NuclearSafety Associates

Nuclear Criticality Safety Documents

NSA-TR-09-08, Rev. 0

Nuclear Criticality Safety Assessment of Sub-Surface Structure Decommissioning at the Hematite Site

NSA-TR-09-09, Rev. 0

Nuclear Criticality Safety Assessment of Waste Evaluation and Assay Activities at the Hematite Site

NSA-TR-09-10, Rev. 0

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

NSA-TR-09-11, Rev. 0

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

NSA-TR-09-12, Rev. 0

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

NSA-TR-09-13, Rev. 0

Nuclear Criticality Safety Assessment of Water Collection and Treatment Activities at the Hematite Site

NSA-TR-09-15, Rev. 0

Nuclear Criticality Safety Assessment of Buried Waste Exhumation and Contaminated Soil Remediation at the Hematite Site

NSA-TR-09-18, Rev. 0

Nuclear Criticality Safety Assessment of Decontaminated and Decommissioned Equipment Handling, Transit, and Storage at the Hematite Site

Supplemental Documents to the Hematite Decommissioning Project

Decommissioning Plan Submitted August 12, 2009

NuclearSafety Associates

Nuclear Criticality Safety Assessment of Sub-Surface Structure Decommissioning at the Hematite Site

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Revision History

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0	D. Vaughn	Original issue

List of Items To Be Verified

TBV #	Description
TBV1	The Hematite site sampling plan outlines the procedure for extracting core samples from HDP remediation areas (including concrete cores), and addresses the need for representative sampling [Section 2.4].

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Glossary of Acronyms, Abbreviations, and Terms

Acronym/Term	Definition
AEC	Atomic Energy Commission
ALARA	As Low As Reasonably Achievable
CD	Collared Drums (CDs) are used (as relevant to this NCSA) for *Field Container* transit between the excavation site and a WEA. Each CD has a cylindrical geometry, possessing a minimum internal diameter of 57cm. Each CD, irrespective of dimension, is fitted with a collar that extends 18" beyond the external radial surface of the CD. The CD collar is designed to ensure that any un-stacked arrangement of CDs would guarantee a minimum 36" separation distance between the outer surfaces of the CDs. The affixed collar is permanently secured to the CD and is not removed at any time the CD is being used, except when secured in a FMSA or CDRA.
CDRA	Collared Drum Repack Area
CDSA	Collared Drum Staging Area
CFR	Code of Federal Regulations
cm	centimeter
CSC	Criticality Safety Control
cut depth	Term used to define the appropriate exhumation depth that can be excavated before needing to assay exposed debris. The calibration document for the particular assay equipment used on a particular type of debris determines this maximum thickness of debris than can be exhumed before needing to perform additional assays.
DCGL	Derived Concentration Guideline Levels
D&D	Decontamination and Decommissioning
Double Contingency Principle	Safety principle interpreted by ANSI/ANS-8.1 as "Process designs should incorporate sufficient factors of safety to require at least two *unlikely*, independent, and concurrent changes in process conditions before a criticality accident is possible."
Extracted Piping Fissile Material Limit	Upper threshold of 75 grams of ^{235}U within a section of intact subterranean piping. Uranium content within a contiguous pipe section higher than this value cannot be extracted intact.
Field Container	Container used to collect suspected *Fissile Material* discovered during decommissioning activities (limited in volume to 20 liters)
Fissile Material	Material that contains a significant quantity of enriched uranium such that criticality safety controls are required when handling.
Fissile Material Exhumation Limit	Upper threshold of 38 grams of ^{235}U within a 10 liter volume of debris. Debris with concentrations above this value cannot be exhumed without further evaluation and approval from NCS staff.
FMSA	Fissile Material Storage Area – area used to interim store containerized *Fissile Materials* that have an ascribed ^{235}U mass content. The containerized *Fissile Material* are sealed within CDs.
g	gram
g/cc	gram per cubic centimeter

highly improbable	Probability of occurrence not expected during the anticipated decommissioning duration and involves concurrent fruition of at least two independent and *unlikely* occurrences
HRGS	High Resolution Gamma Spectrometer
HVAC	Heating, Ventilation, and Air Conditioning
likely	Probability of occurrence anticipated to occur frequently
MC&A	Material Control and Accountancy
MO	Missouri
NaI	sodium iodide
NCS Exempt Material	Decommissioning debris containing less than 1 gram of ^{235}U within a 10 liter volume of debris
NCSA	Nuclear Criticality Safety Analysis
poly	polyethylene
PPE	Personal Protective Equipment
Ref.	Reference (followed by citation number)
SNM	Special Nuclear Material (synonymous with '*Fissile Material*' used in this document)
Soil	A natural body comprised of solids (minerals and organic matter), liquid, and gases that occur naturally on land surfaces. Stones, gravels and other back-fill type materials are also defined as *soil* in this document.
SSC	System, structure, or component
TRU	Transuranic (isotopes with a proton count larger than uranium)
U	uranium
UF_6	uranium hexaflouride
unlikely	Probability of occurrence no greater than one time during the anticipated decommissioning duration
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.
WHA	Waste Holding Area – area used to stage solid wastes generated from site remediation activities that have been categorized as *NCS Exempt Material.*
wt. %	Percentage by weight

1.0 INTRODUCTION

This Nuclear Criticality Safety Assessment (NCSA) is provided in support of final decommissioning of the Hematite site. The activities assessed in this NCSA encompass excavation of subterranean structures such as piping, surrounding soil, septic systems, and concrete that is to be unearthed at the Hematite site and eventually packaged for disposal to an accepting off-site facility.

This NCSA is organized as follows:

- **Section 1** introduces the NCSA of Sub-Surface Structure Decommissioning at the Hematite site.
- **Section 2** provides the risk assessment of Sub-Surface Structure Decommissioning, as outlined in Section 1.
- **Section 3** summarizes the important engineered and administrative requirements identified in the criticality safety risk assessment provided in Section 2.
- **Section 4** details the conclusions of the NCSA of Sub-Surface Structure Decommissioning 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 have included the manufacturing of uranium metal and compounds from natural and enriched uranium for use as nuclear fuel. Specifically, operations have 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.

1.3 Subterranean Structures

Several former process buildings and facility administration buildings are situated on the Hematite Site. Each of the former process buildings required a combination of storm water drains and lines, sanitation drains and lines, and process drains and lines. The storm water drains and lines are tied into large external site drains and downspouts from the gutters bordering the buildings. These storm water lines are interconnected with the process drain lines from the former process buildings. The process drain lines (when in use) were intended to collect condensate from evaporation processes, overflow of water from various systems, and provide a route for free-release solutions from laboratory sinks. Both the storm water lines and the process drain lines are interconnected and tie into a large main trunk that extends to the nearby local creek. The sanitation lines are completely independent from the other lines and lead to septic tanks which filter into a sand and gravel drain field.

This evaluation assumes that the former process buildings and other structures will have been demolished and reduced to grade level prior to decommissioning concrete slabs, foundations, subterranean process piping, and other subterranean structures.

There are several building drawings and site plans that depict the location and dimensions of the subterranean structures. However, these are used only as a guide for this NCSA. Specifically, no reliance is placed on the content depicted on the existing drawings and plans.

1.4 Excavation Operations

In order to excavate the subterranean structures such as piping, surrounding soil, and septic systems, it is necessary to first remove any concrete slabs that are located on the surface of the ground above the piping. Once concrete slabs are removed, soil is then exhumed exposing the structures. Exposed piping and septic systems are either crushed in place or lifted intact dependent upon the appropriate excavation method. If excavated intact, the structure is applied with an internal immobilizing agent and then removed from the ground in various lengths and sizes. Once above-ground and located on a stand, the structure is permanently filled with a solidifying and immobilizing agent such as grout or concrete. If excavated as crushed debris, the excavated material is bulked into a large conveyance by excavating the crushed debris and any comingled soil/stones/gravel in layers. Each excavation is limited to an appropriate *cut depth*. The following subsections provide further detail for the aforementioned operations.

1.4.1 Concrete Slab Removal

The former process buildings were built on a foundation of concrete. Typically concrete structures such as foundations and slabs are exempt from criticality safety scrutiny during decommissioning operations due to the small potential to contain significant quantities of *Fissile Material*. However, spills of process materials during manufacturing operations at the Hematite site have been documented. It is possible that these incidents, especially those involving solutions, may have involved significant quantities of *Fissile Material*. Because of the potential for cracks, expansion joints, and seams in the concrete surfaces, it is possible that non-trivial quantities of *Fissile Material* could have collected in pockets within the portions of concrete subject to contamination.

It has been reported that the concrete slabs subject to non-trivial contamination from spillages during manufacturing operations, were either scrubbed clean, scabbled, and/or were re-surfaced by overlaying the contaminated concrete with an additional layer of concrete. These remedial actions were performed during the manufacturing era and were likely necessary at the time to ensure that the subject areas could be safely occupied for manufacturing operations. The remaining portions of concrete not known to have been subject to significant contamination incidents during manufacturing operations were cleaned and sprayed with fixative to immobilize any surface contamination during prior decommissioning activities at the site.

To address the potential for encountering significant quantities of *Fissile Material* associated with contaminated concrete during decommissioning operations, all concrete excavation is strictly controlled. This control consists of thoroughly assaying the concrete prior to excavation. The assay methods used are a combination of destructive core sampling and non-destructive surface survey. One or both methods are used on all concrete structures prior to excavation. A single surface assay is performed on all surfaces of concrete and representative core samples are extracted for areas known or suspected to contain non-trivial levels of uranium contamination.

Following determination that a portion of concrete meets *NCS Exempt Material* criteria, equipment is used to crush, break, cut, scabble, or hammer the respective portion. The concrete debris is subsequently excavated and bulked in a waste transfer vehicle, which is used to transfer the concrete debris to an appropriate stockpile in a Waste Holding Area (WHA). If a portion of the concrete is determined to exceed *NCS Exempt Material* criteria, but does not exceed the *Fissile Material Exhumation Limit**, then the associated portion is removed and packaged in a *Field Container*, and transferred to a Waste Evaluation Area (WEA) in a *Collared Drum* (CD).

* Remediation operations in the affected area will cease and the NCS Organization will be notified in the event of discovery of portions of concrete containing a *Fissile Material* concentration exceeding the *Fissile Material Exhumation Limit*.

The two different *Fissile Material* quantification methods relevant to concrete slabs are discussed below.

Destructive Core Sampling
Core sampling provides an effective method of establishing the extent of uranium contamination within a portion of a concrete slab. When core sampling is used, the sampling pattern and frequency used is sufficiently adequate to assure representative sampling. The core sampling assay method is reserved for portions of concrete that are known, or are suspected, to have been resurfaced because of contamination during manufacturing operations. The core sampling assay method is also used for portions of concrete associated with cracks, expansion joints, and seams near walls. This is because these features could have provided a mechanism for penetration of *Fissile Material* beyond the surface of the concrete to its underlying bulk.

Non-destructive Surface Survey
The surface survey assay method is performed with calibrated equipment and can be used to quantify *Fissile Material* deposited on and within the concrete*. The surface assay method is less effective than the representative core sampling method when the uranium contamination has penetrated the concrete beyond its surface. However, the surface assay method is very effective when the contamination is confined to the upper surface layer of the concrete. For this reason, this assay method is employed only when the following criteria are met:

- The area of concrete is not known, or suspected, to have been resurfaced; and
- The area of concrete is free of cracks, expansion joints, and seams.

Concrete surfaces free of cracks, expansion joints and seams are inherently less likely to exhibit contamination in non-surface strata. For this reason, *Fissile Material* is not expected to have penetrated more than fractions of an inch into concrete surfaces free of cracks, expansion joints and seams. Therefore, a surface assay of the concrete slabs in these areas provides an effective method for quantifying *Fissile Material* that may be embedded on or within the surface.

1.4.2 Soil Exhumation Surrounding Substructures

Soil is carefully exhumed when in close proximity to potentially heavily contaminated substructures such as concrete, septic systems, and piping. Prior to exhuming soil, two independent surface assay measurements of the soil are performed. The surface assay is performed with calibrated equipment and can be used to quantify *Fissile Material* within the soil.

Following determination that a layer of soil meets *NCS Exempt Material* criteria, the soil is carefully exhumed as a layer not exceeding the maximum *cut depth*†. The exhumed soil is

* The maximum thickness of concrete that can be adequately characterized by in-situ assay equipment is established in the calibration basis document associated with the type of assay equipment.

† The maximum thickness of soil that can be adequately characterized by in-situ assay equipment is established in the calibration basis document associated with the type of assay equipment.

bulked in a waste transfer vehicle and transferred to an appropriate stockpile in a WHA. However, the exhumed soil may be set aside the excavation and used as back-fill material if the soil is determined to not exceed the Derived Concentration Guideline Level (DCGL). If a portion of the soil is determined to exceed *NCS Exempt Material* criteria, but does not exceed the *Fissile Material Exhumation Limit*[*], then the associated portion is removed and packaged in a *Field Container,* and transferred to a WEA in a CD.

1.4.3 Subterranean Piping Removal

There are several hundred feet of subterranean piping located within the Hematite site. Much of the piping comprises the site storm water system that flows into a nearby local creek. Typically, storm water piping is not decommissioning debris that necessitates concern regarding criticality safety. However, the legacy processing plant was designed such that the process piping used for evaporator overflows, process water runoff, and laboratory sinks were directly conjoined with this underground system. Consequently, excavation of the storm water piping extending to the nearby local creek is handled as if the storm water piping were process piping.

Much of the subterranean piping also comprises the sanitation lines that feed into underground septic tanks. Typically, this type of decommissioning debris also does not necessitate concern regarding criticality safety. However, the legacy processing plant was designed in a manner that tied the laboratory sinks and industrial washing machines used to clean personal protective equipment to the sanitation lines. As a consequence, excavation of the sanitation lines up to the septic tanks is handed as if the sanitation lines were process piping as well.

The remaining portion of the subterranean piping consists of the processing lines used for evaporator overflows, process water runoff, and laboratory sinks that were formerly used during fuel manufacturing operations. In practice, the design of the equipment used in the various former production operations that were connected to these lines would have ensured that release of significant quantities of *Fissile Material* into these drain lines was not a frequent occurrence. However, no credit is taken for this in this NCSA and the process lines are assumed to contain no upper bound in terms of *Fissile Material* mass content.

Prior to excavating any section of piping, the pipe section is first assayed using in-pipe *Fissile Material* detection equipment. This equipment is used irrespective of whether the pipe section is part of the process piping, sanitation, or storm water system. The results of the in-pipe assays are used to quantify the *Fissile Material* content and distribution along the length of the pipe. This information is used to determine whether the pipe section must be extracted in-tact from the ground or whether it can be crushed in place and exhumed as debris. This operational flexibility is necessary because significant portions of the piping system is believed to be composed of concrete or vitrified clay. As typical with most storm water and sewer systems, these materials are prone to fracture and breakage during

[*] Remediation operations in the affected area will cease and the NCS Organization will be notified in the event of discovery of portions of soil containing a *Fissile Material* concentration exceeding the *Fissile Material Exhumation Limit.*

excavation. The process piping is expected to be composed of iron while some of the sanitation lines could comprise PVC.

If the decision is made to excavate piping using the "crush and exhume" method, then it must first be confirmed that the material within the piping to be crushed, as determined by the in-pipe assay equipment, meets *NCS Exempt Material* criteria. If this criterion is met, then the pipe is crushed in place. Prior to exhuming the debris (i.e., mixture of pipe contents, piping material, and soil/stones/gravel), two independent surface assays are performed on the debris. The two assays are identical in function and method to soil surveys. Provided that both surface assays establish that the crushed debris meets *NCS Exempt Material* criteria, the debris is carefully exhumed as a layer not exceeding the maximum permitted *cut depth**. The exhumed debris is bulked in a waste transfer vehicle and transferred to an appropriate stockpile in a WHA. If a portion of the debris is determined to exceed *NCS Exempt Material* criteria, but does not exceed the *Fissile Material Exhumation Limit*†, then the associated portion is removed and packaged in a *Field Container,* and transferred to a WEA in a CD.

If the decision is made to excavate piping in-tact, then it must first be confirmed that the material within the pipe section to be removed, as determined by the in-pipe assay equipment, contains less than or equal to the *Extracted Piping Fissile Material Limit.* Prior to removal of the pipe section from the ground, the pipe is coated internally with a fixative or filled with a grouting material to prevent any loose material within the piping escaping during lifting and other handling. All pipe removal occurs from a lower grade elevation to a higher grade elevation as the subterranean system is traversed to ensure loose material is not "pushed" down the pipe.

After a pipe section is removed from the ground, it is placed onto stand in the vicinity of the excavation. The pipe is positioned in an horizontal orientation on the stand while an operator surveys the entire length of the pipe with calibrated assay equipment. The pipe is then filled with a grout material or concrete to immobilize any loose material within the pipe, unless the pipe was already filled with grout or concrete while in the ground.

Once the above-ground assay on the pipe section confirms that the pipe section meets *NCS Exempt Material* criteria, the pipe is bulked in a waste transfer vehicle and transferred to an appropriate stockpile in a WHA. However, if the above-ground assay establishes that the uranium contamination within any section of the pipe does not meet *NCS Exempt Material* criteria but does not exceed the *Fissile Material Exhumation Limit* ‡, then that associated portion(s) are removed, bulked in a CD, and transferred to a WEA for evaluation.

* The maximum thickness of piping material and/or soil/stones/gravel that can be adequately characterized by in-situ assay equipment is established in the calibration basis document associated with the type of assay equipment.

† Remediation operations in the affected area will cease and the NCS Organization will be notified in the event of discovery of portions of crushed piping material and/or soil/stones/gravel containing a *Fissile Material* concentration exceeding the *Fissile Material Exhumation Limit.*

‡ Remediation operations in the affected area will cease and the NCS Organization will be notified in the event of discovery of piping containing a *Fissile Material* concentration exceeding the *Fissile Material Exhumation Limit.*

1.4.4 Septic Tank and Drain Field Extraction

The site contains a septic system that is connected to the lavatories within the former process buildings. This septic system consists of sanitation lines, treatment tank, and drain field. In addition, an older, already decommissioned treatment tank that has been filled with gravel is embedded in the ground near the current septic tank. Typically, this type of decommissioning debris does not necessitate concern regarding criticality safety. However, the laboratory sinks and industrial washing machine drain lines used during fuel manufacturing operations may be connected to the septic system. For this reason, excavation of the septic tanks (and potentially the drain fields) must be strictly controlled. Prior to exhuming septic tank content, two independent surface assay measurements of the septic tank content are performed. The surface assay is performed with calibrated equipment and can be used to quantify *Fissile Material* within the septic tank content.

By design, septic tanks collect organic material allowing solids or solutions denser than water to settle or layer in the bottom of the tank. Natural bacteria in the organic sludge (and bacteria supplemented regularly into the sanitation lines) convert the organic material into heat with water as a by-product. The drain field is connected to a drain attached near the top surface of the septic tank. As the aqueous layer (primarily water) reaches the height of the drain, the water is gravity fed slowly into the drain field to evaporate. The drain field consists of many small diameter tubing that is perforated along hundreds of feet.

Any uranium solids discarded into sanitation lines during fuel manufacturing operations would be expected to have settled to the bottom of the septic tank (due to the relatively high density). Uranium solutions would also tend to settle towards the bottom of the septic tanks because of their high density relative to water. Consequently, any uranium solutions would be expected to be confined to the septic tank and would not be expected to have migrated to the drain field. Based on these considerations, excavation of the drain field will be initiated <u>after</u> excavation of the septic tanks. If the content of the septic tanks is determined to meet *NCS Exempt Material* criteria, then it is very reasonable to assume that the drain fields will also meet *NCS Exempt Material* criteria. Conversely, if the septic tank contents are determined to contain *Fissile Material*, then the drain fields and the septic tank structure will not be excavated without further evaluation and direction from the NCS Organization. Note that only the perforated tubes and soil/rock/sand/gravel beneath the tubes are considered to constitute the drain field (i.e., not the soil above the tubes).

Following determination that the content of the septic tanks meets *NCS Exempt Material* criteria, the septic tank content is carefully exhumed as a layer not exceeding the maximum *cut depth**. The exhumed material is bulked in a waste transfer vehicle and transferred to an appropriate stockpile in a WHA. If the entire content of the septic tank is found to not contain any material with a uranium concentration exceeding the *NCS Exempt Material* criteria, then the septic tank structure and associated drain field may be exhumed without Criticality Safety Controls (CSCs).

* The maximum thickness of septic tank content material that can be adequately characterized by in-situ assay equipment is established in the calibration basis document associated with the type of assay equipment.

If a portion of the septic tank content is determined to exceed *NCS Exempt Material* criteria, but does not exceed the *Fissile Material Exhumation Limit**, then the associated portion is removed and packaged in a *Field Container,* and transferred to a WEA in a CD. In this event, the septic tank structure and associated drain field is not approved for excavation until further evaluation is performed and approval is obtained from the NCS Organization).

1.5 Overview of Equipment used for Sub-Surface Structure Decommissioning

This section provides an overview of safety significant equipment employed for sub-surface structure decommissioning activities, as relevant to this NCSA.

1.5.1 Field Containers

Field Containers are readily identifiable and are used to containerize loose *fissile materials* and suspect *fissile materials* identified during excavation operations. Each *Field Container* possess a maximum volumetric capacity of 20 liters (equivalent to the volume of a nominal 5 gallon container). This limited volume minimizes the potential to accommodate an unsafe mass of *fissile material.*

1.5.2 Collared Drums

CDs are used for *Field Container* transit between the excavation site and the WEA. CDs are also used for *Field 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. 3).

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 Fissile Material Storage Area (FMSA) or Collared Drum Repack Area (CDRA).

1.5.3 Fissile Material Monitoring Equipment

The *fissile material* monitoring equipment employed for sub-surface structure decommissioning activities comprise a variety of assay equipment. The assay equipment that may be used includes, but is not limited to, NaI scintillator probes for surface surfaces, hand-held gamma survey instruments for surface surveys, in-pipe probes for in-pipe surveys, and High Resolution Gamma Spectrometers (HRGS). Other assay equipment may be used provided the equipment satisfies the functional requirements credited in this NCSA.

The assay equipment used are suitable for the detection of gamma radiation from uranium

* Remediation operations in the affected area will cease and the NCS Organization will be notified in the event of discovery of portions of septic tank content material containing a *Fissile Material* concentration exceeding the *Fissile Material Exhumation Limit.*

sources at the full range of enrichment. When calibrated and used in accordance with applicable procedures, this equipment provides confidence in the avoidance of unrevealed or underestimated potential ^{235}U content of any surveyed item.

The HRGS equipment is used to obtain nuclide specific abundance, and in particular, ^{235}U assay. The HRGS equipment automatically analyzes the assay data to produce an estimate of the ^{235}U content of the item presented for assay. When calibrated and used in accordance with applicable procedures, this equipment provides confidence in the avoidance of unrevealed or underestimated ^{235}U content of any surveyed item.

1.6 Scope of Assessment

The activities addressed in this NCSA include all actions associated with the excavation of subterranean piping, concrete slabs, septic systems, and surrounding soil.

1.7 Methodology

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 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 reasonably achievable.

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

2.0 CRITICALITY SAFETY ASSESSMENT

The criticality safety assessment is organized as follows:

- **Section 2.1** describes the hazard identification method employed in the criticality safety assessment of Sub-Surface Structure Decommissioning 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 Sub-Surface Structure Decommissioning under normal (i.e., expected) conditions.
- **Section 2.4** contains the criticality safety assessment of Sub-Surface Structure Decommissioning under abnormal (i.e., unexpected) conditions.

2.1 Criticality Hazard Identification

This section outlines the method used to identify criticality hazards associated with Sub-Surface Structure Decommissioning. A summary of the hazards identified is also provided, together with a brief description of their disposition in the NCSA.

2.1.1 Hazard Identification Method

The hazard identification method employed in the criticality safety assessment of Sub-Surface Structure Decommissioning 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.

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-process 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 2. Hazards that result in events with similar consequences and safeguards are grouped in single criticality accident event sequences, then analyzed in Section 2.4.

Table 2-1 Criticality Hazards Identified from the Sub-Surface Structure Decommissioning *What-if/Checklist* Analysis

What-if	Causes	Consequences	Accident Sequence in NCSA
Mass and Concentration			
What if an unexpected quantity/concentration of *Fissile Material* is accumulated as a result of concrete slab extraction?	• Scabbling of heavily contaminated surfaces into a localized volume • Segregation of heavily contaminated surfaces into a localized volume	Potential for credible criticality accident if proper excavation techniques are not employed	**Section 2.4.1**
What if soil contains an unexpected quantity/concentration of *Fissile Material*?	• *Fissile Material* discarded into an undocumented ground area during past production operations • Unrecognized pipe crack or breach in the vicinity • *Fissile Material* penetrated through concrete slabs and saturated soil below	Potential for credible criticality accident if proper excavation techniques are not employed	**Section 2.4.2**
What if an unexpected quantity/concentration of *Fissile Material* accumulates when subterranean pipe sections are excavated?	• *Fissile Material* having been poured into non-fissile drains and pipes during past production operations • Crushing of pipe sections in the ground leads to significant concentration of *Fissile Material* in a localized volume • Tilting or breakage of pipe section when exhumed leads to significant concentration of *Fissile Material* in a localized volume	Potential for credible criticality accident if proper excavation techniques are not employed	**Section 2.4.3**
What if an unexpected quantity/concentration of *Fissile Material* is accumulated as a result of septic tank or drain field excavation?	• *Fissile Material* discarded into lab sinks during past production operations • *Fissile Material* removed during cleansing of (personal protective equipment) PPE	Potential for credible criticality accident if proper excavation techniques are not employed	**Section 2.4.4**

What-if	Causes	Consequences	Accident Sequence in NCSA
Volume and Interaction			
A limited volume *Field Container* is used to collect exhumed debris detected to contain *Fissile Material* not exceeding the *Fissile Material Exhumation Limit.* The controls associated with preventing use of larger containers are discussed in Sections 2.4.1 through 2.4.4. CDs are used for confinement and transport of *Fissile Material* between different areas of the site. The CD design ensures safe interaction between *Fissile Materials* in transit.			
Geometry			
There are no geometrical dimensions credited to ensure criticality safety during Sub-Surface Structure Decommissioning.			
Density			
There are no identified causes that could create a density more onerous than that assumed as a normal condition (i.e., theoretical density of uranium as metal).			
Heterogeneity			
There are no identified causes that could create a material configuration more onerous than that assumed as a normal condition (i.e., homogeneous high-enriched uranium).			
Neutron Absorbers			
There are no neutron absorbers credited to ensure criticality safety during Sub-Surface Structure Decommissioning.			
Reflection			
There are no identified causes that could create a reflection condition more onerous than that assumed as a normal condition (i.e., close fitting full water reflection).			
Isotopic/Enrichment			
There are no identified causes that could create an isotopic/enrichment condition more onerous than that assumed as a normal condition (i.e., 100 wt.% $^{235}U/U$).			
MODERATION			
There are no identified causes that could create a moderated condition more onerous than that assumed as a normal condition (i.e., optimally moderated uranium-water mixtures for finite systems and optimally moderated uranium-soil mixtures for infinite systems).			

Source: Original

2.2 Generic Safety Case Assumptions

This section outlines the generic assumptions on which this criticality safety assessment is based. The pertinent underlying assumptions of this NCSA related to the assessed Sub-Surface Structure Decommissioning 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* mass limits have been derived assuming homogeneous* mixtures of 100% enriched uranium (^{235}U) and water (H_2O). This approach is applicable since the decommissioning debris to be exhumed is expected to be intermixed with water from ground sources and precipitation. The septic systems, subterranean piping, soil, and concrete debris are not anticipated to contain significant quantities of more adverse moderators (such as hydrocarbons typically found in solid process wastes).
- *Fissile Material* concentration limits have been derived assuming an unrealistic infinite sea of ^{235}U and soil. This is conservative with respect to infinite aqueous systems due to the small neutron absorption provided by soil in an infinite sea, relative to water. Therefore, rather than using the ANSI/ANS-8.1 maximum subcritical enriched uranium concentration of 11.6 g^{235}U/L, this analysis uses a far more conservative lower threshold of 4 g^{235}U/L based on soil matrices (see Appendix A of Reference 1 for additional discussion).
- With respect to concrete slabs and foundations, it is assumed that demolition of the former process buildings and removal of any contamination control membranes covering concrete slabs will have been completed prior to implementing this NCSA for decommissioning operations involving excavating of concrete slabs and foundations.

2.3 Normal Conditions

This section contains the criticality safety assessment of Sub-Surface Structure Decommissioning assuming anticipated (normal) conditions.

As detailed in Section 1.4, Sub-Surface Structure Decommissioning includes the following operations:

- Removal of concrete slabs (i.e., the floor of the decommissioned buildings and associated walkways);
- Exhumation of soil that covers and surrounds subterranean piping and concrete slabs;
- Extraction of subterranean piping; and
- Extraction of septic treatment tank(s) and associated drain fields.

* Homogenous systems involving uranium enriched 100% with ^{235}U isotope are always more reactive than heterogeneous systems due to lack of the ^{238}U isotope self-shielding and resonance effects present in low enriched systems.

2.3.1 Concrete Slab Anticipated Conditions

Under normal conditions, the concrete slabs free of cracks, expansion joints, and seams along walls, are anticipated to have only surface contamination. This expectation is based on prior decommissioning activities, and on operational practices during the manufacturing era, which would have required floor surfaces to be periodically cleaned. In addition, the surface contamination of the concrete is anticipated to be fixed based on prior decommissioning activities in the former process buildings. The concrete walkways and pathways on-site are not anticipated to be contaminated.

Concrete slabs comprising cracks, expansion joints, and seams along walls, are anticipated to have elevated levels of contamination. However, the magnitude of the contamination is expected to be well within limits that would be of concern to criticality safety. *NCS Exempt Material* criteria is anticipated to be met for the vast majority of concrete, with an exception of concrete portions that were, historically, in the vicinity of uranium processing equipment, and which contain cracks, expansion joints, and seams near walls. In addition, it is anticipated that *NCS Exempt Material* criteria may not be met for portions of concrete that were subject to historic process material/solution spill incidents, including portions that were re-surfaced. However, these portions are not anticipated to contain an enriched uranium concentration in excess of the *Fissile Material Exhumation Limit.*

2.3.2 Soil Anticipated Conditions

Under normal conditions, the soil surrounding subterranean piping that is not in the vicinity of pipe breaches or cracks is anticipated to meet *NCS Exempt Material* criteria, because the piping would have provided a barrier against entrainment of uranium into the surrounding soils. In addition, soil that is not near concrete slabs associated with fuel manufacturing operations in the former process buildings is also anticipated to meet *NCS Exempt Material* criteria. This is because these soils were likely protected against contamination by "non-production use" concrete slabs. Soil that does not meet *NCS Exempt Material* criteria but is established to not lie within the vicinity of pipe breaches or cracks, or within the vicinity of concrete slabs associated with fuel manufacturing operations in the former process buildings, is not exhumed or otherwise manipulated without prior evaluation and direction by the NCS Organization. This conservative pre-caution precludes the potential to exhume an unsafe mass or concentration of *Fissile Material.*

Under normal conditions, the soil surrounding subterranean piping that is in the vicinity of pipe breaches or cracks and the soil that is near concrete slabs that were used as a floor for fuel manufacturing operations in the former process buildings is very conservatively anticipated to be without upper bound in terms of *Fissile Material* quantity or concentration. With regard to soil near concrete slabs that were in the vicinity of fuel manufacturing operations in the former process buildings, this conservative assumption is due to the potential events during the fuel manufacturing era, that could have released significant quantities of *Fissile Material* into subterranean process piping, or resulted in significant spills of *Fissile Material* solution onto nearby concrete floors. Furthermore, it is conservatively assumed that a crack or breach in subterranean piping could have resulted in entrainment of *Fissile Material* solutions into soils surrounding the crack(s) or breach(es).

2.3.3 Subterranean Piping Anticipated Conditions

Under normal conditions, the subterranean process piping which is connected with the storm water system is very conservatively assumed to be without upper bound in terms of *Fissile Material* quantity, concentration, or volume. This very conservative assumption is due to the potential events during the fuel manufacturing era that could have released unknown quantities of *Fissile Material* into the subterranean process piping. In addition, the diameters of the subterranean piping are anticipated to range from 3 inches to 15 inches and so no upper bound on volume is assumed. Under realistic conditions, it is expected that any prior introduction of *Fissile Material* to the subterranean process piping would have flowed continuously (as designed) until reaching the nearby site creek. Nonetheless, it is conservatively assumed that any *Fissile Material* within the subterranean process piping did not drain from the system and is deposited within the piping. Since *Fissile Material* deposits within piping is an assumed condition, any clogs or blockages identified in subterranean piping are conservatively assumed to comprise *Fissile Material* until adequately determined otherwise.

Under normal conditions, the subterranean sanitation piping which is connected to the septic treatment tank(s) is also very conservatively assumed to be without upper bound in terms of *Fissile Material* quantity, concentration, or volume. This very conservative assumption is due primarily to the relative proximity that this piping system shares with the subterranean process and storm water piping system. This conservative assumption ensures that there is no concern in the event the two underground systems are misidentified during excavation operations. This conservative assumption also accounts for the potential for *Fissile Material* to have entered the subterranean sanitation piping (and septic system) via laboratory sinks and drains connected to personal protective equipment (PPE) washing machines.

2.3.4 Septic Treatment Tank(s) and Associated Drain Field Anticipated Conditions

Under normal conditions, the septic tanks are anticipated to contain only small (in-significant) quantities of uranium. This is due to the fact that the subterranean piping connected to the septic tanks originates primarily from the lavatories (obvious non-fissile material handling locations). However, due to the conservative assumptions noted in the preceding section, it is assumed that any portion of septic tank contents could contain more significant quantities of *Fissile Material.* Under normal (anticipated) conditions, any *Fissile Material* associated with the septic tank content will have a low mass/concentration, well below safely subcritical limits. It is considered at least *unlikely* to have an enriched uranium concentration in excess of the *Fissile Material Exhumation Limit.*

The drain fields associated with septic tanks are of no concern to criticality safety as long as the septic tanks are confirmed to not contain *Fissile Material.* Therefore, as discussed in Section 1.4.4, drain fields are anticipated to meet *NCS Exempt Material* criteria even without verification by assay. However, if *Fissile Material* is present within a septic tank, the drain fields and the septic tank structure cannot be excavated until further evaluation and approval is gained from NCS staff. For this reason, the septic tanks will be decommissioned prior to decommissioning of the associated drain fields.

2.4 Abnormal Conditions

This section provides an assessment of the criticality hazards identified from the *What-if* analysis of Sub-Surface Structure Decommissioning.

2.4.1 Unexpected *Fissile Material* Quantities/Concentration in Concrete

2.4.1.1 Discussion

As discussed in Section 2.3.1, the condition of a vast majority of concrete is anticipated to meet *NCS Exempt Material* criteria since only insignificant fixed surface contamination is expected. However, an exception to this occurs for concrete portions in the vicinity of legacy uranium processing equipment which contain cracks, expansion joints, seams near walls, or re-surfaced layers of concrete. While these concrete portions may not meet *NCS Exempt Material* criteria they are not anticipated to contain sufficient *Fissile Material* such that the *Fissile Material Exhumation Limit* could be exceeded.

To alleviate a concern of bulking significant quantities of *Fissile Material* associated with exhumed, all concrete excavation is strictly controlled. This control consists of thoroughly assaying a concrete portion prior to its excavation. Two different *Fissile Material* quantification methods are utilized:

1) Surface assay; and
2) Core sampling.

The surface assay is performed with calibrated equipment (with results interpreted by multiple personnel) and can be used to quantify *Fissile Material* on and within the concrete*. The surface assay is used on every concrete surface prior to its excavation irrespective of the concrete's location or physical condition.

The core sampling method is used on portions of concrete that have been re-surfaced. This method is also employed for portions of concrete comprising cracks, expansion joints, and seams near walls. This is because these features could have provided a mechanism for penetration of *Fissile Material* beyond the surface of the concrete to its underlying bulk. All of the abovementioned features are identified and core sampling locations marked on the surface of the concentrate, consistent with the requirements of the site wide sampling plan **[TBV1]** †. The exhumed concrete cores are analyzed for uranium content.

One of the two appropriate assay methods outlined above is performed and results are determined prior to determining the appropriate excavation technique.

Following determination that a portion of concrete meets *NCS Exempt Material* criteria, equipment is used to crush, break, cut, scabble, or hammer the respective portion. The

* The maximum thickness of concrete that can be adequately characterized by in-situ assay equipment is established in the calibration basis document associated with the type of assay equipment.

† The Hematite site sampling plan outlines the procedure for extracting core samples from HDP remediation areas (including concrete cores), and addresses the need for representative sampling **[TBV1]**.

concrete debris is subsequently excavated and bulked in a waste transfer vehicle, which is used to transfer the concrete debris to an appropriate stockpile in a WHA.

If a portion of the concrete is determined to exceed *NCS Exempt Material* criteria, does not exceed the *Fissile Material Exhumation Limit*, then the associated portion is removed and packaged into a *Field Container*. Once the *Field Container* is filled or an adequate portion of the concrete has been removed, the *Field Container* is lidded and placed singly within a CD. The CD is then transferred to an approved CD staging area or directly to a WEA.

Portions of concrete determined to contain a quantity of *Fissile Material* greater than the *Fissile Material Exhumation Limit* requires operations in the affected area to cease and not resume until evaluated and directed by the NCS Organization.

2.4.1.2 Risk Assessment

A criticality accident cannot be realized when exhuming portions of concrete as long as one of the two following criteria* is met:

- The mass of ^{235}U associated with the exhumed materials does not exceed 760 $g^{235}U$;
<u>**or**</u>
- The macroscopic concentration of ^{235}U associated with the exhumed materials does not exceed 4 $g^{235}U/L$.

It is important to note that the concrete slabs of particular concern to criticality safety involve portions of concrete that were in the vicinity of process equipment during fuel manufacturing operations (particularly equipment containing process solution). These are the areas where a spill of *Fissile Material* onto the surrounding concrete floor could have resulted in entrainment of *Fissile Material* into expansion joints, cracks, or seams adjacent to walls. Of equal concern are portions of concrete that were resurfaced during the fuel manufacturing era. All of these areas will be subject to the core sampling assay method prior to excavation.

Concrete surfaces free of cracks, expansion joints and seams are inherently less likely to exhibit contamination in non-surface strata. For this reason, *Fissile Material* is not expected to have penetrated more than fractions of an inch into concrete surfaces free of cracks, expansion joints and seams. Therefore, a surface assay of the concrete slabs not exhibiting these features provides an effective method for quantifying *Fissile Material* that may be embedded on or within the surface.

Even without assaying concrete portions prior to excavation, it is considered at least *unlikely* that concrete slabs or rubble could be bulked into a configuration leading to a criticality accident. This is due to the fact that any *Fissile Material* that has embedded itself into the concrete would be essentially fixed in place. Excavation operations would not be expected to result in any significant redistribution of uranium throughout the concrete matrix (which is known to be subcritical prior to excavation). In order for a criticality safety concern to be

* Appendix A of Reference 1 establishes the maximum subcritical mass limit as 760 $g^{235}U$ and the maximum subcritical infinite sea concentration of 4.0 $g^{235}U/L$, which are both applicable to the operations evaluated in this NCSA.

significant, large quantities of *Fissile Material* associated with the surface of the concrete or within pockets of the concrete must be mobilized and accumulated in a localized region. This potential is extremely small. It is reasonable to assume that the concrete surfaces experienced routine foot traffic during the fuel manufacturing era and that housekeeping policies at that time would have ensured that significant quantities of enriched uranium would not have been discarded into the recesses of the concrete floor or left lying on its surface. Furthermore, decommissioning operations conducted since then have further reduced the potential for significant contamination levels, and especially the potential for loose *Fissile Materials* on the concrete surfaces. Based on these considerations, loose *Fissile Material* is not expected to be found on the surface or within open or porous regions of the concrete.

Even though the risk of a criticality accident during unmitigated concrete excavation is exceedingly minute as explained above, CSCs are nonetheless implemented to reduce the probability even further. The controls consist of performing detailed assay of the concrete surface and all identified open and porous regions.

The surface assay utilizes calibrated equipment (with results interpreted by multiple personnel) that is effective in identifying and quantifying the *Fissile Material* present. The operators that are responsible for performing the surveys are trained and qualified to perform the task. In addition, the concrete surfaces are carefully inspected by multiple personnel to identify any features that could have resulted in elevated contamination levels, including expansion joints, cracks, and seams near walls. These potential holdup regions, in addition to regions that were resurfaced during the fuel manufacturing era, are destructively analyzed by extracting core samples. The core samples are not only extracted from the identified location, but also in nearby areas to ensure representative sampling [**TBV1**].

Once the assay results confirm that the concrete meets *NCS Exempt Material* criteria, then the concrete portions are excavated and bulked. This criterion is defined as no greater than 1 gram of ^{235}U within a 10 liter volume of decommissioning debris*. By assuring that no more than 1 gram is associated with every 10 liters of debris, the macroscopic homogenous concentration of the debris is 0.1 $g^{235}U/L$ which is a factor of 40 below the maximum safely subcritical concentration. Even accounting for a conservative factor to two reduction in this large safety margin to account for credible non-homogeneity, a large factor of safety (20) still exists. Based on the low enriched uranium concentration limit of 1 $g^{235}U$ associated with every 10 liters of debris, and the large safety margin outlined, criticality safety is assured for bulked decommissioned concreted debris.

If the assay results do not confirm that the concrete portion meets *NCS Exempt Material* criteria and instead concludes that the concrete portion meets *Fissile Material* classification, then the associated concrete portion is carefully extracted and placed into a *Field Container* as long as the *Fissile Material* content is determined to be lower than the *Fissile Material Exhumation Limit*. The *Fissile Material* classification is defined as any decommissioning

* The surface assay response and function used for converting radiation counts to enriched uranium concentration is described in the detector calibration basis document for the given material.

debris that contains more than 1 gram of ^{235}U within a 10 liter volume. The *Fissile Material Exhumation Limit* is an upper threshold set at 38 grams of ^{235}U per 10 liter volume which is exactly a factor of 10 below the enriched uranium concentration necessary to reach a potential critical state in a 20 liter volume (equivalent to the maximum volume of a *Field Container*).

The potential adverse conditions which could lead to a condition favorable for criticality include:

- Misinterpreting the assay results (either from surface assay or core sampling);
- Improperly calibrating the assay equipment;
- Excavating portions of concrete that have not been assayed;
- Using containers other than *Field Containers* for concrete debris classified as *Fissile Material; and*
- Placing multiple *Field Containers* of concrete debris into a single CD.

Each of these scenarios is discussed in turn.

<u>Misinterpreting the assay results</u>
It is considered at least *unlikely* that multiple personnel would inadvertently misinterpret the results of a single assay by more than a factor of 10 (minimum margin of error required to reach a potentially unfavorable condition). This is due to the qualification and training required of the operators, the fact that more than single person is responsible for interpretation of the assay results, and the large safety margin taken into account in the thresholds. If the assay results for a particular concrete portion were mistakenly interpreted as meeting *NCS Exempt Material* criteria when in fact the debris contained more than 1 gram of ^{235}U per 10 liter volume, then significant quantities of *Fissile Material* could potentially be bulked. However, to attain a unsafe condition the actual enriched uranium concentration in the concrete must be at least 20 times higher than the misinterpreted assay result (refer to the preceding discussion).

Training is essential for any nuclear facility decommissioning activity and this excavation activity is treated no differently. The 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. Reading and interpreting a surface assay measurement result is a simple task. Since a decision to excavate and bulk material requires concurrence from multiple operators performing the same simple task, unknowingly exhuming an unsafe concentration of *Fissile Material* due to misinterpretation of a single assay result is considered at least *unlikely* to occur during the decommissioning activities. If a single assay result for a particular concrete portion was mistakenly interpreted as meeting *Fissile Material* classification but was actually above the *Fissile Material Exhumation Limit* of 38 grams of ^{235}U per 10 liter volume, then significant quantities of *Fissile Material* could potentially be loaded into a single *Field Container*. The *Field Container* is limited in maximum usable volume to only 20 liters. Therefore, a misinterpretation of assay results would have to be in error by more than a factor of 10 before an unsafe mass of *Fissile Material* could be collected into a single

Field Container (i.e., more than 760 grams ^{235}U in a 20 liter volume). Based on this safety margin, the requirement for multiple persons to follow the procedures, and the human reliability arguments presented, this gross failure is also considered at least *unlikely* to occur during the decommissioning activities.

Improperly calibrating the assay equipment

It is considered at least *unlikely* that a single assay device could be inadvertently used without proper calibration to the extent that *Fissile Material* content in a portion of concrete could be underestimated by a factor of more than 10 (minimum margin of error required to reach a potentially unfavorable condition). This is due to the knowledge, training and qualification of the operators, the fact that more than one person is responsible for ensuring calibration of the assay equipment, the reliability of the assay equipment even without frequent calibration, and the large safety margin taken into account in the thresholds. If improperly calibrated assay equipment was used on a particular concrete portion resulting in a reading that confirmed the debris as meeting *NCS Exempt Material* criteria when in fact the debris contained more than 1 gram of ^{235}U per 10 liter volume, then significant quantities of *Fissile Material* could potentially be bulked. However, to attain a unsafe condition the actual enriched uranium concentration in the concrete must be at least 20 times higher than the result provided by the improperly calibrated equipment.

Training is essential for any nuclear facility decommissioning activity and this excavation activity is treated no differently. The 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. Ensuring proper calibration of assay equipment prior to its use is a simple task. Since a decision to excavate with a bulking method requires concurrence from multiple operators performing the same simple task, unknowingly exhuming an unsafe concentration of *Fissile Material* due to using an improperly calibrated assay device is considered at least *unlikely* to occur during the decommissioning activities. If an improperly calibrated assay device was used on a particular concrete portion resulting in a reading that confirmed the debris as meeting *Fissile Material* classification but was actually above the *Fissile Material Exhumation Limit* of 38 grams of ^{235}U per 10 liter volume, then significant quantities of *Fissile Material* could potentially be loaded into a single *Field Container*. The *Field Container* is limited in maximum usable volume to only 20 liters. Therefore, a misinterpretation of assay results would have to be in error by more than a factor of 10 before an unsafe mass of *Fissile Material* could be collected into a single *Field Container* (i.e., more than 760 grams ^{235}U in a 20 liter volume). Based on this safety margin, the simplicity of the procedures, the requirement for multiple persons to follow the procedures, and the human reliability arguments presented, this gross failure is also considered at least *unlikely* to occur during the decommissioning activities.

Excavating portions of concrete that have not been assayed

If portions of concrete are excavated without an associated assay value, then significant quantities of *Fissile Material* could potentially be bulked. For this reason, it is required that the surface of all concrete portions is surfaced assayed and cracks, expansion joints, seams along walls, and contaminated layers beneath clean layers of concrete are core sampled prior to excavation.

It is considered at least *unlikely* that multiple personnel could inadvertently excavate portions of concrete that have not been thoroughly assayed, to the extent that *Fissile Material* content could be underestimated by more than a factor of 10. This is justified by the safety margin outlined, the simplicity of the procedures, the requirement for multiple persons to follow the procedures, and the generic human reliability arguments presented for *Misinterpreting the assay results.* Similarly, and consistent with the generic arguments presented in the preceding contingency discussions, it is also at least *unlikely* that an unsafe mass of *Fissile Material* could be exhumed and loaded into a single *Field Container.*

<u>Using containers other than *Field Container* for concrete debris classified as *Fissile Material*</u>

It is considered *highly improbable* that multiple personnel would inadvertently allow repeated excavation of concrete portions classified as *Fissile Material* debris to be collected into a container larger than a *Field Container.* Ensuring that a *Field Container* is used to collect debris classified as *Fissile Material* is a simple task. Even if a container as large as a CD were mistakenly used to collect debris classified as *Fissile Material*, the largest *Fissile Material* content that could be collected is 760 $g^{235}U$ which is still safely subcritical (assuming no other concurrent *unlikely* procedural failures). Since *Field Container* loading operations involve multiple operators performing simple tasks, inadvertently loading an unsafe mass of *Fissile Material* into a non approved container is considered *highly improbable* to occur during the decommissioning activities.

<u>Placing multiple *Field Containers* into a single CD or larger container</u>

It is considered *highly improbable* that multiple personnel would inadvertently allow multiple *Field Containers* comprised of concrete rubble classified as *Fissile Material* debris to be collected concurrently into the same CD or a larger container. Multiple procedural steps would need to be disregarded by multiple personnel before this scenario could be achieved. The consideration of the low probability is due to the qualification and training required of the operators and the fact that more than one person is responsible for ensuring that only one *Field Container* is placed within a CD. If multiple *Field Containers* comprised of debris classified as *Fissile Material* were collected into the same CD or larger container, then significant quantities of *Fissile Material* could potentially be placed in close proximity.

Training is essential for any nuclear facility decommissioning activity and this excavation activity is treated no differently. The 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. Ensuring that only a single *Field Container* comprised of debris classified as *Fissile Material* is placed into a particular CD is a simple task. Procedure requires not only verification that the CD is empty prior to its acceptance for use at the excavation site, but also verification prior to placing any item into the CD. Furthermore, immediately after placing a single lidded *Field Container* into a CD, operating procedure requires that the CD be fixed with a lid and transferred to an approved staging/storage area or directly to a WEA.

It should be noted that containers larger than CDs are reserved only for over-packing large burial pit waste items. Therefore, the potential to place multiple *Field Containers* into containers large than CDs is very small. Even if a CD or larger container were mistakenly loaded with *Field Containers* comprised of debris classified as *Fissile Material*, more than 10 different *Field Containers* would be required before exceeding a maximum subcritical mass of 760 $g^{235}U$ would be possible (assuming no other concurrent *unlikely* procedural failures). Since *Field Container* loading and handling operations requires concurrence from multiple operators performing simple tasks, collecting more than 10 *Field Containers* comprised of debris classified as *Fissile Material* into the same container is considered *highly improbable* to occur during the decommissioning activities.

As discussed earlier in this section, it is considered at least *unlikely* that excavating concrete from the ground could result in exceeding one of the two criteria necessary before an unsafe condition could exist. This determination is based on the inherent characteristics of contaminated concrete and does not rely on preventative measures being implemented. However, to further reduce the risk of a criticality accident, it is required that all concrete, irrespective of its location, be assayed prior to excavation using appropriate assay techniques, and that safe quarantine practices be employed if concrete debris is identified as *Fissile Material.* The risk of failure involving the assay and safe quarantine practices as described in the various hazards discussed above is also considered at least *unlikely* to result in an unsafe condition.

Recognizing the inherent low risk and utilizing safety controls as described above effectively prevents an unsafe mass or concentration of *Fissile Material* from accumulating during concrete excavation operations. This independence and likelihood of failure meets the criteria of the Double Contingency Principle, because two unlikely concurrent failures would be required before a criticality accident could be possible.

2.4.1.3 Summary of Risk Assessment

Based on the risk assessment provided in Section 2.4.1.2, the following conditions must exist before a criticality accident due to concrete excavation would be possible:

Criticality due to bulking concrete meeting *NCS Exempt Material* criteria:

- Significant entrainment of *Fissile Material* embedded in concrete surfaces; and
- Concrete surface assay or core sampling inaccurately reports *NCS Exempt Material* criteria is met

Criticality due to excavating concrete with *Field Containers*:

- Significant entrainment of *Fissile Material* embedded in concrete surfaces; and
- Concrete surface assay or core sampling inaccurately reports *Fissile Material Exhumation Limit* is met; and

- Containers other than *Field Containers* are used to collect concrete classified as *Fissile Material,* **or,** multiple filled *Field Containers* are improperly loaded into a CD or otherwise situated together in a single location.

2.4.1.4 Safety Controls

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

> **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).*
>
> **Administrative CSC 01:** *At least two qualified individuals SHALL perform a surface assay of concrete debris prior to its excavation.*
>
> **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.*
>
> **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.*
>
> **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).*

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).

> **Safety Feature 01:** *Field Containers (when used in support of a CSC).*

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.*

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

Administrative CSC 07: *Only a single Field Container SHALL be present outside the confines of a CD at one time. This is local to a particular excavation location. Specifically, if individual excavation locations are separated by at least 12 feet without reasonable potential for commingling decommissioning debris, then each excavation location is authorized to contain a single Field Container in use.*

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.*

2.4.2 Unexpected *Fissile Material* Quantities/Concentration in Soil

2.4.2.1 Discussion

As discussed in Section 2.3.2, the soil surrounding subterranean piping that is not in the vicinity of pipe breaches or cracks and the soil that is not near concrete slabs that were used as a floor for former fuel manufacturing operations is anticipated to meet *NCS Exempt Material* criteria. This is because this soil in these areas would have either been protected by "non-production use" concrete slabs or (if not underneath these clean concrete slabs) no documentation exists to suggest that the soil contains buried waste. However, soil that is in the vicinity of these substructures is conservatively assumed to have no upper bound in terms of *Fissile Material* quantity or concentration within the soil.

To address a concern of disposing significant quantities of *Fissile Material* saturated within soil into large volumes, all soil excavation is strictly controlled. This control consists of thoroughly assaying the surface of soil independently using diverse or redundant methods prior to its excavation. Redundant methods would include surface assay performed by two different operators using the same type of equipment. Surface assay is very conservative in *Fissile Material* quantification. The surface assay is performed with calibrated equipment that is effective for *Fissile Material* identification and quantification within soil*. The surface assay is used on all areas of soil prior to its excavation irrespective of the soil's location or physical condition.

Upon determination that the soil meets *NCS Exempt Material* criteria as confirmed by both surface assay results, the *NCS Exempt Material* portions are exhumed to a permitted *cut depth* consistent with the assay equipment calibration basis. The exhumed soil is bulked in a waste transfer vehicle and transfer to a WHA.

If a portion of the soil is determined to meet *Fissile Material* classification but is below the *Fissile Material Exhumation Limit*, then the associated portion is packaged into a *Field Container*. Once the *Field Container* is filled or an adequate portion of the soil has been removed, the *Field Container* is lidded and placed singly within a CD. The CD is then transferred to an approved staging/storage area or directly to a WEA.

In the event soil is determined to contain *Fissile Material* in a concentration greater than the *Fissile Material Exhumation Limit,* affected operations will cease and will not resume without instruction from the NCS Organization.

* The maximum thickness of soil that can be adequately characterized by in-situ assay equipment is established in the calibration basis document associated with the type of assay equipment.

2.4.2.2 Risk Assessment

A criticality accident cannot be realized when exhuming portions of soil as long as one of the two following criteria* is met:

- The mass of ^{235}U associated with the exhumed soil does not exceed 760 g^{235}U; **or**
- The macroscopic concentration of ^{235}U associated with the exhumed soil does not exceed 4 g^{235}U/L.

It is important to note that the soil areas of particular concern to criticality safety involve portions of soil that are in the vicinity of subterranean piping or heavily contaminated concrete that was used as the floor during fuel manufacturing operations in the former process buildings. The subterranean piping has the potential to contain a crack or breach which could have allowed solutions laden with *Fissile Material* to seep into surrounding pockets of soil. The heavily contaminated concrete slabs also had the potential to allow seepage of *Fissile Material* to collect within the soil through cracks, expansion joints, or seams adjacent to walls.

The two different surface assays utilize calibrated equipment that is effective for *Fissile Material* identification and quantification within soil. The operators that are responsible for the detector's response and function are knowledgeable, skilled and trained to perform the task.

Once the assay results confirm that the soil meets *NCS Exempt Material* criteria, then the soil portions are excavated to a depth justified by the calibration document for the assay equipment and then bulked. This criterion is defined as no greater than 1 gram of ^{235}U within a 10 liter volume of decommissioning debris†. By assuring that no more than 1 gram is fixed to every 10 liters of debris, the macroscopic homogenous concentration of the debris is 0.1 g^{235}U/L which is a factor of 40 below the maximum safely subcritical concentration. Even accounting for a conservative factor to two reduction in this large safety margin to account for credible non-homogeneity, a large factor of safety (20) still exists. Based on the low enriched uranium concentration limit of 1 g^{235}U associated with every 10 liters of soil, and the large safety margin outlined, criticality safety is assured for bulked soil.

If the assay results do not confirm that the soil meets *NCS Exempt Material* criteria and instead concludes that the soil meets *Fissile Material* classification, then the associated soil portion is carefully extracted into a *Field Container* as long as the *Fissile Material* content was determined to be lower than the *Fissile Material Exhumation Limit*. The *Fissile Material* classification is defined as any decommissioning debris that contains more than 1 gram of ^{235}U within a 10 liter volume. The *Fissile Material Exhumation Limit* is an upper threshold set at 38 grams of ^{235}U per 10 liter volume which is exactly a factor of 10 below the

* Appendix A of Reference 1 establishes the maximum subcritical mass limit as 760 g^{235}U and the maximum subcritical infinite sea concentration of 4.0 g^{235}U/L, which are both applicable to the operations evaluated in this NCSA.

† The surface assay response and function used for converting radiation counts to enriched uranium concentration is described in the detector calibration basis document for the given material.

enriched uranium concentration necessary to reach an unsafe condition in a 20 liter volume (e.g., a *Field Container*).

The potential risks in the above procedural requirements which could lead to a condition favorable for criticality include:

- misinterpreting the assay results
- improperly calibrating the assay equipment
- excavating portions of soil that have not been assayed
- using containers other than *Field Containers* for soil classified as *Fissile Material*
- placing multiple *Field Containers* of soil into a single CD or larger container

Each of these scenarios is discussed in turn.

<u>Misinterpreting the assay results</u>
It is considered *highly improbable* that multiple personnel would inadvertently misinterpret multiple assay results by more than a factor of 10 (minimum margin of error required to reach a potentially unfavorable condition). This is due to the qualification and training required of the operators, the fact that more than one person is responsible for interpretation of the results, multiple assay results being involved, and the large safety margin taken into account in the thresholds. If the multiple assay results for a particular soil region were mistakenly interpreted as meeting *NCS Exempt Material* criteria when in fact the soil contained more than 1 gram of ^{235}U per 10 liter volume, then significant quantities of *Fissile Material* could potentially be bulked together. However, for conditions favorable for criticality to exist, the actual enriched uranium concentration in the soil must be at least 20 times higher than the misinterpreted result.

Training is essential for any nuclear facility decommissioning activity and this excavation activity is treated no differently. The 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. Converting a reading displayed on surface assay equipment into quantification of *Fissile Material* for a given volume is a simple task. Since a decision to excavate with a bulking method requires concurrence from multiple operators performing the same simple task, unknowingly exhuming an unsafe concentration of *Fissile Material* due to misinterpretation of multiple assay results is considered *highly improbable* to occur during the decommissioning activities. If the multiple assay results for a particular soil portion were mistakenly interpreted as meeting *Fissile Material* classification but was actually above the *Fissile Material Exhumation Limit* of 38 grams of ^{235}U per 10 liter volume, then significant quantities of *Fissile Material* could potentially be loaded into a *Field Container*. The *Field Container* is limited in maximum usable volume to only 20 liters. Therefore, a misinterpretation of assay results would have to be in error by more than a factor of 10 before an unsafe quantity of *Fissile Material* could be collected into a single *Field Container* (i.e., more than 760 grams ^{235}U in a 20 liter volume). Based on this safety margin, the simplicity of the procedures, the requirement for multiple persons to follow the procedures, and the human reliability arguments presented,, this gross failure is also considered *highly* *improbable* to occur during the decommissioning activities.

Improperly calibrating the assay equipment

It is considered *highly improbable* that multiple assay equipment would be inadvertently used without proper calibration that could lead to underestimated *Fissile Material* content in a portion of soil by more than a factor of 10 (minimum margin of error required to reach a potentially unfavorable condition). This is due to the knowledge, qualification and training required of the operators, the fact that more than one person is responsible for ensuring calibration of the assay equipment, multiple assay equipment being used, the reliability of the assay equipment even without frequent calibration, and the large safety margin taken into account in the thresholds.

If multiple improperly calibrated assay equipment was used on a particular soil region resulting in a reading that confirmed the soil as meeting *NCS Exempt Material* criteria when in fact the soil contained more than 1 gram of ^{235}U per 10 liter volume, then significant quantities of *Fissile Material* could potentially be bulked. However, for conditions favorable for criticality to exist, the actual enriched uranium concentration in the soil must be at least 20 times higher than the misinterpreted result.

Training is essential for any nuclear facility decommissioning activity and this excavation activity is treated no differently. The 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. Ensuring proper calibration of assay equipment prior to its use is a simple task. Since a decision to excavate with a bulking method requires concurrence from multiple operators performing the same simple task, unrecognizably unknowingly exhuming an unsafe concentration of *Fissile Material* due to using improperly calibrated assay equipment is considered *highly improbable* to occur during the decommissioning activities.

If multiple improperly calibrated assay equipment were used on a particular soil region resulting in a reading that confirmed the soil as meeting *Fissile Material* classification but was actually above the *Fissile Material Exhumation Limit* of 38 grams of ^{235}U per 10 liter volume, then significant quantities of *Fissile Material* could potentially be loaded into a *Field Container*. The *Field Container* is limited in maximum usable volume to only 20 liters. Therefore, a misinterpretation of assay results would have to be in error by more than a factor of 10 before an unsafe quantity of *Fissile Material* could be collected into a single *Field Container* (i.e., more than 760 grams ^{235}U in a 20 liter volume). Based on this safety margin, the simplicity of the procedures, the requirement for multiple persons to follow the procedures, and the human reliability arguments presented,, this gross failure is also considered *highly improbable* to occur during the decommissioning activities.

Excavating regions of soil that have not been assayed

It is considered *highly improbable* that multiple personnel would inadvertently excavate regions of soil that have not been thoroughly assayed leading to an accidental criticality. This is due to the knowledge, qualification and training required of the operators, the fact that more than one person is responsible for ensuring only soil with an acceptable assay value is excavated, and the inherently *unlikely* probability of exhuming large quantities of highly concentrated *Fissile Material* that surround confirmed insignificant enriched uranium concentrations in soil. Two independent, *unlikely* conditions must first concurrently exist prior to reaching favorable conditions for a criticality accident regarding this hazard scenario.

The first *unlikely* condition is the inadvertent failure of the excavation crew to recognize lifting soil at a greater thickness than the *cut depth* limit and subsequently bulking with other soil. Excavating deeper than the *cut depth* limit is not a criticality concern until the excavated soil is exhumed and bulked with other soil. It is reasonable to assume that the excavating crew will recognize that the *cut depth* has been exceeded and will return the soil to its excavated area and perform multiple surface assays again prior to bulking with other exhumed soil. It should be recognized that exhuming soil in this method (i.e., bulk lifting of soil) implies that the anticipated soil layer was confirmed to meet *NCS Exempt Material* criteria and that any soil beneath or surrounding this layer would undoubtedly be mixed together forming a potentially highly enriched uranium concentrated soil matrix.

This leads to the second *unlikely* condition that would need to occur which is the extremely high enriched uranium concentration required to exist in the unassayed soil. The enriched uranium concentration required in the unassayed soil would have to be as high as 40 grams of ^{235}U in a 5 liter volume. This is more than twice the *Fissile Material Exhumation Limit* and is certainly considered at least *unlikely* to be present in any region of soil to be excavated at the Hematite Site. This high concentration conservatively assumes that a layer of unassayed soil has been excavated that has a thickness just as great as the *cut depth*. For example, if the *cut depth* required by the assay equipment calibration document is 1 foot for soil, the excavator is assumed to have actually lifted 2 feet of soil (i.e., 1 foot of *NCS Exempt Material* and 1 foot of unassayed soil beneath that contains as high as 40 grams of ^{235}U in each 5 liter volume). By assuming a mixture of the two layers upon excavation (which is more than *likely* to occur), the resulting matrix yields an average concentration of ~40 grams ^{235}U per 5 liter volume which is the threshold between safe and potentially unsafe conditions for a criticality accident.

Consequently, due to the two *unlikely* conditions required to reach favorable criticality accident conditions (i.e., the first being inadvertent failure of the multiple responsible personnel to recognize unacceptable *cut depth* and the second being an extraordinarily high ^{235}U concentration in the unassayed layer of exhumed soil), it is considered *highly improbable* that a criticality accident could occur during soil exhumation if a large portion of soil is exhumed that does not have an assay value.

<u>Using containers other than *Field Containers* for soil classified as *Fissile Material*</u>
This scenario is discussed in Section 2.4.1.2 for concrete debris and is equally applicable to soil. Refer to Section 2.4.1.2 for details.

<u>Placing multiple *Field Containers* into a single CD or larger container</u>

This scenario is discussed in Section 2.4.1.2 for concrete debris and is equally applicable to soil. Refer to Section 2.4.1.2 for details.

As discussed in the hazard scenarios above, multiple personnel using multiple assay devices when determining ^{235}U content in soil is credited to prevent a criticality accident when exhuming soil. In addition, use of proper soil quarantine practices by multiple personnel and slight reliance on the likelihood of upper ^{235}U concentrations to be found in soil also is credited. It has been determined that at least two unlikely and concurrent conditions are required before a criticality accident could occur during activities associated with soil exhumation. The independence and likelihood of failure meets the criteria of the Double Contingency Principle, because two unlikely concurrent failures would be required before a criticality accident could be possible.

2.4.2.3 Summary of Risk Assessment

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

Criticality due to bulking soil supposedly meeting *NCS Exempt Material* criteria:

- Subterranean piping must be cracked or breached resulting in surrounding soil to contain greater than 4 $g^{235}U/L$ **or** buried waste containing *Fissile Material* is unrecognizably exhumed **or** soil is located underneath cracked concrete or seams in concrete resulting in surrounding soil to contain greater than 4 $g^{235}U/L$; and
- Bulking of soil containing *Fissile Material* from a pipe leak or seepage from concrete above **or** significant *Fissile Material* within undocumented buried waste
- Multiple soil assays inaccurately report *NCS Exempt Material* criteria is met.

Criticality due to exhuming soil with *Field Containers*:

- Subterranean piping must be cracked or breached resulting in surrounding soil to contain greater than 4 $g^{235}U/L$ **or** buried waste containing *Fissile Material* is unrecognizably exhumed **or** soil is located underneath cracked concrete or seams in concrete resulting in surrounding soil to contain greater than 4 $g^{235}U/L$; and
- Multiple soil assays inaccurately reports *Fissile Material Exhumation Limit* is not met; and
- Containers other than *Field Containers* are used to collect soil classified as *Fissile Material* **or** multiple filled *Field Containers* are improperly loaded into a CD or otherwise situated together in a single excavation location.

2.4.2.4 Safety Controls

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

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).*

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.*

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.*

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.*

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).*

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).

Safety Feature 01: *Field Containers (when used in support of a CSC).*

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.*

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

Administrative CSC 07: *Only a single Field Container SHALL be present outside the confines of a CD at one time. This is local to a particular excavation location. Specifically, if individual excavation locations are separated by at least 12 feet without reasonable potential for commingling decommissioning debris, then each excavation location is authorized to contain a single Field Container in use.*

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.*

2.4.3 Unexpected *Fissile Material* Quantities/Concentration during Subterranean Pipe Section Excavation

2.4.3.1 Discussion

As discussed in Section 2.3.3, the condition of subterranean process piping which is believed to be connected to the storm water system is very conservatively assumed to be without upper bound in terms of *Fissile Material* quantity, concentration, or volume. As a result of the proximity of subterranean sanitation lines, the sanitation drains and pipes are handled identically to subterranean process piping (in an effort to avoid consequences of mistaken identity of subterranean piping and to account for potential *Fissile Material* holdup in these lines). It should be noted that the subterranean process piping and storm water lines are interconnected and flow into the site creek while the sanitation lines terminate into a septic treatment tank. While it may realistically be expected that the subterranean piping contain only trace quantities of *Fissile Material* due to the plant design and legacy production operations ensuring that no *Fissile Material* be flushed into the nearby site creek, there is a single cause that cannot be justifiably deemed with a probability less than *likely*. That cause, as stated in the *What-If/Checklist* analysis, is "*Fissile Material* having been poured into non-fissile drains and pipes during past production". The reason for the *likely* probability to find potentially significant deposits in the subterranean piping stems from the uncertainty surrounding past production operations. While all subterranean process lines terminate to above-grade drains that could have been used for connection into former process equipment to collect condensate or process water overflow, there is some doubt as to whether laboratory sinks or maintenance sinks were used for cleaning equipment or containers with *Fissile Material* residue. This doubt necessitates the need to assume the onerous anticipated conditions of the subterranean piping (i.e., piping contains no upper bound in regards to *Fissile Material* quantity, concentration, or volume). Since this assumed condition is not possible to become more adverse, the bounding abnormal condition is the anticipated condition.

Due to the assumed condition being so stringent, it is conservatively assumed that a criticality accident in the subterranean piping has been avoided over time due only to non-disturbance (since much of the subterranean piping system is non-favorable geometry for ^{235}U metal). Recall again that, realistically, only trace quantities of *Fissile Material* will be discovered in the piping. However, due to assumed bounding initial conditions, a criticality strategy must be developed to disturb the piping in a controlled and safe manner.

Once disturbed, the subterranean piping has the potential to release its *Fissile Material* content into a single accumulation area. However, it is very important to note that water or other liquid cannot release its *Fissile Material* content into a more adverse configuration (e.g., into a hole in the ground). This is due to the over 50 years of flushing water through the subterranean process piping and storm water system. Therefore, the only credible disturbance that can initiate a significant release of *Fissile Material* from its affixed location within the piping walls is physical impact by excavation equipment. Subsequently, it is only deemed credible to postulate a criticality accident due to the process of removing subterranean piping from the ground.

Since it is impossible to ensure that the contents of subterranean piping remain immobile during excavation, the primary prevention of a criticality accident during pipe removal is based on a combination of ensuring that only a safe mass is being disturbed and making every effort to permanently affix material within the confines of the piping prior to crushing, cutting, or lifting.

There are two methods for excavating piping. The subterranean pipe section can be removed either intact or crushed in place. Prior to either method, it is required to first assay the inside of a subterranean pipe section. This in-pipe assay is capable of determining the quantity of *Fissile Material* within the piping and consists of a small assay device remotely guided (i.e., snaked) through the pipe section.

If the method of excavation is to lift an intact pipe section from the ground, a mapping is created that is subsequently used to determine cut locations on the piping. Each section of piping to be removed from the ground intact is limited to a maximum of 75 grams of *Fissile Material* in the entire section, which is defined as the *Extracted Piping Fissile Material Limit*. Recall from earlier discussion, that realistic scenarios involve only trace quantities of *Fissile Material* in the piping; therefore, pipe sections up to 20 feet in length (i.e., the probable maximum length that would be excavated at one time) would be typical when removing from ground. However, if bounding anticipated conditions prevail, pipe sections much smaller (perhaps as little as a single foot) may be excavated at one time. Once the soil is removed exposing a pipe section that contains less than the *Extracted Piping Fissile Material Limit*, a tube is slowly inserted into the piping extending to the proposed cut location. A spray fixative or grout material is then introduced through the tube while the tube is slowly removed from the pipe section. This approach helps to ensure that the fixed residue within the piping remains immobilized once the pipe section is cut and lifted from the ground. It should be noted that piping is excavated from the ground from a low elevation to a high elevation to help ensure that flow of grout or other fixative prevents "pushing" residue to one end of the pipe section. Once a fixative is properly applied, the exposed pipe section is cut and lifted from ground to be placed onto a nearby stand that holds the pipe in a horizontal position. A second assay is then performed on the pipe section while on the stand. While on the stand, operators visually examine the pipe section to verify an adequate filling of grouting material or spray fixative. Any voids identified in the pipe section are filled with a grouting material (this would be a frequent procedural step if only a spray fixative was used when the pipe lay in the ground). After the pipe interior is solidified and reasonably assured to maintain immobilization of all residues even if the pipe were to breach, break, shatter, or crumble, the enriched uranium concentration for each 10 liter volume of pipe is calculated. A 10 liter volume in a 4 inch diameter pipe occurs for each 4 foot section while a 10 liter volume in an 8 inch diameter pipe occurs for each 1 foot section. Other pipe diameters are expected to be excavated and the operators are required to properly calculate the length and diameter combinations of pipe to use in the enriched uranium concentration determination. If the debris within the pipe section is determined to meet the *NCS Exempt Material* criteria (i.e., ≤ 1 g^{235}U per a 10 liter volume), then the pipe is bulked and transferred to a WHA. If the debris within the pipe section instead is classified as *Fissile Material* but is below the *Fissile Material Exhumation Limit* (i.e., ≤ 38 g^{235}U per 10 liter volume), the associated section is cut and placed singly into a CD. The CD containing the single 10 liter pipe section containing *Fissile Material* is lidded and transferred to an approved staging/storage area or directly to a WEA.

If the method of excavation is to crush a pipe section in the ground (as may be necessary for clay and possibly concrete piping), the results of the in-pipe assay are evaluated to determine if the pipe section to be crushed meets the *NCS Exempt Material* criteria. In order to determine acceptance under this criterion, 10 liter volumes of the pipe section need to be established. This is accomplished knowing the outer diameter of the piping which is determined once the piping is exposed. As an example, a 4 inch pipe has a 10 liter volume for each 4 feet of length while an 8 inch pipe has a 10 liter volume for each 1 foot of length. Once the pipe section is confirmed to meet the *NCS Exempt Material* criteria, a tube is slowly inserted into the exposed pipe section. A grout or other filler material is then introduced through the tube while the tube is slowly removed from the pipe section. This application helps to ensure that the residue within the piping is adequately homogenous (fixed in distribution) after crushing with the excavator. The crushed piping debris is then surveyed using two different assay devices by two different operators to verify that the debris meets the *NCS Exempt Material* criteria. Once confirmed, the debris is exhumed identically as if it were soil. If the crushed piping debris (now mixed with surrounding soil) is determined to meet *Fissile Material* classification but is below the *Fissile Material Exhumation Limit*, then the associated portion is packaged into a *Field Container*. Once the *Field Container* is filled or an adequate portion of the crushed piping debris has been removed, the *Field Container* is lidded and placed singly within a CD. The CD is then transferred to an approved staging/storage area or directly to a WEA.

In the event segments of intact piping or portions of crushed piping debris are determined to contain *Fissile Material* with a concentration greater than the *Fissile Material Exhumation Limit,* affected operations will cease and will not resume without instruction from the NCS Organization.

2.4.3.2 Risk Assessment

A criticality accident cannot be realized when exhuming subterranean pipe sections or piping debris as long as one of the two following criteria* is met:

- The mass of ^{235}U associated with the exhumed soil does not exceed 760 g^{235}U; **or**
- The macroscopic concentration of ^{235}U associated with the exhumed soil does not exceed 4 g^{235}U/L.

Based on the discussion of the operations associated with subterranean pipe extraction in Section 2.4.3.1, the identified credible risks associated with subterranean pipe extraction which could potentially exceed either of the two criteria above are as follows:

* Appendix A of Reference 1 demonstrates that a minimum of 760 grams of ^{235}U is required to achieve conditions favorable for a criticality accident at the Hematite site and approved disposal facilities. In addition, the same citation demonstrates that 5.5 g^{235}U/L and 5.5 liters are also the minimum enriched uranium concentration and minimum system volume (respectively) necessary to reach conditions favorable for a criticality accident at the Hematite site and approved disposal facilities.

- Significant deposits of *Fissile Material* not identified within subterranean piping are released during intact section lifting and collect in the ground during excavation;
- Significant enriched uranium concentration in intact piping sections are mistakenly bulked;
- Collection of significant *Fissile Material* deposits are released from intact pipe section during downstream bulking activities;
- Collection of too many pipe sections into a CD;
- Significant concentration of *Fissile Material* created during pipe section crushing;
- Collection of significant *Fissile Material* mixed with crushed piping debris into containers other than *Field Containers*; and
- Collection of too many *Field Containers* containing crushed piping debris into a CD.

<u>Significant deposits of *Fissile Material* not identified within subterranean piping are released during intact section lifting and collected in the ground during excavation</u>
It is important to ensure accurate in-pipe assay prior to excavating a section of subterranean piping. Recall that an intact pipe section to be lifted must meet the *Extracted Piping Fissile Material Limit* prior to removing from the ground (i.e., no greater than 75 grams of ^{235}U per pipe section). This low threshold allows for more than a factor of 10 in in-pipe *Fissile Material* mass quantification error before an unsafe mass is reached. It is considered *highly improbable* that error in in-pipe assay could lead to inadvertent underestimation by a factor of 10. This is justified by the requirement that multiple personnel are responsible for proper calibration, procedural use, and interpretation of the results regarding in-pipe assay equipment. The in-pipe assay equipment are specialized devices that consist of a small spider probe (proportional counter) attached to a single channel analyzer capable of precisely determining the ^{235}U content within piping. Since the piping is assayed while below-grade, background radiation is minimized to insignificant levels. Further, attenuation between the contaminant and the counter is practically nonexistent resulting in a very precise measurement of the *Fissile Material* within the piping. Training is essential for any nuclear facility decommissioning activity and this excavation activity is treated no differently. The 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 cumulative features presented above ensure that results interpreted by the in-pipe assay results are highly improbable to exceed underestimation in assay of a factor of 10 particularly since multiple personnel are responsible for the effectiveness of the device.

The only credible risk to criticality safety in regards to inaccurate quantification of *Fissile Material* within an intact lifted pipe section involves accumulation of pipe residue on the ground over time due to occasional evacuation of pipe contents. Consequently, a second independent control involves the application of a spray fixative or grouting material within an intact pipe section prior to cutting or lifting the pipe from the ground (or application of a grout or other filler material if the section is to be crushed). This affixation is performed and managed by multiple personnel. In addition, the lifting of pipe sections from the ground is performed in a slow, meticulous, and careful manner which helps to ensure that angling and stress on the piping is minimal. There is actually an operational motive to maintain proper control of the pipe while being excavated since stresses on the pipe section could result in fracture or break. Breaking of the pipe section while being lifted results in much more time and labor being expended to remedy the spill, as only one pipe section at a time is able to be assayed on the nearby stand.

It should be recognized that both the loss of *Fissile Material* mass accountability and the loss of its confinement is required before a criticality accident could occur due to lifting intact pipe sections from the ground. If the *Fissile Material* content within intact pipe sections became inaccurate with repeated failure more than an *unlikely* factor of two (>150 grams ^{235}U in a section), criticality safety is still maintained by ensuring its confinement to the pipe section. Conversely, if spray fixatives, grouting, or other filler material became ineffective with an *unlikely* repeated failure resulting in two pipe sections spilling its contents in the same location, criticality safety is maintained by ensuring that the bounding cumulative spill is no more than 300 grams of ^{235}U. Note, failure of mass control on the pipe section beyond a factor of 10 (i.e., greater than 750 grams ^{235}U being within the section) or failure of ensuring fixed distribution and immobilizing of residue within the piping 10 consecutive times (i.e., spilling contents of 10 different pipe sections into the same location) is considered *highly improbable*.

Utilizing both sets of independent safety controls as described above effectively prevents an unsafe quantity of *Fissile Material* from accumulating into an unsafe configuration on the ground during subterranean pipe excavation operations. This independence and likelihood of failure meets the criteria of the Double Contingency Principle, because two unlikely concurrent failures would be required before a criticality accident could be possible.

<u>Significant enriched uranium concentration in bulked intact piping sections</u>

Excavated and filled intact piping sections are bulked into large conveyances once the section meets *NCS Exempt Material* criteria. This low threshold (i.e., no greater than 1 gram in a 10 liter volume of piping) is more than a factor of 20 below the maximum subcritical concentration of 4 $g^{235}U/L$. The enriched uranium concentration for each 10 liter volume within the pipe section is determined, managed, and verified by multiple personnel. The process involves using and managing the data associated with the *Fissile Material* mass quantity determined while the pipe section is stationed on the stand. Each 10 liter segment of pipe is assayed and the *Fissile Material* mass quantity is recorded. The entire pipe section is allowed to be bulked only if each 10 liter segment of piping in the pipe section stationed on the stand meets *NCS Exempt Material* criteria.

Potential failure points in the procedural steps described above could be numerous if following the procedure was limited to only a single individual. However, since multiple personnel are responsible for all steps in the described procedure, failure at any particular point that could culminate into under-determining or under-reporting the ^{235}U concentration in a particular 10 liter volume of pipe could be considered at least *unlikely*. On the contrary, however, this one-time failure is conservatively considered *likely* (i.e., anticipated). The failure point that is considered at least *unlikely* to occur inadvertently is: 1) a repeat failure up to three times whereby pipe sections are bulked even though one of the 10 liter volume segments does not meet *NCS Exempt Material* criteria or 2) failure such that multiple personnel conclude that a particular 10 liter segment meets *NCS Exempt Material* criteria when (in actuality) the segment contains more than the *Fissile Material Exhumation Limit* (a factor of 38 in assay procedure/equipment error).

The worst case that should be considered to occur due to an *unlikely* failure in assay while on the assay stand consists of potentially conglomerating at most 450 grams of ^{235}U. This is determined by considering the following:

> The highest *Fissile Material* mass quantity that could reside in a 10 liter volume (or smaller) pipe segment due to a in-pipe assay procedural misstep but just prior to reaching an *unlikely* probability is limited to 150 grams ^{235}U (see discussion involving previous scenario). Therefore, if the entire mass loading resided into one 10 liter segment of the pipe section, the most ^{235}U that should be expected is 150 grams in that particular segment. Conservatively considering that this very high concentration was inadvertently disregarded by multiple personnel (*unlikely* since this is a factor of 150 above the *NCS Exempt Material* criteria and a factor of ≈4 above the *Fissile Material Exhumation Limit*), the pipe section would be removed from its stand and bulked. Furthermore, considering that there are absolutely no criticality restrictions on bulked materials, it must be assumed that the particular high *Fissile Material* laden 10 liter segment could eventually be removed from its section of piping and preferentially segregated. If this scenario were repeated identically two more times for a total of three different procedural missteps involving at least three different pipe sections, the bounding configuration would result in 450 grams of ^{235}U (i.e., 150 x 3) being commingled somewhere in some volume which is a safely subcritical enriched uranium quantity and would require an additional *unlikely* failure of initial in-pipe assay to be exceeded.

Conversely, the worst case that should be considered to occur due to an *unlikely* failure of in-pipe assay equipment or procedure (while the pipe lay in the ground) that results in lifting a pipe section onto the assay stand that contains up to 750 grams of ^{235}U (*highly improbable* to exceed) consists of potentially conglomerating at most 114 grams of ^{235}U. This is determined by considering the following:

> If a pipe section contains more than 150 grams while situated on the assay stand (due to *unlikely* failure of previous in-pipe assay) and the entire mass loading was in a single 10 liter segment, then a criticality accident is adequately prevented for downstream bulking activities because it would require a concurrent procedural misstep by multiple personnel to not recognize the single segment containing a factor of at least 150 greater than the *NCS Exempt Material* criteria threshold. If the mass loading was evenly distributed along the pipe section, then at most 114 grams of ^{235}U could credibly be conglomerated downstream because exceeding this value would require more than three failures of multiple personnel to recognize segments exceeding *NCS Exempt Material* criteria (i.e., 38 x 3).

As described above, the worst *unlikely* event would result in 450 grams of ^{235}U being potentially localized during some process beyond the bulk storage which is a safely subcritical quantity. Extending beyond an *unlikely* probability, it is consider *highly improbable* for multiple personnel responsible for ensuring confirmation of ^{235}U concentration determination to make this such a gross error. Note that even with 5 failures and subsequent commingling of these highly concentrated segments, this scenario would still result in a safe mass being accumulated over time (i.e., 750 g ^{235}U).

Utilizing both sets of independent safety controls as described above (i.e., ensuring pipe sections contain no greater than 75 grams of ^{235}U and ensuring no 10 liter segment of pipe is bulked that does not meet *NCS Exempt Material* criteria) effectively prevents an unsafe quantity of *Fissile Material* from accumulating into an unsafe configuration during the process of bulking (or any other process downstream) as a result of subterranean intact pipe excavation operations. This independence and likelihood of failure meets the criteria of the Double Contingency Principle, because two unlikely concurrent failures would be required before a criticality accident could be possible.

<u>Collection of significant *Fissile Material* deposits released during intact pipe bulking activities</u>

Excavated and filled intact piping sections are bulked once debris in each 10 liter volume is confirmed to meet *NCS Exempt Material* criteria. The bulking process is approved after this confirmation due in part to the contents of the intact pipe being permanently affixed within the volume of the pipe. To ensure that contents are indeed affixed to the interior of the pipe section, a two step process is implemented. The first process involves multiple personnel applying a either a spray fixative or grouting material to the inside of the pipe section prior to excavating the intact pipe section from the ground. This step is an easy process involving multiple personnel that is considered very difficult to not implement properly. The second process occurs once the pipe is stationed onto the nearby assay stand and involves completely filling the inside of the piping with concrete, cement, or other type of grouting material. This second process also involves multiple personnel.

Potential failure points in the procedural steps described above could be numerous if following the procedure was limited to only a single individual. However, since multiple personnel are responsible for all steps in the described procedure, failure at any particular point that could culminate into not adequately affixing the residing *Fissile Material* within the pipe section could be considered at least *unlikely*. On the contrary, however, this one-time failure is conservatively considered *likely* (i.e., anticipated). The failure point that is considered at least *unlikely* to occur is a repeat failure up to two times whereby pipe sections are bulked even though the contents of the section have not been applied any fixative or grouting material.

The worst case considered to occur due to an *unlikely* failure of two repeat failures of multiple personnel not immobilizing pipe residue leading to eventual seepage of pipe contents consists of:

1) Bulking two different pipe sections in which each release their *Fissile Material* into the same accumulation location; and
2) Maximum of 150 grams of ^{235}U in each pipe section (see discussion involved with

previous scenarios); and

3) Total of 300 grams of ^{235}U (i.e., 150 x 2) in some accumulated and commingled volume which is a safely subcritical quantity.

Conversely, the worst case that should be considered to occur due to an *unlikely* failure of in-pipe assay equipment or procedure (while the pipe is situated in the ground) consists of a maximum of 750 grams of ^{235}U in a pipe section (*highly improbable* to exceed - see discussion involved with previous scenarios). Another unlikely failure is required before exceeding this safely subcritical enriched uranium mass (i.e., another pipe section would need to be void of immobilizing agent).

It should be considered that there are two opportunities for multiple personnel to apply a fixative or grouting material to the pipe sections. The first opportunity is presented prior to cutting and lifting the pipe while the second opportunity exists while the pipe section is on the assay stand.

Extending beyond an *unlikely* probability, it is considered *highly improbable* that multiple personnel responsible for ensuring proper fill of intact pipe sections prior to bulking would make this drastic of an error up to 5 times during the decommissioning life. Note that even with 5 failures and subsequent accumulation and commingling of the entire *Fissile Material* content of pipe sections, these errors would still result in a safe mass being accumulated over time (i.e., 750 grams of ^{235}U assuming no *unlikely* failures during in-pipe assay).

Utilizing both sets of independent safety controls as described above (i.e., ensuring intact pipe sections contain no greater than 75 grams of ^{235}U and ensuring adequate pipe section fill such that *Fissile Material* cannot reasonably flow from the intact pipe section), effectively prevents an unsafe quantity of *Fissile Material* from accumulating into an unsafe configuration during the process of bulking (or any other process downstream) as a result of subterranean pipe excavation operations. This independence and likelihood of failure meets the criteria of the Double Contingency Principle, because two unlikely concurrent failures would be required before a criticality accident could be possible.

<u>Placing multiple pipe sections into a single CD or larger container</u>

It is considered *highly improbable* that multiple personnel would inadvertently allow multiple pipe sections classified as *Fissile Material* debris to be collected concurrently into the same CD or a larger container. Multiple procedural steps would need to be disregarded by multiple personnel before this scenario could occur. The consideration of the low probability is due to the knowledge, qualification and training required of the operators and the fact that more than one person is responsible for ensuring that only one 10 liter pipe section containing *Fissile Material* is placed within a CD.

If multiple pipe sections comprised of debris classified as *Fissile Material* were collected into the same CD or larger container, then significant quantities of *Fissile Material* could potentially be bulked together. Training is essential for any nuclear facility decommissioning activity and this excavation activity is treated no differently. The 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. Ensuring that only a single pipe section comprised of debris classified as *Fissile Material* is placed into a particular CD is a simple task. Procedure requires verification that the CD is empty prior to placing any item into the CD. Furthermore, after placing a single pipe section into a CD, operating procedure requires that the CD be fixed with a lid and exported to an approved area.

It should be noted that containers larger than CDs are reserved only for over-packing large burial pit waste items. Therefore, the potential to place pipe sections comprised of debris classified as *Fissile Material* into non-approved larger containers is very small. Even if multiple pipe sections were placed in a CD, or a larger container was used, more than 20 different pipe sections would have to be accumulated before a maximum subcritical mass of 760 g ^{235}U could be assembled (assuming no other concurrent *unlikely* procedural failures).

Since the abovementioned procedures are performed by multiple operators performing the same simple task, unrecognizably collecting more than 20 pipe sections classified as *Fissile Material* into the same container is considered *highly improbable* to occur during the decommissioning activities.

Significant concentration of *Fissile Material* created during pipe section crushing
Some of the subterranean piping may not be conducive to excavating as intact sections due to the material properties (e.g., cracked clay or concrete). Consequently, crushing of subterranean piping in-situ is a requirement for operations.

Prior to crushing subterranean piping in place, the section of piping must first meet *NCS Exempt Material* criteria. This confirmation is accomplished by evaluating the results of the in-pipe assay. Recall from earlier discussion that this low threshold allows for more than a factor of 20 in in-pipe enriched uranium concentration determination error before an unsafe concentration could be reached. Specifically, the *NCS Exempt Material* criteria is set at 1 gram of ^{235}U in every 10 liter volume of piping; however, for conditions favorable for criticality to exist, the actual enriched uranium concentration in the piping must be at least 20 times higher than the misinterpreted result. It is considered more than *highly improbable* that an error in in-pipe assay could lead to underestimation by a factor of 20. In fact, it is considered *highly improbable* that an error in in-pipe assay could be in error by more than a factor of 10 (as demonstrated earlier in this section). This is justified by the requirement that multiple personnel are responsible for equipment calibration, procedural adherence, and interpretation of the results regarding in-pipe assay equipment. Training is essential for any nuclear facility decommissioning activity and this excavation activity is treated no differently. The 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.

In addition, a filling agent such as grout or concrete is applied to the inside of the pipe while it is situated in the ground prior to crushing. This material fills the void within the pipe to ensure an adequately homogenous (fixed in distribution) mixture will form when crushed and that loose *Fissile Material* will remain adequately immobilized within the mixture. It is considered at least *unlikely* that error in in-situ grouting or other type of pipe filling could lead to conglomeration of *Fissile Material* by more than a factor of 2. A factor of 2 in conglomeration is defined as enriched uranium that should maintain a concentration of 1 gram in a 10 liter volume migrates into a concentration of 2 grams in a 10 liter volume. Note, that this *unlikely* conglomeration is still a factor of 10 below the safety limit. Furthermore, it is considered *highly improbable* that crushing an inadequately filled pipe section in the ground (whereby surrounding soil would undoubtedly be part of the mixture) could lead to compressing 100 liters of piping into a 10 liter volume (i.e., compression of a factor of 10). A factor of 10 in conglomeration is defined as enriched uranium that should maintain a concentration of 1 gram in a 10 liter volume migrates into a concentration of 10 grams in a 10 liter volume. Note, that this *highly improbable* conglomeration is still lower than the maximum safely subcritical limit. This is justified by the requirement that multiple personnel are responsible for following procedure when applying filler material. Training is essential for any nuclear facility decommissioning activity and this excavation activity is treated no differently. The 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.

It should be recognized that both the loss of enriched uranium concentration accountability and the loss of its immobilization is required before a criticality accident could occur at the excavation site due to crushing pipe sections in the ground. Specifically:

- The enriched uranium concentration within the pipe section determined by the in-pipe assay must be inaccurate or the assay result interpreted incorrectly to such a degree that leads to an enriched uranium concentration up to 2 grams of ^{235}U in a 5 liter volume (factor of 2 error in in-pipe assay – beyond this value is considered *unlikely*); and
- Grouting or other filler material must not be applied correctly to an *unlikely* degree that leads to material within 100 liters of pipe being compressed into 10 liters of pipe during crushing of the piping (factor of 10 compression of material within a fixed distribution).

If the in-pipe assay resulted in an *unlikely* undervaluing of the *Fissile Material* content (up to a *highly improbable* 10 grams of ^{235}U in a particular 10 liter volume – factor of 10 beyond *NCS Exempt Material* criteria), then criticality safety is also maintained because the *Fissile Material* could only be compressed by as much as a factor of 2 due to application of the fixative or grouting material. The combination of the *highly improbable Fissile Material* loading of 10 grams of ^{235}U in a particular 10 liter volume being compressed by a factor of 2 results in only 20 grams of ^{235}U in a particular 10 liter volume (which is still much lower than the subcritical limit).

During crushing of pipe sections while they are situated in the ground, it is likely that surrounding soil will be added to the mixture of pipe fragments, filling material, and residues within the pipe. To ensure that no material is bulked without confirmation that the material meets *NCS Exempt Material* criteria, two independent scans with assay equipment are performed on the crushed debris prior to bulking. This is performed by two different operators using two different assay devices. By requiring this stringent approach to material classification after crushing a piping section, it is considered *highly improbable* that crushed pipe debris will be bulked that does not meet *NCS Exempt Material* criteria. When exhuming debris, the same bulking method is used which entails lifting debris no greater in depth than the *cut depth** dictated by the assay equipment calibration basis document.

If the assay results cannot confirm that the crushed debris meets *NCS Exempt Material* criteria and instead concludes that the soil meets *Fissile Material* classification, then the associated debris portion is carefully extracted into a *Field Container* as long as the *Fissile Material* content is determined to be lower than the *Fissile Material Exhumation Limit.* Note, remediation of this debris is identical to collection of soil not meeting *NCS Exempt Material* criteria and is not repeated here for brevity.

Utilizing both sets of independent safety controls as described above (i.e., ensuring pipe sections meet *NCS Exempt Material* criteria prior to crushing and ensuring adequate pipe section fill such that migration of *Fissile Material* is minimized) effectively prevents an unsafe quantity of *Fissile Material* from accumulating into an unsafe configuration during the process of in ground pipe crushing activities. In addition, utilizing independent and reliable surface assays of crushed debris effectively prevents an unsafe quantity of *Fissile Material* from accumulating into an unsafe configuration during the process of bulking (or any other process downstream). This independence and likelihood of failure meets the criteria of the Double Contingency Principle, because two unlikely concurrent failures would be required before a criticality accident could be possible.

<u>Using containers other than *Field Container*s for crushed piping debris classified as *Fissile Material*</u>
This scenario is discussed in Section 2.4.2.2 for soil and is equally applicable to crushed piping debris. Refer to Section 2.4.2.2 for details.

<u>Placing multiple *Field Container*s into a single CD or larger container</u>
This scenario is discussed in Section 2.4.2.2 for soil and is equally applicable to crushed piping debris. Refer to Section 2.4.2.2 for details.

2.4.3.3 Summary of Risk Assessment

Based on the risk assessment provided in Section 2.4.3.2, the following conditions must exist before a criticality accident due to subterranean pipe excavation would be possible:

Criticality in ground due to subterranean intact piping extraction:

- Significant *Fissile Material* during past production operations was discarded into non-fissile process piping and storm water system flowing into the site creek or septic system; and
- Intact subterranean piping must contains *Fissile Material* above the *Extracted Piping Fissile Material Limit*; and
- In-situ application of spray fixative or grouting material of intact subterranean pipe section is ineffective in immobilizing residue within pipe section when lifted

* The *cut depth* of debris consisting of pipe fragments and soil is provided in the calibration basis document for the assay equipment.

multiple times; and
- Extraction of intact pipe section results in a severe angling, fracture, or load drop; and
- Residue within intact piping section does not configure into a slab or mound on the ground but rather into a de minimis surfaced sphere (i.e., into a hole) repeatedly.

Criticality during intact pipe bulking activities due to ineffective immobilization of residues:
- Significant *Fissile Material* during past production operations was discarded into non-fissile process piping and storm water system flowing into the site creek or septic system; and
- Multiple intact subterranean piping sections are extracted from the ground with no or severely ineffective in-situ spray fixative or grouting material; and
- Multiple intact subterranean piping sections while on the stand are ineffectively inspected and/or not applied with effective grouting material; and
- Multiple intact pipe sections are bulked together in such a manner whereby all of its *Fissile Material* loading is accumulated in single location; and
- Residue within intact piping section does not configure into a slab spread out within the bulked debris but rather into a de minimis surfaced sphere (i.e., into a corner or pocket of the bulked pipe sections) repeatedly.

Criticality during intact pipe bulking activities due to highly *Fissile Material* concentrated pipe segments:
- Significant *Fissile Material* during past production operations was discarded into non-fissile process piping and storm water system flowing into the site creek or septic system; and
- Multiple subterranean piping sections are extracted from the ground and a single 10 liter segment of piping contains the entire *Fissile Material* mass of each pipe section; and
- Multiple intact pipe sections are incorrectly determined for enriched uranium concentration by multiple personnel; and
- After bulking activities, the highly *Fissile Material* concentrated intact pipe segments are extracted from the remaining portion of the pipe and randomly bulked together.

Criticality due to collecting pipe sections in CDs:
- Significant *Fissile Material* during past production operations was discarded into non-fissile process piping and storm water system flowing into the site creek or septic system; and
- Multiple pipe section assays inaccurately reports *Fissile Material Exhumation Limit* is not met; and
- Containers other than *CDs* are used to collect piping segments classified as *Fissile Material* **or** multiple piping segments are improperly loaded into a CD or otherwise situated together in a single excavation location.

Criticality as result of in-situ pipe crushing and subsequent bulking:

- Significant *Fissile Material* during past production operations was discarded into non-fissile process piping and storm water system flowing into the site creek or septic system; and
- Subterranean piping must be significantly above the *NCS Exempt Material* criteria
- Grouting or other filler material was not applied correctly to subterranean piping to such a degree that compresses the Fissile Material from 10 segments into one segment; and
- Multiple personnel would need to incorrectly calibrate, misinterpret, or otherwise improperly perform surface assay procedure multiple times with two sets of assay devices prior to bulking crushed debris.

Criticality due to exhuming crushed piping debris with *Field Container*s:

- Significant *Fissile Material* during past production operations was discarded into non-fissile process piping and storm water system flowing into the site creek or septic system; and
- Multiple crushed piping debris assays inaccurately reports *Fissile Material Exhumation Limit* is not met; and
- Containers other than *Field Container*s are used to collect crushed piping debris classified as *Fissile Material* **or** multiple filled *Field Container*s are improperly loaded into a CD or otherwise situated together in a single excavation location.

2.4.3.4 Safety Controls

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

> **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).*

> **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 <u>and</u> 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.*

> **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.

Administrative CSC 13: *Prior to extracting an intact subterranean piping section, a spray fixative or grouting material SHALL be applied to the inside surfaces of the pipe section to effectively immobilize any residue within the pipe section. This application SHALL be ensured effective by at least two qualified individuals.*

Administrative CSC 14: *All reasonably practicable measures SHALL be taken to minimize the potential to fracture or break intact pipe sections during lifting from the ground, or to release any contained materials from the piping during lifting. The pipe section lifting operations SHALL be controlled by at least two qualified individuals.*

Administrative CSC 15: *Extracted intact pipe sections SHALL be positioned on a inspection stand in a horizontal orientation.*

Administrative CSC 16: *Grouting or other filling material SHALL be applied or reapplied as necessary to the internal surfaces of the intact pipe section while on the inspection stand. At least two qualified individuals SHALL ensure that grouting material has been adequately applied to the inside of pipe sections prior to removal from the inspection stand.*

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.*

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.*

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.*

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).*

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).

Safety Feature 01: *Field Containers (when used in support of a CSC).*

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.*

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

Administrative CSC 07: *Only a single Field Container SHALL be present outside the confines of a CD at one time. This is local to a particular excavation location. Specifically, if individual excavation locations are separated by at least 12 feet without reasonable potential for commingling decommissioning debris, then each excavation location is authorized to contain a single Field Container in use.*

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.*

2.4.4 Unexpected *Fissile Material* Quantities/Concentration in Septic Tanks and Drain Fields

2.4.4.1 Discussion

As discussed in Section 2.3.4, septic tanks are not anticipated to contain significant quantities of *Fissile Material* since the vast majority of content stems from lavoratories. However, because the septic system may be connected to the laboratory sinks and industrial washing machine drain lines used during fuel manufacturing operations, the septic systems may be contaminated. Therefore, it is conservatively assumed that there is no upper bound in terms of *Fissile Material* quantity or concentration within the septic tanks.

The remediation of the septic tanks' content is performed identically to that for soil remediation. Specifically, the contents are independently assayed with confirmation of results by multiple personnel. If the results satisfy *NCS Exempt Material* criteria, the contents are exhumed to a *cut depth* consistent with the calibration basis of the assay equipment, which in turn is based, in part, on the material composition of the septic tank contents. If the results do not satisfy *NCS Exempt Material* criteria but do not exceed the *Fissile Material Exhumation Limit*, then the septic tank content is recovered into *Field Containers*, which are handled individually and placed (singly) within CDs. Refer to Section 2.4.2.1 for further details. Portions of septic tank contents determined to contain *Fissile Material* in excess of the *Fissile Material Exhumation Limit* will result in immediate cessation of septic tank content excavation operations pending evaluation and instruction from the NCS Organization.

Once the septic tanks are completely emptied and their entire content has been exhumed meeting the *NCS Exempt Material* criteria, then the septic tank structure and the associated drain field may be excavated without CSCs. Otherwise, if the septic content is determined to contain *Fissile Material*, then exhumation of the associated drain field and the septic tank structure is <u>not</u> permitted without further evaluation and instruction from the NCS Organization.

It is noted that the soil above a drain field is not considered part of the drain field in this NCSA. Exhumation of this top soil may be performed without implementing any CSCs, irrespective of the conditions encountered in the septic tanks. However, the perforated tubing of the drain field and soil/gravel/sand/rock below is considered part of the drain field and must <u>not</u> be exhumed without further evaluation and instruction from the NCS Organization if any portion of the connected septic tank contents is established to meet *Fissile Material* classification.

2.4.4.2 Risk Assessment

The risks associated with exhumation of septic tank content are bounded by the risks associated with soil exhumation. Refer to Section 2.4.2.2 for this risk assessment. In addition, there is no credible criticality risk associated with exhumation of the septic tank structure or the connected drain field as long as the complete septic tank contents are established to meet *NCS Exempt Material* criteria.

2.4.4.3 Summary of Risk Assessment

The risks associated with exhumation of septic tank content are bounded by the risks associated with soil exhumation. Refer to Section 2.4.2.3 for a summary of this risk assessment.

2.4.4.4 Safety Controls

The CSCs associated with exhumation of septic tank content are identical to the CSCs established for soil exhumation operations in Section 2.4.2.4, except that the CSC emphasis is on septic tank content material rather than soil. These CSCs are repeated below but with emphasis on septic tank content material.

> **Safety Related Equipment 01:** *Assay equipment used to classify sub-surface structure decommissioning debris as NCS Exempt Material (i.e., $\leq 1\ g^{235}U$ 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).*
>
> **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.*
>
> **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.*
>
> **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.

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).*

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).

Safety Feature 01: *Field Containers (when used in support of a CSC).*

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.*

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

Administrative CSC 07: *Only a single Field Container SHALL be present outside the confines of a CD at one time. This is local to a particular excavation location. Specifically, if individual excavation locations are separated by at least 12 feet without reasonable potential for commingling decommissioning debris, then each excavation location is authorized to contain a single Field Container in use.*

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.*

Administrative CSC 19: *If any portion of the content of a septic tank is exhumed as Fissile Material, then the septic tank structure and its associated drain field (i.e., perforated tubing and soil/rock/gravel/sand below) SHALL NOT be exhumed without approval from the NCS Organization.*

3.0 SUMMARY OF CRITICALITY SAFETY CONTROLS

3.1 Criticality Safety Parameters

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

Table 3-1 Criticality Safety Parameters

Nuclear Parameter	Controlled (Y/N)	Basis	Reference
Mass	Y	*Fissile Material* mass control is necessary because many operations associated with sub-surface structure decommissioning could potentially involve heterogeneous forms of *Fissile Material* in a volume potentially larger than a maximum safely subcritical volume. Accumulation of heterogeneous *Fissile Material* is demonstrated to be adequately limited below the maximum safely subcritical enriched uranium mass limit (i.e., 760 g ^{235}U) under all credible conditions.	Section 2.4.1 Section 2.4.2 Section 2.4.3 Section 2.4.4
Isotopic/ Enrichment	N	The safety assessment of sub-surface structure decommissioning activities is conservatively based on subcritical limits derived for uranium with 100 wt.% $^{235}U/U$ enrichment.	N/A
Volume	Y	The safety assessment of sub-surface structure decommissioning activities credits administrative CSCs that ensure that exhumed *Fissile Materials* will be packaged into limited volume *Field Containers*.	Section 2.4.1 Section 2.4.2 Section 2.4.3 Section 2.4.4
Geometry	N	There are no specific dimensions of equipment or containers credited in this NCSA.	N/A
Concentration	Y	Upper limits on enriched uranium concentration have been established to prevent criticality in this analysis. Many forms of decommissioning debris are anticipated to consist of a relatively uniform mixture of *Fissile Material* and other debris leading to the acceptability of concentration control.	Section 2.4.1 Section 2.4.2 Section 2.4.3 Section 2.4.4
Density	N	The safety assessment of sub-surface structure decommissioning activities is conservatively based on subcritical limits derived for uranium metal at maximum theoretical density.	N/A
Moderation	N	The safety assessment of sub-surface structure decommissioning activities is conservatively based on bounding credible moderation conditions.	N/A

Interaction	Y	*Field Containers* are used to collect debris that does not meet *NCS Exempt Material* criteria but is less than or equal to *Fissile Material Exhumation Limit*. The 20-liter maximum capacity of the *Field Container* helps to ensure that it is beyond *highly improbable* to assemble more than a maximum safely subcritical enriched uranium mass (i.e., 760 g ^{235}U). Therefore, multiple *Field Containers* are prevented from being within a particular excavation site to adequately minimize the risk of accumulating too much *Fissile Material* in a single location.	Section 2.4.1 Section 2.4.2 Section 2.4.3 Section 2.4.4
Reflection	N	The safety assessment of sub-surface structure decommissioning activities is conservatively based on bounding credible reflection conditions.	N/A
Neutron Absorber	N	No neutron absorbers are credited in this NCSA.	N/A
Heterogeneity	N	The safety assessment of sub-surface structure decommissioning activities is conservatively based on subcritical limits derived for homogeneous uranium-moderator mixtures (with 100 wt.% $^{235}U/U$ enrichment), for which subcritical limits are smaller than equivalent heterogeneous uranium-moderator mixtures. The potential reduction in safety factors (due to credible non-homogeneity) credited for concentration limits derived for homogenous systems is addressed in the various event sequences of this NCSA .	N/A

Source: Original

3.2 Engineered and Administrative Controls

This section provides a schedule of Systems Structures and Components (SSCs) and CSCs that have been established as important to safety in the risk assessment of sub-surface structure decommissioning activities. The SSCs and CSCs are numbered sequentially according to their identification in Section 2.4 of this document. Note that when SSCs and CSCs 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-09-08 Administrative CSC 01*.

3.2.1 Systems Structures and Components

The following SSCs have been recognized as important to ensuring the criticality safety of sub-surface structure decommissioning activities. The SSCs are identified as Safety Features (passive function) and Safety Related Equipment (active function). Based on their safety designation, the equipment listed in this Section is integral to this NCSA and sub-surface structure decommissioning activities would not be able to continue in their absence.

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).*

Safety Feature 01: *Field Containers (when used in support of a CSC).*

3.2.2 Criticality Safety Controls

The following CSCs have been recognized as important to ensuring the criticality safety of Sub-Surface Structure Decommissioning.

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

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.*

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.*

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).*

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.*

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

Administrative CSC 07: *Only a single Field Container SHALL be present outside the confines of a CD at one time. This is local to a particular excavation location. Specifically, if individual excavation locations are separated by at least 12 feet without reasonable potential for commingling decommissioning debris, then each excavation location is authorized to contain a single Field Container in use.*

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.*

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.*

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.*

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* <u>*and*</u> *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.*

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.*

Administrative CSC 13: *Prior to extracting an intact subterranean piping section, a spray fixative or grouting material SHALL be applied to the inside surfaces of the pipe section to effectively immobilize any residue within the pipe section. This application SHALL be ensured effective by at least two qualified individuals.*

Administrative CSC 14: *All reasonably practicable measures SHALL be taken to minimize the potential to fracture or break intact pipe sections during lifting from the ground, or to release any contained materials from the piping during lifting. The pipe section lifting operations SHALL be controlled by at least two qualified individuals.*

Administrative CSC 15: *Extracted intact pipe sections SHALL be positioned on a inspection stand in a horizontal orientation.*

Administrative CSC 16: *Grouting or other filling material SHALL be applied or reapplied as necessary to the internal surfaces of the intact pipe section while on the inspection stand. At least two qualified individuals SHALL ensure that grouting material has been adequately applied to the inside of pipe sections prior to removal from the inspection stand.*

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.*

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.*

Administrative CSC 19: *If any portion of the content of a septic tank is exhumed as Fissile Material, then the septic tank structure and its associated drain field (i.e., perforated tubing and soil/rock/gravel/sand below) SHALL NOT be exhumed without approval from the NCS Organization.*

4.0 CONCLUSION

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

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

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

It is noted that all analysis is assessed against limits derived for optimally moderated and idealized uranium systems. Thus, the presence of moderator during the assessed operations would not impact the analysis. Furthermore, there are no restrictions on the use of water for operations or for fire suppression.

5.0 REFERENCES

1. NSA-TR-09-15, Rev. 0, Buried Waste Exhumation and Contaminated Soil Remediation NCSA, B. Matthews, May 2009.

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

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