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DETERMINATION OF THE AIRBORNE RELEASE FRACTION OF A 3013 CONTAINER SUBJECTED TO A FIRE

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ABSTRACT

Plutonium oxide bearing materials stabilized and packaged per DOE-STD-3013 are currently stored at the US Department of Energy Savannah River Site (SRS) in a shipping package such as a 9975. All 3013 outer containers are designed identically, however, there are two fabrication techniques; machined and flow-formed. The 3013 container is removed from the shipping package and introduced into a glove box for subsequent direct can cutting of the outer and inner 3013 containers where the oxide is down blended with an inert adulterant for permanent disposition. The hypothetical accident of interest is a fire which occurs after the 3013 is removed from the shipping package and prior to it being cut open. This calculation determines the ARF from a 3013 container during a fire by utilizing the calculation methodology from NUREG/CR-6410 and 3013 fire test data from Sandia National Laboratory.

INTRODUCTION

Radioactive materials, such as plutonium bearing oxides, are stored in 3013 containers at the US Department of Energy Savannah River Site (SRS) near Aiken, South Carolina. The 3013 containers are packaged in 9975 shipping packages which are palletized for long term storage. Figure 1 provides a photograph of typical 3103 containers used to package plutonium oxide bearing materials. The triple nested 3013 containers are each made of stainless steel. The outermost 3013 container is designed to the ASME BPV Code with a 699 psig design pressure and utilizes a welded closure [1]. The second layer container, referred to as the inner 3013 container, also utilizes a welded closure, however, the innermost container, referred to as the 3013 convenience container, contains the plutonium oxide materials and utilizes a screw lid closure. The innermost container is designed to be leaky to allow for purging and backfilling of helium gas in both the convenience and inner container prior to the inner container being welded. After welding, the inner container is then leak tested. Subsequently, the welded inner container is placed inside the outer most container which is purged and backfilled with helium prior to being welded. The outer container is also leak tested and radiography is used to verify that the outer container weld is free of defects. The outer 3013 container may be fabricated using a machining process or a flow forming process. In this paper the machined containers are referred to as EPD containers while the flow-formed are designated FF. The materials of construction and design dimensions of the EPD and FF outer containers are identical.

Figure 1: 3013 Outer, Inner, and Convenience Containers

The 3013 containers are stored in 9975 shipping packages until the plutonium oxide materials are dispositioned via down blending with an inert adulterant at SRS, packaged in authorized waste containers, and transported to the Waste Isolation Pilot Plant (WIPP) for final geologic disposal. Figure 2 illustrates the 9975 shipping container by showing its two nested containment vessels, lead shielding, and fiberboard overpack within an outer stainless steel 35 gallon drum; the 3013 container is not shown. These 9975 shipping packages are palletized and stacked to store 3013 containers at the Savannah River Site as seen in Figure 3. In order to initiate the down blending process, the 3013 must be removed from the 9975 and introduced into a glove box where each welded 3013 container is cut open.

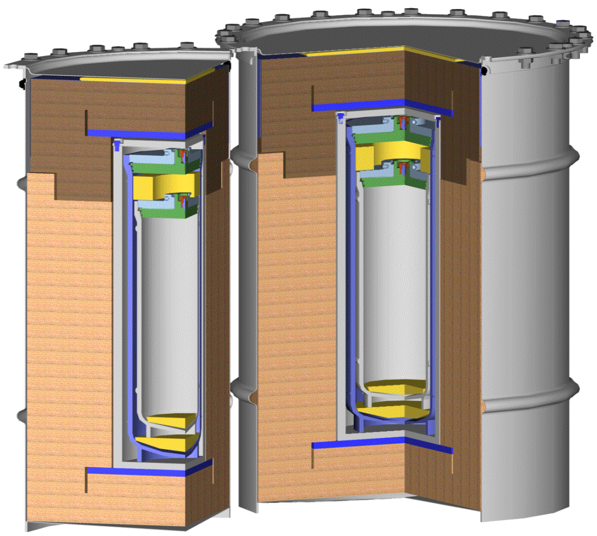

Figure 2: 9975 Shipping Package

Figure 3: 9975 Shipping Packages At Savannah River Site

A hypothesized pressurized release of plutonium bearing oxide could occur should the 3013 container outside of the 9975 shipping package and prior to being cut open in the glove box be subjected to a fire event. During a hypothetical fire event the 3013 container would pressurize due to evaporation of adsorbed moisture on the plutonium oxide materials and heating of the 3013 fill gases. Additionally, the fire would severely weaken the 3013 outer container to the extent that it may fail (e.g. rupture) catastrophically. The purpose of this paper is to determine the release of plutonium oxide in the form of an airborne release fraction (ARF) from a 3013 container during a fire.

The analysis incorporates recently published results from 3013 fire testing which was performed at the US Department of Energy Sandia National Laboratory [2]. The 3013 test containers were packaged with inner and convenience containers filled with plutonium oxide simulant. A hole was drilled in the inner container to allow for pressurization of the outer 3013 container. Heating was provided by a dedicated furnace and heating rates followed ASTM standards up to 1100C. These fire tests included both EPD and FF containers with varying amounts of water with and without chloride salts which are present in approximately one third of the plutonium oxide 3013 containers to be down blended.

PRESSURIZED RELEASE OF PLUTONIUM OXIDE

Pressurized release of plutonium oxides could occur during a fire accident event where the container holding the radioactive materials ruptures catastrophically due to excessive pressurization. The pressurization occurs due to the vapor pressure associated with the moisture present in the container and volatilization of chloride salts which may be also present. Limited data exists regarding the fraction of oxide that becomes airborne upon pressurized failure of containers. However, the US Nuclear Regulatory Commission has published a regulatory document, NUREG/CR-6410, which provides a first principle framework for estimating airborne release fractions due to a pressurized release [3]. This approach has been used to estimate the ARF for 3013 containers subjected to a fire [4]. However, the work in reference 4 was based on conservative assumptions regarding the container pressurization and failure pressure for the 3013 container. The fire testing documented in reference 2 provides the necessary inputs to utilize the analytical method in NUREG/CR-6410 to determine the ARF.

NUREG/CR-6410

A correlation for the ARF as a function of potential powder velocity is provided in NUREG/CR-6410 where the potential powder velocity is based on the energy of the pressurized gas,

$$v_p = (\frac{2PV}{m})^{1/2} \qquad (1)$$

where v_p is the potential powder velocity, P is the container failure pressure, V is the container gas volume, and m is the total mass of the plutonium oxide contents. The NUREG references a limited amount of pressurized release experimental data to establish the following upper bound correlation.

$$ARF_{ub} = 2.74E - 04\ v_p^{1.4} \qquad (2)$$

APPLCIATION TO 3013 A CONTAINER RUPTURE

Equations 1 and 2 can be used to determine the ARF for a 3013 container that ruptures during an accidental fire event. The primary parameters are failure pressure, gas volume (including container expansion due to plastic deformation during the fire event), and plutonium oxide mass. As expected, a higher rupture pressure results in substantially higher ARF for the same plutonium oxide mass, while increasing plutonium oxide mass decreases the ARF for a given rupture pressure. The 3013 fire tests provide failure pressures and gas volume data.

A summary of relevant Sandia test results are provided in Table 1. The tests focused on two moisture loadings 6 g and 12 g which essentially bounds the current 3013 container inventory. The tests resulted in several EPD containers which did not leak (those tested without salts) while all FF and all EPD containers with salts leaked. In general, the leak was caused by excessive strain due to container pressurization coupled with weakened container strength. None of the containers exploded in a manner which caused the container to tear apart into fragments or create shrapnel. For those which did leak, the maximum pressure, container initial free volume, change in container free volume during the test, and moisture/salt content of the 3013 containers are provided in Table 1. The uncertainty of the pressure measurement during the Sandia fire test was 25 psi [2]. This value will be added to the measured peak pressures listed in Table 1 to account for measurement uncertainty.

Table 1: Sandia 3013 Test Results For Containers Which Leaked

Test ID	Type (EPD or FF)	Water (g)	Salt (Y or N)	P_{max} (psig)*	Init. Vol. (cc)	Delta Vol. (cc)
ID05	EPD	5.9	Y	229	1350	399
ID06	EPD	12.0	Y	284	1348	448
ID08	FF	6.1	N	244	1613	995
ID10	FF	12.0	N	324	1607	1238
ID11	FF	6.0	Y	253	1615	1357
ID12	FF	11.9	Y	332	1609	967

* does not include 25 psi measurement uncertainty

The maximum allowed plutonium oxide mass is 5 kg per DOE-STD-3013 [1]. Additionally, reference 4 evaluated the high pressure release sensitivity to the oxide mass and showed that the maximum allowed oxide mass results in the greatest release of plutonium oxide mass.

RESULTS

The test results in Table 1 provide the necessary inputs to determine the airborne release fraction. Free volume, failure pressure, and plutonium oxide mass (5 kg) are used to determine the potential powder velocity (eq. 1) which is then used to determine the corresponding ARF (eq. 2). Determination of the ARF is provided in Table 2.

The results in Table 2 show that the ARF varies from 0.0465 to 0.0662 for the 12 g with salt cases for the EPD and FF containers, respectively. The FF container leaks at higher pressure and more importantly with significantly greater volume expansion compared with the EPD container. This results in ~ 40% increase in the ARF for the FF containers. To date, all FF container have been packaged with no more the 6 g moisture (including moisture measurement uncertainty). The ARF for FF containers with only 6 g of moisture is 0.0548 for those without salts and 0.0614 for those with salts which is a ~12% increase. All the FF containers bound the EPD containers such that an EPD container with 12 g moisture and salt has an ARF of 0.0465 while a FF container with 6 g moisture and no salts has an ARF of 0.0548.

Table 2: Calculated ARF for Each of The Failed Test Containers

Test ID	Type (EPD or FF)	Water (g) and Salt (Y or N)	P_{max} (psig)*	Final Vol. (cc)	Pot. Vel. (m/s)	ARF (Upper Bound)
CID05	EPD	5.9 Y	254	1749	35.0	0.0398
CID06	EPD	12.0 Y	309	1796	39.1	0.0465
CID08	FF	6.1 N	269	2608	44.0	0.0548
CID10	FF	12.0 N	349	2845	52.3	0.0698
CID11	FF	6.0 Y	278	2972	47.7	0.0614
CID12	FF	11.9 Y	357	2576	50.4	0.0662

* value includes the 25 psi measurement uncertainty

EXTRAPOLATED RESULTS

The test results in Table 1 are used to linearly extrapolate failure pressure and container volume expansion up to 25 g moisture. This allows determination of the ARF for the maximum allowed adsorbed moisture in a 3013 container which is 25 g (0.5 wt.% on 5000 g of plutonium oxide) [1]. The extrapolated analysis is for salt bearing containers only as they are most likely to contain 25 g of water due to the hygroscopic nature of salts. The inputs used for the extrapolated results are given in Table 3. Both EPD and FF containers are considered.

Table 3: Extrapolated Pressures and Container Volumes

Type (FF/EPD)	Salts (Y/N)	Water (g)	P_{max} (psig)*	Volume Increase (cc)	Final Volume (cc)
EPD	Y	25	401	552	1904
FF	Y	25	507	1773	3388

* does not include 25 psi measurement uncertainty

The ARF is calculated using the pressure and volume values in Table 3 as input and the results are presented in Table 4.

Table 4: Calculated ARF For Up to 25 g Moisture

Type (FF/EPD)	Salts (Y/N)	Moisture (g)	Potential Velocity (m/s)	ARF
EPD	Y	25	47.3	0.0606
FF	Y	25	70.5	0.1061

DISCUSSION

The ARF for EDP and FF 3013's as a function of adsorbed moisture and salt content has been determined using 3013 fire test data. The ARF determinations include extrapolated test conditions of 3013 moisture content up to 25 g. Table 5 provides a summary of the results of interest. A bounding value of 0.1061 could conservatively be used in safety analyses, however, this value is 1.73 times greater than the value of 0.0614 which bounds current and anticipated future inventory. The large ARF for FF container with 25 g of water is primarily due to the extrapolated volume expansion shown in Table 3, although achieving such high strains prior to leaking seem unlikely to occur even with increased water loading.

Table 5: Calculated ARF For Up to 25 g Moisture

Type (FF/EPD)	Salts (Y/N)	Water (g)	ARF
EPD	Y	12	0.0465
EPD	Y	25	0.0606
FF	N	6	0.0548
FF	Y	6	0.0614
FF	Y	25	0.1061

CONCLUSIONS

This paper utilizes the calculation methodology from NUREG/CR-6410 and 3013 fire test data from Sandia National Laboratory to determine the ARF for plutonium oxide released during the hypothesized fire event. The hypothetical accident of interest is a fire which occurs after the 3013 container is removed from a shipping package and prior to it being cut open. An ARF of 0.0614 bounds the 3013 inventory of interest. Lastly, the 3013 fire test data was extrapolated to determine the ARF of 0.1061 for a bounding moisture loading of 25 g.

REFERENCES

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