Nuclear Criticality Safety Assessment of Collared Drum Staging, Buffer Storage, and Transit at the Hematite Site

Revision 0

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Revision History

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Glossary of Acronyms, Abbreviations, and Terms

Acronym/Term	Definition
'	Foot (12")
"	Inch (2.54 cm)
ACM	Asbestos Containing Material
AEC	Atomic Energy Commission
ALARA	As Low As Reasonably Achievable
Assay Containers	Containers presented for radiological characterization at a MAA and which comprise exhumed *fissile material*, suspect *fissile material* or the material content of exhumed intact containers.
Bq	One radioactive disintegration per second
BWCSR	Buried Waste and Contaminated Soil Remediation
cc	Cubic centimeter
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.
CDBS	Collared Drum Buffer Store – area used to interim store *Field Containers* and *Assay Containers* that do not have assigned ^{235}U mass contents and are loaded in sealed CDs.
CDRA	Collared Drum Repack Area - area used to repackage or batch the contents of CDs to allow consolidation of CDs.
CDSA	Collared Drum Staging Area – area used to stage *Field Containers* (loaded in sealed CDs) that have been generated from site remediation activities and are believed to have the potential to contain SNM in a quantity/concentration sufficient to require NCS controls/oversight.
CFR	Code of Federal Regulations
Ci	Curie (equivalent to 3.7 x 10^{10} Bq)
cm	Centimeter
cpm	Counts per minute
CSC	Criticality Safety Control
Cut Depth	Maximum permitted thickness of a layer of buried wastes/contaminated soils that is permitted to be exhumed following implementation of in-situ radiological survey and visual inspection procedures and removal of fissile items and the other items noted in the *Field Container* definition.
DCGL	Derived Concentration Guideline Levels
DCP	Double Contingency Principle

D&D	Decontamination and Decommissioning
DinD	Defense-in-Depth
Field Containers	Containers comprising exhumed *fissile material*, suspect *fissile material*, and: • items that resemble intact containers; • bulky objects with linear dimensions exceeding the permitted *cut depth*; and • any other items with properties that are not consistent with the calibration basis of the in-situ radiological survey equipment (e.g., large metallic or dense items).
Fissile Material Containers	Containers comprising material with an established ^{235}U gram content.
Fissile Material	Material containing fissile nuclides (e.g., ^{235}U) in a quantity/concentration sufficient to require NCS controls/oversight.
FMSA	Fissile Material Storage Area – area used to interim store *Fissile Material Containers* that have an ascribed ^{235}U mass content. The *Fissile Material Containers* are sealed within CDs.
FSS	Final Status Survey
g	Gram
gallon	3.785 L
GUNFC	Gulf United Nuclear Fuels Corporation
HDP	Hematite Decommissioning Project
HEU	Highly Enriched Uranium
HPT	Health Physics Technician
HRGS	High Resolution Gamma Spectrometer
keV	Kilo Electron Volt
kg	Kilogram
L	Liter
LLW	Low Level Waste
µ	Micro (1.0×10^{-6})
m	Meter
MAA	Material Assay Area - area used to assay exhumed *fissile material*, suspect *fissile material* or the material content of exhumed intact containers, in order to provide a ^{235}U gram inventory estimate.
MARSSIM	Multi Agency Radiation Survey and Site Investigation Manual
MC&A	Material Control and Accountability
mg	Milligram
NCS	Nuclear Criticality Safety
NCSA	Nuclear Criticality Safety Assessment
NCS Exempt Material	Material containing an insufficient quantity/concentration of fissile nuclides (e.g., ^{235}U) to require NCS controls/oversight
p	Pico (1.0×10^{-12})
PCE	Perchloroethylene

Survey Area	Clearly delineated area of land subject to in-situ radiological survey, and for which excavation activities are planned.
SNM	Special Nuclear Material - material containing fissile nuclides (e.g., ^{235}U)
SSC	System, Structure and Component
TCE	Trichloroethene
U	Uranium
UNC	United Nuclear Corporation
vol. %	Percentage by volume
Waste Container	Containers used to hold materials classified as *NCS Exempt Material* following operations in a WEA and/or MAA.
WHA	Waste Holding Area – area used to stage solid wastes generated from site remediation activities that have been categorized as *NCS Exempt Material.*
WEA	Waste Evaluation Area – area used to evaluate solid wastes generated from site remediation activities that are believed to have the potential to contain SNM in a quantity/concentration sufficient to require NCS controls/oversight.
WTS	Water Treatment System
wt. %	Percentage by weight
yd	Yard (36")

1.0 INTRODUCTION

This Nuclear Criticality Safety Assessment (NCSA) is provided to support final decommissioning of the Hematite site. The operations assessed in this NCSA encompass Collared Drum (CD) staging, buffer storage, and transit activities. The results of this NCSA will be applied to all Waste Evaluation Areas (WEAs) and Material Assay Areas (MAAs) used in support of Hematite Decommissioning Project (HDP) remediation operations.

This NCSA is organized as follows:

- **Section 1** introduces the NCSA of CD staging, buffer storage, and transit activities at the Hematite site and provides an overview of the operations to be performed.
- **Section 2** provides the risk assessment of the CD staging, buffer storage, and transit activities outlined in Section 1.
- **Section 3** summarizes the important facility design features, equipment and procedural requirements identified in the criticality safety risk assessment provided in Section 2.
- **Section 4** details the conclusions of the NCSA of CD staging, buffer storage, and transit activities 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 hexafluoride (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.

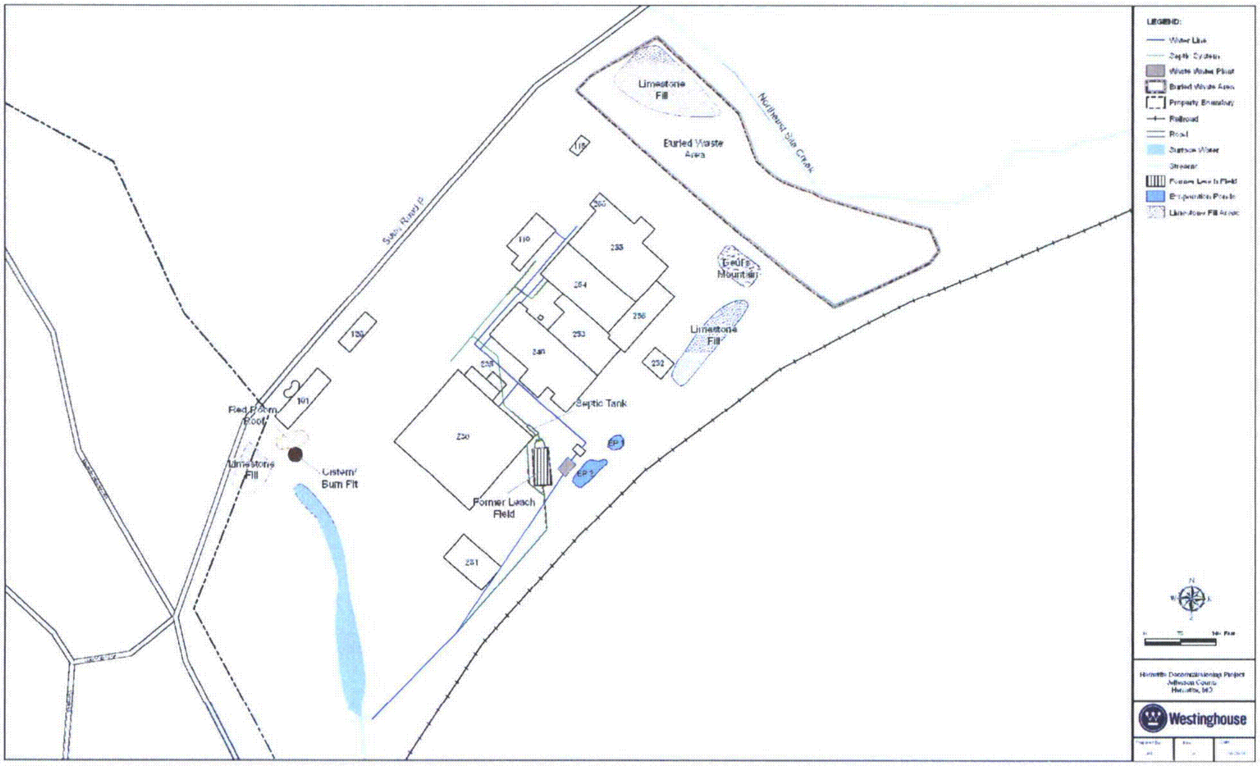
The Hematite facility was used for the manufacture of low-enriched (i.e., ≤ 5.0 wt.% ^{235}U), intermediate-enriched (i.e., >5 wt.% and up to 20 wt.% ^{235}U) and high-enriched (i.e., > 20 wt.% ^{235}U) materials during the period 1956 through 1974. In 1974 production of intermediate and high-enriched 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 sites central tract.

1.2.1.1 Documented Process Waste Burials

Based on historic documentation (Ref. 6), 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. 6

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. 7). Facility operating procedures (Ref. 8) 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. 9) 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. 10). 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. 6

The recorded (Ref. 9) 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. 6) 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. 10), it is possible that on-site burials other than burials conducted under 10CFR20.304 (1964; Ref. 7) 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. 5). 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. 11). No specific information has been found to indicate the explicit nature of the waste consignments associated with these undocumented burials.

1.2.1.3 Other Burials

1.2.1.3.1 Red Room Roof Burial Area

The Building 240 Red Room roof burial area is described in Reference 6. The Building 240 Red Room roof was replaced during the mid 1980s. The removed roofing materials were buried on site near Building 101 - the Tile Barn. The Red Room roof burial area has the potential to contain residual radioactivity in excess of natural background due to the high enriched processes that took place within the Red Room from 1956 through 1973. However, since only roofing materials were known to be consigned to this burial area, it is believed that the potential to encounter any significant residual uranium is very small.

1.2.1.3.2 Cistern Burn Pit Area

The cistern burn pit area southwest of Building 101, the Tile Barn, was used to burn wood pallets that may have contained some level of contamination. Therefore, this area may include residual radioactivity in excess of natural background.

1.2.2 Current State

The burial pits are currently in a quiescent state, although the pits may have been subjected to disturbances in the past and have been subjected to characterization sampling initiatives (Ref. 1). The results of sampling campaigns indicate a maximum ^{235}U concentration of 53.5 pCi/g, corresponding to a ^{235}U concentration of approximately 2.5 µg/g(waste matrix). Based on the sample data and the original burial logs, the burial pits are believed to contain only small quantities of ^{235}U (i.e., less than 1 kg ^{235}U per burial pit).

During 2008 an extensive site sampling and survey program was implemented. The site-wide survey included sampling of soils within the burial pit area, the gas line, the leach field, and land areas adjacent to the process buildings. The burial pit area sampling activities were focused on providing better understanding of the location of the individual burial pits, associated overburden, depth and nature of buried wastes, and contamination levels immediately beneath the individual pits. The other sampling activities were focused on soils surrounding the natural gas line that runs adjacent to the burial pit area and soils around the former process buildings. In addition, samples were extracted from the leach field to complement previous sampling efforts. A breakdown of the sampling program is provided in Table 1-2.

Table 1-2 2008 Sampling Program Breakdown

Area	Number of Cores	Maximum Core Depth (ft)
Burial Pit	73#	16#
Gas Line	4	16
	7	16
	8	10
	8	10
	10	~5
	3	5-6
Leach Field	5	10
Adjacent Soils	28	10
Total	146	

Source: Ref. 5

Notes: # Three (3) of the burial pit sample locations were used for water drawdown well construction and measured ~30' in depth.

In total, 146 sample cores were exhumed across the site, seventy-three (73) of which were exhumed from the area of land occupied by the documented burial pits. The field activities included surface sampling with shovels and scoops, auguring by hand, and advancement of soil borings using hollow stem augers equipped with split spoon samplers. Each exhumed soil core was screened in the field using instruments to detect radiological and chemical contaminants, including the presence of ^{235}U.

Analysis of all of the sample cores exhumed from the burial areas of the site revealed a maximum ^{235}U concentration of 153 pCi/g, equivalent to 0.11 g^{235}U/L*.

1.3 Overview of the Site Remediation Objectives

The site remediation objectives relevant to buried waste exhumation and contaminated soil remediation are described below. These site-wide remediation objectives are applicable to all HDP remediation areas. These are relevant to CD staging, buffer storage, and transit operations because the materials exhumed from these areas will be subject to staging, buffer storage, and transit operations.

HDP remediation areas will be excavated to a depth where historical knowledge, and/or visible and radiological evidence indicate that buried wastes, radiological contaminants and chemical contaminants of concern have been removed. Once these objectives are met, Final Status Survey (FSS) and hazardous material remediation goals can be verified. FSS goals are based on area and depth specific Derived Concentration Guideline Levels (DCGL). Verification of FSS goals is accomplished by a combination of in-situ radiological surveys and sample extraction and analyses. Verification of hazardous material remediation goals is accomplished by a combination of direct measurements and sample extraction and analyses. In all cases, excavation activities in HDP remediation areas will be conducted in accordance with the governing NCSA requirements until the FSS and hazardous material remediation goals are achieved and verified.

Following verification that FSS and hazardous material remediation goals have been achieved, the subject HDP remediation areas may be declared 'remediated', allowing initiation of site restoration activities such as backfilling and grading.

* Conversion of pCi/g to g^{235}U/L concentration:

Specific activity of $^{235}U = 2.16107\text{x}10^{-6}$ Ci/g^{235}U = $2.16107\text{x}10^{6}$ pCi/g^{235}U,

$$\frac{153\ pCi/g(sample)}{2.16107\times10^{6}\ pCi/g^{235}U} = 7.08\times10^{-5}\ g^{235}U/g(sample),$$

$$7.08\times10^{-5}\ g^{235}U/g(sample)\times1.6\ g(sample)/cc = 0.11\ mg^{235}U/cc = 0.11\ g^{235}U/L$$

1.4 Overview of HDP Operations

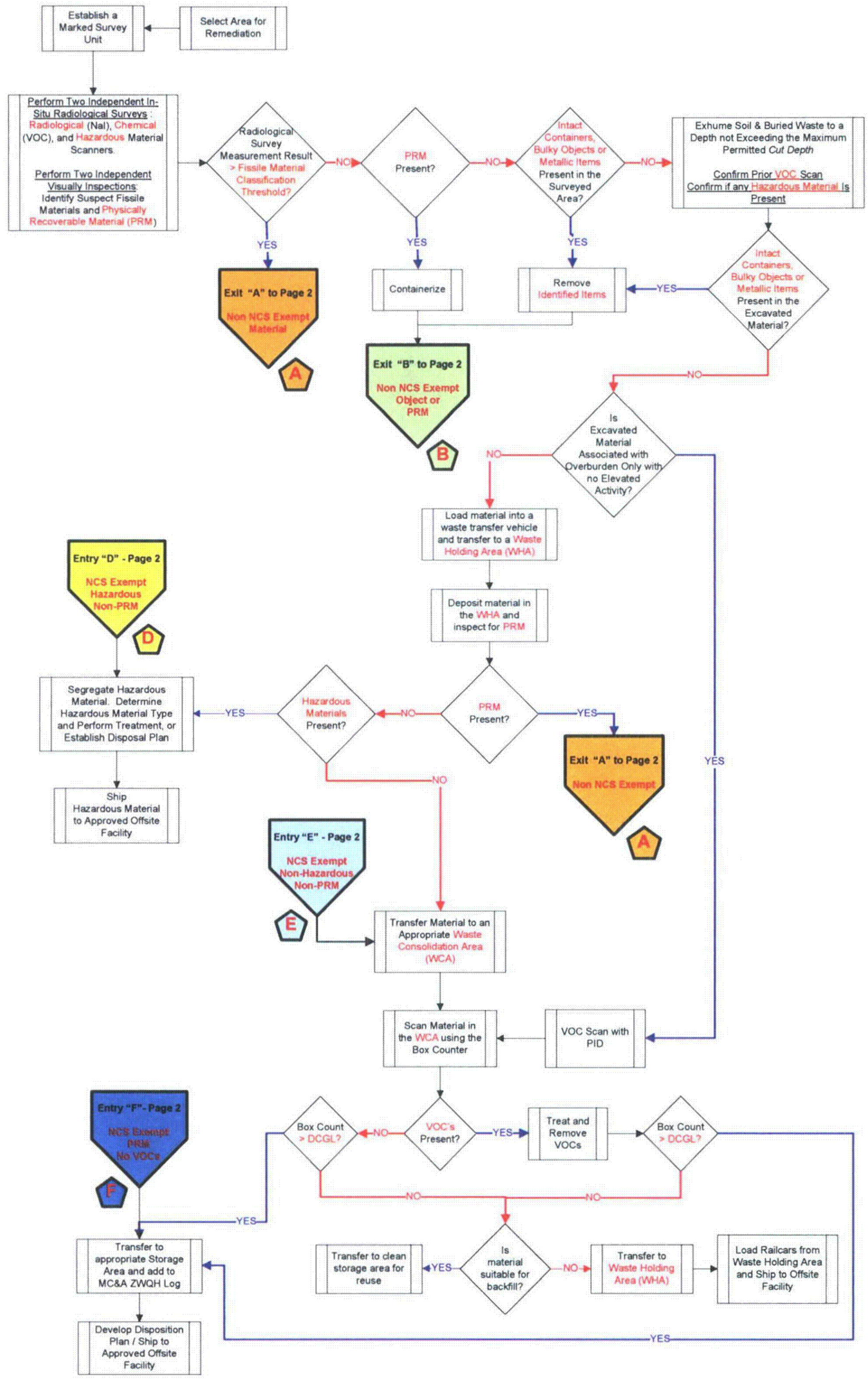
This Section provides an overview of HDP operations. The process presented is the result of an iterative engineering assessment that has received input from engineers, safety personnel and operators knowledgeable in the process. This section provides only a criticality overview of operations and is not intended to provide an exhaustive or comprehensive process description.

A simplified schematic of the key HDP operations are encompassed within the flowcharts presented in Figure 1-2 and Figure 1-3. The flowcharts illustrate the basic process that will be followed and provide an indication of material flow paths throughout the entire process. The information presented in the flow charts is highly generalized and should not be misconstrued as representing formal controls.

The buried waste and contaminated soil remediation processes presented in Figure 1-2 and Figure 1-3 encompass a range of 'functional areas' where operations are performed. The functional areas of interest from a Nuclear Criticality Safety (NCS) perspective are areas where *fissile materials* may be recovered, containerized, staged, evaluated, packaged, characterized or interim stored. These functional areas comprise:

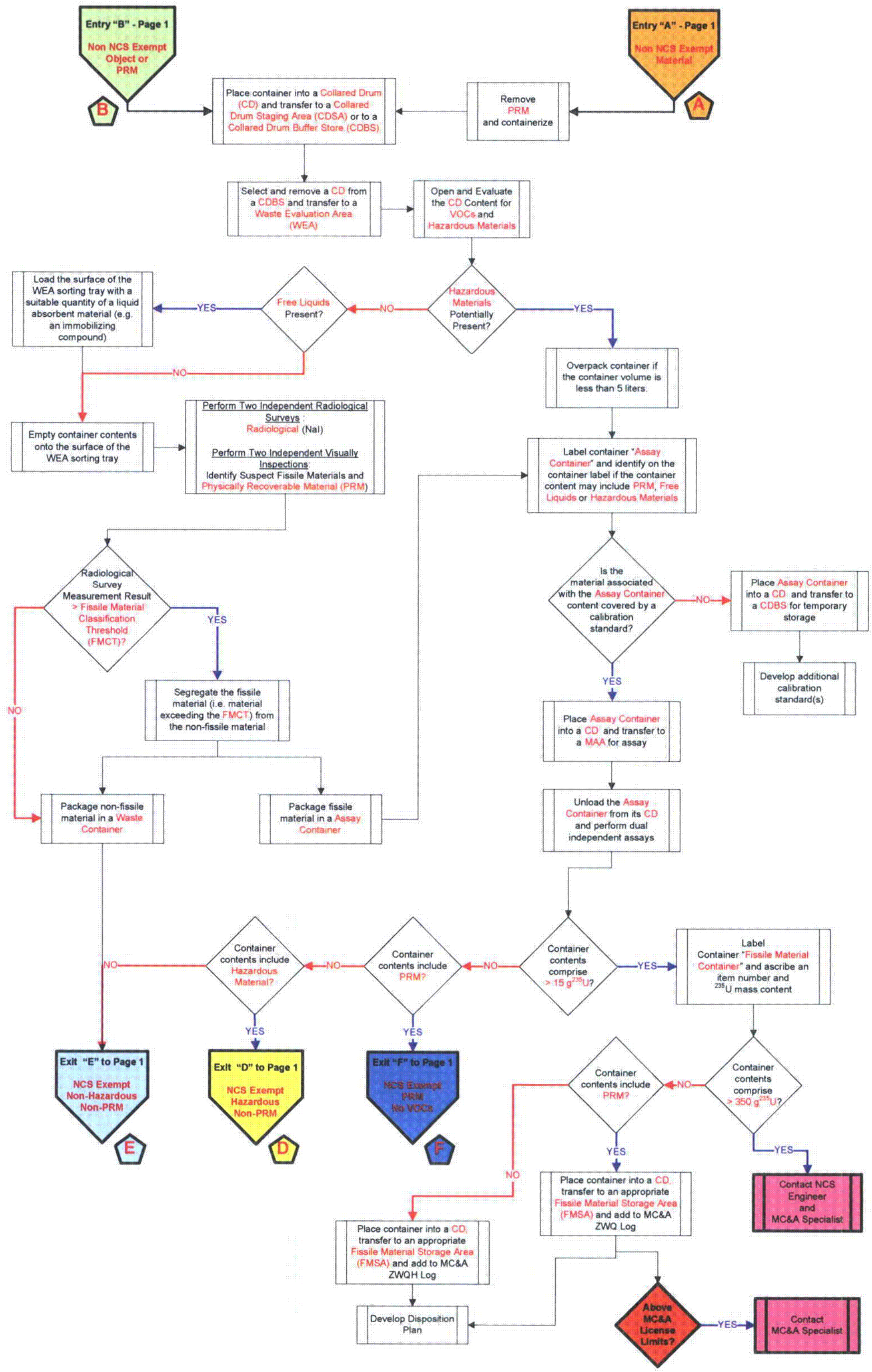
1) Land areas being remediated (i.e., the areas occupied by burial wastes and contaminated soils);
2) Collared Drum Staging Area(s) (CDSAs);
3) Collared Drum Buffer Store(s) (CDBSs)
4) Waste Evaluation Area(s) (WEAs);
5) Material Assay Area(s) (MAAs);
6) Collared Drum Repack Area(s) (CDRAs); and
7) Fissile Material Storage Area(s) (FMSAs).

An overview of operations in each of the abovementioned functional areas is provided in the following sub-sections to orient the reader. The functional areas addressed in this NCSA concern WEAs and MAAs. These areas are discussed in Sections 1.4.4 and 1.4.5.



Source: Original

Figure 1-2 Simplified Schematic of Buried Waste Exhumation and Contaminated Soil Remediation – PAGE 1: Excavation, Waste Management, and Disposition



Source: Original

Figure 1-3 Simplified Schematic of Buried Waste Exhumation and Contaminated Soil Remediation – PAGE 2: Fissile Material Extraction, Containerization, Staging, Evaluation, Assay, Handling, and Storage

1.4.1 Buried Waste and Contaminated Soil Areas

A simplified schematic of the buried waste and contaminated soil exhumation processes is provided in Figure 1-2 and Figure 1-3.

Prior to removal of soil/waste from a remediation area of the Hematite site, comprehensive in-situ radiological survey and visual inspection of a clearly defined survey area (i.e., the area to be exhumed) is undertaken to identify potential item(s) or region(s) containing *fissile material.*

The in-situ radiological survey will typically use NaI scintillator probes to provide gamma ray measurements of the surface area of interest. The survey technique that may be routinely performed is the Multi Agency Radiation Survey and Site Investigation Manual (MARSSIM) protocol which involves walking straight parallel lines over an area while moving the detector in a serpentine motion, 2 inches to 4 inches above the surface. Employing the MARSSIM protocol provides a high degree of assurance that all areas will be properly characterized prior to exhumation. Other in-situ radiological survey equipment and survey techniques may be employed provided that they meet procedural requirements. Other radiological survey equipment may include, but is not limited to, the use of High Resolution Gamma Spectrometers (HRGS). Examples of other survey techniques may include, but is not limited to, the use of motorized equipment.

The objective of the in-situ radiological surveys is to identify any item or region of soil/waste with a fissile concentration exceeding 1 g^{235}U in any contiguous 10 liter volume. The 1 g^{235}U/10L threshold provides a high degree of assurance that any items with elevated (i.e., non-trivial) levels of ^{235}U contamination would be identified. The in-situ radiological surveys are complemented by visual inspection of the survey area with the aim of identifying:

1) any items with the potential to contain *fissile material* (e.g., a process filter);
2) items that resemble intact containers;
3) bulky objects with linear dimensions exceeding the permitted *cut depth*; and
4) metallic items*.

Any item(s) or region(s) containing, or potentially containing, *fissile material* (identified from the results of the radiological survey and visual inspection) are carefully removed, loaded into a *Field Container* and placed inside a sealed CD†. Loaded CDs are transferred to a CDSA for staging, a CDBS for interim storage, an available WEA for evaluation, or to an available MAA for characterization. The remaining portion(s) of the surveyed area, to a depth not exceeding the maximum permitted *cut depth* represents material not of interest from a NCS perspective. These *NCS exempt materials* are exhumed and transferred to a suitable material stockpile in a Waste

* The concern with metallic items is that their properties may not be consistent with the calibration basis of the in-situ radiological survey equipment. For example, their high atomic number and/or density could provide more photon attenuation than accounted for in the calibration basis of the in-situ radiological survey equipment.
† Refer to Section 1.5.1 for a description of CDs.

Holding Area (WHA)*.

An exception to the above process occurs in the event objects meeting criteria (2), (3) or (4) above are encountered. This is because their exhumation could constitute the removal of material with a depth exceeding the maximum permitted *cut depth*, and/or their content could comprise dense and/or high atomic number material (e.g., items or fragments constructed of steel), which could provide more attenuation than accounted for in the in-situ radiological survey equipment calibration basis. For this reason, objects meeting these criteria are extracted and treated equivalently to item(s) or region(s) known to contain *fissile material* (from the results of the in-situ radiological surveys), as described above.

1.4.2 Collared Drum Staging Area(s)

Depending on the generation rate of *Field Containers* during remediation work it may be operationally advantageous to stage CDs loaded with *Field Containers* in a protected area local to the excavation site(s). Each CDSA will comprise a clearly delineated area that have an even and level terrain and is protected against accident disturbance (e.g., impact from moving excavation equipment or waste transfer vehicles) by a robust physical barrier (e.g., concrete barricades similar to the type used to provide median barriers for road traffic). Due to material security and shelter requirements (i.e., shelter from precipitation and the environment) all CDs staged in a CDSA during an operation shift are removed and placed into a CDBS prior to completion of the operations shift.

1.4.3 Collared Drum Buffer Store(s)

Depending on the generation rate of *Field Containers* during remediation work and the availability of WEAs and MAA(s), it may be necessary to interim store CDs loaded with *Field Containers* in a CDBS. CDBSs may also be used for interim storage of any other CDs loaded with containers with un-assigned fissile mass content. For example, CDs loaded with *Assay Containers* may be stored on an interim basis in a CDBS in the event that a MAA is not available or if the approved calibration algorithms available at a MAA are not valid due to the material properties of the *Assay Container* content.

Each CDBS will be established within an enclosed structure to protect the CDs within their environs against accident disturbance and to afford access control and shelter from precipitation and the environment.

1.4.4 Waste Evaluation Area(s)

Each WEA is equipped with one sorting tray and gamma survey instrument(s) and is bounded by a clearly defined perimeter. A simplified schematic of the WEA operations is provided in Figure 1-3.

All *fissile materials*, suspect *fissile materials*, items resembling intact containers, bulky objects and

* An overview of WHA operations is not provided in this NCSA because operations in WHAs are not subject to NCS controls or oversight. WHAs are used to stage and accumulate exhumed wastes and impacted soils in preparation for waste consolidation and shipment from the site in large gondola rail cars.

metallic items identified during operations in a HDP remediation area will be containerized (individually) in CDs and ultimately transferred to a WEA for evaluation of fissile content. In addition, solids recovered from the site Water Treatment System (WTS) will be containerized in CDs and may be transferred to a WEA for evaluation of fissile content.

Following WEA operations, *fissile materials* are transferred to a MAA for radiological counting to establish ^{235}U mass content*. The general aim of waste evaluation operations is to identify and extract uranium associated with the material content of an incoming CD that would be of concern from a NCS perspective. Identification of uranium is achieved by spreading/disassembling the material content of the CD across the surface of a sorting tray, and using hand-held gamma survey instruments and visual inspection to locate the uranium.

The waste evaluation process (conducted at a WEA) is summarized below:

1) A CD loaded with either a *Field Container,* any item resembling an intact container, a bulky object or a metallic item is received and accepted in a WEA;
2) The content of the CD is removed and transferred to the WEA sorting tray;
3) If the CD content comprised a *Field Container* or an item resembling an exhumed intact container then the container is opened and an approved volume of its content tipped onto the surface of the WEA sorting tray;
4) The material tipped onto the surface of the sorting tray is spread across the surface of the tray. If the CD content comprised a bulky object or metallic item the items is disassembled to permit evaluation of any interior void spaces;
5) The spread/disassembled material is visually inspected and radiologically surveyed using hand-held gamma counters to locate uranium;
6) Any item or region of the spread/disassembled material that has a fissile concentration exceeding 1 g^{235}U in any contiguous 10 liter volume is identified, collected, and placed in an *Assay Container*;
7) When all material exceeding the 1 g^{235}U/10L concentration threshold has been identified and placed into the *Assay Container*, the *Assay Container* is lidded and transferred to a MAA for radiological assay. The remaining portions of the spread/disassembled material (i.e., the residual potion not containing any significant uranium) is gathered and loaded into a *Waste Container*; and
8) The *Waste Container* is removed from the WEA and dispositioned as *NCS Exempt Material* (i.e., transferred to a WHA).

1.4.5 Material Assay Area(s)

Each MAA will comprise a clearly delineated and sheltered area equipped with assay equipment.

* Note that in some instances, the content of a CD may not actually be 'evaluated' in a WEA (e.g., due to the potential for hazardous material content). These CDs may be transferred directly to a MAA for assay. Also note that CDs may be buffer stored in a CDBS at any time, if necessary (e.g., a WEA or MAA is unavailable).

A simplified schematic of the MAA operations is provided in Figure 1-3.

Fissile materials loaded into *Assay Containers* in WEAs will be radiologically counted in a MAA to establish ^{235}U mass content. In addition, other solid wastes generated from HDP remediation areas and the site WTS may be directly transferred to a MAA for assay.

The MAA operations are summarized below:

1) A CD loaded with an *Assay Container* is received and accepted at a MAA;
2) The *Assay Container* is removed from the CD and placed into the counting position at the assay equipment (note that in some cases the entire CD may be the *Assay Container*);
3) The assay equipment calibration routine is selected and the radiological counting initiated;
4) Following counting, the total ^{235}U content established for the *Assay Container* is recorded and the container dispositioned as follows:
    - In the event the total ^{235}U content of the *Assay Container* is estimated to be less than or equal to 15 $g^{235}U$, the *Assay Container* is declared a *Waste Container*, removed from the MAA, and dispositioned as *NCS Exempt Material*;
    - In the event the total ^{235}U content of the *Assay Container* is estimated to be greater than 15 $g^{235}U$, the *Assay Container* is declared a *Fissile Material Container,* marked with a unique identification number, and accompanied by paperwork describing the fissile contents (i.e., a description of the waste, its origin, and its total estimated ^{235}U gram content); and
5) The labeled *Fissile Material Container* and accompanying paperwork are placed into a sealed CD and removed from the MAA and transferred to a CDRA or FMSA for storage*.

1.4.6 Collared Drum Repack Area(s)

Depending on the generation rate of *Fissile Material Containers* during remediation work and their fissile loading, it may be desirable to consolidate the content of CDs. This could be particularly likely in the event of storage of a large number of CDs in a FMSA, with the majority of CDs containing only small quantities of *fissile material.* CDRAs may be used for these CD repack operations. For efficiency and to reduce CD handling, loaded CDs identified as potentially requiring repack may also be interim stored in a CDRA.

Any CDRAs used for HDP operations will be established within an enclosed structure to protect the CDs within their environs against accident disturbance and to afford access control and shelter from precipitation and the environment.

* Note that future disposition of *Fissile Material Containers* in any FMSA is not addressed in this NCSA and will be covered under documented case-specific NCSAs.

1.4.7 Fissile Material Storage Area(s)

FMSAs are used to store CDs with known fissile content. Operations conducted in a FMSA concern only CD receipts, storage and export. FMSAs employed for HDP operations will be established within an enclosed structure to protect the CDs within their environs against accident disturbance and to afford access control and shelter from precipitation and the environment.

1.5 Overview of Equipment used for CD Staging, Buffer Storage, and Transit Activities

This section provides an overview of safety significant equipment employed for CD staging, buffer storage, and transit activities, as relevant to this NCSA.

1.5.1 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. This geometry and dimension ensures that an unlimited quantity of CDs, each loaded with up to 350 g ^{235}U, will remain safely subcritical in any unstacked configuration (Ref. 20).

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.

1.6 Scope of Assessment

The remediation activities assessed in this NCSA encompass CD staging, buffer storage, and transit activities at the Hematite site. The scope of materials assessed in this NCSA is limited to the following:

- Materials exhumed from HDP remediation areas; and
- Solid waste recovered from the site WTS; and
- Materials evaluated/assayed in a WEA/MAA.

In the event that any *fissile materials* or suspect *fissile materials* not originating from the above areas, require transit, staging or buffer storage, approval shall first be obtained from the NCS Organization.

The following activities are specifically excluded from this assessment:

- HDP remediation area operations. These operations are evaluated in References 14 and 17.
- Activities related to D&D operations associated with removal of remaining equipment and structures in the former process buildings, and building decontamination and demolition. It is planned that these activities will be conducted under a separate safety case.

- Operations associated with evaluation and assay of *fissile materials*, suspect *fissile materials*, objects resembling intact containers, bulky items, and metallic objects (refer to Section 1.4.4 and 1.4.5 for a description of waste evaluation and assay activities). These operations are addressed in Reference 18.
- CD repacking or batching operations in a designated CDRA (refer to Section 1.4.6 for a description of a CDRA). The criticality safety assessment of these operations is provided in Ref. 16.
- Storage of containerized *fissile material* (i.e., material containing ^{235}U in a quantity/concentration sufficient to require NCS controls/oversight) in a designated FMSA (refer to Section 1.4.7 for a description of a FMSA). The criticality safety assessment of *fissile material* storage in designated FMSAs is provided in Ref. 13.
- Activities related to the management and collection of site water, including water collected from the burial pits during their remediation. The criticality safety assessment of water collection, treatment, and management activities is addressed in Ref. 12.
- Inspection, swabbing, and monitoring of additional waste items that will be produced during, and as a result of, the HDP site remediation activities (e.g., buried waste exhumation and contaminated soil remediation operations). These process wastes may comprise items such as protective clothing, hoses, swabs, and tools. Typically, these items can be seen to be free of significant quantities of *fissile material* by inspection and swabbing. The nature of the items is such that, by virtue of their composition, shape or form, they cannot act as efficient reflectors or moderators.
- The transportation of recovered *fissile material* and *fissile material* samples off the Hematite site (e.g., to an offsite waste facility or an offsite sampling laboratory). The transportation of *Fissile Material Containers* from the Hematite site will be performed under either a generic or case-specific evaluation.

1.7 Methodology

1.7.1 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 susceptible to faults important to nuclear criticality safety.

The risk informed approach is complemented with an As Low As Reasonably Achievable (ALARA) 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 not credible.

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.

1.7.2 Criticality Control Philosophy

This section provides an overview of the criticality control philosophy for the scope of operations addressed in this NCSA (Section 1.6). The specific safety measures established in support of these operations are derived in the assessment of abnormal condition event sequences in Section 2.4.

1.7.2.1 Fissile Material Extraction, Containerization, and Handling Prior to Assay

The general philosophy for handling of CDs with un-evaluated/un-assayed content is to ensure that the conditions experienced by the containerized materials do not become more onerous than those previously experienced. This, in large measure, is achieved by the soil/waste extraction and containerization practices documented in References 12, 14, and 17.

For prudence and caution, all CDs loaded with materials exhumed from a HDP remediation area or recovered from the WTS are treated as high fissile content containers until proven otherwise by radiological screening at a WEA, or radiological counting at a MAA. This requires:

- Containerizing all loose exhumed *fissile materials* and suspect *fissile materials* in a limited volume *Field Container*; and
- Promptly placing each loaded *Field Container* and other exhumed bulky objects and metallic items into a CD; and
- Limiting the content of each CD to only one item; and
- Transferring each loaded CD to a CDSA, CDBS or WEA/MAA prior to exhuming any additional *fissile materials*, suspect *fissile materials*, bulky objects or metallic items from the subject remediation area; and
- Maintaining separation between loaded CDs at all times to reduce the possibility of increased reactivity due to increased neutron interaction. Where this is achieved via spacing restrictions, these are maintained where practicable by engineered features (e.g., use of engineered drum collars).

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

1.7.2.2 Container Handling Following Assay

All *fissile materials* loaded into *Assay Containers* in WEAs will be radiologically counted at a MAA to establish ^{235}U mass content. Following counting, the total ^{235}U content established for the *Assay Container* is used to determine the disposition of the container, as follows:

- In the event the total ^{235}U content of the *Assay Container* is estimated to be less than or equal to 15 g^{235}U, the *Assay Container* is declared a *Waste Container*, removed from the MAA, and dispositioned as *NCS Exempt Material.*
- In the event the total ^{235}U content of the *Assay Container* is estimated to be greater than 15 g^{235}U, the *Assay Container* is declared a *Fissile Material Container,* marked with a unique identification number, and accompanied by paperwork describing the fissile contents (i.e., a description of the waste, and its total estimated ^{235}U gram content). The labeled *Fissile Material Container* and accompanying paperwork is subsequently removed from the MAA and transferred to a FMSA for interim storage*.

All *Fissile Material Containers* are recorded in a central system - the site Criticality Control Inventory System (CCIS), immediately following radiological assay at a MAA. The CCIS provides a means to record all *Fissile Material Containers* as they are generated across the site. The CCIS runs in parallel to the Material Control and Accountability (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. The CCIS is not intended to provide a means to control fissile mass for NCS purposes because the criticality safety basis for each functional area of the site that is approved to contain *fissile material* is based on either single container limits (i.e., processing only one container at a time) or on the provision of interaction controls that assure safe separation of containers in staging or storage areas. Instead, the CCIS is intended to provide a basis for monitoring the global inventory of *fissile material* across the site, which has the benefit of providing a documented basis to track and monitor *fissile material* accumulation rates.

Following the transfer and receipt of any *fissile material* package at an off-site facility (e.g., an off-site sampling laboratory or waste acceptance facility), the site CCIS log is updated and the *fissile material* balance adjusted accordingly (i.e., reduced).

* Note that future disposition of *Fissile Material Containers* in any FMSA is not addressed in this NCSA and will be covered under documented case-specific NCSAs.

2.0 CRITICALITY SAFETY ASSESSMENT

The criticality safety assessment is organized as follows:

- **Section 2.1** describes the hazard identification technique employed in the criticality safety assessment of CD staging, buffer storage, and transit activities 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 CD staging, buffer storage, and transit activities under normal (i.e., expected) conditions.
- **Section 2.4** contains the criticality safety assessment of CD staging, buffer storage, and transit activities under abnormal (i.e., unexpected) conditions.

2.1 Criticality Hazard Identification

This section outlines the technique used to identify criticality hazards associated with the CD staging, buffer storage, and transit activities outlined in Section 1.3. 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 for the criticality safety assessment of CD staging, buffer storage, and transit activities is based on the *What-If/Checklist* analysis method. The *What-If/Checklist* analysis technique is a combination of two hazard evaluation methods: *What-If* analysis and *Checklist* analysis. This evaluation technique is a brainstorming approach in which a group or team familiar with the facility equipment and processes ask questions or voice concerns about possible undesirable events. The checklist adds a systematic nature to the process by ensuring all applicable hazards are addressed. The *What-If/Checklist* method identifies hazards, hazardous situations and specific events that could produce undesirable consequences. Consequences and existing controls are listed and suggestions are made for further risk reduction.

As part of the *What-If/Checklist* analysis, the eleven (11) criticality safety controlled parameters are examined to determine the extent of their importance to criticality safety for each activity identified in the remediation objectives (Section 1.3).

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 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 15). 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 CD Staging, Buffer Storage, and Transit Activities What-if/Checklist Analysis

Event ID	What-if	Causes	Consequences	Accident Sequence in NCSA
Geometry				
Geometry control is credited in the safety assessment of CD staging, buffer storage, and transit activities, however no credible criticality accident event sequences related to loss of geometry control have been identified.				
Interaction				
CDT-C-03	There is neutron interaction between *fissile materials* in transit.	• Wrong mass per container. • Wrong location. • Wrong container.	Potential for excess neutron interaction between *fissile materials* in transit.	**Section 2.4.2**
CDS-C-01	There is neutron interaction between *fissile materials* within a functional area approved to contain *fissile material.*	• Wrong mass per container. • Wrong location. • Wrong container.	Potential to exceed a maximum safe mass of ^{235}U due to congregation of *fissile material* in a functional area.	**Section 2.4.4**
CDS-C-02	There is neutron interaction between *fissile materials* associated with different functional areas approved to contain *fissile material.*	• Loss of isolation between functional areas on account of failure to establish, and/or demarcate functional area boundaries.	Potential for excess neutron interaction between *fissile materials* situated in different functional areas.	**Section 2.4.4**
CDS-C-03 (see note 1)	There is a loss of configuration control in a CDSA or CDBS	• CD stacking. • Physical disturbance. • Natural phenomena events.	Potential for excess neutron interaction.	**Section 2.4.5**

Event ID	What-if	Causes	Consequences	Accident Sequence in NCSA
Mass & Concentration				
CDT-C-01	There is loss of containment of *fissile material.*	• Spillage during container loading. • Spillage during transfer between functional areas.	Potential to spill and accumulate a maximum safe mass of ^{235}U within any discrete location of the site.	**Section 2.4.1**
CDT-C-02	Fissile material is misdirected during transfer between functional areas.	• Procedure non-compliance. • Incorrect labeling of a container such that the container type is not recognized or misidentified.	Potential to exceed a maximum safe mass of ^{235}U within any discrete location of the site, other than an approved functional area.	**Section 2.4.3**
Isotopic/Enrichment				
There are no identified hazards associated with presence of variable enrichment uranium in solid wastes generated from the CD staging, buffer storage, and transit activities. This is because the safety assessment is conservatively based on subcritical limits derived for uranium with 100 wt.% $^{235}U/U$ enrichment.				
Moderation				
There are no identified hazards associated with moderation because the safety assessment of CD staging, buffer storage, and transit activities is based on subcritical limits derived for idealized spherical geometry uranium-water mixtures that are optimally-moderated.				
Density				
There are no identified hazards associated with presence of variable density uranium because the safety assessment of CD staging, buffer storage, and transit activities is conservatively based on subcritical limits derived for uranium metal at maximum theoretical density.				
Heterogeneity				
There are no identified hazards associated with the presence of heterogeneous distributions of uranium (i.e., solid pieces of SNM or an conglomeration of SNM particulate) because the safety assessment of CD staging, buffer storage, and transit activities Is conservatively based on subcritical limits derived for homogeneous uranium-H_2O mixtures (with 100 wt.% $^{235}U/U$ enrichment), for which subcritical limits are smaller than equivalent heterogeneous uranium-H_2O mixtures.				
Neutron Absorbers				
There are no identified hazards associated with absence of fixed neutron absorbers because the safety assessment of CD staging, buffer storage, and transit activities does not credit fixed neutron absorbers.				

Event ID	What-if	Causes	Consequences	Accident Sequence in NCSA
Reflection				
There are no identified hazards associated with reflection conditions because the safety assessment of CD staging, buffer storage, and transit activities is based on subcritical limits derived for idealized spherical geometry uranium-water mixtures with conservative reflection conditions.				
Volume				
Volume control is indirectly credited in the safety assessment of CD staging, buffer storage, and transit activities, however no credible criticality accident event sequences related to loss of volume control have been identified.				

Source: Events are identified in Ref. 15.

NOTES: 1. This event sequence was identified subsequent to the identification of events in Ref. 15 and is based on engineering judgment.

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

The pertinent underlying assumptions of this NCSA related to the assessed CD staging, buffer storage, and transit activities are as follows:

- This assessment does not consider fissile nuclides other than ^{235}U. Based on the history of the site and site documentation (refer to Section 1), there is no expectation that fissile nuclides other than ^{235}U could exist within the site boundary.
- Fissile material limits have been derived assuming homogeneous mixtures of ^{235}U and water (H_2O). This approach is conservative with respect to other materials containing uranium, including process wastes.

2.2.2 Operational Practice and Equipment Assumptions

The pertinent underlying assumptions of this NCSA related to the operational practice and equipment used for the CD staging, buffer storage, and transit activities addressed are as follows:

- The CD staging, buffer storage, and transit activities are as described in Section 1.4.
- The safety related equipment used for the CD staging, buffer storage, and transit activities outlined in Section 1.4 are as described in Section 1.5.

2.3 Normal Conditions

This section contains the criticality safety assessment of CD staging, buffer storage, and transit activities under normal (i.e., expected) conditions.

Based on historical knowledge of site activities and site characterization data, it is expected that CDs containing *fissile materials* and other items extracted from HDP remediation areas for evaluation/assay in a WEA/MAA will likely comprise material with some degree of ^{235}U contamination. However, the quantities of ^{235}U involved are expected to be very small under normal conditions with up to a few grams ^{235}U per CD on an average basis and up to a few tens of grams ^{235}U per CD on an intermittent basis (refer to References 14 and 17 for justification). The expected low fissile loading of CDs is also sustained for CDs containing solid wastes recovered from the site WTS. This expectation is supported by the NCSA of water collection and treatment activities (Ref. 12) which determines that solid wastes from the WTS would be expected to contain trivial ^{235}U loading.

Under normal conditions a small congregation of unopened CDs may temporarily reside in a WEA or MAA while awaiting evaluation/assay of their content. In addition, loaded CDs generated from WTS solids recovery operations may be temporarily staged in the area surrounding the WTS. Each CDSA and CDBS could, as a whole, contain more significant quantities of ^{235}U under normal conditions due to the potential for retention of a significant number of CDs.

Reference 20 provides an assessment of the separation distance that is required to ensure a safe neutron interaction distance between loaded CDs. The calculations establish that an infinite array of unstacked CDs is safely subcritical with each CD containing 350 g^{235}U under optimal geometry, concentration and moderation conditions, and with bounding credible reflection conditions. This is also sustained if the collars affixed to the CDs are not modeled (i.e., the container walls are touching). Based on the maximum few tens of grams ^{235}U loading per CD and the fact that CDs will not be stacked anywhere on site, a congregation of CDs in any of the abovementioned areas will be safely subcritical under normal conditions. Based on the low anticipated ^{235}U loadings, very large margins of safety are expected under normal conditions.

The assessment of CD staging and buffer storage above bounds operations involving transit of loaded CDs between functional areas of the site. This is because these operations would involve single CDs and any congregation of CDs in transit would not exceed the potential congregation of CDs in a CDSA or CDBS.

2.4 Abnormal Conditions

This section provides an assessment of the criticality hazards identified from the *What-if* analysis conducted for the CD staging, buffer storage, and transit activities addressed in this NCSA (Section 1.6). The *What-if* analysis (summarized in Table 2-1) identified potential criticality hazards requiring further evaluation. The postulated hazards are grouped and assessed in the following event sequences:

- Section 2.4.1: There is Loss of Containment of Fissile Material During Transfers.
- Section 2.4.2: There is Neutron Interaction between Fissile Material in Transit.
- Section 2.4.3: Fissile Material is Misdirected during Transfer between Functional Areas.
- Section 2.4.4: There is Neutron Interaction between Fissile Material within a Functional Area Approved to Contain Fissile Material, *or* different Functional Areas Approved to Contain Fissile Material.
- Section 2.4.5: There is a Loss of Configuration Control in a CDSA or CDBS.

2.4.1 There is Loss of Containment of Fissile Material During Transfers

2.4.1.1 Discussion

Loss of containment of the content of any loaded CD within any functional area, or during transit between functional areas, will not alone lead to a criticality hazard. This is because each CD is loaded in a manner that provides a high degree of assurance that its fissile content will not exceed 350 g ^{235}U. However, protracted spillage and accumulation of *fissile material* from multiple containers could potentially result in collection of a mass with a fissile content exceeding the maximum subcritical mass limit of 760 g ^{235}U. Realization of these conditions would present a criticality hazard.

2.4.1.2 Risk Assessment

In general, loss of containment of any loaded CD would result in spillage of material that would generally adopt a geometry characterized by lower neutron reflection, greater neutron leakage and lower fissile density. In addition, interaction with *fissile material* remaining in the originating CD would be greatly reduced. All of these effects would lower the reactivity of the originating CD and interacting spillage, thus increasing the mass required for criticality. The only credible means of achieving a criticality due to loss of containment of *fissile material* is if gradual spillage of *fissile material* from multiple CDs occurs over time, and if these spillages result in a localized accumulation of material with a high fissile content.

Gradual spillage of *fissile material* from a CD could occur within a functional area or during transit between functional areas. This potential is examined in the succeeding paragraphs, with the exception of the potential for gradual spillage of *fissile material* within a WEA, which is explicitly addressed in Reference 18.

The potential for protracted spillage and accumulation of *fissile material* in any area other than a WEA is considered small due to:

- the prompt and careful placement of exhumed *fissile materials* and suspect *fissile materials* in a lidded *Field Container*, which is subsequently placed into a lidded CD; and
- the prompt and careful placement of exhumed bulky objects and metallic items requiring evaluation in a lidded CD; and
- the careful loading of *fissile materials* evaluated in a WEA into a lidded *Assay Container*, which is subsequently placed into a lidded CD; and
- the retention of *fissile materials* within their respective CD at all times, other than during waste evaluation in a WEA (addressed in Ref. 18) or during CD repacking operations in a CDRA (addressed in Ref. 16).

While it is possible that the content of any individual CD could be spilled (e.g., during handling or transfer) the potential for spillage and accumulation of a maximum subcritical mass of 760 g ^{235}U would, in practice, require spillage from a very large number of CDs to go unnoticed. The potential for spillage of material from a large number of CDs is very remote considering the lidding of each CD following loading to ensure containment of its content.

The *Fissile Material Exhumation Limit** of 38 $g^{235}U$/10L applied to each HDP remediation area, and the *Field Container* volume limit of 20 liters (refer to Ref. 17 for details) limits the content of each CD loaded in a HDP remediation area to a maximum of 76 $g^{235}U$ at one time. While these arguments do not strictly apply to bulky objects recovered from a HDP remediation area (because their volume may exceed 20 liters), the risk presented by such items would be expected to be small in comparison to items known to contain *fissile material.* In addition, bulky objects would naturally present lower risk if spilled relative to a compact volume of loose *fissile material* on account of their size. For this reason, it is improbable that the content of any spilled CD would contain more than 76 $g^{235}U$. This maximum mass is an order of magnitude smaller than the 760 $g^{235}U$ (Table A-1) maximum safe mass established for an idealized, optimally-moderated, full water reflected, spherical-geometry system. Thus, spillage and accumulation of the content of at least ten CDs would have to occur before a criticality accident could be possible, even if each CD contained the maximum permitted ^{235}U mass content.

While over-batching a CD or loading a CD with high fissile content material could be possible, it is considered at least unlikely that the content of any loaded CD could exceed 350 $g^{235}U$. This is supported by the following considerations:

- Provision of simple and unambiguous procedures related to material exhumation, evaluation, assay, and CD loading activities (Refer to References 12, 14, 17, and 18);
- The very low probability of encountering significant uranium concentrations; and
- The large factor of safety (five) between the 76 $g^{235}U$ maximum CD mass (based on the controls outlined above) and the maximum 350$g^{235}U$ CD mass credited as being unlikely to exceed.

Ensuring that each CD is lidded following loading and prior to movement limits the potential to spill *fissile material.* Spilling the content of three of more CDs in a single location is considered unlikely because:

- Ensuring that each CD is lidded is a simple administrative control and would effective in preventing spillage incidents; and
- The probability of multiple spillages would be low; and
- The probability of multiple spillages in a single location would be low.

Since it is unlikely that any CD in transit could contain more than 350 $g^{235}U$, and that spilling the content of three of more CDs in a single location is independently unlikely, this event sequence satisfies the Double Contingency Principle (DCP).

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* The *Fissile Material Exhumation Limit* of 38 $g^{235}U$/10L represents the highest permitted concentration of fissile material that may be transferred to a WEA under non-exceptional circumstances.

Further risk reduction is provided by the expectation that each loaded CD will contain relatively small quantities of ^{235}U and that any spilled material would adopt a geometry characterized by lower neutron reflection, greater neutron leakage and lower fissile density than its containerized condition.

2.4.1.3 Summary of Risk Assessment

Based on the risk assessment provided above there is no potential for a criticality accident due to loss of containment of *fissile material* because:

- It is unlikely that any CD in transit could contain more than 350 g ^{235}U; and
- Spilling the content of three of more CDs in a single location is independently unlikely.

The following additional criteria serve to further decrease the likelihood of a criticality accident:

- Each loaded CD will, in practice, contain relatively small quantities of ^{235}U; and
- Any spilled material would adopt a geometry characterized by lower neutron reflection, greater neutron leakage, and lower fissile density than its containerized condition; and
- The spilled uranium would have to be of a high ^{235}U enrichment; and
- Non fissile and non hydrogenous elements (e.g., soil) would have to be absent, or at least present in small quantities within the waste matrix/assembled ^{235}U accumulation (otherwise these constituents would result in dilution and parasitic neutron absorption).

2.4.1.4 Safety Controls

The explicit Criticality Safety Controls (CSCs) relevant to preventing criticality due to loss of containment of *fissile material* are established below. These CSCs are credited to provide the criticality safety barriers identified above. The CSCs relevant to ensuring that it would be unlikely for any loaded CD to contain more than 350 g ^{235}U are provided in References 12, 14, 17, and 18 and are not repeated here for brevity. However, these CSCs are listed in Section 3 for completeness. An additional practicable measure for further reducing criticality risk is included below and captured as a Defense-in-Depth (DinD) control. These measures ensure that the risks from criticality are as low as is reasonably achievable.

Administrative CSC 01: *All loaded CDs SHALL be lidded prior to transfer.*

DinD Administrative Control 01: *Prior to accepting a CD into the environs of any functional area, the CD should be inspected for integrity. If there is any evidence that any content of the CD could have spilled during transit (e.g., the CD lid is missing or displaced, or the CD is punctured or ruptured in anyway) the NCS Organization should be notified.*

2.4.2 There is Neutron Interaction between Fissile Material in Transit

2.4.2.1 Discussion

The various functional areas of the site where *fissile materials* may be recovered, staged, evaluated, packaged, characterized or stored are defined in Section 1.4. The movement of *fissile material* between functional areas raises the potential for neutron interaction between *fissile material* in transit and between *fissile materials* within the environs of the various functional areas. In the event that any such neutron interaction were to occur, safety margin could be eroded, potentially presenting a criticality risk.

2.4.2.2 Risk Assessment

All *fissile material* in transit will be containerized in a CD. Based on the arguments presented in Section 2.4.1.2, it is considered at least unlikely that the content of any loaded CD could exceed 350 g^{235}U. This is supported by the following considerations:

- Provision of simple and unambiguous procedures related to material exhumation, evaluation, assay, and CD loading activities (Refer to References 12, 14, 17, and 18);
- The very low probability of encountering significant uranium concentrations; and
- The large factor of safety (five) between the 76 g^{235}U maximum CD mass (based on the controls outlined above) and the maximum 350g^{235}U CD mass credited as being unlikely to exceed.

Reference 20 provides an assessment of the separation distance that is required to ensure a safe neutron interaction distance between loaded CDs. The calculations establish that an infinite array of unstacked CDs is safely subcritical with each CD containing 350 g^{235}U under optimal geometry, concentration and moderation conditions, and with bounding credible reflection conditions. The calculations were based on CDs without affixed collars to ensure a separation distance with other CDs in the vicinity (i.e., the container walls were modeled as touching). Thus, based on this calculation and the 350g^{235}U maximum CD mass loading, it would be unlikely for any interaction between any number of CDs in transit to result in an unsafe condition.

Reference 21 reports the results of additional CD calculations and shows that a 36" surface-to-surface separation distance between loaded CDs is sufficient to reduce neutron interaction to a negligible level. As described in Section 1.5.1, the each CD used at the Hematite site, 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. Based on this engineered design feature, an array of CDs would be safely subcritical even if each individual CD contained a maximum safe mass of ^{235}U, because their 36" spacing would ensure negligible neutron interaction. Because the design of the CDs represents a robust safety control, it would be at least unlikely for any interaction between any number of CDs in transit to result in an unsafe condition, irrespective of their ^{235}U mass content. Note that the safety of individual CDs is addressed in References 12, 14, 17, and 18.

As demonstrated above, it is unlikely that any CD in transit could contain more than 350 g ^{235}U, and based on the argument in Section 2.4.1.2, it is not credible to exceed a subcritical mass in a CD. It is also unlikely for any interaction between any number of CDs in transit to result in an unsafe condition (irrespective of their ^{235}U mass content). Therefore, this event sequence satisfies the DCP because two unlikely concurrent failures must occur before a criticality incident could be possible.

2.4.2.3 Summary of Risk Assessment

Based on the risk assessment provided above there is no potential for a criticality accident due to interaction between CDs in transit because:

- It is unlikely that any CD in transit could contain more than 350 g ^{235}U, ensuring that an infinite planar array of CDs would be safely subcritical without any separation; and
- The fixed 36"separation distance between CDs (provided by their physical design) ensures that unsafe neutron interaction between any number of CDs in transit is independently unlikely (i.e., is unlikely irrespective of the ^{235}U mass content of each individual CD)*.

The following additional criteria serve to further decrease the likelihood of a criticality accident:

- Each loaded CD will, in practice, contain relatively small quantities of ^{235}U; and
- The contained uranium would have to be of a high ^{235}U enrichment ; and
- The contained uranium would have to experience idealized or near-idealized geometry, concentration, moderation, and reflection conditions.

2.4.2.4 Safety Controls

The explicit CSCs and engineered design features relevant to preventing unsafe neutron interaction between CDs in transit are established below. These CSCs and engineered design features are credited to provide the criticality safety barriers identified above. The CSCs relevant to ensuring that it would be unlikely for any loaded CD to contain more than 350 g ^{235}U are provided in References 12, 14, 17, and 18 and are not repeated here for brevity. However, these CSCs are listed in Section 3 for completeness. No additional practicable measures for further reducing criticality risk have been identified in the risk assessment. It is judged that the risks from criticality are as low as is reasonably achievable.

* Note that the safety of individual CDs is addressed in References 12, 14, 17 and 18.

Administrative CSC 02: *All non NCS Exempt Materials SHALL be confirmed to be containerized in a lidded CD by at least two qualified individuals prior to transit between any functional areas of the site.*

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 57cm and to provide 36" isolation distance with any other CDs on account of the affixed collar that extends 18" beyond the external radial surface of the CD. 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.

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

2.4.3 Fissile Material is Misdirected during Transfer between Functional Areas

2.4.3.1 Discussion

This event sequence addresses the implications on criticality safety due to misdirection of loaded CDs during transit between functional areas of the site. Misdirection of loaded CDs would be a concern if it resulted in the contents of the CD being improperly dispositioned as *NCS Exempt Material.* If this were to occur, the resultant transfer of *fissile material* could compromise the safety basis of the receiving area, potentially resulting in a criticality incident.

2.4.3.2 Risk Assessment

Misdirection of a CD during transfer between functional areas approved to contain *fissile material* will not, by itself, compromise the safety basis of the receiving area. This is because the assessment of CD transit in Section 2.4.2 demonstrates that an accumulation of loaded CDs in any area is safely subcritical since:

- It is unlikely that any CD in transit could contain more than 350 g ^{235}U, ensuring that an infinite planar array of CDs would be safely subcritical without any separation; and
- The fixed 36"separation distance between CDs (provided by their physical design) ensures that unsafe neutron interaction between any number of CDs in transit is independently unlikely (i.e., is unlikely irrespective of the ^{235}U mass content of each individual CD)*.

Based on the above, the only potential for an unsafe condition would be if the content of at least three misdirected CDs was removed and accumulated in a single location.

The potential for misdirection of *fissile material* between functional areas approved to contain *fissile material* is considered unlikely based on the CSCs established in References 12, 14, 17, and 18, which stipulate the functional areas to which CDs may be transferred following loading.

As noted above, if CDs were inadvertently misdirected during transfer there would be no imminent criticality concern in the receiving area. However, it is important that operations in all areas of the site (including those areas not involving *fissile materials*) recognize CDs and do not disturb their content on receipt, unless permitted by procedure in accordance with the functions of the area (e.g., an operating procedure in a WEA). This is achieved by site wide procedures to ensure awareness of CDs and by ensuring that CDs are clearly identifiable and are only used for *fissile material* operations.

Disturbing the content of CDs in any area not approved to contain CDs is considered unlikely because:

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* Note that the safety of individual CDs is addressed in References 12, 14, 17 and 18.

- The abovementioned procedures are simple and unambiguous, and would be effective in preventing disturbance of the content of CDs in areas not approved to contain CDs; and
- CDs are inherently readily identifiable; and
- CDs are used only to contain *fissile materials* and suspect *fissile materials*; and
- The probability of a sufficient number of CDs containing sufficient mass to result in a criticality incident following disturbance would be low; and
- CD transit operators and functional area operators are knowledgeable, trained and qualified to perform their assigned tasks, and fully recognize the importance in performing their tasks independently and according to procedure.

The site wide procedures noted above rely on human agency. Due to the wide range of decommissioning activities at the site and the need for flexibility in operations, there is no practicable engineered alternative to ensure that CDs are not received and disturbed in unapproved areas.

Since it is unlikely that any CD in transit could be misdirected and that it is independently unlikely that any misdirected CDs would be sufficiently disturbed to result in accumulation of a maximum safe mass of ^{235}U, this event sequence satisfies the DCP.

Further risk reduction is provided by the expectation that each loaded CD will contain relatively small quantities of ^{235}U and that any reconfigured material would adopt a geometry characterized by greater neutron leakage and lower fissile density than its containerized condition.

2.4.3.3 Summary of Risk Assessment

Based on the risk assessment provided above, there is no potential for a criticality accident due to misdirection of *fissile material* during transfer between functional areas because:

- It is unlikely that any CD in transit could be misdirected to an area not approved to contain CDs; and
- It is independently unlikely that any misdirected CDs could be sufficiently disturbed to result in accumulation of a maximum safe mass of ^{235}U.

The following additional criteria serve to further decrease the likelihood of a criticality accident:

- Each loaded CD will, in practice, contain relatively small quantities of ^{235}U; and
- Any reconfiguration of material from misdirected CDs would generally adopt a geometry characterized by greater neutron leakage and lower fissile density than its containerized condition; and
- The uranium associated with the misdirected CDs would have to be of a high ^{235}U enrichment; and

- Non fissile and non hydrogenous elements (e.g., soil) would have to be absent, or at least present in small quantities within the waste matrix/assembled ^{235}U accumulation (otherwise these constituents would result in dilution and parasitic neutron absorption).

2.4.3.4 Safety Controls

The explicit CSCs relevant to preventing criticality due to misdirection of *fissile material* during transfer between functional areas are established below. These CSCs are credited to provide the criticality safety barriers identified above. The CSCs established relevant to ensuring that it would be unlikely to misdirect any CD in transit are established in References 12, 14, 17, and 18 and are not repeated here for brevity. However, these CSCs are listed in Section 3 for completeness. No additional practicable measures for further reducing criticality risk have been identified in the risk assessment. It is judged that the risks from criticality are as low as is reasonably achievable.

Administrative CSC 03: *Loaded CDs SHALL only reside in the following functional areas:*

- *Active HDP remediation areas;*
- *The area occupied by the WTS;*
- *CDSAs and CDBSs;*
- *WEAs and MAAs;*
- *CDRAs; and*
- *FMSAs.*

Notes:

1. *CDs may traverse other areas during transit between functional areas but SHALL NOT reside in any such areas.*

Administrative CSC 04: *In the event that a loaded CD is identified in any unapproved locations of the site, operations SHALL cease in the subject area and SHALL NOT resume until the NCS Organization has been notified and has approved resumption of operations.*

2.4.4 There is Neutron Interaction between Fissile Material within a Functional Area Approved to Contain Fissile Material, *or* different Functional Areas Approved to Contain Fissile Material

2.4.4.1 Discussion

The movement of *fissile material* within a functional area raises the potential for increased neutron interaction with other *fissile material* within the same functional area. In addition, the movement of *fissile material* within a functional area raises the potential for increased neutron interaction with *fissile material* situated within the environs of adjacent or nearby functional areas. Excessive neutron interaction between *fissile materials* could potentially present a criticality risk.

2.4.4.2 Risk Assessment

The various functional areas of the site where *fissile materials* may be recovered, staged, evaluated, packaged, characterized or stored are defined and described in Section 1.4. These areas include:

- Active HDP remediation areas;
- The area occupied by the WTS;
- CDSAs and CDBSs;
- WEAs and MAAs;
- CDRAs; and
- FMSAs.

The criticality safety basis of operations in active HDP remediation areas, the area occupied by the WTS, WEAs, MAAs, CDRAs, and FMSAs is addressed in References 12, 13, 14, 16, 17, and 18. These documents present the criticality safety basis for operations in these areas and establish controls to preclude the potential for an unsafe condition due to neutron interaction between *fissile materials* within each individual area.

The criticality safety basis for neutron interaction between *fissile materials* within a CDSA or CDBS is provided below. This assessment bounds any concerns related to neutron interaction between different functional areas approved to contain *fissile material* because the assessment of CDSAs/CDBSs is based on an unlimited number of CDs (and thus an unlimited quantity of *fissile material*).

Depending on the generation rate of CDs during excavation activities in HDP remediation areas it may be necessary to stage loaded CDs in a CDSA. Staging CDs provides a mechanism to accumulate a significant quantity of *fissile material* within a confined area. More significant numbers of CDs (and thus a more significant quantity of *fissile material*) could be present in a CDBS one time.

The assessment of CD transit in Section 2.4.2 demonstrates that an accumulation of loaded CDs in any area is safely subcritical because:

- It is unlikely that any CD could contain more than 350 $g^{235}U$, ensuring that an infinite planar array of CDs would be safely subcritical without any separation; and
- The fixed 36"separation distance between CDs (provided by their physical design) ensures that unsafe neutron interaction between any number of CDs in an area is independently unlikely (i.e., is unlikely irrespective of the ^{235}U mass content of each individual CD)*.

Consequently, staging/buffer storing any number of CDs in a CDSA/CDBS would not result in an unsafe condition because two independent concurrent unlikely upsets would be require before a criticality accident could occur. Therefore, this event sequence satisfies the DCP.

2.4.4.3 Summary of Risk Assessment

Based on the risk assessment provided above there is no potential for a criticality accident due to neutron interaction between *fissile materials* in a functional area or between functional areas because:

- It is unlikely that a CD within any functional area could contain more than 350 $g^{235}U$, ensuring that an infinite planar array of CDs would be safely subcritical without any separation; and
- The fixed 36"separation distance between CDs (provided by their physical design) ensures that unsafe neutron interaction between any number of CDs in any area is independently unlikely (i.e., is unlikely irrespective of the ^{235}U mass content of each individual CD)*.

The following additional criteria serve to further decrease the likelihood of a criticality accident:

- Each loaded CD will, in practice, contain relatively small quantities of ^{235}U; and
- The contained uranium would have to be of a high ^{235}U enrichment; and
- The contained uranium would have to experience idealized or near-idealized geometry, concentration, moderation, and reflection conditions.

2.4.4.4 Safety Controls

The explicit engineered design features relevant to preventing a criticality accident due to neutron interaction between *fissile materials* in a CDSA and CDBS are provided in below. These engineered design features are credited to provide the criticality safety barriers identified above. The CSCs relevant to ensuring that it would be unlikely for any loaded CD to contain more than 350 $g^{235}U$ are provided in References 12, 14, 17, and 18 and are not repeated here

* Note that the safety of individual CDs is addressed in References 12, 14, 17 and 18.

for brevity. However, these CSCs are listed in Section 3 for completeness. Refer to References 12, 13, 14, 16, 17, and 18 for CSCs related to ensuring subcriticality in HDP remediation areas, the area occupied by the WTS, WEAs, MAAs, CDRAs, and FMSAs.

No additional practicable measures for further reducing criticality risk have been identified in the risk assessment. It is judged that the risks from criticality are as low as is reasonably achievable.

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

CDs are designated as Safety Features, the Safety Functional Requirement being to possess a minimum internal diameter of 57cm and to provide 36" isolation distance with any other CDs on account of the affixed collar that extends 18" beyond the external radial surface of the CD. 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.

2.4.5 There is a Loss of Configuration Control in a CDSA or CDBS

2.4.5.1 Discussion

The movement of *fissile material* within a functional area raises the potential for increased neutron interaction with other *fissile material* within the same functional area. In addition, the movement of *fissile material* within a functional area raises the potential for increased neutron interaction with *fissile material* situated within the environs of adjacent or nearby functional areas. Excessive neutron interaction between *fissile materials* could potentially present a criticality risk.

2.4.5.2 Risk Assessment

The criticality safety basis for neutron interaction between *fissile materials* within a CDSA or CDBS is provided in Section 2.4.4 and is reliant on the following unlikely conditions:

- It is unlikely that any CD could contain more than 350 g^{235}U, ensuring that an infinite planar array of CDs would be safely subcritical without any separation; and
- The fixed 36"separation distance between CDs (provided by their physical design) ensures that unsafe neutron interaction between any number of CDs in an area is independently unlikely (i.e., is unlikely irrespective of the ^{235}U mass content of each individual CD)*.

Inherent to the above safety basis is the geometry and design of the CDs which ensures configuration control. Also inherent is the fact that CDs are not stacked at any time. Loss of configuration control in a CDSA or CDBS could result from:

- CD stacking;
- Uneven terrain;
- Physical disturbance; or
- Natural phenomena events.

CD Stacking

Stacking of CDs is a concern because the unlikely conditions noted above are based, in part, on the results of calculations which modeled infinite planar arrays of drums.

Based on the size of CDs, their loaded weight, and the absence of equipment in a CDSA or CDBS that could assist in stacking CDs, it is considered at least unlikely that CDs would be stacked in a CDSA or CDBS. This is further supported by establishing an administrative CSC to prohibit CD stacking.

Reference 20 reports the results of additional CD calculations that shows that an infinite planar

* Note that the safety of individual CDs is addressed in References 12, 14, 17 and 18.

array of CDs containing 350 g ^{235}U each would still be safely subcritical with up to seven CDs stacked on a second tier. Consequently, a large safety margin is provided against an unlikely CD stacking incident. Based on the magnitude of this safety margin (i.e., tolerance to seven control failures) it is considered not credible that a sufficient number of CDs could be stacked in a CDSA or CDBS to present a criticality hazard.

Based on the above discussion, two independent concurrent unlikely upsets would be required before a criticality accident could occur due to stacking of CDs in a CDSA or CDBS. Therefore, this loss of configuration control failure mode satisfies the DCP (i.e., unlikely stacking upsets concurrent with unlikely mass upsets).

Uneven Terrain

Uneven terrain would be a concern if it could compromise or impair the function of the drum collars credited as providing fixed spacing between CDs in a CDSA and CDBS. However, the physical design of the CD collars ensures that any potential difference in height between adjacent CDs (due to uneven terrain) would not compromise their function. This passive design feature is considered sufficiently robust to prevent a criticality accident due to loss of spacing between CDs because of uneven terrain in a CDSA or CDBS. Further risk reduction is achieved by capturing a DinD control to ensure that, prior to use, the floor areas of CDSAs and CDBS' consist of level concrete free of raised surfaces, holes, and other imperfections that could result in an uneven CD height in the respective areas.

Based on the above discussion, the provision of highly robust passive engineered design features ensures that a criticality accident will not occur due to uneven terrain in a CDSA or CDBS.

Physical Disturbance

Physical disturbance of a CDSA or CDBS could occur in the event of collision with moving equipment.. This is a concern because it could alter the geometry of individual CDs and/or could compromise the aspect of their physical design that provides fixed spacing (i.e., the drum collars). Physical disturbance events could also result in release of the content of CDs. These concerns necessitate the need to ensure that CDSAs and CDBS' are protected against physical disturbance events.

In respect of the above requirement, the provision of raised concrete barricades to enclose CDSAs (other than a small entrance/exit area) and protect their CDs is credited. This passive design feature is considered sufficiently robust to prevent a criticality accident due to physical disturbance of a CDSA. However, further risk reduction is achieved by establishing an administrative DinD control to prohibit operation of motorized equipment (other than equipment used to transfer CDs to/from the respective CDSA) within 12' distance of the environs of any CDSA.

The physical structure (i.e., building) within which CDBS' are enclosed is also credited. This passive design feature is considered sufficiently robust to prevent a criticality accident due to physical disturbance of a CDBS. However, further risk reduction is achieved by establishing an administrative DinD control to prohibit operation of motorized equipment (other than equipment used to transfer CDs to/from the respective CDBS) within 12' distance of the environs of any CDBS.

Based on the above discussion, the provision of highly robust passive engineered design features ensures that a criticality accident will not occur due to physical disturbance of a CDSA or CDBS.

Natural Phenomena Events

Natural phenomena events such as extreme wind, precipitation or flooding would be a concern if they had the potential to result in a loss of configuration control in a CDSA or CDBS. Extreme wind has the potential to tip-over staged CDs and release their content. Extreme precipitation or flooding could also potentially result in a loss of containment of CDs due to flooding of their content resulting in overflow and spillage of contained *fissile material.*

Section 2.4.1 provides an assessment of loss of containment events. This assessment is considered to bound potential loss of containment due to natural phenomena events impacting a CDSA or CDBS because it is based on multiple spillage events involving very high fissile content CDs.

2.4.5.3 Summary of Risk Assessment

Based on the risk assessment provided above there is no potential for a criticality accident due to:

- Loss of configuration control in a CDSA or CDBS due to CD stacking because:
  - Stacking of CDs is unlikely because it would be very difficult and is prohibited by procedure; and
  - Bounding stacking upsets remains subcritical; and
  - Concurrent unlikely mass failure must also occur.

- Loss of configuration control in a CDSA or CDBS due to uneven terrain because:
  - The physical design of the CD collars is sufficiently robust to ensure that any potential difference in height between adjacent CDs (due to uneven terrain) would not compromise their function; and
  - Further risk reduction is achieved by a DinD control to ensure that prior to use, the floor areas of CDSAs and CDBS' consist of level concrete free of raised surfaces, holes, and other imperfections that could result in an uneven CD height in the respective areas.

- Loss of configuration control in a CDSA due to physical disturbance because:
  - ➢ The provision of raised concrete barricades to enclose CDSAs (other than a small entrance/exit area) provides a highly robust physical barrier to protect against physical disturbance events; and
  - ➢ Further risk reduction is achieved by an administrative DinD control to prohibit operation of motorized equipment (other than equipment used to transfer CDs to/from the respective CDSA) within 12' distance of the environs of any CDSA.

- Loss of configuration control in a CDBS due to physical disturbance because:
  - ➢ The physical structure (i.e., building) within which CDBS' are enclosed represent highly robust physical barriers to protect against physical disturbance events; and
  - ➢ Further risk reduction is achieved by an administrative DinD control to prohibit operation of motorized equipment (other than equipment used to transfer CDs to/from the respective CDBS) within 12' distance of the environs of any CDBS.

Refer to Section 2.4.1 for a summary of the risk assessment that demonstrates that a loss of containment of loaded CDs would not result in a criticality accident. As previously noted, this risk assessment bounds events associated loss of containment of *fissile material* due to natural phenomena events.

In addition to each of the above statements, the following additional criteria serve to further decrease the likelihood of a criticality accident:

- Each loaded CD will, in practice, contain relatively small quantities of ^{235}U; and
- The contained or spilled uranium would have to be of a high ^{235}U enrichment to present a credible criticality hazard; and
- The contained or spilled uranium would have to experience idealized or near-idealized geometry, concentration, moderation, and reflection conditions to present a credible criticality hazard.

2.4.5.4 Safety Controls

The explicit CSCs and engineered design features relevant to preventing a criticality accident due to loss of configuration control in a CDSA or CBDS are provided below. These CSCs and engineered design features are credited to provide the criticality safety barriers identified above. Additional practicable measures for further reducing criticality risk are also included below and are captured as a DinD controls. These measures ensure that the risks from criticality are as low as is reasonably achievable. Refer to Section 2.4.1 for a summary of controls that ensure that a loss of containment of loaded CDs would not result in a criticality accident. These controls are also applicable to events associated with loss of containment of *fissile material* due to natural phenomena events. Refer to References 12, 14, 17, and 18 for CSCs relevant to ensuring that it would be unlikely for any loaded CD to contain more than 350 g^{235}U. These CSCs are also listed in Section 3 for completeness.

Administrative CSC 05: *Loaded CDs SHALL NOT be stacked in any area of the Hematite site at any time.*

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

In respect of the above Safety Feature, the Safety Functional Requirement credited concerns the design of the CD collars which is sufficiently robust to ensure that any potential difference in height between adjacent CDs (due to uneven terrain) would not compromise their function.

Safety Feature 02: *The raised concrete barricades (other than at a small entrance/exit area) prevents physical disturbance of staged CDs.*

Safety Feature 03: *The physical structure enclosing CDBS' (other than their small entrance/exit area) prevents physical disturbance of stored CDs.*

DinD Administrative Control 02: *The floor areas of CDSAs and CDBS' should consist of level concrete free of raised surfaces, holes, and other imperfections that could result in an uneven CD height in the respective areas.*

DinD Administrative Control 03: *Motorized equipment should not be used within 12' distance of the environs of any CDSA or CDBS, other than the equipment used to transfer CDs to/from the respective CDSA/CDBS.*

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 3.1 is summarized in Table 3-1.

Table 3-1 Criticality Safety Parameters

Nuclear Parameter	Controlled (Y/N)	Basis	Reference
Geometry	Y	The safety assessment of CD staging, buffer storage, and transit activities credits the geometry of CDs.	Section 2.4.2 Section 2.4.3 Section 2.4.4 Section 2.4.5
Interaction	Y	The safety assessment of CD staging, buffer storage, and transit activities credits the physical design of CDs, in regard to their affixed 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.	Section 2.4.2 Section 2.4.3 Section 2.4.4 Section 2.4.5
Mass	Y	The safety assessment of CD staging, buffer storage, and transit activities credits that it would be unlikely for any loaded CD to contain greater than 350 g ^{235}U.	Section 2.4.1 Section 2.4.2 Section 2.4.3 Section 2.4.4 Section 2.4.5
Isotopic / Enrichment	N	The safety assessment of CD staging, buffer storage, and transit activities is conservatively based on subcritical limits derived for uranium with 100 wt.% ^{235}U/U enrichment.	N/A
Moderation	N	The safety assessment of CD staging, buffer storage, and transit activities does not credit moderation control.	N/A
Density	N	The safety assessment of CD staging, buffer storage, and transit activities is conservatively based on subcritical limits derived for uranium metal at maximum theoretical density.	N/A

Nuclear Parameter	Controlled (Y/N)	Basis	Reference
Heterogeneity	N	The safety assessment of CD staging, buffer storage, and transit activities is conservatively based on subcritical limits derived for homogeneous uranium-H_2O mixtures (with 100 wt.% $^{235}U/U$ enrichment), for which subcritical limits are smaller than equivalent heterogeneous uranium-H_2O mixtures.	N/A
Neutron Absorbers	N	The safety assessment of CD staging, buffer storage, and transit activities does not credit fixed neutron absorbers.	N/A
Reflection	N	The safety assessment of CD staging, buffer storage, and transit activities conservatively uses subcritical limits based on conservative or bounding reflection conditions.	N/A
Concentration	Y	The safety assessment of CD staging, buffer storage, and transit activities does not directly credit concentration control. However, concentration control is indirectly credited when declaring that it would be unlikely for any loaded CD to contain greater than 350 g^{235}U.	Section 2.4.1 Section 2.4.2 Section 2.4.3 Section 2.4.4 Section 2.4.5
Volume	Y	The safety assessment of CD staging, buffer storage, and transit activities does not directly credit volume control. However, volume control is indirectly credited when declaring that it would be unlikely for any loaded CD to contain greater than 350 g^{235}U.	Section 2.4.1 Section 2.4.2 Section 2.4.3 Section 2.4.4 Section 2.4.5

Source: Original

3.2 Criticality Safety Controls and Defense-in-Depth Controls

This section provides a schedule of Systems, Structures, and Components (SSCs), CSCs, and DinD controls that have been established as important to safety in the risk assessment of CD staging, buffer storage, and transit activities. The SSCs, CSCs, and DinD controls are numbered sequentially according to their identification in Section 2.4 of this document. Note that when SSCs, CSCs, and DinD controls captured in an NCSA are used in other documents (including other NCSAs), they are referenced using the numeric identifier from the originating NCSA and proceeded by the NCSA document number. For example, other documents citing the first CSC captured in this NCSA use the following reference; *NSA-TR-09-10 Administrative CSC 01*.

3.2.1 Systems, Structures, and Components

The following SSCs have been recognized as important to ensuring the criticality safety of CD staging, buffer storage, and transit activities. The SSCs are identified as Safety Features (passive function). Based on their safety designation, the equipment listed in this Section are integral to the HDP safety case and HDP operations would not be able to continue in their absence.

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

Safety Feature 02: *The raised concrete barricades (other than at a small entrance/exit area) prevents physical disturbance of staged CDs.*

Safety Feature 03: *The physical structure enclosing CDBS' (other than their small entrance/exit area) prevents physical disturbance of stored CDs.*

3.2.2 Criticality Safety Controls

The following CSCs have been recognized as important to ensuring the criticality safety of CD staging, buffer storage, and transit activities. Additional CSCs established in other NCSAs have been recognized as important to ensuring the criticality safety of CD staging, buffer storage, and transit activities. These are noted in Section 2.4 and are not repeated here for brevity.

Administrative CSC 01: *All loaded CDs SHALL be lidded prior to transfer.*

Administrative CSC 02: *All non NCS Exempt Materials SHALL be confirmed to be containerized in a lidded CD by at least two qualified individuals prior to transit between any functional areas of the site.*

Administrative CSC 03: *Loaded CDs SHALL only reside in the following functional areas:*

- *Active HDP remediation areas;*
- *The area occupied by the WTS;*
- *CDSAs and CDBSs;*
- *WEAs and MAAs;*
- *CDRAs; and*
- *FMSAs.*

Notes:

1. *CDs may traverse other areas during transit between functional areas but SHALL NOT reside in any such areas.*

Administrative CSC 04: *In the event that a loaded CD is identified in any unapproved locations of the site, operations SHALL cease in the subject area and SHALL NOT resume until the NCS Organization has been notified and has approved resumption of operations.*

Administrative CSC 05: *Loaded CDs SHALL NOT be stacked in any area of the Hematite site at any time.*

In respect of the scope of this NCSA (Section 1.6), the following CSC is captured:

Administrative CSC 06: *The NCS organization SHALL be notified prior to transit, staging, or buffer storage of any CD containing material not originating from a HDP remediation area, the site WTS, or a WEA/MAA.*

The following controls are relevant to ensuring that it would be unlikely for any loaded CD to contain more than 350 g^{235}U. These controls are captured in References 14, 17, and 18, and are also important to this NCSA. Note that Reference 12 concludes that it is not credible for CDs with WTS solids to contain greater than 350 g^{235}U. DinD controls identified in References 12, 14, 17, and 18 which are relevant to minimizing the ^{235}U mass loading of CDs are not captured here. Refer to References 12, 14, 17, and 18 for these additional controls.

NSA-TR-09-15 Administrative CSC 01: *All HDP remediation area in-situ radiological survey and visual inspection procedures SHALL be independently followed by at least two qualified individuals. Equipment used by each qualified individual in support of these procedures SHALL be independent.*

NSA-TR-09-15 Administrative CSC 06: *In conjunction with in-situ radiological survey for fissile content, all HDP remediation areas SHALL be visually inspected prior to exhumation of any material. In the event that any of the following items are identified, the identified items SHALL be extracted and containerized individually in a CD (i.e., one item per CD):*

- *items that resemble intact containers;*
- *bulky objects with linear dimensions exceeding the permitted cut depth; and*
- *metallic items.*

NSA-TR-09-15 Administrative CSC 10: *All HDP remediation areas SHALL be radiologically surveyed for fissile content prior to exhumation of any material. In the event that the fissile concentration of any region of the surveyed material exceeds 38 g ^{235}U in any contiguous 10 liter volume, the soil/waste exhumation activities in the associated excavation area SHALL cease and the NCS Organization informed as soon as is practicable and at least before excavation operations in the subject area resume.*

In support of the above Administrative CSCs, equipment used in support of in-situ radiological surveys are designated as Safety Related Equipment, the Safety Functional Requirement being to measure gamma radiation emission from ^{235}U nuclides, which will permit estimation of ^{235}U content when properly calibrated and used in accordance with applicable procedures.

NSA-TR-09-15 Safety Related Equipment 01: *Instruments used in support of in-situ radiological surveys (when used in support of a CSC).*

NSA-TR-09-15 Administrative CSC 04: *All operations related to removal of material from a HDP remediation area SHALL be independently observed for adherence to procedure by at least one individual.*

NSA-TR-09-15 Administrative CSC 11: *Fissile materials and suspect fissile materials identified during in-situ radiological survey and/or visual inspection of a remediation area SHALL be extracted and loaded into a Field Container.*

In support of the above Administrative CSC, *Field Containers* are designated as a Safety Feature, the Safety Functional Requirement being to possess a maximum volumetric capacity of 20 liters (equivalent to the volume of a nominal 5 gallon container).

NSA-TR-09-15 Safety Feature 01: *Field Containers (when being used in support of a CSC).*

NSA-TR-09-15 Administrative CSC 12: *All loaded Field Containers SHALL be placed inside an empty CD and transferred to a CDSA, CDBS or WEA/MAA prior to exhuming any additional fissile materials from the subject excavation area.*

Notes:

1. *This CSC SHALL also apply to fissile materials exhumed from adjacent excavation areas (e.g., other burial pits in the vicinity) unless a separation distance of at least 12 feet is maintained between the exhumed materials at all times prior to their loading into a CD.*

NSA-TR-09-15 Administrative CSC 13: *The content of all CDs SHALL be limited to a maximum of only container at any one time, except when repackaged in a CDRA according to the governing CSCs.*

NSA-TR-09-08 Safety Related Equipment 01: *Assay equipment used to classify sub-surface structure decommissioning debris as NCS Exempt Material (i.e., ≤ 1 g ^{235}U per 10 liter of debris) or Fissile Material (i.e., > 1 g ^{235}U per 10 liter of debris) (when used in support of a CSC).*

NSA-TR-09-08 Safety Feature 01: *Field Containers (when used in support of a CSC).*

NSA-TR-09-08 Administrative CSC 01: *At least two qualified individuals SHALL perform a surface assay of concrete debris prior to its excavation.*

NSA-TR-09-08 Administrative CSC 02: *Representative core samples shall be taken in and surrounding cracks, expansion joints, seams that were adjacent to legacy production walls, and layers of concrete that covered contaminated layers.*

NSA-TR-09-08 Administrative CSC 03: *All sub-surface structure decommissioning debris (i.e., concrete, crushed piping, surrounding soils, and septic system material) irrespective of its location SHALL be independently assayed prior to exhumation using independent assay devices. The enriched uranium concentration of the decommissioning debris SHALL be no greater than 1 gram ^{235}U in a 10 liter volume prior to bulking during or following exhumation. In addition, the enriched uranium concentration of the decommissioning debris classified as Fissile Material SHALL be no greater than 38 grams ^{235}U in a 10 liter volume prior to exhumation into a Field Container. Decommissioning debris with a concentration exceeding 38 grams ^{235}U in a 10 liter volume SHALL NOT be excavated without approval from the NCS Organization.*

NSA-TR-09-08 Administrative CSC 04: *Only Field Containers SHALL be used for collection of decommissioning debris classified as Fissile Material (i.e., > 1 g^{235}U per 10 liter of debris).*

NSA-TR-09-08 Administrative CSC 05: *Field Containers used for collection of sub-surface structure decommissioning debris classified as Fissile Material (i.e., > 1 g^{235}U per 10 liter of debris) SHALL be lidded prior to placement inside a CD.*

NSA-TR-09-08 Administrative CSC 06: *Only a single Field Container containing sub-surface structure decommissioning debris SHALL reside within a CD at one time.*

NSA-TR-09-08 Administrative CSC 08: *CDs SHALL be lidded after loading with a single Field Container containing decommissioning debris. Lidding SHALL occur prior to collecting decommissioning debris into another Field Container at the respective excavation location, and prior to exporting the CD to an approved downstream area.*

NSA-TR-09-08 Administrative CSC 09: *Each assayed layer of sub-surface structure decommissioning debris (i.e., concrete, piping, surrounding soils, and septic system material) SHALL be exhumed cognizant of the maximum permitted cut depth established in the assay equipment calibration basis document. At least two qualified individuals SHALL ensure that the exhumed material is deposited in the excavation area and re-assayed if its exhumation results in the removal of a layer of material exceeding the maximum permitted cut depth.*

NSA-TR-09-08 Administrative CSC 10: *All reasonably practicable measures SHALL be taken to minimize the potential to exhume a layer of decommissioning debris exceeding the maximum permitted cut depth. Consideration should be given to:*

- *Controlling the excavation depth to a value smaller than the maximum permitted cut depth to provide margin;*
- *Employing excavation techniques and equipment that allow for an optimally controlled depth excavation; and*
- *Use of markers or other tools to provide indication when exceeding the maximum permitted cut depth.*

NSA-TR-09-08 Administrative CSC 11: *Prior to extracting a subterranean piping section, the Fissile Material mass loading of the pipe section SHALL be determined using an in-pipe assay detector and the cut location determined for the pipe section SHALL correspond to the pipe section containing no greater than 75 grams ^{235}U per intact section. Each of these determinations SHALL be ensured accurate by at least two qualified individuals.*

NSA-TR-09-08 Administrative CSC 12: *Prior to crushing a subterranean piping section for bulk removal, the enriched uranium concentration of the pipe section SHALL be determined using an in-pipe assay detector. The section of piping to be crushed SHALL contain no greater than 1 gram ^{235}U per 10 liter volume of pipe prior to crushing. This determination SHALL be ensured accurate by at least two qualified individuals.*

NSA-TR-09-08 Administrative CSC 17: *Each 10 liter segment of a pipe section SHALL be assayed to determine its Fissile Material (i.e., > 1 g ^{235}U per 10 liter of debris) mass content. At least two qualified individuals SHALL ensure the accuracy of the result and documenting on a log record.*

NSA-TR-09-08 Administrative CSC 18: *If a 10 liter segment in a particular intact pipe section is determined to contain a Fissile Material mass greater than 1 gram ^{235}U in a 10 liter volume of pipe and no greater than 38 grams ^{235}U in a 10 liter volume of pipe, then the segment SHALL be removed from the intact section and placed singly into a CD. At least two qualified individuals SHALL ensure each of these requirements is completed accurately. In addition, any intact segment of piping containing greater than 38 grams ^{235}U in a 10 liter volume SHALL NOT be placed into a CD without approval from the NCS Organization.*

NSA-TR-09-09 Safety Related Equipment 01: *Instruments used in support of WEA radiological surveys (when used in support of a CSC).*

NSA-TR-09-09 Administrative CSC 03: *All waste evaluation operations SHALL be independently observed for adherence to procedure by at least one individual.*

NSA-TR-09-09 Administrative CSC 09: *Material designated for fissile material content evaluation SHALL be spread/disassembled on the surface of the WEA sorting tray and radiologically surveyed. In the event that the fissile concentration of any region of the surveyed material exceeds 1 g ^{235}U in any contiguous 10 liter volume, the material at those locations SHALL be extracted and containerized in a labeled and lidded Assay Container. The remaining portion(s) of the surveyed material may be loaded into a Waste Container and dispositioned as NCS Exempt Material.*

Notes:

1. *Prior to performing radiological surveys:*
   a. *Loose materials SHALL be spread over the surface of the WEA sorting tray to create a layer of material with depth as small as practicable; and*
   b. *Objects with interior spaces SHALL be disassembled/cut to the extent required to survey all interior spaces, unless the intervening material is accounted for in the radiological survey equipment calibration basis.*
2. *Any materials which cannot be verified to contain less than 1 g ^{235}U in any contiguous 10 liter volume (e.g., due to accessibility constraints or equipment calibration issues) SHALL be assumed to be fissile material (i.e., containerized in a labeled and lidded Assay Container).*

NSA-TR-09-09 Administrative CSC 10: *Radiological surveys performed in support of WEA CSCs SHALL use only equipment that is approved and appropriately calibrated to account for potential under-reading due to the effect of credible variation in uranium distribution, particle size and attenuation of the photon intensity within the surrounding material.*

NSA-TR-09-09 Administrative CSC 11: *In conjunction with WEA radiological surveys, all materials deposited on a WEA sorting tray SHALL be visually inspected. In the event that any items are identified to potentially contain fissile material (e.g., a process filter is identified), the item(s) SHALL be extracted and containerized in a Assay Container.*

NSA-TR-09-09 Administrative CSC 12: *Each Assay Container loaded in a WEA SHALL be limited to:*

- *Materials originating from only a single CD; and*
- *A maximum content of 20 liters of loose material or one single item (in the event that the evaluated single item has a volume exceeding 20 liters).*

3.2.3 Defense-in-Depth Controls

This section lists those controls that do not directly support event sequence DCP compliance determinations, or directly support a not credible determination. These DinD controls either reinforce CSCs, or provide additional protection to ensure that the risk of criticality is as low as is reasonably achievable.

DinD Administrative Control 01: *Prior to accepting a CD into the environs of any functional area, the CD should be inspected for integrity. If there is any evidence that any content of the CD could have spilled during transit (e.g., the CD lid is missing or displaced, or the CD is punctured or ruptured in anyway) the NCS Organization should be notified.*

DinD Administrative Control 02: *The floor areas of CDSAs and CDBS' should consist of level concrete free of raised surfaces, holes and other imperfections that could result in an uneven CD height in the respective areas.*

DinD Administrative Control 03: *Motorized equipment should not be used within 12' distance of the environs of any CDSA or CDBS, other than the equipment used to transfer CDs to/from the respective CDSA/CDBS.*

4.0 CONCLUSION

This criticality safety assessment demonstrates that activities related to CD staging, buffer storage, and transit 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 faults under abnormal conditions.

All event sequences identified in the *What-if* 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
- The provision of highly robust passive engineered design features that have no failure mode that could credibly 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 $^{235}U\text{-}H_2O$ mixtures at optimum concentration (i.e., that the assessment is not reliant on moderation control). Consequently, there are no restrictions on the use of water for operations or for fire suppression.

5.0 REFERENCES

1. Buried Waste Characterization Plan for the Hematite Site, NRC Docket 070-0036, June 2006.

2. American National Standard for Nuclear Criticality Safety in Operations with Fissionable Materials Outside Reactors, ANS-8.1, American Nuclear Society.

3. Atlantic Richfield Hanford Company (1969), Criticality Handbook Volume II, R D Carter, G R Kiel, K R Ridgway.

4. LA-10860-MS, Critical Dimensions of Systems Containing ^{235}U, ^{239}Pu, and ^{233}U, 1986 Revision.

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

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

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

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

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

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

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

12. NSA-TR-09-13, Rev. 0, NCSA of Water Collection and Treatment Activities at the Hematite Site, B. Matthews, May 2009.

13. NSA-TR-09-12, Rev. 0, NCSA of Fissile Material Storage at the Hematite Site, D. Vaughn, May 2008.

14. NSA-TR-09-08, Rev. 0, NCSA of Sub-Surface Structure Decommissioning at the Hematite Site, D. Vaughn, May 2009.

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

16. NSA-TR-09-11, Rev. 0, NCSA of Collared Drum Repack Area Operations at the Hematite Site, D. Vaughn, May 2009.

17. NSA-TR-09-15, Rev. 0, NCSA of Buried Waste Exhumation and Contaminated Soil Remediation at the Hematite Site, B. Matthews, May 2009.

18. NSA-TR-09-09, Rev. 0, NCSA of Waste Evaluation and Assay Activities at the Hematite Site, B. Matthews, May 2009.

19. NSA-TR-09-05 Rev. 0, Nuclear Criticality Safety Calculations to Support Criticality Parameter Sensitivity Studies for ^{235}U Contaminated Soil/Wastes, April 2009.

20. NSA-CS-03, Rev. 0, Nuclear Criticality Safety Calculations for 350 $g^{235}U$ Drum Arrays, D. Vaughn, April 2009.

21. NSA-CS-04, Rev. 0, Nuclear Criticality Safety Calculations for Isolated Drum Storage, D. Vaughn, April 2009.

APPENDIX A

Relevant Criticality Data

CHARACTERISTICS OF BURIED WASTES AND CONTAMINATED SOILS

It is considered that the SNM residues associated with the buried wastes and contaminated structures and soils at the Hematite site is generally a low-risk *fissile material* because the form and associated matrix conditions are far from optimum for a neutron chain reaction. The characteristics of the wastes are completely dissimilar to those of an efficient fissile system. Efficient critical systems comprise:

- Efficient moderating materials;
- Uniform fissile / moderator mixtures;
- Concentrations of several tens of grams fissile per liter;
- Compact arrangements;
- Lack of voidage and diluents;
- Lack of neutron poisons; and
- Efficient reflectors or interaction with other *fissile material.*

As each parameter, or combination of parameters, moves away from the optimum the fissile mass required for a criticality increases. As this mass increases the probability that such a high fissile mass could have arisen and remained undetected decreases.

While criticality would be possible under highly non-optimum conditions (e.g., in low density, poisoned systems) the fissile mass needed for criticality (i.e., many kilograms) would far exceed credible quantities.

Single Items

The presence of a sufficiently large fissile mass (i.e., ≥ a minimum critical mass) in a single accumulation could potentially result in a criticality. The maximum subcritical mass for ^{235}U in water is 760 g (Ref. 2), corresponding to optimum conditions of:

- Spherical homogeneous accumulation of ^{235}U/ water;
- Full water moderation (i.e., full density water, no poisons, diluents, voidage etc.);
- Optimum concentration of approximately 55 g^{235}U/L (corresponding to a volume of approximately 14 liters);
- Full water reflection; and
- Isotopic content of 100 wt. % ^{235}U.

This value has traditionally been used in the assessment of isolated Highly Enriched Uranium (HEU) units as a pessimistic but bounding case to generically consider all possible conditions within contaminated wastes.

As discussed above, the nature of SNM residues is such that it is not considered credible that a situation could arise in which all parameters are optimized and the presence of a minimum critical mass would result in a criticality. The reactivity of any system and hence the fissile mass that would be required for criticality is dependent on the combination of a number of parameters (e.g., concentration, moderating properties of the waste matrix, geometry, and reflection conditions).

CRITICAL AND SUBCRITICAL LIMITS

Table A-1 outlines the subcritical and critical limits for ^{235}U-water systems used in the safety assessment. It is acknowledged that there is potential to exhume or encounter hydro-carbon based liquids that could be more efficient moderators than water. However, due to the nature of the uranium residues and their associated waste matrix, the aqueous limits are considered conservative.

Table A-1 Single Parameter Limits for homogeneous ^{235}U/water mixtures

Parameter	**Critical Limit** (see Note 1)	**Maximum Subcritical Limit** (see Note 2)	**Description / Restrictions**
Mass	820 g^{235}U	760 g^{235}U	Any geometrical configuration, even when optimally moderated and fully reflected by water. Applies to all chemical forms (e.g., oxides as powders, metals, etc.).
Concentration	11.8 g^{235}U/L	11.6 g^{235}U/L	Unlimited volume of homogeneous solution in any chemical form (e.g., nitrate, oxalate, etc.), and in any geometry.
Volume	6.1 L	5.5 L	Homogeneous solution in any chemical form (e.g., nitrate, oxalate, etc.), at any concentration, fully reflected by water.
Geometry (∞ Cylinder Diameter)	14.3 cm	13.7 cm	Homogeneous solution in any chemical form (e.g., nitrate, oxalate, etc.), at any concentration and volume, and fully reflected by water.
Geometry (∞ Slab Thickness)	4.9 cm	4.4 cm	Homogeneous solution in any chemical form (e.g., nitrate, oxalate, etc.), at any concentration and volume, and fully reflected by water.
Geometry (∞ Slab Areal Concentration)	390 g/ft^2 (0.42 g/cm^2)	372 g/ft^2 (0.40 g/cm^2)	Homogeneous solution in any chemical form (e.g., nitrate, oxalate, etc.), any volume (i.e., any slab depth) and fully reflected by water.

Source: Ref. 2 and Ref. 3

Notes:
1. Ref. 3, page III.B-2
2. Ref. 2, Table 1

Table A-2 outlines the single parameter critical limits for homogeneous U-water systems as a function of the U enrichment.

Table A-2 Critical Limits for homogeneous U/water mixtures as a function of U enrichment

U Enrichment wt.% $^{235}U/U$	Spherical Critical Mass (g)	Spherical Critical Volume (L)	Critical ∞ Cylinder Diameter (cm)	Critical ∞ Slab Thickness (cm)
3#	3200	80.0	38.0	20.0
5#	1950	37.0	28.0	14.0
30.3#	990	11.0	19.0	7.4
100##	820	6.1	14.3	4.9

Source: Ref. 3 and Ref. 4

Notes:
- # Ref. 3, page III.B-2
- ## Ref. 4, Figures 14-17

Reference 19 presents the results of a broad and comprehensive set of calculations performed to compare the reactivity of various finite and infinite systems containing uranium. This calculation established a minimum critical infinite sea concentration for a ^{235}U/soil mixture of 5.5 g^{235}U/L. Assuming a maximum safe fissile concentration of 4.0 g^{235}U/L provides a substantial subcritical margin of 0.15 g^{235}U/L. This margin is considered sufficiently large to also address any additional penalty that may be appropriate to account for validation of the materials modeled in the calculations used to establish the limit.