Author(s)	Department	Location	Date
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Title
US-LHC Collaboration
Luminosity Detector
Case pressure calculations

1. Introduction

The LHC beam luminosity monitor is a gas ionization chamber that observes minimum ionization particles near the shower maximum in the zero degree neutral particle absorbers (TAN) of IP's 1 and 5. The ionization chamber resides in a stainless steel case with a mixture of 94% argon and 6% nitrogen gas continuously flowing through at a pressure of up to 1 MPa absolute. This engineering note documents stress analysis of the case. CERN refers to the luminosity monitors as Beam Rate of Neutrals (BRAN), and LBNL uses the term "LUMI" for these LHC luminosity monitors during its development stage.

2. Previous pressure vessel design engineering note

An Engineering Note was previously authored by Bill Ghiorso (titled "LUMI Pressure Vessel Design Safety Note" and dated 1/23/2006), and a copy is appended to this Engineering Note. This note builds on the previous engineering note and documents stress effects due to a thickness reduction on two walls of the case. The thickness reduction provides greater clearance between the BRAN units and slot walls in the TAN units.

3. Finite element analysis

A new ANSYS finite element model was used for the analysis. The model used nominal dimensions as shown in LBNL drawings 27D909E, 27D910C, 27D911C, and 27D912E. The width of the case is nominally 93.98 mm, with a wall thickness of 3.175 mm for each of the two walls. For a maximum operating pressure load of 132 psig (0.91 MPa), the ANSYS model indicates a peak von Mises stress of 16520 psi (113.9 MPa), 5% higher than the value of 15740 psi (108.5 MPa) reported in the engineering note by B. Ghiorso. This difference is due to a higher mesh density in the ANSYS model (the mesh density in the ANSYS model was increased until stress values converged with a convergence criteria of 2%). Figures 1 and 2 show stress contour plots for the nominal case of no thickness reduction. Note that the peak stress at the side of the walls is 16520 psi (113.9 MPa) and is higher than at the bottom (16050 psi [110.7 MPa]).

The overall width of the model is reduced by up to 1.2 mm (wall thickness reduction of 0.6 mm for each wall), and the ultimate safety factors were evaluated. Two different values of ultimate strength were used in the evaluation: an ultimate strength of 73200 psi (504.7 MPa) representing annealed stainless steel 304, and a value of 81372 psi (561.0 MPa) representing the measured value of the material used to fabricate the cases (as supplied by the material vendor). The annealed strength value is used for stresses near the weld joint Figure 3 shows safety factor reductions as a function of thickness reduction in the part. Since the peak stress values are highly dependent on mesh density, the mesh was refined until stress values converged. Figure 4 shows an example of how the peak von Mises stress values converge as the mesh density is increased (for the analysis case of 0.5 mm width reduction). The values shown in figure 4 are peak values along the side of the case and at the corner of the base (peak values are at the same locations as for the zero-width reduction case shown in figures 1 and 2)

4. Conclusion

To maintain an ultimate safety factor of 4.0, width reduction in the case must be no greater than 0.7 mm (0.35 mm for each wall). A width reduction of 0.7 mm results in an ultimate safety factor of 4.0 at the case ends, where the welding operation may reduce its ultimate strength from 81372 psi (561.0 MPa) to 73200 psi (504.7 MPa). At the sides of the case, even though the stress levels are higher, they are considerably distant from the weld location and the ultimate safety factor is 4.25 (using 81372 psi [561.0 MPa] as the material ultimate strength).

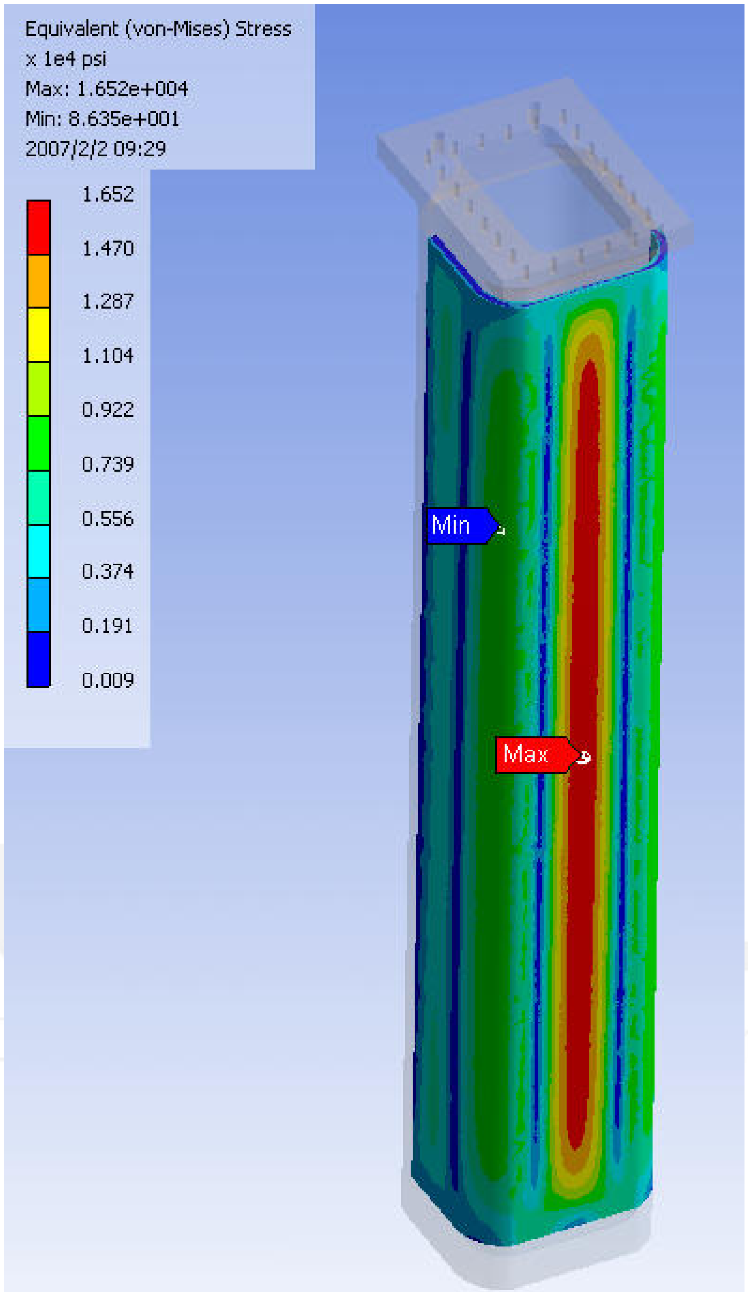


Figure 1. Contour plot of von Mises stress in the body of the case.

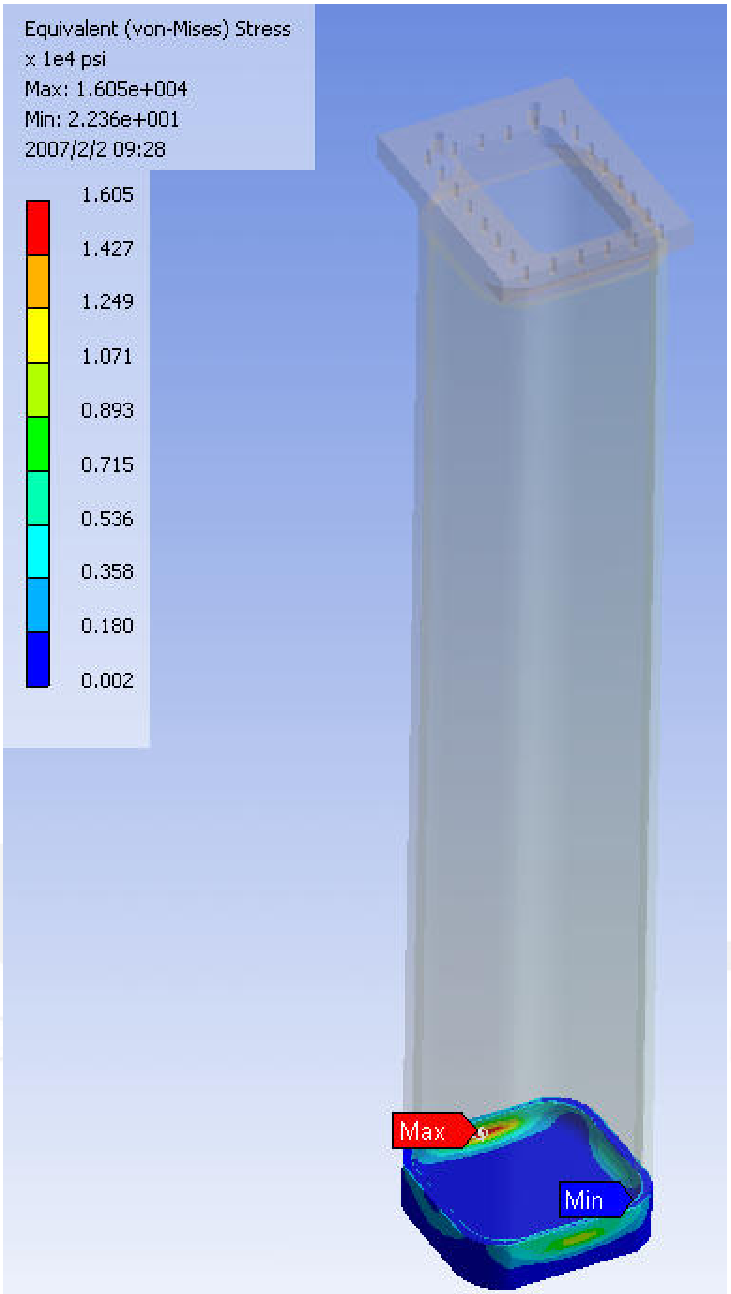


Figure 2. Contour plot of von Mises stress in the base of the case.

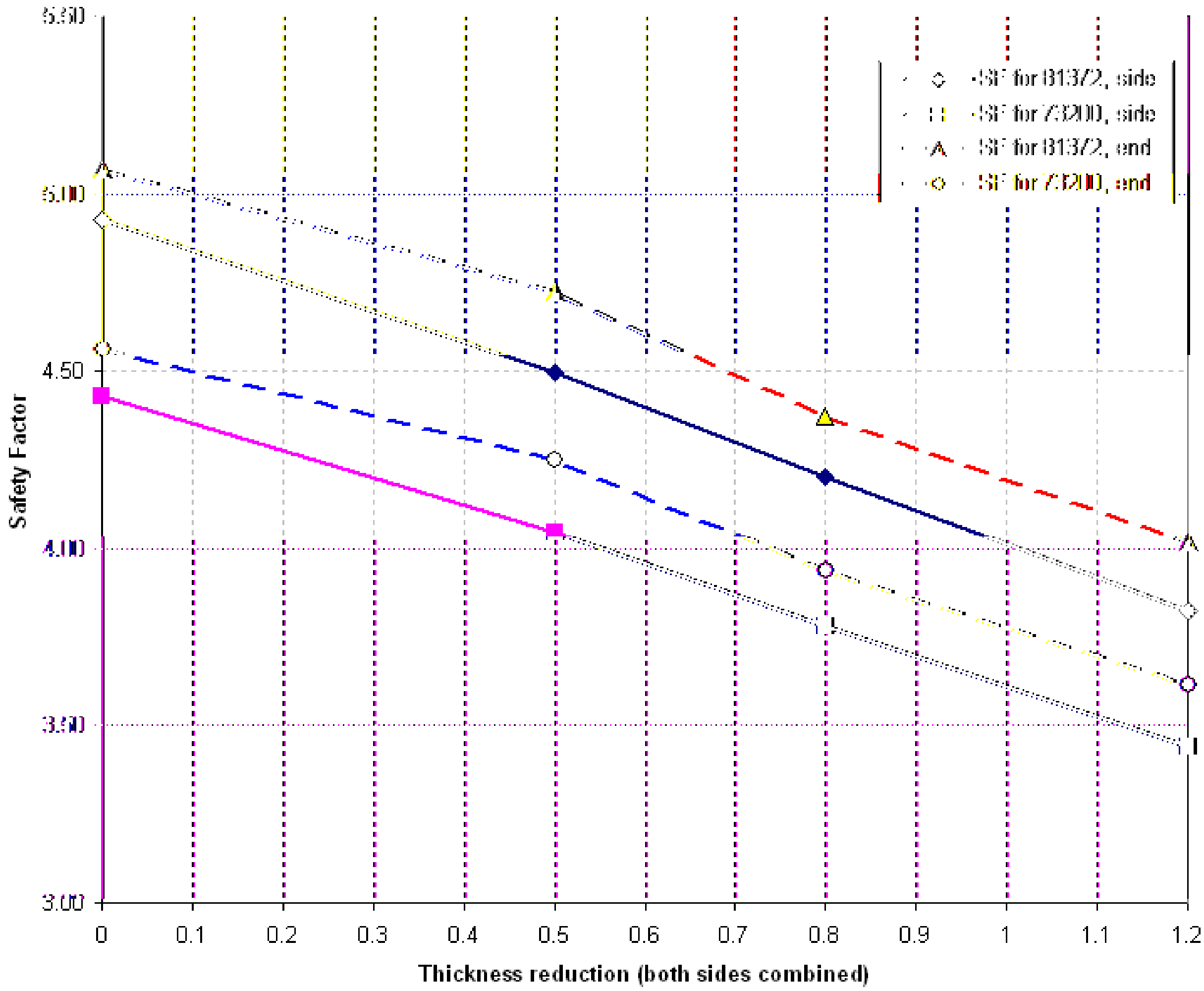


Figure3. Reduction in safety factor (ultimate) as a function of width reduction in the case.

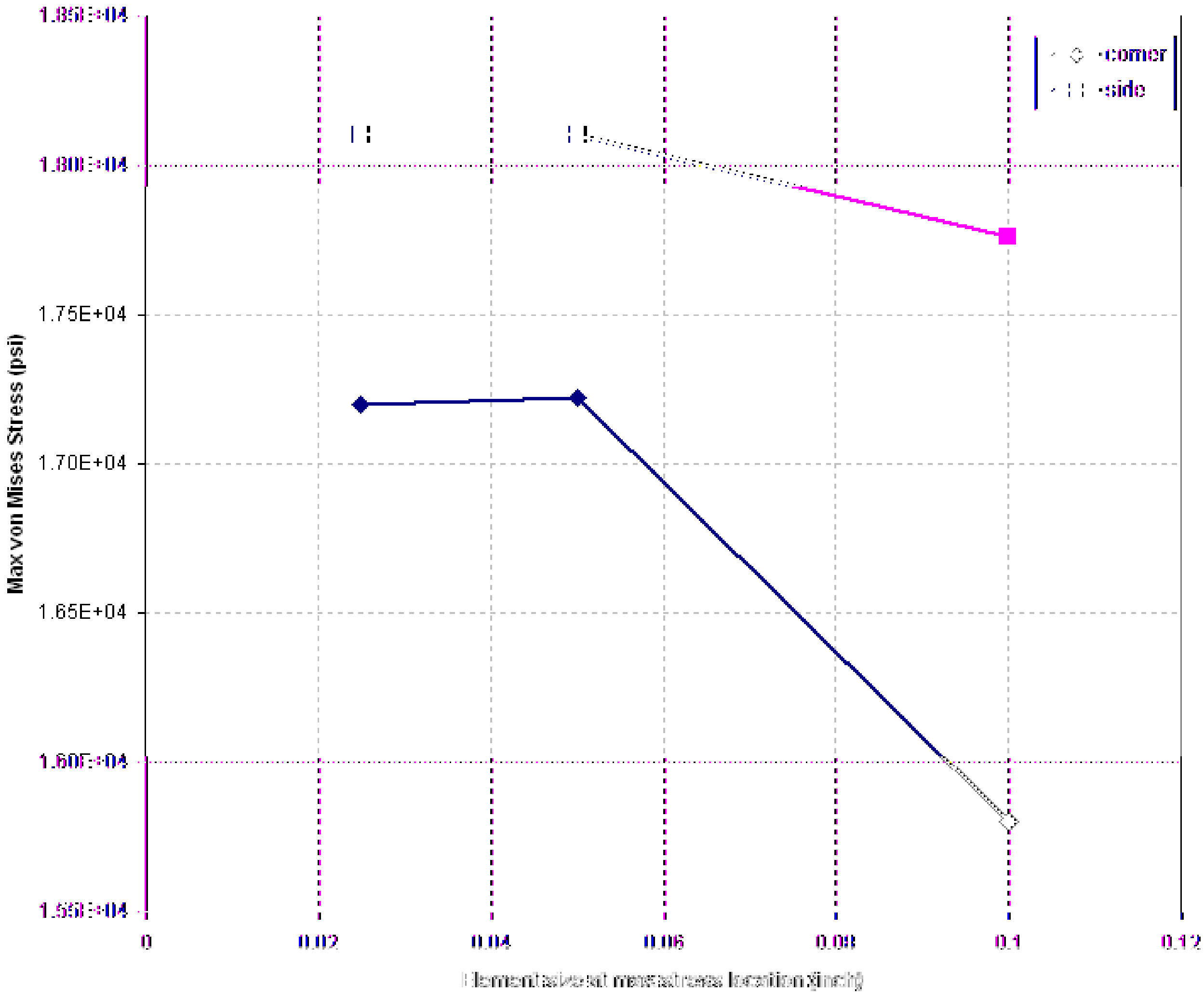


Figure 4. Convergence of peak stress values with increases in mesh density.
For analysis case of 0.5mm width reduction.

APPENDIX A: PREVIOUS ENGINEERING NOTE ON PRESSURE SAFETY CALCULATIONS ON LUMI CASE, by BILL GHIORSO

AUTHOR	DEPARTMENT	LOCATION	DATE
B. Ghiorso	Mech. Engr.	BERKELEY	01/23/06

PROGRAM-PROJECT-JOB

US - LHC COLLABORATION

LUMI PRESSURE VESSEL DESIGN SAFETY NOTE

Design Features:

- Vessel is designed to be used at up to 132 psi using a mix of 96% argon, 4% nitrogen (inert gas) with a total stored energy of less than 5000 joules without contents, less that 2600 joules with its contents, thereby placing it in the low-hazard pressure systems category (see section 7.5.1 of PUB-3000 Rev'd 1/99)
- Constructed from EDM'ed solid Type 304 stainless steel billet with resulting wall thicknesses of 0.188 inch [4.7mm] and 0.125 inch [3mm]
- Tank maximum stress is 15740 psi: safety factor on ultimate strength is 4.8 (Type 304 stainless steel tensile strength = 75400 psi).
- Top and bottom vessel components are machined with corner transition regions so welds are removed from high stress areas [see drawing] and have less than 6300 psi stress.
- Vessel cover plate fastener stress is: 10.6 in^2 x 14.7 psi x 9 atm. / 24 fasteners / .01948 in^2 (area of fastener) = 3000 psi
- Tank exterior is plasma coated with alumina (coating thickness aproximately 0.004 inches) prior to hydrostatic testing.
- All units are hydrostatically tested at 1.5 x design pressure and are stamped: "TESTED: MAX PRESSURE 132 PSI" <PRESSURE TEST NO.> on side of tank flange. Test data is appended to and filed as a revision of this engineering note.
- Pressure delivery system is limited to 132 psi by an overpressure safety valve in gas delivery system.
- Vessel will normally be used in an un-manned area.

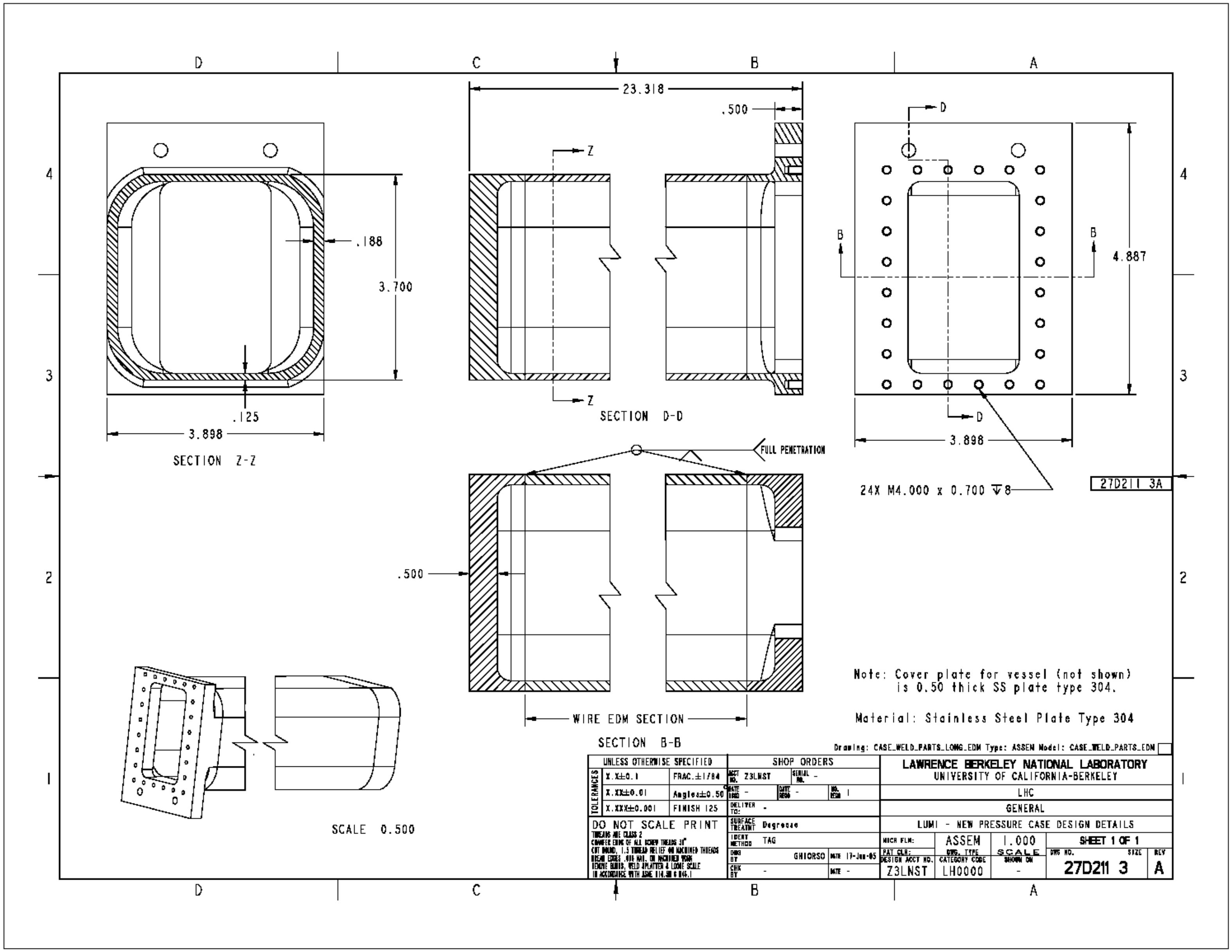
Refer to the following pages:

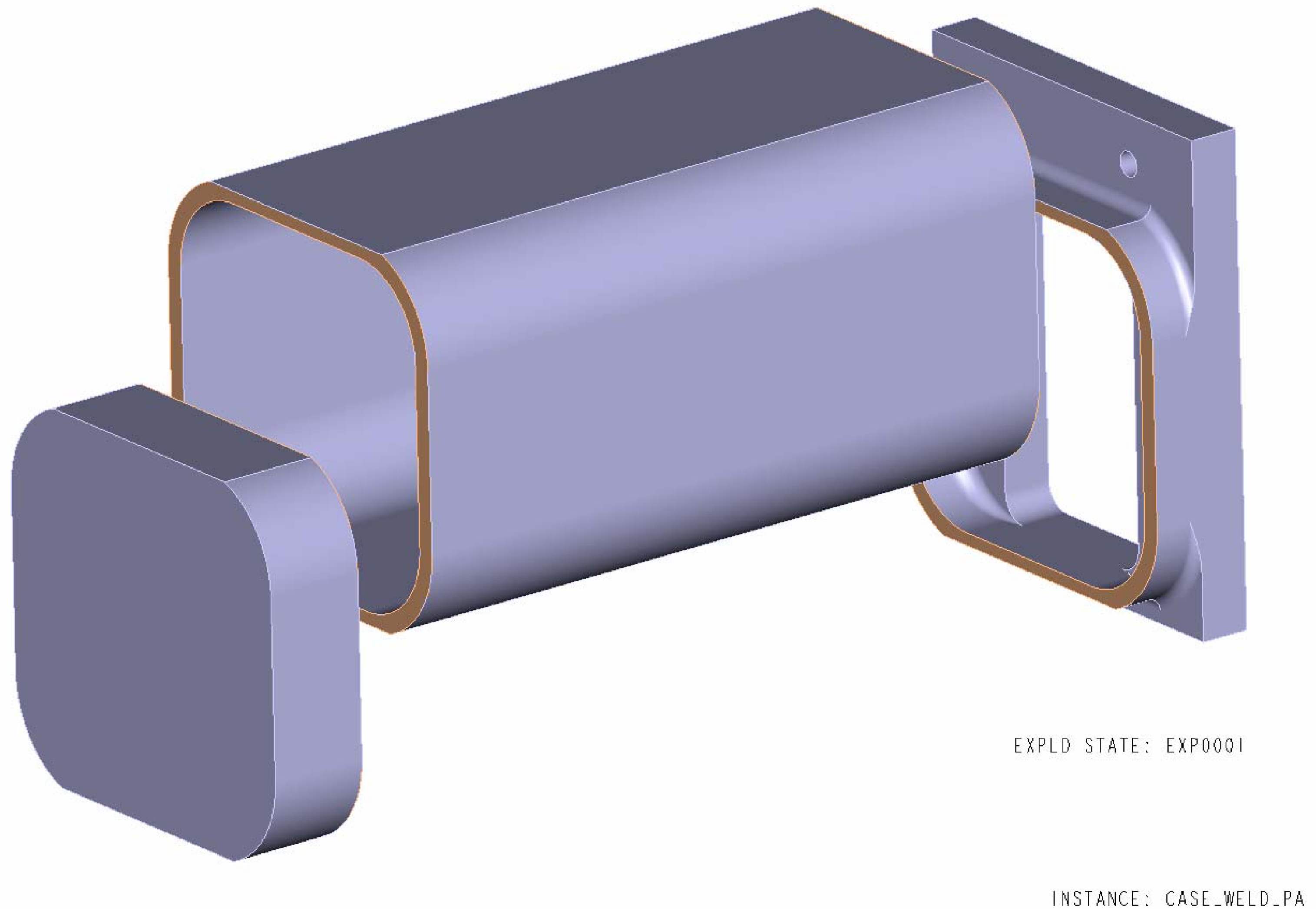
2) Mechanical drawing

3) Pre-weld assembly exploded view showing weld seam locations

4) Stored energy calculation

5-7) Stress plots showing stress at weld seam locations as well as maximum stress in model


23.318
.500
.188
3.700
.125
3.898
SECTION Z-Z
SECTION D-D
4.887
3.898
24X M4.000 x 0.700 ↧8
27D211 3A
FULL PENETRATION
.500
WIRE EDM SECTION
SECTION B-B
SCALE 0.500
Note: Cover plate for vessel (not shown)
is 0.50 thick SS plate type 304.
Material: Stainless Steel Plate Type 304
Drawing: CASE_WELD_PARTS_LONG_EDM Type: ASSEM Model: CASE_WELD_PARTS_EDM
UNLESS OTHERWISE SPECIFIED
TOLERANCES
X.X±0.1
FRAC.±1/64
X.XX±0.01
Angles±0.50
X.XXX±0.001
FINISH 125
DO NOT SCALE PRINT
SHOP ORDERS
ACCT NO. Z3LNST
SERIAL NO. -
DELIVER TO: -
SURFACE TREATMT Degrease
IDENT METHOD TAG
DWG BY GHIORSO
DATE 17-Jun-05
CHK BY -
LAWRENCE BERKELEY NATIONAL LABORATORY
UNIVERSITY OF CALIFORNIA-BERKELEY
LHC
GENERAL
LUMI - NEW PRESSURE CASE DESIGN DETAILS
ASSEM
DWG. TYPE
1.000
SCALE
SHEET 1 OF 1
DESIGN ACCT NO. Z3LNST
CATEGORY CODE LH0000
DWG NO. 27D211 3
REV A



Pressure vessel components

Appendix E (LBNL PUB 3000)
STORED ENERGY OF A PRESSURED GAS VESSEL

Although the pressure section of this publication is not intended to be a primer on pressure calculation, the following formula is used sufficiently frequently, but is obscure enough, that it has been included.

When a gas is compressed, energy is stored in it. If the energy is released in an unfavorable way, it will cause damage. Stored energies in excess of 100 kJ are considered high hazard. Sometimes it is helpful to think of stored energy in terms of grams of TNT. One gram of TNT contains 4.62 kJ of energy.

Volume of vessel: $Vh := 283 \cdot in^3$ $\quad Vh = 0.004638\ m^3$

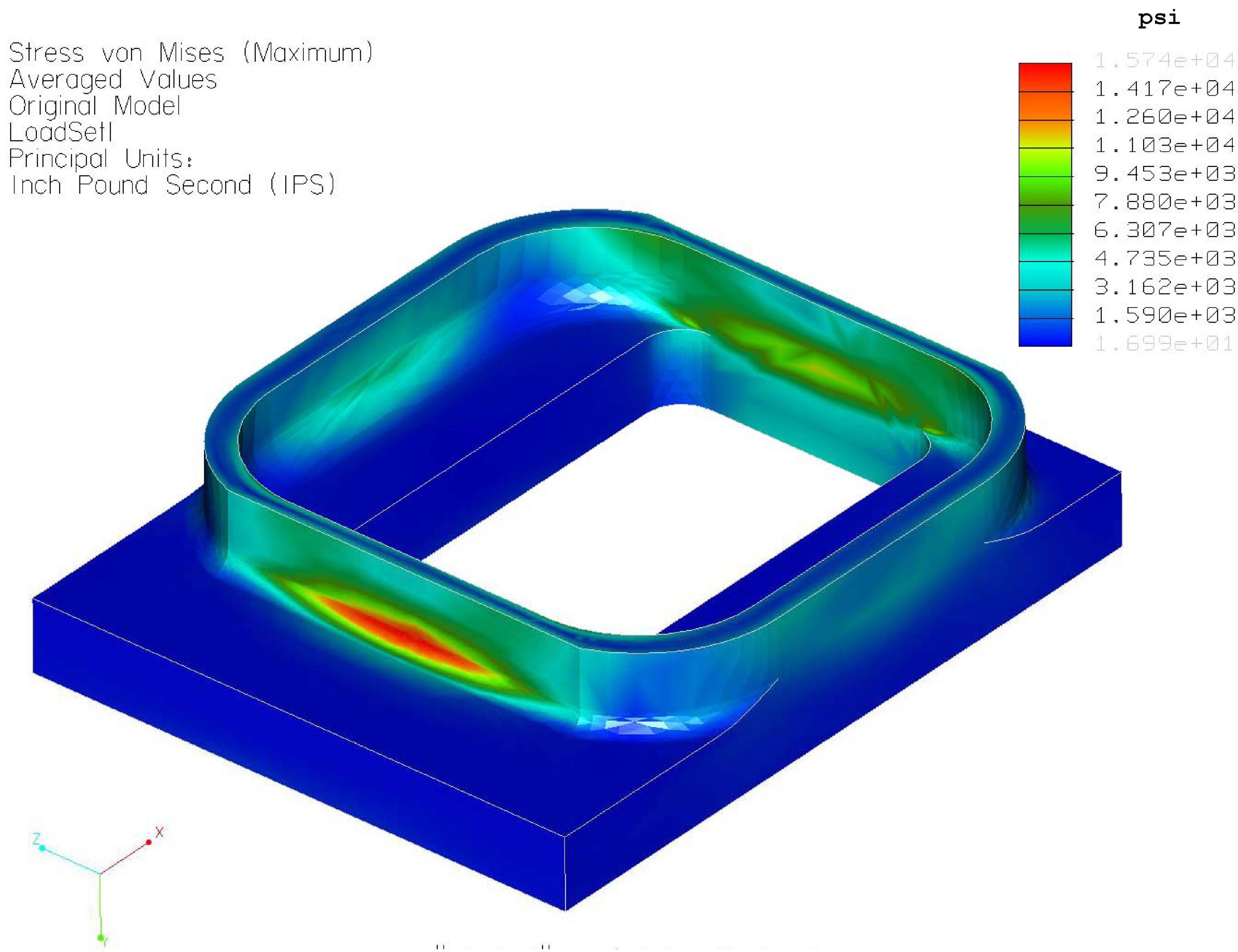
Absolute pressure of vessel: $Ph := 147 \cdot psi$ $\quad Ph = 1.01353 \times 10^6\ Pa$

Pressure to which vessel would drop if burst: $P1 := 14.7 \cdot psi$ $\quad P1 = 1.01353 \times 10^5\ Pa$

γ = The adiabatic exponent or ratio of specific heats, Cp/Cv. The value is 1.666 for monatomic gases such as argon and helium; 1.4 for diatomic gases such as nitrogen, oxygen, hydrogen, and air; and variable for polyatomic gases such as methane, water, and carbon dioxide but generally very nearly 1.3.

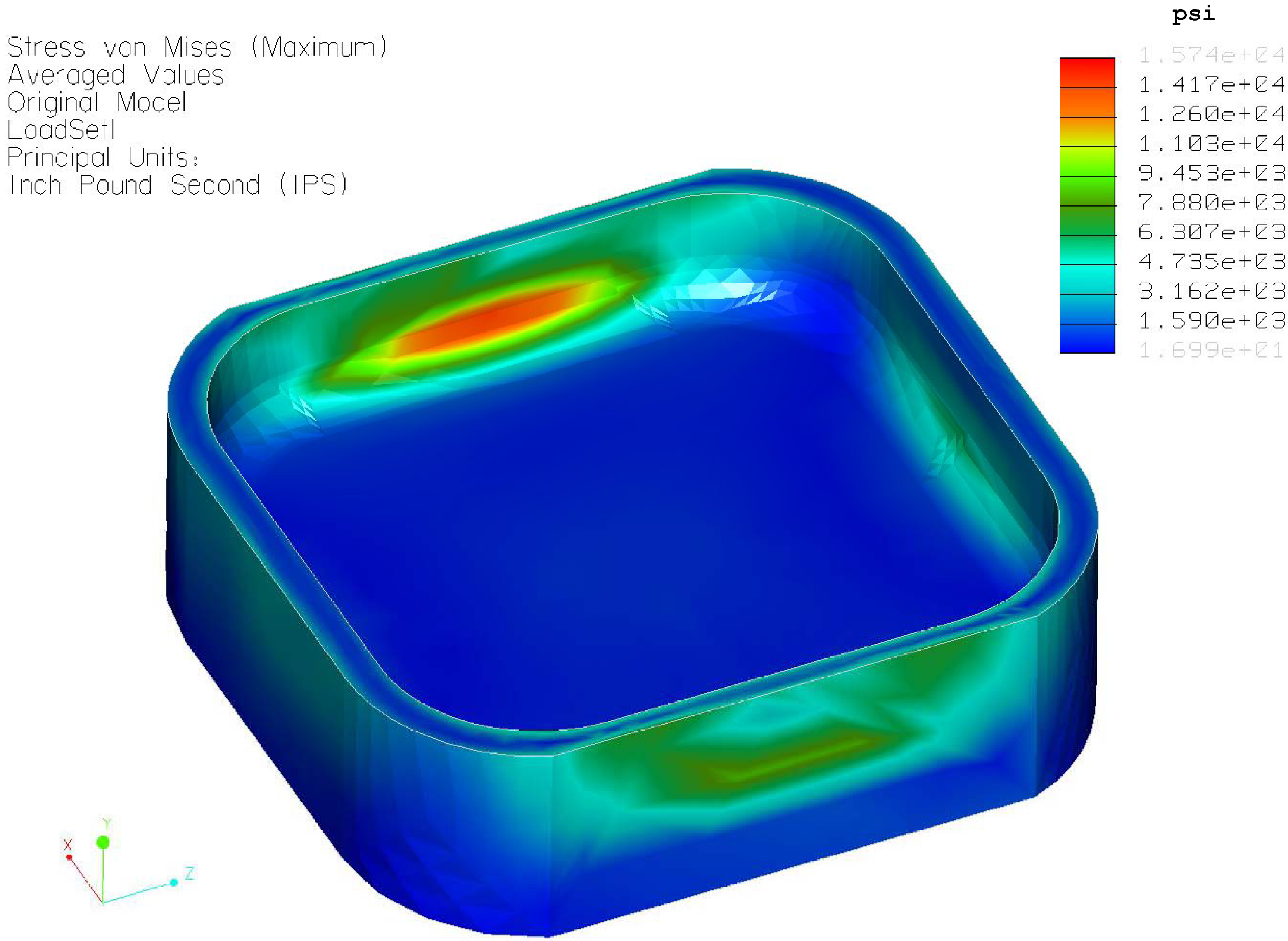
$\gamma := 1.66667$ (argon)

$$\frac{Ph \cdot Vh}{\gamma - 1} \cdot \left[1 - \left(\frac{P1}{Ph}\right)^{\frac{\gamma-1}{\gamma}}\right] = 4243.59\ N \cdot m$$ (joules)

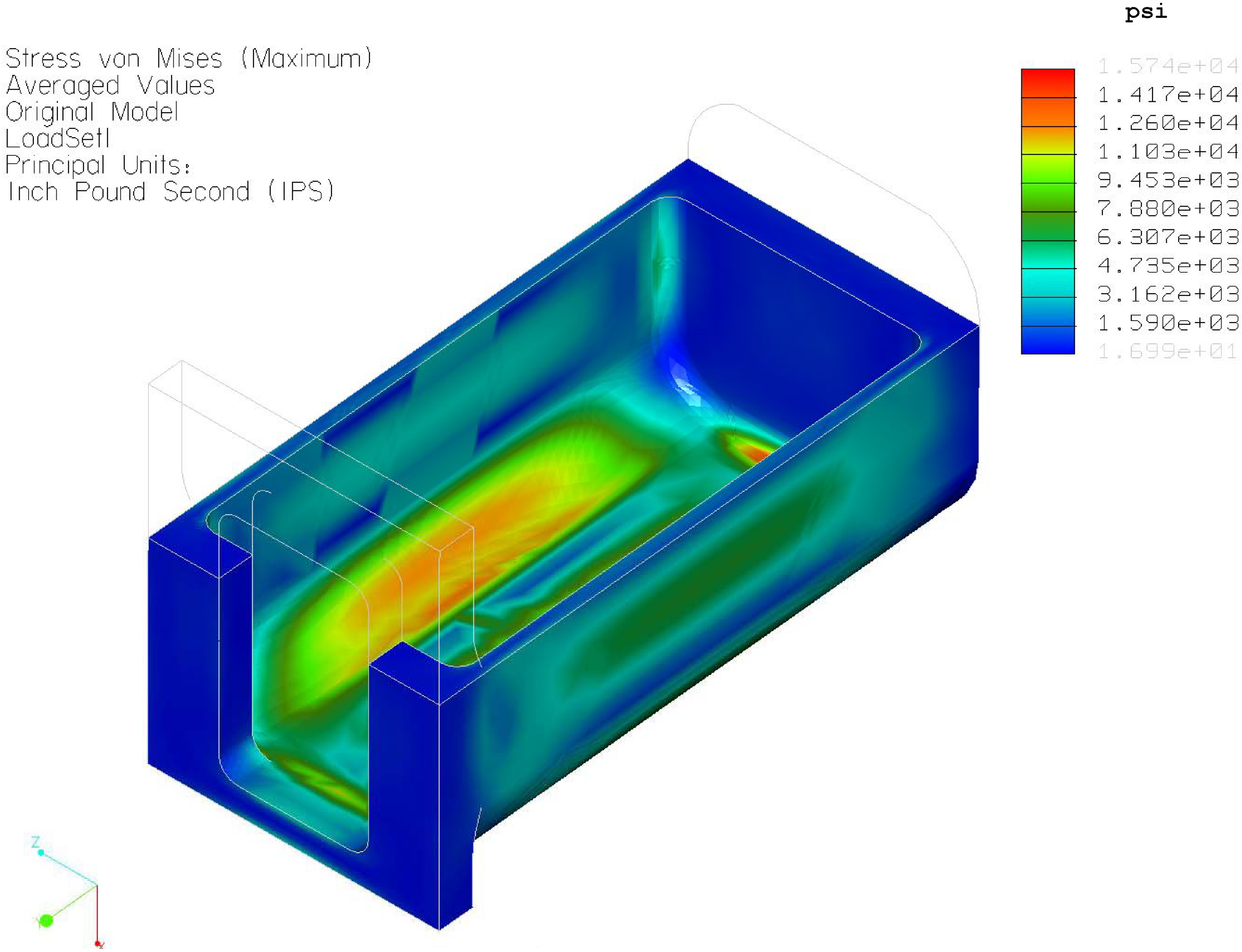


Pressure vessel top at 132 psi showing weld seam stress < 6300 psi

LUMI



Pressure vessel bottom at 132 psi showing weld seam stress < 6300 psi



Pressure vessel interior view at 132 psi showing maximum stress < 16000 psi