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Title: IHS-60 Stored Energy Analysis

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IHS-60 Stored Energy Analysis

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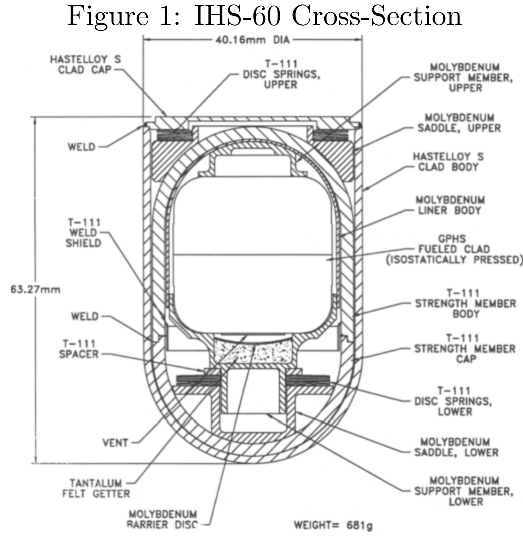
1 Purpose

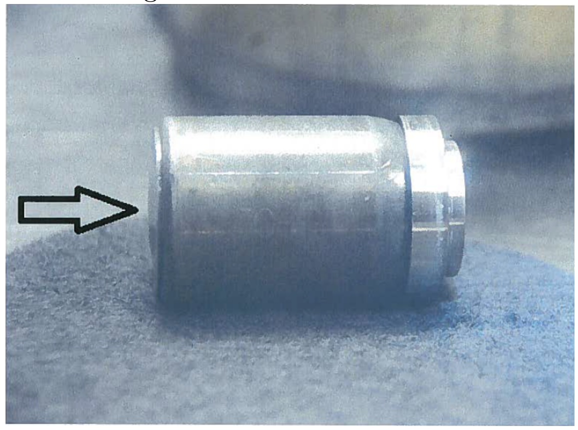
The IHS-60 consists of a General Purpose Heat Source (GPHS) Fueled Clad (FC) that has been hot isostatically pressed to eliminate the gap between the iridium clad and the fuel pellet, thus preventing differential motion between the pellet and the clad in shock and vibration environments. The vented FC is enclosed within a Molybdenum barrier comprising the liner body and the lower support member. The slip-fit Molybdenum liner members serve as a mechanical barrier to plutonia contact of the tantalum alloy (T-111) strength member in the event the iridium clad should fail. The slip-fit liner is not a barrier to gaseous transport, so a tantalum getter is installed near the vent region of the FC to preclude potential oxygen transport to the T-111 interior surface. The T-111 strength member encloses the Molybdenum liner assembly and provides for both helium gas retention and isotope fuel containment under impact and external pressure environments. It is surrounded by an outer clad of Hastelloy-S which protects the strength member from external oxidation and corrosive sources during nominal operation and in the event of off-nominal operation or accidents. Both the strength member and outer clad parts are closed with seal welds. The strength member and outer clad are the primary containment members of the 60-Watt IHS. The iridium clad contains the fuel pellet during nominal operation and mild accident environments, but it is not considered to be a primary containment member. A cross-section of the IHS-60 is shown in Figure 1.

Figure 1: IHS-60 Cross-Section



Four IHS-60 heat source were shipped from Idaho National Laboratory to LANL. for treatment and recovery of Pu-238. During the preparation for shipping deformation of the clad cap was observed on one unit (SN 16-025). The deformation was measured and found to approximately .050-inches at the center of the cap. The deformed unit is shown in Figure 2

Figure 2: IHS-60 Deformed



2 Methodology

Stored energy analysis was performed on the IHS-60 to evaluate the hazard associated with a catastrophic rupture of the Hastelloy lid. This analysis allows operations personnel to implement hazard controls in to the fuel recover plans to protect workers and the facility. It will also be used to determine if the cutting and fuel recover of a pressurized vessel is within the DSA safety envelope. The work or energy done by the expansion of a gas is given by:

$$\mathbf{W} = -\int \mathbf{PdV} \tag{1}$$

Where "P" is the absolute pressure, "V" is the volume and "W" is the work of expansion. For a polytropic expansion of an ideal gas. Ref [1]

$$\mathbf{PV^n} = \mathbf{constant} \tag{2}$$

The solution to the integral of Equation 1 for the stored energy of the vessel containing an ideal gas is:

$$\mathbf{U} = \frac{\mathbf{P_1 V_1}}{\mathbf{k-1}} \left[1 - \left(\frac{P_0}{P_1} \right)^{\frac{(k-1)}{k}} \right] \tag{3}$$

The amount of energy released determines the strength of the blast wave. A blast wave is the pressure disturbance at a given distance from the energy release site. The peak pressure at the explosion site itself depends on the energy released per unit volume. However, a more complete understanding of both the damage potential and various explosion protection alternatives also requires knowledge of the approximate time duration of the energy release. Therefore, it is helpful to characterize the various types of explosions in terms of their peak pressures, energies, and energy release durations. Various models of ideal blast waves (produced from instantaneous, point sources releases of energy) have shown that the shock pressure P_{s0} can be correlated with the energy-scaled distance of the following form:

$$\mathbf{Z_G} = \frac{\mathbf{R_G}}{\mathbf{W^1/3}} \tag{4}$$

Where:
Z_G = scaled distance
R_G = distance from the explosion
W = TNT equivalent weight from the same blast wave energy

The energy of explosion of TNT is given by Lees Ref [1] as 4850 J/g. With this relationship, the internal energy calculated from Eq. [3] can be expressed in terms of an equivalent quantity of TNT so that the scaled distance Z_G may be determined. Positive Shock pressure parameters as a function of scaled distance are given in Ref [2]. From These data, positive shock pressure consequences to personnel and equipment for a point of interest are determined using Ref. [1] and Ref. [3].

3 Acceptance Criteria

The results of the stored energy analysis of the IHS-60 capsule will be used to inform the hazard analysis and control development for storage and disassembly of these legacy heat source items.

4 Open Items

There are no open items.

5 Assumptions/Inputs

1. The fill gas inside the IHS-60 behaves as a monatomic ideal gas.
2. All helium gas generated due to the radioactive decay of the Pu-238 remains inside the IHS-60 capsule.

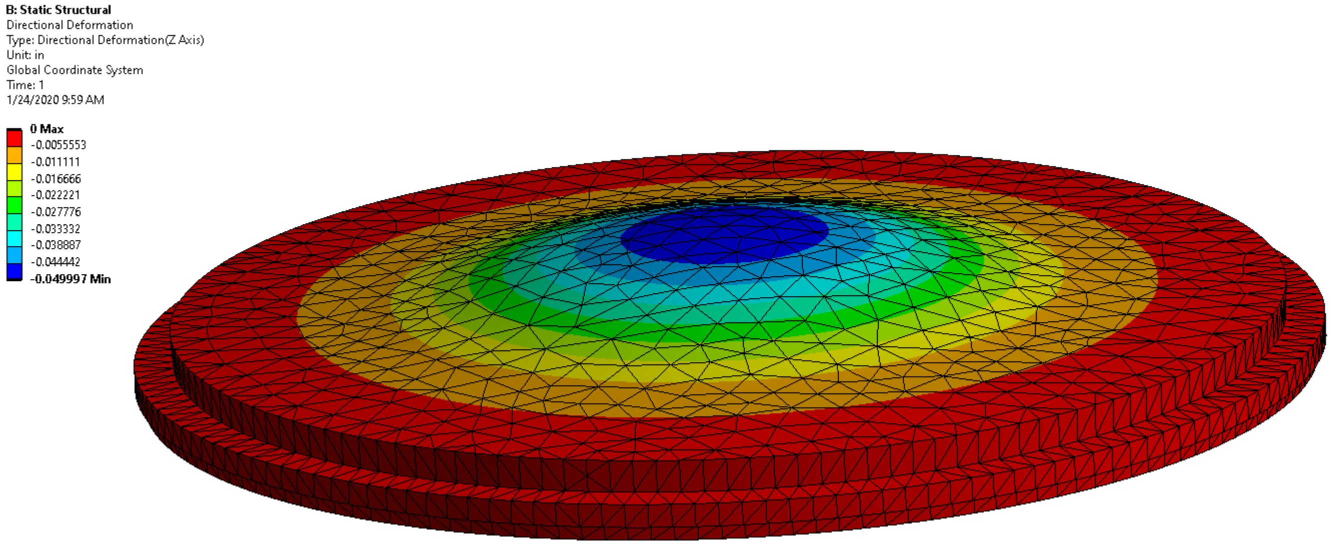
6 Computer Hardware and Software

1. ANSYS Workbench/Mechanical Version 2020 R1
2. MathCad 15.0 M50
3. Dell Precision 7550 Mobile Workstation, Windows 10 Enterprise Version 1909

7 Results and Conclusions

A finite element analysis was performed to determine the internal pressure necessary to cause the observed .050-inches of deflection in the Hastelloy clad lid. The finite element model showed that an internal pressure of 3689 psi would be required to cause the observed deformation. Displacement results from the finite element analysis are shown in Figure 3. Using the expressions developed above and the calculated internal pressure from the finite element model, the blast overpressure can be determined at any desired distance. Because the IHS-60 must be handled by hand, the overpressure at a distance of 1-ft was calculated. The overpressure resulting from sudden rupture of 3689 psi at a distance of 1 ft is 5 psi. According to the Fire Protection Handbook Table 2.8.1 a blast overpressure of 5 psi corresponds with personnel being knocked down, ear drum rupture and glass breakage. These results should be used to inform the controls needed to protect workers and the facility in the event of a catastrophic rupture of the heat source.

Figure 3: IHS-60 Displacement FEA



References

[1] Lees, Frank P., *Lees Loss Prevention in the Process Industry Hazard identification Assessment and Control*, Reed Educational and Professional Publishing Ltd. 1996, 2nd Edition

[2] Department of Defense, *Unified Facilities Criteria Structures to Resist the Effects of Accidental Explosions*, UFC-3-340-02-2008, Chapter 2 Figure 2-15

[3] Cote, Grant, Hall, Solomon, Powell, *Fire Protection Handbook*, National Fire Protection Association, 2008, Twentieth Edition, Volume I, Section II, Chapter 8

8 Appendix

IHS-60 Bulged Capusle Stored Energy Analysis

Lee's *Loss Prevention in the Process Industry* provides the expression for the stored energy of a vessel containing an ideal gas.

$$U = \frac{P_v \cdot V}{k-1} \cdot \left[1 - \left(\frac{P_a}{P_v}\right)^{\frac{(k-1)}{k}}\right]$$

$P_v := 3700\text{psi}$

$V := .987\text{in}^3 = 16.174 \cdot \text{cm}^3$ Internal volume of the pressure vessel

$P_a := 11.3\text{psi}$ Ambient Pressure at Los Alamos

$k := 1.667$ Ratio of Specific Heats for Helium Ref: Fundamentals of Engineering Thermodynamics - Moran & Shapiro

$$U := \overrightarrow{\left[\frac{P_v \cdot V}{k-1} \cdot \left[1 - \left(\frac{P_a}{P_v}\right)^{\frac{(k-1)}{k}}\right]\right]}$$

$U = 558 \cdot J$ Stored energy results for corresponding pressures given in Pv

The internal energy is now expressed in terms of equivalent quantity of TNT. This allows an analysis of blast damage and personnel injury caused by overpressure using scaled distance correlations.

$$E_{tnt} := 4850\,\frac{J}{g}$$

Energy of explosion of TNT Ref: Lee's Loss Prevention Section 17.4.1

$$W := \frac{U}{E_{tnt}} = 0.115 \cdot g$$

Equivalent grams of TNT for the pressure cases

Various correlations and theoretical models of ideal blast waves have shown that the shock pressure can be correlated with an energy-scaled distance of the following form:

$$Z_G = \frac{R_G}{W^{\frac{1}{3}}}$$

Where:
Z_G = The scaled distance
R_G = The distance from the explosion site
W = The TNT equivalent weight for the same blast wave energy

Now the over-pressure or blast pressure can be calculated for a range of distances as follows:

Overpressure at a Distance of 1 ft

$$R_G := 1\,ft$$

$$Z_G := \overrightarrow{\left[\frac{R_G}{\left(\frac{W}{453.59\,\frac{g}{lb}}\right)^{\frac{1}{3}}}\right]} = 15.801 \cdot \frac{ft}{lb^{\frac{1}{3}}}$$

Scaled distance for the internal pressure at a distance of 1 ft from the explosion

The positive shock pressure parameters for a hemispherical TNT explosion on the surface are given by the Department of Defense Unified Facilities Criteria UFC-3-340-02 Table 2-15.

$P_{so} = 5psi$

High Explosives Overpressure Consequences are given in The Fire Protection Handbook (FPH) Section 2, Chapter 8 Table 2.8.1 and in Lee's Loss Prevention Section 17.38 and 17.39

For overpressures of 5.1-14.5 psi the FPH Table 2.8.1 indicates that the consequences to personnel would be ear drum rupture while Lee's indicates that 5 psi overpressure corresponds with the threshold of eardrum rupture. Personnel are knocked down and normal glass breaks.