ATTACHMENT 2

NSA-TR-09-25

Nuclear Criticality Safety Assessment of Decontamination and Decommissioning Operations within the Former Process Buildings at the Hematite Site

Revision 0

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Glossary of Acronyms, Abbreviations, and Terms

Acronym / Abbreviation / Term	Definition
ALARA	As Low As Reasonably Achievable
CSC	Criticality Safety Control
D&D	Decontamination and Decommissioning
DinD	Defense-in-Depth
Fissile Material	Material containing fissile nuclides (e.g. ^{235}U) in a quantity/concentration sufficient to require NCS controls/oversight.
g	Gram
kg	Kilogram
L	Liter
LEU	Low Enriched Uranium
NCS	Nuclear Criticality Safety
NCS Exempt Material	Material containing an insufficient quantity/concentration of fissile nuclides (e.g. ^{235}U) to require NCS controls/oversight.
SNM	Special Nuclear Material - material containing fissile nuclides (e.g. ^{235}U)
SSC	Systems Structure, or Component
U	Uranium
UO_2	Uranium Dioxide
wt. %	Percentage by weight

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 cover Decontamination and Decommissioning (D&D) operations within the former process buildings at the Hematite site. These activities entail:

- Removal of selected piping, ventilation duct, and miscellaneous items/components from the various process buildings;
- Decontamination of the removed piping, ventilation duct, equipment, and miscellaneous items/components, as necessary;
- Transit of the decontaminated piping, ventilation duct, and miscellaneous items/components to a packaging/shipping area; and
- Loading of the decontaminated piping, ventilation duct, and miscellaneous items/components into a designated shipping container.

In addition to the above activities, recovery of UO_2 from selected items not intended for removal from the buildings prior to building demolition work will be performed on an as-needed basis to ensure that the building demolition debris meets the relevant criteria for transportation and off-site disposal. All UO_2 reclaimed during the abovementioned D&D operations will be recovered into a safe volume vacuum cleaner and transferred to a safe volume container, which will subsequently be sealed and placed in a secure area for interim storage and packaging pending shipment.

This NCSA is organized as follows:

- **Section 1** introduces the NCSA of D&D operations within the former process buildings and provides an overview of relevant operations.
- **Section 2** provides the risk assessment of the D&D operations outlined in Section 1.
- **Section 3** summarizes any 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 D&D operations within the former process buildings.

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

10CFR20.304 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.

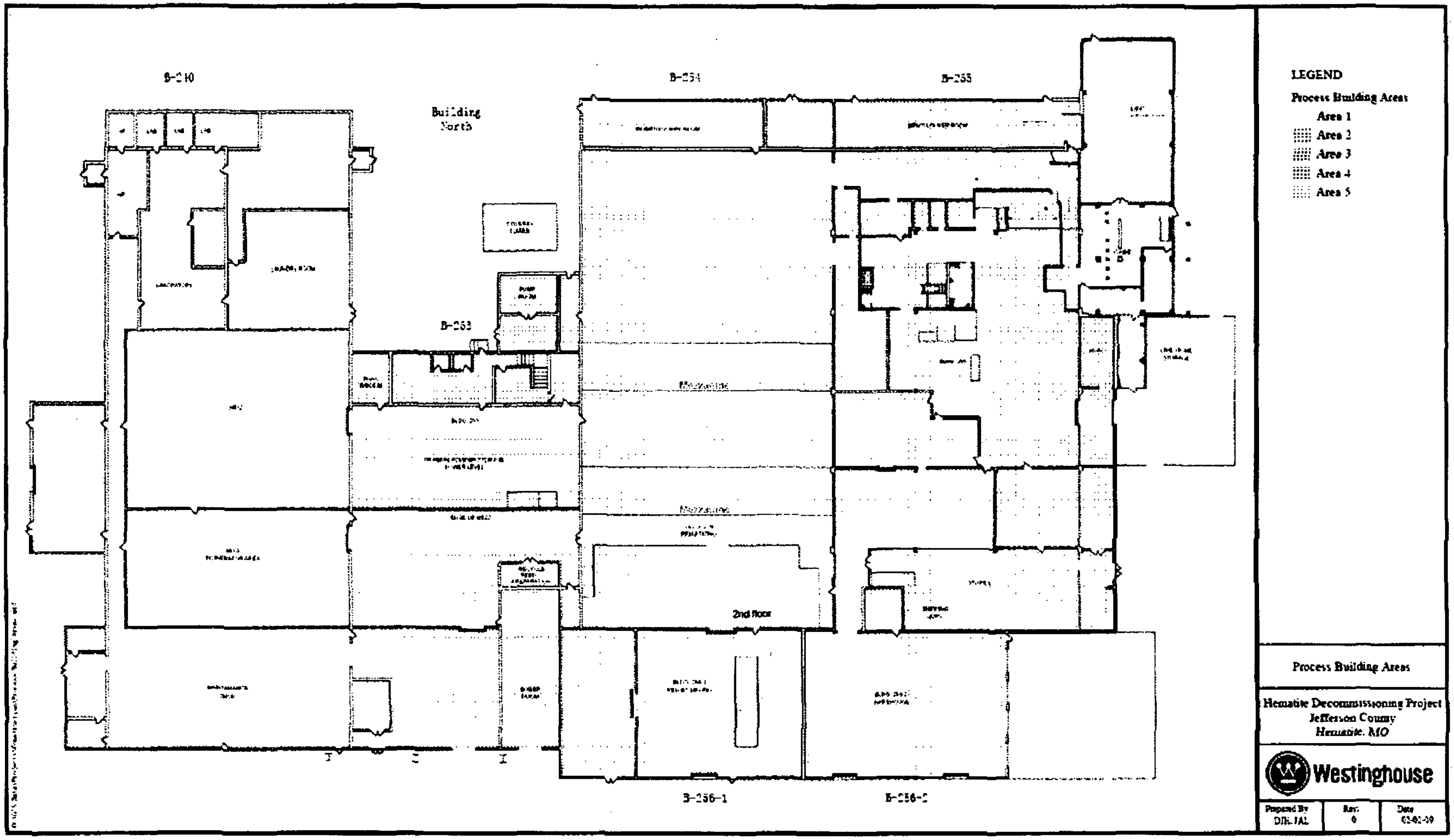
The Hematite facility was used for the manufacture of low-enriched (i.e., $\leq$ 5.0 wt.% ^{235}U), intermediate-enriched (i.e., >5 wt.% and up to 20 wt.% ^{235}U) and high-enriched (i.e., > 20 wt.% ^{235}U) materials during the period 1956 through 1974. In 1974 production of intermediate and high-enriched material was discontinued and all associated materials and equipment were removed from the facility. From 1974 to cessation of manufacturing operations in 2001, the Hematite facility produced nuclear fuel assemblies for commercial nuclear power plants. In 2001, fuel manufacturing operations were terminated and the facility license was amended to reflect a decommissioning scope. Accountable uranium inventory was removed and decontamination and decommissioning 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.

1.3 Current State

This section describes the existing condition of the former process buildings at the Hematite site.

The process buildings which were formerly used for fuel manufacturing operations are shown in Figure 1-1. The current condition of these former process buildings is far removed from the conditions that existed prior to initiation of the past decommissioning work. The existing conditions are generally typified by empty buildings, with a relatively small quantity of remaining equipment consisting of mainly ventilation ducts, piping, and bulky equipment. The majority of the remaining equipment was cleaned and inspected during that project phase, and accessible surfaces sprayed with fixatives to lock-down any surface contamination.

The former process buildings are currently quiescent, with no activities being performed, although routine maintenance and inspection activities are planned prior to performing final decommissioning operations.



Source: Original

Figure 1-1 Hematite Site Process Buildings and Delineation of Facility Areas

1.4 Former Process Building Characterization

A comprehensive radiological survey program was undertaken during 2009 to provide radiological data to assist in quantifying the residual mass of ^{235}U associated with elevated piping, ventilation duct, and miscellaneous items/components remaining within the former process buildings at the Hematite site. In addition, the radiological survey program encompassed building surfaces, including the floors, walls, ceilings, and roof*. The characterization activities were initiated in response to the results of preliminary radiological surveys of piping performed during late 2008, which indicated the presence of residual ^{235}U in various process pipes.

The results of the 2009 characterization program are presented in Table 1-2, Table 1-3, and Table 1-4, which summarize the mass and areal density of ^{235}U associated with the process buildings. Table 1-2 presents the ^{235}U mass estimates derived for the elevated piping, ventilation duct, and miscellaneous items/components remaining within the former process buildings. Table 1-3, and Table 1-4 provide a summary of the ^{235}U mass and average areal density estimates derived for the building surfaces in each facility area. All results presented in Table 1-2, Table 1-3, and Table 1-4 are categorized according to the item or building surface type and the Facility Area in which the item or building surface resides. The grouping of buildings to create five individual Facility Areas is consistent with Reference 1. The five individual Facility Areas are defined and illustrated in Table 1-1 and Figure 1-1, respectively.

Table 1-1 Facility Area / Building Nomenclature

Facility Area	Encompassed Buildings
1	240, Maintenance Building & Misc. Non-Production Buildings
2	253
3	254, 256-1
4	255, 256-2
5	UF_6 Storage Building, Oxide Building & Limestone Storage Building

Source: Original

* Note that characterization of the building roof included consideration of the possibility that the ^{235}U associated with the building roof may have penetrated the surface over time. For example, contamination may have been covered over by roofing materials used in repair activities. Also, rainfall could have caused contamination to migrate into the roof substrate over time.

Table 1-2 ^{235}U Mass Estimates Derived for Equipment, Piping, and Miscellaneous Components/Items

Category	Mass Estimate ($g^{235}U$)				
	Area 1	Area 2	Area 3	Area 4	Area 5
Equipment	16	8	357	21	2
Main Piping	0	0	68	410	152
Miscellaneous Components/Items (1)	63	8	308	64	290
Combined Total	79	16	733	495	444

Source: Table 3, Ref. 1

NOTES: 1) The ^{235}U mass values provided for the miscellaneous components/items includes the contribution from elevated ventilation ducts

Table 1-3 ^{235}U Mass Estimates Derived for Building Surfaces

Category	Mass Estimate ($g^{235}U$)				
	Area 1	Area 2	Area 3	Area 4	Area 5
Floors	896	254	977	629	758
Walls and Ceilings Combined	104	57	196	135	126
Roof (1)	631	360	680	941	167

Source: Table 4, Ref. 1

NOTES: 1) Note that the derivation of the roof values in Ref. 4 included consideration of the possibility that the ^{235}U associated with the building roof may have penetrated the surface over time. For example, contamination may have been covered over by roofing materials used in repair activities. Also, rainfall could have caused contamination to migrate into the roof substrate over time.

Table 1-4 ^{235}U Areal Density Estimates Derived for Building Surfaces

Category	Average Areal Density Estimate ($g^{235}U/ft^2$)				
	Area 1	Area 2	Area 3	Area 4	Area 5
Floors	0.053	0.031	0.033	0.028	0.118
Walls and Ceilings Combined	0.002	0.002	0.003	0.002	0.006
Roof (1)	0.033	0.033	0.034	0.040	0.035

Source: Table,5, Ref. 1

NOTES: 1) Note that the derivation of the roof values in Ref. 4 included consideration of the possibility that the ^{235}U associated with the building roof may have penetrated the surface over time. For example, contamination may have been covered over by roofing materials used in repair activities. Also, rainfall could have caused contamination to migrate into the roof substrate over time.

The building surfaces analysis reported in Ref. 4 also determined a peak areal density of 2.1 $g^{235}U/ft^2$ for the roof, which is bounding of all building surfaces in each of the five facility areas (i.e., floors, walls, ceilings, and roof, including the roof substrate). This peak areal density value corresponds to a limited portion of the building roof and explains why the average areal density values derived for each facility area are substantially smaller - by a factor of greater than 17, 350, and 52 for the building floors, walls/ceilings, and roof, respectively. The concrete floors and walls also exhibited variation in contamination levels. The peak areal density derived for floors was 1.8 $g^{235}U/ft^2$. The peak areal density derived for the building walls was very small (0.028 $g^{235}U/ft^2$) compared to that for the floors and roof.

1.5 Overview of Operations Concerning D&D Equipment Handling, Transit, and Storage/Packaging

D&D operations* may be necessary to prepare the former process buildings for demolition and to remove and decontaminate any equipment, piping, ventilation duct, and miscellaneous items/components as necessary to ensure that they meet the relevant criteria for transportation and off-site disposal.

When performed, D&D operations will be conducted under a task specific work package and will adhere to the criticality safety precautions identified in this and any other relevant NCSAs. The approach that will be used includes removal and decontamination of selected piping, ventilation duct, and miscellaneous items/components from the various process buildings, followed by their transit and loading into a transportation package/container situated either within or outside the environs of the former process buildings. In addition to the above activities, recovery of UO_2 from selected items not intended for removal from the buildings prior to building demolition work will be performed on an as-needed basis to ensure that the building demolition debris meets the relevant criteria for transportation and off-site disposal.

The decontamination methods that will be employed during D&D operations will be limited to removal of any UO_2 holdup, as necessary, using mechanically induced agitation and suction provided by a safe volume vacuum cleaner. The decontamination operations will generally be conducted in the area occupied by the item within a designated floor area. The approach used involves taping, sealing and/or bagging any open ends or other surfaces of the subject item, as necessary, to prevent potential spillage of UO_2 from the item during its removal. Following removal, if decontamination of the item is indicated by waste management considerations, the item is placed in the designated decontamination area and visually inspected for UO_2 holdup. Items with interior spaces not visible may be dissembled to facilitate inspection, depending on the extent of contamination indicated by the radiological surveys of the item and the existing characterization data. Following inspection, the item may be decontaminated by mechanically agitating any identified UO_2 deposits and recovering the loose UO_2 with a safe volume vacuum cleaner. Any UO_2 recovered from the decontaminated equipment, piping, ventilation duct, and miscellaneous items/components will be transferred from the safe volume vacuum cleaner receptacle to a safe volume container. The safe volume container

* This section provides a high level overview of planned D&D operations. The overview provided is intended to orient the reader and should not be construed as constituting a detailed process description.

will be placed in a secure area for interim storage and will be sealed at all times except when being filled/emptied or while its content is being packaged for shipment. Based on the small total projected total mass of UO_2 that will be recovered from the D&D operations (a small fraction of the total 1767 $g^{235}U$), it is anticipated that only one safe volume container will be required to accommodate all recovered UO_2. In the unlikely event that additional capacity is necessary (e.g., due to recovery of significant quantities of non-fissile materials and contaminants comingled with the recovered UO_2) a request will be made to the NCS organization to permit use of an additional container. Note that this assumption on operational practice is reinforced by the Defense-in-Depth (DinD) control established in Section 2.4.3.4.

As part of the D&D operations work package development, the results of the 2009 characterization program were examined to identify the explicit equipment, piping, ventilation duct, and miscellaneous items/components that will be decontaminated and/or removed from former process buildings prior to their demolition. The explicit equipment, piping, ventilation duct, and miscellaneous items/components targeted for removal from the process buildings are listed in Table 1-5. These items will be decontaminated within the former process buildings following their removal if deemed necessary from a waste management standpoint.

Table 1-5 List of Items Targeted for Removal during D&D Operations

Item	Characterization Radiological Survey Report(s)	Mass Estimate ($g^{235}U$)
blue valve 260-66	0666 CH 090810	157.0
y-duct 254-33	0821 CH 090827, 0614 CH 090729	132.1
sink p-trap 255-47	0730 CH 090814	52.2
254-9	0818 CH 090826	33.7
sample racks 240-10C	0707 CH 090813	29.3
overhead sample lines 1 254-33	0744 CH 090818, 0762 CH 090819	18.7
254-10	0819 CH 090827	17.9
sample lines 255-56	0777 CH 090824	10.9
sink 240-14	0799 CH 090826	8.9
filter basket 260-76	1061 CH 090924, 1065 CH 090924	7.4
260-8	0761 CH 090819	6.1
254-6, 254-7	0592 CH 090727	6.0
ceiling stub 2 240-11	0589 CH 090727, 0599 CH 090728	5.8
260-10	0782 CH 090824	5.3
overhead sample lines 2 254-33	0741 CH 090818, 0763 CH 090818	5.2
260-4	0700 CH 090811, 0749 CH 090819	3.3
254-8	0613 CH 090729	1.6
elbow 3in 254-34	1053 CH 090924	1.1
Pipe 254-1	0562 CH 090721, 0635 CH 090803, 0734 CH 090818	53.0
Pipe 255-1	0550 CH 090720, 0619 CH 090730 0623 CH 090730, 0631 CH 090803 0647 CH 090804, 0661 CH 090805 0670 CH 090806, 0672 CH 090806 0673 CH 090806, 0674 CH 090806 0675 CH 090806, 0687 CH 090810	149.7
Pipe 255-2	0543 CH 090717, 0618 CH 090730 0634 CH 090803, 0645 CH 090804 0657 CH 090805, 0669 CH 090806 0671 CH 090806, 0677 CH 090806 0681 CH 090806, 0688 CH 090810	140.8
Pipe 255-3	0544 CH 090717, 0547 CH 090720 0622 CH 090730, 0633 CH 090803 0646 CH 090804, 0656 CH 090805 0665 CH 090806, 0691 CH 090811	50.8
Pipe 255-4	0551 CH 090720, 0694 CH 090810	68.5
Pipe 260-2	0602 CH 090727, 0703 CH 090812	121.1
Pipe 260-3	0578 CH 090723, 0704 CH 090812, 0748 CH 090819	29.0
Combined Total		1115.4

Source: Original

Table 1-6 provides a schedule of the explicit equipment, piping, ventilation duct, and miscellaneous items/components targeted for decontamination only (i.e., not removal). The decontamination method used for these items consists of vacuuming any loose UO_2 powders. Following decontamination additional fixative will be applied to the contaminated surfaces of these items, as necessary from a waste management standpoint. It is anticipated that the majority of these items will not have any loose UO_2 holdup. In this case, decontamination operations would only comprise application of fixative.

Table 1-6 List of Items Targeted for Decontamination Only during D&D Operations

Item	Characterization Radiological Survey Report(s)	Mass Estimate ($g^{235}U$)
HEPA 1 240-12	0724 CH 090812	8.0
HEPA 2 240-12	0724 CH 090812	7.1
HEPA 3 253-26	0724 CH 090812	7.1
HEPA 4 256-38	0724 CH 090812	0.6
HEPA 5 254-34	0724 CH 090812	47.2
HEPA 6 254-34	0724 CH 090812	146.2
HEPA 7 254-35	0724 CH 090812	13.9
HEPA 8 254-35	0724 CH 090812	6.5
HEPA 9 254-41	0773 CH 090819, 0783 CH 090824	0.0
HEPA 10 254-41		0.0
HEPA 11 254-42		3.7
HEPA 12 254-42		0.4
HEPA 13 254-42	0774 CH 090820, 0783 CH 090824	0.0
HEPA 14 254-42		56.8
HEPA 15 254-39		0.0
HEPA 16 255-53		3.2
HEPA 17 255-53		3.3
HEPA 18 255-51		9.2
HEPA 19 255-51		4.9
HEPA 20 260		1.2
HEPA 21 260		0.4
HEPA intake duct west 254-34	0731 CH 090813	47.2
cable tray 260	0849 CH 090904	27.6
254-5	0585 CH 090727, 0747 CH 090819	21.0
HEPA intake duct east 254-34	0725 CH 090813	14.4
filter shredder components - north	0790 CH 090825, 0843 CH 090902 0852 CH 090902	14.1
pipe stubs 254-34 254-35	0814 CH 090827, 0826 CH 090831	4.4
pipe stubs 254-33 254-34	0823 CH 090831, 0826 CH 090831	3.2
Combined Total		451.6

Source: Original

1.6 Overview of Equipment used for D&D Equipment Handling, Transit, and Storage/Packaging

No equipment is relied on for D&D equipment handling, transit, and storage/packaging operations, as relevant to this NCSA.

1.7 Scope of Assessment

The activities assessed in this NCSA encompass decontamination and removal of equipment, piping, ventilation duct, and miscellaneous items/components as necessary to ensure that they meet the relevant criteria for transportation and off-site disposal.

The scope of this NCSA is limited to decontamination and removal of only those equipment, piping, ventilation duct, and miscellaneous items/components within the former process buildings that were previously identified, characterized (i.e., assigned a ^{235}U mass estimate), and documented in the October 2009 Characterization reports (References 2 and 3).

In the event that any contaminated equipment, piping, ventilation duct, and miscellaneous items/ components not previously identified in the October 2009 Characterization reports (References 2 and 3) are encountered during D&D operations, the subject items shall not be disturbed without evaluation and instruction from the NCS Organization.

1.8 Methodology

1.8.1 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.

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

1.8.2 Criticality Control Philosophy

The criticality control philosophy for the scope of operations addressed in this NCSA (Section 1.7) is based on limitation of ^{235}U mass. This is assured by handling and decontaminating only those equipment, piping, ventilation duct, and miscellaneous items/components within the former process buildings that were previously identified, characterized (i.e., assigned a ^{235}U mass estimate), and documented in the October 2009 Characterization reports (References 2 and 3).

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 the D&D operations evaluated in this NCSA. This section also 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 the D&D operations under normal (i.e., expected) conditions.
- **Section 2.4** contains the criticality safety assessment of the D&D operations under abnormal (i.e., unexpected) conditions.

2.1 Criticality Hazard Identification

This section outlines the technique used to identify criticality hazards associated with the D&D operations outlined in Section 1.5. A summary of the hazards identified is also provided, together with a brief description of their disposition in the NCSA.

2.1.1 Hazard Identification Method

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

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

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

The eleven (11) parameters listed above are traditionally considered in criticality safety assessments of processes at operating facilities possessing Special Nuclear Material (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* analysis is presented in Table 2-1. If applicable, hazards that result in events with similar consequences and safeguards are grouped in single criticality accident event sequences. The criticality accident event sequences are provided in Section 2.4.

Table 2-1 Criticality Hazards Identified from the D&D Equipment Handling, Transit, and Storage/Packaging Activities What-If Analysis

Event ID	What-if [Source]	Causes	Consequences	Accident Sequence in NCSA
Mass & Interaction				
D&DO-C-01	Greater than a maximum safe mass of UO_2 is removed from an item during decontamination [Event Sequence 1.12, Ref. 5]	• Inaccurate estimate of amount of UO_2 contained in an individual item	Potential to accumulate a maximum safe mass of ^{235}U within a discrete location.	**Section 2.4.1**
D&DO-C-02	Greater than a maximum safe mass of UO_2 is accumulated in a decontamination area [Event Sequence 2.6, Ref. 5]	• Inaccurate estimate of amount of UO_2 contained in individual items • Multiple items decontaminated simultaneously	Potential to accumulate a maximum safe mass of ^{235}U within a discrete location.	**Section 2.4.2**
D&DO-C-03	Greater than a maximum safe mass of UO_2 is accumulated in a vacuum cleaner, container, or in any other item/equipment used for decontamination operations [Event Sequence 1.13, Ref. 5]	• Failure to routinely empty vacuum contents • More UO_2 recovered from D&D items than indicated by their assigned UO_2 mass values.	Potential to accumulate a maximum safe mass of ^{235}U within a discrete location.	**Section 2.4.3**
N/A	Unapproved items are decontaminated and/or removed [Event Sequence 2.5, Ref. 5]	• Failure to follow work package controls	None. The scope of the D&D operations NCSA encompasses all identified elevated items within the former process buildings.	**N/A**

Event ID	What-if [Source]	Causes	Consequences	Accident Sequence in NCSA
D&DO-C-04	Greater than a maximum safe mass of UO_2 is accumulated due to consolidation of UO_2 recovered from decontaminated items [Event Sequence 2.7, Ref. 5]	• Incorrect assignment of UO2 mass, incorrect procedure, human error	Potential to accumulate a maximum safe mass of ^{235}U within a discrete location; or Potential for excess neutron interaction between fissile materials associated with D&D operations.	**Section 2.4.4**
D&DO-C-05	UO_2 recovered from decontaminated items is misdirected to an unapproved area [Event Sequence 2.11, Ref. 5]	• More UO_2 recovered from D&D items than indicated by their assigned UO_2 mass values.	Potential to accumulate a maximum safe mass of ^{235}U within a discrete location.	**Section 2.4.5**
D&DO-C-06	There is loss of containment of UO_2 associated with D&D items in transit or storage [Event Sequence 2.10, Ref. 5]	• Failure to follow work package controls	Potential to accumulate a maximum safe mass of ^{235}U within a discrete location.	**Section 2.4.6**
D&DO-C-06	There is loss of containment of recovered UO_2 during transit or storage [Event Sequence 2.12, Ref. 5]	• Failure to follow work package controls	Potential to accumulate a maximum safe mass of ^{235}U within a discrete location.	**Section 2.4.6**

Event ID	What-if [Source]	Causes	Consequences	Accident Sequence in NCSA
D&DO-C-07	Removed items are transferred to and/or received in a D&D equipment storage area/container without prior decontamination [Event Sequence 2.8, Ref. 5]	• Any	Potential to accumulate a maximum safe mass of ^{235}U within a discrete location.	**Section 2.4.7**
D&DO-C-07	There is neutron interaction between D&D items in transit or in storage [Event Sequence 2.9, Ref. 5]	• Any	Potential for excess neutron interaction between fissile materials associated with D&D operations.	**Section 2.4.7**
Geometry and Concentration				
There are no identified hazards associated with geometry and concentration. This is because the safety assessment of D&D operations within the former process buildings establishes that subcriticality is assured by the low mass of UO_2 associated with the elevated equipment, piping, ventilation duct, and miscellaneous items/components, without regard to its geometry and concentration.				
Isotopic/Enrichment				
There are no identified hazards associated with presence of variable enrichment uranium associated with contamination of the elevated equipment, piping, ventilation duct, and miscellaneous items/components involved in the D&D operations. This is because the safety assessment is conservatively based on an upper bound uranium enrichment of 5 wt.% $^{235}U/U$, as justified in Section 2.2.1.				
Moderation				
There are no identified hazards associated with moderation. This is because the safety assessment of D&D operations establishes that subcriticality is assured under bounding credible moderation conditions consisting of optimized homogeneous UO_2-H_2O mixtures.				

Event ID	What-if [Source]	Causes	Consequences	Accident Sequence in NCSA
Density				
There are no identified hazards associated with the presence of variable density uranium. This is because the subcritical limits used in the safety assessment of D&D operations are bounding of all UO_2 densities, including maximum theoretical density.				
Heterogeneity				
The criticality safety assessment of D&D operations uses subcritical limits derived for optimized homogeneous UO_2-H_2O mixtures because the uranium associated with the D&D items (with the exception of a single UO_2 fuel pellet) consists of UO_2 powders rather than pellets or pellet fragments. Consequently, there are no identified hazards associated with heterogeneity of the UO_2 encountered during D&D operations.				
Neutron Absorbers				
There are no identified hazards associated with absence of fixed neutron absorbers because the safety assessment of D&D operations does not credit fixed neutron absorbers.				
Reflection				
There are no identified hazards associated with reflection conditions. This is because the safety assessment of D&D operations is based either on subcritical limits derived for compact spherical geometry UO_2-H_2O mixtures with conservative reflection conditions.				
Volume				
There are no identified hazards associated with volume. This is because the safety assessment of D&D operations establishes that subcriticality is assured by the low mass of UO_2 associated with the elevated equipment, piping, ventilation duct, and miscellaneous items/components, without regard to the volume it occupies.				

Source: Events are Identified in Ref. 5.

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 are as follows:

- This assessment does not consider fissile nuclides other than ^{235}U. Based on the history of operations within the former process buildings, there is no expectation that fissile nuclides other than ^{235}U could be encountered during D&D operations within the former process buildings.
- Fissile material limits have been derived assuming optimized homogenous aqueous mixtures of UO_2 and water (H_2O). This approach is conservative with respect to the materials involved in the evaluated D&D operations (predominantly steel components with UO_2 surface contamination). Further justification is provided below:
  - If heterogeneous compounds of UO_2 (e.g., fuel pellets) were present use of the slightly more restrictive heterogeneous system subcritical limits could be warranted. However, the results of the 2009 characterization program indicate that the UO_2 is present as a powder at low areal density, with the exception of a single UO_2 pellet. Furthermore, this determination is consistent with the known use of the various equipment, piping, ventilation duct and miscellaneous items/components during fuel manufacturing operations. Thus, use of subcritical limits based on optimized homogeneous mixtures is appropriate.
  - In theory, some solutions represent excellent moderators, and in some cases, are more effective than full density water. Solutions with the potential to represent more effective moderators than full density water include hydro-carbon based solutions such as oils and hydraulic fluids with high bulk densities (i.e., >0.7 g/cc). However, the potential for the introduction of hydrogenous and hydro-carbon based fluids with moderating properties superior to that provided by full density water is very small. This is because there are no sources of such fluids except for a small number of sealed components spread throughout the buildings. The exceptions include two forklift trucks, a plate truck, a scissor lift, and a small volume of oil potentially associated with some air conditioning components and two cranes (estimated to contain less than 5 liters total). In all cases, the noted exceptions involve oil/hydraulic fluid that are contained within an enclosed system and are not freely available. For this reason, the probability that a maximum safe mass of ^{235}U could be assembled in a highly idealized compact spherical geometry comprising only UO_2 and a high density hydro-carbon based solution is exceptionally small. Thus, use of subcritical limits based on optimized homogeneous aqueous mixtures of UO_2 and water (H_2O) is appropriate.
- The subcritical limits considered in this NCSA are based on an enrichment of 5 wt.% $^{235}U/U$. This enrichment value represents an upper bound on the enrichment

level associated with the UO_2 that could be encountered during the evaluated D&D operations. This is because this enrichment value is based on the maximum enrichment level permitted under the site license at the time of low enriched uranium operations.

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 D&D equipment handling, transit, and storage/packaging activities addressed are described and documented in Sections 1.5 and 1.6.

2.3 Normal Conditions

This section presents the criticality safety assessment of D&D operations within the former process buildings under normal (i.e., expected) conditions.

Under normal conditions, D&D items will be removed and decontaminated according to a prescribed methodical process involving the following basic process steps:

- Identification of an item designated for decontamination and/or removal.
- Decontamination of the item in-situ using a safe volume vacuum cleaner (if the item is not indicated for removal).
- Taping, sealing and/or bagging any open ends or other surfaces of the items designated for removal prior to their removal/disturbance, as necessary, to prevent potential spillage of UO_2 during movement.
- Transfer and placement of removed items in a floor area designated for inspection and decontamination operations (if indicated by waste management considerations), following their removal.
- Decontamination of each removed item within the designated decontamination area, as necessary from a waste management standpoint. The decontamination operations may entail disassembly, cutting, and/or mechanical agitation to access and/or mobilize any UO_2 deposits. In all cases, a safe volume vacuum cleaner will be used to recover any loose UO_2.
- Transfer of the UO_2 recovered from decontamination operations from the safe volume vacuum cleaner receptacle to a safe volume container. The safe volume container will be retained in a secure area for interim storage when not in use and will be lidded at all times except when being filled/emptied or while its content is being packaged for shipment.

The explicit elevated equipment, piping, ventilation duct, and miscellaneous items/components targeted for removal and/or decontamination during D&D operations are listed in Table 1-5 and Table 1-6. Based on waste management considerations it is anticipated that only a small fraction of the listed items scheduled for removal (Table 1-5) will be subject to UO_2 recovery operations. It is expected that the majority of the items listed in Table 1-5 will be removed and consigned to a transportation container/package without any additional decontamination. In addition, it is expected that the majority of the items listed in Table 1-6 will also not be subject to UO_2 recovery operations. The majority of D&D operations involving these items will only entail application of fixative to seal any residual surface contamination without recovery of any residual UO_2.

Removal, Transit, and, Storage/Packaging of D&D items

The total mass associated with all items designated for removal from the former process buildings is 1115.4 $g^{235}U$ (Table 1-5). This combined maximum value is significantly smaller than the maximum sub-critical mass limit for UO_2 with 5 wt.% $^{235}U/U$ enrichment (1640 $g^{235}U$, Table 6, Ref. 6). Thus, the total mass of UO_2 associated with D&D items planned for removal, transit, and storage/packaging operations is insufficient to present a criticality safety hazard, under any condition. Consequently, removal, transit, and storage/packaging of D&D items under normal conditions present no criticality safety concerns.

Recovery, Transit, and Storage/Packaging of UO_2

Based on waste management considerations it is anticipated that only a small fraction of the items scheduled for removal from the process buildings (Table 1-5) will be subject to UO_2 recovery operations under normal conditions. Furthermore, it is expected that the majority of the items listed in Table 1-5 will be removed and consigned to a transportation container/package without any additional decontamination. In addition, it is expected that the majority of the items listed in Table 1-6 will also not be subject to UO_2 recovery operations. The majority of D&D operations involving these items will only entail application of fixative to seal any residual surface contamination without recovery of any residual UO_2. Based on this approach only small quantities of UO_2 will be recovered during D&D operations. It is expected that the total mass of UO_2 recovered from D&D operations would not exceed ~11.3 $kgUO_2$, equivalent to ~500 $g^{235}U$. This anticipated maximum value is substantially smaller than the maximum sub-critical mass limit for UO_2 with 5 wt.% $^{235}U/U$ enrichment (1640 $g^{235}U$, Table 6, Ref. 6) by a factor of greater than three. Thus, under normal conditions, recovery, transit, and storage/packaging of UO_2 from during D&D operations would not present any criticality safety concerns.

2.4 Abnormal Conditions

This section provides an assessment of the criticality hazards identified from the *What-if* analysis conducted for the D&D operations evaluated in this NCSA. The *What-if* analysis (summarized in Table 2-1) identified potential criticality hazards requiring evaluation. The postulated hazards are assessed and grouped in the following event sequences:

- Section 2.4.1: Excess UO_2 is removed from an item during decontamination.
- Section 2.4.2: Excess UO_2 is accumulated in a decontamination area.
- Section 2.4.3: Excess UO_2 is accumulated in a vacuum cleaner, container, or in any other item/equipment used for decontamination operations.
- Section 2.4.4: Excess UO_2 is accumulated due to consolidation of UO_2 recovered from decontaminated items.
- Section 2.4.5: UO_2 recovered from decontaminated items is misdirected to an unapproved area.
- Section 2.4.6: There is loss of containment of UO_2 associated with D&D items or recovered UO_2 during transit or storage.
- Section 2.4.7: All items removed during D&D operations are stored in a single D&D item storage area/container without prior decontamination.

2.4.1 Excess UO_2 is removed from an item during decontamination

2.4.1.1 Discussion

This event sequence addresses the implications on criticality safety due to recovery of an abnormally high mass of UO_2 from a single item during D&D operations. This could potentially result from erroneous or inadequate characterization of the item and would be a concern if it resulted in collection of greater than a maximum subcritical mass.

2.4.1.2 Risk Assessment

The explicit elevated equipment, piping, ventilation duct, and miscellaneous items/components targeted for decontamination and/or removal from the former process buildings during D&D operations are listed in Table 1-5 and Table 1-6. It is seen from these tables that each individual item contains only a small mass of ^{235}U. The item with the largest recorded inventory is the blue diverter valve situated in building 260, which has an assigned ^{235}U mass content of 157 $g^{235}U$ (Table 1-5). This maximum value is smaller than the maximum sub-critical mass limit for UO_2 with 5 wt.% $^{235}U/U$ enrichment (1640 $g^{235}U$, Table 6, Ref. 6) by a factor of greater than ten. Thus, each individual item is highly subcritical and recovery of even 100% of the mass of UO_2 associated with any single item during D&D operations would not present any criticality safety concerns.

The potential for underestimation of the ^{235}U mass values assigned to the individual items listed in Table 1-5 and Table 1-6 is considered to be small because of the conservatisms associated with the analytical method employed, and the pessimisms inherent in the material spatial distribution assumptions used. These conservatisms and pessimisms are documented in Reference 2 and 3 and are outlined in the characterization summary report (Ref. 1) prepared following completion of the 2009 characterization program. Even if the ^{235}U mass content of an item was underestimated, the underestimation factor would have to exceed a factor of ten before recovery of a maximum safe mass of ^{235}U would be possible. Even if such gross deviations were realized the potential for a criticality incident would be very small because the credible worst case condition that could be achieved for an accumulation of UO_2 would not closely match the idealized compact spherical geometry, optimum water moderation, and full water reflection conditions on which the maximum subcritical mass limit is based. Although non-optimized moderation, geometry, concentration, and reflection conditions could theoretically result in an unsafe condition, the mass of ^{235}U that would be required to achieve the critical state would have to be far greater than the maximum subcritical limit of 1640 $g^{235}U$. This is because as each parameter (moderation, geometry, concentration, and reflection) departs from its optimum condition the mass of ^{235}U required for the critical state increases. Departure of combinations of parameters from their optimum condition would require a disproportionately large increase in the ^{235}U mass to achieve the critical state.

The potential for non-trivial neutron interaction between excess UO_2 removed from an item during decontamination and ^{235}U contamination bound to the building surfaces is essentially zero. The extremely low areal density of the building surfaces assures that any interaction potential would be negligible and can be ignored. To illustrate the triviality of the interaction potential with ^{235}U contamination associated with the building surfaces, one need only consider that a maximum subcritical mass of 1640 $g^{235}U$ occupies a volume of only ~16 L*, corresponding to a sphere of diameter ~31 cm. This compares with a bounding peak and average areal density for building surfaces of 2.1 $g^{235}U/ft^2$ and 0.118 $g^{235}U/ft^2$, respectively. So, the building surfaces in the vicinity of a maximum subcritical mass of 1640 $g^{235}U$ would contain only a small amount of ^{235}U, and based on this small mass and large spatial distribution, would present no discernable interaction potential.

Based on the above assessment it is concluded that recovery of an abnormally high mass of UO_2 from a single item during D&D operations could not credibly result in a criticality accident.

2.4.1.3 Summary of Risk Assessment

Based on the risk assessment provided above, a criticality accident due to recovery of an abnormally high mass of UO_2 from a single item during D&D operations is not credible. This determination is supported by the following considerations:

- The recovered UO_2 would have to comprise a total mass more than ten times the maximum mass assigned to any individual item within the former process buildings; and
- The recovered UO_2 would have to be configured into a geometry that would favor a low critical mass system (i.e., assembled into a compact spherical or near spherical geometry); and
- The recovered UO_2 would have to be suspended at optimum, or near optimum, concentration in an efficient (e.g., water) moderating medium.

2.4.1.4 Safety Controls

No Criticality Safety Control (CSCs) have been identified in the risk assessment. However, further risk reduction can be achieved by recovering UO_2 into safe volume vessels/containers during D&D operations. In this regard, the following DinD control is recognized and ensures that the risk of criticality due to recovery of an abnormally high mass of UO_2 from a single item during D&D operations is as low as is reasonably achievable.

> **DinD Administrative Control 01:** *A single safe volume vacuum cleaner (maximum internal volumetric capacity of 4.49 gallons) should be used for recovery of UO_2 from items decontaminated during D&D operations.*

* The optimum concentration of a spherical full water reflected sphere containing a homogeneous UO_2-H_2O mixture is ~2100 gU/L (Fig III.B.3-6 of Ref. 7). Applying this optimum concentration value to the maximum subcritical mass limit of 1640 $g^{235}U$ (Table 6, Ref. 6) results in a derived UO_2-H_2O mixture volume of approximately 16 L.

2.4.2 Excess UO_2 is accumulated in a decontamination area

2.4.2.1 Discussion

Excess accumulation of UO_2 in a decontamination area could potentially arise if decontamination operations were conducted on multiple items simultaneously or concurrently, without removal of each decontaminated item and recovered UO_2 prior to the introduction of an additional contaminated item to the decontamination area. Under these abnormal conditions, protracted accumulation of UO_2 in a decontamination area could potentially result in collection of a significant mass of UO_2, which would reduce criticality safety margin.

2.4.2.2 Risk Assessment

Table 1-5 and Table 1-6 provide a schedule of the elevated equipment, piping, ventilation duct, and miscellaneous items/components targeted for removal and/or decontamination during D&D operations. This list comprises all of the elevated items that were identified within the process buildings during the 2009 characterization program. Based on the mass assigned to the individual items in Table 1-5 and Table 1-6 it is seen that the total mass of ^{235}U associated with all elevated items is 1767 $g^{235}U$. Thus, the decontamination area could not contain more than 1767 $g^{235}U$ even if every single item was removed and placed in a decontamination area, including those items not designated for removal (see Table 1-6), and the UO_2 recovered from those items in-situ.

As noted in Section 2.4.1.2, the potential for underestimation of the ^{235}U mass values assigned to the individual items listed in Table 1-5 and Table 1-6 is considered to be small because of the conservatisms associated with the analytical method employed, and the pessimisms inherent in the material spatial distribution assumptions used. In fact, because of the conservative approach used as part of the characterization of the individual items, the combined mass total is expected to be considerably larger than actually exists. Even if the assigned mass value for several items was actually underestimated, the potential for the collective mass total to be underestimated would still be small. On this basis, the bounding worst-case condition relevant to aggregation of the UO_2 associated with the elevated D&D items is an accumulation of UO_2 comprising 1767 $g^{235}U$.

A worst case accumulation of 1767 $g^{235}U$ would exceed the maximum sub-critical mass limit for UO_2 with 5 wt.% $^{235}U/U$ enrichment (1640 $g^{235}U$, Table 6, Ref. 6) by a small margin. However, the following factors ensure that an accumulation exceeding 1640 $g^{235}U$ could not credibly occur:

- The large spatial distribution of the UO_2 associated with the individual items sharply contrasts with the compact (~16 L) spherical geometry on which the maximum sub-critical mass limit is based. Although recovery of UO_2 from decontamination operations provides a mechanism to re-configure the UO_2 into a more reactive compact geometry, only a small population of items will be targeted for decontamination during D&D operations, and hence only a small accumulation of UO_2 within a localized area could credibly be realized.

- The potential to liberate all of the UO_2 associated with every elevated item is effectively zero, even if decontamination operations are performed on every elevated item. This is because the majority of elevated items comprise surface contamination rather than loose hold-up, and even the use of extensive mechanical agitation methods would not be expected to mobilize a majority fraction of the contained UO_2.

If a worst case accumulation of 1767 g ^{235}U was somehow realized a criticality accident would still not be credible. This is because the worst case credible condition that could be achieved for an accumulation of UO_2 would not closely match the idealized compact spherical geometry, optimum water moderation, and full water reflection conditions on which the maximum subcritical mass limit is based. Although non-optimized moderation, geometry, concentration, and reflection conditions could theoretically result in an unsafe condition, the mass of ^{235}U that would be required to achieve the critical state would have to be far greater than the maximum subcritical limit of 1640 g ^{235}U. This is because as each parameter (moderation, geometry, concentration, and reflection) departs from its optimum condition the mass of ^{235}U required for the critical state increases. Departure of combinations of parameters from their optimum condition would require a disproportionately large increase in the ^{235}U mass to achieve the critical state. This effect can be demonstrated by examining a simple conservative analogue of an optimally concentrated and full water reflected spherical accumulation of highly enriched uranium in water. When only one attribute of this idealized system is adjusted by replacing the water moderator with a fully water saturated soil moderator the minimum critical mass increases by a factor of ~2.5*. Thus, even a relatively small perturbation of a single parameter results in a disproportionately large increase in the minimum critical mass. Recognizing the highly inefficient moderation, geometry, concentration, and reflection conditions presented by contaminated piping, ventilation duct, equipment, and miscellaneous items, an increase in the maximum subcritical mass limit by a factor significantly larger than 2.5 would be expected. While recovery of some UO_2 from decontamination operations would give rise to a more efficient geometry condition, an accumulation of even 1767 g ^{235}U could not credibly achieve a critical state.

Although the above assessment did not address interaction potential with ^{235}U contamination bound to the building surfaces, the extremely low areal density of the building surfaces assures that any interaction potential would be negligible and can be ignored. Refer to the related discussion in Section 2.4.1.2 for justification.

Based on the above assessment it is concluded that excess accumulation of UO_2 in a

* The minimum critical mass in a plutonium system moderated by fully water saturated soil (40% soil-in-water) (Fig III.A.6(97)-4 of Ref. 7) is a factor of ~2.5 greater than the minimum critical mass for an otherwise equivalent aqueous system (Fig III.A.6-1 of Ref. 7). Although this ratio is derived for plutonium, the derived factor of ~2.5 can be applied to a uranium system because the fission cross-section for ^{235}U (as a function of the incident neutron energy) follows a similar trend to the fission cross-section for plutonium. Note that the soil composition for the above data is defined in Table III.A.1-6 of Ref. 7.

decontamination area during D&D operations could not credibly result in a criticality accident.

2.4.2.3 Summary of Risk Assessment

Based on the risk assessment provided above, a criticality accident due to an excess accumulation of UO_2 in a decontamination area during D&D operations is not credible. This determination is supported by the following considerations:

- The accumulated UO_2 would have to comprise a very high fraction (93%) of the total mass of UO_2 associated with every identified elevated item within the former process buildings, which is not credible. This is because the majority of elevated items comprise surface contamination rather than loose hold-up, and even extensive mechanical agitation methods would not be expected to mobilize a majority fraction of the contained UO_2; and
- The accumulated UO_2 would have to be configured into a geometry that would favor a low critical mass system (i.e., assembled into a compact spherical or near spherical geometry); and
- The accumulated UO_2 would have to be suspended at optimum, or near optimum, concentration in an efficient (e.g., water) moderating medium.

2.4.2.4 Safety Controls

No CSCs have been identified in the risk assessment. However, further risk reduction can be achieved by limiting decontamination operations to only single items within any individual decontamination area at one time. In this regard, the following DinD control is recognized and ensures that the risk of criticality due to excess accumulation of UO_2 in a decontamination area is as low as is reasonably achievable.

> **DinD Administrative Control 02:** *Each item designated for decontamination (i.e. recovery of UO_2) should be introduced to a decontamination area individually, decontaminated, and removed from the decontamination area prior to the introduction of any additional contaminated items.*

2.4.3 Excess UO_2 is accumulated in a vacuum cleaner, container, or in any other item/equipment used for decontamination operations

2.4.3.1 Discussion

This event sequence addresses the implications on criticality safety due to excessive accumulation of UO_2 recovered from items during D&D operations within a single vessel, container, or equipment used for decontamination operations. Excessive accumulation of UO_2 would be a concern if it resulted in collection of greater than a maximum subcritical mass.

2.4.3.2 Risk Assessment

The explicit elevated equipment, piping, ventilation duct, and miscellaneous items/components targeted for removal and/or decontamination during D&D operations are listed in Table 1-5 and Table 1-6. Based on waste management considerations it is anticipated that only a small fraction of the listed items scheduled for removal will be subject to UO_2 recovery operations. It is expected that the majority of the items listed in Table 1-5 will be removed and consigned to a transportation container/package without any additional decontamination. In addition, it is expected that the majority of the items listed in Table 1-6 will also not be subject to UO_2 recovery operations. The majority of D&D operations involving these items will only entail application of fixative to seal any residual surface contamination without recovery of any residual UO_2.

Based on the approach described above only small quantities of UO_2 will be recovered during D&D operations. It is expected that the total mass of UO_2 recovered from D&D operations would not exceed ~11.3 kgUO_2, equivalent to ~500 g^{235}U. This anticipated maximum value is substantially smaller than the maximum sub-critical mass limit for UO_2 with 5 wt.% ^{235}U/U enrichment (1640 g^{235}U, Table 6, Ref. 6) by a factor of greater than three. Thus, under anticipated conditions, recovery and collection of UO_2 from during D&D operations would not present any criticality safety concerns, regardless of how the UO_2 is collected or stored.

Section 2.4.2.2 provides a generic assessment of the implications of uncontrolled UO_2 accumulation during D&D operations and concludes that any accumulation of UO_2 from D&D operations could not credibly result in a criticality accident. The generic assessment in Section 2.4.2.2 bounds this event sequence because the assessment in Section 2.4.2.2 demonstrates that recovery and accumulation of 100% of the UO_2 mass assigned to every elevated item would not comprise a significant fraction of the 1767 g^{235}U (Table 2) mass total derived for all items. This is because, with the exception of a small number of items, the ^{235}U is generally present only as surface contamination and would not be recoverable. Thus, the potential to recover greater than a maximum subcritical mass of ^{235}U during D&D operations is essentially zero. Even if every gram of ^{235}U was recovered from every elevated item there still would be no credible potential for a criticality incident. This is because of the incredibility of achieving the highly idealized conditions required for a critical state to be possible, as highlighted in Section 2.4.2.2.

Based on the above discussion and the supporting bounding generic assessment provided in Section 2.4.2.2, excess accumulation of UO_2 in a vacuum cleaner, container, or in any other item/equipment used for decontamination operations could not credibly result in a criticality accident.

2.4.3.3 Summary of Risk Assessment

This event sequence is bounded by the generic assessment of UO_2 accumulation in Section 2.4.2.2. Refer to Section 2.4.2.3 for a summary of this bounding risk assessment.

2.4.3.4 Safety Controls

Based on the bounding risk assessment provided in Section 2.4.2 no CSCs have been identified as relevant to this event sequence. However, further risk reduction can be achieved by only recovering UO_2 into safe volume vessels/containers during D&D operations. In this regard, the following DinD controls are recognized and ensure that the risk of criticality due to accumulation of UO_2 recovered from decontamination operations is as low as is reasonably achievable.

> **DinD Administrative Control 01:** *A single safe volume vacuum cleaner (maximum internal volumetric capacity of 4.49 gallons) should be used for recovery of UO_2 from items decontaminated during D&D operations.*
>
> **DinD Administrative Control 03:** *A single safe volume container (maximum internal volumetric capacity of 4.49 gallons) should be used for collection and containerization of all UO_2 recovered from items decontaminated during D&D operations. In the event additional storage capacity than a single safe volume container is required the NCS organization should be notified.*

2.4.4 Excess UO_2 is accumulated due to consolidation of UO_2 recovered from decontaminated items

2.4.4.1 Discussion

This event sequence concerns the potential to accumulate large quantities of UO_2 due to consolidation of UO_2 recovered from decontamination operations. Consolidation of UO_2 would be a concern if it resulted in collection of greater than a maximum subcritical mass.

2.4.4.2 Risk Assessment

The preceding event sequence (Section 2.4.3) evaluated the potential for an unsafe condition from excessive accumulation of UO_2 recovered from items during D&D operations within a single vessel, container, or equipment used for decontamination operations. This assessment highlighted the expectation that the total mass of UO_2 recovered from D&D operations will not exceed ~11.3 kgUO_2, equivalent to ~500 g^{235}U. Thus, consolidation of UO_2 recovered during D&D operations would be expected to result in an accumulation of UO_2 not exceeding ~11.3 kgUO_2, equivalent to ~500 g^{235}U. However, the assessment in Section 2.4.3 demonstrates that recovery and collection of all UO_2 associated with every elevated item could not credibly result in a criticality accident, even if the UO_2 was collected in a single vessel, container, equipment or location. Consequently, this event sequence is bounded by the risk assessment provided in Section 2.4.3.2, which in turn is bounded by the generic assessment of UO_2 accumulation in Section 2.4.2.2. Thus, excess accumulation of UO_2 due to consolidation of UO_2 recovered from decontaminated items could not credibly result in a criticality accident.

2.4.4.3 Summary of Risk Assessment

This event sequence is bounded by the risk assessment provided in Section 2.4.3.2, which in turn is bounded by the generic assessment of UO_2 accumulation in Section 2.4.2.2. Refer to Section 2.4.2.3 for a summary of this bounding risk assessment.

2.4.4.4 Safety Controls

Based on the bounding risk assessment provided in Section 2.4.2 no CSCs have been identified as relevant to this event sequence. However, further risk reduction is achieved by only recovering UO_2 into safe volume vessels/containers during D&D operations. The associated DinD controls are provided in Section 2.4.3.4 and are not restated here for brevity. These DinD controls ensure that the risk of criticality due to accumulation of UO_2 recovered from decontamination operations is as low as is reasonably achievable.

2.4.5 UO_2 recovered from decontaminated items is misdirected to an unapproved area

2.4.5.1 Discussion

This event sequence addresses the implications on criticality safety due to misdirection of UO_2 to an unapproved area. Misdirection of UO_2 recovered from D&D operations would be a concern if it resulted in a loss of control of fissile material in the receiving area.

2.4.5.2 Risk Assessment

The Hematite site does not currently have any fissile material in storage because all non-exempt materials were removed from the site between 2001 and 2006 during former D&D operations*. Future site operations related to the activities described in the comprehensive 2009 site decommissioning plan may result in the generation of fissile materials from remediation of the site burial pits and contaminated land areas. However these operations will not be initiated prior to completion of the D&D operations evaluated in this NCSA. On this basis, there is no potential for an unsafe condition as a result of misdirection of UO_2 recovered from D&D operations to an unapproved area.

2.4.5.3 Summary of Risk Assessment

Misdirection of UO_2 recovered from D&D operations to an unapproved area could not result in a criticality accident because the Hematite site currently does not contain fissile material outside the environs of the former process buildings††, and because the D&D operations evaluated will be completed in advance of initiation of site wide remediation activities.

2.4.5.4 Safety Controls

Based on the risk assessment provided above no CSCs have been identified as relevant to this event sequence. Furthermore, no additional practicable measures for further reducing criticality risk have been identified. It is judged that the risks from criticality are as low as is reasonably achievable.

* It is noted that the site vault currently contains a total of 13 low enriched uranium fuel pellets. These pellets constitute a total mass of ~3 g ^{235}U and are not used for any operations, with the exception of limited activities related to instrument calibration. It is also acknowledged that Building 230 contains various contaminated samples (e.g., soil cores) which are exempt from criticality safety controls on the basis of their very low ^{235}U concentration.

2.4.6 There is loss of containment of UO_2 associated with D&D items or recovered UO_2 during transit or storage

2.4.6.1 Discussion

The general aim of decontamination operations is to ensure that any loose uranium deposits associated with the decommissioned items are removed and that any residual uranium is immobilized with the application of fixatives. In the event that D&D items in transit or in storage or shipping package(s) contained loose UO_2 there would be a potential to spill and accumulate UO_2, presenting a criticality safety concern if the mass of UO_2 involved was greater than a maximum subcritical mass. Similarly, spillage of UO_2 recovered from items during decontamination operations would be a concern if it could lead to an accumulation greater than a maximum subcritical mass.

2.4.6.2 Risk Assessment

Loss of Containment of UO_2 from D&D items in Transit or in Storage or Shipping Package(s)

In general, loss of containment of UO_2 from D&D items in transit would result in dispersal of the spilled UO_2 which would be expected to generally adopt a geometry characterized by lower neutron reflection, greater neutron leakage, and lower fissile density. This is because the dispersed uranium would tend to form a layer of contamination at low concentration, which would be substantially un-optimized compared with the idealized conditions on which the maximum subcritical limits are based (i.e., compact spherical geometry at optimum concentration and with close fitting full water reflection). In addition, interaction with any uranium remaining affixed to the D&D item in transit would be greatly reduced. All of these effects would lower the reactivity of the D&D item and interacting spillage, thus increasing the mass required for criticality. The only credible means of achieving a criticality due to loss of containment of UO_2 is if spillage of UO_2 occurs and accumulates over time, and if these spillages result in a localized accumulation of uranium with a sufficient fissile content (i.e., > 1640 $g^{235}U$) and in the condition necessary for a low critical mass system (i.e., optimum or near optimum moderation, geometry, and reflection). This potential is analyzed below.

In practice, any spillage incidents would be expected to involve only small quantities of UO_2 because individual items removed during D&D operations would contain no greater than the mass values assigned in Table 1-5, which show a maximum value of 157 $g^{235}U$ for any individual item. Thus, isolated spillage incidents from D&D items in transit could not result in an unsafe condition. Even if 100% of the UO_2 associated with every individual elevated item designated for removal (Table 1-5) were somehow spilled in a single coincident location, the total mass of ^{235}U associated with the spillage would not exceed 1115.4 $g^{235}U$ (Table 1-5). This combined maximum value is significantly smaller than the maximum sub-critical mass limit for UO_2 with 5 wt.% $^{235}U/U$ enrichment (1640 $g^{235}U$, Table 6, Ref. 6). Thus, loss of containment of UO_2 from during D&D items in transit would not present any criticality safety concerns, regardless of whether the D&D items are decontaminated prior to their transit. Because this safety basis is founded on collection of 100% of the UO_2 associated with every individual elevated item designated for removal (Table 1-5), the same bounding arguments apply to D&D items within a storage area/container, including items packaged for shipment. Thus, loss of containment of UO_2 from D&D items in storage or in shipping package(s) would not present any credible criticality safety concerns, regardless of whether the D&D items are decontaminated prior to their storage.

Independent to the subcritical mass arguments used above, the following considerations indicate that the actual risk of a criticality incident from spillage of UO_2 from D&D items in transit or in storage or shipping package(s) is exceptionally low:

- The probability of multiple spillages of UO_2 from D&D items in transit or in storage or shipping packages would be inherently low because of the precautions exercised to ensure contamination control/radiological safety. Note that this assumption on operational practice is supported by the DinD controls captured in Section 2.4.6.4; and
- The probability of multiple spillages in the same location would be low, because radiological controls to limit employee exposures would require clean-up of any spills upon discovery. Note that this assumption on operational practice is also supported by the DinD controls captured in Section 2.4.6.4; and
- Spills of UO_2 would generally result in a less reactive condition because the spillage would tend to adopt a geometry characterized by lower neutron reflection, greater neutron leakage, and lower fissile density.

<u>Loss of Containment of Recovered UO_2 during Transit or during Storage or Packaging</u>

The total mass of UO_2 that could be recovered from D&D operations is not expected to exceed ~11300 gUO_2, equivalent to ~500 $g^{235}U$. Thus, loss of containment of UO_2 recovered from D&D operations would not be expected to result in any criticality safety concerns.

Section 2.4.2.2 provides a generic assessment of the implications of uncontrolled UO_2 accumulation during D&D operations and concludes that any credible accumulation of UO_2 from D&D operations could not credibly result in a criticality accident. The generic assessment in Section 2.4.2.2 bounds this event sequence because the assessment in Section 2.4.2.2 demonstrates that a maximum accumulation of UO_2 from D&D operations would not theoretically exceed 1767 $g^{235}U$ and would not credibly exceed the maximum sub-critical mass limit for UO_2 with 5 wt.% $^{235}U/U$ enrichment (1640 $g^{235}U$, Table 6, Ref. 6). This is because, with the exception of a small number of items, the ^{235}U is generally present only as surface contamination and would not be recoverable even if desired by operations. Thus, loss of containment of UO_2 recovered from decontamination operations during transit or in storage or shipping package(s) would not credibly result in a criticality accident because there would be insufficient mass for a criticality incident to be credible.

2.4.6.3 Summary of Risk Assessment

Based on the risk assessment provided above, a criticality accident due to loss of containment of UO_2 from D&D items in transit or in storage or shipping package(s) is not credible. This determination is supported by the following considerations:

- The spilled UO_2 would have to comprise a total mass approximately 50% greater than the combined mass of every item indicated for removal from the former process buildings (Table 1-5); and
- The spilled UO_2 would have to be configured into a geometry that would favor a low critical mass system (i.e., assembled into a compact spherical or near spherical geometry); and
- The spilled UO_2 would have to be suspended at optimum, or near optimum, concentration in an efficient (e.g., water) moderating medium.

Any loss of containment of UO_2 recovered from decontamination operations would likely involve only very small quantities of UO_2 and could not credibly result in collection of a maximum subcritical mass of UO_2. Thus, loss of containment of UO_2 recovered from decontamination operations could not credibly result in an unsafe condition.

2.4.6.4 Safety Controls

No CSCs have been identified as relevant to this event sequence. However, further risk reduction can be achieved by requiring that precautions are exercised to prevent spillage of UO_2, and by requiring that any identified spillages are promptly recovered. These defense-in depth precautions are captured in the following DinD controls, and ensure that the risk of criticality due to loss of containment of UO_2 is as low as is reasonably achievable.

DinD Administrative Control 04: *Any spillages of material from D&D items in transit should be recovered as soon as is practicable and before additional D&D item transit operations are conducted. The recovered materials should be assayed or sampled for UO_2 content. Any identified UO_2 should be recovered into a safe volume vacuum cleaner or safe volume container and transferred to an approved UO_2 storage area.*

DinD Administrative Control 05: *D&D items designated for removal from the process buildings should be taped, sealed, and/or bagged as appropriate to prevent the spillage of contained UO_2 during removal and subsequent transit.*

DinD Administrative Control 06: *The surfaces of the decontamination areas used during D&D operations should be vacuumed following completion of decontamination operations involving each individual D&D item, or otherwise confirmed to be free of loose UO_2.*

DinD Administrative Control 07: *The hose of the safe volume vacuum cleaner used for decontamination operations should be taped and/or bagged when not in use to prevent inadvertent spillage of contained UO_2.*

DinD Administrative Control 08: *The safe volume container used for consolidation of UO_2 recovered from decontamination operations should be lidded when not in use.*

2.4.7 All items removed during D&D operations are stored in a single D&D item storage area/container without prior decontamination

2.4.7.1 Discussion

This event sequence addresses the implications on criticality safety due to:

- conglomeration of D&D items in transit or in storage; and
- storage of D&D items which have not been subject to decontamination operations.

Storage of items without prior decontamination would be a concern if it resulted in a loss of mass control in the respective D&D item storage area.

2.4.7.2 Risk Assessment

This event sequence is bounded by the assessment of loss of containment of UO_2 from D&D items in storage or in shipping package(s) (Section 2.4.6.2), which concludes that an accumulation of UO_2 from any number of D&D items in storage or shipping package(s) could not credibly result in a criticality accident, even if all D&D items were not subject to any decontamination operations prior to their consignment to a storage area or shipping package(s). Thus, storage or packaging of any number of D&D items presents no credible criticality safety concerns, regardless of whether the items have been subject to decontamination operations. Because these arguments are not dependent on the location or attributes of the D&D item storage area or shipping package(s), this not credible determination also applies to any conglomeration of D&D items in transit.

2.4.7.3 Summary of Risk Assessment

This event sequence is bounded by the assessment of loss of containment of UO_2 from D&D items in storage or in shipping package(s) (Section 2.4.6.2). Refer to Section 2.4.6.3 for a summary of this bounding risk assessment.

2.4.7.4 Safety Controls

Based on the bounding risk assessment provided in Section 2.4.6.2 no CSCs have been identified as relevant to this event sequence. Furthermore, no additional practicable measures for further reducing criticality risk have been identified, as relevant to this particular event sequence. It is judged that the risks from criticality are as low as is reasonably achievable.

3.0 SUMMARY OF CRITICALITY SAFETY CONTROLS

3.1 Criticality Safety Parameters

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

Table 3-1 Criticality Safety Parameters

Nuclear Parameter	Controlled (Y/N)	Basis	Reference
Geometry	N	The safety assessment of D&D operations involving elevated piping, ventilation duct, and miscellaneous items/components uses subcritical limits based on bounding spherical geometry.	N/A
Interaction	N	The safety assessment of D&D operations involving elevated piping, ventilation duct, and miscellaneous items/components credits does not credit segregation of D&D items.	N/A
Mass	N	The safety assessment of D&D operations involving elevated piping, ventilation duct, and miscellaneous items/components does not credit CSCs to control mass but establishes numerous DinD controls to limit the potential to accumulate mass during operations.	Section 2.4.1 through Section 2.4.7
Isotopic / Enrichment	N	The safety assessment of D&D operations involving elevated piping, ventilation duct, and miscellaneous items/components is conservatively based on a bounding credible uranium enrichment of 5 wt.% $^{235}U/U$.	N/A
Moderation	N	The safety assessment of D&D operations involving elevated piping, ventilation duct, and miscellaneous items/components does not credit moderation control.	N/A
Density	N	The safety assessment of D&D operations involving elevated piping, ventilation duct, and miscellaneous items/components conservatively uses subcritical limits derived for UO_2 at maximum theoretical density.	N/A
Heterogeneity	N	The safety assessment of D&D operations involving elevated piping, ventilation duct, and miscellaneous items/components does not credit heterogeneity control.	N/A

Nuclear Parameter	Controlled (Y/N)	Basis	Reference
Neutron Absorbers	N	The safety assessment of D&D operations involving elevated piping, ventilation duct, and miscellaneous items/components does not credit fixed neutron absorbers.	N/A
Reflection	N	The safety assessment of D&D operations involving elevated piping, ventilation duct, and miscellaneous items/components uses subcritical limits based on bounding credible reflection conditions.	N/A
Concentration	N	The safety assessment of D&D operations involving elevated piping, ventilation duct, and miscellaneous items/components does not credit concentration.	N/A
Volume	N	The safety assessment of D&D operations involving elevated piping, ventilation duct, and miscellaneous items/components does not credit CSCs to control volume but establishes numerous DinD controls related to volume control of recovered UO_2.	Section 2.4.1 Section 2.4.3 Section 2.4.4

Source: Original

3.2 Criticality Safety Controls and DinD 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 D&D operations within the former process buildings. 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 DinD control captured in this NCSA use the following reference; *NSA-TR-09-25 DinD Administrative Control 01.*

3.2.1 Systems Structures and Components

No SSCs have been identified as directly important to ensuring criticality safety of the evaluated D&D operations.

3.2.2 Criticality Safety Controls

No CSCs have been recognized from the assessment of hazards identified for the proposed D&D operations. However, to affirm the assumptions on operational practice outlined in Section 1.5, the following CSCs are captured:

> **Administrative CSC 01:** *D&D operations SHALL be limited to only those items listed in Table 1-5 and Table 1-6 of this NCSA. In the event that any contaminated equipment, piping, ventilation duct, or miscellaneous components/items are identified that are not associated with these identified items the subject item(s) SHALL NOT be disturbed, unless approved by the NCS Organization.*

> **Administrative CSC 02:** *D&D operations SHALL only be conducted prior to initiation of any DP related activities that have the potential to encounter/generate fissile material, unless approved by the NCS Organization.*

3.2.3 Defense in Depth Controls

This section lists those controls that provide additional protection to ensure that the risk of criticality is as low as is reasonably achievable.

> **DinD Administrative Control 01:** *A single safe volume vacuum cleaner (maximum internal volumetric capacity of 4.49 gallons) should be used for recovery of* UO_2 *from items decontaminated during D&D operations.*

DinD Administrative Control 02: *Each item designated for decontamination (i.e. recovery of UO_2) should be introduced to a decontamination area individually, decontaminated, and removed from the decontamination area prior to the introduction of any additional contaminated items.*

DinD Administrative Control 03: *A single safe volume container (maximum internal volumetric capacity of 4.49 gallons) should be used for collection and containerization of all UO_2 recovered from items decontaminated during D&D operations. In the event additional storage capacity than a single safe volume container is required the NCS organization should be notified.*

DinD Administrative Control 04: *Any spillages of material from D&D items in transit should be recovered as soon as is practicable and before additional D&D item transit operations are conducted. The recovered materials should be assayed or sampled for UO_2 content. Any identified UO_2 should be recovered into a safe volume vacuum cleaner or safe volume container and transferred to an approved UO_2 storage area.*

DinD Administrative Control 05: *D&D items designated for removal from the process buildings should be taped, sealed, and/or bagged as appropriate to prevent the spillage of contained UO_2 during removal and subsequent transit.*

DinD Administrative Control 06: *The surfaces of the decontamination areas used during D&D operations should be vacuumed following completion of decontamination operations involving each individual D&D item, or otherwise confirmed to be free of loose UO_2.*

DinD Administrative Control 07: *The hose of the safe volume vacuum cleaner used for decontamination operations should be taped and/or bagged when not in use to prevent inadvertent spillage of contained UO_2.*

DinD Administrative Control 08: *The safe volume container used for consolidation of UO_2 recovered from decontamination operations should be lidded when not in use.*

4.0 CONCLUSION

This criticality safety assessment demonstrates that activities related to D&D operations involving elevated piping, ventilation duct, and miscellaneous items/components remaining within the former process buildings at the Hematite site 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 have no credible potential to result in a criticality accident.

5.0 REFERENCES

1. Westinghouse (E. K. Hackmann) letter to NRC (Document Control Desk), HEM-09-121, dated October 23, 2009, "Hematite Decommissioning Project Summary Report of the 2009 Process Building".

2. NSA-TR-09-21, Rev. 0, Calculations to Establish an Estimate of the Mass of ^{235}U Associated with Piping, Ventilation Duct, and Miscellaneous Components in the Hematite Facility Former Process Buildings, B. Matthews, October 2009.

3. NSA-TR-09-22, Rev. 0, Calculations to Establish an Estimate of the Mass of ^{235}U Associated with Equipment Remaining in the Hematite Facility Former Process Buildings, M. Corum, October 2009.

4. NSA-TR-09-23, Rev. 0, Calculations to Establish an Estimate of the Mass of ^{235}U Associated with the Floors, Walls, Ceilings, and Roof of the Hematite Facility Former Process Buildings, C. Henkel, October 2009.

5. DO-09-003, Rev 0, Process Hazards Analysis for the Removal of Equipment and Piping from the HDP Process Building, November 2009.

6. ANSI/ANS-8.1-1998, Nuclear Criticality Safety in Operations with Fissionable Materials Outside Reactors, American National Standards Institute, American Nuclear Society.

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