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Peak Pressures from Hydrogen Deflagrations in the PFP Thermal Stabilization Glovebox

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U.S. Department of Energy Contract DE-AC06-96RL13200

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Abstract: This document describes the calculations of the peak pressures due to hydrogen deflagrations in the glovebox used for thermal stabilization (glovebox HC-21A) in PFP. Two calculations were performed. The first considered the burning of hydrogen released from a 7 inch Pu can in the Inert Atmosphere Confinement (IAC) section of the glovebox. The peak pressure increase was 12400 Pa (1.8 psi). The second calculation considered burning of the hydrogen from 25 g of plutonium hydride in the airlock leading to the main portion of the glovebox. Since the glovebox door exposes most of the airlock when open, the deflagration was assumed to pressurize the entire glovebox. The peak pressure increase was 3860 Pa (0.56 psi).

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1. INTRODUCTION

The metal stabilization process involves handling of plutonium which may have reacted to form hydrides or to release hydrogen gas. The hydrogen could ignite and pressurize the glovebox. The calculations of the peak pressures for two limiting hydrogen deflagrations accidents are described in this document. The first accident is the venting of hydrogen from a 7 inch Pu can into the Inert Atmosphere Confinement (IAC). The IAC is assumed to be filled with air and the hydrogen is assumed to ignite. This calculation is described in Section 3.

The second accident assumes a release and ignition of the hydrogen from 25 g of plutonium hydride in the airlock. The outer airlock door is assumed to be open to the glovebox, and the inner door is assumed to be closed. The pressure on the closed door is computed. This calculation is described in Section 4.

2. SUMMARY OF RESULTS

2.1 RELEASE OF HYDROGEN FROM A 7 INCH PU CAN

2.1.1 Statement of the Problem

A 7 inch Pu can is filled with hydrogen at a pressure of 15 psig. The hydrogen is assumed to vent to the IAC and ignite and burn. The peak pressure in IAC is calculated.

2.1.2 Peak Pressure

The peak pressure increase in the IAC is 1.8 psi.

2.2 SUMMARY OF RESULTS RELEASE IN AIRLOCK

2.2.1 Statement of the Problem

The airlock between the IAC and the glovebox is assumed to contain air plus the hydrogen released from 25g of $PuH_{2.7}$. The airlock door is open at the end interfacing with the glovebox. The hydrogen is assumed to ignite and burn, and the force on other air lock door is calculated. The dimensions of the airlock are assumed to be 6 3/4 inches by 9 inches by 16 inches. The door to the glovebox opens with a "fliptop" that opens the top and the front wall of the glove box.

2.2.2 Peak Pressure

The peak pressure on the walls of the glovebox and the closed door is 0.56 psi

3. CALCULATION OF HYDROGEN RELEASE FROM A PU CAN IN THE IAC - DETAILED RESULTS

3.1 DESCRIPTION OF PROBLEM.

Hydrogen from a 7 inch Pu can at a pressure of 2.05×10^5 Pa (29.7 psia) is assumed to be released to the IAC. This is a very conservative assumption in that the can is not filled entirely with hydrogen since the can contains some plutonium as well as air. Also, the total volume of hydrogen released from the can due to depressurization will be less than the total hydrogen in the can, but the values assumed in the analysis are bounding. Hydrogen is assumed to vent from the can to the IAC and to ignite and burn. The IAC is assumed to contain sufficient oxygen to support the combustion. The peak pressure in IAC is calculated assuming complete combustion.

3.2 ASSUMPTIONS

The dimensions of IAC are 2 ft by 3 ft by 4 ft resulting in a volume of 24 ft^3 (0.68 m^3). The IAC is filled with air at a temperature of 300 K and 1.01×10^5 Pa (14.7) psia pressure.
The volume of the 7 inch Pu can is 1.5 L.
The pressure of hydrogen in the can = 2.05×10^5 Pa = 29.7 psia.
The temperature of the hydrogen in the can is 300 K.

Material properties used:

Heat of combustion of hydrogen = 240 kJ/g-mole (Sandler ,1989)
Specific heat of air = 1.007 kJ/kg-K (Weast 1965)
Density of dry air at 300 K = 1.16 kg/m^3 (Weast, 1965)

3.3 CALCULATION OF PRESSURE

The pressure, volume and temperature are related for an ideal gas by

$$PV = nRT$$

where P = pressure
V = volume
T = absolute temperature

n = number of moles
R = Universal gas constant

Comparing the number of moles in two different volumes, temperature and pressures,

$(n2/n1) = (P2/P1)(V2/V1)(T1/T2)$

At standard temperature and pressure (273.16 K, 1 atmosphere), 1 mole of an ideal gas occupies 22.4 liters. The number of moles of H_2, n, in the 7 inch Pu can at 300 K and 15 psig is therefore:

$n = 1 \text{ mole } (1.5 \text{ L}/22.4 \text{ L})(273.16\text{K}/300 \text{ K})(29.7 \text{ psia}/14.7 \text{ psia})$

$n = 0.123$ moles

The volume of the IAC is 680 L which will contain approximately 28 moles of air at 1 atmosphere and 300 K. The concentration of hydrogen if the hydrogen is spread uniformly over the IAC is therefore 0.123/28 =0.004. This concentration is an order of magnitude below the lower flammability limit for hydrogen. The local concentration of hydrogen leaving the can may, however, be higher, and the hydrogen will be conservatively assumed to burn.

The energy released assuming complete combustion of the H_2 is the heat of combustion of the hydrogen times the number of moles of the hydrogen, or :

$Q = (240 \text{ kJ/g-mole})(0.123 \text{ moles}) = 29.5 \text{ kJ}$

ΔT is the temperature rise of the air in the IAC. Assuming the IAC is adiabatic and 100% of the heat from the hydrogen burn is transferred to the air, ΔT is given by:

$\Delta T = Q/mC_p$

where Q = heat generated(kJ)
M = mass of air in IAC (kg)
C_p = Specific heat of air (kJ/kg-K)

$M = \text{mass of air} = (\text{Volume})(\text{Density}) = (0.68\text{m}^3)(1.16\text{kg/m}^3) = 0.79 \text{ kg}$

$$\Delta T = \frac{(29.5 \text{ kJ})}{(0.79 \text{ kg})(1.007 \text{ kJ/kg-K})}$$

$= 37$ K

Assuming ideal gases,

$(P_{final}/P_{initial}) = (T_{final}/T_{initial})$

$P_{final} = (14.7)(300+37)/(300) = 16.5$ psia

$\Delta P = 1.8$ psi = 12,500 Pa

4 CALCULATION OF HYDROGEN BURN IN AIRLOCK- DETAILED RESULTS

4.1 DESCRIPTION OF PROBLEM.

The airlock between IAC and glovebox is assumed to contain air plus all the hydrogen in 25 g of plutonium hydride ($PuH_{2.7}$). The airlock door is open at the end interfacing with the glove box. The airlock door opens by flipping up exposing almost the entire to top of the airlock and the long wall to the glovebox. This creates a path for the hydrogen with almost no resistance which does not confine the hydrogen or the energy of the burn to the airlock. A hydrogen burn in the airlock will pressurize the entire glovebox volume. The force on other air lock door is calculated assuming the hydrogen ignites and burns. The airlock dimensions are assumed to be 6 3/4 inches by 9 inches by 16 inches and the volume is 972 in^3 or 15.9 L.

4.2 ASSUMPTIONS

The total volume of the glove box is 3200 L. The IAC volume is approximately 680 L resulting in an available volume of approximately 2500 L in the area of the glovebox where the airlock is located. The airlock and glovebox are assumed to be filled with air at a temperature of 300 K and 1.01×10^5 Pa (14.7) psia pressure prior to the deflagration.

Material properties used:

Heat of combustion of hydrogen = 240 kJ/g-mole (Sandler ,1989)
Specific heat of air = 1.007 kJ/kg-K (Weast 1965)
Density of dry air at 300 K = 1.16 kg/m^3 (Weast, 1965)

4.3 CALCULATION OF PRESSURE

Since $PuH_{2.7}$ is the typical formula for plutonium hydride, a hydrogen to Pu ratio of 2.7 is assumed. The hydrogen is assumed to be released as hydrogen gas. A typical reaction is shown below:

$$PuH_{2.7} + O_{2.7} \rightarrow PuO_{2.7} + H_{2.7}$$

The hydrogen is assumed to all be available for combustion.

For 25 g of $PuH_{2.7}$, the hydrogen content is equal to (25g) (2.7)(1.008)/(239+2.7) = 0.282 g

The volume of the airlock is 15.9 L which contains 0.65 moles of air at 300 K and 1 atmosphere. The number of moles of hydrogen available is 0.282 g/2.016g/mole = 0.140 moles. The hydrogen concentration in the airlock could be in the flammable region. However, if the hydrogen spreads to the glovebox, which has a volume of 2500 L containing 100 moles of air, the concentration would be 0.0014, well below the flammability limit. This calculation conservatively assumes the hydrogen will burn.

Energy if the hydrogen is burned = (Heat of combustion)(Mass of H_2)/Molecular Weight

=(240 kJ/g-mole) (0.282 g)/2.016 g/g-mole

= 33.6 kJ

Since the top and one wall of the airlock is open to the glovebox, it is assumed that the heat generated by burning of the hydrogen in the airlock is transferred to the air in the glove box.

The mass of air in the glovebox is the density of air times the volume of glove box minus the IAC volume. Since the top of the airlock is essentially open, heat from the hydrogen burn is assumed to be transferred to the glove box atmosphere. The entire mass of air in the glovebox will be used to calculate a temperature increase. No credit is taken for heat transfer to the walls or internals of the glove box.

Density of dry air at 300 K = 1.16 kg/m^3

Mass of air m = (1.16 kg/m^3)(2.5 m^3) = 2.9 kg

ΔT is the temperature rise of the air in the glovebox Assuming the glovebox is adiabatic and 100% of heat from the hydrogen burn is transferred to the air, ΔT is given by:

$\Delta T = Q/mC_p$

where Q = heat generated (kJ)
m = mass of air in the glovebox (kg)
C_p = Specific heat of air (1.007 kJ/kg-K)

$$\Delta T = \frac{(33.6\ \text{kJ})}{(2.9\ \text{kg})(1.007\ \text{kJ/kg-K})}$$

$$= 11.5\ \text{K}$$

Assuming ideal gases,

$(P_{final}/P_{initial}) = (T_{final}/T_{initial})$

$P_{final} = (14.7)(300+11.5)/(300) = 15.26$ psia

$\Delta P = 0.56$ psi = 3860 Pa

5. REFERENCES

Sandler, S. I., 1989, *Chemical and Engineering Thermodynamics*, John Wiley and Sons, New York, N.Y.

Weast, R. C., 1965, editor, *Handbook of Chemistry and Physics*, 46th edition, Chemical Rubber Company, Cleveland, Ohio.

PEER REVIEW CHECKLIST

Document Reviewed: Peak Pressures from Hydrogen Deflagrations in the PFP Thermal Stabilization Glovebox
Author: J. C. Van Keuren
Date: August 5, 1998
Scope of Review: Entire Document

Yes	No	NA	
☐	☐	☒	Previous reviews complete and cover analysis, up to scope of this review, with no gaps.
☒	☐	☐	Problem completely defined.
☒	☐	☐	Accident scenarios developed in a clear and logical manner.
☐	☐	☒	Necessary assumptions explicitly stated and supported.
☐	☐	☒	Computer codes and data files documented.
☒	☐	☐	Data used in calculations explicitly stated in document.
☒	☐	☐	Data checked for consistency with original source information as applicable.
☒	☐	☐	Mathematical derivations checked including dimensional consistency of results.
☒	☐	☐	Models appropriate and used within range of validity or use outside range of established validity justified.
☒	☐	☐	Hand calculations checked for errors. Spreadsheet results should be treated exactly the same as hand calculations.
☐	☐	☒	Software input correct and consistent with document reviewed.
☐	☐	☒	Software output consistent with input and with results reported in document reviewed.
☐	☐	☒	Limits/criteria/guidelines applied to analysis results are appropriate and referenced. Limits/criteria/guidelines checked against references.
☐	☐	☒	Safety margins consistent with good engineering practices.
☐	☐	☒	Conclusions consistent with analytical results and applicable limits.
☒	☐	☐	Results and conclusions address all points required in the problem statement.
☐	☐	☒	Format consistent with appropriate NRC Regulatory Guide or other standards
☐	☐	☒	Review calculations, comments, and/or notes are attached.
☒	☐	☐	**Document approved.**

Robert Marusich Robert Marusich 8/5/98
Reviewer (Printed Name and Signature) Date

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