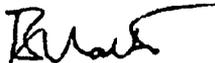


Nuclear Criticality Safety Assessment of Water Collection and Treatment Activities at the Hematite Site

Revision 0

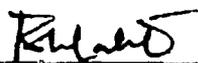
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List of Items To Be Verified

TBV #	Description
TBV1	When issued, the <i>Final Water Treatment System Preliminary Design Report</i> will be consistent with the <i>Draft Water Treatment System Preliminary Design Report</i> (Reference 9) assessed in this NCSA.

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Glossary of Acronyms, Abbreviations, and Terms

Acronym/Term	Definition
'	Foot (12")
"	Inch (2.54 cm)
ACM	Asbestos Containing Material
AEC	Atomic Energy Commission
ALARA	As Low As Reasonably Achievable
Assay Containers	Containers presented for radiological characterization at a MAA and which
Bq	One radioactive disintegration per second
cc	Cubic centimeter
CD	<p>Collared Drums (CDs) are used for <i>Field Container</i>, <i>Assay Container</i> or <i>Fissile Material Container</i> transit between functional areas of the site, and for <i>Field Container</i>, <i>Assay Container</i> or <i>Fissile Material Container</i> staging/storage. Each CD has a cylindrical geometry, possessing a minimum internal diameter of 57cm.</p> <p>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.</p>
CDBS	Collared Drum Buffer Store – area used to interim store <i>Field Containers</i> and <i>Assay Containers</i> that do not have assigned ²³⁵ U mass contents and are loaded in sealed CDs.
CDRA	Collared Drum Repack Area
CFR	Code of Federal Regulations
Ci	Curie (equivalent to 3.7 x 10 ¹⁰ Bq)
cm	Centimeter
CSC	Criticality Safety Control
DCGL	Derived Concentration Guideline Levels
DCP	Double Contingency Principle
Draw-down	The difference between static water levels before and after pumped discharge
D&D	Decontamination and Decommissioning
DinD	Defense-in-Depth
Field Containers	Containers loaded with solids recovered from a HDP remediation area or the site WTS, that comprise <i>fissile material</i> , or suspect <i>fissile material</i> .
Fissile Material Containers	Containers comprising material with an established ²³⁵ U gram content.
Fissile Material	Material containing fissile nuclides (e.g., ²³⁵ U) in a quantity/concentration sufficient to require NCS controls/oversight.



FMSA	Fissile Material Storage Area – area used to interim store <i>Fissile Material Containers</i> that have an ascribed ²³⁵ U mass content. The <i>Fissile Material Containers</i> are sealed within CDs.
g	Gram
GAC	Granular Activated Carbon
gallon	3.785 L
gpm	Gallons per minute
GUNFC	Gulf United Nuclear Fuels Corporation
HDP	Hematite Decommissioning Project
HDPE	High Density PolyEthylene
HEU	Highly Enriched Uranium
HPT	Health Physics Technician
HRGS	High Resolution Gamma Spectrometer
IX	Ion eXchange
kg	Kilogram
L	Liter
μ	Micro (1.0 x 10 ⁻⁶)
m	Meter
MAA	Material Assay Area - area used to assay exhumed <i>fissile material</i> , suspect <i>fissile material</i> or the material content of exhumed intact containers, in order to provide a ²³⁵ U gram inventory estimate.
mg	Milligram
NCS	Nuclear Criticality Safety
NCSA	Nuclear Criticality Safety Assessment
NCS Exempt Material	Material containing an insufficient quantity/concentration of fissile nuclides (e.g., ²³⁵ U) to require NCS controls/oversight
p	Pico (1.0 x 10 ⁻¹²)
PCE	Perchloroethylene
SNM	Special Nuclear Material - material containing fissile nuclides (e.g., ²³⁵ U)
SSC	System, Structure and Component
TCE	Trichloroethene
U	Uranium
UNC	United Nuclear Corporation
WEA	Waste Evaluation Area – area used to evaluate solid wastes generated from site remediation activities that are believed to have the potential to contain SNM in a quantity/concentration sufficient to require NCS controls/oversight.
WTS	Water Treatment System
wt. %	Percentage by weight

1.0 INTRODUCTION

This Nuclear Criticality Safety Assessment (NCSA) is provided to evaluate water treatment activities in support of final decommissioning of the Hematite site. The water treatment activities include processing of burial pit leachate, ground water, and storm water collected during final decommissioning of the Hematite site.

This NCSA provides the criticality safety basis for the waste Water Treatment System (WTS) and associated water collection and treatment operations. Recovery, containerization and handling of solid wastes generated as part of the water treatment activities are also addressed in this NCSA. However, operations involving evaluation/assay of the containerized solids and their final disposition (e.g., storage or waste shipment) are excluded from this NCSA. These operations are addressed in Reference 14. Also excluded from the scope of this NCSA are operations involving buffer storage of un-evaluated/un-assayed containerized solids and storage of assayed containerized solids with SNM in quantities of concern (i.e., requiring NCS controls). These storage operations are addressed in References 15 and 13, respectively.

This NCSA is organized as follows:

- **Section 1** introduces the NCSA of water treatment activities at the Hematite site and provides an overview of the specific equipment to be used as well as the activities to be performed.
- **Section 2** provides the risk assessment of the water treatment equipment and activities outlined in Section 1.
- **Section 3** summarizes the important facility design features, equipment and procedural requirements identified in the criticality safety risk assessment provided in Section 2.
- **Section 4** details the conclusions of the NCSA for water treatment activities at the Hematite site.

1.1 Description of the Hematite Site

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

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

1.2 Hematite Site History

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

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

1.2.1 Historic Operations

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

1.2.1.1 Documented Burials

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



Source: Ref. 2

Figure 1-1 Documented Burial Pit Area

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

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

The information recorded in the Burial Pit log books indicates that the waste consignments comprised a wide variety of waste types. This is further supported by interviews with past employees (Ref. 6). A listing of the types of waste materials that may be present in the Burial Pits is provided in Table 1-1. The primary waste types expected to be encountered are trash,

empty bottles, floor tile, rags, drums, bottles, glass wool, lab glassware, acid insolubles, and filters. Buried chemical wastes include hydrochloric acid, hydrofluoric acid, potassium hydroxide, trichloroethene (TCE), perchloroethylene (PCE), alcohols, oils, and waste water.

Table 1-1 Buried Waste Characteristics

Process Metals and Metal Wastes	
<ul style="list-style-type: none"> • High enriched uranium (93-98%) • Depleted and natural uranium • Beryllia UO₂ • Beryllium plates • Uranium-aluminum • Uranium-zirconium • Thorium UO₂ 	<ul style="list-style-type: none"> • UO₂ samarium oxide • UO₂ gadolinium • Molybdenum • Uranium dicarbide • Cuno filter scrap that included beryllium oxide • Niobium pentachloride
Chemical Wastes	
<ul style="list-style-type: none"> • Chlorinated solvents, cleaners and residues (perchloroethylene, trichloroethylene) • Acids and acid residues • Potassium hydroxide (KOH) insolubles • Ammonium nitrate • Oxidyne • Ethylene glycol 	<ul style="list-style-type: none"> • Ammonium bichloride • Sulfuric acid • Uranyl sulfate • Acetone • Methyl-alcohol • Chlorafine • Pickling solution • Liquid organics
Other Wastes	
<ul style="list-style-type: none"> • Tiles from Red Room floor • Process equipment waste oils • Oily rags • TCE/PCE rags • Used sample bottles • Green salt (UF₄) • Calcium metal 	<ul style="list-style-type: none"> • Contaminated limestone • UO₂ THO₂ Paper Towels • Pentachloride from vaporizer • Used Magnorite • NbCl₅ vaporizer Cleanout • Item 51 Poison equipment • Asbestos and Asbestos Containing Materials (ACM)

Source: Adapted from Ref. 2

The recorded total uranium mass associated with the waste consignments range from 178 g²³⁵U to 802 g²³⁵U per burial pit with a maximum amount associated with any single waste consignment (i.e., burial item) of 44 g²³⁵U (Ref. 5). The uranium enrichment of waste items consigned to the burial pits ranged from 1.65 wt. % to 97.0 wt. % ²³⁵U/U. According to the Burial Pit log books, the five most frequent waste consignments comprised:

- Acid insolubles (2,050 entries);

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

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

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

1.2.1.2 Undocumented Burials

It is assumed (Ref. 2) that additional, undocumented, burial pits may exist within the area between the former process buildings and the documented burial pit area. Based on interviews with former site employees (Ref. 6), it is possible that on-site burials other than burials conducted under 10CFR20.304 (1964; Ref. 3)) may have occurred as early as 1958 or 1959. Specifically, three or four burials may have been performed each year prior to 1965 for disposal of general trash and items that were lightly contaminated by then current radiological free release standards (Ref. 8). Based on this information, it is estimated that a total of 20-25 burial pits may exist for which there are no records. Waste consignments to these burial pits (i.e., prior to 1965) were not documented (logged) as they were not considered to contain significant quantities of SNM (Ref. 7). No specific information has been found to indicate the explicit nature of the waste consignments associated with these undocumented burials.

1.2.1.3 Other Burials

1.2.1.3.1 Red Room Roof Burial Area

The Building 240 Red Room roof burial area is described in Reference 2. The Building 240 Red Room roof was replaced during the mid 1980s. The removed roofing materials were buried on site near Building 101 - the Tile Barn. The Red Room roof burial area has the potential to contain residual radioactivity in excess of natural background due to the high enriched processes that took place within the Red Room from 1956 through 1973. However, since only roofing materials were known to be consigned to this burial area, it is believed that the potential to encounter any significant residual uranium is very small.

1.2.1.3.2 Cistern Burn Pit Area

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

1.2.2 Current State

The burial pits are currently in a quiescent state, although the pits may have been subjected to disturbances in the past and have been subjected to characterization sampling initiatives (Ref. 9). The results of sampling initiatives indicate a maximum ^{235}U concentration of 53.5 pCi/g, corresponding to a ^{235}U concentration of approximately 2.5 $\mu\text{g/g}$ (waste matrix). Based on this sample data and the original burial logs, the burial pits are believed to contain only small quantities of ^{235}U (i.e., less than 1 kg ^{235}U per burial pit). The findings of more recent (May 2008) extensive site sampling initiatives further support this expectation (refer to Section 1.2.2 of Reference 1 for further details).

1.3 Overview of the Water Treatment Activities

Soil and ground water at the site have been contaminated with former processing by-product materials such as volatile organic compounds (VOCs) and radioactive materials (uranium and technetium). During excavation and recovery of contaminated solid wastes from the burial pits a considerable amount of water is expected to intrude into the open excavations, including ground water seepage and rainwater. This water will be evacuated from the excavations to allow recovery of the buried wastes. Water removed during this process will be treated to remove entrained and soluble contaminants prior to release to the site water outfall.

Water will be generated from the following sources:

- Ground water associated with buried waste (leachate);
- Ground water that may seep into the excavation from surrounding soil;
- Precipitation that falls directly into an excavation; and
- Precipitation that falls onto waste and adjacent waste-processing areas.

Treatment of the water collected from in and around the burial pit excavations involves a number of collection and treatment stages:

- Collection of leachate, ground, and storm water from an excavation or wells;
- Settling of coarse solids in holding tanks;
- Filtration and volatiles adsorption; and
- Filtration and ion exchange polishing.

The abovementioned activities are described in detail in the following sub-sections based on the equipment design report (Ref. 9). A schematic of the system equipment and process flow are shown in Figure 1-2 (adapted from Ref. 9).

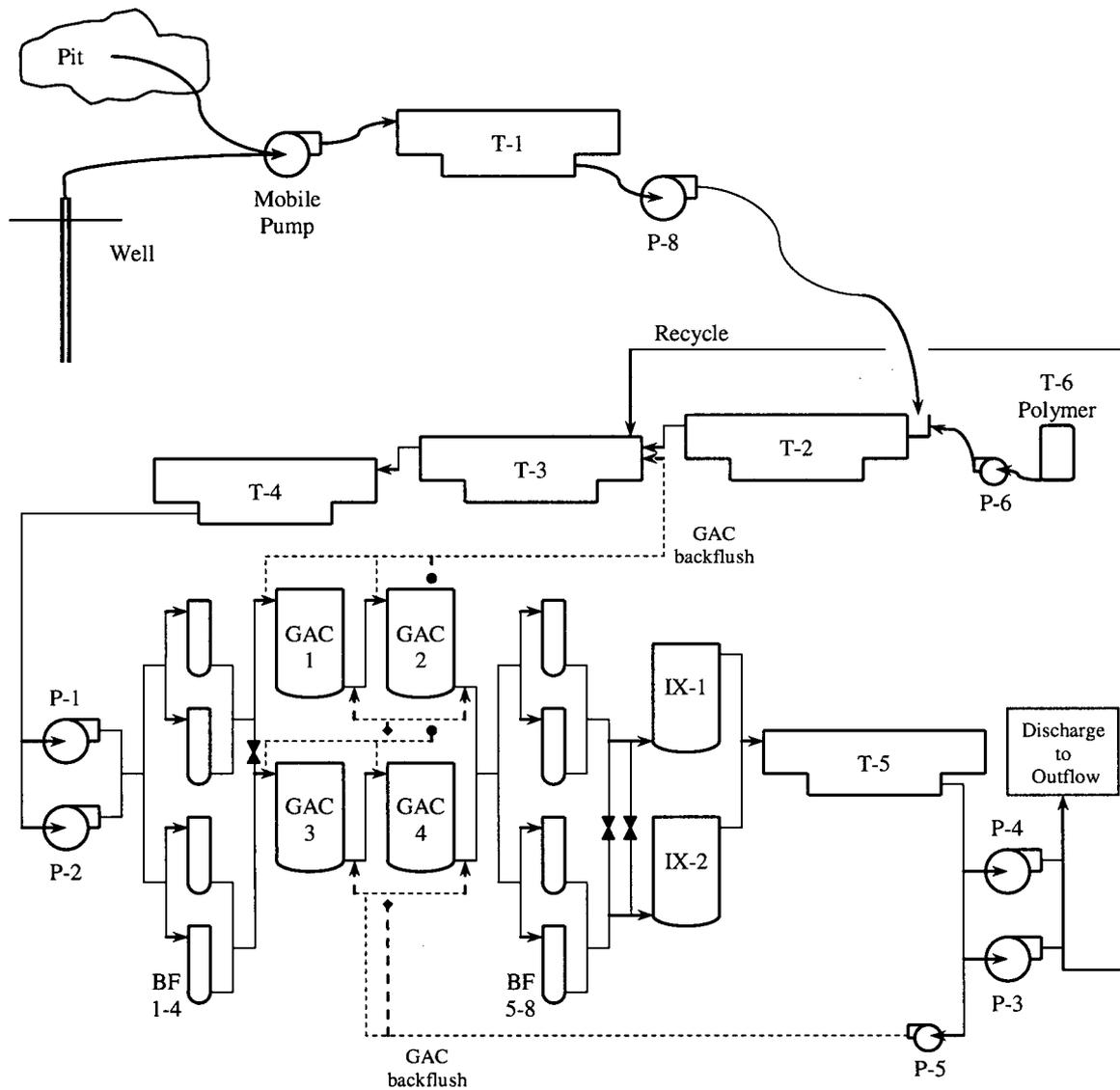


Figure 1-2 Waste Water Treatment System Schematic

1.3.1 Collection of Leachate, Ground Water, and Storm Water

During exhumation of buried wastes from burial pits, ground water, and any water from precipitation will be removed from the excavations, as necessary, to support the contaminated solid waste remediation efforts. Water collection will be achieved through strategically placed nearby water collection wells and use of portable water collection pumps (with a hose and strainer intake) used directly in the excavation, as necessary. All collected water will be pumped to a mobile 20,000-gallon steel tank (Tank T-1, Figure 1-1) positioned within the vicinity of the excavation. Commercially-available mobile construction water pumps will be used for both well pumping and for retrieval of water from the burial pits.

1.3.2 Settling of Solids in Holding Tanks

The water from the wells will be relatively clean, with very little entrained particulate matter due to the “filtered” construction of the wells. Leachate and excavation seep water, including rainwater that falls into the open excavations, will likely be laden with soil and relatively coarse solids that could rapidly foul the various downstream treatment media. The WTS is designed to allow the solids to settle out of the water in three successive tanks (T-1, T-2, and T-3, Figure 1-2).

Each tank will serve to progressively clarify the water. At the excavation site, the T-1 tank will collect the heaviest, most-course mud and any gravel entrained in the water as it is directly pumped from the burial pit excavation. The outlet to the transfer pump is positioned on the sidewall of the tank to allow some settling of the heaviest soils and gravel. Periodic inspections and cleanouts of the tank will be performed to keep the collected material level below that of the outlet.

Tank T-2 serves as the first active treatment step where the influent waste water is first mixed with a polymer flocculent before it overflows into the tank itself. The gravity overflow outlet to the next tank in line (T-3) is positioned near the tank roof to allow most of the flocculated materials to drop to the bottom of the tank and not be carried over to the next tank. Periodic inspections and cleanouts of the tank will be performed to limit the collected material level.

Both tanks T-3 and T-4 allow for additional settling of solids. As with tank T-2, the T-3 tank overflow outlet is positioned near the roof of the tank, providing suspended solids with a relatively undisturbed volume within which to settle out. Tank T-3 also serves as the inlet for the system clean recycle flow as well as the carbon bed back-flush receiving vessel. It is expected that little entrained solid material will be carried over to tank T-4 which serves primarily as the feed reservoir to the downstream WTS filtration and treatment equipment. Transfer pumps drawing their suction from an outlet near the base of tank T-4 move the water from the holding tanks through the treatment media (described in Sections 1.3.3 and 1.3.4).

1.3.3 Filtration and Volatiles Adsorption

The waste water is pumped from T-4 through two parallel treatment streams. Each stream passes through a bag filter (two redundant / parallel filter units on each stream path) and on through two Granular Activated Carbon (GAC) beds in series on each stream. The filters remove any remaining entrained solid particulates while the GAC units serve to remove any remaining VOCs in solution in the waste water.

Periodically, the GAC units will require back-flushing to break up the carbon bed and remove accumulated solids plugging or blinding the GAC bed. Clean water from tank T-5 (see section 1.3.5) will be pumped from T-5 through the GAC units (opposite normal flow) to an inlet on tank T-3 separate from its normal overflow inlet from T-2 where the solids will settle out.

1.3.4 Filtration and Ion Exchange

After passing through the GAC beds the waste water is filtered again with a finer bag filter mesh

to polish out any remaining solids. From this second set of bag filters the water is passed through an ion exchange (IX) bed (one on each treatment stream) to remove any radiological contaminants remaining in solution. Finally, the treated water is deposited in tank T-5.

1.3.5 Recycle and Discharge

Tank T-5 serves as the final holding point for the waste water – now cleaned and ready to be discharged. Two flows are continuously pumped out of the tank including the final discharge back to the environment at the site outflow in the Site Creek, as well as the variable clean water recycle diversion back to tank T-3.

Samples for water purity and system effectiveness will be extracted from either tank T-5 or the WTS water discharge system on a regular basis.

1.3.6 Collection of Sediments from Tanks

A Collared Drum (CD) vacuum will be used to remove wet sediments from the bottom of the WTS Holding tanks. As operationally necessary, the water in a tank to be cleaned will first be emptied using a portable sump pump (tanks T-2 and T-3) or the normal drain transfer pump (tanks T-1, T-4, and T-5). The sediments will be sampled and analyzed for fissile contamination before removal from the holding tank and at least once a month during tank operations. Once sample results are returned and verified acceptable, an operator will then access the tank and guide the vacuum suction hose intake around the tank floor as necessary to remove and transfer sediments directly into CDs pre-loaded with absorbent material (e.g., an immobilizing compound) to soak up any residual water associated with the sediments.

Each loaded CD will be lidded, transferred to a WEA/MAA for evaluation/assay to determine ^{235}U content. The waste evaluation/assay results will be used to determine the final disposition of the content of each CD. Note that buffer storage of un-evaluated/un-assayed CDs containing solids recovered from the WTS is permitted. CD transit and buffer storage of un-assayed CDs in a Collared Drum Buffer Store (CDBS) is addressed in Reference 15.

1.3.7 Filtration and Treatment Media Change-Outs

Periodically, the filtration and treatment media, such as GAC and IX media, will require removal and replacement. The following sub-sections discuss the handling activities for these solid waste materials.

1.3.7.1 Filter Bags

The polypropylene filter bags (or similar material) will likely require frequent replacement (need for replacement is determined by measurement of the head pressure required to pump water through the filter). Prior to replacement, the bag filter pair is valved out of service and blown down with a portable air compressor, as necessary, to effectively dry the sediments and filter bag. Following removal of the bag filter from its filter unit, the discharged filter is containerized in a CD and transferred to a WEA/MAA for evaluation/assay to determine ^{235}U content. The assay results are used to determine the final disposition of the filter. Note that buffer storage of un-evaluated/un-assayed CDs containing solids recovered from the WTS is

permitted. The transit and buffer storage of un-assayed CDs in a CDBS is addressed in Reference 15.

1.3.7.2 Treatment Media

The treatment beds (GAC and IX) will require periodic changing (need for changing is determined by measurement of the head pressure required to pump water through the respective treatment vessel). Unlike the bag filters, the GAC units will be backwashed to break up the carbon bed and remove entrained solids that are plugging or blinding the carbon bed. Treated effluent water from tank T-5 will be used as backwash water. Water will be pumped from tank T-5 backwards (up) through the GAC vessel being backwashed. The system is designed so that one set of two (2) GAC absorbers can be taken off-line for servicing or backwashing while the system runs at capacity (50 gpm) with only the second set of two (2) GAC units on-line. Backwash water from the GAC vessel being backwashed flows under pressure back to the inlet of storage tank T-3 for removal of suspended solids from the backwash water.

Prior to any replacement of the GAC media, the GAC vessel is valved out of service and the treatment media blown down with a portable air compressor, as necessary, to effectively dry the media. Samples of the media are extracted via the access ports on the media vessel and analyzed for fissile contamination at least once a week during operation to further ensure no significant *fissile material* concentration accumulates. Following confirmation of acceptable fissile contamination (limits are specified in Section 0), the treatment media is extracted and transferred directly into CDs pre-loaded with absorbent material (e.g., an immobilizing compound), as necessary. Each loaded CD is lidded and transferred to a WEA/MAA for evaluation/assay to determine ^{235}U content. The assay results are used to determine the final disposition of the content of each CD.

1.4 WTS Equipment Description

The WTS system comprises numerous pumps, transfer piping, tanks/vessels, and treatment media, as described in the following sub-sections. The descriptions provided are based on the general descriptions provided in Reference 9.

1.4.1 Intakes

Water transferred to the WTS may be drawn into the system through either wells or directly from the excavation pits (using a pumped portable hose with strainer intake).

Well Intake

The existing wells, or newly-drilled wells, may be used to draw-down ground water to assist in keeping the excavations dry. All wells will have a maximum 6" internal diameter. Portable sump pumps equipped with a 100 micron specification sock filters will be used to draw water from each of the various wells, with their discharge directed to the mobile holding tank (T-1 described in Section 1.4.2).

Excavation Intake

Water will be drawn directly from open burial pits during excavation of buried process wastes, if necessary, using a hose equipped with a rough-mesh debris strainer. The hose will serve as input to the suction pump, with its discharge directed to the mobile holding tank (T-1 described in Section 1.4.2).

1.4.2 Holding Tanks

Five 20,000 gallon steel tanks will be used in various stages of the WTS. All of the five tanks are similar, with one mobile and the others fixed in place. The single mobile tank (T-1) will be moved as necessary within the burial pit area to service the various burial pits as they are excavated.

Each holding tank is approximately 35 feet long and 8 feet wide, with a stairway at one end to the tank roof deck equipped with guardrails all around the perimeter. Cleanout hatches and personnel access hatches (with internal ladders) are provided, and a floor sump is provided at both ends of the tank to facilitate cleanout. Removable baffles may be installed inside to compartmentalize the tanks or provide overflow/underflow paths to aid in settling. The first treatment tank (T-2) will be modified to accommodate the flash mix compartment and the hydrogen peroxide feed system. Each tank is vented through the rooftop hatchways.

1.4.3 Chemical Tanks

The polymer mix tank (T-6) is a portable High Density Polyethylene (HDPE) chemical storage tank with a capacity of approximately 264 gallons. The polymer mix tank vented to the atmosphere and equipped with side-mounted inlet and outlet fittings, in addition to top fitting and manway hatch.

1.4.4 Pumps

A total of seven pumps are used to move the waste water from the excavation area through the WTS to the discharge point. The main system pumps (P-1, P-2, P-3, P-4, P-5, and P-7), including the pump between the excavation and first holding tank (T-1), are all rated in excess of 100 gpm to provide the maximum system design flow. Pump P-6 is a small chemical feed pump with a capacity of less than 2 gpm. The portable intake pumps are commercially-available self-priming gas- or diesel-driven pumps with a capacity in excess of 100 gpm. All of the other pumps are electrically-driven and are mounted in place within the environs of the WTS berm.

1.4.5 Bag Filters

The water treatment system employs eight bag filters, with each housing 8 inches in diameter by 30 inches long. Two sets of four filters – one set before the GAC beds, and one set after the GAC beds – provide sediment removal to minimize fouling of the GAC and ion exchange media.

The filters are paired on each of the two water streams split from the T-3 outlet stream, with only one of each pair online at a time. Each employs a polypropylene fabric bag filter media, with the mesh sizes set based on operational efficiency as necessary.

1.4.6 Granular Activated Carbon Beds

Four GAC beds, two in series on each water stream split from the T-3 outlet stream, provide for adsorption removal of VOCs from the waste water. Each GAC unit consists of a media-filled tank approximately 48 inches in diameter and 104 inches tall, with a GAC capacity of 2000 pounds. The tanks are made of mild steel with an epoxy coating lining the inside of the tanks. Access ports allow the media to be removed and replaced.

1.4.7 Ion Exchange Beds

Two ion exchange beds, one on each water stream split from the T-3 outlet stream, provide for adsorption removal of soluble radiological (i.e., uranium and technetium) compounds from the waste water. Each ion exchange unit consists of a media-filled tank approximately 48 inches in diameter and 104 inches tall, with a Zeolite (Type 1 Strong Base Anion Resin) capacity of 2000 pounds. The tanks are made of mild steel with an epoxy coating lining the inside of the tanks. Access ports allow the media to be removed and replaced.

1.5 Fissile Material

Any *fissile material* collected in the water treatment system will predominantly originate as entrained contamination from solid wastes buried in the numerous burial pits excavated as part of the remediation program. Historic consignment of contaminated materials to the burial pits was reported to have been conducted under a controlled program requiring documentation of each waste consignment. Contaminant controls at the time of disposal (e.g., containerization, bagging, etc.) in conjunction with the documented low surface contamination levels minimize the potential for significant migration of any radiological contaminants by ground water. There were no documented fissile liquid waste consignments (e.g., uranyl nitrate, etc.), possibly due to the inherent risk of contaminating ground water that could migrate offsite.

Quarterly sampling data (^{235}U data excerpted in Appendix B) from wells both within the burial pit area and around the site periphery consistently indicates minimal fissile contaminant presence in the ground water. The quarterly well samples show little to no ^{235}U presence, with results indicating a few pCi/L. The worst-case contamination was noted in some of the leachate for the pits where up to 340 pCi/L ^{235}U (~0.157 mg/L*) was noted (Ref. 9). The following data excerpted from Reference 9 (compiled from water sampling data) provide the basis for the waste water treatment system design.

* Conversion of pCi to mg:

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

$$\frac{3.40 \times 10^{-10} \text{ Ci/L}}{2.16107 \times 10^{-6} \text{ Ci/g}} = 0.15733 \text{ mg/L}$$

Table 1-2 Burial Pit Leachate Uranium Data

Radioisotope	Min.	Max.	Units
Uranium 233/234	24	7,900	pCi/L
Uranium 235	1	340	pCi/L
Uranium 238	24	449	pCi/L

Source: Adapted from Ref. 9

Table 1-3 Overburden Groundwater Uranium Data

Radioisotope	Min.	Max.	Units
Uranium 233/234	0.024	315	pCi/L
Uranium 235	<0.002	17	pCi/L
Uranium 238	0.002	56	pCi/L

Source: Adapted from Ref. 9

For the purpose of this criticality safety assessment, a conservative uniform contamination level of 340 pCi/L ²³⁵U will be assumed as a normal condition to address actual expected concentrations and anticipated upset conditions involving elevated contamination in some of the water collected and treated.

1.6 Scope of Assessment

The water treatment activities addressed in this NCSA include field activities related to water collection in excavation area (e.g. the burial pit area), the leach field, and land areas adjacent to the process buildings as dictated by the evolution of the remediation activities. Also addressed is treatment of water from collection of precipitation that falls onto waste and outside waste-processing areas.

The safety of any Special Nuclear Material (SNM) collected in the waste water during the burial pit remediation activities is assessed, including any solid SNM recovery (i.e., collection), containerization and handling. Operations involving assay of containerized solids are addressed in Reference 1. Interim storage of containerized solids with SNM in quantities of concern (i.e., requiring NCS controls) is addressed in Reference 13. Transportation of containerized solids to off-site facilities (e.g., to an offsite waste facility or an offsite sampling facility) is also specifically excluded from this assessment.

1.7 Methodology

1.7.1 NCSA Approach

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

The risk informed approach is complemented with an As Low As Reasonably Achievable (ALARA) assessment that is focused on identifying practicable measures that can be reasonably implemented to further reduce the risk of criticality to a level as low as is reasonably achievable.

The ALARA assessment also serves to provide an additional degree of confidence that a criticality incident resulting from the activities assessed is not credible.

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

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

1.7.2 Method of Criticality Control

The criticality safety basis for water treatment activities, including collection and handling of solid waste materials such as contaminated sediments and used treatment media is outlined in the following sub-sections.

1.7.2.1 Water Treatment System

Water treated for release to the environment is strictly regulated and requires removal of radiological contamination to very low levels. The ground water pumped from the burial pit excavations or wells is not expected to entrain significant (e.g., g/L level) concentrations of fissile contamination and previous routine sampling programs support this view. The low concentration of *fissile material* entrained in liquids collected during burial pit remediation activities is an underlying basis for safety of the WTS. The waste water is expected to contain pCi/L levels of contamination; at such concentration millions of liters of water must be processed before even a minimum critical mass of 760g ²³⁵U (for optimum conditions; Table A-1) could pass through the treatment equipment. Simple periodic cleanout of the holding tanks and filter media is expected to reduce and maintain any fissile contamination from the ground water to minimal levels such that potential accumulation of *fissile material* over time, as settled out / captured solids in holding tanks and filtration / treatment media, will not present

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

a criticality risk. Also, the equipment will be periodically inspected, sampled, or scanned to provide further assurance that significant *fissile material* quantities/concentrations are not accumulated.

1.7.2.2 Solid Wastes from Water Treatment System

The waste water treatment equipment installed for the excavation activities will collect entrained *fissile material* as solid wastes in various filtration steps. The solids generated by these processes will require recovery, containerization, handling, characterization and storage as a SNM package, or disposition as *NCS Exempt Material*, which is not subject to NCS controls.

The underlying criticality control philosophy for the collection and containerization of solids from the WTS (e.g., holding tank sediment and used treatment media) is based on limitation of SNM mass to within established maximum safe mass limits. This is achieved by collecting solids from the WTS into CDs, which together with maximum credible SNM concentration, will ensure that an unsafe mass of SNM cannot be collected into a container. Following collection of solids into a CD, the CD is sealed and transferred to the Waste Evaluation Area (WEA) for evaluation or directly to a Material Assay Area (MAA) for assay, to establish the total ^{235}U content. Any containers identified to hold sufficient SNM mass to require control of mass will be transferred to an approved Fissile Material Storage Area (FMSA). Containers established to contain insufficient SNM mass to require control of mass will be dispositioned as *NCS Exempt Material*, as defined in Reference 1. Note that buffer storage of un-evaluated/un-assayed CDs containing solids recovered from the WTS is permitted. The transit and buffer storage of un-assayed CDs in a CDBS is addressed in Reference 15.

2.0 CRITICALITY SAFETY ASSESSMENT

The criticality safety assessment is organized as follows:

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

2.1 Criticality Hazard Identification

This section outlines the technique used to identify criticality hazards associated with the waste water treatment system and handling of its solid wastes. A summary of the hazards identified is also provided, together with a brief description of their disposition in the NCSA.

2.1.1 Hazard Identification Method

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

As part of the *What-If/Checklist* analysis, the eleven (11) criticality safety controlled parameters are examined to determine the extent of their importance to criticality safety for water collection and treatment activities.

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

- Geometry
- Interaction
- Mass
- Isotopic/Enrichment
- Moderation
- Density

- Heterogeneity
- Neutron Absorbers
- Reflection
- Concentration
- Volume

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

2.1.2 Hazard Identification Results

A summary of the criticality hazards identified from the *What-If/Checklist* analysis is presented in Table 2-1 and are based on Reference 16. Hazards that result in events with similar consequences and safeguards are grouped in single criticality accident event sequences (analyzed in Section 2.4).

Table 2-1 Criticality Hazards Identified from the Water Treatment System What-if/Checklist Analysis

Event ID	What-if...	Causes	Consequences	Accident Sequence in NCSA
Geometry				
There are no identified hazards associated with geometry because the safety assessment of the individual WTS equipment is conservatively based on idealized simple geometries.				
Interaction				
There are no identified hazards associated with interaction between the WTS equipment containing uranium. This is because the safety assessment of the individual WTS equipment is conservatively based on collection and retention/deposition of 100% of the uranium contaminants in the respective equipment.				
Mass				
WTS-C-01	There is an accumulation of SNM in a pool of water in an open burial pit.	<ul style="list-style-type: none"> High removable contamination level in a burial pit with more fissile mass available than anticipated. 	Potential to exceed a maximum safe mass in a pool of water in an open burial pit.	Section 2.4.1
WTS-C-05	There is a reconfiguration of high ²³⁵ U content solids within WTS Equipment results in a significant accumulation of SNM.	<ul style="list-style-type: none"> High concentration of SNM in the WTS equipment in conjunction with significant disturbance during recovery of solids from the WTS equipment. 	Potential to exceed a maximum safe mass in WTS equipment.	Section 2.4.5
WTS-C-06	There is loading of high ²³⁵ U content solids into a Collared Drum.	<ul style="list-style-type: none"> High concentration of SNM in the WTS equipment. 	Potential to exceed a maximum safe mass in a CD.	Section 2.4.6
WTS-C-07	There is an accumulation of loaded CDs.	<ul style="list-style-type: none"> Procedure non-compliance. 	Potential to exceed a maximum safe mass in the area surrounding the WTS.	Grouped with event sequence in Section 2.4.6
Isotopic/Enrichment				
There are no identified hazards associated with presence of variable enrichment uranium in the WTS. This is because the safety assessment is conservatively based on subcritical limits derived for uranium with 100 wt.% ²³⁵ U/U enrichment.				

Event ID	What-if...	Causes	Consequences	Accident Sequence in NCSA
Moderation				
There are no identified hazards associated with moderation of uranium particulates in the WTS. This is because the safety assessment is conservatively based on subcritical limits derived for uranium-H ₂ O mixtures at optimum concentration.				
Density				
There are no identified hazards associated with presence of variable density uranium in the WTS. This is because the safety assessment is conservatively based on subcritical limits derived for uranium metal at maximum theoretical density.				
Heterogeneity				
There are no identified hazards associated with heterogeneity of uranium in the WTS. This is because the safety assessment is conservatively based on subcritical limits derived for homogeneous uranium-H ₂ O mixtures (with 100 wt.% ²³⁵ U/U enrichment), for which subcritical limits are smaller than equivalent heterogeneous uranium-H ₂ O mixtures.				
Neutron Absorbers				
There are no identified hazards associated with absence of fixed neutron absorbers in the WTS. This is because the safety assessment does not credit fixed neutron absorbers.				
Reflection				
There are no identified hazards associated with reflection of uranium in the WTS. This is because the safety assessment conservatively uses subcritical limits based on full (i.e., 30 cm) thickness close fitting water reflection conditions, which are considered to bound any credible reflection condition.				
Concentration				
WTS-C-02	There is excessive accumulation of ²³⁵ U in a well?	<ul style="list-style-type: none"> High removable contamination level in a burial pit with more fissile mass available than anticipated 	Potential to exceed a maximum safe concentration of 11.6 g ²³⁵ U/L in a water collection well.	Section 2.4.2
WTS-C-03	There is excessive accumulation of ²³⁵ U in a holding tank?	<ul style="list-style-type: none"> High removable contamination level in a burial pit w/ more fissile mass available than anticipated 	Potential to exceed a maximum safe areal concentration of 0.40 g ²³⁵ U/cm ² in a holding tank.	Section 2.4.3

Event ID	What-if...	Causes	Consequences	Accident Sequence in NCSA
WTS-C-04	There is excessive accumulation of ^{235}U in treatment / filtration equipment?	<ul style="list-style-type: none"> • High removable contamination level in a burial pit w/ more fissile mass available than anticipated • Operator error(s); failure to periodically replace filter/treatment media 	Potential to exceed a maximum safe concentration of $11.6 \text{ g}^{235}\text{U/L}$ in WTS filter <i>or</i> Potential to exceed a maximum safe areal concentration of $0.40 \text{ g}^{235}\text{U/cm}^2$ in a WTS GAC/IX bed	Section 2.4.4
Volume				
Volume control is not viable for the WTS due to the very large ground water feed rate to the WTS, and the consequent need for use of large volume vessels and tanks for water collection and treatment.				

Source: Events are identified in Ref. 16.

2.2 Generic Safety Case Assumptions

The water collection and treatment activities considered in this criticality safety assessment relate to contaminated water treatment and solid wastes from the treatment process as defined in Section 1.3. This section outlines the generic assumptions on which this criticality safety assessment is based.

2.2.1 Fissile Material Assumptions

The pertinent underlying assumptions of the assessment related to the *fissile material* that may be encountered in these activities are as follows:

- This assessment does not consider fissile nuclides other than ^{235}U . Based on the history of the site and site documentation (refer to Section 1.2.1.1), there is no expectation that fissile nuclides other than ^{235}U could exist within the site boundary.
- *Fissile material* limits have been derived assuming homogeneous mixtures of ^{235}U and water (H_2O). This approach is conservative with respect to other *fissile materials* containing uranium, including process wastes.
- The *fissile material* associated with ground water is predominantly insoluble particulates of uranium as opposed to dissolved, or water-soluble compounds.

2.2.2 Operational and Equipment Assumptions

The pertinent underlying assumptions of the assessment related to the equipment used in these activities are as follows:

- The equipment and process is as described in Sections 1.3 and 1.4, based on Reference 9.

2.3 Normal Conditions

This section provides the criticality safety assessment of water collection and treatment activities under normal conditions.

2.3.1 Water Collection and Treatment

Under normal (i.e., expected) conditions water collected from the wells or open burial pits will contain only trace quantities of radionuclides, or at worst, a very low presence of fissile nuclides. The highest ^{235}U concentration observed in samples collected from site wells is only 340 pCi/L (Section 1.5), corresponding to $\sim 0.16 \text{ mg}^{235}\text{U/L}$. The maximum safe fissile concentration for an infinite system comprising only ^{235}U and water is $11.6 \text{ g}^{235}\text{U/L}$ (Table A-1). This limiting concentration is nearly five orders of magnitude greater than the highest concentration of $0.16 \text{ mg}^{235}\text{U/L}$ observed for samples collected from site wells. Thus, under normal (i.e., anticipated) conditions, there is a very large margin of safety owing to the extremely low concentration of *fissile material* anticipated to be entrained in collected ground water.

Under normal conditions, the only potential significant accumulation points for contaminants/particulate carried through the WTS by collected ground water concerns settled solids in the five Holding Tanks (in particular the first Holding Tank T-1 at the excavation site), in addition to filtration equipment, including filter media, GAC, and IX beds. Based on the very low concentration of fissile contaminants anticipated to be associated with collected ground water (i.e., $\text{mg}^{235}\text{U/L}$ levels or less), extremely large volumes of ground water would need to be processed, and all entrained ^{235}U removed and accumulated, before an unsafe mass of *fissile material* could accumulate. For example, based on the highest concentration of $0.16 \text{ mg}^{235}\text{U/L}$ observed for samples collected from site wells, it is seen that a total of 4.75 million liters (~ 1.25 million gallons) of water would be required before an accumulation of a $760 \text{ g}^{235}\text{U}$ maximum subcritical mass limit of ^{235}U would be possible* (based on an ideal, optimally-moderated, fully-reflected, spherical-geometry system, Table A-1), representing several months of operations. Even under these extreme conditions, enormous quantities of non-fissile contaminants/particulates would be associated with any filtered *fissile material*, providing a low concentration, inefficient system from a criticality standpoint. In practice, the WTS Holding Tanks, filter media, and GAC/IX beds would block due to the vast volume of non fissile particulates collected (e.g., soil, silt, etc.) long before an unsafe mass of *fissile material* could be collected.

Based on the above discussion, under normal (i.e., anticipated) conditions the WTS and associated water collection and treatment activities do not pose any criticality risk and very large margins of safety are expected.

* Derivation of volume to maximum safe mass:

$$\frac{760 \text{ g}}{0.16 \times 10^{-3} \text{ g/L}} = 4.75 \times 10^6 \text{ L}$$

2.3.2 WTS Solid Wastes Recovery, Containerization, and Handling

The contaminated sediments collected in the WTS Holding tanks as well as the filtration and treatment media will be collected and handled for disposal as part of routine operations associated with the water treatment processes. No further treatment or processing activities are planned for any solid materials recovered from the WTS other than containerization, characterization (i.e., assay), and disposition (e.g., storage, shipment, etc.). The WTS solid wastes are anticipated to have a very low concentration of *fissile material* (i.e., on the order of < 1 mg/L), but could potentially be concentrated with uranium to a level that exceeds the free release limit.

Based on the anticipated low contamination levels (i.e., < 1mg/L) and the largest individual equipment capacity of 20,000 gallons (each of the five Holding tanks), the total quantity of ^{235}U associated with the feed water will be of the order of tens of grams ^{235}U or less. Under these anticipated bounding normal conditions, at least order of magnitude batching of ^{235}U would be necessary before a maximum safe mass of 760 g ^{235}U (Table A-1) could accumulate in any individual WTS equipment. Under normal conditions, such a chronic accumulation of ^{235}U could only be associated with a far superior quantity of non-fissile solids, such as soil particulates and sediments, which would serve to dilute any ^{235}U and greatly increase the maximum safe mass*.

From the above discussion, it is seen that disturbance of solids within the large volume WTS equipment (i.e., Holding tanks and GAC/IX treatment vessels) does not present any criticality risk under normal conditions, due to insufficient *fissile material* mass within the respective equipment.

Normally, solid wastes are recovered from only one WTS component at any one time. Recovery and containerization of solids from a WTS vessel/tank is achieved by pumping the solids into a CD. Recovery and containerization of soiled filters from filtration equipment is achieved by manually accessing the filtration unit, removing the soiled filter and placing the soiled filter in a CD. Based on the insufficient *fissile material* mass within any individual equipment, and the servicing (i.e., recovery of solids) from only one component at any one time, it is seen that containerization of solid wastes does not present any criticality risk under normal conditions.

Following loading of a CD with solid wastes, the loaded CD is lidded and transferred to a WEA/MAA for evaluation/assay to determine ^{235}U content. CD handling and transit operations are addressed in Reference 15.

* Soil is a significantly poorer moderator than water. For example, the minimum critical mass in a plutonium system moderated by fully water saturated soil (40% soil-in-water) (Fig III.A.6(97)-4 of Ref. 11) is a factor of ~2.5 greater than the minimum critical mass for an otherwise equivalent aqueous system (Fig III.A.6-1 of Ref. 11). Scaling the minimum critical mass of ^{235}U in water (820 g, Table A-1) by the this ratio (2.5), it is estimated that a minimum of ~2 kg (^{235}U) would be required for a criticality to be possible by adsorption in soil. Note that the soil composition for the above data is defined in Table III.A.1-6 of Ref. 11.

2.4 Abnormal Conditions

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

- Section 2.4.1: Accumulation of SNM in a Pool of Water in an Open Burial Pit.
- Section 2.4.2: Excessive Accumulation of ^{235}U in a Well.
- Section 2.4.3: Excessive Accumulation of ^{235}U in a Holding Tank.
- Section 2.4.4: Excessive Accumulation of ^{235}U in Treatment / Filtration Equipment.
- Section 2.4.5: Reconfiguration of High ^{235}U Content Solids within WTS Equipment.
- Section 2.4.6: Loading of High ^{235}U Content Solids into a Collared Drum and/or Accumulation of Loaded Collared Drums.

2.4.1 Accumulation of SNM in a Pool of Water in an Open Burial Pit

2.4.1.1 Discussion

Remediation of the burial pits will result in disturbance of buried wastes. Due to the hydrology of the site and the un-lined construction of the burial pits, it is expected that ground water will be prevalent, which could result in accumulations of pools of water within burial pits undergoing remediation. In addition, precipitation occurring during remediation will further increase the potential for accumulation of pools of water in open burial pits. Water draw-down efforts (via both pumped wells in the vicinity of the pits and direct pumping from the pits via a hose and strainer intake) will minimize the potential for accumulation of pools of water in open pits. However, it is considered likely that pools of water will form during burial pit remediation.

The presence of water within burial pits undergoing remediation could provide a mechanism to remove SNM particulates from buried process wastes and entrain the removed SNM particulates in pooled water. Chronic accumulation of SNM within pooled water could potentially result in greater than a maximum subcritical mass (i.e., $>760 \text{ g}^{235}\text{U}$) in a localized volume, potentially presenting a criticality risk.

2.4.1.2 Risk Assessment

Based on historic data it is unlikely that the burial pits, individually, could contain an unsafe mass of ^{235}U , diminishing the probability of entrainment and suspension in a pool of water within a burial pit.

According to the documented burial logs (Ref. 5), the recorded total uranium mass associated with the waste consignments range from $178 \text{ g}^{235}\text{U}$ to $802 \text{ g}^{235}\text{U}$ per burial pit with a maximum amount associated with any single waste consignment (i.e., burial item) of $44 \text{ g}^{235}\text{U}$. Based on best available information, it is believed that the burial pits are nominally $20' \times 40'$ and $12'$ deep. Based on these approximate burial pit dimensions, $802 \text{ g}^{235}\text{U}$ corresponds to an average ^{235}U concentration of $\sim 3.0 \text{ mg}^{235}\text{U/L}$. It is acknowledged, however, that it is possible a pit could be excavated that contains burial waste with an elevated concentration of ^{235}U .

The maximum safe ^{235}U mass of $760 \text{ g}^{235}\text{U}$ corresponds to a full water-reflected spherical homogeneous mixture of ^{235}U and water $\sim 14 \text{ L}$ in volume at an optimum concentration of $55 \text{ g}^{235}\text{U/L}$; Table A-1). It is not reasonable to postulate that such idealized conditions could be achieved or even approximated in a burial pit. The random factors of water seep pathways through the contaminated wastes (to entrain uranium), uneven geometry of the excavation (both the water catch basin and surrounding wet dirt "reflection" surfaces), and entrained inert diluents (soil, clay, etc.) combined with the insolubility of the uranium contamination and its very low average concentration, prevent the assemblage of $>760 \text{ g}^{235}\text{U}$ in an idealized system. All of these factors would serve to drive the fissile mass necessary to achieve criticality to a much greater value, well exceeding the $\sim 0.8 \text{ kg}^{235}\text{U}$ documented maximum burial pit inventory.

Based on the above discussion, it is seen that the optimized conditions necessary for assemblage of a mass $>760 \text{ g}^{235}\text{U}$ in an efficient geometry, with a compact volume and optimum or near optimum concentration, are far removed from the conditions inherent in the excavations. Therefore, it is expected that actual safety margin would be very large. Even if the documented burial logs were grossly in error with regard to fissile loading, these factors would still prevent selective water entrainment and collection of uranium contamination into an efficient geometry, with a compact volume and optimum or near optimum concentration.

2.4.1.3 Summary of Risk Assessment

Based on the discussion provided in Section 2.4.1.2, it is concluded that there are no credible scenarios in which a criticality accident could occur as a result of collection of ^{235}U in pooled water within a burial pit. This assessment is supported by the following considerations:

- Most or all of the fissile mass in a worst-case burial pit would have to be entrained in random seepage of water through the contaminated items in the pit, despite its large spatial distribution and very low average concentration, in addition to its insolubility in water; and
- The entrained uranium would have to be of a high ^{235}U enrichment; and
- The ^{235}U contained in the pooled water would have to be assembled into an efficient geometry (i.e., spherical or near spherical); and
- The assembled ^{235}U mass would have to occupy a compact (i.e., small) volume; and
- The ^{235}U contained in the pooled water would have to be suspended at optimum, or near optimum, concentration; and
- Non fissile and non hydrogenous elements (e.g., sediment) would have to be absent, or at least present in negligible quantities within the assembled ^{235}U accumulation (otherwise these constituents would result in dilution and parasitic neutron absorption).

2.4.1.4 Safety Controls

The following procedural requirement (recognized as a Defense-in-Depth (DinD) control) is considered a practicable measure for further reducing criticality risk. It is considered that its implementation will ensure that the risks from criticality are as low as is reasonably achievable.

DinD Administrative Control 01: *Ground water management and collection activities should be conducted in a manner that minimizes the potential for pooling of water within an open burial pit(s).*

2.4.2 Excessive Accumulation of ^{235}U in a Well

2.4.2.1 Discussion

The main wells used for ground water pumping, as well as the ground water sampling and observation wells, provide collection volumes for water that has potentially been exposed to fissile contaminants associated with buried wastes. Chronic accumulation of SNM, in water suspension, in an unsafe geometry well could potentially present a criticality risk.

2.4.2.2 Risk Assessment

All sampling to date from wells both within the burial pit area and around the site periphery consistently indicates minimal fissile contaminant presence in the ground water. The highest concentration observed for samples collected from site wells is only 0.16 mg $^{235}\text{U}/\text{L}$. This highest recorded concentration is nearly five orders of magnitude less than the maximum safe fissile concentration for an infinite system comprising only ^{235}U and water (11.6 g $^{235}\text{U}/\text{L}$), Table A-1). Owing to the large spatial distribution and very low average concentration of *fissile material* within the burial pits, it is considered that the water collection wells would clog with *non-fissile material* long before a significant concentration of *fissile material* could entrain in a well. Based on this extremely large margin between expected uranium concentrations and the maximum safe concentration limit of 11.6 g $^{235}\text{U}/\text{L}$ for an uncontrolled geometry system, a criticality incident due to uranium in a well is not credible.

It is acknowledged that due to the inefficient geometry of the water collection wells (maximum 6" diameter cylinders, Section 1.3.1) the actual concentration that would be required before a criticality incident would be considered credible would be ~ 200 g $^{235}\text{U}/\text{L}$. This concentration corresponds to the maximum subcritical concentration for an infinitely long, full (i.e., 30 cm thick) water reflected cylinder 6.0" in diameter (Figure III.B.4(100)-2, Ref. 11). Chronic entrainment of fissile contaminants into a water collection well would also be expected to result in significant entrainment of non-fissile contaminants (e.g., soil, sediment, etc.), providing substantial dilution and parasitic neutron absorption. This would further increase the concentration required for a criticality incident in a well.

2.4.2.3 Summary of Risk Assessment

Based on the discussion provided above, it is concluded that there are no credible scenarios in which a criticality accident could occur as a result of collection of ^{235}U in a well. This assessment is supported by the following considerations:

- The collected well water would have to contain water with a ^{235}U concentration of at least 11.6 g $^{235}\text{U}/\text{L}$, i.e., nearly five orders of magnitude (1.0×10^5) greater than supported by previous sampling data; and
- The entrained uranium would have to be of a high ^{235}U enrichment; and
- The ^{235}U contained in the well water would have to be suspended at optimum, or near optimum, concentration; and
- Non fissile and non hydrogenous elements (e.g., sediment) would have to be

absent, or at least present in negligible quantities (otherwise these constituents would result in dilution and parasitic neutron absorption).

2.4.2.4 Safety Controls

The following DinD feature is recognized as a practicable measure for further reducing criticality risk. Its implementation will ensure that the risks from criticality are as low as is reasonably achievable, by ensuring very large concentrations of ^{235}U would have to be realized in a well before a criticality incident could occur.

DinD Design Feature 01: *Wells used for water draw-down activities have a maximum 6" internal diameter.*

2.4.3 Excessive Accumulation of ^{235}U in a Holding Tank

2.4.3.1 Discussion

Water pumped from the various water collection wells will be collected in large, 20,000 gallon capacity holding tanks, before being treated in the downstream WTS equipment. Due to the large volume and conventional geometry of the holding tanks, an accumulation of *fissile material* could potentially present a criticality risk.

2.4.3.2 Risk Assessment

All sampling to date from wells both within the burial pit area and around the site periphery consistently indicates minimal fissile contaminant presence in the ground water. The highest concentration observed for samples collected from site wells is only $0.16 \text{ mg}^{235}\text{U/L}$. This highest recorded concentration is nearly five orders of magnitude less than the maximum safe fissile concentration for an infinite system comprising only ^{235}U and water ($11.6 \text{ g}^{235}\text{U/L}$), Table A-1). Based on this minimal concentration, ground water collection and treatment in the WTS, including the large volume holding tanks, poses little risk of criticality.

It is not expected that large volumes of ground water will be contaminated to a level of $0.16 \text{ mg}^{235}\text{U/L}$, however, even if this were to occur, the total mass of ^{235}U associated with a completely filled 20,000 gallon capacity holding tank would be only $\sim 12 \text{ g}$. However, it is recognized that any settling of uranium particulates within a holding tank could result in a progressive accumulation of SNM over time.

Based on a water collection rate of $\sim 12,500$ gallons/day (Ref. 10) and a conservative 24-month project window, the water holding tanks and downstream treatment system could see a total water collection/treatment volume of ~ 9.13 million gallons. Even if all of this water were contaminated with only ^{235}U (i.e., no soils, sediment, ^{238}U or other diluents/parasitic neutron absorbers) at a concentration of $0.16 \text{ mg}^{235}\text{U/L}^*$, the maximum areal slab fissile concentration would be only $\sim 0.07 \text{ kg}^{235}\text{U/ft}^{2\dagger}$. The maximum safe areal slab fissile concentration for ^{235}U is almost a factor of six (6) greater; $0.37 \text{ kg}^{235}\text{U/ft}^2$ (Table A-1, Appendix A) corresponding to a full water reflected infinite slab of $^{235}\text{U-H}_2\text{O}$ at an optimum thickness of $\sim 7''$ ($\sim 17.8 \text{ cm}$). Thus, considerable margin of subcriticality would exist even under ideal conditions involving a conservative average leachate uranium concentration of $0.16 \text{ mg}^{235}\text{U/L}$, complete settling and

* It is recognized that limited amounts of leachate water may exceed a uranium concentration of $0.16 \text{ mg}^{235}\text{U/L}$, however, it is noted that on an average basis, a uranium concentration of $0.16 \text{ mg}^{235}\text{U/L}$ is considered very conservative due to the fact that over half of the water projected to be collected (i.e., ~ 5 million gallons) will originate in wells that have continually proven through sampling to have a maximum uranium concentration on average two orders of magnitude *less* than assumed of the leachate. The $340 \text{ pCi}(^{235}\text{U})/\text{L}$ value represents the maximum leachate sample value observed; most leachate will likely be of less uranium concentration, making the assumption of a higher average concentration very conservative.

† Based on a Holding Tank floor area of $70,606 \text{ cm}^2$, which is 50% of the actual tank floor area, measuring $19' \times 8'$, to account for raised end floor sections and baffles (which reduce the available cross-sectional area).

deposit of all ^{235}U entrained in the received leachate (i.e., no ^{235}U transferred downstream to the subsequent treatment equipment) and the absence of all other solids (e.g., soil, sediment, ^{238}U , etc.).

It is important to note that the assumption of complete deposition and settling of fissile contaminants within a holding tank while its contents are continually cycled over a two-year period represents an extremely conservative assumption. In addition, any fissile contaminants will be in the presence of far greater quantities of *non-fissile materials* such as sand, clay, etc. that will serve as diluents and potential parasitic neutron absorbers depending on the mineral content of the material. These materials would act to either immobilize the *fissile material* against random disturbances at the bottom of the tank, or be carried along with the *fissile material* and dilute it such that an even greater fissile concentration would be required before a criticality could be realized.

Considering this process and these maximum concentrations, it is not credible that a criticality could occur in a holding tank as a result of collection of contaminated water even if a single tank experienced the deposition of all entrained uranium contamination over the duration of the excavation activities. However, a DinD control is also added to sample the sediments in the holding tank to verify the uranium concentration does not exceed $0.1 \text{ g}^{235}\text{U/L}$ (far below the subcritical concentration limit of $11.6 \text{ g}^{235}\text{U/L}$). Based on this sampling frequency and volume of 12,500 gallons processed a day, this equates to a mass of $234 \text{ g}^{235}\text{U}$ that could be accumulated from an original concentration of $0.16 \text{ mg}^{235}\text{U/L}$. This is also less than the subcritical mass limit of $760 \text{ g}^{235}\text{U}$, and thus this control would have to fail significantly or several times before a minimum critical mass could be even collected. This therefore further supports that it is not credible for a criticality to occur in the holding tanks (i.e., sampling will detect off normal concentrations well before there could be a criticality concern).

2.4.3.3 Summary of Risk Assessment

Based on the discussion provided in Section 2.4.3.2, it is concluded that there are no credible scenarios in which a criticality accident could occur as a result of accumulation of ^{235}U in a holding tank. This assessment is supported by the following considerations:

- Uranium would have to accumulate in a holding tank and achieve an areal concentration of greater than $0.37 \text{ kg}^{235}\text{U/ft}^2$. Even if the uranium was accumulated in only a confined $2\text{m} \times 2\text{m}$ area, this would require the presence of $16 \text{ kg}^{235}\text{U}$ (more than half the quantity of ^{235}U associated with all documented burials on the Hematite site); and
- The accumulated uranium would have to be of a high ^{235}U enrichment; and
- Non fissile and non hydrogenous materials would have to be absent, or at least present in negligible quantities (otherwise these constituents would result in dilution and parasitic neutron absorption) – this being extremely unlikely given the significant presence of the predominant inert, diluting sediments.

2.4.3.4 Safety Controls

The following procedural requirement (recognized as a DinD control) is considered a practicable measure for further reducing criticality risk. It is considered that its implementation will ensure that the risks from criticality are as low as is reasonably achievable.

DinD Administrative Control 02: *Settled sediments in each of the WTS Holding Tanks (T-1, T-2, T-3, T-4 and T-5) should be sampled and assayed for ^{235}U content according to the following schedule:*

- *At least once per month during excavation activities; and*
- *Prior to clean-out of the sediments from a tank.*

In the event a sample assay result indicates a ^{235}U concentration >0.1 mg/cc (0.1g/L) further use of the associated tank(s) should be discontinued and the NCS organization notified.

2.4.4 Excessive Accumulation of ^{235}U in Treatment / Filtration Equipment

2.4.4.1 Discussion

Filtration and treatment (adsorption, ion exchange, etc.) equipment is designed to capture particulates out of a parent liquid stream either by simple entrapment (filters) or chemical reaction. In the case of the excavation pumping operations, the water removed from the wells or open burial pits may contain fissile contamination in the form of uranium oxides that will be retained in the WTS treatment and filter media (uranium oxides are not soluble in water). Additionally, the ion exchange beds are included in the system to polish the discharge stream of any limited contamination that may be in solution. During the course of site remediation, fissile concentration could increase in any or all of the treatment / filtration equipment and potentially accumulate over time. Due to the conventional geometry of the treatment / filtration equipment (i.e., non geometrically favorable with respect to criticality safety), it is possible that a chronic accumulation of ^{235}U in the filters or other treatment beds (GAC / ion exchange) could potentially present a criticality risk.

2.4.4.2 Risk Assessment

All sampling to date from wells both within the burial pit area and around the site periphery consistently indicates minimal fissile contaminant presence in the ground water. The highest concentration observed for samples collected from site wells is only $0.16 \text{ mg}^{235}\text{U/L}$. This highest recorded concentration is nearly five orders of magnitude less than the maximum safe fissile concentration for an infinite system comprising only ^{235}U and water ($11.6 \text{ g}^{235}\text{U/L}$, Table A-1). Based on this minimal concentration, ground water collection and treatment in the WTS, including the numerous treatment / filtration equipment, poses little risk of criticality.

In practice, any fissile contaminants entrained in collected water would be accompanied by a far greater quantity of non-fissile, inert particulates, such as soil sediments, etc. Consequently, any fissile particulates deposited in the WTS treatment / filtration equipment will likely be diluted by a significant quantity of *non-fissile material*, which generally represent significantly poorer moderators than water*. These material characteristics serve to increase the mass of *fissile material* required before a criticality accident would be possible.

In addition to the inefficient material characteristics noted above, the narrow cylindrical geometry of the bag filters (~7" (17.8 cm) in diameter), ensures that the mass of *fissile material* required before a criticality accident would be possible would significantly exceed that of an ideal spherical geometry system.

* Soil is a significantly poorer moderator than water. For example, the minimum critical mass in a plutonium system moderated by fully water saturated soil (40% soil-in-water) (Fig III.A.6(97)-4 of Ref. 11) is a factor of ~2.5 greater than the minimum critical mass for an otherwise equivalent aqueous system (Fig III.A.6-1 of Ref. 11). Scaling the minimum critical mass of ^{235}U in water (820 g, Table A-1) by the this ratio (2.5), it is estimated that a minimum of ~2 kg(^{235}U) would be required for a criticality to be possible by adsorption in soil. Note that the soil composition for the above data is defined in Table III.A.1-6 of Ref. 11.

The GAC and ion exchange beds offer much larger, unfavorable, geometry (the GAC and Ion exchange vessels are 48" in diameter and 104" in height) compared with the bag filters. However, their function is to distribute incoming liquid streams evenly across the face of a media bed. Consequently, any fissile loading will be approximately even throughout the cross-sectional area of the media bed. Based on:

- a total water collection/treatment volume of ~9.13 million gallons*,
- a vessel surface area of ~11,675 cm² (for the 48" diameter [121.92 cm] vessels, Ref. 10), and
- a conservative average concentration of 0.16 mg²³⁵U/L for all received ground water

it is seen that the maximum areal slab fissile concentration would be ~0.44 kg²³⁵U/ft². Even though this maximum concentration slightly exceeds the maximum safe areal slab fissile concentration of 0.37 kg²³⁵U/ft² (Table A-1, Appendix A), it is noted that the maximum safe areal slab fissile concentration is based on idealized conditions consisting of a full water reflected infinite slab of ²³⁵U-H₂O at an optimum thickness of ~7" (~17.8 cm). These conditions could not be achieved or even closely approximated in the WTS treatment / filtration equipment, including the large GAC and Ion exchange vessels. In particular, the presence of the media beds and non-fissile contaminants such as soil sediments, etc., will act as diluents and potential parasitic neutron absorbers depending on the mineral content of the material. The presence of these materials results in an increase in the fissile concentration required before a criticality could be realized. Even if idealized conditions were somehow created, the maximum safe areal slab fissile concentration (0.37 kg²³⁵U/ft²) corresponds to a total vessel mass of ~4.65 kg²³⁵U, which is far in excess of any credible arising. It is difficult to hypothesize conditions that could result in the accumulation of kilogram quantities of ²³⁵U in one of the GAC/Ion exchange vessels without also resulting in chronic accumulation of non-fissile contaminants to the extent that the filtration media would be blocked and dysfunctional.

Based on the above assessment, it is not credible that a criticality could occur in a GAC/Ion exchange vessel as a result of collection and accumulation of *fissile material* from operation of the WTS during course of the site remediation program. However, DinD measures are added that further demonstrates this scenario not to be credible. The filtration (bag filters) and treatment media (GAC and ion exchange beds) will be required to be monitored for radiological contaminant buildup at least once per week during excavation activities to ensure that the ²³⁵U mass is verified not to exceed 350 g²³⁵U. Also, the GAC and ion exchange media will be sampled and assayed for ²³⁵U content prior to clean-out of the media†. These additional controls will further ensure that a maximum safe mass will not be exceeded, but would also indicate a problem well before an safe areal density could be exceeded. Therefore, this further demonstrates that a criticality is not credible in this system.

* Estimated with a water collection rate of ~12,500 gallons/day (Ref. 10) and a conservative 24-month project window

† It is noted that extracting a representative sample from a ion exchange bed may be difficult due to the design of the equipment. Consequently, it is possible that samples may not be extracted from ion exchange beds prior to clean out. However, since the not credible determination for this event sequence is sustained without reliance on sampling, this is acceptable.

2.4.4.3 Summary of Risk Assessment

Based on the discussion provided in Section 2.4.4.2, it is concluded that there are no credible scenarios in which a criticality accident could occur as a result of collection of ^{235}U in filtration and treatment equipment. This assessment is supported by the following considerations:

- Uranium would have to accumulate in treatment and/or filtration equipment and achieve an areal concentration of greater than $0.37 \text{ kg}^{235}\text{U}/\text{ft}^2$. Based on the largest 48' diameter GAC vessels, this would require the presence of $\sim 4.65 \text{ kg}^{235}\text{U}$ (approximately one sixth the quantity of ^{235}U associated with all documented burials on the Hematite site); and
- The accumulated uranium would have to be of a high ^{235}U enrichment; and
- Non fissile and non hydrogenous materials would have to be absent, or at least present in negligible quantities (otherwise these constituents would result in dilution and parasitic neutron absorption) – this being extremely unlikely given the known presence of the filtration media and the significant presence of the predominant inert, diluting sediments.

2.4.4.4 Safety Controls

The following procedural requirements (recognized as a DinD controls) are considered practicable measures for further reducing criticality risk. It is considered that their implementation will ensure that the risks from criticality are as low as is reasonably achievable.

DinD Administrative Control 03: *The filtration (bag filters) and treatment media (GAC and ion exchange beds) should be monitored for radiological contaminant buildup at least once per week during excavation activities. In the event radiological monitoring indicates a ^{235}U mass $>350 \text{ g}^{235}\text{U}$ further use of the associated media should be discontinued and the NCS organization notified.*

DinD Administrative Control 04: *GAC and ion exchange media should be sampled and assayed for ^{235}U content prior to clean-out of the media. In the event a sample assay result indicates a ^{235}U concentration $>0.1 \text{ mg/cc}$ ($>0.1 \text{ g/L}$) further use of the associated GAC/ion exchange bed should be discontinued and the NCS organization notified.*

Notes:

1. *If an ion exchange bed cannot be practicably sampled (e.g., due to difficulty in extracting a representative sample), the ion exchange media may be removed without sampling but should first be monitored for radiological contaminant buildup.*

2.4.5 Reconfiguration of High ^{235}U Content Solids within WTS Equipment

2.4.5.1 Discussion

The *fissile material* associated with the process wastes consigned to the burial pits could potentially be drawn into the WTS through collection of water entrained with particulate. Water collection will be achieved through strategically placed nearby water collection wells and use of portable water collection pumps (with a hose and strainer intake) used directly in the excavation, as necessary. The water from the wells will be relatively clean, with very little entrained particulate matter due to the “filtered” construction of the wells. However, leachate and excavation seep water, including rainwater that falls into the open excavations, will likely be laden with soil and relatively coarse solids that will likely pass through the excavation hose strainer intake.

All collected water will be pumped to a mobile 20,000-gallon steel tank (Tank T-1, Figure 1-2) positioned within the vicinity of the excavation. The WTS is designed to allow the solids to settle out of the water in Holding Tank T-1, in addition to two successive Holding Tanks T-2 and T-3, Figure 1-2).

Based on the system design, it is likely that Holding Tank T-1, and to a lesser extent, Holding Tanks T-2 and T-3 will contain a significant quantity of solids. Subsequent filtration and treatment equipment is also expected to receive solids, but to an even lesser extent due to their downstream position.

The settling of solids in the WTS Holding tanks and treatment equipment (i.e., GAC/IX vessels) presents the potential to accumulate *fissile material*. This potential could be accentuated in the event of collection and treatment of water with abnormal (i.e., elevated) fissile contamination levels (i.e., $> 1\text{mg/L}$). Based on the assessment provided in Sections 2.4.3 and 2.4.4, it is seen that even under conservative chronic accumulation conditions, any build up of *fissile material* associated with settled solids is safely subcritical by virtue of its low concentration. However, activities related to recovery of solids from the WTS equipment raises the potential to reconfigure any settled *fissile material* into a more efficient geometry/arrangement, potentially presenting a criticality risk.

2.4.5.2 Risk Assessment

Based on a WTS water collection rate of ~12,500 gallons/day (Ref. 10) and a conservative 24-month project window, the WTS Holding tanks and downstream treatment vessels and filtration equipment could receive a total water volume of ~9.13 million gallons. Even if all of this water were contaminated with ^{235}U at the highest recorded concentration level of $0.16\text{ mg}^{235}\text{U/L}$, the total mass of ^{235}U associated with any WTS equipment could not exceed ~5.5 kg^{235}U . This bounding estimate of ^{235}U accumulation in an individual WTS tank, vessel or filtration unit is extremely conservative and clearly not credible because it is based on a very conservative average ^{235}U concentration extrapolated over 24-months of continual operation of the WTS, and without any removal of solids from the system or replacement of filtration

media. Furthermore, the bounding estimate is based on 100% deposition of *fissile material* in only a single component of the WTS (i.e., a single tank, vessel or filtration unit). In practice, water collected and treated in the WTS would be expected to have a very low average concentration of *fissile material* (i.e., $<<0.16 \text{ mg}^{235}\text{U/L}$, on an average basis). In addition, while it is acknowledged that the Holding tanks (in particular the mobile collection tank T-1) would collect the majority of any entrained solids (and hence the majority of entrained *fissile material*), distribution of solids throughout the entire WTS would occur, rather than exclusive accumulation in only one component of the WTS.

Any *fissile material* accumulation in the WTS would be accompanied by a much larger accumulation of non *fissile material* such as soil particulates and sediments, which would serve to dilute any ^{235}U and greatly increase the maximum safe mass. In practice, the presence of large quantities of soil/sediments in a single tank, vessel or filtration unit would cause operational problems long before a significant mass of ^{235}U could accumulate. Given these inherent conditions, it is difficult to envisage a situation in which a maximum safe mass of ^{235}U could accumulate in a single component of the WTS.

Based on the above discussion, accumulation of a maximum safe mass of ^{235}U in a single component of the WTS is deemed not credible. Because the assessment is based on a consideration of mass and does not credit geometry, any potential reconfiguration of accumulated ^{235}U (e.g., due to solids removal activities) does not present any criticality risk. However, DinD measures are added that further demonstrates this scenario not to be credible. A DinD control is also added to sample the sediments in the holding tank to verify the uranium concentration does not exceed $0.1 \text{ g}^{235}\text{U/L}$ (far below the subcritical concentration limit of $11.6 \text{ g}^{235}\text{U/L}$). Based on this sampling frequency and volume of 12,500 gallons processed a day, this equates to a mass of $234 \text{ g}^{235}\text{U}$ that could be accumulated from an original concentration of $0.16 \text{ mg}^{235}\text{U/L}$. This is also less than the subcritical mass limit of $760 \text{ g}^{235}\text{U}$, and thus this control would have to fail significantly or several times before a minimum critical mass could be even collected. Therefore, this further supports that it is not credible for a criticality to occur from solid collection from the holding tanks (i.e., sampling will detect off normal concentrations well before there could be a criticality concern). The filtration (bag filters) and treatment media (GAC and ion exchange beds) will be required to be monitored for radiological contaminant buildup at least once per week during excavation activities to ensure that the ^{235}U mass is verified not to exceed $350 \text{ g}^{235}\text{U}$. Also, the GAC and ion exchange media will be sampled and assayed for ^{235}U content prior to clean-out of the media*. These additional controls will detect a problem well before a safe mass could be accumulated. Thus, this further supports that it is not credible for a criticality during solids collection.

* It is noted that extracting a representative sample from a ion exchange bed may be difficult due to the design of the equipment. Consequently, it is possible that samples may not be extracted from ion exchange beds prior to clean out. However, since the not credible determination for this event sequence is sustained without reliance on sampling, this is acceptable.

2.4.5.3 Summary of Risk Assessment

Based on the discussion provided above, it is concluded that there are no credible scenarios in which a criticality accident could occur as a result of the reconfiguration of solids within WTS equipment. This assessment is supported by the following considerations:

- The individual tank, vessel or filtration unit would have to accumulate more than 760 g²³⁵U; and
- The accumulated uranium would have to be of a high ²³⁵U enrichment; and
- The accumulated ²³⁵U would have to be suspended at optimum, or near optimum, concentration in an efficient (i.e., water) moderating medium; and
- The accumulated ²³⁵U would have to be configured into a geometry that would favor a low critical mass system (i.e., assembled into a spherical or near spherical geometry); and
- Non fissile and non hydrogenous materials would have to be absent, or at least present in negligible quantities (otherwise these constituents would result in dilution and parasitic neutron absorption) – this being extremely unlikely given the presence of the predominant inert, diluting sediments and/or treatment media; and
- The assembled ²³⁵U content would have to be well reflected over at least a large majority of its surface area; and
- Chronic build-up of solids (which would be necessary for accumulation of a significant ²³⁵U mass) would likely present significant operational problems, which would result in equipment clean-out on a periodic basis to ensure minimal accumulation of ²³⁵U.

2.4.5.4 Safety Controls

The following procedural requirements (recognized as DinD controls) are considered practicable measures for further reducing criticality risk. It is considered that their implementation will ensure that the risks from criticality are as low as is reasonably achievable. Note that these DinD controls are also captured in the event sequences assessed in Sections 2.4.3 and 2.4.4.

DinD Administrative Control 02: *Settled sediments in each of the WTS Holding Tanks (T-1, T-2, T-3, T-4, and T-5) should be sampled and assayed for ²³⁵U content according to the following schedule:*

- *At least once per month during excavation activities; and*
- *Prior to clean-out of the sediments from a tank.*

In the event a sample assay result indicates a ²³⁵U concentration >0.1 mg/cc (>0.1 g/L) further use of the associated tank(s) should be discontinued and the NCS organization notified.



DinD Administrative Control 03: *The filtration (bag filters) and treatment media (GAC and ion exchange beds) should be monitored for radiological contaminant buildup at least once per week during excavation activities. In the event radiological monitoring indicates a ^{235}U mass $>350\text{ g }^{235}\text{U}$ further use of the associated media should be discontinued and the NCS organization notified.*

DinD Administrative Control 04: *GAC and ion exchange media should be sampled and assayed for ^{235}U content prior to clean-out of the media. In the event a sample assay result indicates a ^{235}U concentration $>0.1\text{ mg/cc}$ ($>0.1\text{ g/L}$) further use of the associated GAC/ion exchange bed should be discontinued and the NCS organization notified.*

Notes:

1. *If an ion exchange bed cannot be practicably sampled (e.g., due to difficulty in extracting a representative sample), the ion exchange media may be removed without sampling but should first be monitored for radiological contaminant buildup.*

2.4.6 Loading of High ^{235}U Content Solids into a Collared Drum and/or Accumulation of Loaded Collared Drums

2.4.6.1 Discussion

The WTS is designed to clarify collected water by capturing solids at various stages in the system, through settling, filtration, and GAC/IX treatment processes. Collection of solids in the WTS equipment could result in an accumulation of ^{235}U in various stages of the system. Recovery of collected solids into CDs raises the potential to concentrate and/or reconfigure any ^{235}U into a more efficient geometry/arrangement than experienced in the WTS, potentially presenting a criticality risk. Similarly, accumulation of multiple loaded CDs in the area around the WTS could potentially present a criticality risk.

2.4.6.2 Risk Assessment

Recovery of Solids into a Single CD

An assessment of the potential for accumulating a maximum safe mass of ^{235}U in a single component of the WTS is provided in Section 2.4.5.2 and is shown to be not credible. Consequently, recovery of solids from the WTS into a CD does not present any credible criticality risk. In fact, the criticality risk would be considered substantially reduced due to the small volume of CDs relative to the volume of the WTS equipment with the most potential to accumulate solids (e.g., the 20,000-gallon holding tanks).

Nevertheless, DinD measures are added that further demonstrates this scenario not to be credible. A DinD control is also added to sample the sediments in the holding tank to verify the uranium concentration does not exceed $0.1 \text{ g}^{235}\text{U/L}$ (far below the subcritical concentration limit of $11.6 \text{ g}^{235}\text{U/L}$). Based on this sampling frequency and volume of 12,500 gallons processed a day, this equates to a mass of $234 \text{ g}^{235}\text{U}$ that could be accumulated from an original concentration of $0.16 \text{ mg}^{235}\text{U/L}$. This is also less than the subcritical mass limit of $760 \text{ g}^{235}\text{U}$, and thus this control would have to fail significantly or several times before a minimum critical mass could be even collected in a CD. Therefore, this further supports that it is not credible for a criticality to occur from solid collection from the holding tanks (i.e., sampling will detect off normal concentrations well before there could be a criticality concern). The filtration (bag filters) and treatment media (GAC and ion exchange beds) will be required to be monitored for radiological contaminant buildup at least once per week during excavation activities to ensure that the ^{235}U mass is verified not to exceed $350 \text{ g}^{235}\text{U}$. Also, the GAC and ion exchange media will be sampled and assayed for ^{235}U content prior to clean-out of the media*. These additional controls will detect a problem well before a maximum safe mass could be accumulated. Thus, this further supports that it is not credible for a criticality during solids collection in a CD.

* It is noted that extracting a representative sample from a ion exchange bed may be difficult due to the design of the equipment. Consequently, it is possible that samples may not be extracted from ion exchange beds prior to clean out. However, since the not credible determination for this event sequence is sustained without reliance on sampling, this is acceptable.

Congregation of loaded CDs

Based on the very low concentration of WTS solids, any assemblage of loaded CDs would not present any credible criticality risk. In addition, the potential for a criticality accident due to congregation of loaded CDs containing very high fissile content is generically assessed in Reference 15. Based on the assessment in Reference 15 (which uses the result of calculations reported in Ref. 17), it is seen that the geometry and design of CDs ensures their safety when arranged in any unstacked configuration, even with each CD containing up to 350 g²³⁵U. Based on the expected very small quantities of ²³⁵U associated with filled CDs, there is no potential for a criticality incident due to a congregation of loaded CDs. Refer to References 15 and 17 for further details and justification.

In addition to the above, further risk reduction is achieved because each CD used at the Hematite site, irrespective of dimension, is fitted with a collar that extends 18" beyond the external radial surface of the CD. The CD collar is designed to ensure that any un-stacked arrangement of CDs would guarantee a minimum 36" separation distance between the outer surface 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 Collared Drum Repack Area (CDRA). Based on this engineered design feature, an array of CDs would be safely subcritical even if each individual CD contained a maximum safe mass of ²³⁵U, because their 36" spacing would ensure negligible neutron interaction (Ref. 18).

2.4.6.3 Summary of Risk Assessment

Based on the discussion provided above, it is concluded that there are no credible scenarios in which a criticality accident could occur as a result of loading of solid wastes, with an abnormally high fissile content, into a CD. This assessment is supported by the following considerations:

- The individual CD would have to be loaded with more than 760 g²³⁵U; and
- The loaded uranium would have to be of a high ²³⁵U enrichment; and
- The loaded ²³⁵U would have to be suspended at optimum, or near optimum, concentration in an efficient (i.e., water) moderating medium; and
- The loaded ²³⁵U would have to be configured into a geometry that would favor a low critical mass system (i.e., assembled into a spherical or near spherical geometry); and
- Non fissile and non hydrogenous materials would have to be absent, or at least present in negligible quantities (otherwise these constituents would result in dilution and parasitic neutron absorption) – this being extremely unlikely given the presence of the predominant inert, diluting sediments and/or treatment media.

The potential for a criticality accident due to congregation of loaded CDs is generically assessed in Reference 15. Refer to Reference 15 for a summary of this generic risk assessment.

2.4.6.4 Safety Controls

The following procedural requirements (recognized as a DinD controls) are considered practicable measures for further reducing the criticality risk associated with collection of solids in a CD. It is considered that their implementation will ensure that the risks from criticality are as low as is reasonably achievable. Refer to Reference 15 for a summary of the Criticality Safety Controls (CSCs) established to ensure the safety of congregation of CDs loaded with high fissile content.

DinD Administrative Control 02: *Settled sediments in each of the WTS Holding Tanks (T-1, T-2, T-3, T-4, and T-5) should be sampled and assayed for ^{235}U content according to the following schedule:*

- *At least once per month during excavation activities; and*
- *Prior to clean-out of the sediments from a tank.*

In the event a sample assay result indicates a ^{235}U concentration >0.1 mg/cc (>0.1 g/L) further use of the associated tank(s) should be discontinued and the NCS organization notified.

DinD Administrative Control 03: *The filtration (bag filters) and treatment media (GAC and ion exchange beds) should be monitored for radiological contaminant buildup at least once per week during excavation activities. In the event radiological monitoring indicates a ^{235}U mass >350 g ^{235}U further use of the associated media should be discontinued and the NCS organization notified.*

DinD Administrative Control 04: *GAC and ion exchange media should be sampled and assayed for ^{235}U content prior to clean-out of the media. In the event a sample assay result indicates a ^{235}U concentration >0.1 mg/cc (>0.1 g/L) further use of the associated GAC/ion exchange bed should be discontinued and the NCS organization notified.*

Notes:

1. *If an ion exchange bed cannot be practicably sampled (e.g., due to difficulty in extracting a representative sample), the ion exchange media may be removed without sampling but should first be monitored for radiological contaminant buildup.*

DinD Administrative Control 05: *All solid wastes associated with the WTS (e.g., settled solids in tanks, used treatment and filtration media, etc.) should be recovered into CDs.*

In support of the above DinD Administrative control, CDs are designated as DinD Safety Features, the Safety Functional Requirement being to possess a minimum internal diameter



of 57cm and to provide 36" isolation distance with any other CDs on account of the affixed collar that extends 18" beyond the external radial surface of the CD. The affixed collar is permanently secured to the CD and is not removed at any time the CD is being used, except when secured in a FMSA or CDRA.

DinD Safety Feature 01: *Collared Drums used for collecting WTS solid wastes.*

3.0 SUMMARY OF CRITICALITY SAFETY CONTROLS

3.1 Criticality Safety Parameters

The extent of control of each of the various criticality safety parameters introduced in Section 3.1 is summarized in Table 3-1.

Table 3-1 Criticality Safety Parameters

Nuclear Parameter	Controlled (Y/N)	Basis	Reference
Geometry	N	The safety assessment of the individual WTS equipment is conservatively based on idealized simple geometries. However, a DinD feature, related to limitation of the diameter of water collection wells is recognized as providing fault tolerance for the event sequence in Section 2.4.2.	Section 2.4.2
Interaction	N	The safety assessment of the individual WTS equipment is conservatively based on collection and retention/deposition of 100% of the uranium contaminants in the respective equipment.	N/A
Mass	N	Mass upsets resulting in the potential to exceed a maximum safe mass in a single location are established to be not credible. However, further fault tolerance in the form of DinD procedural controls has been identified.	Section 2.4.1 Section 2.4.5 Section 2.4.6
Isotopic / Enrichment	N	The safety assessment of WTS equipment is conservatively based on subcritical limits derived for uranium metal at maximum theoretical density, with 100 wt.% ²³⁵ U/U enrichment.	N/A
Moderation	N	The safety assessment of WTS equipment is conservatively based on subcritical limits derived for uranium-H ₂ O mixtures at optimum concentration.	N/A
Density	N	The safety assessment of WTS equipment is conservatively based on subcritical limits derived for uranium metal at maximum theoretical density, with 100 wt.% ²³⁵ U/U enrichment.	N/A

Nuclear Parameter	Controlled (Y/N)	Basis	Reference
Heterogeneity	N	The safety assessment of WTS equipment is conservatively based on subcritical limits derived for homogeneous uranium-H ₂ O mixtures (with 100 wt.% ²³⁵ U/U enrichment), for which subcritical limits are smaller than equivalent heterogeneous uranium-H ₂ O mixtures.	N/A
Neutron Absorbers	N	The safety assessment of WTS equipment does not credit fixed neutron absorbers.	N/A
Reflection	N	The safety assessment of WTS equipment conservatively uses subcritical limits based on full (i.e., 30 cm) thickness close fitting water reflection conditions, which are considered to bound any credible reflection condition.	N/A
Concentration	N	Concentration upsets resulting in the potential to exceed maximum safe concentration limits are established to be not credible. However, further fault tolerance in the form of DinD procedural controls has been identified.	Section 2.4.2 Section 2.4.3 Section 2.4.4
Volume	N	Volume control is not viable for the WTS due to the very large ground water feed rate to the WTS, and the consequent need for use of large volume vessels and tanks for water collection and treatment.	N/A

Source: Original

3.2 Criticality Safety Controls and DinD Controls

This section provides a schedule of Systems, Structures, and Components (SSCs), CSCs, and DinD controls that have been established as important to safety in the risk assessment of water collection and treatment activities. The SSCs, CSCs, and DinD controls are numbered sequentially according to their identification in Section 2.4 of this document. Note that when SSCs, CSCs, and DinD controls captured in an NCSA are used in other documents (including other NCSAs), they are referenced using the numeric identifier from the originating NCSA and preceded by the NCSA document number. For example, other documents citing the first DinD control captured in this NCSA use the following reference; *NSA-TR-09-13 DinD Administrative Control 01*.

3.2.1 Systems, Structures, and Components

No SSCs have been recognized as important to ensuring the criticality safety of water collection and treatment activities.

3.2.2 Criticality Safety Controls

No CSCs have been explicitly recognized as important to ensuring the criticality safety of water collection and treatment activities. However, the following CSC is important to ensuring that the bounding assumptions of this NCSA remain valid.

Administrative CSC 01: *In the event that the presence of fissile nuclides other than ^{235}U are identified (e.g., as a result of sample analysis or radiological assay), operations involving, or with the potential to involve the presence of SNM SHALL cease and the NCS organization notified.*

3.2.3 Defense-in-Depth Controls

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

DinD Design Feature 01: *Wells used for water draw-down activities have a maximum 6" internal diameter.*

DinD Administrative Control 01: *Ground water management and collection activities should be conducted in a manner that minimizes the potential for pooling of water within an open burial pit(s).*

DinD Administrative Control 02: *Settled sediments in each of the WTS Holding Tanks (T-1, T-2, T-3, T-4, and T-5) should be sampled and assayed for ^{235}U content according to the following schedule:*

- *At least once per month during excavation activities; and*
- *Prior to clean-out of the sediments from a tank.*

In the event a sample assay result indicates a ^{235}U concentration >0.1 mg/cc (0.1g/L) further use of the associated tank(s) should be discontinued and the NCS organization notified.

DinD Administrative Control 03: *The filtration (bag filters) and treatment media (GAC and ion exchange beds) should be monitored for radiological contaminant buildup at least once per week during excavation activities. In the event radiological monitoring indicates a ^{235}U mass >350 g ^{235}U further use of the associated media should be discontinued and the NCS organization notified.*

DinD Administrative Control 04: *GAC and ion exchange media should be sampled and assayed for ^{235}U content prior to clean-out of the media. In the event a sample assay result indicates a ^{235}U concentration >0.1 mg/cc (>0.1 g/L) further use of the associated GAC/ion exchange bed should be discontinued and the NCS organization notified.*

Notes:

1. *If an ion exchange bed cannot be practicably sampled (e.g., due to difficulty in extracting a representative sample), the ion exchange media may be removed without sampling but should first be monitored for radiological contaminant buildup.*

DinD Administrative Control 05: *All solid wastes associated with the WTS (e.g., settled solids in tanks, used treatment and filtration media, etc.) should be recovered into CDs.*

In support of the above DinD Administrative control, CDs are designated as DinD Safety Features, the Safety Functional Requirement being to possess a minimum internal diameter of 57cm and to provide 36" isolation distance with any other CDs on account of the affixed collar that extends 18" beyond the external radial surface of the CD. The affixed collar is permanently secured to the CD and is not removed at any time the CD is being used, except when secured in a FMSA or CDRA.

DinD Safety Feature 01: *Collared Drums used for collecting WTS solid wastes.*

4.0 CONCLUSION

This criticality safety assessment demonstrates that operations relating to the WTS and related activities described in Section 1.3 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 criticality accident event sequences identified in the *What-if* analysis and assessed in this NCSA are demonstrated to be not credible.

It is noted that this NCSA does not credit moderation control. Consequently, 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, NCSA of Buried Waste Exhumation and Contaminated Soil Remediation at the Hematite Site, B. Matthews, May 2009.
2. Historical Site Assessment, Revision 0, DO-08-005.
3. Code of Federal Regulations, Title 10, Part 20.304, "Disposal by Burial in Soil," 1964.
4. UNC Internal Memorandum, F. G. Stengel to E. F. Sanders, "Burial of Material," May 14, 1965.
5. Hematite Burial Pit Log Books, Volumes 1 and 2, July 16, 1965, through November 6, 1970.
6. Westinghouse Electric Corporation LLC, Employee Interview Records, 2000 to 2008.
7. CE Internal Memorandum, J. Rode to Bill Sharkey, "The Hematite Burial Grounds," March 5, 1996.
8. Selected Soil Areas Survey Plan For Westinghouse Electric Company Hematite, Missouri, C. Wiblin, May 2008.
9. Draft Water Treatment System Preliminary Design Report, Hematite Decommissioning Project, August 2008 [TBV1].
10. American National Standard for Nuclear Criticality Safety in Operations with Fissionable Materials Outside Reactors, ANS-8.1, American Nuclear Society.
11. Atlantic Richfield Hanford Company (1969), Criticality Handbook Volume II, R D Carter, G R Kiel, K R Ridgway.
12. LA-10860-MS, Critical Dimensions of Systems Containing ^{235}U , ^{239}Pu , and ^{233}U , 1986 Revision.
13. NSA-TR-09-12, Rev. 0, NCSA of Fissile Material Storage at the Hematite Site, D. Vaughn, May 2008.
14. NSA-TR-09-09, Rev. 0, NCSA of Waste Evaluation and Assay Activities at the Hematite Site, B. Matthews, May 2009.
15. NSA-TR-09-10, Rev. 0, NCSA of Collared Drum Staging, Buffer Storage and Transit at the Hematite Site, B. Matthews, May 2009.

16. NC-09-001, Rev. 0, Hazards and Operability Study for Decommissioning Activities in Support of the Hematite Decommissioning Project, April 2009.
17. NSA-CS-03, Rev. 0, Nuclear Criticality Safety Calculations for 350 g²³⁵U Drum Arrays, D. Vaughn, April 2009.
18. NSA-CS-04, Rev. 0, Nuclear Criticality Safety Calculations for Isolated Drum Storage, D. Vaughn, April 2009.

APPENDIX A

Relevant Criticality Data

CHARACTERISTICS OF BURIED WASTES AND CONTAMINATED SOILS

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

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

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

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

Single Items

The presence of a sufficiently large fissile mass (i.e., \geq a minimum critical mass) in a single accumulation could potentially result in a criticality. The maximum subcritical mass for ^{235}U in water is 760 g (Ref. 10), corresponding to optimum conditions of:

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

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

contaminated wastes.

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

CRITICAL AND SUBCRITICAL LIMITS

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

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

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

Source: Ref. 10 and Ref. 11

Notes:

1. Ref. 11, page III.B-2
2. Ref. 10, Table 1

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

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

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

Source: Ref. 11 and Ref. 12

Notes:

Ref. 11, page III.B-2

Ref. 12, Figures 14-17

APPENDIX B

Sampling Data Excerpts

License Well Rad Results

Sample ID	Station ID	Screened Horizon	Sample Date	Analyte	Result	Units	MDL
WS-15	WS-15	Overburden	5/15/2003	U-235	5.0	pCi/L	47.2
WS-15	WS-15	Overburden	3/30/2004	U-235	2.2	pCi/L	20.6
WS-15	WS-15	Overburden	9/29/2004	U-235	-29.2	pCi/L	40.3
WS-15	WS-15	Overburden	12/21/2004	U-235	-17.6	pCi/L	48.8
WS-15	WS-15	Overburden	1/21/2005	U-235	13.8	pCi/L	68.1
WS-16	WS-16	Overburden	5/15/2003	U-235	-58.7	pCi/L	108.0
WS-16	WS-16	Overburden	3/30/2004	U-235	-0.6	pCi/L	13.6
WS-16	WS-16	Overburden	9/29/2004	U-235	-10.8	pCi/L	57.0
WS-16	WS-16	Overburden	12/21/2004	U-235	-12.3	pCi/L	90.0
WS-16	WS-16	Overburden	1/21/2005	U-235	-35.9	pCi/L	55.9
WS-15	WS-15	Overburden	5/15/2003	U-235 (AS)	0.0	pCi/L	0.1
WS-15	WS-15	Overburden	3/30/2004	U-235 (AS)	0.0	pCi/L	0.0
WS-15	WS-15	Overburden	9/29/2004	U-235 (AS)	0.0	pCi/L	0.1
WS-15	WS-15	Overburden	12/21/2004	U-235 (AS)	0.2	pCi/L	0.4
WS-15	WS-15	Overburden	1/21/2005	U-235 (AS)	-0.1	pCi/L	0.2
WS-16	WS-16	Overburden	5/15/2003	U-235 (AS)	1.6	pCi/L	0.4
WS-16	WS-16	Overburden	3/30/2004	U-235 (AS)	0.3	pCi/L	0.1
WS-16	WS-16	Overburden	9/29/2004	U-235 (AS)	0.0	pCi/L	0.2
WS-16	WS-16	Overburden	12/21/2004	U-235 (AS)	0.1	pCi/L	0.3
WS-16	WS-16	Overburden	1/21/2005	U-235 (AS)	0.0	pCi/L	0.1
WS-16	WS-16	Overburden	11/2/2007	U-235 (AS)	0.0	pCi/L	0.5
WS-16	WS-16	Overburden	11/2/2007	U-235 (AS)	0.3	pCi/L	1.0

2nd Quarter 2007 IGMP Rad Results

Sample ID	Station ID	Screened Horizon	Sample Date	Analyte	Result	Units	MDL
GW-WS31-062807	WS-31	Jefferson City	6/28/2007	U-235	0.0	pCi/L	0.1
GW-PZ04-062807	PZ-04	Jefferson City	6/28/2007	U-235	0.0	pCi/L	0.0
GW-WS16-062907	WS-16	Overburden	6/29/2007	U-235	0.0	pCi/L	0.1
GW-BP20A-062607	BP-20A	Overburden	6/26/2007	U-235	0.0	pCi/L	0.1
GW-BP22A-062507	BP-22A	Overburden	6/25/2007	U-235	0.0	pCi/L	0.1
GW-BP21-062607	BP-21	Overburden	6/26/2007	U-235	0.0	pCi/L	0.1
GW-NB80-062807	NB-80	Overburden	6/28/2007	U-235	0.0	pCi/L	0.0
GW-BP17-062807	BP-17	Overburden	6/28/2007	U-235	0.0	pCi/L	0.0
GW-BP22B-062807	BP-22B	Overburden	6/28/2007	U-235	0.0	pCi/L	0.0
GW-BP20B-062707	BP-20B	Overburden	6/27/2007	U-235	0.2	pCi/L	0.1
GW-WS24-062907	WS-24	Overburden	6/29/2007	U-235	2.6	pCi/L	0.1

3rd Quarter 2007 IGMP Rad Results

Sample ID	Station ID	Screened Horizon	Sample Date	Analyte	Result	Units	MDL
GW-PZ04-091907	PZ-04	Jefferson City	9/19/2007	U-235	0.0	pCi/L	0.0
GW-WS31-091907	WS-31	Jefferson City	9/19/2007	U-235	0.0	pCi/L	0.0
GW-BP17-092107	BP-17	Overburden	9/21/2007	U-235	0.1	pCi/L	0.0
GW-BP20A-091807	BP-20A	Overburden	9/18/2007	U-235	0.0	pCi/L	0.0
GW-BP21-092007	BP-21	Overburden	9/20/2007	U-235	0.0	pCi/L	0.0
GW-BP22A-091807	BP-22A	Overburden	9/18/2007	U-235	0.0	pCi/L	0.0
GW-NB80-092007	NB-80	Overburden	9/20/2007	U-235	0.0	pCi/L	0.0
GW-WS16-091807	WS-16	Overburden	9/18/2007	U-235	0.0	pCi/L	0.1
GW-WS24-092107	WS-24	Overburden	9/21/2007	U-235	3.0	pCi/L	0.1

4th Quarter 2007 IGMP Rad Results

Sample ID	Station ID	Screened Horizon	Sample Date	Analyte	Result	Units	MDL
GW-PZ04-120507	PZ-04	Jefferson City	12/5/2007	U-235	0.0	pCi/L	0.0
GW-WS31-120307	WS-31	Jefferson City	12/3/2007	U-235	0.0	pCi/L	0.0
GW-BP17-120307	BP-17	Overburden	12/3/2007	U-235	0.1	pCi/L	0.2
GW-BP20A-120307	BP-20A	Overburden	12/3/2007	U-235	0.1	pCi/L	0.2
GW-BP21-120307	BP-21	Overburden	12/3/2007	U-235	0.0	pCi/L	0.1
GW-BP22A-120307	BP-22A	Overburden	12/3/2007	U-235	0.0	pCi/L	0.0
GW-NB80-120507	NB-80	Overburden	12/5/2007	U-235	0.0	pCi/L	0.1
GW-WS16-120407	WS-16	Overburden	12/4/2007	U-235	0.0	pCi/L	0.0

1st Quarter 2008 IGMP Rad Results

Sample ID	Station ID	Screened Horizon	Sample Date	Analyte	Result	Units	MDL
GW-PZ04-030608	PZ-04	Jefferson City	3/6/2008	U-235	0.0	pCi/L	0.0
GW-WS31-030408	WS-31	Jefferson City	3/4/2008	U-235	0.0	pCi/L	0.0
GW-BP17-030308	BP-17	Overburden	3/3/2008	U-235	0.0	pCi/L	0.1
GW-BP20A-030408	BP-20A	Overburden	3/4/2008	U-235	0.0	pCi/L	0.2
GW-BP20B-030508	BP-20B	Overburden	3/5/2008	U-235	0.0	pCi/L	0.0
GW-BP21-030508	BP-21	Overburden	3/5/2008	U-235	0.0	pCi/L	0.0
GW-BP22A-030508	BP-22A	Overburden	3/5/2008	U-235	0.0	pCi/L	0.0
GW-BP22B-030608	BP-22B	Overburden	3/6/2008	U-235	0.0	pCi/L	0.1
GW-NB80-030608	NB-80	Overburden	3/6/2008	U-235	0.0	pCi/L	0.0
GW-WS16-030508	WS-16	Overburden	3/5/2008	U-235	0.0	pCi/L	0.1
GW-WS24-030408	WS-24	Overburden	3/4/2008	U-235	2.2	pCi/L	0.1