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Prepared for the U.S. Department of Energy
Assistant Secretary for Environmental Management
Project Hanford Management Contractor for the
U.S. Department of Energy under Contract DE-AC06-96RL13200
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ACCIDENT ANALYSIS FOR THE PLUTONIUM FINISHING PLANT POLYCUBE STABILIZATION PROCESS

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Prepared for the U. S. Department of Energy

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Richland, Washington

Hanford Management and Integration Contractor for the
U.S. Department of Energy under Contract DE-AC06-96RL13200

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Abbreviations, Acronyms, and Initials

ARF	Airborne Release Fraction
BTS	Bagless Transfer System
CAM	Continuous Air Monitor
CMU	Container Monitoring Unit
CPS	Criticality Prevention Specification
DCF	Dose Conversion Factor
EDE	Effective Dose Equivalent
FPC	Food Pack Can
FSAR	Final Safety Analysis Report
g	gram
-g	acceleration due to gravity ("gee")
HEPA	High Efficiency Particulate Air (filter)
LFL	Lower Flammability Limit
LOI	Loss on Ignition
MOX	Mixed Oxides
NRC	Nuclear Regulatory Commission
PFP	Plutonium Finishing Plant
P&ID	Piping and Instrumentation Diagram
PSAR	Preliminary Safety Analysis Report
Pu	plutonium
REG	Risk Evaluation Guideline
RMC	Remote Mechanical "C" (processing line)
SFE	Supercritical Fluid Extraction
SSC	Structure, System, or Component
TEDE	Total Effective Dose Equivalent
UNH	Uranium Nitrate Hexahydrate
χ/Q'	Atmospheric Dispersion Coefficient ("chi over q")

1.0 INTRODUCTION AND PURPOSE

The Polycube Stabilization Project involves low temperature oxidation, without combustion, of polystyrene cubes using the production muffle furnaces in Glovebox HC-21C located in the Remote Mechanical "C" (RMC) Line in Room 230A in the 234-5Z Facility. Polycubes are polystyrene cubes containing various concentrations of plutonium and uranium oxides. Hundreds of these cubes were manufactured for criticality experiments, and currently exist as unstabilized storage forms at the Plutonium Finishing Plant (PFP). This project is designed to stabilize and prepare the polycube material for stable storage using a process very similar to the earlier processing of sludges in these furnaces. The significant difference is the quantity of hydrogenous material present, and the need to place additional controls on the heating rate of the material.

This calculation note documents the analyses of the Representative Accidents identified in Section 2.4.4 of *Hazards Analysis for the Plutonium Finishing Plant Polycube Stabilization Process*, HNF-7278 (HNF 2000). These two accidents, "Deflagration in Glovebox HC-21C due to Loss of Power" and "Seismic Failure of Glovebox HC-21C", will be further assessed in this accident analysis.

2.0 SCOPE

The selected representative accident scenarios will be evaluated to estimate bounding releases of the radioactive material present in the polycubes. These estimated releases will then be compared to those for similar scenarios already analyzed in *Plutonium Finishing Plant Final Safety Analysis Report*, HNF-SD-CP-SAR-021 (PFP FSAR) (HNF 2001) to verify that the new scenarios are bounded. It is expected, based on the lack of any toxic materials specific to the process, that no significant toxic releases would occur in any of the accidents associated with the polycube stabilization process.

3.0 SYSTEM DESCRIPTION

3.1 FACILITY

The 234-5Z Building is located within the PFP complex located in the 200 West area on the Hanford Site. The 234-5Z Building is approximately 500 ft long and 180 ft wide, with a basement, first floor, duct level, and second floor. The frame is structural steel with an outer sheathing of aluminum panels over rock wool insulation and 16-gauge sheet metal. Seismic evaluations of the 234-5Z Building have shown that the integrity of the building would not be threatened by the design-basis (0.2-g, frequency = 10^{-4}/y) earthquake, but that wall panel separations would occur, so it is expected that dispersible material released inside the building could reach the environment.

The facilities to be used for the polycube stabilization process are parts of the RMC line (formerly used for plutonium conversion operations) in rooms 230A, 230B, 228C, and 228B. The actual stabilization operation will occur in the muffle furnaces in glovebox HC-21C in room

230A. Glovebox HC-21C is framed in stainless steel, and is 10 ft 8 in. long, 3 ft tall, and 3 ft 6 in. deep. The glovebox is supported on a stand so that the floor of the glovebox is 54 in. above the room floor. The HC-2 conveyer runs along the north end of the glovebox. A filter assembly leads from the top of the glovebox into the zone 4 ventilation exhaust system of the 234-5Z Building. Air is supplied to the glovebox via the HC-2 conveyer. Air in the rooms housing the gloveboxes is exhausted via the Zone 3 ventilation exhaust. Ventilation Zones 3 and 4 have separate High Efficiency Particulate Air (HEPA) filters, but then join and are both exhausted out of the main (291-Z-1) stack. Zone 3 exhaust passes through 1 stage of testable HEPA filtration, while Zone 4 exhaust has two testable stages, plus one nontestable HEPA filter on each glovebox. Glovebox HC-21C is not seismically qualified.

3.2 POLYCUBE STABILIZATION PROCESS

Feed material for the polycube stabilization process consists of plutonium-bearing polystyrene cubes ("polycubes") and fragments of cubes, formerly used in criticality experiments. A typical polycube is approximately 2 in. x 2 in. x 2 in., and contains about 120 g of polystyrene and about 50 g of plutonium. This form is not suitable for long-term storage of plutonium, and must be stabilized.

The polycube stabilization process begins in the 2736-Z vaults, where the polycubes are stored in vented 7-in. food pack cans (FPC). The can vent is covered by a filter (a modified Continuous Air Monitor [CAM] filter) held in place by a tape label. The cans rest on Container Monitoring Unit (CMU) pedestals within vault cubicles.

Prior to removing a can from storage, the top of the can is covered to prevent the potential spread of contamination during moving. The covered can is moved to a temporary work location within the vault were it is placed in a shielded transport overpack. One or more overpack cans are placed in a designated transportation cart which is then pulled from the 2736-Z Building, into the 234-5Z building, and into Room 230B for storage and further processing.

In Room 230B, the transportation overpack is opened, the container is removed from the overpack, and moved into Glovebox HC-21A either through a sphincter port or by sealing in. Once in Glovebox HC-21A, the containers are opened and the polycube material removed for processing. Excess materials (more than can be processed at that time) are temporarily stored in glovebox HC-21A. Polycubes to be processed at that time are placed into a furnace boat which is then covered and transported to the Furnace Glovebox HC-21C via the HC-2 conveyor.

In the furnace glovebox, the boat covers are removed, the boats are placed in the furnace, the offgas system is started, and the heating program is started. The furnaces heat at the normal ramp rate to 350 °C, then at 1 °C/min to 500 °C, which oxidizes the polystyrene matrix of the polycube to carbon "char" which remains in the bottom of the furnace boat.

When the furnace temperature reaches 500 °C, the furnace is turned off and allowed to cool. The furnace boat containing the "char" is pulled from the furnace, and two more polycubes are added. The boat is replaced in the furnace, and the heating program started again. This process is repeated until the maximum amount of "char" is present. The boat will then be heated to 1,000 °C for four hours (or longer as needed) to oxidize away the remaining carbon, resulting in a high-fired oxide form suitable for long term storage.

After the furnace has cooled, the stabilized material is removed, covered, and transported to either Glovebox HC-18M, HA-22B, or HA-20MB. The stabilized material is sieved and sampled. The samples are taken to analytical personnel for analysis. The remaining stabilized material is stored in the glovebox until sample results are returned.

The samples are tested for the presence of excess moisture using the Supercritical Fluid Extraction (SFE) method. When sample results show the material to be properly stabilized, the stabilized material is transported to either glovebox HA-53BTS for packaging (if the Bagless Transfer System [BTS] is approved for packing of oxides), or is sealed out for storage.

3.3 INVENTORY AT RISK

It is expected that 8 polycubes will be present in glovebox HC-21C at any one time. Two cubes could be in each of the two furnaces being heated, with four more cubes staged to go into the furnaces during the next run. A maximum of five runs (with two polycubes each) are planned for each furnace before the accumulated char from those ten polycubes (per furnace) is processed at 1,000 °C to burn off the carbon. During the high-temperature run, it is expected that no polycubes will be staged in the glovebox for that furnace.

For conservatism, however, it is assumed for this analysis that four additional polycubes have been brought into the glovebox during the final high-temperature runs in the two furnaces. This puts the inventory at 8 polycubes in the glovebox (two polycubes per furnace, and two staged outside each furnace), along with an amount of char in each furnace boat equivalent to 8 more polycubes, for a total amount of Pu equivalent to 24 polycubes. As soon as the high-temperature run is completed in each furnace, and the oxide material in the boat has cooled sufficiently, it will be moved out of the glovebox before any new polycubes are brought in (to reduce radiation exposure to personnel).

The expected inventory in glovebox HC-21C at any one time is, therefore, 8 polycubes as polycubes (or equivalent in pieces or fines based on Pu weight) containing about 400 g of Pu, plus about another 800 g of Pu (equivalent of 16 polycubes) in the form of char in the two furnace boats. The release characteristics of the two forms will be different, so they must be accounted for separately.

4.0 PRELIMINARY SYSTEM ANALYSIS

As part of the initial evaluation and design of this process, a number of scoping calculations and simulations were carried out, as documented in *Final Letter Report – Safety Case for Low Temperature Oxidation of Polycubes*, Letter no. 1AF00-00-009 R2 (Cooper 2000) to determine the effects of various abnormal events associated with the process. Under all normal operating conditions, the flammable gases will not exceed 25% of the lower flammability limit (LFL).

The parameters that will be controlled to maintain normal operating conditions are furnace temperature and heat-up rate, sample exposure time, air flow rate through the furnace, and sample mass. The analysis summarized in the Letter Report (Cooper 2000) assumed a total of 800 grams of pure polystyrene undergoing oxidation in the furnaces. Each furnace load of polystyrene undergoing processing is limited by the available air flow to no more than 2 cubes, or a total of 4 cubes in the two furnaces in the glovebox. Thus, the amount of polystyrene expected to be undergoing oxidation at any one time is approximately 480 g. In addition, since the glovebox can relieve into the large volume of the HC-2 conveyer, and the furnaces can relieve past their doors into the glovebox, the pressure within the furnaces and the glovebox can be considered to remain approximately constant (normal operating pressure) for the scenarios considered here.

The analysis reported in the Letter Report (Cooper 2000) arrived at the following conclusions:

- It was determined that 800 g of pure polystyrene, if heated at the highest attainable heat-up rate (assuming a failed temperature controller, about 5 °C/min), can produce flammable gas concentrations above the Lower Flammability Limit (LFL) within the furnace given design air flow (2 cfm). It is therefore necessary to limit the heat-up rate, as well as maintain a minimum air flow, in order to avoid a potential deflagration within the furnace during the polystyrene oxidation phase of the process.
- If burning of flammable gasses occurs in the furnace (failure of temperature control) while design air flow is passing through the furnace, it was shown that the gases will burn at the LFL for approximately 3 seconds before the combustion becomes oxygen-limited. Oxygen-limited combustion will then continue; within a short time the off-gas filters will plug due to the large amount of soot generated by the combustion. Air flow will then be cut off, and combustion will cease. Existence of high temperatures within the furnace for short times during burning of flammable gases are not considered significant from a safety point of view.

- If burning of flammable gases occurs with no air flow through the furnace (failure of temperature control and furnace air flow), but with design air flow continuing through the glovebox, the oxygen within the furnace is consumed. Combustion within the furnace will then cease after about 15 seconds when the flammable gas concentration increases above the high flammability limit. The flammable gases will then leak past the furnace door into the glovebox. If these gases are above ignition temperature they will continuously ignite upon entering the glovebox, the temperature within the glovebox will increase and reach equilibrium at a bounding temperature of about 60 °C. This is not considered significant from a safety viewpoint, as long as combustibles are kept away from the furnace doors. (Such events have actually been observed in the past with no resultant harmful consequences.) If the pyrolytic gases fail to ignite upon entering the glovebox, the gas concentration will remain about an order of magnitude below the LFL as long as design air flow is maintained through the glovebox.

Given the conditions above, but with the added failure of the glovebox ventilation, it was shown that the flammable gas concentration within the glovebox increases linearly with time, and exceeds the LFL for styrene monomer in this mixture of gases of 1.3 vol% after about 900 seconds (15 minutes). This assumes that the furnace heaters remain energized, and that there is a sufficient supply of polystyrene in the furnace. The glovebox will then be vulnerable to a deflagration if an ignition source is present. It is expected that such a deflagration would generate enough energy to breach the glovebox containment.

5.0 METHODOLOGY

Each of the representative accidents considered here was compared to similar accidents in the PFP FSAR (HNF 2001) to determine whether the exiting FSAR accident analyses bound the new Polycube accident scenarios. Radiological doses, D, are calculated using the standard formula:

$$D = R\,(\chi/Q')(BR)(DCF)$$

Where R is the release in grams of Pu mix, χ/Q' is the Atmospheric Dispersion Coefficient (s/m^3), BR is the receptor Breathing Rate (m^3/s), and DCF is the Dose Conversion Factor for the Pu mix (rem/gram inhaled). The values of χ/Q' for various types of releases to the maximum onsite and site boundary individual receptors are shown Tables 9-39 and 9-40, respectively, in the FSAR. The χ/Q's relevant to the polycube process representative accidents are shown in Table 1.

The receptor breathing rates used in the PFP accident analyses are listed in Table 9-48 in the PFP FSAR (HNF 2001). The breathing rate applicable to the polycube process representative accidents is the "acute release" (< 24 h), light activity breathing rate, i.e. 3.3×10^{-4} m^3/s. The 24-hour average breathing rate is used for the site boundary receptor only if the release is relatively constant over the 24-hour period following the accident.

Dose conversion factors (unit inhalation doses) for the various lung clearance classes and Pu mixes are given in Table 9-46 in the PFP FSAR (HNF 2001). The Pu mix in the polycubes is conservatively specified to be a >10% ^{240}Pu mix (90th percentile for the deflagration accident and mass weighted average for the seismic accident). Since the heavy metal in the polycubes is in oxide form, the Y lung clearance class was assumed. The applicable dose conversion factors for the polycube accidents are 1.7×10^8 and 8.8×10^7 rem/g inhaled, respectively.

Since neither of the accidents considered here involve any significant direct radiation exposure, the Effective Dose Equivalent (EDE) is the same as the Total Effective Dose Equivalent (TEDE). Radiological doses calculated here will be compared to the Risk Evaluation Guidelines (REGs) given in *Hazard and Accident Process*, HNF-PRO-704 (HNF 2000b). No significant toxic hazards were identified for the polycube stabilization process, so no toxic hazards were evaluated.

6.0 ACCIDENT ANALYSIS

The Hazards Analysis for the Polycube Stabilization Process (HNF 2000a) identified two representative accidents. These two accidents are (1) Deflagration in Glovebox HC-21C, and (2) Seismic Failure of Glovebox HC-21C. The deflagration in glovebox HC-21C was not expected to produce significant consequences outside the facility, but could cause serious injuries or fatalities among the process operators. The Seismic release was the only accident identified with the potential to cause a significant release outside the facility and, therefore, to significantly affect the onsite receptor.

6.1 DEFLAGRATION IN GLOVEBOX HC-21C

6.1.1 Scenario Development

A loss of plant power results in the loss of glovebox (Zone 4) ventilation, and loss of airflow through the two muffle furnaces due to loss of the 26-in. Hg vacuum system. This failure is assumed to occur when both furnaces are processing polycube material, in the temperature ramp range from 350 to 500 °C where the polystyrene is being oxidized. Although loss of facility power would also imply loss of power to the furnaces, the furnaces are expected to remain hot for some period of time. It is therefore assumed that, with no airflow, the hot material in the furnace boats produces a stream of pyrolytic gases that fill the glovebox to a concentration greater than the LFL. Initially, the evolution of pyrolytic gases without cover gas flow in the furnaces would consume and then displace all the oxygen out of the furnace cavities, but as the furnaces cool some air could be drawn back into the furnace cavities forming a flammable mixture there also. As long as there is no power to the facility, there will likely be no ignition source within the glovebox (see Section 9.2.10.2.1 of the PFP FSAR [HNF 2001]). However, if power is restored while the flammable conditions still exist, an ignition event could occur within the glovebox before the ventilation system has significantly reduced the flammable gas concentration.

This scenario is very similar to one already analyzed in Section 9.2.10.2, "Deflagration in Glovebox HC-21C", in the PFP FSAR (HNF 2001). In the FSAR accident, there is a deflagration in a furnace that sweeps up oxide powder in the boat and blows it out into the glovebox. Based on data for a deflagration within a glovebox, and for powder releases from a pressurized container, it was conservatively assumed that a glove is blown out and the material loads the air to a concentration of 10 mg/m^3 over the entire volume of the room (see Section 9.2.10.2.4 of the PFP FSAR [HNF 2001]). This represents an effective release of 1.5 g of oxide powder which is then exhausted by the Zone 3 ventilation system through a single stage, testable HEPA filter. This release is very conservative for the FSAR accident. In addition, the FSAR scenario assumed that the maximum plutonium inventory at risk is 5 kg based on criticality limits. In the polycube process, however, only the part of the plutonium that has completed the polystyrene pyrolysis/oxidation process (about 800 g) will be dispersible, and will have the same physical form and release fraction as assumed in the FSAR. The plutonium that is still mixed with polystyrene is not mechanically dispersible as a powder. The polystyrene is not expected to be able to burn after the deflagration (due to lack of air) unless power is restored and airflow through the furnace resumes. If combustion of the polycubes occurs after the deflagration, therefore, any releases would end up in the downstream filters in the 26-inch vacuum system. As discussed in Section 4.0, these filters would quickly plug due to the large amount of soot generated by the combustion. This would cut off airflow through the furnace and extinguish the combustion.

The gloves in the glovebox would fail at 0.6 psid (see Section 9.2.10.2.4 of the PFP FSAR [HNF2001]), and the overpressure in the glovebox due to the deflagration would also relieve through an 18-in. square opening into the large volume of the HC-2 conveyer (which also serves as the supply plenum for the glovebox ventilation). In addition, the final exhaust HEPA filters servicing the glovebox and room are located some distance away, and are in rooms with considerable volumes. The overpressure in the glovebox associated with the deflagration accident is therefore not expected to threaten the two stages of HEPA filters serving the glovebox or the single-stage HEPA filter serving the room.

The FSAR release is therefore considered to bound any release from the glovebox/furnace deflagration considered here. After passing through the single-stage HEPA filter (reduction factor = 5×10^{-4}) the release to the environment was found to be 7.5×10^{-4} g of Pu mix. If the deflagration were to occur with no room or glovebox ventilation in operation, there would be no driving force to move the material out of this section of the building and there would be no significant release to the environment.

6.1.2 Frequency

A series of conditions must occur to produce this accident. First, the cover gas stream through the furnaces must fail and, concurrently, ventilation to the glovebox must be lost. (Note that, since the same exhaust fans service both the Zone 3 and Zone 4 ventilation systems, room ventilation would probably be lost also.) The most likely event that could cause both conditions is a complete loss of electrical power to the facility, even though the facility is supplied by two independent power sources. This would also cause a loss of power to the furnaces. Second, the loss of facility power must occur while at least one of the furnaces is processing a load of polycubes on the ramp from 350 - 500 °C after processing previous loads of polycubes so that there is char in the boat with the polycubes. This is the temperature range in which the polystyrene is able to undergo combustion, and, therefore, where the ramp rate must be carefully controlled. Above this range the polystyrene has already been oxidized and only metal oxide powder will be present in the boat. Only the char and oxide powder are considered to be mechanically dispersible, not the polycubes. Third, sufficient flammable gas must be expelled from the furnaces to fill the glovebox with a flammable gas mixture while the power is off, but before the furnaces cool below 350 °C. Fourth, the flammable mixture in the glovebox must be ignited. This probably could occur only when power is restored to the glovebox, causing a contact to spark before the glovebox ventilation system cleared the air within the glovebox. Once ventilation is restarted, the glovebox would be effectively purged in 7 to 10 minutes (see Section 9.2.10.2.1 of the PFP FSAR [HNF 2001]). Either the glovebox or room ventilation exhaust must be operating after the deflagration occurs to transport a significant amount of material out of the facility.

Given the train of events required for this release to occur, and especially the complete loss of power during the short time required for the 350 – 500 °C heating ramp, it is conservatively estimated that this accident is in the unlikely frequency range (10^{-4} - 10^{-2}/y).

6.1.3 Consequence Analysis

Taking credit for at least one stage of HEPA filtration, the release associated with the FSAR accident was determined to be 7.5×10^{-4} g out of the 291-Z-1 stack. The resulting EDE doses to the onsite and site boundary receptors assuming the 90th percentile >10% ^{240}Pu mix (with a DCF = 1.7×10^{8} rem/g) are shown in Table 2.

Mitigated Dose Calculations:

$$D = R\,(\chi/Q')(BR)(DCF)$$

Onsite Dose = $(7.5 \times 10^{-4}\ \text{g})(1.62 \times 10^{-5})(3.3 \times 10^{-4})(1.7 \times 10^{8}) = 6.8 \times 10^{-4}$ rem
Offsite Dose = $(7.5 \times 10^{-4}\ \text{g})(5.73 \times 10^{-6})(3.3 \times 10^{-4})(1.7 \times 10^{8}) = 2.4 \times 10^{-4}$ rem

Assuming the HEPA filters to be the mitigators for this accident, the unmitigated doses would be a factor of 2×10^{3} (the reciprocal of the filter reduction factor) greater.

Unmitigated Dose Calculations:

Onsite Dose = $(2 \times 10^{3})(6.8 \times 10^{-4}) = 1.4$ rem
Offsite Dose = $(2 \times 10^{3})(2.4 \times 10^{-4}) = 4.8 \times 10^{-1}$ rem

The resulting unmitigated doses, which take no credit for fallout/plateout within the facility, are also shown in Table 2. It is apparent that even the unmitigated doses are well below guidelines for both the onsite and site boundary receptors for an accident frequency in the unlikely range.

6.2 SEISMIC FAILURE OF GLOVEBOX HC-21C

6.2.1 Scenario Development

Except for the amount and physical form of the material being stabilized, this accident is identical to the PFP FSAR seismic failure of glovebox HC-21C (Section 9.2.4.6.3.1.Q of the PFP FSAR [HNF 2001]). In the PFP FSAR, the material in the furnaces and glovebox is assumed to be Pu oxide powder, while in this process the material will be a mix of oxide powder and fresh and partially oxidized polycubes. Powder within the polycubes will not be mechanically dispersible, but could burn in a fire with a release fraction higher than that for oxide powder. The glovebox inventory in the FSAR was assumed to be the Criticality Prevention Specification (CPS) limit of 5 kg of 90th percentile >10% ^{240}Pu mix.

The FSAR seismic event (probability 10^{-4}/y) was assumed to cause the glovebox to fall over onto the floor. The primary release was assumed to be a mechanical dispersal of oxide powder due to a 2 m drop onto a hard surface. In addition, it was determined that a seismically-induced fire could occur in glovebox HC-21C due to hot furnace equipment and contents contacting and igniting the Lexan™ panels in the glovebox. The total release into the room was calculated to be 1.05 g of Pu. A leak path factor of 0.84 was applied, to produce a stack release of 0.882 g originating in Glovebox HC-21C.

Two scenarios for release of the material from the 234-5Z Building were evaluated (see Section 9.2.4.6 of the PFP FSAR [HNF 2001]). In the first case, the building ventilation was assumed to be shut down due to loss of electrical power. A detailed model of the airflow and particle deposition through the building was developed. The RMC Line was determined to be in an area of the building protected from wind infiltration, so that no significant release to the environment would occur from glovebox HC-21C in the absence of ventilation flow.

In the second case, it was assumed that the all the exhaust fans continue to run, that all HEPA filtration fails, and that the Zone 3 duct system remains intact with air flows the same as those during normal operation. In addition, no credit was taken for loss due to impaction within the ductwork or agglomeration at the point of release or in the ducts. In this case (with ventilation), the release from Glovebox HC-21C was combined with all of the other seismic releases within Buildings 234-5Z and 236-Z for a total of 15.1 g. Sixteen percent of this release was calculated to be trapped within the buildings due to gravitational settling. The remaining 12.7 g was assumed to be respirable and to escape to the environment. 10.1 g of this release was determined to be >10% ^{240}Pu mix. The release from glovebox HC-21C (0.882 g) was therefore a minor component of the seismic release from the whole facility.

6.2.2 Frequency

The frequency of a seismically induced failure of glovebox HC-21C was assumed to be the same as the frequency of the design basis seismic event, i.e., 10^{-4}/y, placing this event in the unlikely frequency range.

6.2.3 Consequence Analysis

The FSAR analysis of the seismic event led to an overall set of consequences to onsite and site boundary receptors for the whole PFP Facility due to releases from all the inventories and processes within it. The consequences of this accident for the polycube stabilization process was, therefore, developed in terms of the releases from the glovebox to the room to permit a direct comparison with the FSAR results for this particular release point in the facility.

The primary component of the FSAR seismic release from the HC-21C glovebox to the room is a direct mechanical dispersion due to the agitation associated with the failure and fall of the glovebox. This was modeled as a 2 m free fall of powder onto a hard surface, with a respirable release fraction of 1.5×10^{-4} (see Section 9.2.4.6.1 of the PFP FSAR [HNF 2001]) leading to a respirable release of 0.75 g into the room. The PFP FSAR glovebox fire accident (seismic or non-seismic) assumed a respirable release fraction (ARF x RF) of 6×10^{-5} for exposed Pu oxide powder. Applied to the maximum 5 kg inventory in the glovebox, this produced a release of 0.3 g of Pu into the room due to the seismically-induced fire. The total seismic release from Glovebox HC-21C into the room was therefore calculated to be 1.05 g of Pu in the form of oxide powder.

The Airborne Release Fraction (ARF) for polystyrene in DOE-HDBK-3010-94 (DOE 1994) comes from experiments in which small pieces of polystyrene (small, angular beads) were coated with uranium nitrate hexahydrate (UNH) solution (Halverson, Ballinger, and Dennis 1987). It was stated that the uranium release from the burning contaminated polystyrene occurred prior to ignition of the polystyrene. The authors concluded that the uranium release was due to evaporation of the UNH solution from the surface of the beads. The remaining uranium (the part not released) had become trapped in the thick, viscous mass of molten polystyrene. The data showed that the ARF for the larger quantities tested (35 g) was less than for the small quantity tested (6 g), indicating that surface material in the interior of the mass of beads was more likely to become entrapped when the polystyrene melted.

Since the polystyrene cubes are much larger than the beads used in the experiment, the ARF for the largest quantity of beads (2×10^{-3}) was initially assumed. In addition, since the Pu is in the form of an oxide powder mixed with the volume of the polycubes instead of being a solution on the outside surfaces, the ARF was reduced by a factor of 5 to 4×10^{-4}. This value is slightly larger than for uranium release from a pool of kerosene-TBP burning to extinguishment. The respirable fraction (RF) was assumed to be 1.0. The respirable release fraction in fire for the oxide powder (after burn-off of the polystyrene), whether or not mixed with carbon char, was assumed to be 6×10^{-5}, consistent with the FSAR. The respirable release fraction for mechanical dispersion of the oxide powder due to the collapse of the glovebox was assumed to be 1.5×10^{-4}, consistent with the FSAR. The polycube material is considered to be non-dispersible in a 2 m fall.

Given the above release fractions, the total release into the room R from the seismic glovebox failure and fire is given by:

$$R = (4 \times 10^{-4})(\text{g Pu in polycubes}) + (6 \times 10^{-5})(\text{g Pu as powder}) + (1.5 \times 10^{-4})(\text{g Pu as powder})$$

The first two terms are the releases from the fire while the third term is the mechanical dispersion from the spill. Evaluating the release for 400 g of Pu as polycube material (including pieces and fines) and 800 g of Pu as powder yields a total of 0.328 g of Pu released into the room. This is less than the FSAR release of 1.05 g into the room by a factor of 3.2. Applying the leak path factor, 0.84 x 0.328, produces a stack release of .275 g. The EDE doses assuming the mass weighted average dose conversion factor of 8.8×10^7 (Table 9-46, HNF 2001) are:

Dose calculations:

$$D = R(\chi/Q')(BR)(DCF)$$

Onsite dose = $(.275\text{ g})(1.62 \times 10^{-5})(3.3 \times 10^{-4})(8.8 \times 10^{7}) = 0.13$ rem
Offsite Dose = $(.275\text{ g})(5.73 \times 10^{-6})(3.3 \times 10^{-4})(8.8 \times 10^{7}) = 0.05$ rem

The EDE doses are 0.13 onsite and 0.05 offsite, and are shown in Table 3.

7.0 MAJOR ASSUMPTIONS

The major assumptions specific to the development of the scenarios and calculations of consequences related to the polycube stabilization process in Section 6.0 are as follows:

- Each complete polycube is assumed to contain 50 g of Pu mix in the form of oxide powder dispersed throughout the polystyrene. The expected operating inventory in glovebox HC-21C is about 8 polycubes (or equivalent in pieces or fines based on Pu weight) containing about 400 g of Pu, with two in each furnace boat and two staged outside each furnace, plus about another 800 g of Pu (equivalent of 16 polycubes) in the form of char in the two furnace boats. Because of variations in the Pu content of individual polycubes, the amount of material in the glovebox could be slightly higher than assumed here. However, the inventory would have to be increased by more than a factor of three (e.g., 1,280 g of polycube Pu and 2,560 g of Pu powder) to produce a potential release greater than that already analyzed in the FSAR.

- Based on the series of conditions that must occur concurrently to produce a deflagration in glovebox HC-21C, the frequency of this event was assumed to be in the unlikely frequency range (10^{-4} - 10^{-2}/y). The time during the heating ramp from 350 °C to 500 °C (2.5 hours/batch) is the only time the process is exposed to this accident. During that time the facility power must fail for a time sufficient to fill the glovebox with a flammable mixture above the LFL (about 15 minutes – see Section 4.0). The facility power must then be restored, and the flammable mixture ignited before the glovebox ventilation purges it, so that there is a driving force to release suspended material from the facility. The assumed frequency range for this sequence of events is considered to be very conservative. However, even if the frequency were to be increased to the anticipated range (10^{-2} - 10^{-1}/y), the unmitigated consequences would still be less than the corresponding risk guidelines. To assure that conditions allowing a build-up of flammable gases leading to a deflagration cannot occur, procedures do require verifying airflow through the furnaces before the heating program is started .

- The airborne release fraction (ARF) for Pu oxide powder in burning polystyrene was assumed to be 4×10^{-4}, with a respirable fraction (RF) of 1.0 as developed in

Section 6.2.3. This is considered to be extremely conservative, because the smoke from a plastic fire tends to contain a high proportion of large particles (resembling black snowflakes) that fall out close to the fire unless they are kept suspended by rapid air movement. This is one reason that burning polystyrene in the furnace will quickly plug the downstream filters in the vacuum system.

8.0 CONCLUSIONS

Each of the two representative accidents was compared to the corresponding accident in the PFP FSAR to determine whether the FSAR accident is bounding. It should be noted that the polycube stabilization process does not represent a new addition to the PFP Facility. The RMC line and the HC-21C glovebox are already analyzed in the FSAR assuming the material being stabilized is Pu oxide powder. The only change is the substitution of the Pu oxide-doped polystyrene polycubes for the loose powder previously assumed.

8.1 Deflagration In Glovebox HC-21C

In this scenario it is assumed that airflow is lost to both the furnaces and the glovebox due to a facility power failure. Pyrolytic gases continue to evolve from the material in the furnaces long enough to fill the glovebox with a flammable mixture. It is further assumed that when power is restored, an ignition event occurs which causes a deflagration. Despite the large relief volume available in the HC-2 conveyer, it is assumed that sufficient overpressure develops to blow out one or more gloves, and that the entire room air volume is loaded to 10 mg/m^3 with oxide powder.

The corresponding accident in the FSAR is very similar, except for the quantity of plastic in the furnaces. The FSAR analysis is very conservative, however, and does not depend on the amount of plastic present. In addition there would actually be less dispersible material present in the polycube case since part of the assumed 5 kg inventory would be in a less dispersible form than powder. It was therefore determined that the glovebox deflagration with polycubes is bounded by the corresponding FSAR accident.

The primary mitigator for this accident would normally be the testable HEPA filters in the Zones 3 and 4 exhaust systems. It was further determined that, even without mitigation (i.e., with ventilation, but no filters) the consequences for this accident would be well below applicable risk guidelines for both the onsite and site boundary receptors. This accident is, however, considered to be a serious safety concern for facility personnel near the glovebox.

8.2 Seismic Failure Of Glovebox HC-21C

In the 10^{-4}/y seismic event analyzed in the PFP FSAR, Glovebox HC-21C is assumed to fall over and breach, spilling the material in the glovebox and in the furnaces. The seismic event release from Glovebox HC-21C into the room has two components: (1) the mechanical dispersion of the oxide powder due to the fall of the glovebox and agitation of the material, and (2) a fire due to hot equipment and furnace contents contacting flammable material in the glovebox (notably the Lexan™ side panels). Polycube material is not mechanically dispersible as a powder, so the first component of the release does not occur to any appreciable extent from the polycube material. The release fraction for oxide material in burning polystyrene is, however potentially higher than that for loose oxide powder in a fire. Note that this scenario assumes that the ventilation continues but that the HEPA filters fail, resulting in an unfiltered release from the stack.

It was found that the expected inventory of polycubes and oxide powder in glovebox HC-21C produced a potential release into the room far less (by a factor of 3.2) than that already analyzed in the PFP FSAR, such that a control is not necessary to protect this assumption. This is considered to provide ample operational margin for the minor variations expected in the Pu contents of the individual polycubes. If, however, it is desired to have more inventory in the glovebox than is assumed here, the acceptability of the inventory can easily be determined using the total release formulation developed in Section 6.2.3. If the FSAR Pu release into the room (1.05 g) is symbolized by R_O, then the seismic release into the room from the polycube process in glovebox HC-21C relative to the FSAR release is given by:

$$R/R_O = (3.8 \times 10^{-4})M_C + (2.0 \times 10^{-4})M_P$$

where M_C is the mass of Pu mix in the polycube material (including pieces and fines) in grams, and M_P is the mass of Pu mix in the form of oxide powder in grams. As long as R/R_O is less than 1, the seismic event (10^{-4}/y) releases from the polycube process will be bounded by the FSAR analysis of oxide powder. If there is any doubt as to whether to treat a part of the inventory as polycube material or as powder, it is conservative to count it as polycube material.

The expected inventory for the process was calculated, and it is expected that only minor variations of the process will occur. The risk of this operation is well-bounded by the Thermal Stabilization operation, and is such that significant perturbations could occur without challenging the bounding release of Thermal Stabilization. Therefore, no inventory control is required other than for criticality control.

8.3 Summary Conclusion

The Polycube Stabilization Process has no unique Hazards. Hazards for the Polycube Stabilization Process were compared with the hazards presented in the PFP FSAR (HNF 2001), and were found to be similar to, and bounded by, those hazards.

Accidents analyzed for the Polycube Stabilization Process are also similar to, and bounded by, accidents analyzed in the PFP FSAR (See PFP FSAR Sections 9.2.4.6 "Seismic Accident Analysis", 9.2.10.2 "Deflagration in Glovebox HC-21C", and 9.2.10.5 "Seismically Induced Fire in Glovebox HC-21C"). A comparison of accidents and accident consequences is given in Table 3.

Calculated accident consequences for the Polycube Stabilization Process are below REGs, and are bounded by accident consequences as shown in the PFP FSAR. Therefore, there are no new OSR-level controls required for this process. Any required Operational-level controls are given in the Letter Report (Cooper 2000). There are no new Safety Class or Safety Significant Structures, Systems, and Components (SSCs) required for this process, and no modifications required to existing SSCs.

The Polycube Stabilization Process can be safely operated at the PFP.

9.0 REFERENCES

Cooper 2000, *Final Letter Report – Safety Case for Low Temperature Oxidation of Polycubes*, Letter no. 1AF00-00-009 R2, Fluor Hanford, Richland, Washington, January, 2001.

Halverson, Ballinger, and Dennis 1987, *Combustion Aerosols Formed During Burning of Radioactively Contaminated Materials – Experimental Results*, NUREG/CR-4736 (PNL-5999), Pacific Northwest Laboratory, Richland, Washington, March 1987.

HNF 2000a, *Hazards Analysis for the Plutonium Finishing Plant Polycube Stabilization Process*, HNF-7278, Rev. 0, Fluor Hanford, Richland, Washington, November 2000.

HNF 2000b, *Hazard and Accident Process*, HNF-PRO-704, Rev. 1, Fluor Daniel Hanford, Inc., Richland, Washington.

HNF 2001, *Plutonium Finishing Plant Final Safety Analysis Report*, HNF-SD-CP-SAR-021, Rev. 2, Fluor Daniel Hanford, Richland, Washington, January 2001.

DOE 1994, DOE Handbook – *Airborne Release Fractions/Rates and Respirable Fractions for Nonreactor Nuclear Facilities*, DOE-HDBK-3010-94, U.S. Department of Energy, Washington, D.C., October 1994.

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TABLES

Table 1: Atmospheric Dispersion Coefficients

Release Type	Receptor	χ/Q' (s/m^3)
Elevated release from 61-m (200-ft) stack	Onsite 930 m SSE	1.62×10^{-5}
	Site Boundary 12.5 km W	5.73×10^{-6}
Ground-level release with building wake and plume meander	Onsite 550 m WNW	4.74×10^{-4}
	Site Boundary 12.5 km W	1.01×10^{-5}

Table 2: Receptor EDEs for Deflagration in Glovebox HC-21C

Receptor	Mitigated Dose (rem)	Unmitigated Dose (rem)	Risk Evaluation Guidelines (rem)
Onsite	6.8×10^{-4}	$1.4 \times 10^{+0}$	25
Site Boundary	2.4×10^{-4}	4.8×10^{-1}	5

Table 3: Comparison of Polycube Accidents to FSAR Accidents

	FSAR			**Polycube Accident Analysis**		
	Source Term (g)	Release (g)	Dose (rem EDE)	Source Term (g)	Release (g)	Dose (rem EDE)
Deflagration in HC-21C (FSAR Section 9.2.10.2)	2,500 g	4.5 g into room 2.3×10^{-3} g out stack (via E-3)	2.1×10^{-3} onsite 7.4×10^{-4} offsite	8 Polycubes as Polycubes, 16 Polycubes as char = 1,200 g	1.5 g into room 7.5×10^{-4} g out stack (via E-3)	6.8×10^{-4} onsite 2.4×10^{-4} offsite (Unmitigated: 1.4 onsite, 0.48 offsite)
Seismic with Fire (FSAR Sections 9.2.4.6 & 9.2.10.5)	CPS Limit = 5,000 g oxide, 4,800 g metal	1.05 g to room 0.882 g out stack (via E-3)	0.41 onsite 0.15 offsite	8 Polycubes as Polycubes, 16 Polycubes as char = 1,200 g	0.328 g to room 0.275 g out stack (via E-3)	0.13 onsite 0.05 offsite

Appendix A: Peer Review Checklist

Practice 134 290 1112
Publication Date 22Nov99
Attachment 02 - Sheet 1 of 1

FLUOR DANIEL NORTHWEST

TECHNICAL PEER REVIEWS

CHECKLIST FOR TECHNICAL PEER REVIEW

Document Reviewed: HNF-7288
Title: Accident Analysis for the Plutonium Finishing Plant Polycube Stabilization Process
Author: D A Himes
Date: December 19, 2000
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.
☒ ☐ ☒ JLK 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 applicable guides or other standards.
☐ ☒ ** Review calculations, comments, and/or notes are attached.
☒ ☐ ☐ Document approved (for example, the reviewer affirms the technical accuracy of the document).

J C Van Keuren J C Van Ke 12/19/00
Reviewer (printed name and signature) Date

* All "no" responses must be explained below or on an additional sheet.

** Any calculations, comments, or notes generated as part of this review should be signed, dated, and attached to this checklist. The material should be labeled and recorded in such a manner as to be intelligible to a technically qualified third party.

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