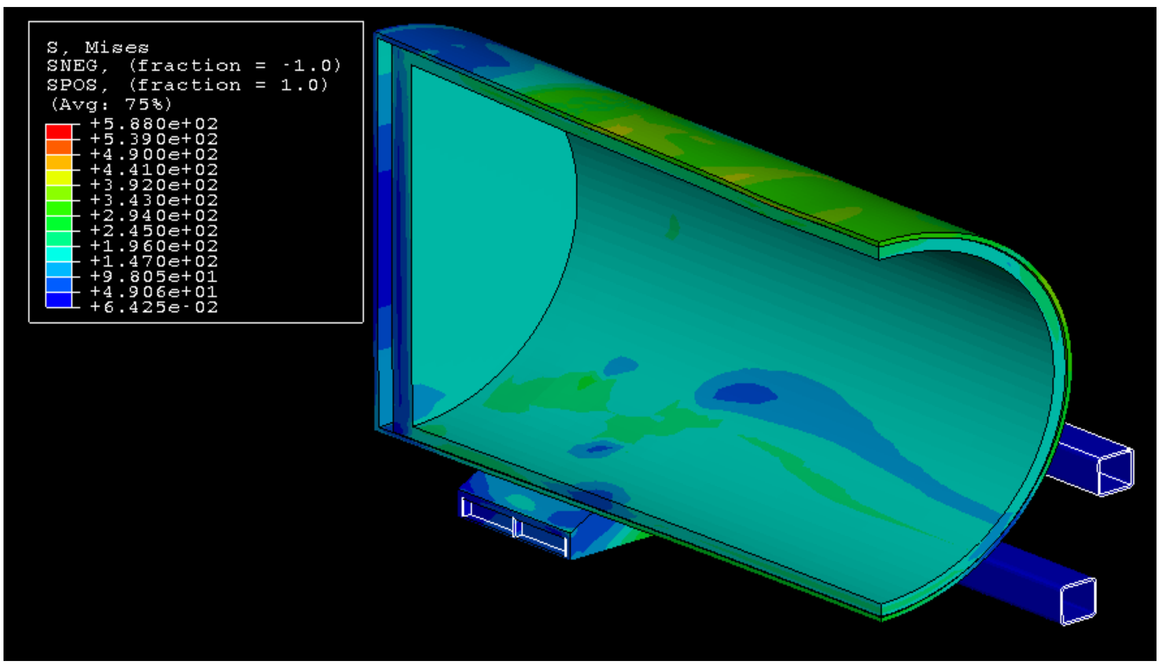


Figure 39: Von Mises Stress distribution at 31.43% of loading (maximum stress of 588 MPa)

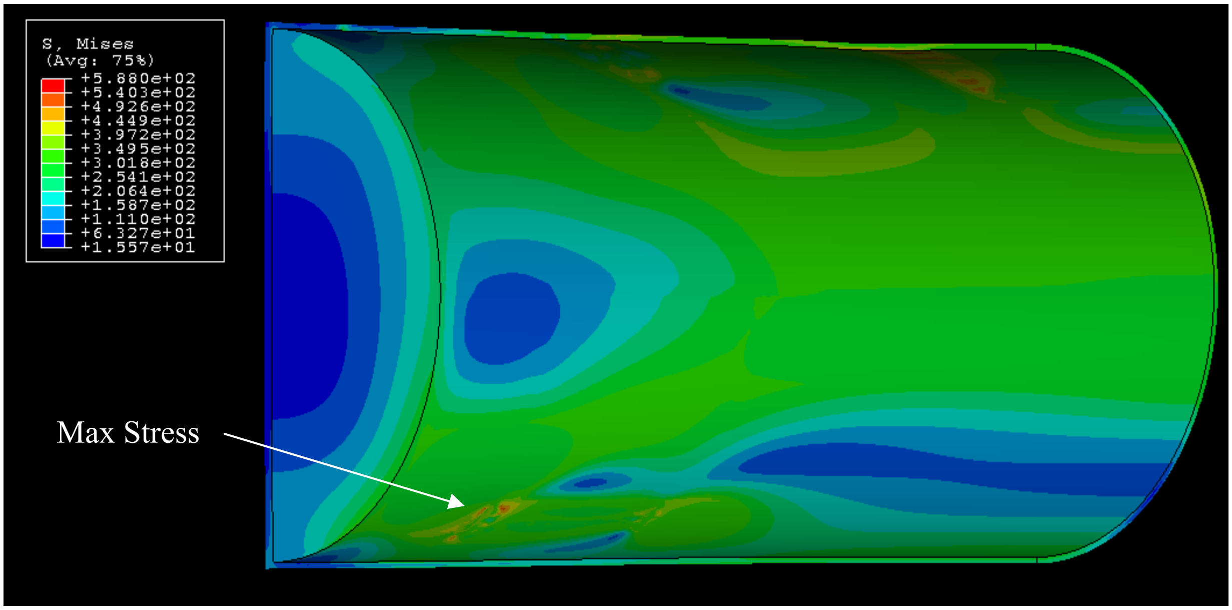


Figure 40: Von Mises Stress distribution on the inside of the Outer Shell at 31.43% of loading (maximum stress of 588 MPa)

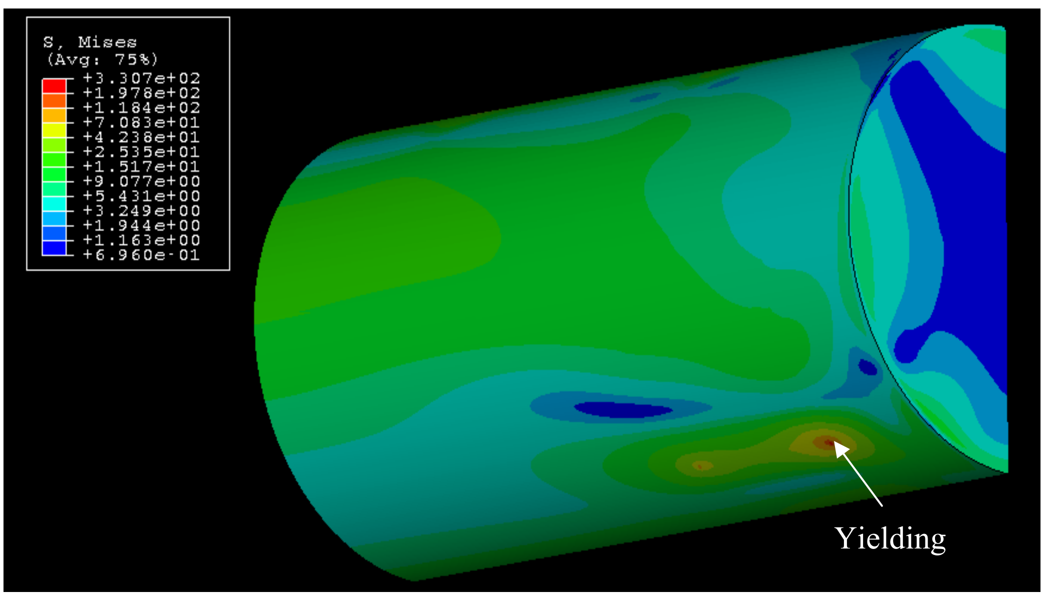


Figure 41: Outer Shell shown at first indication of yielding in the model (yielding @ 12.6 kPa)

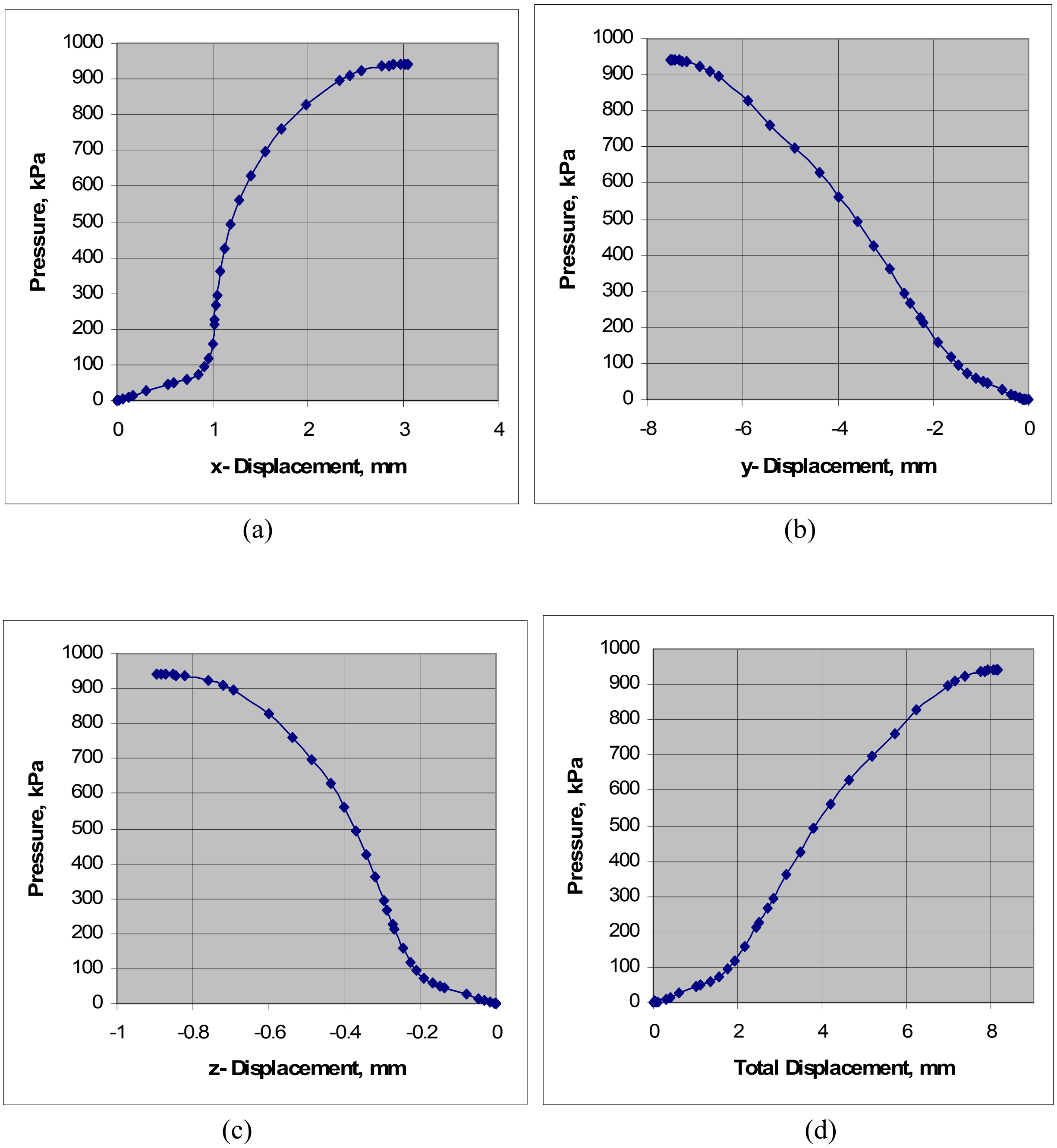


Figure 42: Displacement of node with maximum stress due to applied pressure

Date: July 10, 2007
Entry by: Laura C. Domyancic

Description and Geometry of the Waste Package and Pallet – Refined Outer Shell FEM

The finite element model is composed of the following:

(i) Waste Package
(a) Alloy 22 Outer Shell
(b) 316 Stainless Steel Inner Vessel

(ii) Emplacement Pallet with Alloy 22 Plates and Tubes

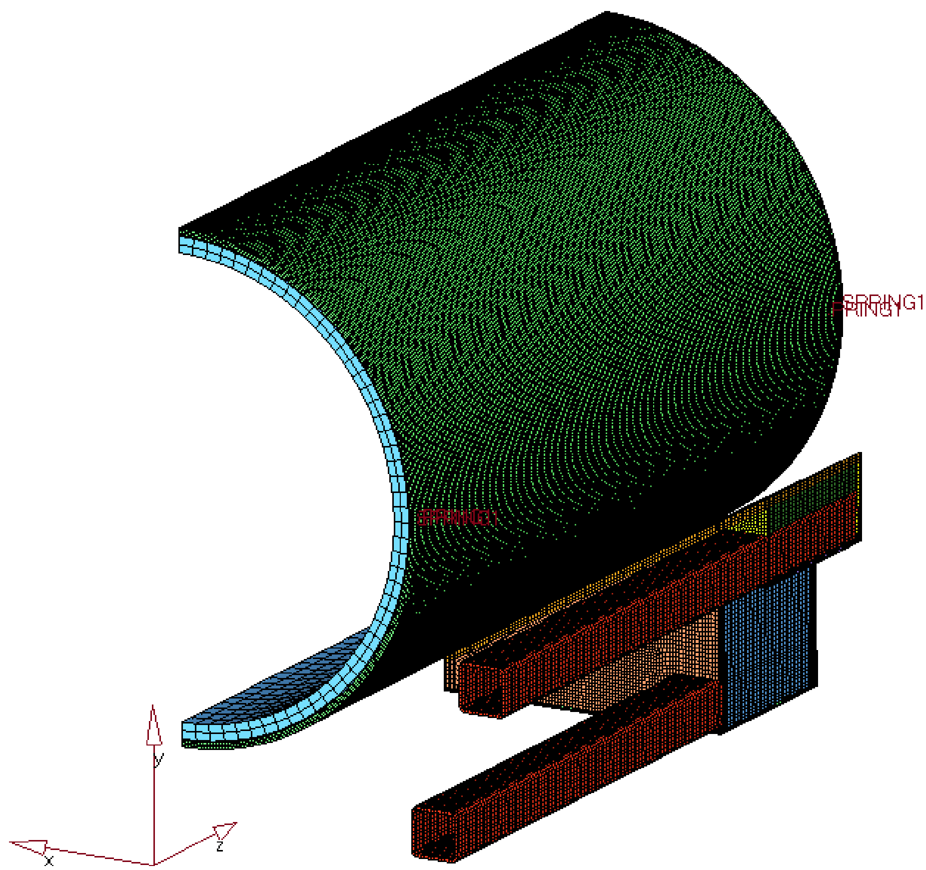


Figure 43

The FE model of the waste package is created using solid 8-node linear hexahedral elements (C3D8). The size of the elements in the Outer Shell that contact Plate #6 of the pallet is 10.1×6.7×10.9 mm. The average size of an element in the Inner Vessel is 45×25×60 mm.

The FE model of the pallet is meshed using solid 8-node linear hexahedral elements (C3D8) for Plates#1-7. A few 6-node solid elements (C3D6) are used to complete the mesh for Plate #2, Plate #3, and Plate #7. The average size of an element in the contact region of Plate #6 (where the Outer Shell of the waste package will rest) is 10.1×9.77×14.1 mm. The size of an element in the other plates ranges from 5×10×15 mm to 11×12×15 mm. All other components are meshed using 8-node continuum shell elements (SC8R). The average size of an element in Plate #8 is 9.52×6.35×14.1 mm. The size of an element in the 254×76.2×6.35 mm Tubes ranges from 6.5×14.8×15 mm to 6.8×14.8×6.4 mm. The average size of an element in the 152.4×152.4×9.53 mm Tubes is 9.52×11.5×14.1 mm. The nodes on the shared surfaces within the pallet are equivalenced to create a continuous mesh.

Kinematic Constraints: The components of the waste package are constrained along the yz-plane of symmetry to prevent displacement in the horizontal direction (x-axis). Displacement in the transverse direction (z-axis) is prevented by constraints along the rear plane of symmetry.

The ends of the 152.4×152.4×9.53 mm Tubes are constrained along the xy-plane of symmetry to prevent displacement in the transverse direction. The pallet is also constrained along the side plane of symmetry to prevent displacement in the horizontal direction. All nodes on the bottom surface of the pallet are constrained from vertical displacement.

A friction coefficient of 0.4 is applied to the Outer Shell/Pallet contact surface and the Outer Shell/Inner Vessel contact surface to properly model friction surface interaction.

The displacement of the waste package in the vertical direction is constrained by two SPRING1 elements of a relatively small stiffness on both the Outer Shell and Inner Vessel to prevent an initial rigid body mode.

Loads: The load set applied to the model represent the pressure of two bulkheads of the drip shield contacting the Outer Shell of the waste package. The load set representing the pressure of the bulkheads on the waste package is equal to the 300 kPa pressure that is carried by the drip shield crown.

The surface area of the waste package that will be affected by one bulkhead is approximated to be 1000 mm × 150 mm. Because the model corresponds to ¼ of the waste package, the contact area is 500 mm × 150 mm.

In the contact area, the average length and width of one element is 10.41 mm and 10.92 mm, respectively. 686 elements (49 columns × 14 rows) are loaded to reproduce the contact area of 500 mm × 150 mm, which results in an actual area of 510.09 mm × 152.91 mm.

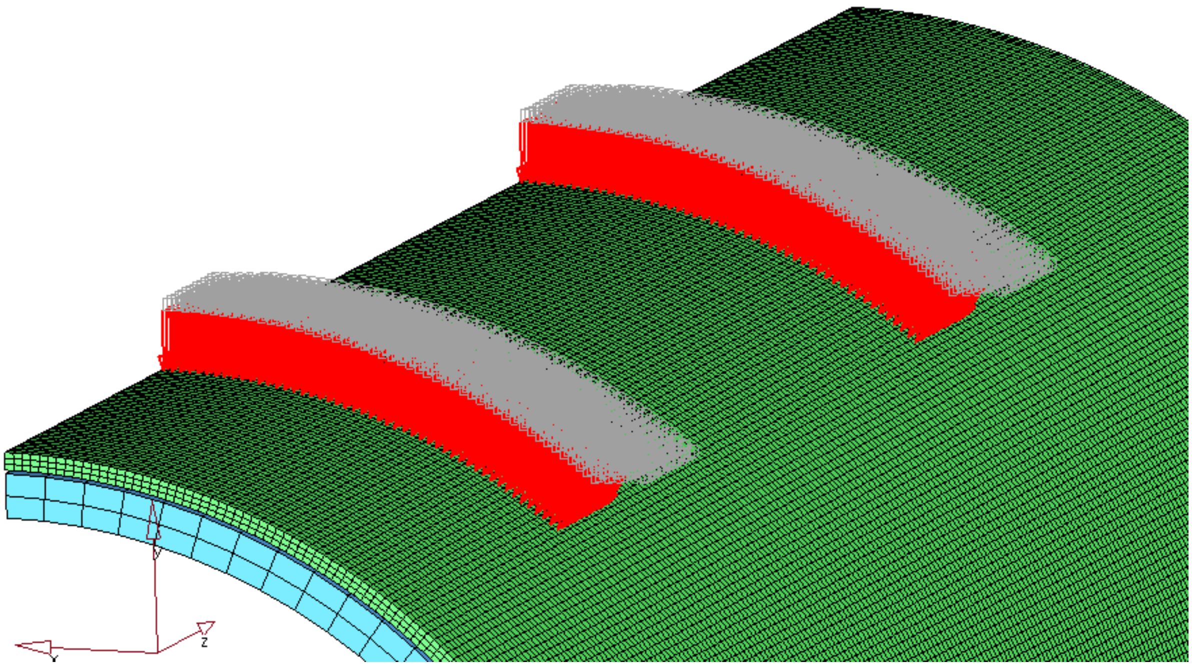


Figure 44: Outer Shell loading

Surface Area calculations:

$$S_{DS} = L_{DS} \cdot C_{DS} = 5805 \cdot 1374.12 = 7976778.2\ mm^2$$

$$S_{WP} = L_{WP} \cdot C_{WP} = 152.91 \cdot 510.09 = 77997.86\ mm^2$$

Pressure calculations:

$$P_{DS} \cdot S_{DS} = 4 \cdot P_{WP} \cdot S_{WP}$$

$$P_{DS} = 300\ kPa = 3.0 \times 10^{-1}\ N/mm^2$$

$$P_{WP} = \frac{P_{DS} \cdot S_{DS}}{4 \cdot S_{WP}} = \frac{3.0 \times 10^{-1} \cdot 7976778.2}{4 \cdot 77997.86} = 7.6702\ N/mm^2$$

The resulting pressure is 7.6702 N/mm^2.

Date: July 12, 2007
Entry by: Laura C. Domyancic

Results for the Waste Package and Pallet – Refined Outer Shell FEM

The computational analysis of the "Waste Package and Pallet – Refined Outer Shell" model was terminated at 26.9% of 3000 kPa. The maximum load applied before structural instabilities occurred was approximately equal to 808 kPa of pressure on the Drip Shield. The first incidence of yielding in the model occurred on the inner surface of the Outer Shell above the area which contacts the Pallet.

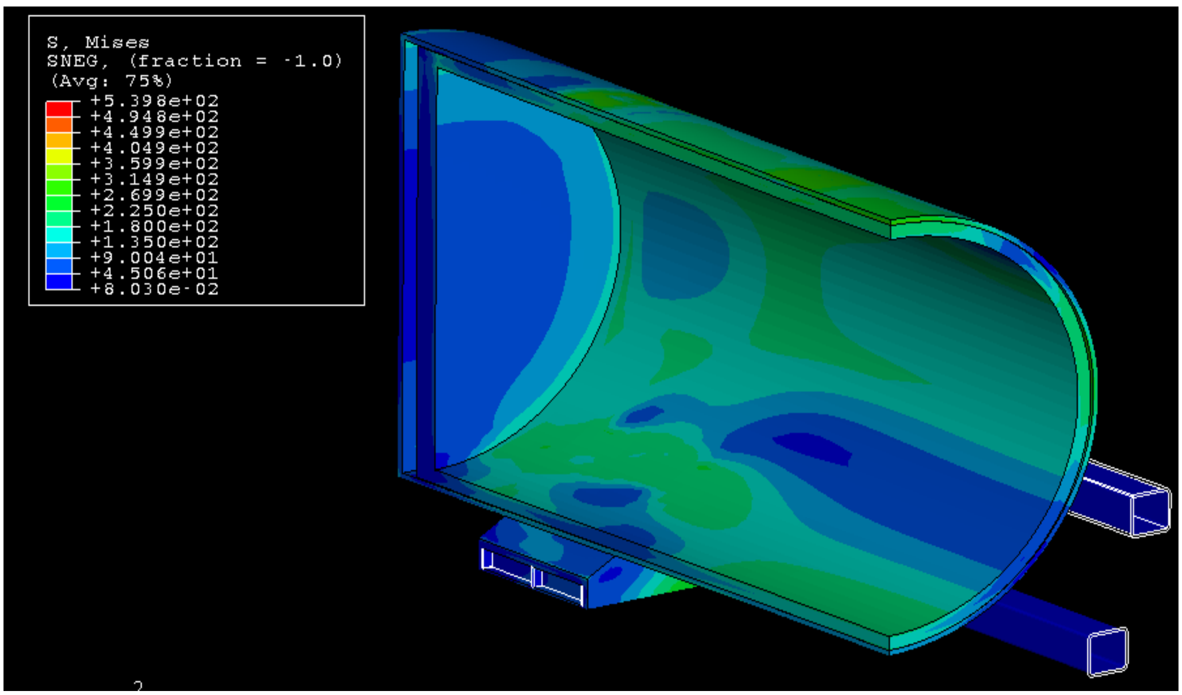


Figure 45: Von Mises Stress distribution at 26.9% of loading
(maximum stress of 539.8 MPa)

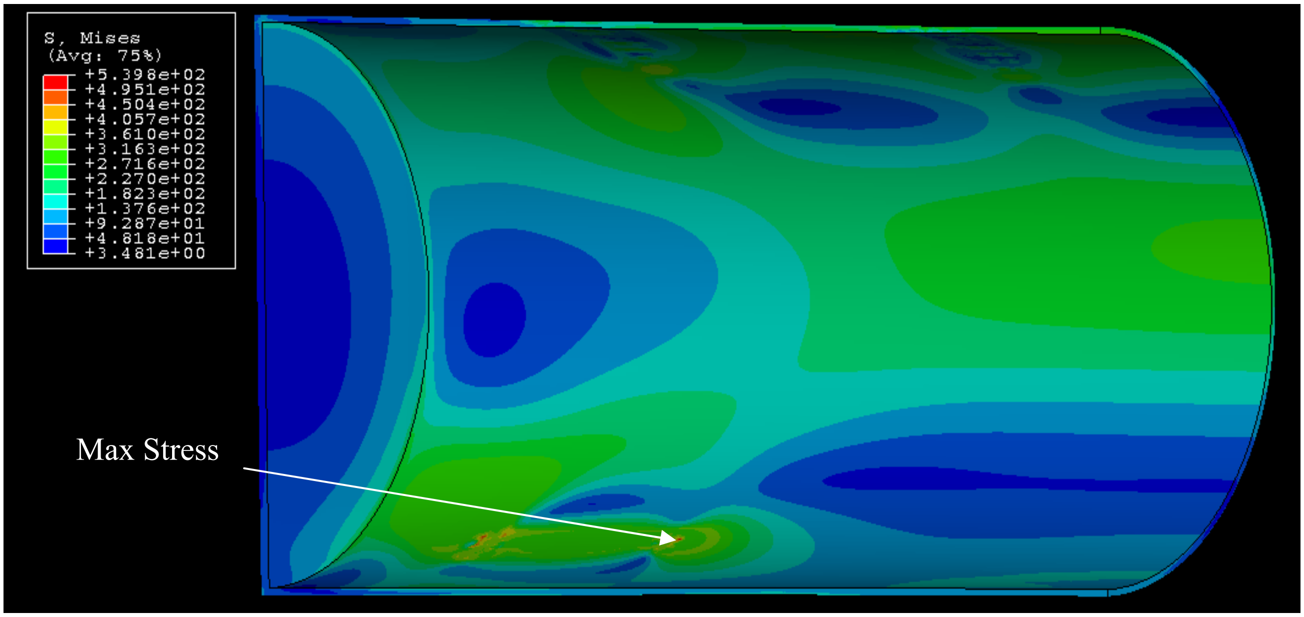


Figure 46: Von Mises Stress distribution on the inside of the Outer Shell at 26.9% of loading (maximum stress of 539.8 MPa)

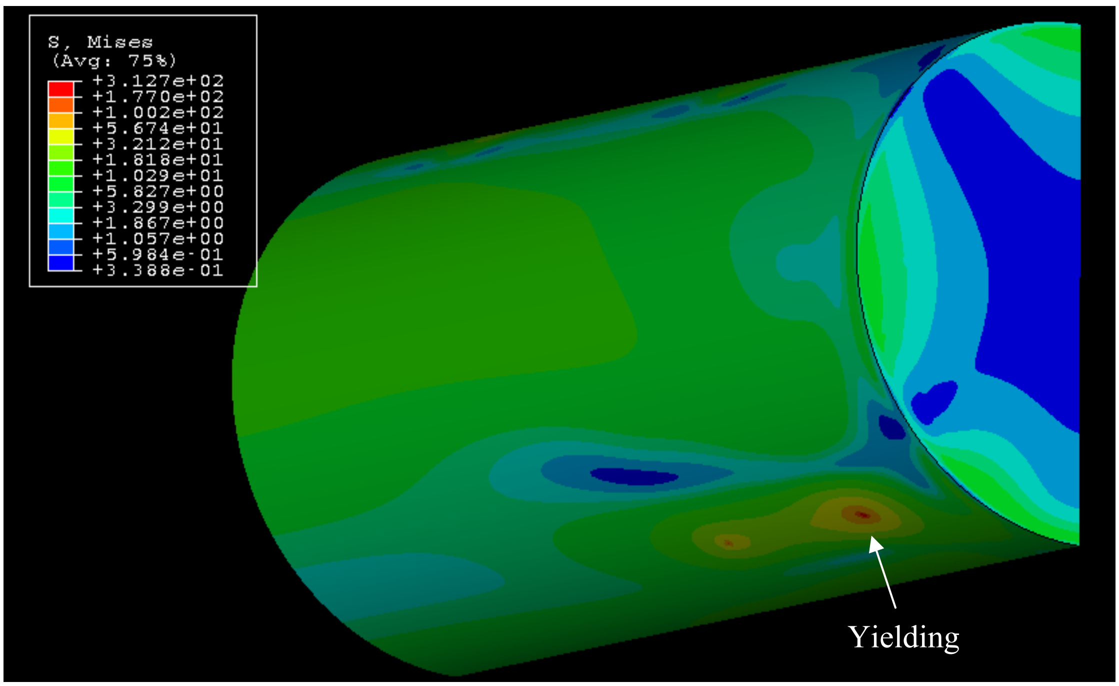


Figure 47: Outer Shell shown at first indication of yielding in the model (yielding @ 12.4 kPa)

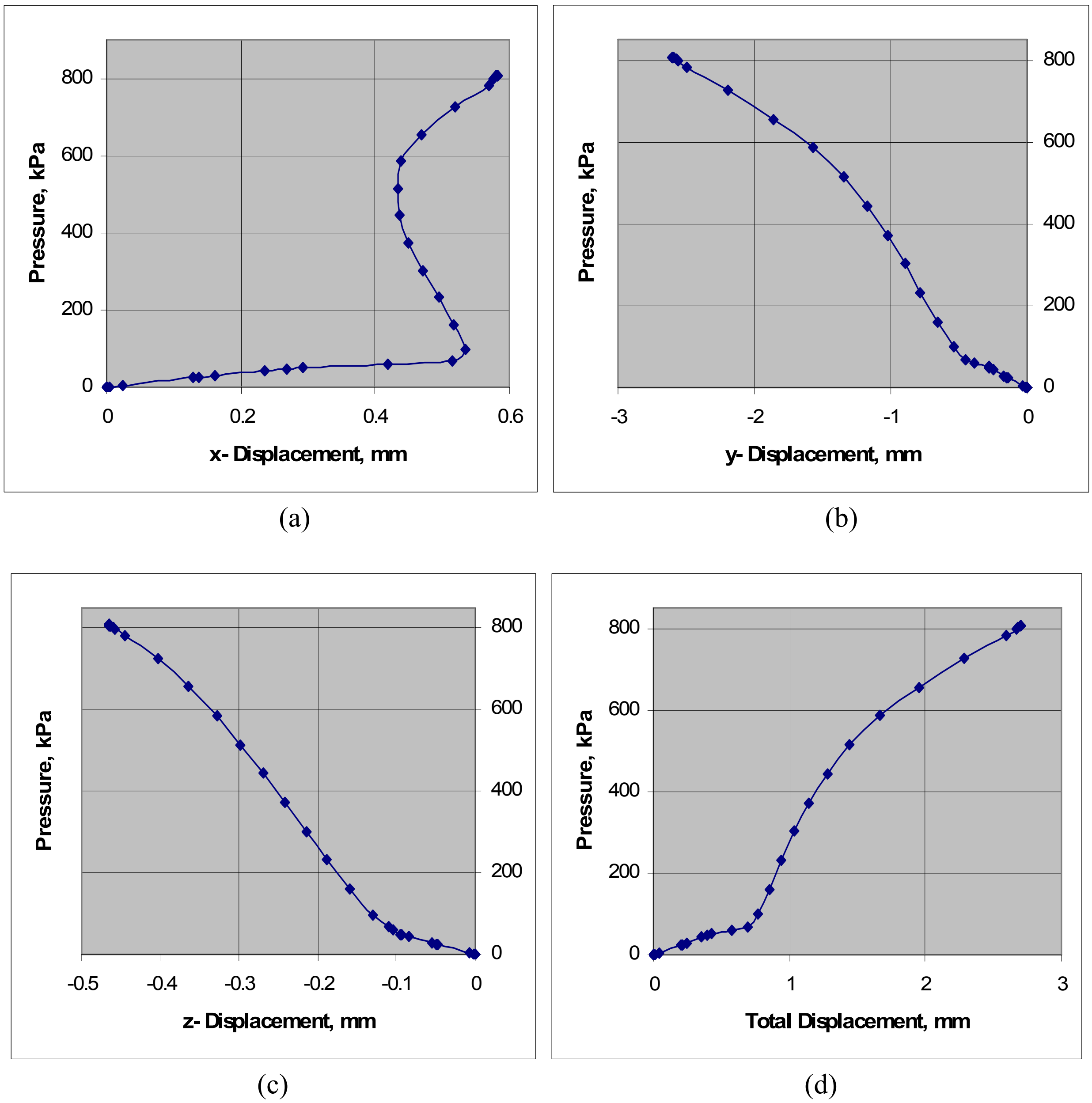


Figure 48: Displacement of node with maximum stress due to applied pressure

Date: July 20, 2007
Entry by: Laura C. Domyancic

<u>Description and Geometry of the Pallet and S4-element Waste Package FEM</u>

The finite element model is composed of the following:

(i) Waste Package
 (a) Alloy 22 Outer Shell
 (b) 316 Stainless Steel Inner Vessel

(ii) Emplacement Pallet with Alloy 22 Plates and Tubes

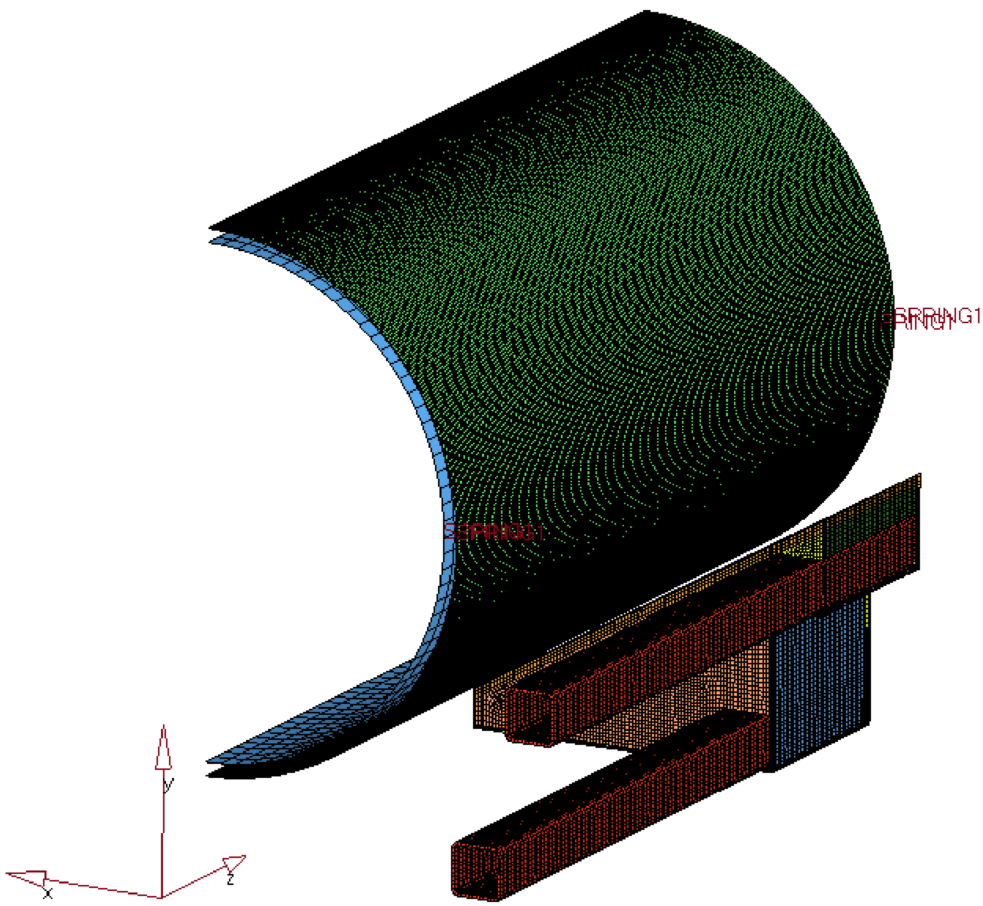


Figure 49

The FE model of the waste package is created using 4-node conventional shell elements (S4). The size of the elements in the Outer Shell that contact Plate #6 of the pallet is 10.1×10.9 mm with a thickness of 20 mm. The size of an element in the Inner Vessel is 45×60 mm with a thickness of 50 mm. The average size of an element in the Outer Shell lid is 9.6 × 9.0 mm, with a thickness of 25 mm. The average size of an element in the Inner Vessel lid is 35 ×35 mm, with a thickness of 95 mm.

The FE model of the pallet is meshed using solid 8-node linear hexahedral elements (C3D8) for Plates#1-7. A few 6-node solid elements (C3D6) are used to complete the mesh for Plate #2, Plate #3, and Plate #7. The average size of an element in the contact region of Plate #6 (where the Outer Shell of the waste package will rest) is 10.1×9.77×14.1 mm. The size of an element in the other plates ranges from 5×10×15 mm to 11×12×15 mm. All other components are meshed using 8-node continuum shell elements. The average size of an element in Plate #8 is 9.52×6.35×14.1 mm. The size of an element in the 254×76.2×6.35 Tubes ranges from 6.5×14.8×15 mm to 6.8×14.8×6.4 mm. The average size of an element in the 152.4×152.4×9.53 Tubes is 9.52×11.5×14.1 mm. The nodes on the shared surfaces within the pallet are equivalenced to create a continuous mesh.

Kinematic Constraints: The nodes of the waste package along the yz-plane of symmetry are constrained to prevent displacement in the horizontal direction (x-axis). Additionally, these nodes are also constrained against rotation around the z- and y- axes to achieve the same constraints of a three dimensional model.

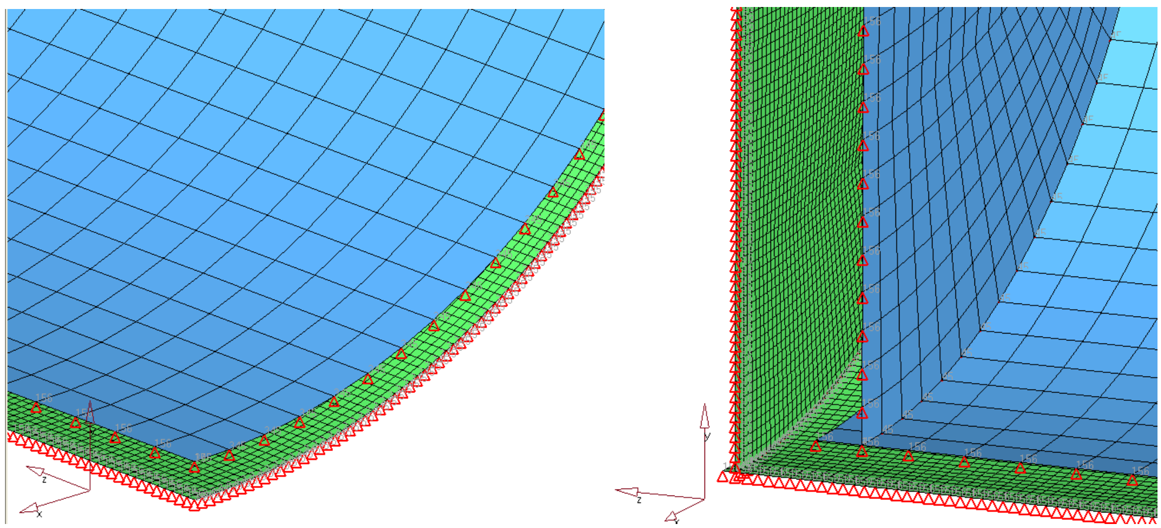
Also for the waste package, displacement in the transverse direction (z-axis) is prevented by constraints along the rear plane of symmetry. These nodes are also constrained to prevent rotation around the x- and y- axes to achieve the same constraints of a three dimensional model.

The ends of the 152.4×152.4×9.53 Tubes are constrained along the xy-plane of symmetry to prevent displacement in the transverse direction. The pallet is also constrained along the side plane of symmetry to prevent displacement in the horizontal direction. All nodes on the bottom surface of the pallet are constrained from vertical displacement.

A friction coefficient of 0.4 is applied to the Outer Shell/Pallet contact surface and the Outer Shell/Inner Vessel contact surface to properly model friction surface interaction.

The displacement of the waste package in the vertical direction is constrained by two SPRING1 elements of a relatively small stiffness on both the Outer Shell and Inner Vessel to prevent an initial rigid body mode.

Contact Pairs: The outer surface of the Outer Shell is defined as an SPOS surface, which displaces the contact surface 10 mm (half the thickness) from the S4 reference surface in the same direction as the surface normals. The inner surface of the Outer Shell is defined as an SNEG surface, which displaces the contact surface 10 mm from the S4 reference surface in the opposite direction of the surface normals. The outer surface of the Inner Vessel is defined as an SPOS surface, which displaces the contact surface 25 mm from the S4 reference surface. In order to properly analyze the contact pairs, both pairs are calculated using the small-sliding, node-to-surface formulation.



(a) (b)

Figure 50: Constraints on the waste package {(a) inside back, (b) inside front}

Loads: The two load sets applied to the model represent the pressure of two bulkheads of the drip shield contacting the Outer Shell of the waste package. The load set representing the pressure of the bulkheads on the waste package is equal to the 300 kPa pressure that is carried by the drip shield crown.

The surface area of the waste package that will be affected by one bulkhead is approximated to be 1000 mm × 150 mm. Because the model corresponds to ¼ of the waste package, the contact area is 500 mm × 150 mm.

In the contact area, the length and width of one element in the SPOS surface is 10.41 mm and 10.92 mm, respectively. 672 elements (48 × 14) are loaded to reproduce the contact area of 500 mm × 150 mm, which results in an actual area of 499.68 mm × 152.91 mm.

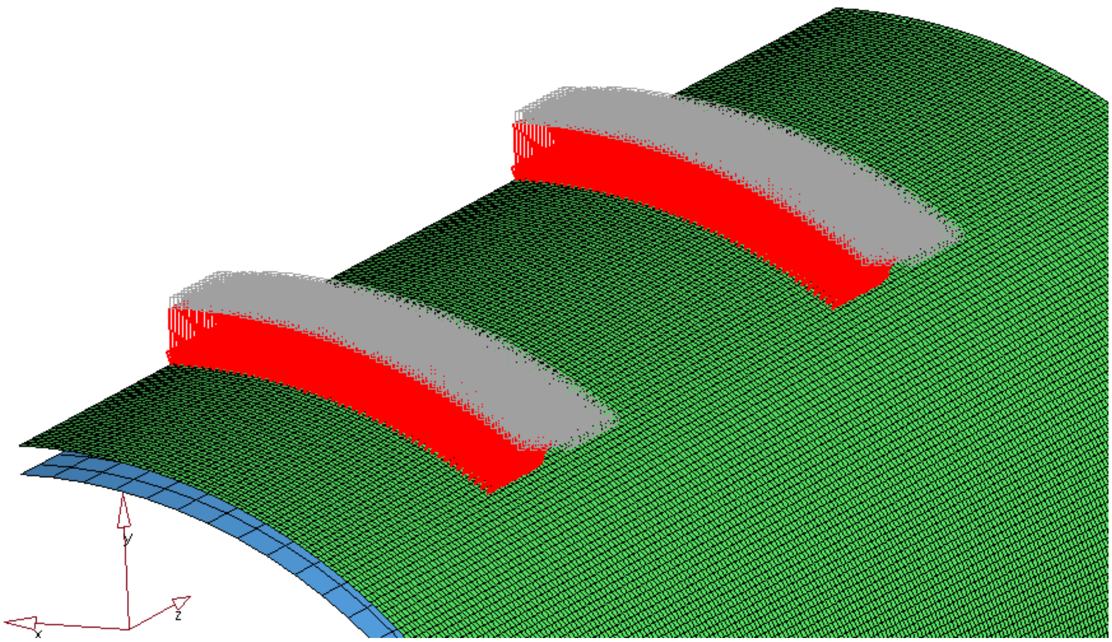


Figure 51: Outer Shell loading

Surface Area calculations:

$$S_{DS} = L_{DS} \cdot C_{DS} = 5805 \cdot 1374.12 = 7976778.2 \ mm^2$$

$$S_{WP} = L_{WP} \cdot C_{WP} = 152.91 \cdot 499.68 = 76406.07 \ mm^2$$

Pressure calculations:

$$P_{DS} \cdot S_{DS} = 4 \cdot P_{WP} \cdot S_{WP}$$

$$P_{DS} = 300 \ kPa = 3.0 \times 10^{-1} \ N/mm^2$$

$$P_{WP} = \frac{P_{DS} \cdot S_{DS}}{4 \cdot S_{WP}} = \frac{3.0 \times 10^{-1} \cdot 7976778.2}{4 \cdot 76406.07} = 7.8300 \ N/mm^2$$

The resulting pressure is 7.8300 N/mm^2.

Date: July 23, 2007
Entry by: Laura C. Domyancic

Results for the Pallet and S4-element Waste Package

The computational analysis of the "Waste Package and Pallet – Refined Outer Shell" model was terminated at 31.1% of 3000 kPa. The maximum load applied before structural instabilities occurred was approximately equal to 933 kPa of pressure on the Drip Shield. The first incidence of yielding in the model occurred on the Outer Shell above the area which contacts the Pallet.

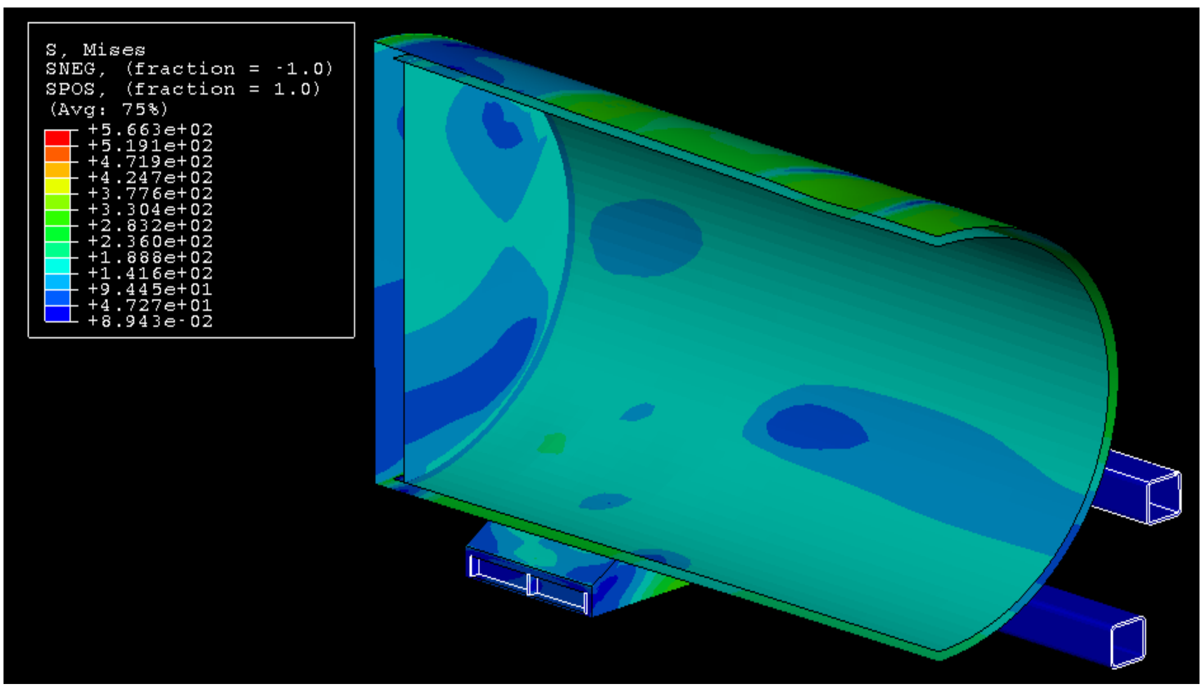


Figure 52: Von Mises Stress distribution at 31.1% of loading
(maximum stress of 566.3 MPa)

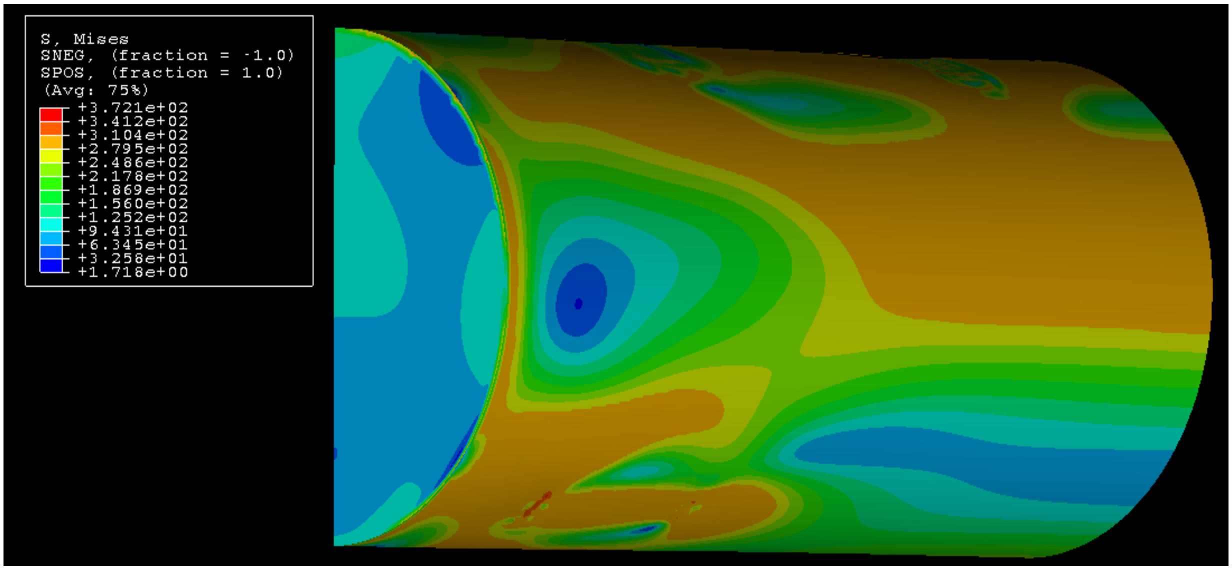


Figure 53: Von Mises Stress distribution on the inside of the Outer Shell at 31.1% of loading (maximum stress of 372.1 MPa)

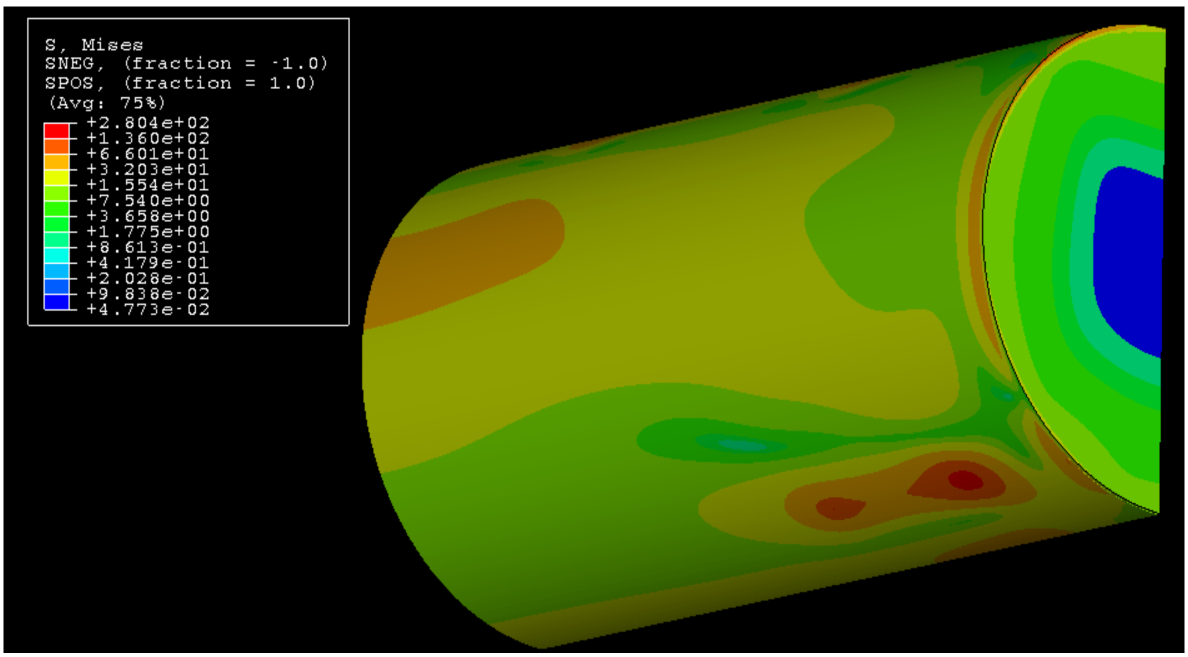
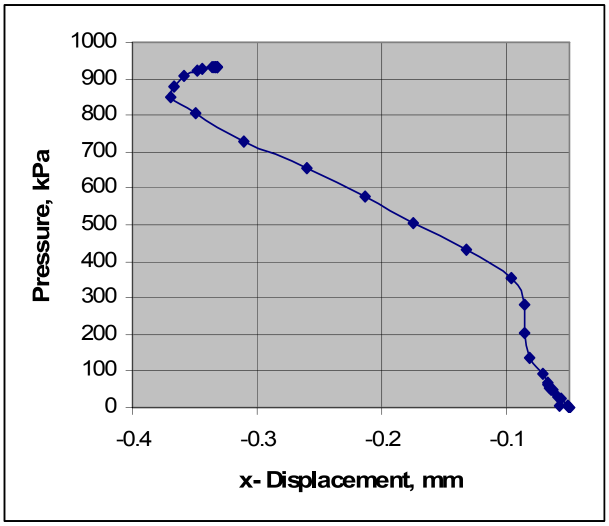
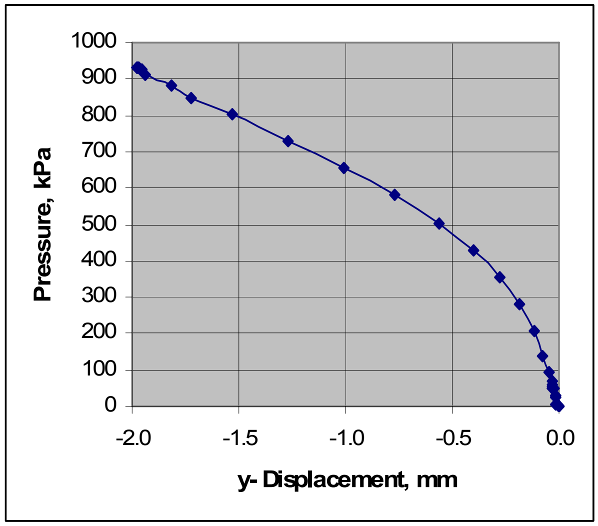


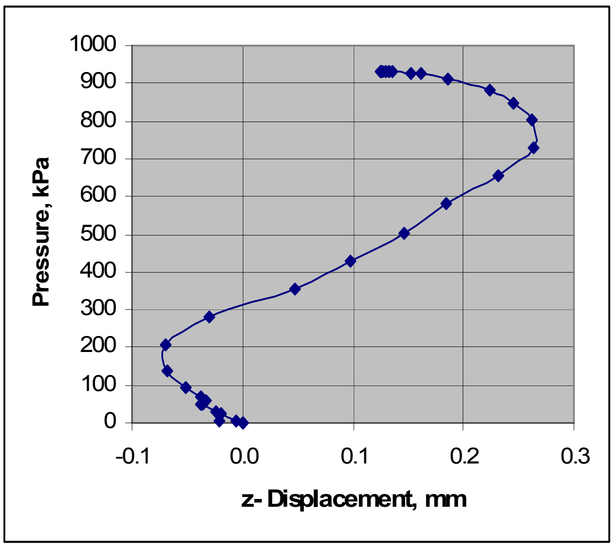
Figure 54: Outer Shell shown at first indication of yielding in the model (yielding @ 27 kPa)



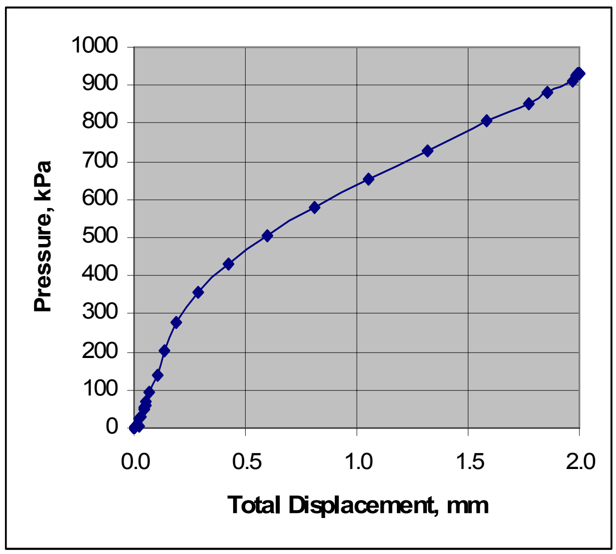
(a)



(b)



(c)



(d)

Figure 55: Displacement of node with maximum stress due to applied pressure

Date: July 24, 2007
Entry by: Laura C. Domyancic

Description and Geometry of the Pallet and S4-element Outer Shell FEM

The finite element model is composed of the following:

(i) Waste Package Alloy 22 Outer Shell

(ii) Emplacement Pallet with Alloy 22 Plates and Tubes

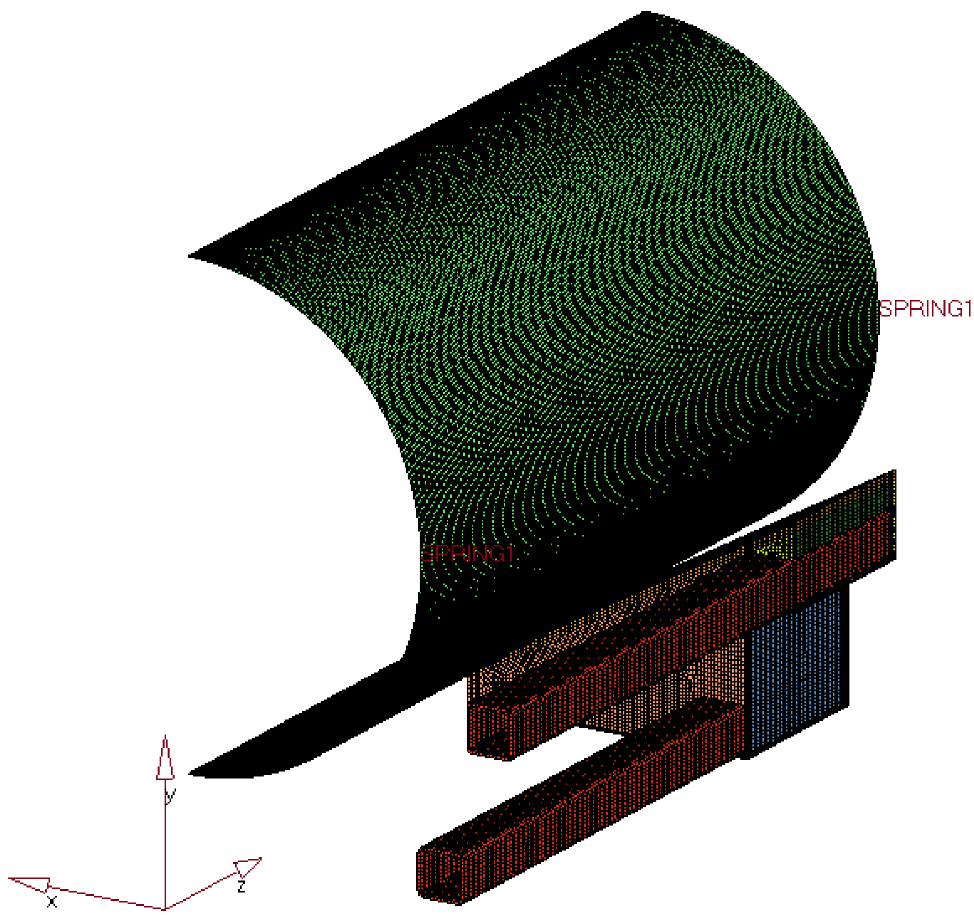


Figure 56

The FE model of the Outer Shell is created using 4-node conventional shell elements (S4). The average size of the elements is 10.1×10.9 mm with a thickness of 20 mm. The average size of an element in the Outer Shell lid is 9.6 × 9.0 mm, with a thickness of 25 mm.

The FE model of the pallet is meshed using solid 8-node linear hexahedral elements (C3D8) for Plates#1-7. A few 6-node solid elements (C3D6) are used to complete the mesh for Plate #2, Plate #3, and Plate #7. The average size of an element in the contact region of Plate #6 (where the Outer Shell of the waste package will rest) is 10.1×9.77×14.1 mm. The size of an element in the other plates ranges from 5×10×15 mm to 11×12×15 mm. All other components are meshed using 8-node continuum shell elements. The average size of an element in Plate #8 is 9.52×6.35×14.1 mm. The size of an element in the 254×76.2×6.35 Tubes ranges from 6.5×14.8×15 mm to 6.8×14.8×6.4 mm. The average size of an element in the 152.4×152.4×9.53 Tubes is 9.52×11.5×14.1 mm. The nodes on the shared surfaces within the pallet are equivalenced to create a continuous mesh.

Kinematic Constraints: The nodes of the waste package along the yz-plane of symmetry are constrained to prevent displacement in the horizontal direction (x-axis). Additionally, these nodes are also constrained against rotation around the z- and y- axes to achieve the same constraints of a three dimensional model.

Also for the waste package, displacement in the transverse direction (z-axis) is prevented by constraints along the rear plane of symmetry. These nodes are also constrained to prevent rotation around the x- and y- axes to achieve the same constraints of a three dimensional model.

The ends of the 152.4×152.4×9.53 Tubes are constrained along the xy-plane of symmetry to prevent displacement in the transverse direction. The pallet is also constrained along the side plane of symmetry to prevent displacement in the horizontal direction. All nodes on the bottom surface of the pallet are constrained from vertical displacement.

A friction coefficient of 0.4 is applied to the Outer Shell/Pallet contact surface to properly model friction surface interaction.

The displacement of the waste package in the vertical direction is constrained by two SPRING1 elements of a relatively small stiffness on the Outer Shell to prevent an initial rigid body mode.

Contact Pair: The outer surface of the Outer Shell is defined as an SPOS surface, which displaces the contact surface 10 mm (half the thickness) from the S4 reference surface in the same direction as the surface normals. The contact pair is modeled using the small sliding, node-to-surface formulation in order to perform a proper analysis.

Loads: The two load sets applied to the model represent the pressure of two bulkheads of the drip shield contacting the Outer Shell of the waste package. The load set representing the pressure of the bulkheads on the waste package is equal to the 300 kPa pressure that is carried by the drip shield crown.

The surface area of the waste package that will be affected by one bulkhead is approximated to be 1000 mm × 150 mm. Because the model corresponds to ¼ of the waste package, the contact area is 500 mm × 150 mm.

In the contact area, the length and width of one element in the SPOS surface is 10.41 mm and 10.92 mm, respectively. 672 elements (48 × 14) are loaded to reproduce the contact area of 500 mm × 150 mm, which results in an actual area of 499.68 mm × 152.91 mm.

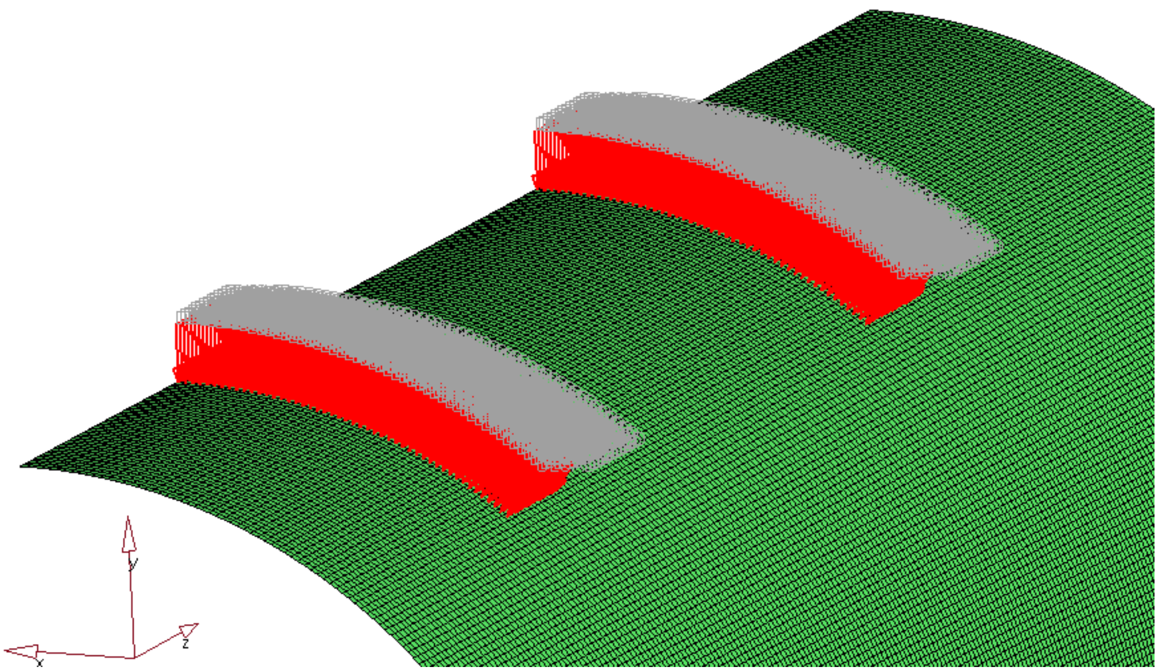


Figure 57: Outer Shell loading

Surface Area calculations:

$$S_{DS} = L_{DS} \cdot C_{DS} = 5805 \cdot 1374.12 = 7976778.2 \ mm^2$$

$$S_{WP} = L_{WP} \cdot C_{WP} = 152.91 \cdot 499.68 = 76406.07 \ mm^2$$

Pressure calculations:

$$P_{DS} \cdot S_{DS} = 4 \cdot P_{WP} \cdot S_{WP}$$

$$P_{DS} = 300\ kPa = 3.0 \times 10^{-1}\ N/mm^2$$

$$P_{WP} = \frac{P_{DS} \cdot S_{DS}}{4 \cdot S_{WP}} = \frac{3.0 \times 10^{-1} \cdot 7976778.2}{4 \cdot 76406.07} = 7.8300\ N/mm^2$$

The resulting pressure is 7.8300 N/mm^2.

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Entry by: Laura C. Domyancic

<u>Results of the Pallet and S4-element Outer Shell FEM</u>

The computational analysis of the "Waste Package and Pallet – Refined Outer Shell" model was terminated at 6.9% of 3000 kPa. The maximum load applied before structural instabilities occurred was approximately equal to 207 kPa of pressure on the Drip Shield. The first incidence of yielding in the model occurred on the Outer Shell above the area which contacts the Pallet.

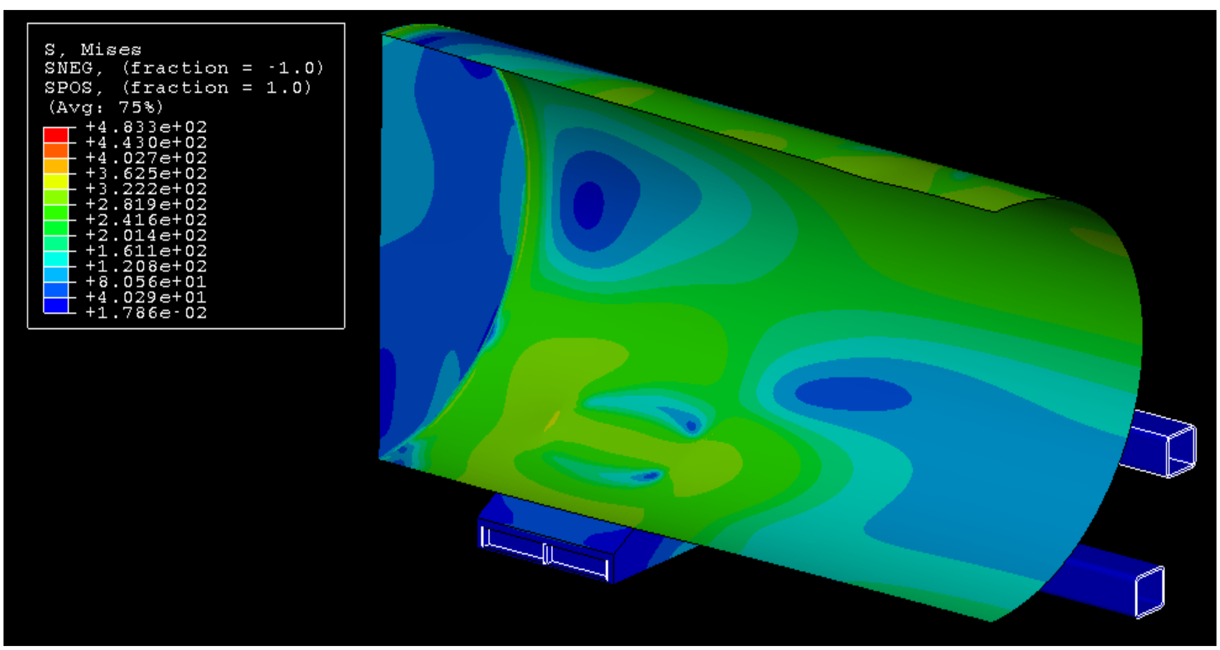


Figure 58: Von Mises Stress distribution at 6.9% of loading
(maximum stress of 483.3 MPa)

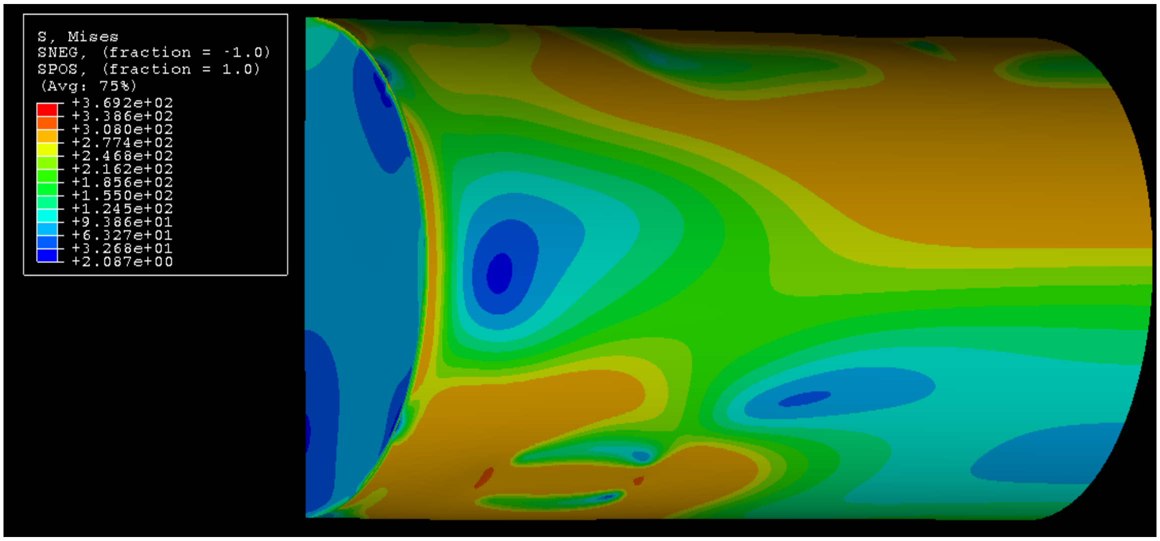


Figure 59: Von Mises Stress distribution on the inside of the Outer Shell at 6.9% of loading (maximum stress of 369.2 MPa)

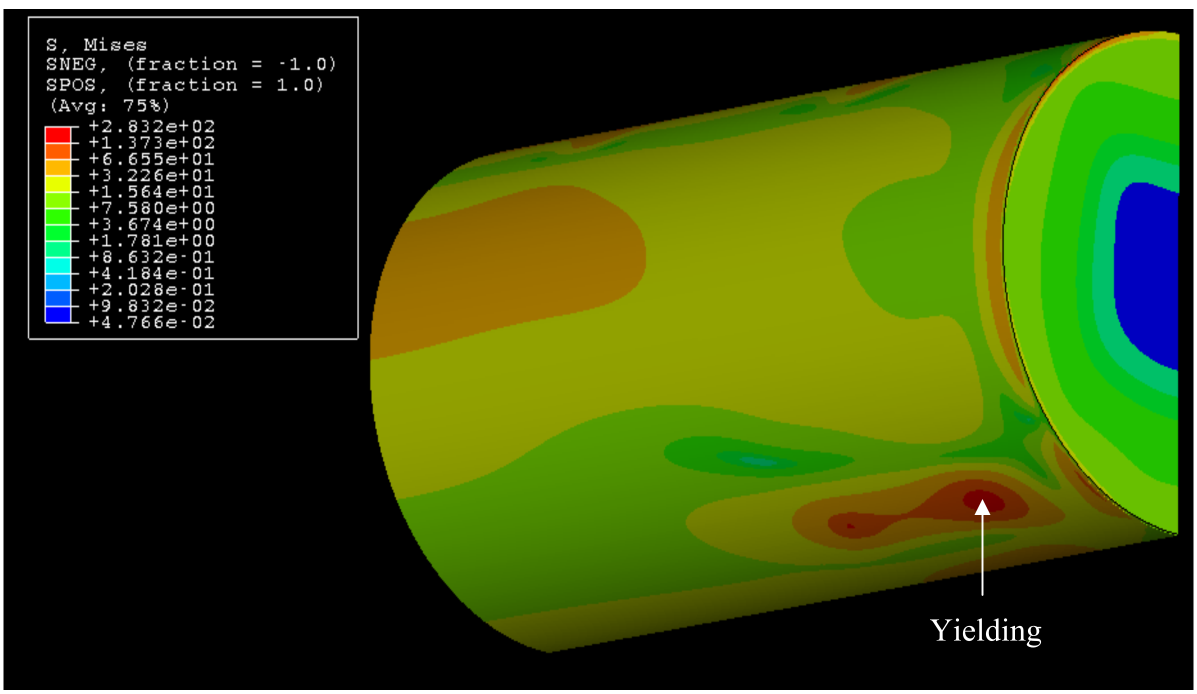
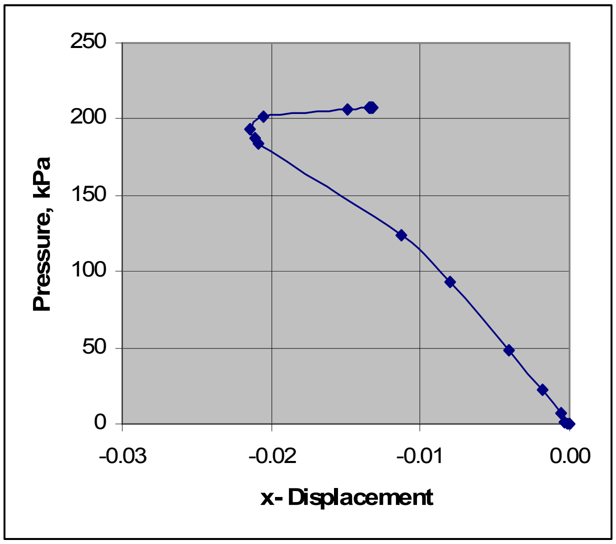
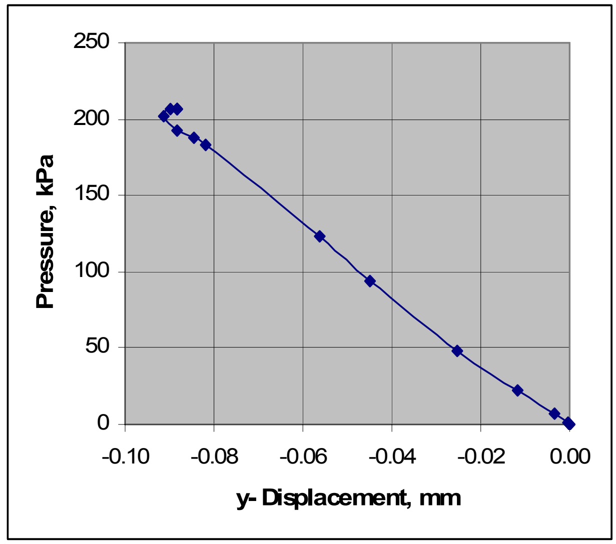


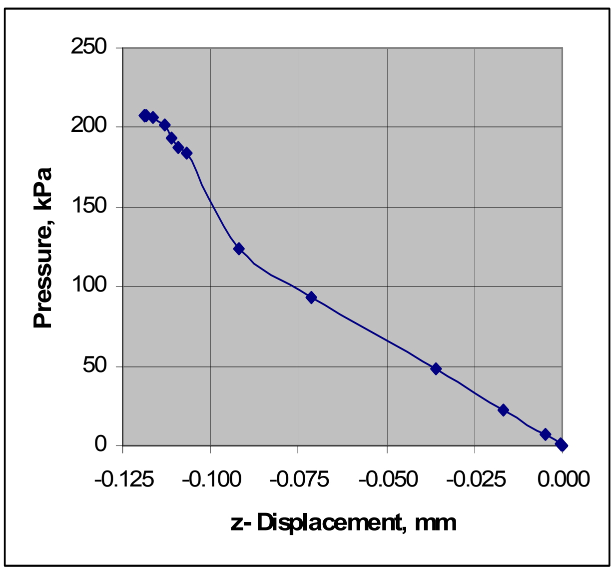
Figure 60: Outer Shell shown at first indication of yielding in the model (yielding @ 26 kPa)



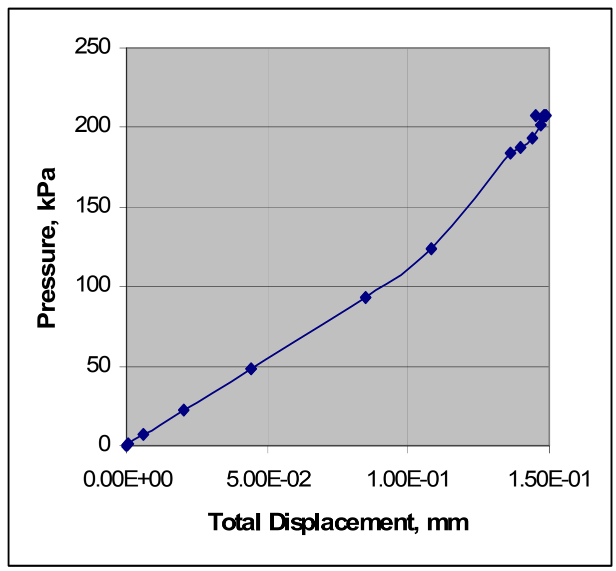
(a)



(b)



(c)



(d)

Figure 61: Displacement of node with maximum stress due to applied pressure

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Entry by: Laura C. Domyancic

<u>Inner Vessel Analyses</u>

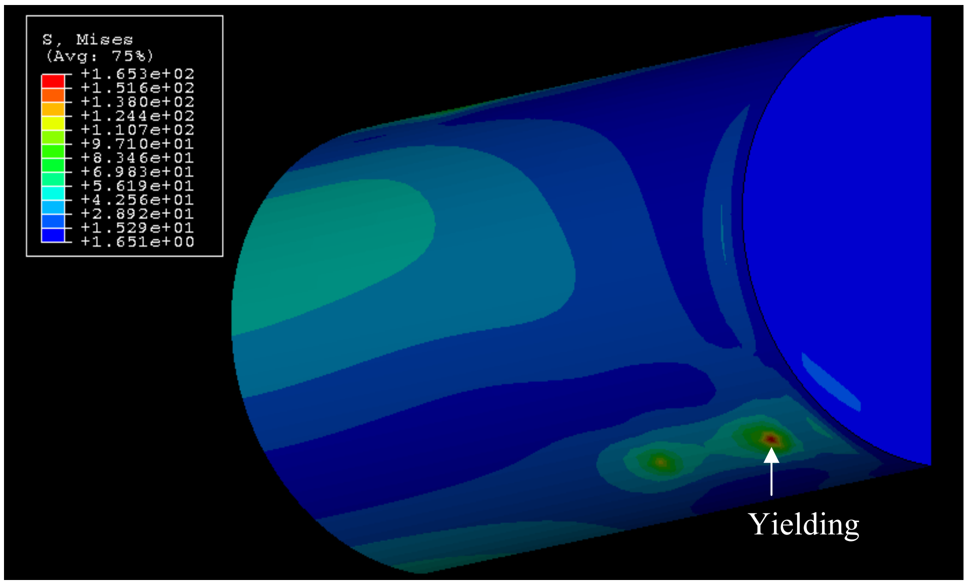

Figure 62: Outside surface of the Inner Vessel shown at first indication of yielding (Waste Package and Pallet FEM, yielding at 215 kPa)

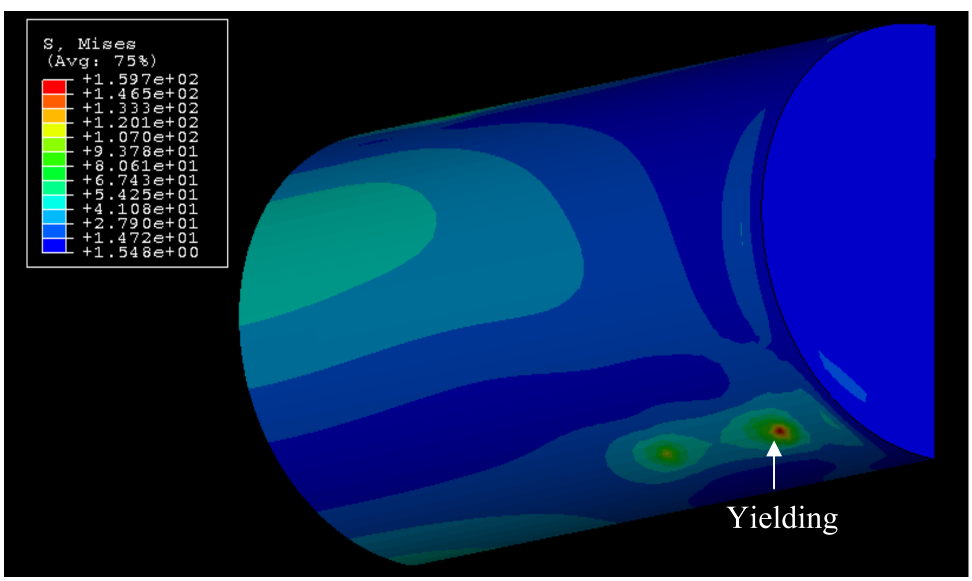

Figure 63: Outside surface of the Inner Vessel shown at first indication of yielding (Waste Package and Pallet – Refined Pallet FEM, yielding at 213 kPa)

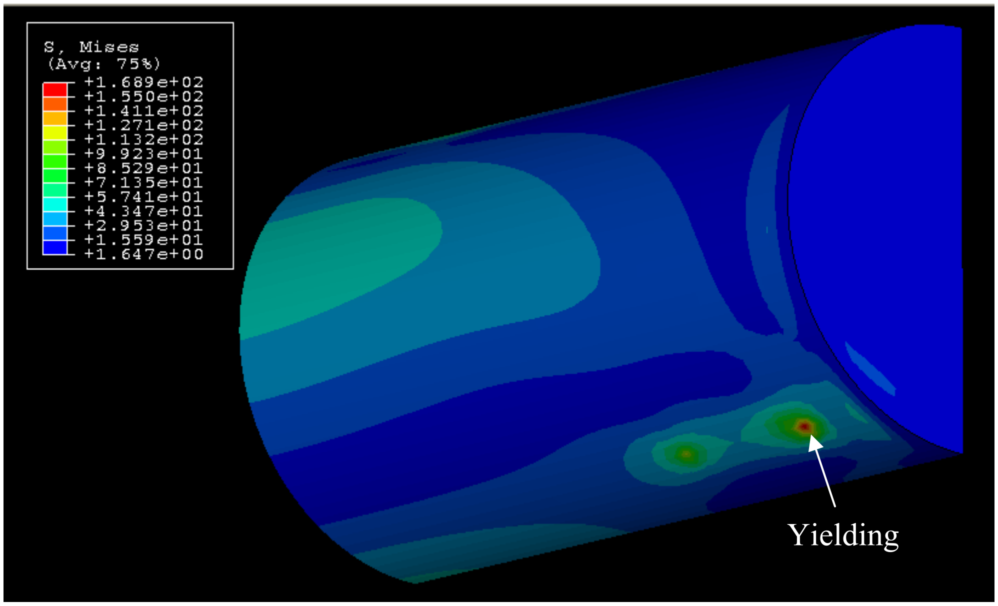

Figure 64: Outside surface of the Inner Vessel shown at first indication of yielding (Waste Package and Pallet – Refined Outer Shell FEM, yielding at 218 kPa)

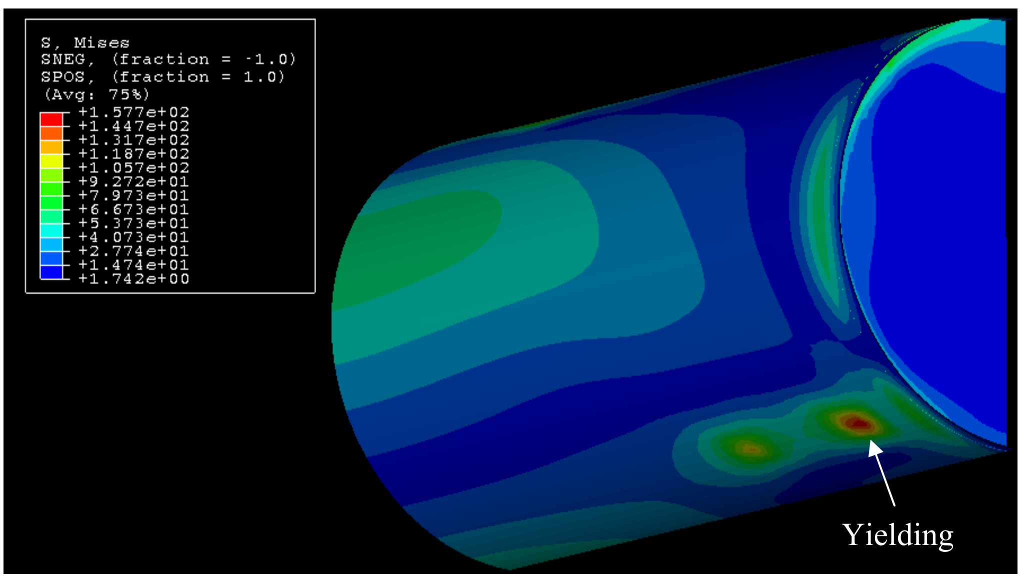

Figure 65: Outside surface of the Inner Vessel shown at first indication of yielding (Pallet and S4-element Waste Package, yielding at 265 kPa)