Nuclear Criticality Safety Assessment of Collared Drum Repack Area Operations at the Hematite Site

Revision 0

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Glossary of Acronyms, Abbreviations, and Terms

Acronym/Term	Definition
ACM	Asbestos Containing Material
AEC	Atomic Energy Commission
ALARA	*as low as reasonably achievable*
Assay Container	Container used to collect decommissioning debris into a known geometry to assist in efficient assay
CCIS	Criticality Control Inventory System
CD	Collared Drums (CDs) are used for *Field Container*, *Assay Container* or *Fissile Material Container* transit between functional areas of the site, and for *Field Container*, *Assay Container* or *Fissile Material Container* staging/storage. Each CD has a cylindrical geometry, possessing a minimum internal diameter of 57cm. Each CD, irrespective of dimension, is fitted with a collar that extends 18" beyond the external radial surface of the CD. The CD collar is designed to ensure that any un-stacked arrangement of CDs would guarantee a minimum 36" separation distance between the outer surfaces of the CDs. The affixed collar is permanently secured to the CD and is not removed at any time the CD is being used, except when secured in a FMSA or CDRA.
CDRA	Collared Drum Repack Area
CFR	Code of Federal Regulations
cm	centimeter
CSC	Criticality Safety Control
DCD	Decollared Drum
D&D	Decontamination and Decommissioning
DOT	Department of Transportation
Double Contingency Principle	Safety principle interpreted by ANSI/ANS-8.1 as "Process designs should incorporate sufficient factors of safety to require at least two *unlikely*, independent, and concurrent changes in process conditions before a criticality accident is possible."
EALF	energy corresponding to the average lethargy of neutrons causing fission
Field Container	Container used to collect suspected *Fissile Material* discovered during decommissioning activities (limited in volume to 20 liters)
Fissile Material	Material that contains a significant quantity of enriched uranium such that criticality safety controls are required when handling.
FMSA	*Fissile Material* Storage Area
g	gram
g/cc	gram per cubic centimeter
GUNFC	Gulf United Nuclear Fuels Corporation
H/X	Ratio of hydrogen atoms to fissile isotope atoms
highly improbable	Probability of occurrence not expected during the anticipated decommissioning duration and involves concurrent fruition of at least two independent and *unlikely* occurrences
HRGS	High resolution gamma spectrometer
HVAC	Heating, Ventilation, and Air Conditioning
MC&A	Material Control and Accountancy
MCNP	Monte Carlo Neutron-Photon
MO	Missouri
NaI	sodium iodide
NCSA	Nuclear Criticality Safety Analysis
PCE	Perchloroethylene

poly	polyethylene
SNM	Special Nuclear Material (synonymous with '*Fissile Material*' used in this document)
SSC	System, structure, or component relied upon for safety
TRU	Transuranic (nuclides with a larger proton count than uranium)
U	uranium
UF_6	uranium hexaflouride
UNC	United Nuclear Corporation
unlikely	Probability of occurrence no greater than one time during the anticipated decommissioning duration
UO_2	uranium dioxide
WEA	Waste Evaluation Area
wt. %	Percentage by weight

1.0 INTRODUCTION

This Nuclear Criticality Safety Assessment (NCSA) is provided in support of final decommissioning of the Hematite site. The activities assessed in this NCSA involve only Collared Drum Repack Area (CDRA) operations.

This NCSA is organized as follows:

- **Section 1** introduces the NCSA of CDRA operations at the Hematite site.
- **Section 2** provides the risk assessment of CDRA operations, as outlined in Section 1.
- **Section 3** summarizes the important engineered and administrative requirements identified in the criticality safety risk assessment provided in Section 2.
- **Section 4** details the conclusions of the NCSA of CDRA operations at the Hematite site.

1.1 Description of the Hematite Site

The Westinghouse Hematite site, located near Festus, MO, is a former nuclear fuel cycle facility that is currently undergoing decommissioning. The Hematite site consists of approximately 228 acres, although operations at the site were confined to the "central tract" area which spans approximately 19 acres. The remaining 209 acres, which is not believed to be radiologically contaminated, is predominantly pasture or woodland.

The central tract area is bounded by State Road P to the north, the northeast site creek to the east, the union-pacific railroad tracks to the south, and the site creek/pond to the west. The central tract area currently includes former process buildings, facility administrative buildings, a documented 10 CFR 20.304 burial area, two evaporation ponds, a site pond, storm drains, sewage lines with a corresponding drain field, and several locations comprising contaminated limestone fill.

1.2 Hematite Site History

Throughout its history, operations at the Hematite facility included the manufacturing of uranium metal and compounds from natural and enriched uranium for use as nuclear fuel. Specifically, operations included the conversion of uranium hexaflouride (UF_6) gas of various ^{235}U enrichments to uranium oxide, uranium carbide, uranium dioxide pellets, and uranium metal. These products were manufactured for use by the federal government and government contractors and by commercial and research reactors approved by the Atomic Energy Commission (AEC). Research and Development was also conducted at the facility, as were uranium scrap recovery processes.

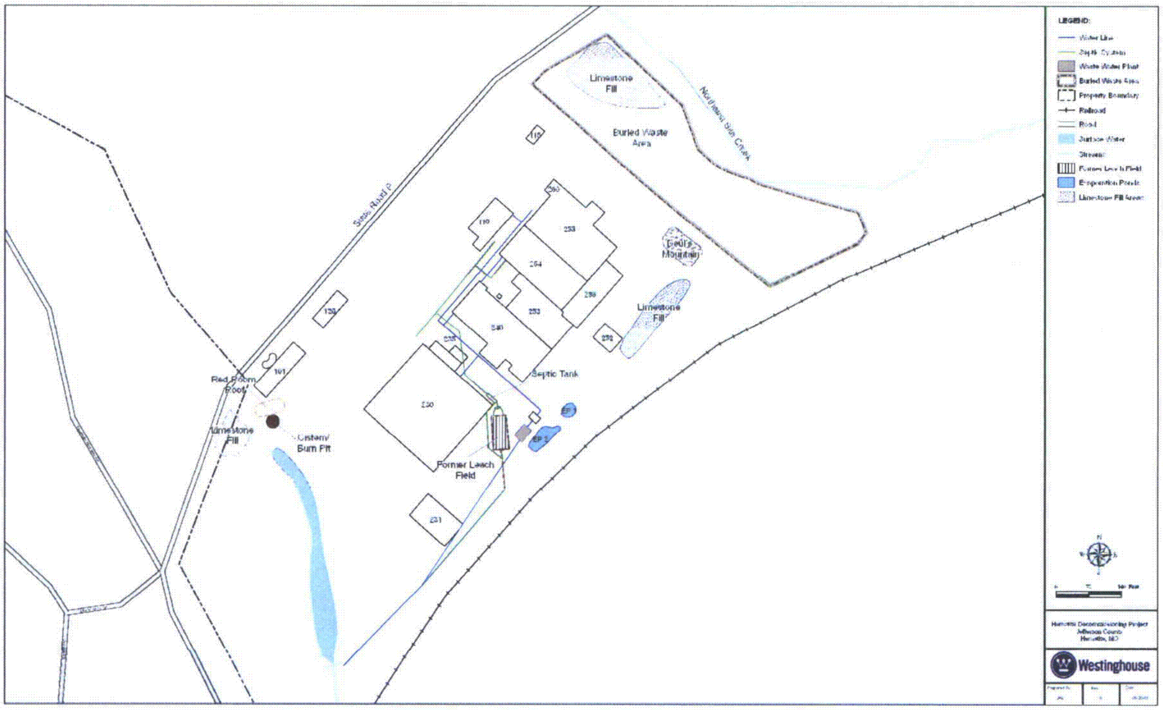
The Hematite facility was used for the manufacture of low-enriched (i.e., $\leq$ 5.0 wt.% ^{235}U), intermediate-enriched (i.e., >5 wt.% and up to 20 wt.% ^{235}U) and high-enriched (i.e., > 20 wt.% ^{235}U) materials during the period 1956 through 1974. In 1974 production of intermediate and high-enriched material was discontinued and all associated materials and equipment were removed from the facility. From 1974 to cessation of manufacturing operations in 2001, the Hematite facility produced nuclear fuel assemblies for commercial nuclear power plants. In 2001, fuel manufacturing operations were terminated and the facility license was amended to reflect a decommissioning scope. Accountable uranium inventory was removed and Decontamination and Decommissioning (D&D) of equipment and surfaces within the process buildings was undertaken. This effort resulted in the removal of the majority of process piping and equipment from the buildings. At the conclusion of that project phase, the accessible surfaces of the remaining equipment and surfaces of the buildings were sprayed with fixative in preparation for building demolition.

1.2.1 Historic Operations

Historic operations at the Hematite site resulted in the generation of a large volume of process wastes contaminated with uranium of varying enrichment. Records indicate that as early as 1958, facility process wastes were consigned to unlined burial pits situated in the North East corner of the site's central tract.

1.2.1.1 Documented Burials

Based on historic documentation (Ref. 2), 40 unlined pits were excavated northeast of the plant buildings and southwest of "Northeast Site Creek" and were used for the disposal of contaminated materials generated by fuel fabrication processes at Hematite between 1965 and 1970. The documented burial area perimeter is outlined in Figure 1-1. Based on best available information, it is believed that the burial pits are nominally 20' × 40' and 12' deep.



Source: Ref. 2

Figure 1-1 Documented Burial Pit Area

Consignment of waste to the burial pits was reported to be in compliance with Atomic Energy Commission (AEC) regulation 10 CFR 20.304 (1964; Ref. 3). Facility operating procedures (Ref. 4) described the size and spacing requirement for the burial pits, in addition to the required thickness of the overlying soil cover (4'), and the quantity of radioactive material that could be buried in each pit. The procedures in place at the time of operation of the burial pits required that buried waste be covered with approximately 4' of soil following completion of pit filling operations. However, it is possible that the soil cover thickness may have been modified over time as the area where the burial pits are located was re-graded on several occasions.

United Nuclear Corporation (UNC) and Gulf United Nuclear Fuels Corporation (GUNFC) maintained detailed logs of burials for the period of July of 1965 through November of 1970. The Burial Pit log books (Ref. 5) contain approximately 15,000 data entries listing the date of burial, pit number, a description of the particular waste consignment, the uranium mass associated with the subject waste, and miscellaneous logging codes. Some logbook entries also list percent enrichment for the uranium. On-site burial of radioactive material ceased in November of 1970.

The information recorded in the Burial Pit log books indicates that the waste consignments comprised a wide variety of waste types. This is further supported by interviews with past employees (Ref. 6). A listing of the types of waste materials that may be present in the Burial Pits is provided in Table 1-1. The primary waste types expected to be encountered are trash, empty bottles, floor tile, rags, drums, bottles, glass wool, lab glassware, acid insolubles, and filters. Buried chemical wastes include hydrochloric acid, hydrofluoric acid, potassium hydroxide, trichloroethene (TCE), perchloroethylene (PCE), alcohols, oils, and waste water.

Table 1-1 Buried Waste Characteristics

Process Metals and Metal Wastes	
• High enriched uranium (93-98%) • Depleted and natural uranium • Beryllia UO_2 • Beryllium plates • Uranium-aluminum • Uranium-zirconium • Thorium UO_2	• UO_2 samarium oxide • UO_2 gadolinium • Molybdenum • Uranium dicarbide • Cuno filter scrap that included beryllium oxide • Niobium pentachloride
Chemical Wastes	
• Chlorinated solvents, cleaners and residues (perchloroethylene, trichloroethylene) • Acids and acid residues • Potassium hydroxide (KOH) insoluables • Ammonium nitrate • Oxidyne • Ethylene glycol	• Ammonium bichloride • Sulfuric acid • Uranyl sulfate • Acetone • Methyl-alcohol • Chlorafine • Pickling solution • Liquid organics
Other Wastes	
• Tiles from Red Room floor • Process equipment waste oils • Oily rags • TCE/PCE rags • Used sample bottles • Green salt (UF_4) • Calcium metal	• Contaminated limestone • UO_2 THO_2 Paper Towels • Pentachloride from vaporizer • Used Magnorite • $NbCl_5$ vaporizer Cleanout • Item 51 Poison equipment • Asbestos and Asbestos Containing Material (ACM)

Source: Adapted from Ref. 2

The recorded total uranium mass associated with the waste consignments range from 178 g^{235}U to 802 g^{235}U per burial pit with a maximum amount associated with any single waste consignment (i.e., burial item) of 44 g^{235}U. The uranium enrichment of waste items consigned to the burial pits ranged from 1.65 wt. % to 97.0 wt. % ^{235}U/U. According to the Burial Pit log books, the five most frequent waste consignments comprised:

- Acid insolubles (2,050 entries);
- Glass wool (2,080 entries);
- Gloves and liners (900 entries);
- Red Room trash (570 entries); and
- Lab trash (515 entries).

The waste consignments representing the highest recorded ^{235}U content included:

- Wood filters (4 entries ranging from 22 to 44 $g^{235}U$);
- Metal shavings (one entry at 41 $g^{235}U$);
- Leco crucibles (4 entries ranging from 29-31.6 $g^{235}U$); and
- Reactor tray (one entry at 40.4 $g^{235}U$).

1.2.1.2 Undocumented Burials

It is assumed (Ref. 2) that additional, undocumented, burial pits may exist within the area between the former process buildings and the documented burial pit area. Based on interviews with former site employees (Ref. 6), it is possible that on-site burials other than burials conducted under 10CFR20.304 (1964; Ref. 3)) may have occurred as early as 1958 or 1959. Specifically, three or four burials may have been performed each year prior to 1965 for disposal of general trash and items that were lightly contaminated by current radiological free release standards (Ref. 1). Based on this information, it is estimated that a total of 20-25 burial pits may exist for which there are no records. Waste consignments to these burial pits (i.e., prior to 1965) were not documented (logged) as they were not considered to contain significant quantities of SNM (Ref. 7). No specific information has been found to indicate the explicit nature of the waste consignments associated with these undocumented burials.

1.2.2 Current State

The presence of SNM at the Hematite site is currently limited to residues associated with the former process buildings and process wastes consigned to the burial pits. During remediation of the burial pits it is possible that quantities of SNM may be identified and recovered from the process wastes following their exhumation. Any recovered SNM will be interim stored pending future export to an off-site facility or an on-site SNM dispersion process. Note that the storage or repacking of CDs containing residues recovered during final decommissioning of the former process buildings is outside the scope of this NCSA.

1.3 Anticipated SNM Consignments

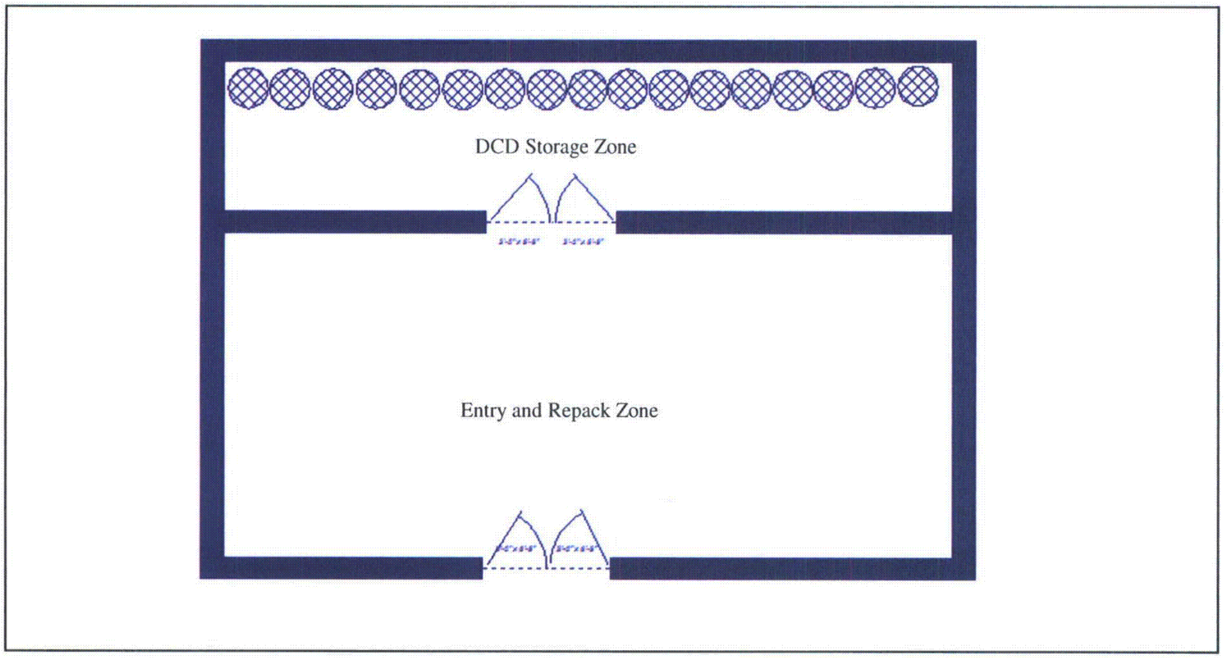
The remediation operation for the burial pit area of the site will result in the exhumation of buried process wastes. Based on the results of in-situ monitoring, high concentrated pockets of soil and other small debris will be exhumed into a *Field Container* which is then placed singly in a Collared Drum (CD). Larger intact containers (such as drums pulled from the burial pits) or bulky items are placed directly into a CD bypassing the *Field Container*. The CD is subsequently transferred, one at a time, to a Waste Evaluation Area (WEA) for detailed characterization. In the WEA, the material within a *Field Container* will be spread to create a thin layer on a 'sorting surface'. Visual inspection and gamma survey (using hand-held NaI detectors) will be used to identify any uranium that is discrete within the debris matrix. Portion(s) of the debris matrix determined to not contain uranium (or to contain acceptably low uranium content) will be extracted and returned to the main waste stream. The remaining portion(s) of the debris matrix will be packaged into an *Assay Container* and transferred to an adjacent area for counting using a High

Resolution Gamma Spectrometer (HRGS). The HRGS equipment returns a total ^{235}U mass content for the package. The HRGS mass estimate is assigned to the *Assay Container*, which is labeled with a description of the container content, an item number, date, U mass, ^{235}U mass, and U enrichment. In addition, CDs may be reclassified as an *Assay Container* if the entire CD is assayed (which is necessary for large bulky items or large intact containers within a CD). The *Assay Container* is then transferred within a CD (if the CD is not the *Assay Container*) to a *Fissile Material* Storage Area (FMSA) for storage or a CDRA for *Fissile Material* repack and subsequent storage. In the CDRA, the items are removed from the CD and placed into an empty or partially filled Decollared Drum (DCD) (if allowed by *Fissile Material* packing limits).

1.4 Overview of the CDRA Operations

As depicted in the following sketch, two zones comprise a CDRA:

1) Entry and Repack Zone and
2) DCD Storage Zone



Source: Original

Figure 1-2 Representation of a CDRA

1.4.1 Entry and Repack Zone Operations

The Entry and Repack Zone is the only entrance/exit into or from the CDRA. All *Fissile Material* recovered from the site is brought in CDs into this Entry and Repack Zone for proper logging. The CDRA personnel are given advance notice prior to all transfers of *Fissile Material* to the CDRA. The doors of the Entry and Repack Zone are maintained in a locked condition when the CDRA is not in operation.

When a CD is introduced into the Entry and Repack Zone, personnel first ensure that other

Fissile Material is not present in the Entry and Repack Zone. Since the purpose of this Entry and Repack Zone is to consolidate *Fissile Material* into DCDs for subsequent storage, the personnel determine an appropriately stored DCD to retrieve from the DCD Storage Zone and transfer it to the Entry and Repack Zone. The item from the CD is removed and placed into the retrieved DCD. The *Fissile Material* content tally on the DCD is properly updated. The DCD is then re-lidded and returned to the DCD Storage Zone. The empty CD is verified clean and empty and removed from the CDRA. If consolidation of the *Fissile Material* is too large or the debris too bulky for repack into an existing stored DCD, then an empty DCD (staged within the Entry and Repack Zone) is used to transfer the *Fissile Material* from the CD. The DCD is then lidded, properly documented with the *Fissile Material* transfer, and transferred to the DCD Storage Zone. The repacking *Fissile Material* limit is ≤ 125 g^{235}U per DCD.

All *Fissile Material* introduced into the Entry and Repack Zone and subsequent consolidations/transfers are logged by the personnel. To ensure that too much *Fissile Material* does not exist at any given time within the Entry and Repack Zone, a minimum of two operators with adequate supervision/oversight (such as security cameras) are always present when the CDRA doors are unlocked. This ensures that *Fissile Material* is not brought into the Entry and Repack Zone without the recognition and acceptance of the CDRA personnel and supervision. In addition, only a single CD containing *Fissile Material* (along with an appropriate consolidation DCD) is approved at a time within the Entry and Repack Zone thereby also preventing too much *Fissile Material* in this zone.

1.4.2 DCD Storage Zone Operations

The DCD Storage Zone within the CDRA is used only for storage of lidded DCDs containing *Fissile Material* no greater than 125 g^{235}U in each. The DCDs are stored in a close-contact planar array. The entry doors to this zone are maintained in a dual locked condition such that two different personnel are required to enter and maintain presence while transferring DCDs in and out of this zone. No stacking of DCDs is permitted in this zone. It is important to note that records and labels are kept for every DCD in the DCD Storage Zone.

1.5 Scope of Assessment

The activities addressed in this NCSA include all actions associated with the CDRA operations. The following activities are specifically excluded from this assessment:

- The recovery, handling and transit of *Fissile Material* to the CDRA. The criticality safety assessment of buried waste exhumation and contaminated soil remediation activities is provided in Ref. 8.
- The transportation of *Fissile Material* from the Hematite site (e.g., to an off-site waste facility or an off-site sampling laboratory).
- Activities related to the on-site processing or dispersion of *Fissile Material.*
- Storage or repacking of CDs containing residues recovered during final decommissioning of the former process buildings.

1.6 Methodology

1.6.1 NCSA Approach

This NCSA uses a risk-informed approach. Risk insights, gained from the findings of the risk assessment, are used to establish aspects of the design and process (if any) that are susceptible to faults important to nuclear criticality safety.

The risk-informed approach is complemented with an ALARA (*as low as is reasonably achievable*) assessment that is focused on identifying practicable measures that can be reasonably implemented to further reduce the risk of criticality to a level *as low as is reasonably achievable.* The ALARA assessment also serves to provide an additional degree of confidence that a criticality incident resulting from the activities assessed is *highly improbable.*

In summary, the approach used in this NCSA is as follows:

1) Establish the margin of safety between normal (i.e., expected) conditions and foreseen credible abnormal conditions.
2) Determine whether the inherent margin of safety is sufficient to safely accommodate the credible deviations from normal conditions, and if not, identify feature(s) of the process* that are important to ensuring criticality safety under all credible conditions.
3) Establish what additional practicable measures, if any, can reasonably be implemented to ensure that the risks from criticality are *as low as is reasonably achievable.*

1.6.2 Method of Criticality Control

This section outlines the criticality safety basis of CDRA operations.

The underlying criticality control philosophy is based on the management of *Fissile Material* within established safe mass and geometry limits.

For the purpose of Criticality Control, all areas of the site are subject to an inventory control system similar to that used for Material Control and Accountancy (MC&A) purposes. All identified *Fissile Material* on the site, irrespective of location and including all *Fissile Material* in transit within the site boundary, will be recorded and entered into the Criticality Control Inventory System (CCIS). The CCIS will run in parallel to the MC&A system and the Material Custodian will be responsible for both. However, the MC&A system does not form part of the CCIS and is not necessarily aligned.

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* In the selection of safety controls, preference is placed on use of engineered controls over procedural controls.

2.0 CRITICALITY SAFETY ASSESSMENT

The criticality safety assessment is organized as follows:

- **Section 2.1** describes the hazard identification method employed in the criticality safety assessment of CDRA operations and provides a summary of the hazard identification results.
- **Section 2.2** outlines the generic assumptions used in the criticality safety assessment.
- **Section 2.3** contains the criticality safety assessment of CDRA operations under normal (i.e., expected) conditions.
- **Section 2.4** contains the criticality safety assessment of CDRA operations under abnormal (i.e., unexpected) conditions.

2.1 Criticality Hazard Identification

This section outlines the technique used to identify criticality hazards associated with CDRA operations. A summary of the hazards identified is also provided, together with a brief description of their disposition in the NCSA.

2.1.1 Hazard Identification Method

The hazard identification technique employed in the criticality safety assessment of CDRA operations uses a *What-if/Checklist* analysis method where the remediation approach and overall objectives are scrutinized and examined against postulated situations, focused on challenging criticality safety. As part of this process, the *What-if/Checklist* analysis steps through the eleven (11) criticality safety controlled parameters to determine the extent of their importance to criticality safety.

The eleven (11) criticality safety controlled parameters examined include:

- Geometry
- Interaction
- Mass
- Isotopic/Enrichment
- Moderation
- Density
- Heterogeneity
- Neutron Absorbers
- Reflection
- Concentration
- Volume

The eleven (11) parameters listed above are traditionally considered in criticality safety assessments of processes at operating facilities possessing SNM. Typically, the non-processed based nature of decommissioning operations and associated residues limits the ability to control many parameters, resulting in the need to use bounding values for parameters in the NCSA in many instances.

2.1.2 Hazard Identification Results

A summary of the criticality hazards identified from the *What-if/Checklist* analysis is presented in Table 2-1 and are based on Reference 11. Hazards that result in events with similar consequences and safeguards are grouped in single criticality accident event sequences, analyzed in Section 2.4.

Table 2-1 Criticality Hazards Identified from the CDRA Operations What-if/Checklist Analysis

What-if	Causes	Unmitigated Consequences	Accident Sequence in NCSA
		Geometry	
What if containers other than CDs or DCDs are collected, stored, or used for repack within a CDRA?	Empty DCDs are no longer available Smaller containers are easier to store	Potential criticality accident due to unevaluated storage configuration	**Section 2.4.1**
		Interaction	
What if DCDs get placed on top of each other in the DCD Storage Zone?	Loss of floor space leads to vertical storage	Potential criticality accident if DCDs are stacked too high	**Section 2.4.2**
		Mass	
What if a significant quantity of *fissile material* is localized within the Entry and Repack Zone at a time?	Entry and repack zone is used for storage because the DCD Storage zone is full The doors are locked to the DCD Storage zone Significant floor space in Entry and Repack Zone as compared to DCD Storage zone leads to storage in Entry and Repack Zone Entry and Repack Zone becomes inundated with requests to store and/or repack debris more quickly	Potential criticality accident if too many high mass DCDs are placed in close proximity	**Section 2.4.3**
What if a significant quantity of *fissile material* becomes localized into a DCD while in the CDRA?	Lack of available DCDs leads to combining contents of too many DCDs	Potential criticality accident if *Fissile Material* quantity is unchecked and quantity reaches high values in the DCDs.	**Section 2.4.4**

What-if	Causes	Unmitigated Consequences	Accident Sequence in NCSA
What if *fissile material* reported within CDs is lower than actual when introduced into a CDRA for repack or storage?	This hazard is identified and evaluated in Ref. 8. The cited reference reports that the probability of adverse consequence to the criticality safety of the repacking and storage operations in a CDRA is sufficiently low such that consideration of the consequences is not necessary in this present analysis.		
Isotopic/Enrichment			
There are no identified hazards associated with creating a more adverse condition in a CDRA in respect to the "Isotopic/Enrichment" parameter. No hazards have been identified because the bounding normal condition within the CDRA assumes that the *Fissile Material* within CDs and DCDs consists of theoretically dense uranium metal enriched to 100% of the ^{235}U isotope thereby anticipating an isotopic/enrichment condition that cannot be credibly challenged further.			
Moderation			
What if the debris within CDs contains significant hydrogenous material or other material that has a significant neutron moderating efficacy?	Undocumented waste forms on historical data records or Liquids remain in debris after being evaluated in upstream WEA	None. Bounding conditions of internal moderation are shown to maintain safe levels of reactivity within the CDRA.	**Section 2.4.5**
What if rainwater/snow or hydrogenous fire suppressive material infiltrates DCDs while in storage?	Building/structure fatigue or activation/use of fire suppressive material	None. Bounding conditions of external moderation are shown to maintain safe levels of reactivity within the CDRA.	**Section 2.4.6**
What if CDRA floods to or beyond the height of the DCDs?	Inclement weather followed by massive infiltration of water	None. Bounding conditions of external moderation are shown to maintain safe levels of reactivity within the CDRA.	**Section 2.4.7**
Density			
There are no identified hazards associated with creating a more adverse condition in the CDRA in respect to the "Density" parameter. No hazards have been identified because the bounding normal condition within the CDRA assumes that the *Fissile Material* within CDs and DCDs consists of theoretically dense uranium metal thereby anticipating a density condition that cannot be credibly challenged further.			
Heterogeneity			
There are no identified hazards associated with creating a more adverse condition in the CDRA in respect to the "Heterogeneity" parameter. No hazards have been identified because the bounding normal condition within the CDRA assumes that the *Fissile Material* is homogenously intermixed with other constituents thereby anticipating a heterogeneity condition that cannot be credibly challenged further (since the *fissile material* is assumed 100% enriched).			

<table>
<tr><th>What-if</th><th>Causes</th><th>Unmitigated Consequences</th><th>Accident Sequence in NCSA</th></tr>
<tr><td colspan="4">Neutron Absorbers</td></tr>
<tr><td colspan="4">There are no identified hazards associated with creating a more adverse condition in the CDRA in respect to the “Neutron Absorbers” parameter. No hazards have been identified because the bounding normal condition within the CDRA accepts no credit for neutron absorbing material that is certain to be present within the debris matrix and debris surroundings thereby anticipating a neutron absorbing condition that cannot be credibly challenged further.</td></tr>
<tr><td colspan="4">Reflection</td></tr>
<tr><td colspan="4">There are no identified hazards associated with creating a more adverse condition in the CDRA in respect to the “Reflection” parameter. No hazards have been identified because the bounding normal condition within the CDRA assumes full water (30 cm) reflection atop the DCDs and full concrete (60 cm) reflection below the DCDs thereby anticipating a reflection condition that cannot be credibly challenged further.</td></tr>
<tr><td colspan="4">Concentration</td></tr>
<tr><td colspan="4">There are no identified hazards associated with creating a more adverse condition in the CDRA in respect to the “Concentration” parameter. No hazards have been identified because the bounding normal condition within the CDRA assumes an optimally concentrated <i>Fissile Material</i> matrix appropriate for credible mass loadings thereby anticipating a concentration condition that cannot be credibly challenged further.</td></tr>
<tr><td colspan="4">Volume</td></tr>
<tr><td colspan="4">The “Volume” parameter is not an applicable parameter in respect to the operations occurring within the CDRA. Therefore, changes in volume are not a concern for criticality safety of the CDRA. However, a related parameter may include “Geometry” which has been previously addressed.</td></tr>
</table>

Source: Original

2.2 Generic Safety Case Assumptions

This section outlines the generic assumptions on which this criticality safety assessment is based.

2.2.1 Fissile Material Assumptions

This assessment does not consider fissile nuclides other than ^{235}U.

Fissile Material limits have been derived assuming homogeneous mixtures of ^{235}U and polyethylene and ^{235}U and water. This approach is conservative with respect to other materials containing uranium, including process wastes, because polyethylene and/or water bounds the hydrogen and carbon content found in most nuclear waste materials.

2.2.2 Operational Practice and Equipment Assumptions

The pertinent underlying assumptions of the assessment of CDRA operations are provided below:

- It is assumed for the purposes of this assessment that all CDs and DCDs introduced into a CDRA are typical and industry standard DOT Type A 55-gallon drums. They are assumed to have and maintain the following nominal dimensions with only typical tolerances:
  - Minimum inner diameter is 57.15 cm
  - Minimum inner height is 84.698 cm

  This assessment does not address adverse changes in regards to the above dimensions; therefore, it is imperative that this assumption be confirmed by operations and mandated within high level configuration-control and project change-control documents for the purposes of procurement and maintenance. Note, DCDs with larger dimensions than DOT Type A 55-gallon drums are acceptable for storage.
- It is assumed for the purposes of this assessment that the debris within the planned excavations of the Hematite site is NOT transuranic (TRU). This assessment only considers the *Fissile Material* handled as uranium with a highest possible ^{235}U enrichment of 100%. The *Fissile Material* is assumed to comprise the bounding form of metal (as opposed to the less conservative, however, more realistic form of oxide). This assessment does not address adverse changes in regards to the *Fissile Material* composition.
- It is assumed for the purposes of this assessment that the credible neutron reflective conditions associated with the CDRA operations will be no more adverse than 2 feet (or 60cm) of single sided concrete reflection or 1 foot (or 30cm) of water reflection on the remaining system surfaces. This assessment does not address adverse changes in regards to the system reflection conditions.

2.3 Normal Conditions

This section contains the criticality safety assessment of CDRA operations. The normal conditions assessment is structured as follows.

2.3.1 Entry and Repack Zone

As discussed in Section 1.4.1, operating personnel introduce CDs containing decommissioning debris classified as *Fissile Material* singly and individually into the Entry and Repack Zone of the CDRA. The purpose of the Entry and Repack Zone is to combine the *Fissile Material* within a CD with the *Fissile Material* contained within stored DCDs. The individual packages of *Fissile Material* are tightly controlled upstream (due to the requirements for sorting, labeling, and tracking). A CD is typically expected to have between 15 grams and 40 grams of ^{235}U equivalent since enriched uranium content below 15 grams is expected to be mixed with very large bulk debris quantity or is otherwise considered to meet *NCS Exempt Material* criteria and since the historical data log records rarely have line items documenting higher enriched uranium content values than 40 grams.

The normal operation within the Entry and Repack Zone allows for only a single DCD at a time to be filled with *Fissile Material.* This procedural requirement is extremely simple and very easily audited. Once a DCD is filled to its capacity (either by volume or by reaching its *Fissile Material* limit of 125 grams ^{235}U), the DCD is sealed, appropriately labeled, and carted into the nearby DCD Storage Zone where the DCD is placed side-by-side other filled DCDs.

Since DCDs are eventually positioned into a closely packed configuration, it should be relatively obvious that criticality safety is primarily concerned with the tight grouping of loaded DCDs rather than an isolated DCD being filled with packets one at a time. Therefore, criticality safety is maintained for this repack operation as long as criticality safety is subsequently maintained for the DCD storage operations (which are discussed below).

2.3.2 DCD Storage Zone

Computed reactivity results have been calculated in Ref. 9 using explicit three-dimensional modeling of credible DCD storage configurations. The computation method used for this reactivity determination is a probabilistic neutron multiplication factor technique that is packaged in the popular Monte Carlo Neutron-Photon (MCNP Version 5) neutronics software program initiated and maintained by the Los Alamos National Laboratory.

Detail of the MCNP computer models representing anticipated (normal) conditions and unusual (abnormal) conditions are provided along with their respective MCNP calculated reactivity results. In-depth discussion is also provided with the calculated results that provide the reader with a connection between the computer models and the practical applications as well as providing insight associated with the reactivity results. Under normal conditions, the bounding system configuration models that represent anticipated operations associated with the DCD Storage Zone is described below.

A single DCD is programmed with close-contact triangular and mirrored vertical surfaces. Modeled atop the single DCD is a layer of water 30 cm thick while modeled below the single DCD is a layer of concrete 60 cm thick. This modeling treatment is equivalent to the practical application of having a planar array of DCDs stored in triangular pitch with each DCD touching other. This treatment also accounts for any neutron return due to practical reflecting surfaces such as humans, equipment, shielding, walls, floors, etc., that may be near the DCDs. It should be noted that the inner diameter of the DCD is assumed 57.15 cm and the inner height of the DCD is assumed 84.698 cm. No material or thickness associated with the walls, lid, or bottom of the DCD is represented in this model.

Modeled within the single DCD is a centralized, spherical matrix comprised of a homogeneous mixture of 125 grams of full-density ^{235}U metal and 0.35 g/cc polyethylene. The centralized, spherical positioning of the debris matrix within the DCD is considered grossly conservative due to the practical application of hand-packing debris (particularly for a normal condition consideration). Since enriched uranium less than 1kg requires neutron moderation to reach a critical state, a reduced-density polyethylene is chosen for the bounding normal condition. The primary concern for criticality safety associated with neutron moderators is the hydrogen density that the material possesses. The hydrogen density associated with 0.35 g/cc density polyethylene is roughly equivalent to 50 grams of hydrogen per liter of debris *. There have many studies performed in the industry concluding that this chosen hydrogen concentration in nuclear waste is very conservative to the actual average; however, in the spirit of being overly conservative for safety sake, this quantity is adopted for the bounding normal condition. It should be noted that evaluation of higher (even bounding) hydrogen content in the debris is considered for other conditions in this assessment. The quantity of ^{235}U metal modeled within the DCD (i.e., 125 grams) is simply the operational limit allowed by procedure.

The spherical matrix within the single DCD is increased and decreased in diameter to search for the optimum hydrogen to ^{235}U atom ratio (a.k.a H/X). Since the optimum H/X is completely dependent upon the concentration (or mass) of the *Fissile Material*, this "varying" approach ensures that the fission neutrons in the matrix are allowed to sufficiently lose just the right amount of energy to be absorbed by an awaiting fissionable ^{235}U isotope. This modeling treatment is also grossly conservative (particularly for a normal condition consideration) since, in reality, nuclear waste contains diluent constituents (in particular pockets of void due to packing efficacy) and parasitic neutron absorbers (such as salts and heavy metals).

Due to the variation in spherical diameter of the debris within the mirror reflected DCD, a total of 24 models (a.k.a cases) are generated and programmed with MCNP. The results of the calculated reactivity are presented in graphical form below (tabular results as well as details associated with H/X values, uncertainties, and EALF are provided in electronic form – see spreadsheet associated with Ref. 9).

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* Polyethylene has the chemical formula of CH_2. Being that carbon has an atomic mass of 12.0107 g/mole and hydrogen having an atomic weight of 1.00794 g/mole, the hydrogen weight percent of polyethylene is 14.37 wt%. The hydrogen density percent of 0.35 g/cc polyethylene is simply the hydrogen weight percent of the compound times the density of polyethylene (0.1437 x 0.35 g/cc) which is 50 gH/L.

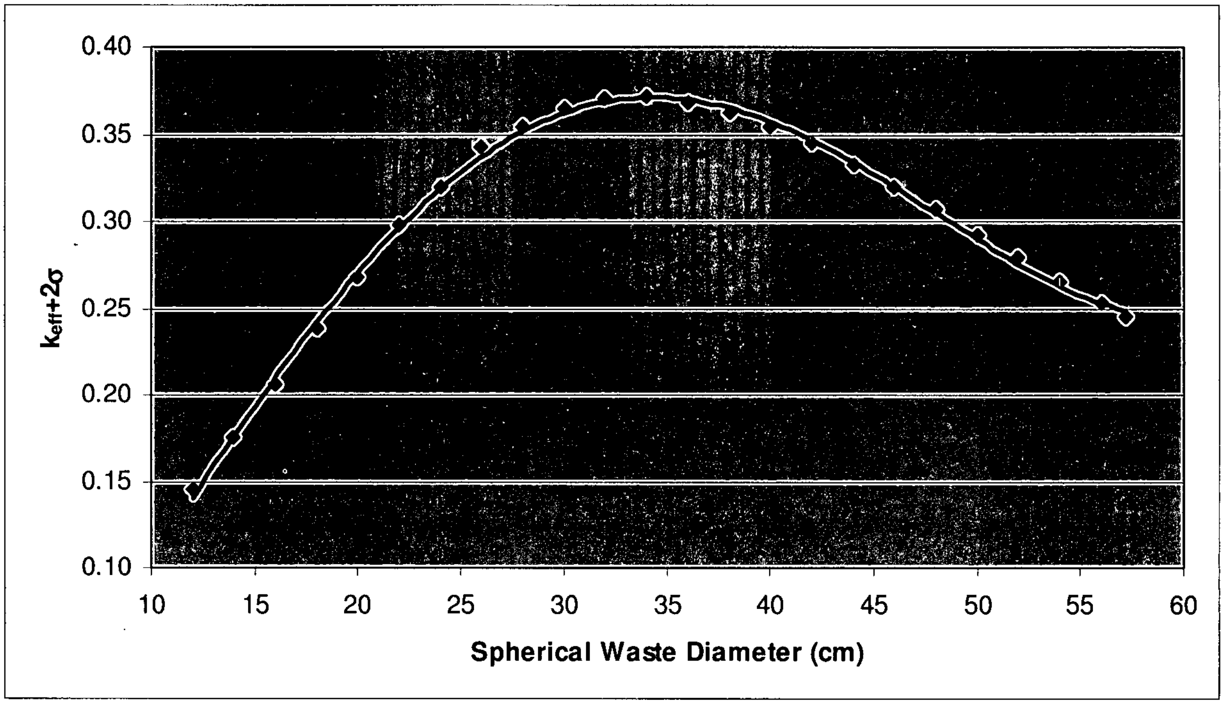

Figure 2-1 DCD Storage Zone Reactivity (Normal Condition)

As seen in the graph above, the normal (anticipated) reactivity associated with DCD Storage Zone is well below the upper safety limit of k_{eff}=0.95. It should also be noted that this normal condition assumes that the debris configuration within the DCD is in a state that should be considered unreachable during typical DCD packaging (i.e., the debris is considered spherical and centered directly in the center of the DCD).

To satisfy the most conservative of safety analysts, a replica of this normal model is recreated with one difference: the spherical debris within the DCD is relocated from the center to close-contact with the inner surface of the DCD. This modeling difference is intended to demonstrate the reactivity effects associated with the debris being preferentially packaged such that the debris within a DCD is practically touching the debris within another DCD. Recall, that the single DCD modeled is mirror reflected on its sides which represents that an array of DCDs would have this effect. The following graph demonstrates that adverse reactivity effects of this remodeling are non-existent when compared with the centralized debris modeling technique. In fact, the reactivity results are statistically identical to those for the centralized debris results.

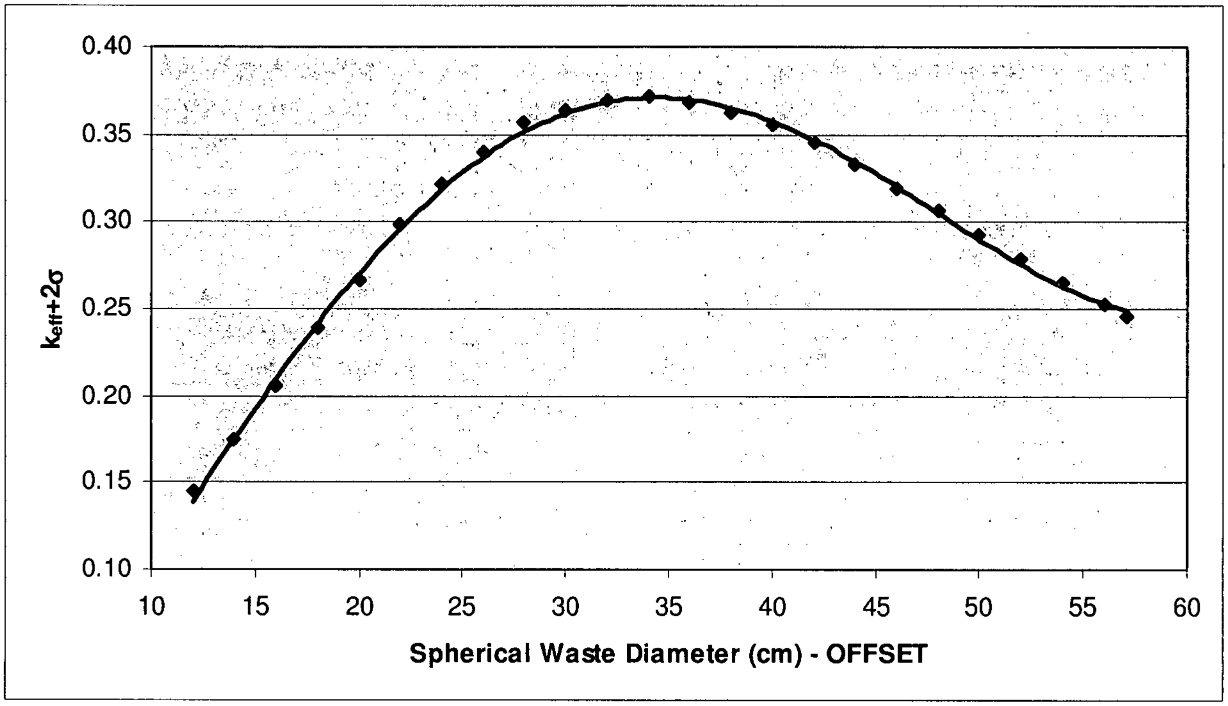

Figure 2-2 DCD Storage Zone Reactivity (Normal Condition) with offset debris

2.4 Abnormal Conditions

This section provides an assessment of the criticality hazards identified from the *What-if/Checklist* analysis of CDRA operations.

2.4.1 Loading/Storing Other Than CDs and DCDs

2.4.1.1 Discussion

DCDs are used for the collection of *Fissile Material* packaged together within the Entry and Repack Zone. The DCDs are subsequently stored in the DCD Storage Zone and then shipped off-site. The loading of *Fissile Material* into drums or other containers which are dimensionally smaller than DCDs followed by subsequent storage would result in an unevaluated condition which could lead to a potential for a criticality accident within the CDRA.

2.4.1.2 Risk Assessment

Use of containers in the CDRA other than DCDs for collection of *Fissile Material* is considered *highly improbable.* Even without proper training of personnel, loading *Fissile Material* into containers other than DCDs is prohibited by the unavailability of empty and available containers within the CDRA. Procurement of the DCDs is performed at a high level of Site Configuration Control.

Containers dimensionally smaller than DCDs that are brought into the CDRA must be first over-packed into a CD. There are only two scenarios that could result in the removal of a *Fissile Material* laden container with smaller dimensions than a DCD from the Entry and Repack Zone. The first scenario involves a single untrained operator, acting on his/her own cognition, moving the "small" container from the Entry and Repack Zone. This would imply that the operator is untrained, the door to the DCD Storage Zone is completely unlocked (there are two different locks on the doors), and that other personnel are completely incognizant of this occurring. The second scenario involves collusion of at least one other person to purposefully disregard the proper procedures. Obviously, the personnel and shift supervisor are considered adequately trained to implement proper repack and storage procedure. However, it is possible (and typically considered probable) that a procedural mistake either coherently or accidentally will occur at some point during operations. The task is to determine conservative probability for each failure. Recall from above that in order for a person to act alone when removing a "small" container without collecting in a DCD from the Entry and Repack Zone would first have to not know or not abide to this prohibition. This is not expected due to the training qualifications imposed on the personnel (particularly those with access to *Fissile Material*). Secondly, this untrained or misguided individual must disregard the placards on the doors to the DCD Storage Zone that reads "Entrance must be accompanied by a second person".

The combination of these two procedural violations is now considered at least *unlikely* to occur during operations. It should be noted that the doors to the DCD Storage Zone are locked by default. Specifically, the doors (when closed) lock themselves and access to the DCD Storage Zone requires knowledge of two different combinations or access to two different keys. The combination of one of the locks or access to the key is attained only by the supervisor, while the combination of the second lock is known only to the operators. Therefore, access to both combinations or both keys is considered a procedure violation and is also needed to gain entrance to the DCD Storage Zone (unless the self-closing doors were left opened either accidentally or purposefully). It is apparent to see that multiple procedural violations would have to occur that culminate into an *unlikely* concurrence probability. By requiring a second operator and supervisory surveillance on hand at all times, it is further deemed at least *unlikely* that recognition of the rouge operator would not be spotted or corrected. Therefore, by having multiple persons present and multiple procedural steps in place, it is considered that a criticality accident as a result of this scenario is prevented by doubly-contingent means.

2.4.1.3 Summary of Risk Assessment

Based on the risk assessment provided in Section 2.4.1.2, several of the following conditions must exist before a criticality accident due to sending a container with dimensions smaller than a DCD from the Entry and Repack Zone would be possible:

- Availability of credible containers other than DCD that could be a substitute for loading and storage of *Fissile Material* in the CDRA would need to be present; and
- The number of qualified personnel present or supervising within the CDRA during loading/storing activities would need to be less than three; and
- Procedural requirement that containers with dimensions smaller than DCDs are not to be removed from the Entry and Repack Zone without proper size over-pack would need to be disregarded; and
- Procedural requirement that the DCD Storage Zone doors are to be closed and locked at all times would need to be disregarded; and
- Procedural requirement that the DCD Storage Zone door lock combinations/keys are to be independent would need to be disregarded; and
- Procedural nonconformance that *Fissile Material* movement/handling requires two persons would need to occur.

2.4.1.4 Safety Controls

The explicit Criticality Safety Controls (CSCs) relied on to provide the criticality safety barriers identified above (and thus relied on to preclude a criticality accident as a result of improper container movement/handling) are listed below. Their implementation will ensure that the risks from criticality are *as low as is reasonably achievable.*

> **Administrative CSC 01:** *Only empty DCDs SHALL be supplied to a CDRA for Fissile Material loading operations.*
>
> **Administrative CSC 02:** *The number of qualified personnel present within (or within cognitive surveillance of) a CDRA during all activities SHALL be a minimum of least three.*

Administrative CSC 03: *CDRA doors (and zone doors within) SHALL be maintained closed when not in use. The doors SHALL be maintained with two locks in proper working condition. The combination or key of each lock SHALL be different. Area supervision SHALL maintain confidentiality from operators of one lock combination/key while operators SHALL maintain confidentiality from supervision of the second lock. Particularly, at no time, will the combination or access to keys of both locks be known by a single individual.*

Administrative CSC 04: *Fissile Material SHALL be conveyed within DCDs while in a CDRA.*

Administrative CSC 05: *Movement/handling of Fissile Material SHALL be accompanied by at least two different persons that are cognizant of fissile material handling responsibilities.*

In support of the above Administrative CSCs, CDs and DCDs are designated as Safety Features, the Safety Functional Requirement being to possess a minimum internal diameter of 57.15 cm and a minimum inner height of 84.698 cm (not including collar for CDs).

Safety Feature 01: *Collared Drums and DeCollared Drums (when being used in support of a CSC).*

2.4.2 Stacking DCDs in the DCD Storage Zone

2.4.2.1 Discussion

As recognized in Section 2.3.2, the DCDs stored in the DCD Storage Zone are anticipated to form a planar array. This requires that DCDs are not to be stacked on top of each other. If the DCDs are stacked (e.g., to help save floor space), then this would upset the anticipated normal condition.

2.4.2.2 Risk Assessment

There is no mechanism within the DCD Storage Zone that could provide assistance to the operators in allowing stacking of DCDs on top of each other. The DCDs are typically filled to capacity (as one would expect) so the weight of the DCD would certainly be a deterrent to an operator if manual stacking was to occur. Recall from Section 2.4.1 that more than one person is required to be present when moving/handling CDs or DCDs. Therefore, the "no stacking" requirement would need to be concurrently violated by multiple persons in the DCD Storage Zone if stacking were to occur. It is considered at least *unlikely* that collusion of the persons present in the DCD Storage Zone would occur such that a DCD is manually hoisted and set atop another DCD. Further, it is *highly improbable* to manually stack DCDs (with no mechanical means) that result in a three-high stack due solely to the minimal height of each DCD and the typical height and strength of humans. Therefore, it is demonstrated that since there is no mechanical means available for stacking (such as a fork lift or hoisting mechanism) and the combination that there are multiple persons necessary to the be within the DCD Storage Zone during operations that stacking a DCD onto another DCD is considered at least *unlikely* and that excessive DCD stacking is considered *highly improbable* (since this is multiple instances of failure of a very simple procedural prohibition).

The normal condition for DCDs stored in the DCD Storage Zone anticipates DCDs in an infinite planar array. Since it is only considered at least *unlikely* to *highly improbable* in procedural failure probability that the DCD array could have multiple DCDs on a second tier, it is imperative to demonstrate by calculation that the resulting reactivity is maintained to a safe level.

The following graph (extracted from Ref. 9) demonstrates acceptable reactivity increase when the normal model representing the DCD Storage Zone is modified to include a complete second tier.

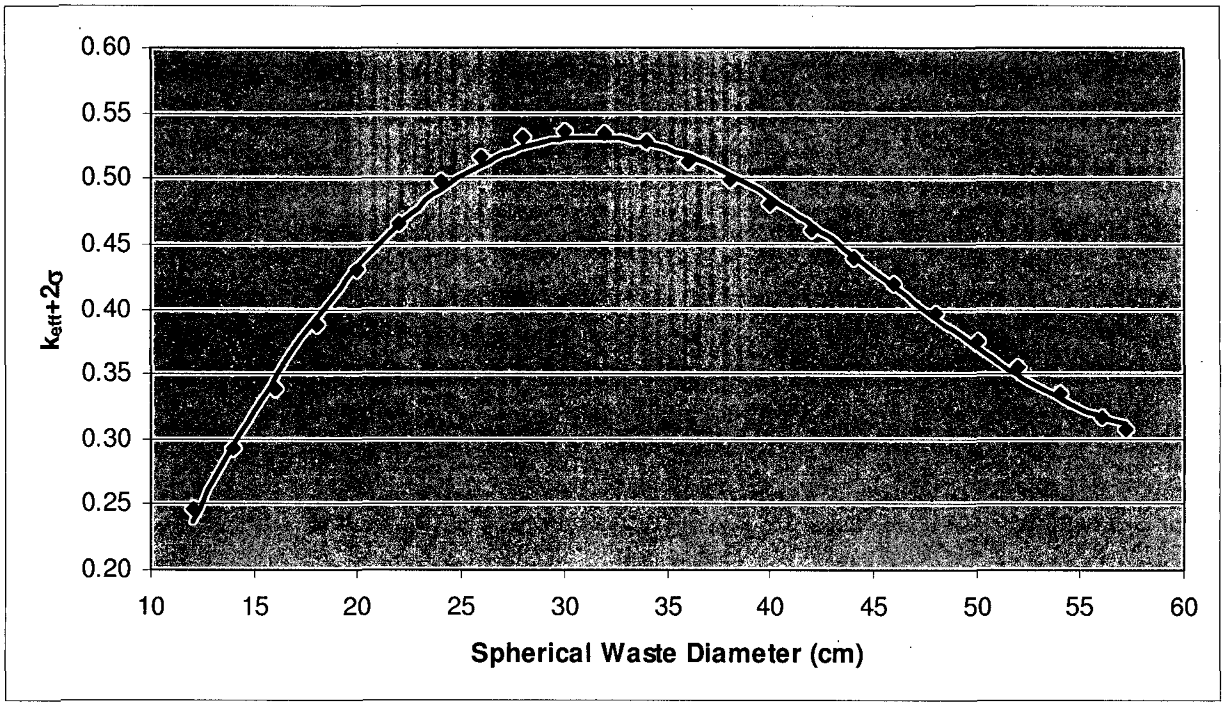

Figure 2-3 DCD Storage Zone Reactivity (Stack Upset)

In summary, Double Contingency Protection is established against stacking DCDs to an unacceptable level within the DCD Storage Zone. It is considered at least *unlikely* for multiple operators to not adhere to a very simple procedural prohibition and it is considered at least *unlikely* for management to provide the mechanical capability (e.g., fork lift or hoist) to stack DCDs beyond the evaluated level. The calculated reactivity results demonstrate that even during this *highly improbable* condition (i.e., multiple DCDs stacked on a second tier) criticality safety is maintained (as long as the other criticality safety parameters such as *Fissile Material* content and moderator efficacy are maintained).

2.4.2.3 Summary of Risk Assessment

Based on the risk assessment provided in Section 2.4.2.2, the following conditions must exist before a criticality accident due to stacking DCDs would be possible:

- Procedural requirement that DCDs are not to be stacked is disregarded; and
- Loss of Site Configuration Control plan which ensures that only no DCD lifting mechanisms are available in the DCD Storage Zone (such as fork lifts or hoists); and
- An insufficient number of qualified personnel present within the DCD Storage Zone during loading/storing activities would have to exist.

*NOTE: The above failure conditions are related only to upsetting the stack height requirement. This section pertains only to losing stack height control. Other parameters associated with the debris (such as *Fissile Material* quantity and moderator efficacy) are obviously also necessary to prevent a criticality accident in the DCD

Storage Zone. These other parameters are discussed in turn and adverse perturbation of each is shown to be at least *unlikely* to occur or *highly improbable* to cause a criticality accident. Therefore, this scenario complies with the Double Contingency Principle because at least two *unlikely* concurrent failures (this parameter failure and another) would be required before reaching potential for a criticality accident.

2.4.2.4 Safety Controls

The explicit CSCs relied on to provide the criticality safety barriers identified above (and thus relied on to preclude a criticality accident as a result of stacking DCDs) are listed below. Their implementation will ensure that the risks from criticality are *as low as is reasonably achievable.*

Administrative CSC 06: CDs and *DCDs within a CDRA SHALL NOT be stacked.*

Administrative CSC 02: *The number of qualified personnel present within (or within cognitive surveillance of) a CDRA during all activities SHALL be a minimum of least three.*

Administrative CSC 07: *Site Configuration Control plan SHALL ensure that no fork lifts or mechanical hoists are available in the DCD Storage Zone of a CDRA.*

*NOTE: The above controls are related only to upsetting the stack height requirement. Other controls/parameters associated with the debris (such as *Fissile Material* quantity and moderator efficacy) are obviously also necessary to prevent a criticality accident in the DCD Storage Zone. These other parameters are discussed in turn.

In support of the above Administrative CSCs, CDs and DCDs are designated as Safety Features, the Safety Functional Requirement being to possess a minimum internal diameter of 57.15 cm and a minimum inner height of 84.698 cm (not including collar for CDs).

Safety Feature 01: *Collared Drums and DeCollared Drums (when being used in support of a CSC).*

2.4.3 Too many items in Entry and Repack Zone

2.4.3.1 Discussion

As discussed in Section 2.3.1, *Fissile Material* laden debris items within the Entry and Repack Zone are limited to one at a time and all items with dimensions smaller than a DCD are loaded into a DCD when dispatching to DCD Storage Zone. If more than one *Fissile Material* laden item is within the Entry and Repack Zone at one time (except for a partially filled DCD retrieved from the DCD Storage Zone to collect the new *Fissile Material* laden item), this scenario would result in an unevaluated condition (i.e., unevaluated in terms of resulting reactivity determination).

2.4.3.2 Risk Assessment

As mentioned in each of the preceding subsections, at least three persons are required to be present and/or cognizant of operations within the Entry and Repack Zone at all times when operations are occurring within. This requirement is again relied upon to mitigate the need for further evaluation of the scenarios highlighted above in Section 2.4.3.1. Coupling this requirement with the procedural requirement that only one *Fissile Material* laden item can be within the Entry and Repack Zone at any time (except for a partially filled DCD retrieved from the DCD Storage Zone to collect the new *Fissile Material* laden item), results in the *high improbability* that multiple *Fissile Material* laden items will occupy the Entry and Repack Zone at one time. The Entry and Repack Zone is always locked (by two different combination/key locks) when the doors are shut. Therefore, entry of *Fissile Material* into this zone is only possible when the CDRA is in operation. The operation of the CDRA requires at least three persons (i.e., at least two that are present and perhaps a third cognizant via a live video feed). Each of the three persons are qualified and trained to the procedures (in particular: only one *Fissile Material* laden item can be within the Entry and Repack Zone at a time with the exception of a partially filled DCD retrieved from the DCD Storage Zone to collect the new *Fissile Material* laden item). Since this is a very simple procedural requirement and three persons are responsible for its compliance, it is considered *highly improbable* to have multiple small containers available within the Entry and Repack Zone at a time (and is also considered compliant with Double Contingency Principle since multiple independent persons have to fail the same simple procedural requirement concurrently).

2.4.3.3 Summary of Risk Assessment

Based on the risk assessment provided in Section 2.4.3.2, the following conditions must exist before a criticality accident due to too many *Fissile Material* laden items in the Entry and repack Zone would be possible:

- An insufficient number of qualified personnel present within the Entry and Repack Zone during loading/storing activities would have to exist; and
- Procedural requirement that *Fissile Material* movement/handling requires two persons would have to be disregarded; and

- Procedural requirement that only one *Fissile Material* laden item be present in the Entry and Repack Zone at a time (except for a partially filled DCD retrieved from the DCD Storage Zone to collect the new *Fissile Material* laden item) would have to be disregarded.

2.4.3.4 Safety Controls

The explicit CSCs relied on to provide the criticality safety barriers identified above (and thus relied on to preclude a criticality accident as a result of accumulation of *Fissile Material* in the Entry and Repack Zone) are listed below. Their implementation will ensure that the risks from criticality are *as low as is reasonably achievable.*

Administrative CSC 02: *The number of qualified personnel present within (or within cognitive surveillance of) a CDRA during all activities SHALL be a minimum of least three.*

Administrative CSC 05: *Movement/handling of Fissile Material SHALL be accompanied by at least two different persons that are cognizant of fissile material handling responsibilities.*

Administrative CSC 08: *Only one fissile laden item SHALL be permitted in the Entry and Repack Zone of a CDRA at a time (except for a partially filled DCD retrieved from the DCD Storage Zone to collect the new fissile laden item).*

2.4.4 Loss of *Fissile Material* Accountability when loading DCDs

2.4.4.1 Discussion

As recognized in Section 2.3.1, each DCD introduced and stored in DCD Storage Zone is anticipated to have been filled with a maximum inventory of 125 grams of ^{235}U equivalency previously in the Entry and Repack Zone. This requires that the amount of *Fissile Material* placed into each DCD be tracked and accounted appropriately. If the accountability of the *Fissile Material* loaded into the DCD becomes corrupted or otherwise lost, then this would upset the anticipated normal condition.

2.4.4.2 Risk Assessment

The DCDs are filled one at a time with debris packets or items introduced one at a time into the Entry and Repack Zone. The tracking and accountability of the *Fissile Material* mass within each packet or item is strictly controlled and computerized. The safety consequences associated with the loss of this upstream accountability is addressed in Ref. 8. Multiple operators present in the Entry and Repack Zone accept responsibility for each debris packet item as it is received and diligently load each awaiting DCD while adhering to the appropriate tracking and accountability procedures. Based solely on the qualifications of the multiple operators responsible for ensuring *Fissile Material* mass loadings are tracked accurately, it is considered at least *unlikely* that a single DCD will be lidded and stored with a mass loading greater than 125 grams of ^{235}U equivalence. Further, based on the conservative *Fissile Material* estimates provided by the upstream assay equipment (see Ref. 8 for detail) and the relatively low *Fissile Material* content of each debris packet or item (anticipated to be between 15 and 40 grams of ^{235}U), it is also considered at least *unlikely* that more than a "double-batch" could be in a lidded and stored single drum. Since the *Fissile Material* loading of a single drum is limited to only 125 grams of ^{235}U equivalence, doubling this amount in a single isolated drum is no consequence to criticality safety since this value (i.e., up to 250 grams ^{235}U) is well below a value that could result in a criticality accident. Therefore, the criticality safety concern is multiple failures of *Fissile Material* accountability in the DCDs. Since it is considered at least *unlikely* to reach a double-batch quantity of ^{235}U in a single DCD, it can certainly be considered equally and independently at least *unlikely* to store each and every DCD within the DCD Storage Zone to more than a double-batch quantity. This propagation of concurrent administrative failures by multiple operators in the CDRA is considered *highly improbable* to occur during the lifetime of the CDRA operations.

The normal condition for DCDs stored in the DCD Storage Zone anticipates each DCD filled to a maximum *Fissile Material* content of 125 grams of ^{235}U equivalency. Since it is only considered at least *unlikely* to *highly improbable* in procedural failure probability that the DCD array could contain all of its DCDs with a *Fissile Material* content greater than 125 grams of ^{235}U, it is imperative to demonstrate by calculation that the resulting reactivity is maintained to a safe level.

The following graph (extracted from Ref. 9) demonstrates acceptable reactivity increase when the normal model (debris centralized within the DCD) is modified such that each DCD contains more than the allowed 125 grams of ^{235}U.

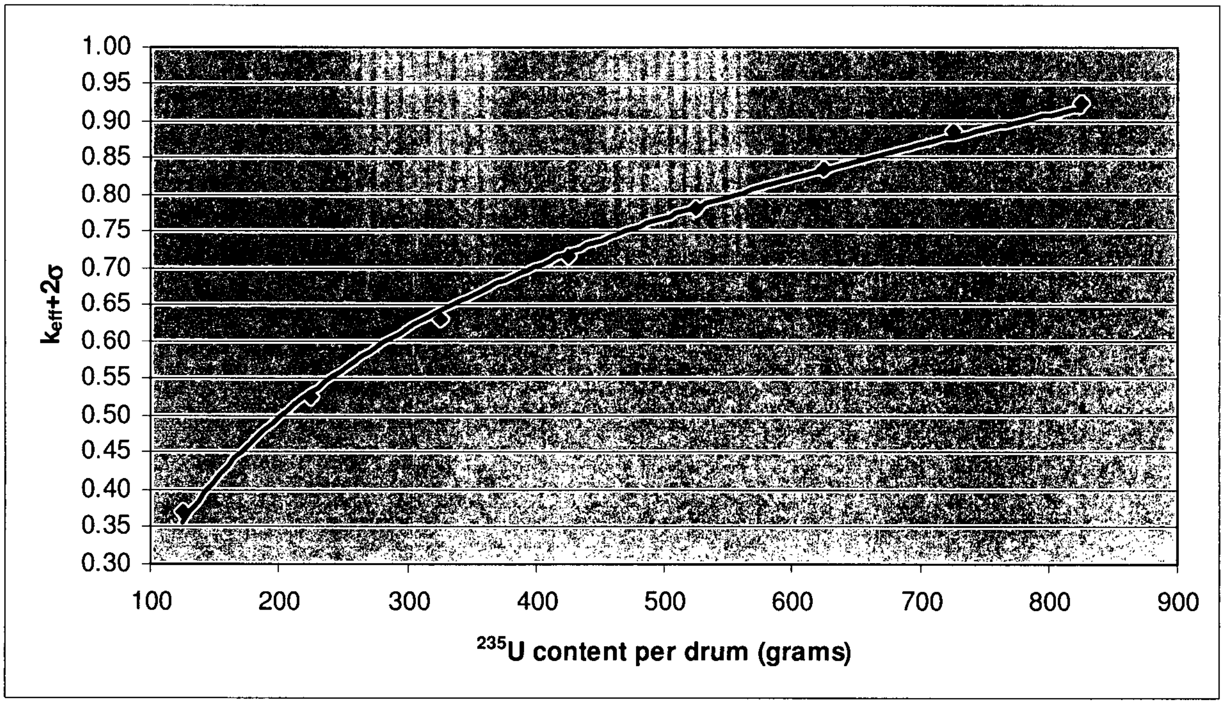

Figure 2-4 DCD Storage Zone Reactivity (*Fissile Material* Upset)

As demonstrated in the above graph, the *Fissile Material* loading in each DCD would have to exceed an inconceivable quantity of approximately 825 grams of ^{235}U before a criticality accident could be realized in the DCD Storage Zone (assuming that the other criticality safety parameters such as moderator efficacy and stack height are maintained at their anticipated levels).

In summary, Double Contingency Protection is established against over-loading the *Fissile Material* content of DCDs to an unacceptable level within the DCD Storage Zone. It is considered at least *unlikely* for multiple operators to not adhere to a very simple procedural prohibition and it is considered at least *unlikely* for propagation of this failure to occur such that the entire DCD Storage Zone is filled with DCDs each containing a *Fissile Material* content in excess of double-batch quantities.

2.4.4.3 Summary of Risk Assessment

Based on the risk assessment provided in Section 2.4.4.2, the following conditions must exist before a criticality accident due to over-loading DCDs with *Fissile Material* would be possible:

- Procedural non-conformance (i.e., not adhering to 125 gram ^{235}U loading requirement); and
- Loss of upstream control on assay equipment or mass tracking labeling/software; and
- An insufficient number of qualified personnel present within the CDRA during

loading/storing activities.

*NOTE: The above failure conditions are related only to upsetting the *Fissile Material* loading requirement. This section pertains only to losing *Fissile Material* control. Other parameters associated with the debris (such as moderator efficacy and stack height) are also necessary to prevent a criticality accident in the DCD Storage Zone. These other parameters are discussed in turn and adverse perturbation of each is shown to be at least *unlikely* to occur or *highly improbable* to cause a criticality accident. Therefore, this scenario complies with the Double Contingency Principle because at least two *unlikely* concurrent failures (this parameter failure and another) would be required before reaching potential for a criticality accident.

2.4.4.4 Safety Controls

The explicit CSCs relied on to provide the criticality safety barriers identified above (and thus relied on to preclude a criticality accident as a result of over-loading DCDs with *Fissile Material*) are listed below. Their implementation will ensure that the risks from criticality are *as low as is reasonably achievable.*

Administrative CSC 09: *DCDs within the DCD Storage Zone SHALL NOT be loaded with more than 125 grams of* ^{235}U *equivalence in the Entry and Repack Zone.*

Administrative CSC 02: *The number of qualified personnel present within (or within cognitive surveillance of) a CDRA during all activities SHALL be a minimum of least three.*

Administrative CSC 05: *Movement/handling of Fissile Material SHALL be accompanied by at least two different persons that are cognizant of fissile material handling responsibilities.*

*NOTE: The above safety controls are related only to maintaining the *Fissile Material* loading requirement. Other parameters/controls associated with the debris (such as moderator efficacy and stack height) are also necessary to prevent a criticality accident in the DCD Storage Zone. These other parameters are discussed in turn.

In support of the above Administrative CSCs, CDs and DCDs are designated as Safety Features, the Safety Functional Requirement being to possess a minimum internal diameter of 57.15 cm and a minimum inner height of 84.698 cm (not including collar for CDs).

Safety Feature 01: *Collared Drums and DeCollared Drums (when being used in support of a CSC).*

2.4.5 Increased neutron moderator efficacy inside DCDs in the DCD Storage Zone

2.4.5.1 Discussion

As discussed in Section 2.3.2, the normal condition in regards to neutron moderator efficacy within the DCDs stored in the DCD Storage Zone is anticipated to be no worse than that afforded by a 0.35 g/cc polyethylene matrix. This normal matrix is considered acceptable due to the types and packing fractions of typical nuclear waste materials. If the matrix within DCDs becomes more adverse compared to 0.35 g/cc polyethylene, then this would upset the anticipated normal condition.

2.4.5.2 Risk Assessment

There are no controls during upstream debris packet packaging or DCD loading within the Entry and Repack Zone that are associated with ensuring a matrix within the DCDs will not contain a matrix more adept to thermalizing fission neutrons. Therefore, this assessment relies solely on the results from Ref. 9 that demonstrate that more adverse matrices (even bounding matrices) will not exceed a safe level of reactivity (see graph below).

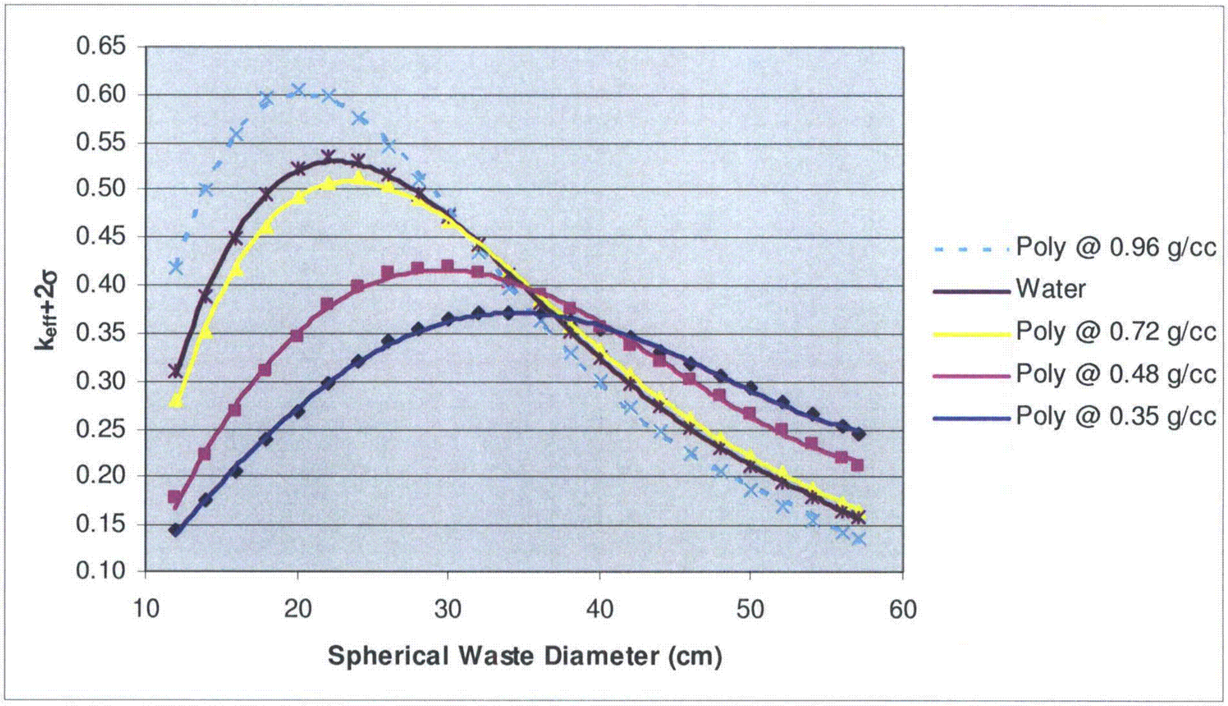

Figure 2-5 DCD Storage Zone Reactivity (Debris Matrix Condition Comparisons)

2.4.5.3 Summary of Risk Assessment

Based on the discussion provided in Section 2.4.5.2 (and particularly, the results depicted on the graph), it is concluded that there are no credible scenarios in which a criticality accident could occur as a result of an upset with the normal neutron moderator efficacy condition.

2.4.5.4 Safety Controls

There are no safety controls, procedural requirements, or equipment associated with preventing a criticality accident concerning upsets of neutron moderator efficacy within the DCDs. It should be noted, however, that the lack of reliance on features is directly attributable to the reliance on other criticality safety parameters being in their anticipated condition (such as *Fissile Material* loading of each DCD and stack height). These other parameters are discussed in turn and adverse perturbation of each is shown to be at least *unlikely* to occur or *highly improbable* to cause a criticality accident. Therefore, this scenario complies with the Double Contingency Principle because at least two *unlikely* concurrent failures (this parameter failure and another) would be required before reaching potential for a criticality accident.

2.4.6 Increased neutron moderator efficacy outside DCDs

2.4.6.1 Discussion

As discussed in Section 2.3.2, the normal condition in regards to neutron moderator efficacy outside the DCDs in the DCD Storage Zone is anticipated to be dry conditions. This normal condition is considered acceptable due to the location of the DCDs being stored within an enclosed facility and the combustible level expected to be low (consequence of fire is hydrogenous suppression). If the facility was to allow infiltration of water or snow or if a fire developed, then this would upset the anticipated normal condition.

2.4.6.2 Risk Assessment

There is no criticality safety concern in regards to adding water, snow, hydrogenous fire suppression, or any other credible neutron moderator outside of the DCDs. The normal condition anticipates up to 30 cm of water reflection atop the DCDs which more than accounts for any accumulation of snow or hydrogenous fire suppression atop the DCDs. Further, the worst credible upset condition involving spherical debris within a matrix optimized for H/X results in a safe condition (as long as *Fissile Material* and "no stacking" of DCDs is maintained). Therefore, interstitial moderation cannot increase the reactivity of the systems already evaluated and determined safe up to this point (i.e., additional moderator beyond optimum conditions results in neutron absorption and consequently reactivity decrease).

2.4.6.3 Summary of Risk Assessment

Based on the discussion provided in Section 2.4.6.2, it is concluded that there are no credible scenarios in which a criticality accident could occur as a result of an upset with the normal interstitial neutron moderation condition.

2.4.6.4 Safety Controls

There are no safety controls, procedural requirements, or equipment associated with preventing a criticality accident concerning upsets of interstitial neutron moderation conditions (e.g., rain water, leaking pipes, snow, fire suppression, etc). It should be noted, however, that the lack of reliance on safety features is directly attributable to the reliance on other criticality safety parameters being in their anticipated condition (such as *Fissile Material* loading of each DCD and stack height). These other parameters are discussed in turn.

2.4.7 Spillage of DCD Contents due to flooding

2.4.7.1 Discussion

As discussed in Section 2.3, the normal condition in regards to debris confinement anticipates that debris will maintain its presence within the DCDs during all times. If the debris was able to evacuate itself from the DCDs due to a phenomenon such as site flooding, then this would upset the anticipated normal condition.

2.4.7.2 Risk Assessment

There is no criticality safety concern in regards to catastrophic flooding of the CDRA. The frequency of flooding the CDRA to the extent whereby debris within the DCDs would escape is a remote possibility that should be considered to have at least an associated *unlikely* probability based on site history. Further, the DCDs contain segregated *Fissile Material*. As such, the basic procedures involved with securing and accounting for *Fissile Material* such as lidding and sealing are to be followed from the practical stand-point of safeguards and security, not to mention the associated radiological concerns. These two points (frequency of catastrophic flooding and DCD sealing/lidding requirements) could certainly be argued as sufficient for adequately preventing a criticality accident due to catastrophic flooding. However, even without the aforementioned discussion, a criticality accident will not occur even if the contents of every DCD escaped their confines and found themselves in a large pool of water and debris. This is due to the fact that in order for the contents of the DCDs to be removed simply by the force of water level increase inside the DCDs, the debris contents must be adequately light in density such that water could displace the DCDs confinement. This type of debris would randomly disperse in a uniform homogenous mixture of water and debris, quickly becoming more like a solution system, rather than a more reactive, uniform, and optimally moderated array configuration.

2.4.7.3 Summary of Risk Assessment

Based on the discussion provided in Section 2.4.7.2, it is concluded that there are no credible scenarios in which a criticality accident could occur as a result of an upset with the normal debris confinement condition (i.e., held within a DCD).

2.4.7.4 Safety Controls

There are no safety controls, procedural requirements, or equipment associated with preventing a criticality accident concerning upsets of debris confinement conditions within a DCD (e.g., displacement by flooding). It should be noted, however, that the lack of reliance on features is directly attributable to the reliance on other criticality safety parameters being in their anticipated condition (such as *Fissile Material* loading of each DCD and stack height). These other parameters are discussed in turn.

2.4.8 Concurrent Criticality Safety Parameter Upsets

2.4.8.1 Discussion

Sections 2.4.1 through 2.4.7 have discussed and alleviated criticality safety concerns associated with upsetting a single criticality safety parameter. This section (2.4.8) is intended to provide a discussion and evaluation of the criticality safety concern associated with concurrent failure of several parameters.

2.4.8.2 Risk Assessment

The individual criticality safety parameters that are determined to have credible potential to lead to a criticality accident if not controlled or if no bounding conditions are assumed involve the following:

- Upset in Geometry (i.e., DCDs stacked on top of each other)
- Upset in *Fissile Material* Mass (i.e., too much *Fissile Material* in each DCD)
- Upset in Moderation efficacy (i.e., debris matrix very hydrogenous)

As discussed in Section 2.4.2, it is considered at least *unlikely* that a single or multiple DCDs would be stacked in the DCD Storage Zone. As discussed in Section 2.4.4, it is considered at least *unlikely* that a single or multiple DCDs would be loaded with a *Fissile Material* content equivalent to 250 grams of ^{235}U in the Entry and Repack Zone. Finally, as discussed in Section 2.4.5, it is considered at least *unlikely* that all of the DCDs in the DCD Storage Zone will each have a neutron moderator efficacy equivalent to full density polyethylene or water. It will now be demonstrated in this section that even if each of these *unlikely* conditions were to occur concurrently in the DCD Storage Zone, criticality safety is still maintained.

The following graph (extracted from Ref. 9) depicts the change in reactivity of an array in the DCD Storage Zone that contains DCDs stacked in two-tiers, the *Fissile Material* loading in each DCD equivalent to 250 grams of ^{235}U, the debris matrix centralized and spherical within each DCD, and the debris matrix consisting of either full density polyethylene or water.

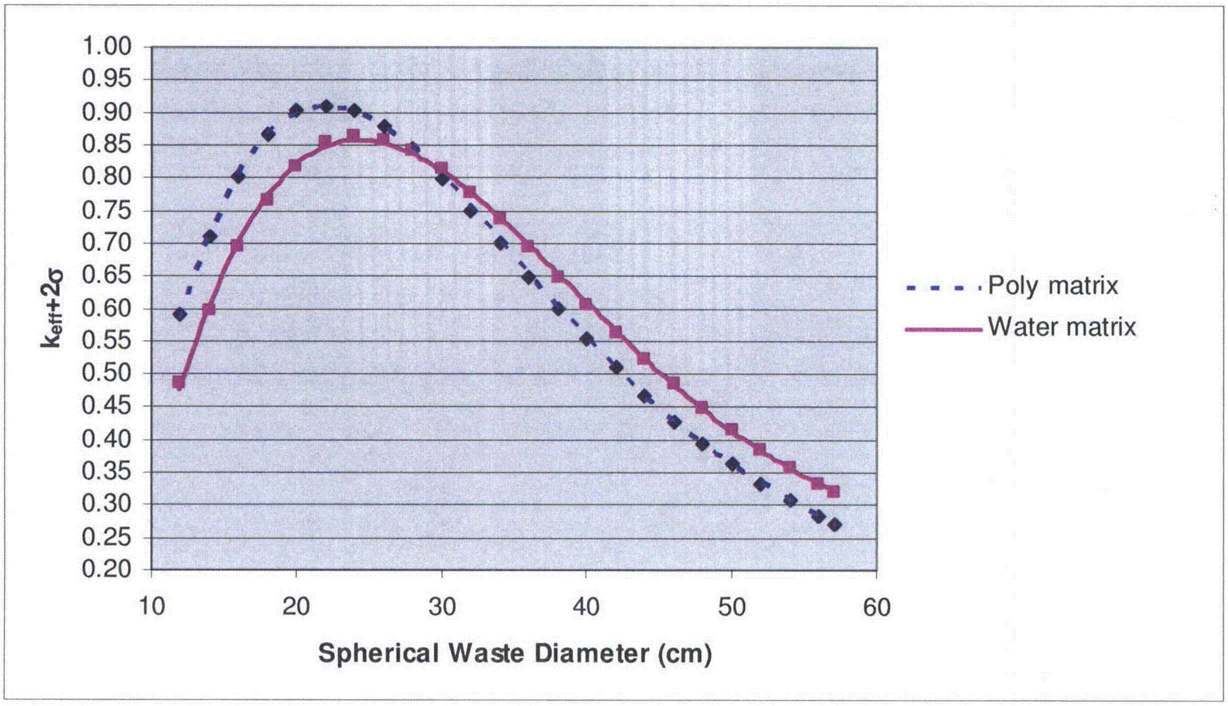

Figure 2-6 DCD Storage Zone Reactivity (Multiple, Concurrent Condition Upsets)

As demonstrated in the above graph, even if three *unlikely* process conditions were to occur concurrently within the DCD Storage Zone, the reactivity level of the DCD array remains safety subcritical.

In summary, Double Contingency Protection is established against the combination of concurrent failure of over-loading the *Fissile Material* content of DCDs to an unacceptable level, stacking DCDs, and assuming *unlikely* neutron moderation efficacy in the DCDs.

In an effort to fully satisfy the most conservative of safety analysts, a replica of this extremely abnormal model is recreated with one difference: the spherical debris within the DCD is relocated from the center to close-contact with the inner top surface of the bottom tier DCD and inner bottom surface of the top tier DCD. This modeling difference is intended to demonstrate the reactivity effects associated with the debris being preferentially packaged such that the debris within a DCD is practically touching the debris within another DCD. Recall, that the two DCD stack modeled is mirror reflected on its sides which represents that an array of DCDs would have this effect. The following graph demonstrates that adverse reactivity effects of this remodeling are hardly noticeable when compared with the centralized debris modeling technique. Note, only the polyethylene debris matrix is depicted.

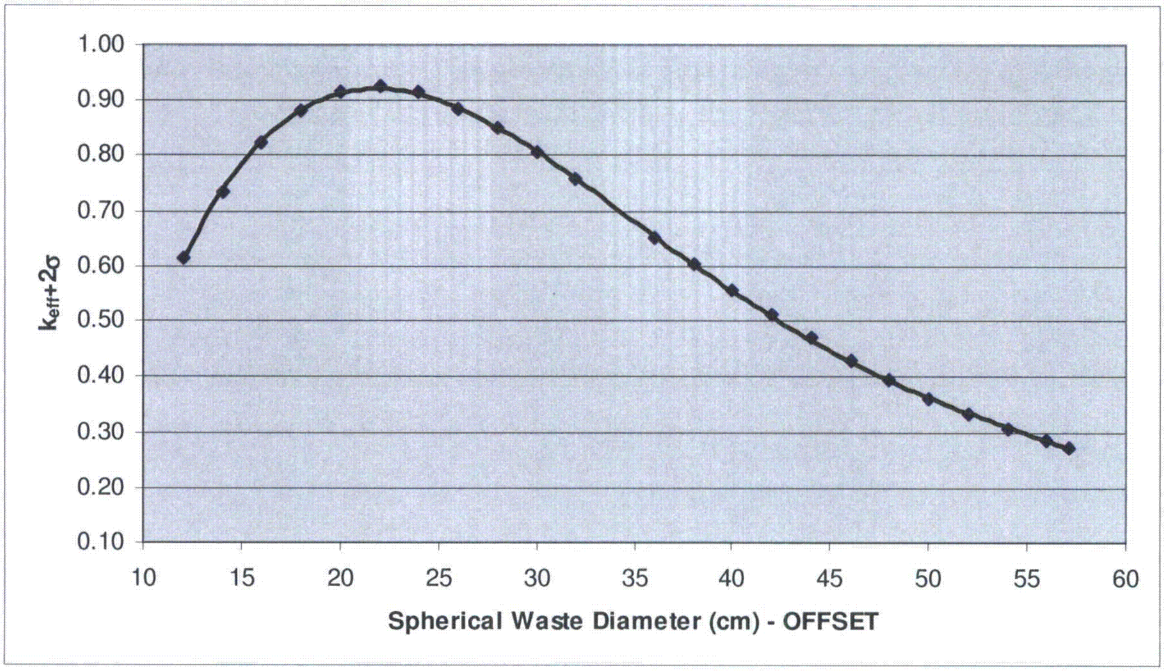

Figure 2-7 DCD Storage Zone Reactivity (Multiple, Concurrent Condition Upsets) with offset debris

To quantify safety margin associated the primary criticality safety parameter (i.e., *Fissile Material* quantity), the following two graphs (extracted from Ref. 9) demonstrate that more than 280 grams of ^{235}U equivalence in a matrix of poly and more than 330 grams of ^{235}U equivalence in a matrix of water is required before reaching the upper safety limit on reactivity.

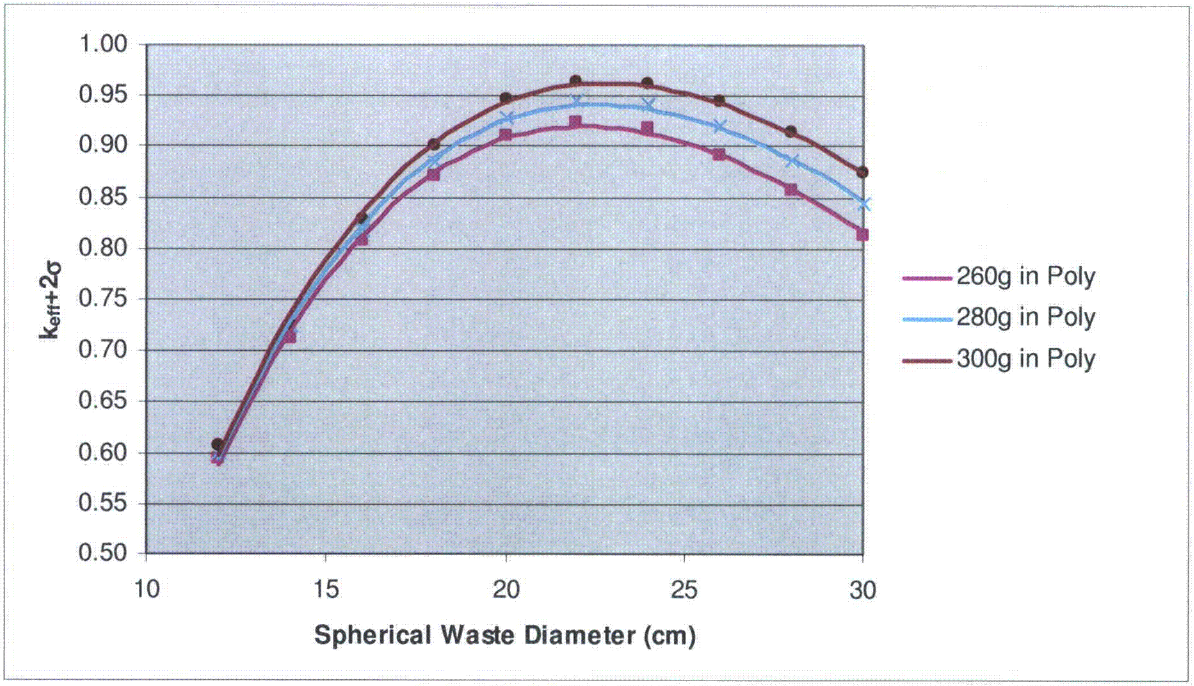

Figure 2-8 DCD Storage Zone Reactivity (Safety Margin Determination) with Polyethylene Matrix

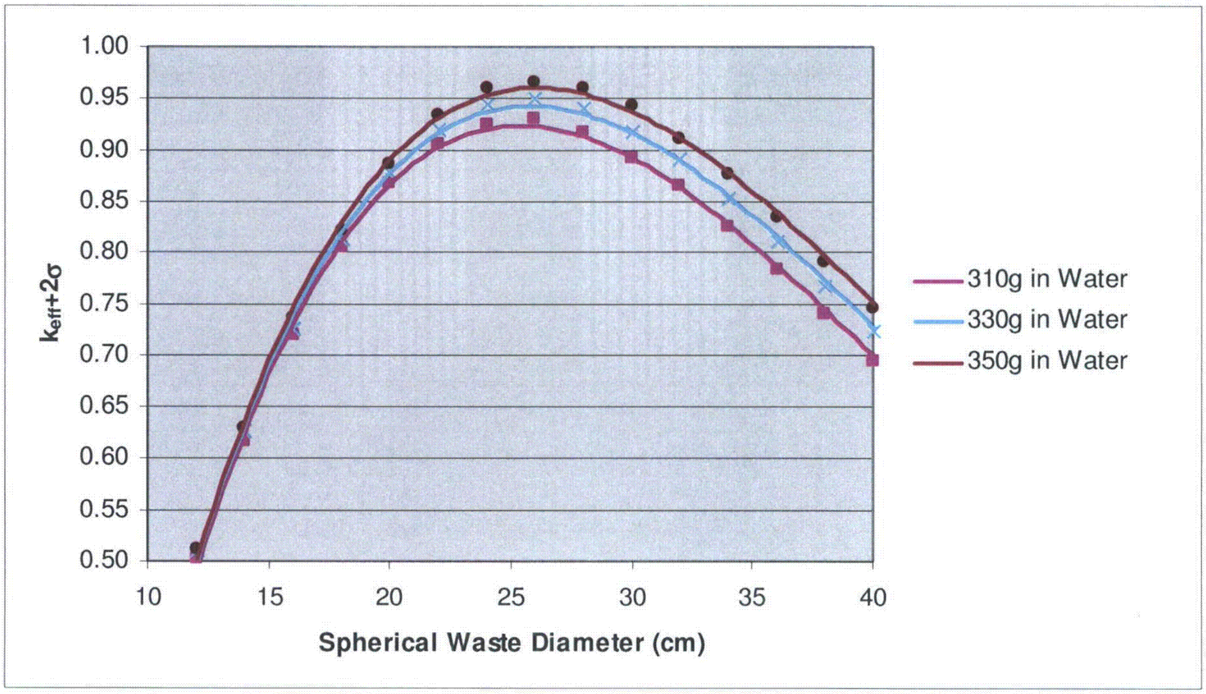

Figure 2-9 DCD Storage Zone Reactivity (Safety Margin Determination) with Water Matrix

2.4.8.3 Summary of Risk Assessment

Based on the risk assessment provided in Section 2.4.8.2, many of the following conditions must exist before a criticality accident would be possible due to concurrent abnormal conditions of over-loading DCD with *Fissile Material* in DCD Storage Zone, stacking DCDs in storage, and having debris intimately mixed within the worst possible type and configuration of hydrogenous matrix:

- Procedural non-conformance (i.e., not adhering to "no stacking" requirement); and
- Loss of Site Configuration Control plan which ensures that no DCD lifting mechanisms are available in the DCD Storage Zone (such as fork lifts or hoists); and
- An insufficient number of qualified personnel present within the CDRA during loading/storing activities; and
- Procedural non-conformance (i.e., not adhering to 125 gram ^{235}U loading requirement); and
- Loss of upstream control on assay equipment or mass tracking labeling/software; and
- An unusual condition of DCDs containing debris intimately mixed within the worst possible type and configuration of hydrogenous matrix.

2.4.8.4 Safety Controls

The explicit CSCs relied on to provide the criticality safety barriers identified above (and thus relied on to preclude a criticality accident as a result of concurrent over-loading DCDs with *Fissile Material* and stacking DCDs) are listed below. Their implementation will ensure that the risks from criticality are *as low as is reasonably achievable.*

Administrative CSC 06: CDs and *DCDs within a CDRA SHALL NOT be stacked.*

Administrative CSC 02: *The number of qualified personnel present within (or within cognitive surveillance of) a CDRA during all activities SHALL be a minimum of least three.*

Administrative CSC 07: *Site Configuration Control plan SHALL ensure that no fork lifts or mechanical hoists are available in the DCD Storage Zone of a CDRA.*

Administrative CSC 09: *DCDs within the DCD Storage Zone SHALL NOT be loaded with more than 125 grams of* ^{235}U *equivalence in the Entry and Repack Zone.*

In support of the above Administrative CSCs, CDs and DCDs are designated as Safety Features, the Safety Functional Requirement being to possess a minimum internal diameter of 57.15 cm and a minimum inner height of 84.698 cm (not including collar for CDs).

Safety Feature 01: *Collared Drums and DeCollared Drums (when being used in support of a CSC).*

3.0 SUMMARY OF CRITICALITY SAFETY CONTROLS

3.1 Criticality Safety Parameters

The extent of control of each of the various criticality safety parameters introduced in Section 2.1 is summarized in Table 3-1.

Table 3-1 Criticality Safety Parameters

Nuclear Parameter	Controlled (Y/N)	Basis	Reference
Mass	Y	Calculations have demonstrated that 125 grams of ^{235}U per DCD in the DCD Storage Zone results in a safe condition. In addition, calculations have demonstrated that more than 280 grams of ^{235}U per DCD in the DCD Storage Zone along with credible loss of geometry sufficiently increases the potential for a criticality accident beyond acceptable bounds. Therefore, reliance on mass control is required.	Section 2.3.2 Section 2.3.3 Section 2.4.3 Section 2.4.4 Section 2.4.8
Isotopic/ Enrichment	N	Anticipated normal conditions assume worst case enrichment of uranium (i.e., 100% enriched in ^{235}U isotope).	N/A
Volume	N	Volume is not applicable to the operations involved in the CDRA.	N/A
Geometry	Y	Calculations have demonstrated that DCDs stored in a planar array results in a safe condition. Therefore, reliance on geometry control is required pertaining to the dimensions of the DCDs such that evaluated areal density is maintained.	Section 2.3.2 Section 2.3.3 Section 2.4.1 Section 2.4.8
Concentration	N	Anticipated normal conditions assume worst case concentrations of uranium by varying concentrations to optimum level.	N/A
Density	N	Anticipated normal conditions assume worst case density of uranium (i.e., 19.05 g/cc)	N/A
Moderation	N	Anticipated normal conditions in the DCD Storage Zone assume a conservative moderation condition of partial density polyethylene as the debris matrix (i.e., 0.35 g/cc). Upsets of this moderation value are evaluated to the worst case condition (i.e., full density polyethylene matrix and water matrix within the DCDs) with favorable results. Because of this favorability and the fact that the composition of debris matrices within DCDs is not easily controlled with safety features, no reliance on moderation control is required. However, reliance on the probability of worst case debris matrices is relied upon such that conclusion is made that worst case debris matrices in the DCD Storage Zone are considered at least *unlikely* to occur. Since optimum H/X values are searched and utilized in the controls on *Fissile Material* and	Section 2.3.2 Section 2.3.3 Section 2.4.5 Section 2.4.6 Section 2.4.7 Section 2.4.8

Nuclear Parameter	**Controlled (Y/N)**	**Basis**	**Reference**
		geometry, there is no control on external sources of hydrogenous material (such as rain water, snow, fire suppression, etc) since these factors will reduce the reactivity of bounding system configurations evaluated.	
Interaction	Y	Anticipated normal conditions assume a worst case interaction condition (i.e., all DCDs are considered in close-packed, triangular pitch within the DCD Storage Zone). In addition, calculations have demonstrated that DCDs stacked with multiple DCDs on a second tier with a credible loss of mass control for each DCD still results in a safe condition. However, DCDs stacked higher than a two-tier array have not been evaluated. Therefore, interaction must be controlled to limit the stack height in this zone.	Section 2.3.2 Section 2.3.3 Section 2.4.2 Section 2.4.8
Reflection	N	Anticipated normal conditions assume a worst case reflection condition (i.e., 60cm of concrete below DCDs, 30cm of water above DCDs, and mirror reflection surrounding the sides of DCDs). Therefore, no reliance on reflection control is required.	N/A
Neutron Absorber	N	No neutron absorbers are used in the calculations supporting DCD storage. Therefore, no reliance on neutron absorber control is required.	N/A
Heterogeneity	N	Anticipated normal conditions assume worst case heterogeneity of uranium by assuming a completely homogeneous mixture of the 100% enriched uranium. Therefore, no reliance on heterogeneity control is required.	N/A

Source: Original

3.2 Engineered and Administrative Controls

This section provides a schedule of Systems Structures and Components (SSCs) and CSCs that have been established as important to safety in the risk assessment of CDRA operations.

3.2.1 Systems Structures and Components

The following SSCs (CDs and DCDs) have been recognized as important to ensuring the criticality safety of CDRA operations. These SSCs are identified as Safety Features (passive function). The Safety Functional Requirement of the CDs and DCDs is to possess a minimum internal diameter of 57.15 cm and a minimum inner height of 84.698 cm (not including collar for CDs). Based on their safety designation, CDs and DCDs are integral to the safety basis of a CDRA and operations would not be able to continue in their absence.

Safety Feature 01: *Collared Drums and DeCollared Drums (when being used in support of a CSC).*

3.2.2 Criticality Safety Controls

The following CSCs have been recognized as important to ensuring the criticality safety of CDRA operations.

Administrative CSC 01: *Only empty DCDs SHALL be supplied to CDRA for Fissile Material loading operations.*

Administrative CSC 02: *The number of qualified personnel present within (or within cognitive surveillance of) a CDRA during all activities SHALL be a minimum of least three.*

Administrative CSC 03: *CDRA doors (and zone doors within) SHALL be maintained closed when not in use. The doors SHALL be maintained with two locks in proper working condition. The combination or key of each lock SHALL be different. Area supervision SHALL maintain confidentiality from operators of one lock combination/key while operators SHALL maintain confidentiality from supervision of the second lock. Particularly, at no time, will the combination or access to keys of both locks be known by a single individual.*

Administrative CSC 04: *Fissile Material SHALL be conveyed within DCDs while in a CDRA.*

Administrative CSC 05: *Movement/handling of Fissile Material SHALL be accompanied by at least two different persons that are cognizant of fissile material handling responsibilities.*

Administrative CSC 06: CDs and *DCDs within a CDRA SHALL NOT be stacked.*

Administrative CSC 07: *Site Configuration Control plan SHALL ensure that no fork lifts or mechanical hoists are available in the DCD Storage Zone of a CDRA.*

Administrative CSC 08: *Only one fissile laden item SHALL be permitted in the Entry and Repack Zone of a CDRA at a time (except for a partially filled DCD retrieved from the DCD Storage Zone to collect the new fissile laden item).*

Administrative CSC 09: *DCDs within the DCD Storage Zone SHALL NOT be loaded with more than 125 grams of* ^{235}U *equivalence in the Entry and Repack Zone.*

4.0 CONCLUSION

This criticality safety assessment demonstrates that activities related to CDRA operations will be safe under all normal and foreseeable abnormal conditions. The assessment has determined that there are very large margins of safety under normal (i.e., expected) conditions and that there is considerable tolerance to abnormal conditions.

All event sequences identified in the *What-if/Checklist* analysis and assessed in this NCSA are shown to result in no criticality consequences, or are demonstrated to not have the potential to result in a criticality accident on account of:

- There being no credible sequence of events that could result in a criticality accident; or
- Demonstration that the event sequence complies with the DCP.

It is noted that all analysis is assessed against limits based on homogeneous ^{235}U-poly and ^{235U}-H_2O mixtures at bounding concentrations. Thus, the presence of moderator during the assessed operations would not impact the analysis. Based on this assessment, there are no restrictions on the use of water for fire suppression.

5.0 REFERENCES

1. Selected Soil Areas Survey Plan For Westinghouse Electric Company Hematite, Missouri, C. Wiblin, May 2008.

2. Historical Site Assessment, Revision 0, DO-08-005.

3. Code of Federal Regulations, Title 10, Part 20.304, "Disposal by Burial in Soil," 1964.

4. UNC Internal Memorandum, F. G. Stengel to E. F. Sanders, "Burial of Material," May 14, 1965.

5. Hematite Burial Pit Log Books, Volumes 1 and 2, July 16, 1965, through November 6, 1970.

6. Westinghouse Electric Corporation LLC, Employee Interview Records, 2000 to 2008.

7. CE Internal Memorandum, J. Rode to Bill Sharkey, "The Hematite Burial Grounds," March 5, 1996.

8. NSA-TR-09-15, Rev. 0, Nuclear Criticality Safety Assessment of Buried Waste Exhumation and Contaminated Soil Remediation at the Hematite Site, B. Matthews, May 2009.

9. NSA-TR-09-02, Rev. 0, Nuclear Criticality Safety Calculation involving ≤ 125 g^{235}U Drum Arrays, D. Vaughn, April 2009.

10. NC-09-001, Rev. 0, Hazards and Operability Study for Decommissioning Activities in Support of the Hematite Decommissioning Project, April 2009.