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Title: Double Contingency Controls in the Pit Disassembly and Conversion Facility

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Double Contingency Controls in the Pit Disassembly and Conversion Facility

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ABSTRACT

A Pit Disassembly and Conversion Facility (PDCF) will be built and operated at DOE's Savannah River Site (SRS) in South Carolina. The facility will process over three metric tons of plutonium per year. There will be a significant amount of special nuclear material (SNM) moving through the various processing modules in the facility, and this will obviously require well-designed engineering controls to prevent criticality accidents.

The PDCF control system will interlock glovebox entry doors closed if the correct amount of SNM has not been removed from the exit enclosure. These same engineering controls will also be used to verify that only plutonium goes to plutonium processing gloveboxes, enriched uranium goes to enriched uranium processing, and that neither goes into non-SNM processing gloveboxes.

INTRODUCTION

The mission of the PDCF will be to recover plutonium from nuclear weapon pits and convert it to oxide for eventual use in making mixed oxide (MOX) reactor fuel. The facility will also have the capability to process highly-enriched uranium and various non-SNM metals that are also products of pit disassembly. The facility will include several storage and processing modules, all of which will require criticality controls.

Vaults

Nuclear weapon pits will be shipped to the PDCF where they will be stored in geometry-controlled storage locations in a vault. Vault operations will be carried out by remote control.

Pit Disassembly

The Pit Disassembly module is where pits are bisected and disassembled. Plutonium parts are size-reduced to maintain a fairly regular loading in the direct metal oxide (DMO) and hydride/dehydride reactors. Highly Enriched Uranium (HEU) is sent to HEU decontamination processing. Non-SNM hemishells are sent to declassification furnaces where they are melted.

Special Recovery Line (SRL)

The SRL line is for processing any pits contaminated with tritium. It is identical to and serves as a backup to the pit disassembly line, but it has furnaces where plutonium can be melted to release tritium.

Direct Metal Oxidation (DMO)

The DMO reactors convert plutonium metal into plutonium oxide, which is blended, stored, and eventually shipped to a MOX fuel fabrication plant where it will be converted to reactor fuel

Hydride/Dehydride

The hydride/dehydride reactor extracts plutonium metal from pit pieces containing plutonium attached to another metal. The resulting plutonium ingot is sent to DMO.

Highly Enriched Uranium (HEU) Processing

HEU hemishells are electrolytically cleaned to remove surface plutonium contamination. Batches of cleaned hemishell pieces will be sent to a DMO reactor to be converted to HEU oxide that will be shipped to Y-12 in Oak Ridge.

Oxide Product Handling

Cans of oxide will be blended, sampled, and sealed in crimp-seal "convenience" cans.

Product Canning

Convenience cans of oxide will be packaged in a welded DOE 3013 "inner" can that will be electrolytically cleaned and packaged in a welded DOE 3013 "outer" can. This DOE 3013 storage package will be sent to Nondestructive Assay (NDA) and then to a geometry-controlled vault for storage prior to being shipped to the MOX facility.

Nondestructive Assay (NDA)

DOE 3013 storage packages will be assayed to measure and record plutonium mass and isotopic content.

Sanitization

Non-SNM hemishells will be collected and melted into ingots to destroy classified shape information. The metal ingots will be discarded as waste.

Criticality Analysis During Design

Given the complexity of PDCF operations and material transfers, it is important that criticality analysis be an integral part of the design process rather than allowing the design process to force the use of less robust criticality controls. Nuclear Criticality Safety Evaluations (NCSEs) are being developed in Title I design for operations and equipment related to the following seventeen systems.

- Disassembly System
- Special Recovery Line System
- Plutonium Separation (Hydride/Dehydride) System
- Plutonium Conversion (Direct Metal Oxidation) System
- Oxide Product Handling System
- Product Canning System
- HEU Processing & Staging System
- NDA System
- Vault Storage System
- Waste Management System
- Shipping & Receiving System
- Sanitization (Declassification) System
- Internal Transport System
- Glovebox System
- Fire Protection System (Fire Water Collection)
- HVAC (Ventilation) System
- Analytical Laboratory System.

From a criticality safety perspective, the facility design must move toward a philosophy of using primarily engineering controls (active and passive) and minimize dependence on administrative controls. It is important that all involved, including the design engineers and managers, understand the meaning of double contingency, the relationship of analysis assumptions to controls (i.e., controls are used to protect assumptions) and that limiting conditions are often the result of considering credible off-normal conditions rather than normal operating conditions. The criticality engineer must be involved in the design process. Management recognition and support for the importance of integrating criticality safety in design is paramount.

During Title I design, the following process has been used to include criticality controls in process and system designs.

- Define the scope of the system/process to be evaluated.
- Identify and analyze the associated criticality safety hazards

- Develop limits and controls to assure safe operation
- Provide for the implementation of limits and controls by establishing the authorization basis.
- Feedback/iterate with design and/or operations

The PDCF is being designed by Washington Group International (WGI) in Denver, CO. Battelle is a subcontractor responsible for tasks related to plutonium processing. Much of the processing equipment was developed and demonstrated at the Los Alamos National Laboratory (LANL), and Jacobs Engineering is working with LANL to produce engineering designs for LANL's prototype equipment.

A Facility Design Description (FDD) was developed to establish design functions and requirements for those designing the facility. System Design Descriptions (SDDs) are being developed to describe design requirements and details for each processing module and facility system.

FDD Criticality Requirements

The FDD cites DOE Order 420.1, which defines criticality controls for new SNM facilities.

"Where a significant quantity of fissionable material is being processed and criticality safety is a concern, passive engineered controls such as geometry control shall be considered as a preferred control method. Where passive engineered control is not feasible, the preferred order of controls is: active engineered controls, followed by administrative controls."

The FDD lists the following specific requirements:

FDD Rev 2, R-1.0-4
The facility shall be designed to include the required design features from nuclear criticality safety evaluations, where all normal and credible abnormal conditions are analyzed, to ensure the facility to be subcritical.

FDD Rev 2, R-1.13-1
The PDCF design shall incorporate design, operations, and maintenance philosophies with engineered systems, structures, and components that assure the PDCF mission can be accomplished safely.

FDD Rev 2, 3.2.6.7
The PCDF shall be designed in accordance with nuclear criticality safety requirements in the WSRC Nuclear Criticality Safety Manual, WSRC-SCD-3.

FDD Rev 2, 3.1.1
Where there is a choice in the design of the Level of Controls (LOC), the following rules apply:

- Structures, Systems and Components (SSC's) are preferred over administrative controls.
- "Passive" features are preferred over "active" features.
- Preventative controls are preferred over mitigative controls.
- Design of the Level of Controls closest to the Hazard and if possible between the Hazard and the nearest receptor is preferred.
- Design of the Level of Controls which are common to many events is preferred.

FDD Rev 2, 3.2.6.36
Both operating and maintenance conditions shall be addressed in the criticality evaluations. Many sites have criticality issues because they have not evaluated maintenance conditions.

FDD Rev 2, 3.2.6.37
Criticality safety controls shall be provided that are easy to validate visually, where feasible.

FDD Rev 2, R.3.2.9-2
Every operational area, equipment, or storage area shall be designed considering engineered criticality controls or by features that enable an emphasis on engineering controls but recognizes that administrative controls may be appropriate where engineered approaches may be overly prescriptive or expensive.

FDD Rev 2, R-2.0-2
A strategy for material movement in process enclosures (gloveboxes, hoods) shall be developed with a nuclear criticality analysis and material balance.

Engineering Controls

The primary process parameters being utilized in establishing criticality controls are: mass, geometry, and density. Geometry controls are used in vault storage and in staging locations in some of the gloveboxes. Density is defined by the metal feed materials and by conservative assumptions of oxide density based on LANL operations.

The criticality limits for most gloveboxes are related to mass and require assuring that the mass limits specified for the criticality control area (CCA) will not be exceeded. Frequently, this constitutes assuring that the glovebox is "basically empty" before additional mass may be introduced into the glovebox.

In developing the engineered control strategy for maintaining mass limits, a number of alternatives were considered. For example, a system to scan part numbers was considered. Experience in the nuclear industry has shown that part numbers are sometimes difficult to read and even when the numbers are very legible, there is a high frequency of error. Therefore, relying on identification numbers to differentiate the parts based on fissile content and non-fissile content is not considered acceptable as a criticality control.

A laser optic system to monitor the glovebox was eliminated as it was assumed to be functionally limited (i.e., would only see material in the open, not in storage containers). Use of an NDA system to verify the box is clean between every operation would require frequent wipedowns and lengthy counting times, i.e., it is not practical for the entire glovebox to be assayed frequently. Placing the entire glovebox on a scale was judged impractical since the mass differences for many of the pieces would be masked by the uncertainty in the mass measurement itself (since the equipment and glovebox would be significantly heavier than the allowed mass of fissile material). Another alternative is to develop and utilize physical interlocks and control logic to provide engineered controls. Physical interlocks to implement mass controls that rely on mass measurements, load cells, gamma scans and other NDA measurements are considered the most practical approach. Redundancy, controls, system reliability, the degree to which the operator interfaces or can override the system will all impact the effectiveness of the control and should be considered in order to optimize the control system design

The feasibility of such an engineered system has only been evaluated in the context of the ability of known NDA techniques to perform the required measurements within a reasonable duration under the geometry conditions anticipated in PDCF operations. Results from the evaluation of the errors associated with the determination of fissile mass by nuclear NDA measurement methods alone were not promising. Capabilities were excellent for small quantities in almost any given geometry. Also, larger quantities in identically repeatable geometries would possess reasonably small total errors. However, larger quantities in varying geometries would possess errors that would soon propagate to values large enough that criticality control area limits on material at risk would be exceeded. This would impact process operation, requiring the process line to be shut down, the criticality control area cleaned, and the residual in the criticality control area re-zeroed.

To minimize errors and to have a conservative approach, a go/no-go NDA counter is coupled with a scale for the determination of fissile mass. Typically, if fissile mass is detected by the go/no-go counter then the weight of the item measured by the scale is ascribed as the total fissile mass of the item. In the case of metal to oxide conversion, a multiplication factor of 0.882 is applied to plutonium oxide weight and a multiplication factor of 0.880 is applied to uranium oxide. Sanitization is an exception because its function is to melt non-SNM. The typical fissile mass of a contaminated item will be only a few to several grams. The fissile mass in the Sanitization module will be determined by nuclear measurements.

PDCF design engineers were concerned that the throughput time, in some cases, would be negatively impacted when a single mass limit is applied to an entire glovebox line. The concept of "Criticality Control Areas, CCAs" was developed to simply subdivide glovebox lines into multiple control areas to address this concern. In general, if the control logic used between CCAs is similar to that used to control fissile material movement into and out of the gloveboxes, the use of multiple CCAs within a single glovebox line is feasible. "Criticality Pass Through" (CPT) areas within a glovebox line (i.e., between adjacent CCAs) shall be designed to provide physical separation between fissile materials in adjacent process areas and provide an interlock system with door sequencing coupled to instrumentation (mass and SNM monitoring) to account for fissile mass. The major impact is a requirement to have a CPT separating individual process areas functioning as CCA's. The CPT would need to have the following attributes:

- Be physically isolated from the process areas leading to and following the pass through with doors that can be tied to an interlock system to positively control the direction of fissile material movement (this requires 2 doors).
- Provide physical separation between the two criticality control areas (a minimum 15" spacing is required)
- Measure and record total mass of the material being passed through
- Confirm the presence/absence of fissile material (plutonium and HEU)
- Preclude manual operations involving fissile material within the pass through area itself (i.e., have no gloveport access).
- Be equipped with an engineered system to "automate" the movement of fissile material through the pass through. This could be either a track system or "drive-thru teller drawer system," where the later provides spacing and does not require the use of a transfer container.

Lag storage locations will be located within gloveboxes to provide a safe-haven for in-process material under upset conditions. These storage locations should only be used in off-normal situations. These lag storage positions should: (1) provide geometrically-safe storage with adequate shielding to protect workers during the maintenance/repair operations, (2) interlock with the entry doors to the criticality control area such that detection of the presence of mass in the lag storage location will lock the entry doors

prohibiting additional mass from entering the criticality control area and (3) remain locked until normal operations can be resumed.
In addition to mass limits for CCAs and/or gloveboxes, mass limits for individual pieces of equipment (e.g., furnaces, blenders, etc.) may be required. These additional limits will be identified and quantified as the design process progresses.

Criticality Pass Through #1 (CPT1) (Usually an Air Lock to Conveyor System)	Process Area 1	Criticality Pass Through #2 (CPT2)	Process Area 2	Criticality Pass Through #3 (CPT3) (Air Lock to Conveyor System)
D1 D2	D3	D4	D5	D6

(D1- Interlocking Door #1, D2 – Interlocking Door #2, etc.)

Strawman Engineered Control Strategy for a PDCF Generic Process

This is a sample of generic control logic that may be used for segregating criticality control areas and ensuring compliance with mass limits within each criticality control area.

- D1 unlocks if the area between doors D1 & D2 is verified to be "empty." (Note: Fissile material entering and exiting gloveboxes from/to the conveyor system are contained in a "Transfer Container" designed to be passively safe.)
- Material enters into Pass Thru Area 1 (generally from a Drop box) thru Door 1 (D1)
- D1 LOCKS
- Total mass is measured (requires scale in pass thru) [the control system may compare measured mass with a known book value as a defense-in-depth measure for criticality or for other purposes not related to criticality]
- Threshold Pu measurement (conditional) to confirm presence/absence or amount of Pu
- Threshold HEU measurement (conditional) to confirm presence/absence of HEU
- Data recorded in control system
- D2 UNLOCKS IF it passes ALL Pu/HEU conditional controls AND it is verified that the sum of the record mass (includes holdup) of fissile material in Process Area 1 (area between D2 & D3) and the mass presently in CPT1 will not exceed the criticality mass limit for Process Area

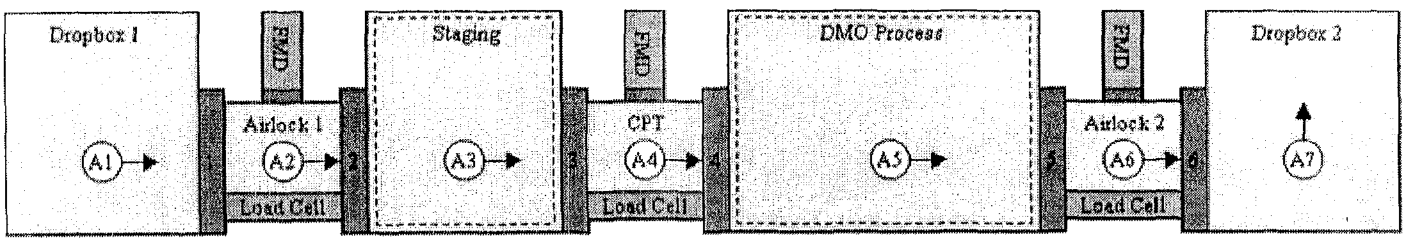
Any failed condition requires shutdown/ operator intervention

- Material enters thru D2 into Process Area 1
- D2 LOCKS
- Criticality Pass Thru #1 (CPT1) is verified to be "empty" - THEN if CPT1 is a drop box fed by a conveyor, the conveyor is now released for operations.

SNM is processed through the rest of the system in a similar manner.

PDCF Example

The sketch of the DMO system shows load cells and a Fissile Material Detector System



(FMD) at each airlock and criticality pass through (CPT). The combination of these two sensors and the Process Control System (PCS) record of material transfer movements will provide sufficient information to verify what fissile material has entered and left these process areas.

The FMD will include a gamma detector and a neutron detector. Manufacturers of gamma spectrum measurement (NaI) and neutron counting (He-3) devices indicate that the measurements will easily verify the presence of the quantities of plutonium and/or highly enriched uranium that will be transferred in the PDCF. The detectors are also able to give precise quantitative mass information for some operations such as for waste transfers. However for most process operations, the FMD will not be capable of providing accurate quantitative masses due to self-shielding of SNM and variations in geometry. This is why a load cell is included to provide a reasonably accurate weight into the control logic. This weight is not meant to be an accountability measurement, just a criticality control logic input. The ability to weigh an item that travels into the airlock on an automated transfer cart is achievable, but it may not be as accurate as the accountability measurements done on precision scales in the glovebox.

For the DMO module shown below, the control system will be able to verify that the plutonium that came into A3 from A2 has exited into and through A4 before the conveyor system is allowed to bring a new plutonium transfer container to A1. A5 is the location of the conversion reactor. Plutonium metal that was weighed and verified in A4 will be measured in A6 (with a corrected weight, since the metal is now an oxide) to verify that it has left the processing area. Also, the control system can verify that the appropriate areas have been cleared before bringing empty oxide bottles from A7 through A6 into A5.

Summary of Requirements for Engineered Controls for Mass Limits

The following is a synopsis of the conditions and requirements for developing and implementing engineered controls for maintaining mass limits in the PDCF.

- Control total and/or fissile mass in and total and/or fissile mass out accounting for limited holdup (depending on whether all mass differences (in/out) are fissile material).
- Use physical interlocks with software controls to manage material movement/criticality mass balances.
- SNM monitoring will be used to positively identify the movement of plutonium and HEU and to detect when fissile material is NOT present (to support movement of routine consumables and supplies).
- Criticality pass through (CPT) areas should be operated "hands-free" (no gloveports)
- Define the conveyor system as spanning between airlock doors (i.e., to include drop boxes).
- The location of lag storage positions (either for upset conditions or for staging) should be carefully considered in developing the control system for individual processes. No lag storage will be allowed in the drop boxes where material is delivered to/from airlocks from the conveyor system. Use of the airlocks themselves for lag storage would only be feasible if fissile material can be introduced into the airlock in a passively-safe transfer container. A detailed evaluation of lag storage in airlocks is dependent on the transfer container design, which has not been finalized.

- Lag storage locations within gloveboxes (for the purpose of providing a safe-haven for in-process material under upset conditions) should be used only in off-normal situations, provide geometrically-safe storage, provide adequate shielding to protect workers during the maintenance/repair operations, interlock the entry doors to the criticality control area such that detection of the presence of mass in the lag storage location will LOCK the entry doors and prohibit the entry of additional mass and shall remain LOCKED until normal operations can be resumed.
- In addition to mass limits for gloveboxes, mass limits for individual pieces of equipment (e.g., furnaces, blenders, etc.) may be required. These constraints should be provided as part of the design for the respective equipment.

Conclusion

The PDCF will process significant quantities of plutonium and highly enriched uranium. There will be a lot of material transfer activity associated with moving SNM and non-SNM to and through the various processing modules. Criticality analysis must be an integral part of the PDCF design process to provide adequate criticality controls. The primary criticality limits for material movement in conveyor systems and in process gloveboxes are related to mass. Engineered controls will be designed into the process equipment to assure that the mass limits specified for the criticality control area (CCA) will not be exceeded.

Weight and SNM isotopic measurements will be recorded in the entrance airlocks and CPT areas designed for each processing module. This information, coupled with logic records of automated material transfer, will be used to limit the mass of SNM that is present in each criticality control area.

The engineered mass control system is combined with engineered controls to preclude flooding (e.g., criticality drains) and otherwise limit moderating materials to provide the foundation for double contingency protection against an inadvertent criticality during PDCF operations. These engineered approaches are complex, but not overly prescriptive or expensive. They will prevent SNM transfers into areas where SNM limits would be exceeded and into areas where SNM doesn't belong. They will also verify that areas are below SNM limits to allow transfer of empty containers, trash, and processing equipment into and out of glovebox spaces.

References:

1. *Nuclear Criticality Safety in the Design of the Plutonium Disposition and Conversion Facility (PDCF)*, Michaele (Mikey) Brady-Raap (Battelle), and Marc Rosser (Westinghouse Safety Management Solutions), B-PDCF-075, Revision 0, (September 12, 2000).
2. DOE-STD-3013-2000, *Stabilization, Packaging, and Storage of Plutonium-Bearing Materials,* September 2000