Closing Monitoring Factors through Risk-Informed Monitoring in Support of Department of Energy’s NDAA Section 3116 Tank Closure Activities

George Alexander, Cynthia Barr, and Christianne Ridge

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• Section 3116 of the National Defense Authorization Act for Fiscal Year 2005 (NDAA):
  – Applies only to the States of South Carolina and Idaho
  – Sec. 3116(a): DOE consults with NRC regarding waste determinations
  – Sec. 3116(b): NRC monitors DOE disposal actions taken pursuant to NDAA Section 3116 to assess compliance with the performance objectives of 10 CFR Part 61
• WIR (Waste Incidental to Reprocessing) implementation in SECY-05-0073
• 2007 NRC staff WIR guidance in NUREG-1854
§ 61.40 – General Requirement
§ 61.41 – Protection of the General Population from Releases of Radioactivity
§ 61.42 – Protection of Individuals from Inadvertent Intrusion
§ 61.43 – Protection of Individuals During Operations
§ 61.44 – Stability of the Disposal Site After Closure
WIR-NDAA Process

• DOE consults with the NRC on a facility-specific basis:
  – DOE submits a draft Waste Determination (WD), Performance Assessment (PA), and other documents
• NRC review documented in a Technical Evaluation Report (TER)
• NRC monitoring of facility begins only after the DOE Secretary signs the DOE final WD for that facility
• NRC issues Monitoring Plan:
  – Used to assess DOE disposal actions to meet performance objectives
  – Developed in coordination with the covered State regulator
### WIR-NDAA Facilities

<table>
<thead>
<tr>
<th>Savannah River Site, Aiken, SC</th>
<th>Savannah River Site, Aiken, SC</th>
</tr>
</thead>
<tbody>
<tr>
<td>F-Tank Farm (FTF)</td>
<td>H-Tank Farm (HTF)</td>
</tr>
<tr>
<td><img src="image" alt="Savannah River Site, Aiken, SC F-Tank Farm (FTF)" /></td>
<td><img src="image" alt="Savannah River Site, Aiken, SC H-Tank Farm (HTF)" /></td>
</tr>
<tr>
<td>Savannah River Site, Aiken, SC</td>
<td>Idaho Tank Farm Facility, Idaho Falls, ID</td>
</tr>
<tr>
<td>Saltstone Disposal Facility (SDF)</td>
<td><img src="image" alt="Idaho Tank Farm Facility, Idaho Falls, ID" /></td>
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</table>

5
• DOE consultation with NRC on the Idaho National Laboratory, Idaho Nuclear Technology and Engineering Center, Tank Farm Facility (INL INTEC TFF) began in September 2005 with DOE’s issuance of a draft waste determination for review
  – In October 2006, NRC concluded in its TER that it had reasonable assurance that DOE could meet performance objectives based on assumptions listed in the report

• NRC Monitoring began in 2007
  – NRC identified key monitoring areas in the INTEC TFF TER which were discussed in more detail in NRC’s INL INTEC TFF Monitoring Plan issued in April 2007
• 7 large 1000 m³ tanks and miles of piping were grouted in 2007 and 2008; NRC conducted 3 onsite observation visits (OOVs) during this timeframe
• Additional OOVs occurred in 2010, 2012, 2014, and 2017
• Technical reviews were documented in Periodic Compliance Monitoring Reports or in technical review reports; these reviews focused on reviewing reports related to the hydrogeological system at the INTEC TFF and environmental monitoring data
• In its TER, NRC identified issues with the INTEC TFF groundwater model but concluded, based on its own independent calculations, that DOE could meet the performance objectives in 10 CFR Part 61, Subpart C
• NRC included hydrological uncertainties as a monitoring area in its TER and Monitoring Plan and listed it as Key Monitoring Area (KMA) 3 in the INTEC TFF Monitoring Plan
• KMA 3: “Relevant recent and future monitoring data and modeling activities should continue to be evaluated to ensure that hydrological uncertainties that may significantly alter the conclusions in the PA and TER are addressed. If significant new information is found, this information should be evaluated against the PA and TER conclusions”
NRC also reviews environmental monitoring and other reports (e.g., exposure calculations and radiation records) under KMA 4 related to 10 CFR 61.43, “Protection of Individuals During Operations.”

Other KMAs listed in the Monitoring Plan include:
- waste sampling,
- cementitious material performance, and
- engineered cover performance
### Table 12. Summary of DOE Idaho Credit for Engineered and Natural Barrier Performance*

<table>
<thead>
<tr>
<th></th>
<th>Tc-99</th>
<th>Sr-90</th>
<th>I-129</th>
</tr>
</thead>
<tbody>
<tr>
<td>Minimum Total Barrier</td>
<td>4 orders of magnitude</td>
<td>9 orders of magnitude</td>
<td>3 orders of magnitude</td>
</tr>
<tr>
<td>Performance Needed for</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Compliance†</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Engineered Barrier</td>
<td>1 to 4 orders of</td>
<td>4 orders of magnitude‡</td>
<td>1 to 2 orders of</td>
</tr>
<tr>
<td>(most effective of</td>
<td>magnitude</td>
<td></td>
<td>magnitude</td>
</tr>
<tr>
<td>grouted tank, vault, or</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>sand pad)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Natural System</td>
<td>3 to 4 orders of</td>
<td>8 to 9 orders of</td>
<td>3 to 4 orders of</td>
</tr>
<tr>
<td></td>
<td>magnitude</td>
<td>magnitude§</td>
<td>magnitude</td>
</tr>
<tr>
<td>Total Barrier</td>
<td>6 orders of magnitude</td>
<td>12 orders of magnitude</td>
<td>4 orders of magnitude</td>
</tr>
<tr>
<td>Performance in DOE PA</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Conservative or Compliance Case</td>
<td></td>
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<td></td>
</tr>
</tbody>
</table>

* Denotes the level of performance required to meet regulatory standards for the protection of the environment and public health.

** Denotes the threshold for effective containment and isolation of radioactive materials.

§ Denotes the additional safety margin required for the reliable disposal of radioactive waste.
INL INTEC TFF
Near-field Model

- Vault Fails at 100 Years
- Tank Grout Fails at 500 Years

Infiltration

Sand Pad

Vault Floor

0.15 m (6 in)

0.76 m (30 in)
INL INTEC TFF
Natural System Performance
• KMA 3 was closed out by letter dated June 9, 2014 (ML14149A337)
• Close-out was based on a technical review report dated May 19, 2014 (ML14113A278)
• Basis for closure
  • NRC evaluation of years of DOE modeling and monitoring data most notably related to Comprehensive Environmental Response, Compensation, and Liabilities Act documentation
  • DOE’s successful grouting of the 7 large tanks
  • NRC’s independent calculations
  • DOE’s supplemental modeling and calculations
DOE consultation with NRC began in 2005 with DOE draft WD
- 2005 NRC TER concluded DOE could meet performance objectives if assumptions were verified during monitoring

NRC monitoring began in 2006

DOE submitted 2009 Performance Assessment

NRC issued new TER and Letter of Concern in April 2012

NRC Monitoring Plan, Rev. 1 in September 2013
NRC-DOE History
Saltstone Disposal Facility

• Onsite Observation Visits and Technical Reviews
• DOE FY2013 Special Analysis (SRR-CWDA-2013-00062), which included new information related to:
  – additional design features in the 150-ft diameter Saltstone Disposal Structures (SDS),
  – modeling of cementitious materials degradation,
  – technetium release
• NRC Request for Additional Information (RAI) (ML14148A153) on DOE FY2013 Special Analysis
• DOE FY2014 Special Analysis (SRR-CWDA-2014-00006)
  – updated DOE analyses to address the 375-ft diameter SDSs
• NRC RAI (ML15161A541) on DOE FY2014 Special Analysis
NRC will monitor the measured values of hydraulic conductivity in field-emplaced saltstone samples, values from other representative studies, and the appropriateness of any new sampling technique.

NRC will monitor the potential variability of as-emplaced saltstone properties and DOE’s quality assessment program for grout.

NRC will monitor the applicability of data on the hydraulic properties measured using laboratory-produced samples to ensure that it adequately reflects the properties of field-emplaced saltstone.

NRC will monitor the effect of the curing temperature profile on the hydraulic properties of as-emplaced saltstone.
### 2013 Saltstone Monitoring Plan

**Monitoring Factors Prioritization Table**

#### Table 1-5: NRC Prioritization of Monitoring Factors under Monitoring Areas 1 - 5

<table>
<thead>
<tr>
<th>MA 1 Inventory</th>
<th>MA 2 Infiltration and Erosion Control</th>
<th>MA 3 Waste Form Hydraulic Performance</th>
<th>MA 4 Waste Form Physical Degradation</th>
<th>MA 5 Waste Form Chemical Degradation</th>
</tr>
</thead>
<tbody>
<tr>
<td>- 1.01 - Inventory in Disposal Structures §</td>
<td>- 2.01 - Hydraulic Performance of Closure Cap §</td>
<td>- 3.01 - Hydraulic Conductivity of Field Emplaced Saltstone §</td>
<td>- 4.01 - Waste Form Matrix Degradation §</td>
<td>- 5.01 - Radiocesium Release from Field Emplaced Saltstone §</td>
</tr>
<tr>
<td>- 1.02 - Methods Used to Assess Inventory §</td>
<td>- 2.02 - Erosion Protection §</td>
<td>- 3.02 - Variability of Field Emplaced Saltstone §</td>
<td>- 4.02 - Waste Form Macroscopic Fracturing §</td>
<td>- 5.02 - Chemical Reduction of Tc by Saltstone §</td>
</tr>
<tr>
<td>- 3.03 - Applicability of Laboratory Data to Field-Emplaced Saltstone §</td>
<td>- 3.04 - Effect of Drying Temperature on Saltstone Hydraulic Properties §</td>
<td>- 5.03 - Reducing Capacity of Saltstone §</td>
<td>- 5.04 - Certain Risk-Significant K&lt;sub&gt;a&lt;/sub&gt; Values for Saltstone §</td>
<td>- 5.05 - Potential for Short-Term Release from Saltstone §</td>
</tr>
</tbody>
</table>

#### Table 1-7: NRC Prioritization of Monitoring Factors under Monitoring Areas 6 - 9, and 11

<table>
<thead>
<tr>
<th>MA 6 Disposal Structure Performance</th>
<th>MA 7 Subsurface Transport</th>
<th>MA 8 Environmental Monitoring</th>
<th>MA 9 Site Stability</th>
<th>MA 11 Radiation Protection Program</th>
</tr>
</thead>
<tbody>
<tr>
<td>- 6.01 - Certain Risk-Significant K&lt;sub&gt;a&lt;/sub&gt; Values in Disposal Structure Concrete §</td>
<td>- 7.01 - Certain Risk-Significant K&lt;sub&gt;a&lt;/sub&gt; Values in Site Sand and Clay §</td>
<td>- 8.01 - Leak Detection §</td>
<td>- 9.01 - Settlement Due to Increased Overburden §</td>
<td>- 11.01 - Dose to Individuals During Operations §</td>
</tr>
<tr>
<td>- 6.02 - To Sorption in Disposal Structure Concrete §</td>
<td>- 7.02 - Groundwater Monitoring §</td>
<td>- 8.02 - Settlement Due to Dissolution of Calcareous Sediment §</td>
<td>- 9.02 - Air Monitoring §</td>
<td></td>
</tr>
<tr>
<td>- 6.03 - Performance of Disposal Structure Roofs and HDPE/GCL Layers §</td>
<td>- 6.04 - Disposal Structure Concrete Fracturing §</td>
<td>- 6.05 - Integrity of Non-conventional Materials §</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

* Legend: (§) High Priority, (†) Medium Priority, (¶) Low Priority
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### 2013 Saltstone Monitoring Plan

**Monitoring Factors Prioritization Table (cont)**

<table>
<thead>
<tr>
<th>Monitoring Factors</th>
<th>Additional Notes</th>
</tr>
</thead>
<tbody>
<tr>
<td>10.01 - Implementation of Conceptual Models</td>
<td></td>
</tr>
<tr>
<td>10.02 - Determination of Conceptual Models</td>
<td></td>
</tr>
<tr>
<td>10.03 - Diffusivity in Degraded Saltstone</td>
<td></td>
</tr>
<tr>
<td>10.04 - (K_v) Values for Saltstone</td>
<td>This could become more risk significant in future assessments. For example, if assumed (K_v) values or inventories of certain radionuclides change, then the assumed (K_v) values could be more risk significant than the (K_v) values used in Case K1. This MF does not include (K_v) values for radionuclides considered under MA 5, which have greater risk significance in Case K1.</td>
</tr>
<tr>
<td>10.05 - Moisture Characteristic Curve</td>
<td>In Case K1, MCCs were not used. If MCCs are used in the future, then this factor could be much more risk significant.</td>
</tr>
<tr>
<td>10.06 - (K_v) Values for Disposal Structure Concrete</td>
<td></td>
</tr>
<tr>
<td>10.07 - Calculation of Build-Up in Biosphere Soil</td>
<td>This could become much more risk significant in future assessments. For example, if assumed (K_v) values or inventories of certain radionuclides change, then the assumed (K_v) values could be more risk significant than the (K_v) values used in Case K1. This MF does not include (K_v) values for radionuclides considered under MA 6, which have greater risk significance in Case K1.</td>
</tr>
<tr>
<td>10.08 - Consumption Factors and Uncertainty Distributions for Transfer Factors</td>
<td></td>
</tr>
<tr>
<td>10.09 - (K_v) Values for SRS Soil</td>
<td></td>
</tr>
<tr>
<td>10.10 - Far-Field Model Calibration</td>
<td></td>
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<tr>
<td>10.11 - Far-Field Model Source Loading Approach</td>
<td></td>
</tr>
<tr>
<td>10.12 - Far-Field Model Dispersion</td>
<td></td>
</tr>
<tr>
<td>10.13 - Impact of Carcineous Zones on Contaminant Flow and Transport</td>
<td></td>
</tr>
</tbody>
</table>

* Low Priority
* Medium Priority
* High Priority
<table>
<thead>
<tr>
<th><strong>Task</strong></th>
<th>Compare the key properties of actual saltstone mixed in Saltstone Production Facility and emplaced/cured in Saltstone Disposal Structure 2A with a simulated saltstone mixed and cured in the laboratory</th>
</tr>
</thead>
</table>
| **Objectives** | Demonstrate that the properties of laboratory-prepared saltstone are representative of the properties of actual saltstone.  
Validate the saltstone property values used for the PA contaminant transport modeling |
Sample Extraction and Storage

Cores drilled at 3 SDU ports

~ 7 ft. vertical drill distance: 2 ft. vapor space and 5 ft. grout

Extracted samples maintained in inert environment
Laboratory Anaerobic Chamber

Samples stored in inert N₂ chamber
Properties
1. Density
2. Porosity
3. Moisture Content
4. Saturated Hydraulic Conductivity
5. Diffusivity
6. Total Activity
7. Leachate Concentrations

Comparison of laboratory-prepared versus field-emplaced samples
MF 3.01 - *Hydraulic Conductivity of Field-Emplaced Saltstone*

The measurements of the saltstone core samples provided the most compelling support for the initial saturated hydraulic conductivity of field-emplaced saltstone.

Those measurements included six core samples tested at the Savannah River National Laboratory and two core samples tested at the Savannah River Ecology Laboratory. The hydraulic conductivity measurements from the core samples were all less than the assumed value in the FY2013 and FY2014 Special Analyses.

In addition to the direct evidence of the hydraulic conductivity of saltstone from the core sample study, the DOE conducted additional studies and analyses to support the assumed hydraulic conductivity value.

The NRC determined that research results provided by the DOE was adequate to support the assumed initial saturated hydraulic conductivity of field-emplaced saltstone in both the FY2013 and FY2014 Special Analysis documents.
MF 3.02 – Variability of Field-Emplaced Saltstone

The recent DOE research results, in particular the measured properties of saltstone core samples, provided significant insight into variability in field-emplaced saltstone.

The NRC determined that the production, placement, and curing conditions that could cause significant variability in saltstone performance were well-controlled and were not expected to result in significant variability.

In addition, the NRC determined that the DOE process to evaluate variability due to potential future changes was an adequate basis for the DOE to use to assess and control saltstone variability.
Recent DOE measurements on the physical and hydraulic properties of saltstone core samples provided support for use of laboratory data in representing field-emplaced saltstone, as long as key field conditions were replicated (e.g., temperature, humidity, and liquid-to-premix ratio.

Although the laboratory-prepared and field-emplaced samples were reasonably consistent, there were small systematic differences in the density and porosity, which may be due to flush-water additions.

Differences in recently observed leaching behavior between laboratory-prepared and field-emplaced samples may be due to differences in physical and hydraulic properties.

For these reasons, the PAB staff recommended narrowing the scope of MF 3.03 to understanding of the short-term changes in the hydraulic conductivity between laboratory-prepared and field-emplaced saltstone samples.
Since the 2009 PA, DOE developed several new lines of evidence, including:
1. Research results that indicated that unrealistic curing conditions were responsible for anomalously high hydraulic properties in previous studies,
2. Laboratory studies of simulated saltstone produced under realistic conditions, and
3. Research results from actual saltstone core samples.

The NRC determined that the DOE research results demonstrated that the effects of curing conditions were adequately accounted for in the assumed initial hydraulic conductivity and effective diffusivity values in both the FY2013 and FY2014 Special Analyses.
Lessons Learned

Communication
a. Clear (e.g., prioritization of monitoring factors and research [DOE])
b. Continuous (e.g., technical reports, onsite observation visits, teleconference calls)
c. Feedback/verification that the right information is being collected to address concerns
d. Avoid confusion regarding terminology in monitoring (e.g., open items versus open issues; open issues versus follow-up actions; key monitoring areas versus monitoring factors)

Research Quality
a. Research planning – share the research plans in advance and discuss it
b. Representative conditions - minimize experimental artifacts
c. Direct versus indirect information
d. Transparent – provide complete details of experimental conditions and results (e.g., raw tabular data)
e. Comprehensive discussion (e.g., research limitations, negative as well as positive results)
f. Anticipation of questions and concerns (e.g., impact of data on PA, future research)
Lessons Learned (cont)

Documentation

a. Interrogation of modeling results is important to ensure that models are well understood and adequately communicated in the PA (incomplete INL INTEC TFF PA documentation led to confusion and additional costs to resolve technical issues)

b. A mechanism to allow DOE to address deviations between the final waste determination and closure activities is important

c. Adequate DOE documentation of closure activities and sharing of information with NRC is helpful to NRC in fulfilling its monitoring responsibilities under the NDAA

d. NRC should have a mechanism in place to track technical issues prior to updating its monitoring plan and should be agile in responding to rapidly changing monitoring conditions
Challenges

Research
a. Extrapolation of results—determine when additional experiments are needed and when existing work can be leveraged
b. Recognition of limitations of research and which issues are more tractable and which are not
c. Optimization of research activities (e.g., will positive results for one monitoring factor obviate the need to address issues associated with another monitoring factor; what research efforts may be cost beneficial)
d. Evaluation of the impact of information gaps on the compliance demonstration

Evaluation of Impacts of Research on PA Results
a. Need for development of special analyses to evaluate impact of revised PA assumptions; when does a new PA need to be developed?
b. Need to perform multi-variate sensitivity and uncertainty analyses
c. Selection of parameter values and consideration of uncertainty when results of research and modeling are ambiguous
Documents related to NRC Saltstone Monitoring and Saltstone Waste Form Hydraulic Properties

**TERs**
ML053010225 2005 Saltstone TER
ML121170309 2012 Saltstone TER

**Monitoring Plans**
ML070730363 2007 Saltstone Monitoring Plan
ML13100A076 2013 Saltstone Monitoring Plan, Rev.1

**Saltstone Waste Form Hydraulic Properties**
ML17018A137 2017 Technical Review: Saltstone Waste Form Hydraulic Performance
ML17097A351 2017 Closure of Monitoring Factors (3.01, 3.02, 3.04) in the 2013 Monitoring Plan
Links to INL INTEC TFF
Key NRC Monitoring Documents

TER
ML062490142 INL INTEC TFF Technical Evaluation Report October 2006

Monitoring Plan
ML070650222 INL INTEC TFF Monitoring Plan April 2007

Onsite Observation Report
ML071300222 OOV Report April 2007 Visit
ML072570173 OOV Report August 2007 Visit
ML082550157 OOV Report August 2008
ML102770022 OOV Report August 2010 Visit
ML12240A037 OOV Report June 2012 Visit
ML14265A092 OOV Report June 2014 Visit

Technical Reviews
ML081960467 NUREG-1911 CY2007
ML091400501 NUREG-1911 CY2008
ML101950372 NUREG-1911 CY2009
ML111890412 NUREG-1911 CY2010
ML12234A576 NUREG-1911 CY2011
ML16013A143 NUREG-1911 CY2012 and 2013
ML14113A278 Technical Review Close Out o KMA 3 Hydrological Uncertainty May 2014
ML14149A337 Letter Closing Out KMA 3 June 2014