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Proposed NRCDA Groundwater Pathway Conceptual Model

J. L. Wohlwend

B. T. Butcher

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This report documents the proposed approach for assessing the impact of changes to the Naval Reactor Component Disposal Area since the 2008 E-Area Low-Level Waste Facility Performance Assessment. The authors gratefully acknowledge L. L. Hamm for his contributions to this report.

EXECUTIVE SUMMARY

As requested by Solid Waste Management (SWM), this report documents the Savannah River National Laboratory's (SRNL's) evaluation of updated Naval Reactor waste container and inventory projections and proposes a Naval Reactor Component Disposal Area (NRCDA) groundwater (GW) pathway modeling approach for the next E-Area Low-Level Waste Facility (LLWF) Performance Assessment (PA).

Two areas within the E-Area LLWF are used as disposal sites for reactor components from the U.S. Navy. Currently, components arrive by rail and are moved by crane to the 643-26E at-grade gravel disposal pad. Prior to operational closure, reactor components were stored and ultimately disposed in-place on the 643-7E NRCDA (Wilhite and Flach 2004). Naval Reactor (NR) waste is comprised of highly radioactive components consisting of activated corrosion-resistant metal alloy contained within welded thick steel casks, and auxiliary equipment primarily contaminated with Activated Corrosion Products (sometimes referred to as "crud" by the U.S. Navy) at low levels and contained within thinner-walled bolted containers. The 643-7E disposal pad, which contains 41 casks and has an interim soil cover, is closed to future receipts. The latest NR waste projections for the 643-26E disposal pad are substantially different from the original estimates due to a change in reactor maintenance. The original estimate was for 50 heavily shielded, welded casks and 50 thinner-walled bolted containers (primarily shield blocks). Currently, NR Programs project 33 heavily shielded, welded casks, of which 31 are already in-place on the 643-26E pad, and 381 thinner-walled bolted containers.

In addition to new waste form projections, there have been changes in facility layout and closure plans as well as PA modeling improvements. This report documents these changes as well as key NRCDA recommendations from the 2015 PA Strategic Plan (Butcher 2016).

Key findings and recommendations are summarized in Table 0-1 below.

Table 0-1. Comparison of Proposed Modeling Approach with 2008 E-Area LLWF PA.

Model Feature-Aspect	New Approach	2008 PA Approach	Justification
Number of NR Containers on 643-26E	Open ended	100 cask limit	Requested by SWM
Type of Analysis	Limits analysis - model unit curie of each rad for comparison with Performance Objectives	Preliminary closure analysis - modeled dose impact of projected inventory supplied by NR - scaled results for limits	Requested by SWM
643-7E	Perform closure analysis on final inventory from 41 containers	Applied results of 643-26E model to 643-7E performance	Changes in flow paths due to new aquifer model
Limits	Separate limits - ACP and activated metal, bolted and welded casks	Single set of limits - combined all forms of inventory into a representative Knolls Atomic Power Laboratory core barrel/thermal shield cask	Limits improvement, more realistic plume overlap analysis
Vadose Zone Model	Model in same manner as other disposal unit types - uniform distribution, placed at grade	No vadose zone model - placed projected inventory directly into aquifer model	Requested by SWM
Modeling Software	PORFLOW - flow and transport	PORFLOW - flow field 1-D GoldSim - contaminant transport	Modeling in same manner as other disposal units
Data	2016-19 data packages - rad-dose, geochemical, hydraulic 2016 NR supplied – 643-26E inventory projections 1990's NR supplied – 643-7E inventories, cask and component descriptions	2006 data packages - rad-dose, geochemical, hydraulic 1990's NR supplied – inventory projections, cask and component descriptions	Use latest data available
Disposal Timing	643-7E - instantaneously placed when first container was received (1987) 643-26E - instantaneously placed when first container was received (1997)	All inventory for both pads placed on first day of E-Area LLWF trench operations (1995)	More realistic plume overlap analysis

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LIST OF ACRONYMS AND ABBREVIATIONS

ACP	Activated Corrosion Products
AP	All-Pathway
BG	Beta-Gamma
CBDC	Core Basket Disposal Container
CB/TS	Core Barrels/Thermal Shields
CLSM	Controlled Low-Strength Material
DOE	Department of Energy
DP	Data Package
ET	Engineered Trench
GSA	General Separations Area
GW	Groundwater
IC	Institutional Control
ICDC	Irradiated Component Disposal Container
Kd	Soil-Water Distribution (Partition) Coefficient
KAPL	Knolls Atomic Power Laboratory
LLW	Low-Level Waste
LLWF	Low-Level Waste Facility
NBS	National Bureau of Standards
NR	Naval Reactor
NRCDA	Naval Reactor Component Disposal Area
PA	Performance Assessment
PD	Post-drilling chronic exposure intruder scenario
PC	Post Closure
PO	Performance Objective
POA	Point of Assessment
RCP	Reactor Coolant Pump
SA	Special Analysis
SOF	Sum of Fractions
SRNL	Savannah River National Laboratory
SRS	Savannah River Site
ST	Slit Trench
SWM	Solid Waste Management
UDQE	Unreviewed Disposal Question Evaluation
VZ	Vadose Zone
yr	year

1.0 Introduction

Two areas within the E-Area Low-Level Waste Facility (LLWF) at the Savannah River Site (SRS) are used as disposal sites for reactor components from the U.S. Navy. These components arrive by rail and are moved by crane to the at-grade gravel disposal pads, 643-26E and (previously) 643-7E, illustrated in Figure 1-1. Naval Reactor (NR) waste is comprised of highly radioactive components consisting of activated corrosion-resistant metal alloy contained within thick steel casks, and auxiliary equipment primarily contaminated with Activated Corrosion Products (ACP) (sometimes referred to as "crud" by the U.S. Navy) at low levels and contained within thinner-walled bolted containers. The 643-7E disposal pad, which contains 41 casks and has an interim soil cover for shielding, is closed to future receipts. The latest NR waste projections for 643-26E are substantially different from the original estimates due to a change in reactor maintenance. The original estimate is for 50 heavily shielded, welded casks and 50 thinner-walled bolted containers through the year 2025. Currently, NR Programs projects 33 heavily shielded, welded casks, of which 31 are already in-place on the 643-26E pad, and 381 thinner-walled bolted containers through the year 2040. A description of typical NR waste components is provided in Section 2.0.

In addition to new waste form projections, there have been changes in facility layout and closure plans as well as Performance Assessment (PA) modeling improvements. This report documents the evaluation of these changes as well as key Naval Reactor Component Disposal Area (NRCDA) recommendations from the 2015 PA Strategic Plan (Butcher 2016) and the proposed NRCDA modeling approach for the next E-Area LLWF PA.

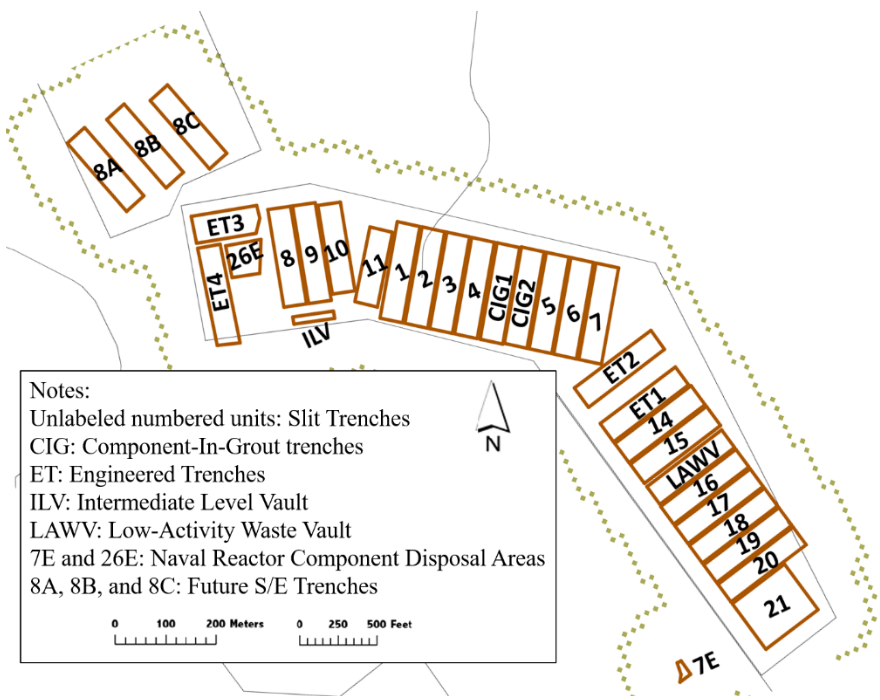

Figure 1-1. Layout of the E-Area LLWF showing location of 643-26E NRCDA (labeled 26E) and 643-7E NRCDA (labeled 7E) and adjacent units

2.0 Historical Naval Reactor Component Disposals at SRS

Above-grade storage of NR waste forms on the 643-7E pad began in 1987. Waste was received from the Bettis Atomic Power Laboratory, Knolls Atomic Power Laboratory (KAPL) and various Naval shipyards. In 1997, after an addendum to the 1994 E-Area Vaults Radiological PA (WSRC 1997), the Department of Energy (DOE) approved disposal of NR waste forms at the E-Area LLWF on the 643-26E pad. In a 2004 evaluation (Wilhite and Flach 2004), the 643-7E storage pad, located outside of the E-Area LLWF, was shown to be suitable for disposal and bounded by the modeling performed for the 643-26E pad in the 2000 E-Area LLWF PA (WSRC 2000) and 2002 Special Analysis (SA) (Yu et al. 2002). The 41 components stored on the pad were declared to be disposed in-place and included in the E-Area LLWF PA. The 2008 PA revision (WSRC 2008) reanalyzed the 643-26E NR pad (now termed the Naval Reactor Component Disposal Area (NRCDA)) versus DOE performance objectives (PO) (DOE 1999) and applied the same type of analysis in determining that 643-26E limits were bounding for 643-7E.

NR components have historically consisted of core barrels, adapter flanges, closure heads, pumps, and other similar equipment from the Navy. Due to the variety of NR waste components and levels of contamination, there is no standard NR waste container. Detailed configurational descriptions of the NR waste components are not available because of the classified nature of this information. According to unclassified data supplied by the NR program, a representative type of activated metal component is the KAPL core barrel/thermal shield (CB/TS) in a heavily shielded, welded cask, and a representative type of surface-contaminated ACP component is the KAPL Closure Head in a thinner-walled bolted container. The KAPL CB/TS (a schematic is shown in Figure 2-1) has been used in PA modeling as a conceptual type of waste form representing the various types of activated metal components (WSRC 1997, 2000 and 2008, and Yu et al. 2002) as the majority of the activity projected for the 643-26E NRCDA will be contained in this type of component. The KAPL CB/TS unit is comprised of components made of Inconel and Zircaloy. The cask is made of low-carbon, low-alloy steel and has been conservatively assumed to breach (and start leaching) in ~750 years based on corroding through a minimum weld of 1.25 inches. The 2008 E-Area LLWF PA assumed a 643-26E NRCDA closure inventory of 100 casks represented by 50 KAPL CB/TS waste components and 50 KAPL Closure Heads.

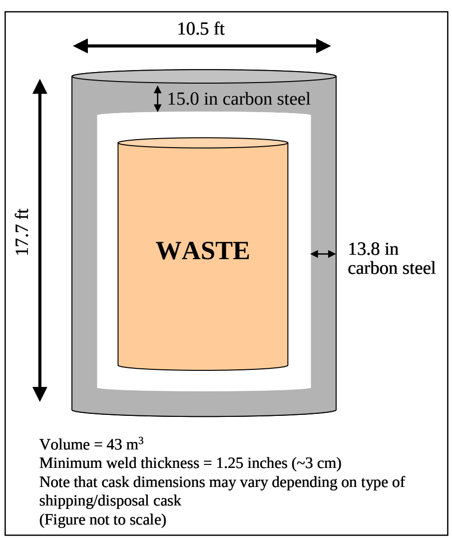

Figure 2-1. KAPL CB/TS Schematic

2.1 Welded Cask Corrosion

In the 2008 PA, corrosion of NR components within a heavily shielded cask was assumed to start 750 years after disposal. The conceptual model assumption was that after 750 years, water would enter the disposal casks via small holes due to corrosion in the welds. This estimate was based on communication from the Pittsburgh Naval Reactors Office (Datovech 1994). Datovech performed a literature review to determine the time it would take to corrode through the cask welds (having a minimum 1.25-inch thickness) resulting in hydraulic failure of the cask and subsequent inventory release. The main reference used by Datovech (1994) in determining the puncture time was a condensed summary of the National Bureau of Standards (NBS) seminal investigation on the corrosion of metals in soils by Romanoff (1957).

In reviewing the NBS data, Romanoff (1957) noted that the physical and chemical nature of the soil controlled whether general or localized (i.e., pitting) corrosion was dominant regardless of the nature of the material sample. Of the soil types included in the NBS investigation, a Cecil clay loam from Atlanta is most representative of the soil at SRS. Although Datovech (1994) did not provide specifics on the calculation employed to arrive at a time-to-puncture of 750 years, he did cite computations by Logan (1939), one of the NBS investigators involved in generating the data reported by Romanoff (1957).

Logan (1939) utilized a combined pit-depth-time and pit-depth-area equation, $P = kT^n(C \log A + 1)$ where *P* is the pit depth on an area, *A*, at any time, *T*, and *C*, *k*, and *n* are constants derived from an analysis of the data on pit depths. Using the above equation, the estimated time to first penetrate a metal thickness of 0.322 inches (Logan's study averaged data from pure open-hearth iron, wrought iron, Bessemer steel, open-hearth steel, and open-hearth steel containing 0.2 percent of copper because they all produced similar results) was 190 years (Romanoff 1957, Table 41). The metal thickness (0.322 inches) divided by the elapsed time to first puncture (190 years) yields a corrosion rate equal to 0.00169 inches per year (in/yr) which is equivalent to 42.9 micrometers per year (μm/yr). Assuming this corrosion rate is constant beyond 190 years (i.e., the pit-depth-time/pit-depth-area equation is not used), the time to first puncture for the NR casks will be 741 years for an assumed minimum weld thickness of 1.25 inches.

Alternatively, the pit-depth-time/pit-depth-area equation above can be used to calculate the minimum corrosion rate. For the Cecil clay loam from Atlanta, Logan (1939) lists in Table 4 of his paper a value of 68.8 for *k* (standard deviation of 2.3), 0.17 for *n* (standard deviation of 0.05), and 0.413 for *C* (standard deviation of 0.082). Using these parameter values to calculate the minimum corrosion rate, a time-to-puncture of 15,600 years is obtained for an NR cask with an assumed weld thickness of 1.25 inches.

Using a different approach, SRNL's Materials Technology Section (Chandler 1998) calculated corrosion rates for carbon steel pipe in Cecil clay loam from NBS data on weight loss versus time (Romanoff 1957, Table 15). Calculated corrosion rates ranged from 52.8 μm/yr (0.00208 in/yr) at two years to 12 μm/yr (0.000472 in/yr) at 14.3 years. Based on these corrosion rates, penetrating a 1.25-inch weld was estimated to take between 600 and 2,650 years. The much lower corrosion rate after 14.3 years of burial is more representative of long-term corrosion; therefore, the time to penetration and hydraulic failure will be closer to 2,650 years than 600 years. At this lower corrosion rate, a time-to-puncture of 750 years as utilized in the 2008 PA is conservative for NR casks constructed from carbon steel.

The majority of the welded casks on the NRCDA pads are constructed from carbon steel; however, a small number are fabricated (cask and welds) from HY-80 steel, a low-carbon, low-alloy steel with nickel, molybdenum, and chromium. A review by SRNL's Materials Technology Section determined that the corrosion performance of low-alloy steels tested by the NBS at the Cecil clay loam site in Atlanta (Romanoff 1957) is representative of corrosion rates for HY-80 steel casks in SRS soils (Dunn 2002). Soil characteristics pertinent to corrosion of low-alloy steels are similar for the two sites (i.e., pH, resistivity, aeration). The chemical compositions of NR HY-80 steel and the steel alloys tested by the NBS are also comparable. Based on these similarities, Dunn expected corrosion rates for HY-80 steel buried at SRS to be in the range of those calculated for the low-alloy steels at the Cecil clay loam site. Using weight loss measurements by the NBS (Romanoff 1957, Table 21), Dunn calculated the corrosion rate of the HY-80 alloy in SRS soils to be in the range of 16.7 µm/yr (0.000657 in/yr) to 42.9 µm/yr (0.001689 in/year) for a two-year period and 8.9 µm/yr (0.00035 in/yr) to 10.9 µm/yr (0.000429 in/yr) for a 12-year period. Taking the highest corrosion rate from Dunn's study (42.9 µm/yr over a two-year period), the time to puncture is estimated to be 740 years. Dunn noted that the corrosion rate of steels with chromium, nickel, and molybdenum tend to decrease over time because the oxide layer that forms provides a protective layer on the steel. Assuming the longer duration period is more representative of long-term corrosion, the time to penetration and hydraulic failure will range from 2,900 to 3,600 years. Considering this rate, a time-to-puncture of 750 years as utilized in the 2008 PA is conservative for NR casks constructed from HY-80 steel.

Carbon steel in soil or air requires the presence of moisture to initiate corrosion. NR has indicated that there may be up to 3.5 gallons of water inside a typical welded KAPL CB/TS cask (Hsu 1997). This amount of moisture represents less than 1% by volume inside the cask. In theory, a pit could be forming on each side simultaneously, reducing the time to hydraulic failure. Chandler (1998) concluded, however, that this small amount of water inside a sealed carbon steel container would be readily absorbed/converted into metal oxide or hydroxide corrosion products on the inner walls and metal component surfaces. Dunn (2002) also noted that an adsorbent material is added to the cask that minimizes the free water. Therefore, corrosion from inside the cask to the outside is expected to be negligible.

SRS subsurface conditions are slightly acidic with soil moisture in the range of pH 5.5. An interim cover constructed of controlled low-strength material (CLSM) rather than native SRS backfill soil would beneficially reduce the rate of corrosion of carbon steel due to the presence of a small amount of cement in the standard SRS CLSM mix. The cement produces a higher-pH environment surrounding the casks. The pH will remain elevated until a sufficient number of pore volumes of slightly acidic infiltrating water consumes the neutralization capacity of the dominant calcium phases, changing the buffering capacity and, ultimately, lowering the pH to background conditions. Assuming a soil (versus CLSM) cover at interim closure, therefore, is conservative.

The 2008 PA modeling timeline for the NRCDA assumed corrosion in soil beginning immediately upon placement of casks on the pad, ignoring the open-air period during operations. A review for weathering of steel open to the atmosphere shows a range of corrosion rates based on atmospheric corrosivity conditions. In a 2013 study (Morcillo et al. 2013), investigators designated four primary corrosivity environments: rural, urban, industrial, and marine, in order of increasing corrosivity. Looking only at rural and urban locations in the U.S., their study gives a corrosion rate in air ranging from 0.000134 in/yr (3.40 µm/yr) to 0.000479 in/yr (12.2 µm/yr). Thus, carbon steel corrosion rates in air are generally at or below the low end of corrosion rates in soil for atmospheric conditions representative of SRS. Assuming immediate burial under a soil cover at the beginning of operations is therefore conservative. Table 2-1 provides a representative summary of the lifecycle of the NRCDA pads to be used in establishing the modeling timeline for the next revision of the E-Area LLWF PA.

Table 2-1. NRCDA Timelines

NRCDA	Period	Duration	Closure Action
643-26E	Operations*	43 years (1997–2040)	None – containers disposed on open gravel pad.
	Institutional Control (IC)	100 years (2040–2140)	Soil or CLSM cover installed for radiation shielding at start of IC period.
	Post Closure (PC)	1,000 years (2140–3140)	Multilayer closure cap installed at start of PC. No cap maintenance during PC period.
643-7E	Operations*	53 years (1987–2040)	41 NR components stored on 643-7E pad declared disposed-in-place in 2004. Operational closure in 2004 with installation of soil cover for radiation shielding.
	Institutional Control	100 years (2040–2140)	Soil cover maintained until the end of the IC period.
	Post Closure	1,000 years (2140–3140)	Multilayer closure cap installed at start of PC. No cap maintenance during PC period.

* For modeling purposes, the NR pad is assumed to be instantaneously filled with the total inventory of containers at the beginning of operations.

Based on the considerations discussed in this section, a time to hydraulic failure for the KAPL CB/TS cask of 750 years is a reasonable lower bound estimate for the next revision of the PA. The period prior to interim closure, when casks are open to the atmosphere, can be treated in the model as being covered with soil if preferred.

2.2 Activated Metal Component Corrosion

As previously discussed, there is no standard NR waste container due to the variety of Naval Reactor waste components. The KAPL CB/TS was used to represent the various types of activated metal components in the 2002 SA and 2008 PA as the majority of the activity projected for the 643-26E NRCDA will be contained in this type of component. The 2008 PA employed a simplifying assumption that activated metal components were constructed of 304 stainless steel in calculating a corrosion-controlled release for each radionuclide. The 2002 SA developed corrosion rates based on the Navy's description of component parts and recommended corrosion model.

The KAPL unit is comprised of component parts made of either Inconel or Zircaloy, both corrosion-resistant alloys. Distribution of activation products and corrosion rates are unequal between Inconel and Zircaloy because of the different constituents in each alloy. In addition, each component had a different geometry and position within the reactor flux field resulting in a different fraction of the total inventory accumulating in each part. The corrosion rate for Inconel is conservatively estimated at 2.5×10^{-5} cm/yr, and for Zircaloy, 2.5×10^{-6} cm/yr, an order of magnitude lower, based on data from the Hanford site (Hanford 1993). These rates double assuming corrosion from both sides of the component. An effective release rate (curies per year) was calculated for each radionuclide in each component part by combining the information on activity distribution between the two types of alloys and different component parts. Thus, the rate of release of each radionuclide from a representative KAPL cask is the sum of releases from the individual parts accounting for radioactive decay.

Because of daughter ingrowth for radionuclides with decay chains, it is difficult to determine the impact of changes in corrosion rates on radionuclide concentrations outside the 100-m groundwater (GW) boundary where performance is evaluated. To simplify the analysis in the next PA, the rate of release from the waste form will be calculated for two cases: 1) all radionuclides reside within Inconel and therefore have a corrosion rate of 5×10^{-5} cm/yr; and 2) all radionuclides reside within Zircaloy and therefore have a corrosion rate of 5×10^{-6} cm/yr. Minimum disposal limits will be selected based on these two cases.

3.0 2008 E-Area LLWF PA NRCDA Modeling Approach

Groundwater pathway modeling of the NRCDA 643-26E pad in the 2008 E-Area LLWF PA assumed 100 component containers: 50 heavily shielded, welded KAPL casks and 50 thinner bolted auxiliary equipment containers. As previously discussed, the KAPL CB/TS was used to represent activated metal components and the KAPL Closure Head to represent surface-contaminated ACP components. NR provided a representative isotopic content for each component type consisting of 65 radionuclides (Yu 2002). A radionuclide screening was performed that reduced this list to seven radionuclides that were modeled in the PA. Greater than 99.9% of the inventory is contained in the heavily shielded, welded casks. Final inventories for the 643-26E NRCDA were obtained by multiplying the average isotopic curie content of each component type by 50 to represent a total closure inventory for the 100 component containers.

To simplify the analysis, the inventories of the activated metal components were conceptually combined with the ACP contaminated components in the KAPL cask. In this scenario, the release of activated metal inventories was corrosion limited (Inconel and Zircaloy) while the ACP inventories were conservatively assumed to be instantaneously released at the time of container breach (750 years after burial) (Hsu 1997). In effect, this analyzed the case where the component casks and equipment containers failed at the same time. In actuality, the bolted thinner-walled equipment containers will breach (and therefore peak) long before the welded casks. This is a conservative assumption because the contributions from the two sources will overlap to a greater degree in the GW pathway during the performance period.

A one-dimensional GoldSim transport model was used where the source term was directly released into the aquifer (i.e., no vadose zone model). Groundwater concentrations at the 100-m GW point of assessment (POA) were obtained by running the projected closure inventories from the Navy through the model, effectively representing a preliminary closure analysis. Plume interaction with other units was ignored because of the very low impact on the GW analysis. Dose impacts were obtained by running the maximum concentration for each radionuclide at the 100-m POA through the SRNL dose and limits calculator. Dose impacts were significantly below DOE O 435.1 PO’s (including EPA drinking water standards interpreted to meet the DOE GW protection requirement) given the projected closure inventories from the Navy. To obtain limits, the source term was adjusted to match GW PO’s at the 100-m well for each radionuclide during the period of performance. The results (curies) are GW radionuclide disposal limits for managing future NR waste receipts. A quantitative sensitivity and uncertainty analysis was also performed where the soil-water distribution (or partition) coefficients (*Kd*), aquifer area, GW velocity, and time of weld breakthrough (conservatively assumed to be the time of contaminant release) were varied. The sensitivity analysis shows that the failure time of the disposal cask welds and the aquifer cross-sectional area are the parameters to which the all-pathways dose is most sensitive.

Modeling results for the 643-26E NRCDA and corresponding radionuclide disposal limits for all the PA pathways were applied to 643-7E NRCDA based on comparable hydrology, disposal configuration, and waste forms.

4.0 Changes since the 2008 E-Area LLWF PA

In addition to PA modeling improvements, there have been notable changes in the projections and types of NR waste and the NRCDA facility layout. Key NRCDA recommendations from the 2015 PA Strategic Plan (Butcher and Phifer 2016) will also be implemented in the upcoming E-Area LLWF PA revision.

The Navy has transitioned to a single lifetime fuel element load, reducing reactor maintenance requirements. This change eliminated the need for periodic removal and disposal of reactor components. As a result, the Navy no longer generates highly activated metal components such as the CB/TS except at decommissioning, and these are currently sent to the Hanford site for disposal (Butcher 2018). A new shielding system of interlocking “shear blocks” is now used to reduce personnel exposures. As shear blocks are removed from service and replaced, they are packaged in standard boxes and sent to SRS for disposal. According to the Navy, shear block contamination consists almost entirely of surface ACP as opposed to activated metal. The typical activity level in each shear block container is orders of magnitude lower than the activated metal components (e.g., CB/TS) they replaced. Sixteen shear block boxes (12 large and 4 small) replace one KAPL CB/TS welded cask in the new reactor maintenance scheme (Butcher 2018).

The 2000 revision of the E-Area PA (WSRC 2000) assumed the final conceptual facility layout of 643-26E to be 100 KAPL CB/TS casks placed one meter apart in a rectangular arrangement. This results in an overall disposal area of approximately 43 meters x 43 meters, or 1849 square meters (m^2). The current, more realistic projected facility configuration in Year 2040 is 33 welded casks and 381 thinner-walled bolted containers of various dimensions with placement dictated by operational, dose rate reduction, and security considerations. In addition, should the NRCDA be needed beyond 2040, based on the projected end of EM site cleanup mission in 2065 (SRNS 2015), additional NR waste would be received. Therefore, it is recommended to use the entire area of the 643-26E gravel pad as the waste footprint as delineated by the current coordinates (SRNS 2016c). The corner coordinates of the 643-26E disposal pad have changed since the 2008 E-Area PA to make room for adjacent engineered trenches (ET03 and ET04) on two sides of the pad. Using the current coordinates, the total area of 643-26E is 4,430 m^2, which is the area that should be used for calculating GW and non-GW disposal limits. The area of the 643-7E NRCDA as calculated by corner coordinates is 546 m^2. This area should be modeled as the waste footprint for 643-7E.

Other changes and PA modeling improvement have occurred as well. A new conceptual closure cap design has been prepared (SRNS 2016a and 2016b) that will influence the infiltration rate and, therefore, radionuclide transport to the aquifer. The projected end of operations has been pushed back from 2025 to 2040 (Sink 2016a), resulting in a higher projected inventory for NR waste (Sink 2016b). Since the 2008 PA, there have also been improvements in modeling techniques as well as a new General Separations Area

(GSA) flow model (Flach 2018). Updated values for the radionuclide and dose (Smith et al. 2015), geochemical (Kaplan 2016), and hydraulic (being developed) parameters will also be utilized.

One key NRCDA GW pathway recommendation from the 2015 PA Strategic Plan (Butcher 2015) will be implemented in the upcoming PA:

- Model the 643-26E NRCDA in the same manner as the other disposal units (i.e., unit curie inventories scaled up to disposal limits based on PO's), rather than assuming a defined number of components and inventory.

Two other recommendations have been evaluated in this report (see Section 5) but will not be implemented:

- Establish time to hydraulic failure of the new NR shear block containers if credit needs to be taken for container holdup.
- Evaluate one or more generic models that could bound NRCDA performance to simplify analysis.

4.1 643-26E NRCDA Existing and Projected Inventory

Updated waste inventory projections were provided by NR Programs in 2016 for each waste form projected for disposal through FY25. These were combined with existing 643-26E NRCDA inventories and projections extended through 2040 by Sink (2016b). In extending NR waste projections, Sink made the simplifying assumption that all radionuclide contamination in welded containers is activated metal and all contamination in bolted containers is ACP.

NR components currently on the 643-26E pad plus future projections through the year 2040 include 33 heavily shielded, welded casks (of which 31 are already in place) and 381 thinner-walled bolted containers (of which 49 are in place – primarily shear blocks). Since 2015, shear blocks in standard bolted boxes have been the largest waste stream from the Navy. According to Sink (2016b), the only bolted containers expected in the future are shield blocks and reactor coolant pumps (RCPs), and the only welded containers expected are two core basket disposal containers (CBDCs). Bolted containers of surface-contaminated ACP equipment that meet criteria for trench disposal will be disposed in a slit trench (ST) or engineered trench (ET). This includes cover plates, adapter flanges, and RCPs currently stored on the pad as well as future RCP waste receipts. At present, shear blocks have too much activity for trench disposal based on current trench limits.

Existing (onsite as of 9-30-2018) and future container totals and activity for 643-26E are listed in Table 4-1. This information is based on NR KAPL and Bettis estimates (Sink 2016b) and meetings with K. Tempel (Butcher 2018). NRCDA 643-26E radionuclide inventories categorized by type of waste (activated metal or ACP) are listed in Table 4-2. Table 4-3 lists the closure inventory for 643-7E (Sink 2007).

Table 4-1. 643-26E NRCDA Existing and Projected Inventory

Source &	Bolted			Welded			Total	Activity
Type	Existing	Future	Total	Existing	Future	Total	Curies	%
Bettis (total)[1]	**16**	**10**	**26**	**20**	**0**	**20**		
- ICDC[2]	NA	NA	NA	20	0	20	8270	1.8
- Cover Plates[3]	8	0	8	NA	NA	NA	0.0027	5.9E-07
- Adapter Flanges[3]	8	0	8	NA	NA	NA	3.5	0.00077
- RCP[4]	0	10	10	NA	NA	NA	0.57	0.00013
KAPL (total)[1]	**33**	**322**	**355**	**11**	**2**	**13**		
- CB/TS[5]	NA	NA	NA	9	0	9	347000	76
- Closure Heads[6]	1	2	3	NA	NA	NA	37.3	0.0082
- CBDC	NA	NA	NA	0	2	2	41200	9.1
- Unique	**NA**	**NA**	**NA**	**2**	**0**	**2**		
- S3G	NA	NA	NA	1	0	1	27000	5.9
- D1G PVA	NA	NA	NA	1	0	1	30200	6.6
- Shear Blocks	**32**	**320**	**352**	**NA**	**NA**	**NA**		
- Large	24	240	264	NA	NA	NA	382	0.084
- Small	8	80	88	NA	NA	NA	113	0.025
TOTAL	**49**	**332**	**381**	**31**	**2**	**33**	**454206**	**100**
			Welded (activated metal) Curies				**453670**	**99.9**
			Bolted (ACP) Curies				**536**	**0.1**
			TOTAL Curies				**454206**	**100**

ICDC: Irradiated Component Disposal Container
CB/TS: Core Barrel/Thermal Shield
CBDC: Core Basket Disposal Container
RCP Reactor Coolant Pumps

[1] From Sink 2016b and 01/21/2016 "Stored Package Age Report for NR1" printout from Kevin Tempel.
[2] All 20 ICDC's onsite per K. Tempel 07/18/2017 personal communication.
[3] May be relocated to a trench (likely ET) in the future.
[4] Almost certain to place in a trench (either ST or ET).
[5] Assumed to be representative type of activated waste component in 2008 PA.
[6] Assumed to be representative type of ACP waste component in 2008 PA.

Table 4-2. 643-26E Projected Inventories by Waste Type

Activated Metal (FY40)		ACP (FY40)	
ISOTOPE	**Activity (Ci)**	**ISOTOPE**	**Activity (Ci)**
AG108	1.15E-07	AC227	1.03E-12
AG108M	1.32E-06	AG108	1.89E-10
AG109M	2.11E-02	AG108m	2.17E-09
AG110	1.48E-04	AG110	4.17E-09
AG110M	4.92E-02	AG110m	3.07E-07
AM241	1.33E-01	AM241	4.94E-04
AM242	1.03E-03	AM242M	2.61E-06
AM242M	2.29E-03	AM243	3.93E-06
AM243	2.78E-03	BA137M	5.52E-02
BA133	2.09E-03	BE10	5.07E-12
BA137M	6.73E+00	BI214	2.02E-13
BA140	4.90E-08	C14	1.43E+00
BE10	2.16E-05	CA45	3.30E-11
BI212	2.60E-08	CE144	5.05E-03
BK249	2.07E-08	CF249	6.56E-13
C14	8.92E+01	CF251	2.62E-14
CA45	1.49E-02	CM242	4.03E-03
CD109	4.02E-02	CM243	3.24E-06
CD113M	1.33E-02	CM244	4.79E-04
CD115M	9.76E-04	CM245	3.28E-08
CE141	4.94E-03	CM246	1.31E-08
CE144	5.80E+00	CM247	3.93E-14
CF249	1.95E-10	CM248	1.24E-13
CF251	4.35E-12	CO58	8.89E+01
CL36	1.27E-02	CO60	1.32E+02
CM242	1.51E+00	CR51	3.36E-01
CM243	2.13E-03	CS134	2.21E-02
CM244	2.55E-01	CS137	5.60E-02
CM245	1.64E-05	FE55	2.46E+02
CM246	8.98E-06	FE59	1.90E+00
CM247	8.33E-12	H3	3.37E-03
CM248	2.59E-11	HF181	6.58E-01
CO58	8.13E+03	I129	5.75E-06
CO60	7.29E+04	IN113m	1.75E-08
CR51	1.16E+02	KR85	2.54E-03
CS134	1.51E+01	MN54	9.16E+00
CS135	5.26E-05	MO93	2.07E-08
CS137	7.14E+00	NB93M	1.97E+00

Activated Metal (FY40)		ACP (FY40)	
ISOTOPE	**Activity (Ci)**	**ISOTOPE**	**Activity (Ci)**
EU152	6.23E-04	NB94	2.86E-02
EU154	5.16E-01	NB95	4.02E+00
EU155	1.18E-01	NB95m	9.44E-12
FE55	6.52E+04	NI59	4.34E-01
FE59	8.56E+00	NI63	4.32E+01
H3	4.56E+01	NP237	3.95E-09
HF175	4.04E+00	PA231	2.24E-12
HF181	6.58E+01	PA234	6.70E-11
I129	1.14E-05	PA234m	5.16E-08
IN113M	1.09E+03	PB214	2.02E-13
IN114	2.02E+00	PM147	6.85E-04
IN114M	3.80E+00	PO214	2.02E-13
IR192	1.30E-02	PO218	2.02E-13
IR192M	2.47E-07	PR144	5.05E-03
KR85	2.61E-01	PU238	3.52E-04
LA140	5.65E-08	PU239	5.68E-05
MN54	6.06E+02	PU240	3.28E-05
MO93	7.51E-01	PU241	1.37E-02
NB93M	9.51E+01	PU242	3.93E-07
NB94	6.03E+00	PU244	5.89E-14
NB95	2.58E+04	RA226	2.02E-13
NB95M	1.23E+02	RH106	4.85E-03
NI59	1.73E+03	RU106	6.25E-03
NI63	2.01E+05	RN222	2.02E-13
NP237	3.20E-06	S35	6.15E-09
NP239	1.26E-03	SB124	6.23E-07
P33	6.32E-03	SB125	1.22E+00
PA234M	2.61E-06	SC46	1.92E-09
PB205	5.68E-08	SE75	3.15E-11
PB212	2.60E-08	SE79	1.96E-07
PD107	3.99E-06	SN113	1.75E-08
PM147	4.23E+00	SN119m	1.68E-07
PO210	6.24E-03	SN121	1.94E-10
PO212	1.66E-08	SN121m	2.50E-10
PO216	2.60E-08	SN123	2.36E-11
PR144	4.73E+00	SN126	5.89E-07
PR144M	6.60E-02	SR89	1.20E-13
PT193	1.14E-04	SR90	5.57E-02
PU238	2.67E-01	TA182	5.54E-02

Activated Metal (FY40)	
ISOTOPE	**Activity (Ci)**
PU239	8.95E-02
PU240	6.18E-02
PU241	1.61E+01
PU242	3.31E-04
PU244	1.57E-11
RA224	2.60E-08
RH103M	3.95E-02
RH106	6.65E+00
RN220	2.60E-08
RU103	4.87E-02
RU106	8.19E+00
S35	1.82E-01
SB124	1.89E+00
SB125	2.04E+04
SB126	2.37E-06
SB126M	1.68E-05
SC46	5.96E-01
SE75	3.27E-01
SE79	2.13E-04
SM151	9.18E-02
SN113	1.09E+03
SN119M	3.49E+04
SN121	6.41E+00
SN121M	1.71E+01
SN123	2.95E+02
SN126	8.25E-05
SR89	7.50E-01
SR90	3.34E+00
TA182	4.54E+03
TC99	1.93E-01
TE123M	6.09E+02
TE125M	2.94E+03
TH228	2.59E-08
TH231	2.81E-08
TH232	3.52E-08
TH234	2.61E-06
U232	2.81E-06
U233	7.84E-06
U234	2.56E-05

ACP (FY40)	
ISOTOPE	**Activity (Ci)**
TC99	1.44E-03
TE125M	2.82E-01
TH230	2.14E-11
TH231	2.41E-09
TH232	1.24E-10
TH234	5.16E-08
U232	1.95E-06
U233	7.94E-09
U234	1.45E-04
U235	6.67E-06
U236	3.23E-11
U238	1.43E-04
Y90	5.55E-02
Y91	4.34E-13
ZN65	4.05E+00
ZR93	2.62E-04
ZR95	1.82E+00
Y90	5.55E-02
Y91	4.34E-13
ZN65	4.05E+00
ZR93	2.62E-04
ZR95	1.82E+00

Activated Metal (FY40)	
ISOTOPE	**Activity (Ci)**
U235	6.94E-07
U236	6.58E-05
U237	6.87E-05
U238	2.20E-05
W181	3.31E+00
W185	9.57E+00
W188	2.79E-02
Y90	3.34E+00
Y91	3.69E+00
ZN65	1.06E+01
ZR93	1.19E+01
ZR95	1.21E+04

Table 4-3. 643-7E Inventory at Closure

ISOTOPE	ACTIVITY (Ci)	ISOTOPE	ACTIVITY (Ci)
Am241	3.52E-01	Nb95m	1.31E+03
Am242m	8.03E-06	Ni59	1.55E+03
Am243	2.41E-03	Ni63	1.80E+05
Ba137m	5.28E+00	Np237	4.03E-06
C14	1.39E+02	Pm147	3.05E+00
Ca45	1.34E-04	Pr144	2.20E-01
Ce144	5.14E+00	Pu238	2.69E-01
Cf249	1.25E-10	Pu239	1.23E-01
Cf251	2.70E-12	Pu240	1.11E-01
Cl36	1.80E-05	Pu241	3.40E+01
Cm242	5.22E+00	Pu242	4.07E-04
Cm243	7.90E-06	Pu244	2.77E-11
Cm244	1.92E-01	Ru106	6.60E-01
Cm245	1.02E-05	S35	3.09E-03
Cm246	3.95E-06	Sb125	4.07E+04
Cm247	7.96E-12	Sc46	3.26E-03
Cm248	1.89E-11	Se79	1.22E-03
Co58	2.07E+04	Sm151	5.38E-02
Co60	9.85E+04	Sn113	4.87E+03
Cr51	7.47E+03	Sn119m	8.08E+04
Cs134	5.33E-02	Sn123	2.35E+03
Cs135	3.45E-05	Sn126	8.59E-06
Cs137	5.29E+00	Sr90	5.39E+00
Eu154	6.72E-02	Ta182	1.76E+04
Eu155	3.83E-02	Tc99	1.46E-01
Fe55	9.03E+04	Te125m	2.54E+04
Fe59	7.48E+03	Th232	3.02E-10
H3	1.34E+02	U232	4.77E-06
Hf181	7.46E+03	U233	7.83E-07
I129	1.48E-05	U234	3.64E-06
In113m	4.87E+03	U235	2.06E-07
Kr85	5.71E-03	U236	4.21E-06
Mn54	1.39E+03	U238	2.32E-05
Mo93	1.43E+00	Y90	5.39E+00
Nb93m	7.46E+03	Zn65	1.13E+01
Nb94	6.54E+00	Zr93	7.46E+03
Nb95	1.31E+05	Zr95	6.16E+04

4.2 Feasibility of a Simple Modeling Approach

4.2.1 ACP Inventory

To determine if the NRCDA conceptual model for ACP waste, primarily new NR shear-block bolted containers, will need to credit container holdup to meet POs, the projected closure inventory provided by the Navy was compared to the 2008 PA ST 8-11 GW limits to determine sum-of-fractions (SOF) impacts. The ST model assumes buried radionuclides are immediately available to the surrounding soil for transport (i.e., no holdup). Radionuclides contributing more than 0.01 (1%) to the Beta-Gamma (BG) SOF are shown in Table 4-4 for the three time-periods established in the 2008 PA. This comparison with 2008 PA limits shows impacts 10 times higher than the BG GW protection requirement in the first two time-intervals (orange highlighted cells). Therefore, employing a generic waste model (i.e., ACP inventory immediately released to the surrounding soil upon disposal) results in unacceptable performance.

Table 4-4. SOF: NRCDA ACP Inventory vs. 2008 PA ST 8-11 GW Limits

Rad	BG1 (0-12 yr)	BG2 (12-100 yr)	BG2 (100-1130 yr)
	Fraction of PO		
C-14	9.7E+00	9.2E+00	2.2E-01
I-129	3.7E-02	3.7E-02	
Nb-94	5.0E-01	4.8E-01	1.2E-02
Tc-99	1.5E-02	1.7E-02	
Ni-59			2.0E-01
Total SOF	**10.25**	**9.74**	**0.4**

Since the 2008 PA, numerous key input parameters and transport models used in the PA have been updated (e.g., from new DOE standards, International Committee publications, and ongoing SRNL research and development activities). An Unreviewed Disposal Question Evaluation (UDQE) in 2013 reevaluated trench performance using updated information available at the time in support of opening a third engineered trench (ET03) (Hamm et al. 2013). One important update was to soil-water distribution coefficients or *Kd* values. These included *Kd* updates for the key radionuclides present in the NRCDA ACP inventory. Table 4-5 shows a comparison of these *Kd* values as they evolved from the 2008 PA, 2013 ET03 UDQE, and most recently, the 2016 geochemical data package (DP) (Kaplan 2016). A higher *Kd* value implies the radionuclide is more strongly sorbed to the soil phase, making it less mobile.

Table 4-5. *Kd* Changes since 2008 PA

Isotope	Sediment	2008 PA *Kd*	2013 UDQE *Kd*	2016 DP *Kd*
C-14	Clay	0	30	30
	Sand	0	1	1
I-129	Clay	0.6	0.9	3
	Sand	0	0.3	1
Nb-94	Clay	0	0	1000*
	Sand	0	0	1000*
Tc-99	Clay	0.2	1.8	1.8
	Sand	0.1	0.6	0.6

*There is very little Nb sediment sorption data. In the previous data package, Nb was assumed to behave like Cl^- or NO_3^-. Recent studies show Nb sorbs very strongly to soils.
NOTE: Changes shown in red.

New estimated ET03 limits were calculated as part of the 2013 UDQE providing information for a more up-to-date comparison with NR ACP inventories. The total projected ACP inventories were compared with these estimated limits. Radionuclides contributing more than 0.01 to the SOF are shown in Table 4-6. Total closure inventories of ACP waste take up approximately 30% of the trench radionuclide capacity for BG limits, a significant improvement over the 2008 PA comparison. Not shown are comparisons for other GW (all-pathways) and non-GW (air, radon, intruder) pathways. Dose impacts for these pathways were one to two orders of magnitude lower than their respective POs.

Table 4-6. SOF: NRCDA ACP Inventory vs. Estimated 2013 ET3 UDQE Limits

Rad	BG1 (0-12 yrs)	BG2 (12-100 yrs)	BG3 (100-1130 yrs)
	Fraction of PO		
C-14			2.2E-01
Nb-94	3.0E-01	2.9E-01	
Ni-59			1.2E-01
Total SOF	**3.0E-01**	**2.9E-01**	**3.4E-01**

Over 90% of the projected closure inventory of ACP waste is contained in shear blocks. Assuming the Navy continues to use the new shielding system of interlocking “shear blocks” to reduce personnel exposures, shear blocks will continue to be removed from service and sent for disposal to SRS over the next 22 years (until E-Area closure in 2040). If trench limits in the next PA provide sufficient margin, disposal in trenches for all ACP waste is possible, especially considering shear block waste receipts and dose impacts will likely be distributed over multiple trench units throughout the remaining operational period. Alternatively, if 643-26E NRCDA disposal is selected, the simplest, most conservative approach to the evaluation would be to superimpose peak GW impacts from ACP components with those from activated metal components as a sensitivity on the amount of plume interaction.

4.2.2 Activated Metal Inventory

Preliminary GW screening was performed by employing a methodology similar to the NCRP Report 123 (NCRP 1996) screening models to determine which radionuclides are important to GW performance. Based upon the discussion on time to hydraulic failure of a representative NR cask of 750 years in Section 2.1, a range of holdup periods (500, 750 and 1,000 years) was selected for the model to determine sensitivity to this factor. This simple screening model accounts for radioactive decay, leaching from the waste zone, and dilution in the aquifer. It does not, however, credit the activated metal component for corrosion-controlled release nor transport and dispersion in the vadose zone (VZ) and aquifer. The estimated inventory for each of the 128 radionuclides reported by NR for welded casks was evaluated by this simple model, and the concentration in the aquifer was converted to a dose impact and compared to the EPA BG drinking water limit (Smith et al. 2015). Results of this preliminary GW screening are shown in Table 4-7. Of the 128 nuclides reported by NR, only 12 exceed one percent of the PO after allowing the radionuclides to decay prior to cask breach at Year 500. Beyond a 750-year holdup period, only nine radionuclides exceed one percent (0.01) of the PO. The additional three radionuclides not screened out at 500 years holdup, Am-242m, Cs-137, and Sr-90, should be included in any sensitivity cases.

Table 4-7. Groundwater Screening: Activated Metal Inventory

Nuclide	Half-Life (yr)	Year of Container Breach		
		500	750	1,000
		Fraction of PO at time of breach		
Am-242m	1.41E+02	**1.46E-02**	4.27E-03	1.25E-03
C-14	5.70E+03	**2.01E+04**	**1.95E+04**	**1.90E+04**
Cl-36	3.01E+05	**8.70E+00**	**8.70E+00**	**8.69E+00**
Cs-137	3.02E+01	**2.02E-02**	6.46E-05	2.07E-07
I-129	1.57E+07	**5.47E+00**	**5.47E+00**	**5.47E+00**
Mo-93	4.00E+03	**8.15E-01**	**7.80E-01**	**7.47E-01**
Nb-94	2.03E+04	**5.01E+00**	**4.96E+00**	**4.92E+00**
Ni-59	1.01E+05	**4.51E+05**	**4.50E+05**	**4.50E+05**
Ni-63	1.00E+02	**9.85E+06**	**1.74E+06**	**3.09E+05**
Sr-90	2.88E+01	**2.68E-01**	6.52E-04	1.59E-06
Tc-99	2.11E+05	**1.56E+02**	**1.56E+02**	**1.56E+02**
Zr-93	1.53E+06	**3.72E+00**	**3.72E+00**	**3.72E+00**

Notes: Exceeds 1% (0.01) of the PO. Baseline case.

The activated metal projected inventory for the nine radionuclides not screened out in the 750-year holdup case were then compared to the 2013 ET03 UDQE estimated limits to obtain a SOF result. Unlike the screening analysis, the 2013 estimated limits account for transport and dispersion in the VZ and aquifer out to the 100-m well. Radionuclides contributing more than 0.01 to any SOF (BG, All-Pathway (AP), and intruder) are listed in Table 4-8 with SOFs greater than 1.0 highlighted in orange.

Table 4-8. SOF: NRCDA Activated Metal Inventory[1] vs. Estimated 2013 ET3 UDQE Limits

Rad	GW Protection			GW All-Pathways			Intruder	
	Fraction of PO			Fraction of PO			Fraction of PO	
	BG1 (0-12 y)	BG2 (12-100 y)	BG3 (100-1130 y)	AP1 (130-200 y)	AP2 (200-1000 y)	AP3 (1000-1130 y)	Resident	PD[2]
C-14			1.3E+01		1.3E+01	2.8E+00		3.5E-02
Cl-36	1.5E-01	1.4E-01						
I-129								
Mo-93		1.1E-01	4.7E-01		8.3E-02	1.0E-01		
Nb-94	6.1E+01	5.9E+01	1.4E+00	2.7E+00	2.7E+00	2.7E+00	7.3E-01	
Ni-59			4.8E+02		5.1E-01	2.7E+00		
Ni-63								
Tc-99			9.2E-02		1.4E-01			
Zr-93	8.5E+00	1.7E+01	1.3E+01		2.5E+00	2.8E+00		
SOF	**7.0E+01**	**7.6E+01**	**5.1E+02**	**2.7E+00**	**1.9E+01**	**1.1E+01**	**7.3E-01**	**3.5E-02**

[1] NR projected inventories decayed for a 750-year hold up period prior to release.
[2] Post-drilling chronic exposure intruder scenario.

Compared to the results in Table 4-7, accounting for transport and dispersion results in a much smaller impact than the simpler screening analysis. However, all GW pathways still exceed a SOF of 1.0. The UDQE limits comparison accounted for container hold-up, but not corrosion-controlled release of nuclides. Therefore, the NRCDA model for activated metal in welded casks will likely need to credit both container holdup and corrosion-controlled release from highly-activated components.

5.0 Proposed NRCDA Modeling Approach

5.1 643-26E

In the upcoming E-Area LLWF PA, a vadose zone model will be developed to simulate intact and degraded waste form conditions. All containers will be conceptually placed on the 643-26E pad on the first day of pad operations in 1997 (02-06-1997). Both ACP and activated metal inventory will be placed vertically at-grade and uniformly distributed over the 643-26E NRCDA pad footprint. Highly activated metal components will be represented by the heavily shielded, welded KAPL CB/TS cask in the model. Justification for this assumption is based on: 1) NR Programs estimates that KAPL CB/TS casks will contain 76% of the total inventory shipped to SRS (see Table 4-1), and 2) the KAPL cask has a weld thickness of 1.25 inches which is representative of the minimum weld thickness in all other casks. Surface-contaminated ACP equipment is contained in thinner-walled bolted containers, predominately shear block boxes. Structural fill will be placed around and over containers at the start of IC (09-28-2040). Bolted containers will be assumed to hydraulically fail immediately when the structural fill is placed, with ACP contamination instantaneously released into the surrounding soil (no holdup). CB/TS casks will be assumed to hydraulically fail at 750 years (estimated time to corrode through minimum 1.25-inch weld) with the releases held up during this period. Dynamic compaction of the NRCDA prior to installation of the final closure cap is prohibited to preserve this assumption.

Welded casks containing activated metal components will be treated as special waste forms taking credit for both the welded vessel and activated metal components in calculating special-waste-form limits. The model will be run assuming a unit curie or mole of each parent radionuclide with the resulting dose impacts/concentrations scaled to GW POs to obtain inventory limits. For activated metal components, the unit curie or mole will decay for 750 years before starting the model to simulate container holdup. Corrosion-limited release of activated metal will utilize individual radionuclide release rates based on differences in activation product distribution and corrosion rates in Inconel and Zircaloy component parts of a KAPL CB/TS (Yu 2002). Baseline special-waste-form disposal limits will be calculated assuming components are effectively either all Inconel or all Zircaloy, and final disposal limits will be selected based on the minimum of these two cases.

Bolted containers with ACP-contaminated equipment will be treated as generic waste taking no credit for the container in calculating disposal limits. This model will also be run assuming a unit curie or mole of each parent radionuclide and scaled to GW POs to obtain inventory limits. Because of the difficulty in determining the impact of daughter ingrowth, ACP waste will be modeled assuming decay starts either at the beginning of the operational period (1997) or upon hydraulic failure at interim closure (2040). Baseline generic disposal limits will be selected based on the minimum of these two cases.

Contaminant fluxes to the water table will be inputs to the latest GSA GW flow model using a cutout for the E-Area LLWF (Flach 2018). Peak GW concentrations at or beyond the 100-m boundary will be used to obtain preliminary GW limits. Preliminary limits will be initially calculated assuming no time windows. Limits will be adjusted for plume overlap with neighboring disposal units for final disposal limits. Final limits will be assessed to determine if time windows are needed for acceptable performance.

In addition to disposal limits, a closure analysis will be performed to demonstrate compliance with DOE 435.1 GW protection and performance objectives. Projected impacts will be calculated based on currently disposed-plus-projected NR inventory. The following sensitivity cases are suggested:

- Assume the NRCDA remains open and continues to receive waste until the projected end of the EM site cleanup mission in 2065.
- Assume a time for weld breakthrough of 500 years for the CB/TS casks.
- Assume an alternate aquifer model.
- To account for uncertainty in time to hydraulic failure of bolted containers, superimpose peak GW impacts from ACP components with those from activated metal components (100% plume interaction) as a sensitivity on the amount of overlap between generic and special waste form GW plumes.

The need for model refinements will be assessed based on results.

5.2 643-7E

Because 643-7E has been operationally closed since 1995 and is no longer accepting new inventory, only a closure analysis will be performed. A total of 41 NR containers will be modeled using the bounding inventory estimates supplied by Solid Waste Management (SWM) based on representative worst-case contaminated components (Tempel 2002). As with 643-26E, a heavily shielded, welded KAPL CB/TS cask will be used as the representative container for highly activated metal components while a thinner-walled bolted container will represent surface-contaminated ACP components. All containers will be conceptually placed on the pad on the first day of disposal operations, assumed to be 01-01-1987. Structural fill was placed around and over containers in 2004 (assumed to occur on 01-01-2004). The CB/TS casks are assumed to hydraulically fail 750 years from this date (01-01-2754). Release of contaminants from activated metal will be corrosion-limited using individual radionuclide release rates based on differences in activation product distribution and corrosion rates in Inconel and Zircaloy component parts of a KAPL CB/TS. The performance evaluation will assume components are effectively either all Inconel or all Zircaloy and final dose impacts will be based on the minimum of these two cases. Bolted containers are assumed to have hydraulically failed and instantaneously released contamination when structural fill was placed around containers in 2004. Inventory will be placed vertically at-grade and uniformly distributed over the 643-7E NRCDA pad footprint within the SWM facility. Vadose zone and aquifer models will be run to obtain GW concentrations at or beyond the 100-m boundary. Suggested sensitivity analyses include the impact of an alternate aquifer model, time-of-weld breakthrough, and ACP/activated metal GW plume peak super-positioning. Due to the location of the 643-7E NRCDA relative to other E-Area LLWF disposal units, plume overlap is an unlikely concern based on GW flow direction and location of the 100-m boundary for this unit (see Figure 1-1). Based on dose impacts of base case and sensitivity cases, the need for model refinements will be addressed.

6.0 Conclusions and Path Forward

The latest NR waste projections are substantially revised from original estimates due to changes in NR maintenance. The original estimate of 50 heavily shielded, welded casks and 50 thinner-walled bolted containers has been superseded by a new estimate of 33 heavily shielded, welded casks (of which 31 are already on the 643-26E pad) and 381 thinner-walled bolted containers (primarily shield blocks). The overwhelming majority of radioactivity (99.9%) is still projected to be contained in heavily shielded, welded casks.

The simple modeling approach described in Section 4.2 indicates that ACP inventory can likely be released immediately without container holdup credit. Highly activated metal components, however, still require credit to be taken for container holdup and corrosion-controlled release of inventory to produce acceptable GW performance. Limits, closure, and sensitivity analyses will be performed for NRCDA 643-26E as described in Section 5.1 using the KAPL CB/TS cask as representative of heavily shielded, welded containers and treating ACP contamination in bolted containers as generic waste. Closure and sensitivity analyses will be performed for NRCDA 643-7E as described in Section 5.2. The proposed approach considers and implements NRCDA recommendations from the 2015 PA Strategic Planning Team report as described in Section 4.0. Key differences between the 2008 E-Area LLWF PA and the proposed approach are highlighted in Table 6-1.

Table 6-1. Comparison of Proposed Modeling Approach with 2008 E-Area LLWF PA

Model Feature-Aspect	New Approach	2008 PA Approach	Justification
Number of NR Containers on 643-26E	Open ended	100 cask limit	Requested by SWM
Type of Analysis	Limits analysis - model unit curie of each rad for comparison with Performance Objectives	Preliminary closure analysis - modeled dose impact of projected inventory supplied by NR - scaled results for limits	Requested by SWM
643-7E	Perform closure analysis on final inventory from 41 containers	Applied results of 643-26E model to 643-7E performance	Changes in flow paths due to new aquifer model
Limits	Separate limits - ACP and activated metal, bolted and welded casks	Single set of limits - combined all forms of inventory into a representative KAPL CB/TS cask	Limits improvement, more realistic plume overlap analysis
Vadose Zone Model	Model in same manner as other disposal unit types - uniform distribution, placed at grade	No VZ model - placed projected inventory directly into aquifer model	Requested by SWM
Modeling Software	PORFLOW - flow and transport	PORFLOW - flow field 1-D GoldSim -contaminant transport	Modeling in same manner as other disposal units

Model Feature-Aspect	New Approach	2008 PA Approach	Justification
Data	2016-19 data packages - rad-dose, geochemical, hydraulic 2016 NR supplied – 643-26E inventory projections 1990's NR supplied – 643-7E inventories, cask and component descriptions	2006 data packages - rad-dose, geochemical, hydraulic 1990's NR supplied – inventory projections, cask and component descriptions	Use latest data available
Disposal Timing	643-7E - instantaneously placed when first container was received (1987) 643-26E - instantaneously placed when first container was received (1997)	All inventory for both pads placed on first day of E-Area LLWF trench operations (1995)	More realistic plume overlap analysis

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Appendix A. Datovech 1994 *Disposal Container Corrosion Issues*

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Disposal Container Corrosion Issues

R. J. Datovech
October 17, 1994

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Disposal Container Corrosion Issues

There is no known underground corrosion data generated by the NR program.

Only one container is made of stainless steel. In Naval Reactors operating environments, stainless steel welds are assumed to corrode at the same rate as the base metal. In 304SS, the heat affected zone in the base metal next to unannealed welds may be susceptible to corrosion, or stress corrosion cracking if the environment contains chlorides, at some rate greater than the base metal, depending on the degree of sensitization and environment. Stress corrosion cracking through the weld heat affected zone could lead to early exposure of the component contained in the container to ground water. Commercial literature was reviewed to determine at what increased rate a sensitized stainless steel material can be assumed to corrode in an assumed environment.

All other containers are made of carbon steel. For example, the Bettis Barrel containers are made of ASTM A737 (carbon-manganese-silicon steel) with welds made with E8018C2 weld wire (low alloy (nickel bearing) steel). For the ASTM A737 steel and its weld metal, the general corrosion rates are assumed to be essentially the same. Further, the materials are assumed to be close enough in composition and structure to preclude enhanced local corrosion due to galvanic effects.

Review of commercial literature indicates the following:

1. Ref: Underground Corrosion, Melvin Romanoff, NACE, 1989 - This text presents the results of underground corrosion tests conducted by the National Bureau of Standards from 1910 to 1955. More than 36,500 specimens of various materials were buried up to 14 years at 128 test locations in the USA. The soil type assumed for the WSRC is Cecil clay loam based on descriptions of report sites closest to WSRC. In 14 years, 304SS exhibited a corrosion rate of .0009 oz./sq.ft. on coupons buried in Atlanta. More detailed analyses were done on carbon steel. It was noted that the nature of the soil controlled the character of the corrosion regardless of the nature of the material sample. A section of this reference dealt with the engineering significance of the test results. One investigator performed a statistical evaluation to determine various predictions; the predictions were based on a volume of material and surface defined by a 1,000 foot length of pipe, 8.625 inches in diameter, with a wall thickness of .322 inches. In that section of material, the expected deepest pit would be .235 inches and the time to first puncture would be expected to be in 190 years. Extrapolating and assuming similar amounts of surface area, a 1.25 inch weld container thickness could be expected to experience a likely breach in approximately 750 years.

(The following papers reviewed were presented at the conference: Scientific Basis for Nuclear Waste Management XVI, Boston, 30 Nov.-4 Dec. 1992. A paper on the Saltstone Disposal Facility at WSRC was presented at this conference.)

2. Ref: "Critical Conditions for Initiation of Localized Corrosion of Mild Steels in Contact with Bentonite Used in Geological Disposal Packages of Nuclear Waste", Guen

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Nakayama and Masatsune Akashi, Ishidawajima-Harima Heavy Industries CO., Ltd., Japan - If the environment remains acidic (as Cecil clay loam is described) to neutral, the steel should undergo general corrosion. If the environment is alkaline (if bentonite or other basic fill is used), the steel can become passivated and liable to develop localized (e.g., pitting or crevice) corrosion which can become locally very deep depending on conditions. No rate factors were given. WSRC information does not assess if the fill to be used is acidic or basic.

3. Ref: "Progress in Waste Package and Engineered Barrier System Performance Assessment and Design", A. Van Luik, et. al., CRWMS MO/Intera, Inc & B&W and DOE - Various barrier system model codes developed by Laurence Livermore, Pacific Northwest Lab, and Sandia are discussed. In one evaluation discussed where the containment is an Alloy 825 inner container surrounded by a steel outer container, the container lifetime is estimated to be 500 to 10,000 years, mean of 3,170 years.

4. Ref: "Research Needs in HLW Disposal Programs", J. Hadermann et. al., Switzerland - The Swiss steel canister is 10 inches thick with 8 inches for strength and 2 inches for corrosion allowance to ensure integrity for at least 1000 years. This 2 inch allowance in 1000+ years agrees well with the assessment in 1. above.

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