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Deflagration in Stainless Steel Storage Containers Containing Plutonium Dioxide

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DEFLAGRATION IN STAINLESS STEEL STORAGE CONTAINERS CONTAINING PLUTONIUM DIOXIDE

by

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ABSTRACT

Detonation of hydrogen and oxygen in stainless steel storage containers produces maximum pressures of 68.5 psia and 426.7 psia. The cylinders contain 3000 g of PuO_2 with 0.05 wt % and 0.5 wt % water respectively. The hydrogen and oxygen are produced by the alpha decomposition of the water. Work Performed for Savannah River Site

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INTRODUCTION

Evidence [1] indicates that the reaction:

$$x\,H_2O(ads) + PuO_2(s) = x\,H_2(g) + PuO_{2+x}(s)$$

occurs when water is adsorbed on plutonia. This study will look at the worst case scenario when all the water adsorbed on the plutonia is decomposed according to the reaction where:

$$H_2O(ads) + \text{particle} = H_2(g) + 1/2\,O_2(g)$$

The maximum pressures obtained after combusting H_2 and O_2 will be calculated for the cases of 0.05 wt % and 0.5 wt % water adsorbed on the oxide.

The proposed storage container [2] is a stainless steel cylinder (material container) with outer dimensions of 4.50 inches OD and 8.98 inches height and inner dimensions 4.37 inches ID by 8.85 inches height. The material container is contained in the primary containment vessel, the outer dimensions of which are 5.00 inches OD and 9.63 inches in height. The interior dimensions are 4.87 inches ID and 9.50 inches in height. The interior volume of the primary containment vessel is 2900 cm^3. The volume occupied by the walls of the material container is 165 cm^3 and the volume occupied by 3000 g of solid oxide (PuO_2) with a theoretical density of 11.46 gm/cm^3 [3] is 261 cm^3. This gives a free volume of 2474 cm^3. It is assumed that the material container is breached so that the gas can occupy this free volume in the material container and the primary containment vessel. The density of the powder is assumed to be 2 gm/cm^3. The empty volume above the oxide is 1235 cm^3. It is assumed that deflagration will occur in this upper volume. Deflagration is defined to be a flame propagated at subsonic speeds from the ignition site.

CALCULATIONS

A total of 0.08326 moles of H_2 is produced from a sample with 0.05 wt % adsorbed water. Ten times this amount will be produced from the 0.5 wt % sample. In the 0.05 wt % case H_2 occupies 43.5% of the volume and in the 0.5 wt % case the volume % of H_2 is 63.3%. In addition to H_2 and O_2, 500 torr of He is added to both the primary containment vessel and to the material container. Both of the concentrations of H_2 are within the flammability limits - 4.0 to 76.0 vol % [4]. Oxygen concentrations are 22% for the "0.05 wt %" case and 32% for the 0.5 wt % case. The maximum flammability limit is not explicitly stated in Zalosh [4], but it is assumed to be greater than 32%.

A mixture of H_2 and O_2 requires 0.02 mJ [4] of energy to ignite it. The ignition source is heat produced by the laser used to drill a hole in the primary containment vessel for gas sampling. The dimensions of the drilled hole are 0.010 inch diameter by 0.028 inches in depth [5]. The energy contained in the molten steel is 0.33 joules [6], which is sufficient to ignite the mixture. The thermodynamic properties of Fe were used as a stand-in for stainless steel.

The peak pressure is calculated from the relation [4]:

$$P_m/P_o = n_bT_b/n_oT_o$$

where

P_m = peak pressure
P_o = initial pressure
n_b = number of moles of gas after combustion
n_o = number of moles of gas before combustion
T_b = adiabatic flame temperature
T_o = initial temperature

Table. Calculated Peak Pressure from Deflagration

Water loading	0.05%	0.5%
n reactant	0.0955 moles	0.6567 moles
n product	0.0433 moles	0.2410 moles
T_b	2100 K	1800 K
P_o	21.4 psia	191.2 psia
P_m	68.5 psia	426.7 psia

CONCLUSIONS

There is sufficient energy in the ignition source to cause a deflagration of the H_2/O_2/He mixture. The pressures in the primary containment vessel are not sufficient to rupture it. The burst pressure is 2000 psia [7].

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