NuclearSafety Associates

Nuclear Criticality Safety Assessment of Fissile Material Storage at the Hematite Site

Revision 0

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20-APR-09
David Vaughn — Date
Author

20-APR-09
Robert Maurer — Date
Technical Reviewer

5-14-09
Brian Matthews — Date
Project Manager

5-14-09
Gerry Couture — Date
Client Reviewer

NuclearSafety Associates

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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 Accountability
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
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 cover only operations within a *Fissile Material* Storage Area (FMSA).

This NCSA is organized as follows:

- **Section 1** introduces the NCSA of FMSA operations at the Hematite site.
- **Section 2** provides the risk assessment of FMSA 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 FMSA 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.

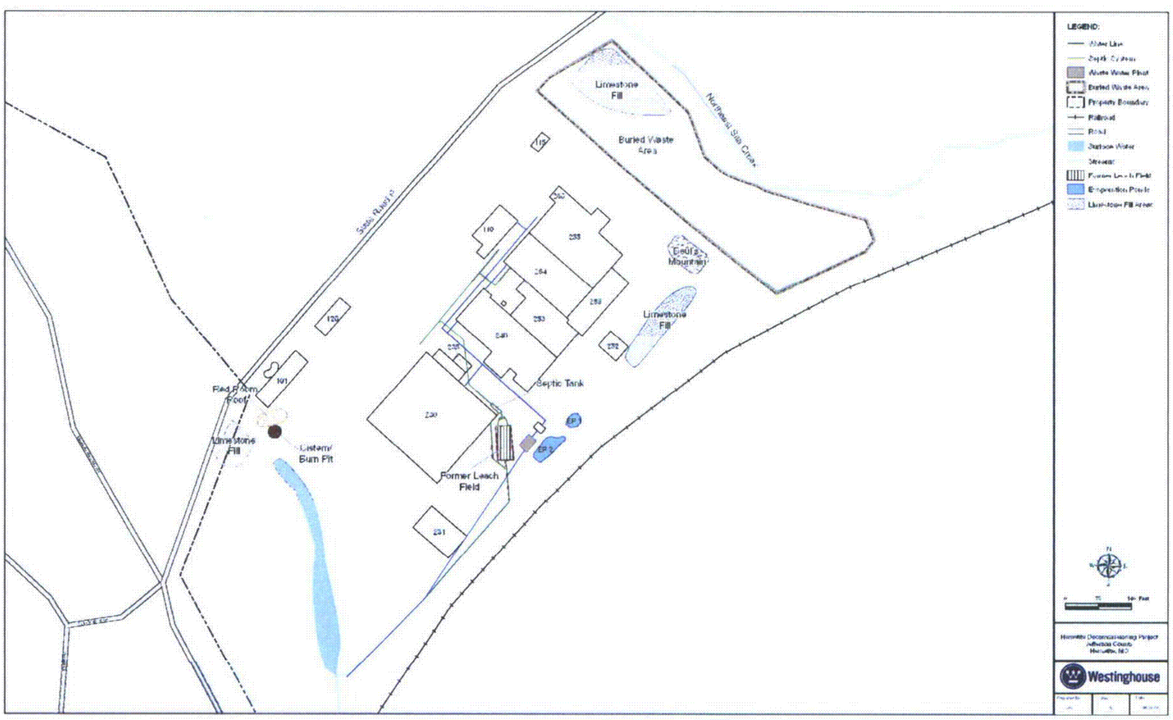
The Hematite facility was used for the manufacture of low-enriched (i.e., $\leq$ 5.0 wt.% ^{235}U), intermediate-enriched (i.e., >5 wt.% and up to 20 wt.% ^{235}U) and high-enriched (i.e., > 20 wt.% ^{235}U) materials during the period 1956 through 1974. In 1974 production of intermediate and high-enriched 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 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 then 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 Special Nuclear Material (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 in a FMSA pending future export to an offsite facility or an onsite SNM dispersion process. Note that the storage of 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 material matrix. Portion(s) of the material 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 material 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 FMSA for storage or a Collared Drum Repack Area (CDRA) for *Fissile Material* repack and subsequent storage. In the FMSA, the collar may be removed from the CD and the Decollared Drum (DCD) may be stored in a planar array.

1.4 Description of an FMSA

A FMSA on the site is defined as an area in which dual controlled entry is required as well as tandem operations with oversight. The FMSA contains access doors maintained in a locked position until opened via two different locking mechanisms (e.g., combination lock or key lock). Two different persons are required when accessing the area and each is required to perform tasks in tandem. In addition, cognitive oversight is required during all active operations.

Only CDs are approved for introduction into a FMSA. 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.

The ^{235}U content within each CD is limited during loading such that each CD is assured to contain ≤ 350 g^{235}U. The collars on a CD may be removed within the FMSA to create a DCD.

Other than not being able to stack CDs or DCDs, there are no other restrictions on operations in regards to criticality safety in a FMSA.

1.5 Scope of Assessment

The activities addressed in this NCSA include all actions associated with storage of *Fissile Material* in a FMSA.

The following activities are specifically excluded from this assessment:

- The recovery, handling and transit of *Fissile Material* to a FMSA. The criticality safety assessment of buried waste exhumation and contaminated soil remediation activities is provided in Ref. 8.
- The transportation of recovered *Fissile Material* from the Hematite site (e.g., to an offsite waste facility or an offsite sampling laboratory).
- Activities related to any type of manipulation of container contents.

- Storage of 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 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 *Fissile Material* storage in a FMSA.

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 Accountability (MC&A) purposes. All identified *Fissile Material* on the site, irrespective of location and including all 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.

* 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 *Fissile Material* storage in a FMSA 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 FMSA operations under normal (i.e. expected) conditions.
- **Section 2.4** contains the criticality safety assessment of FMSA operations under abnormal (i.e. unexpected) conditions.

2.1 Criticality Hazard Identification

This section outlines the technique used to identify criticality hazards associated with *Fissile Material* storage in a FMSA. 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 method employed in the criticality safety assessment of FMSA 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 Fissile Material Storage Area (FMSA) What-if/Checklist Analysis

What-if	Causes	Unmitigated Consequences	Accident Sequence in NCSA
Geometry			
What if containers other than CDs or DCDs are stored within a FMSA?	Smaller containers are easier to store	Potential criticality accident due to unevaluated storage configuration	**Section 2.4.1**
Interaction			
What if CDs or DCDs get placed on top of each other in a FMSA?	Loss of floor space leads to vertical storage	Potential criticality accident if drums are stacked too high	**Section 2.4.2**
Mass			
What if *Fissile Material* reported within a CD is lower than actual when introduced into a FMSA?	This hazard is identified and evaluated in Ref. 8. The cited reference reports that the probability of adverse consequence to the criticality safety of a FMSA 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 FMSA in respect to the "Isotopic/Enrichment" parameter. No hazards have been identified because the bounding normal condition within the FMSA assumes that the *Fissile Material* content within drums 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 material within CDs contains significant hydrogenous material or other material that has a significant neutron moderating efficacy?	Undocumented material forms on historical data records or Liquids remain in material after being evaluated in upstream WEA	None. Bounding conditions of internal moderation are shown to maintain safe levels of reactivity within the FMSA.	
What if rainwater/snow or hydrogenous fire suppressive material infiltrates CDs or 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 FMSA.	**Section 2.4.3**

What-if	Causes	Unmitigated Consequences	Accident Sequence in NCSA
What if FMSA floods to or beyond the height of the CDs or 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 FMSA.	**Section 2.4.4**
Density			
There are no identified hazards associated with creating a more adverse condition in the FMSA in respect to the "Density" parameter. No hazards have been identified because the bounding normal condition within the FMSA assumes that the *Fissile Material* content within drums 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 FMSA in respect to the "Heterogeneity" parameter. No hazards have been identified because the bounding normal condition within the FMSA assumes that the debris matrix 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).			
Neutron Absorbers			
There are no identified hazards associated with creating a more adverse condition in the FMSA in respect to the "Neutron Absorbers" parameter. No hazards have been identified because the bounding normal condition within the FMSA accepts no credit for neutron absorbing material that is certain to be present within the matrix and surroundings thereby anticipating a neutron absorbing condition that cannot be credibly challenged further.			
Reflection			
There are no identified hazards associated with creating a more adverse condition in the FMSA in respect to the "Reflection" parameter. No hazards have been identified because the bounding normal condition within the FMSA assumes full water (30 cm) reflection atop the drums and full concrete (60 cm) reflection below the drums thereby anticipating a reflection condition that cannot be credibly challenged further.			
Concentration			
There are no identified hazards associated with creating a more adverse condition in the FMSA in respect to the "Concentration" parameter. No hazards have been identified because the bounding normal condition within the FMSA assumes an optimally concentrated debris matrix appropriate for credible mass loadings thereby anticipating a concentration condition that cannot be credibly challenged further.			
Volume			
The "Volume" parameter is not an applicable parameter in respect to the operations occurring within the FMSA. Therefore, changes in volume are not a concern for criticality safety of the FMSA. However, a related parameter may include "Geometry" which has been previously addressed.			

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 *Fissile Material* storage in a FMSA is provided below:

- It is assumed for the purposes of this assessment that all CDs introduced into a FMSA are dimensionally equal or larger than typical and industry standard DOT Type A 55-gallon drums. These CDs 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, CDs 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 *Fissile Material* 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 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 operations within an FMSA 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 *Fissile Material* storage in a FMSA.

Computed reactivity results have been calculated in Ref. 9 using explicit three-dimensional modeling of credible *Fissile Material* storage configurations in FMSAs. 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.

Details 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 in a FMSA 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 350 grams of full-density ^{235}U metal and 0.96 g/cc polyethylene. The quantity of ^{235}U metal modeled within the DCD (i.e., 350 grams) is simply the operational limit allowed by procedure.

The spherical debris 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 *Fissile Material* 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 (energy corresponding to the average lethargy of neutrons causing fission) are provided in electronic form – see spreadsheet associated with Ref. 9).

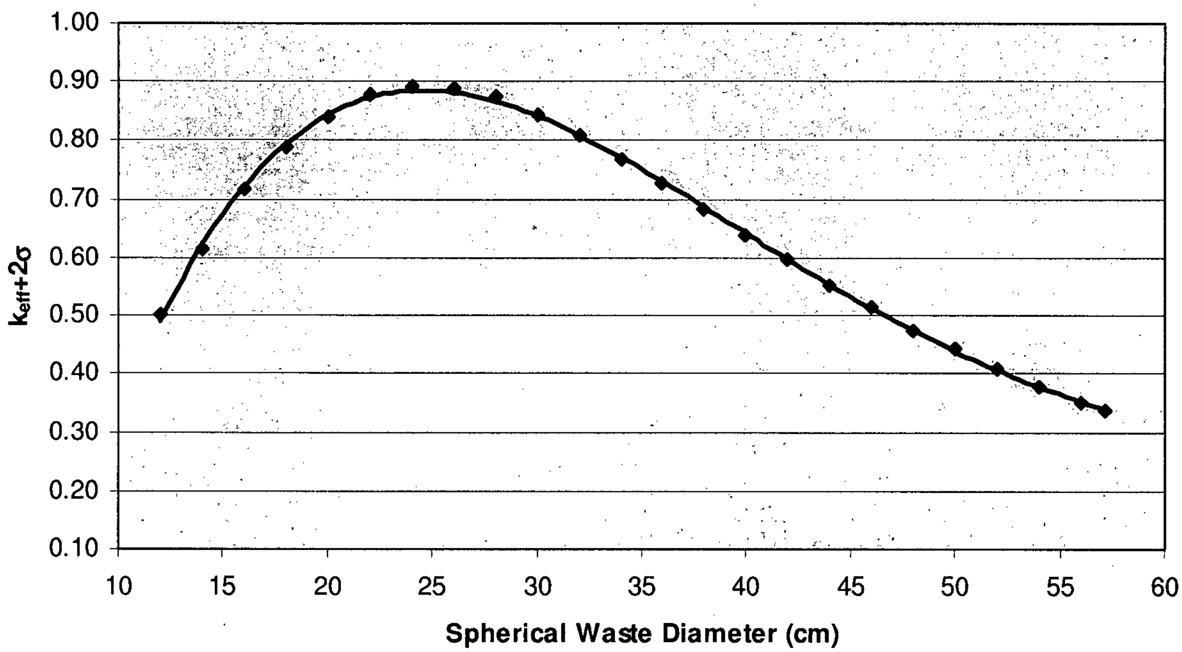


Figure 2-1 ≤350g ^{235}U *Fissile Material* Storage Reactivity (Normal Condition)

As seen in the graph above, the normal (anticipated) reactivity associated with ≤350g ^{235}U *Fissile Material* storage is well below the upper safety limit of k_{eff}=0.95.

2.4 Abnormal Conditions

This section provides an assessment of the criticality hazards identified from the *What-if/Checklist* analysis of *Fissile Material* storage in a FMSA.

2.4.1 Loading/Storing Other Than CDs or DCDs

2.4.1.1 Discussion

Introduction of containers into a FMSA which are dimensionally smaller than a CD would result in an unevaluated condition which could lead to a potential for a criticality accident within a FMSA.

2.4.1.2 Risk Assessment

Introduction of containers with dimensions smaller than CDs into a FMSA is considered *highly improbable*. All activities outside of FMSAs are governed under the nuclear criticality safety analysis of Ref. 8. This cited analysis requires that all transfer of suspected or confirmed *Fissile Material* first be over-packed into a CD prior to relocation and requires multiple personnel to be present and cognizant during all transfers. In addition, the FMSAs used for CD or DCD storage are required to be maintained under dual controlled access during all times. This involves dual combination or keyed locks in which access to the locks are independent between operators and their supervision. In addition, the access doors are configured such that closure of the doors results in automatic locking. Consequently, introducing a container other than a CD into a FMSA for subsequent storage would involve many procedural infractions violated by many personnel in collusion. Therefore, the procedural requirements outside of the FMSAs (governed in Ref. 8) combined with the administrative controls inside of the FMSAs are considered sufficiently adequate in ensuring compliance with the intent of the Double Contingency Principle and reducing the probability of a criticality accident within the FMSA to as low as reasonably achievable.

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 storing a container with dimensions smaller than a CD (without collar) would be possible:

- The number of qualified personnel present or supervising within the FMSA during storing activities would need to be less than three; and
- Procedural requirement that containers with dimensions smaller than CDs are not to be introduced into the FMSA would need to be disregarded; and
- Procedural requirement that FMSA doors are to be closed and locked at all times would need to be disregarded; and
- Procedural requirement that FMSA door lock combinations or key access are to be independent would need to be disregarded; and
- Procedural nonconformance that *Fissile Material* movement/handling outside or inside the FMSA 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 CD or DCD movement/handling) are listed below. Their implementation will ensure that the risks from criticality are as low as is reasonably achievable.

> **Administrative CSC 01:** *The number of qualified personnel present within or in cognitive surveillance of a FMSA during all activities SHALL be a minimum of at least three.*

> **Administrative CSC 02:** *Only CDs are supplied to FMSAs for storage operations.*

In support of the above Administrative CSC, CDs 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).

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

> **Administrative CSC 03:** *Zone doors 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:** *Movement/handling of Fissile Material SHALL be accompanied by at least two different persons.*

2.4.2 Stacking CDs or DCDs in a FMSA

2.4.2.1 Discussion

As recognized in Section 2.3, the CDs and DCDs stored in FMSAs are anticipated to form a planar array. This requires that the CDs and DCDs are not to be stacked on top of each other. If these 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 a FMSA that could provide assistance to the operators in allowing stacking of CDs or DCDs on top of each other. 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 if stacking were to occur. It is considered at least *unlikely* that collusion of the persons present in the FMSA would occur such that a CD or DCD is manually hoisted and set atop another. Furthermore, it is *highly improbable* to manually stack (with no mechanical means) CDs or DCDs that result in a three-high stack due solely to the minimal height of each 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 FMSA during operations that stacking a CD or DCD onto another is considered at least *unlikely* and that excessive stacking is considered *highly improbable* (since this is multiple instances of failure of a very simple procedural prohibition).

The following graph (extracted from Ref. 9) demonstrates acceptable reactivity increase when the normal model representing the $\leq$350g^{235}U *Fissile Material* storage is modified to include seven DCDs centrally located on a second tier.

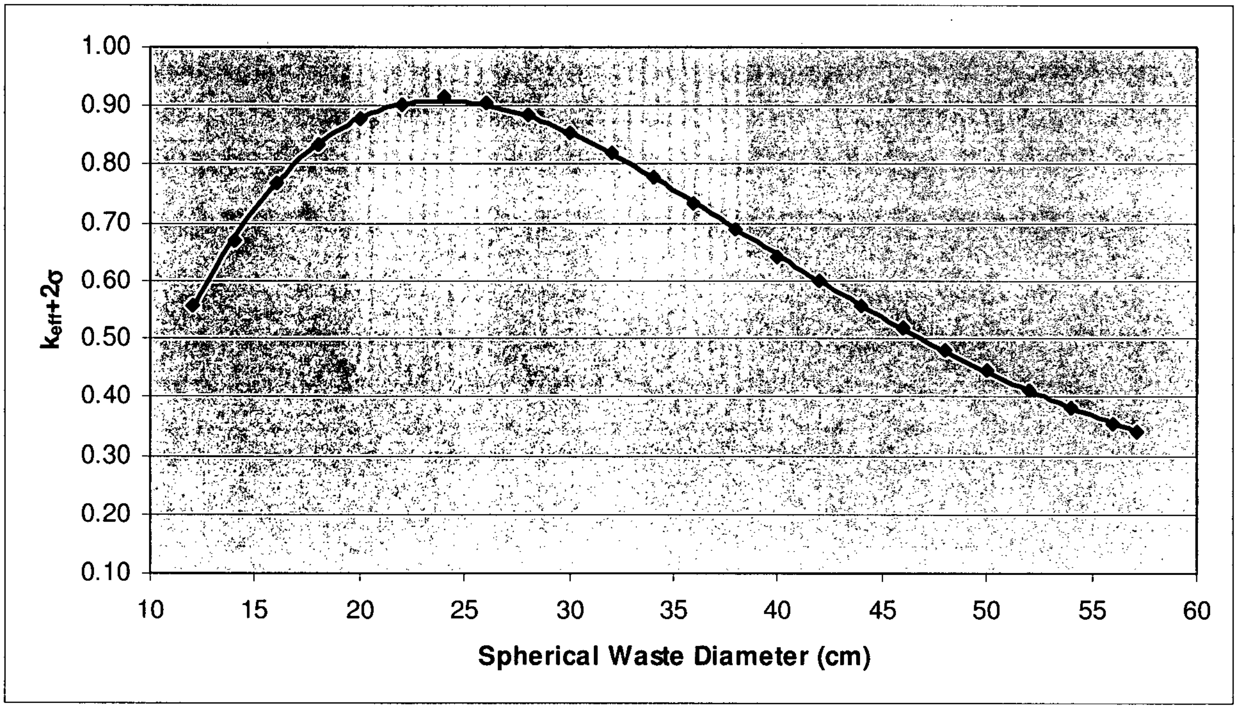


Figure 2-2 ≤350g ^{235}U *Fissile Material* Storage Reactivity (DCD Stack Upset)

In summary, Double Contingency Protection is established against stacking CDs or DCDs to an unacceptable level within the FMSA. It is seen that it is at least *unlikely* for multiple operators to not adhere to a very simple procedural prohibition and it is at least *unlikely* for management to provide the mechanical capability (e.g., fork lift or hoist) which is necessary to stack 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). Therefore, a criticality accident occurring within a FMSA due to credible stacking upsets is beyond *highly improbable* which is considered as low as reasonably achievable.

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 CDs or DCDs would be possible:

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

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 CDs or DCDs) are listed below. Their implementation will ensure that the risks from criticality are as low as is reasonably achievable.

> **Administrative CSC 05:** *CDs and DCDs within a FMSA SHALL NOT be stacked.*
>
> **Administrative CSC 01:** *The number of qualified personnel present within or in cognitive surveillance of the FMSA during all activities SHALL be a minimum of at least three.*
>
> **Administrative CSC 06:** *Site Configuration Control plan SHALL ensure that no fork lifts or mechanical hoists are available in the FMSA.*

2.4.3 Increased neutron moderator efficacy outside CDs and DCDs

2.4.3.1 Discussion

As discussed in Section 2.3, the normal condition in regards to neutron moderator efficacy outside the CDs and DCDs is anticipated to be dry conditions. This normal condition is considered acceptable due to the location of the CDs and 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.

2.4.3.2 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 CDs and DCDs. The normal condition anticipates up to 30 cm of water reflection atop the CDs and DCDs which more than accounts for any accumulation of snow or hydrogenous fire suppression atop the CDs and DCDs. Further, the worst credible upset condition involving spherical *Fissile Material* within a matrix optimized for H/X results in a safe condition (as long as *Fissile Material* and "no stacking" of CDs and 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).

2.4.3.3 Summary of Risk Assessment

Based on the discussion provided in Section 2.4.3.2, 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.

2.4.3.4 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).

2.4.4 Spillage of CD or DCD Contents due to flooding

2.4.4.1 Discussion

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

2.4.4.2 Risk Assessment

There is no criticality safety concern in regards to catastrophic flooding of the FMSA. The frequency of flooding the FMSA to the extent whereby material within the CDs and DCDs would escape is a remote possibility that should be considered to have an associated *unlikely* probability based on site history. Further, the CDs and DCDs contain segregated nuclear 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 CD 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 CD and DCD escaped their confines and found themselves in a large pool of water and material. This is due to the fact that in order for the contents of the CDs and DCDs to be removed simply by the force of water level increase inside the CDs and DCDs, the *Fissile Material* contents must be adequately light in density such that water could displace the CD's and DCD's confinement. This type of material would randomly disperse in a uniform homogenous mixture of water and material, quickly becoming more like a solution system, rather than a more reactive, uniform, and optimally moderated array configuration.

2.4.4.3 Summary of Risk Assessment

Based on the discussion provided in Section 2.4.4.2, 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 material confinement condition (i.e., held within a CD and DCD).

2.4.4.4 Safety Controls

There are no safety controls, procedural requirements, or equipment associated with preventing a criticality accident concerning upsets of material confinement conditions within a CD and DCD (e.g., displacement by flooding).

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	N	*Fissile Material* is controlled for the CDs when being loaded upstream (Ref. 8); therefore, there are no mass controls within the FMSA.	N/A
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 FMSA.	N/A
Geometry	Y	Supporting criticality safety calculations have demonstrated that DCDs stored in a planar array within a CDRA result 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 2.3.1
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 assume worst case moderation levels by varying H/X to optimum level.	N/A
Interaction	Y	Calculations have demonstrated that DCDs stacked multiple on a second tier still results in a safe condition. However, DCDs stacked higher than a two-tier array have not been evaluated. Therefore, reliance on interaction control is required.	Section 2.4.2
Reflection	N	Anticipated normal conditions assume a worst case reflection condition (i.e., 60cm of concrete below CDs and DCDs, 30cm of water above CDs and DCDs, and mirror reflection surrounding their sides). Therefore, no reliance on reflection control is required.	N/A
Neutron Absorber	N	No neutron absorbers are used in the calculations supporting FMSA operations. 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 FMSA operations.

3.2.1 Systems Structures and Components

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

Safety Feature 01: *Collared 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 FMSA operations.

Administrative CSC 01: *The number of qualified personnel present within or in cognitive surveillance of a FMSA during all activities SHALL be a minimum of at least three.*

Administrative CSC 02: *Only CDs are supplied to FMSAs for storage operations.*

Administrative CSC 03: *Zone doors 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: *Movement/handling of Fissile Material SHALL be accompanied by at least two different persons.*

Administrative CSC 05: *CDs and DCDs within a FMSA SHALL NOT be stacked.*

Administrative CSC 06: *Site Configuration Control plan SHALL ensure that no fork lifts or mechanical hoists are available in the FMSA.*

4.0 CONCLUSION

This criticality safety assessment demonstrates that activities related to FMSA 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 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-09-03, Rev. 0, Nuclear Criticality Safety Calculations for ≤350 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.