**FCT Quality Assurance Program Document**

# FCT Document Cover Sheet

| | |
|---|---|
| Name/Title of Deliverable/Milestone | Task Order 22: Engineering and Technical Support Deep Bore Hole Field Test |
| Work Package Title and Number | A&AS to Office of Nuclear Energy DE-NE0000291 |
| Work Package WBS Number | Task Order 22 - Engineering and Technical Support, Deep Borehole Field Test: AREVA Summary Review Report, AREVA RPT-3014934-000 |
| Responsible Work Package Manager | Sven Bader/ [signature] 19-JAN-16<br>(Name/Signature) |

Date Submitted 01/18/16

Quality Rigor Level for Deliverable/Milestone ☒ QRL-3 ☐ QRL-2 ☐ QRL-1 ☐ Nuclear Data ☐ N/A*

This deliverable was prepared in accordance with AREVA Federal Services
*(Participant/National Laboratory Name)*

QA program which meets the requirements of
☐ DOE Order 414.1 ☐ NQA-1-2000 ☒ Other

**This Deliverable was subjected to:**

| | |
|---|---|
| ☒ Technical Review | ☐ Peer Review |
| **Technical Review (TR)** | **Peer Review (PR)** |
| **Review Documentation Provided** | **Review Documentation Provided** |
| ☐ Signed TR Report or, | ☐ Signed PR Report or, |
| ☐ Signed TR Concurrence Sheet or, | ☐ Signed PR Concurrence Sheet or, |
| ☒ Signature of TR Reviewer(s) below | ☐ Signature of PR Reviewer(s) below |

**Name and Signature of Reviewers**

| | |
|---|---|
| Author: Scott Bear/ SBear 1/19/2016 | Technical Reviewer: Sven Bader/ [signature] 19-JAN-16 |

***NOTE** *In some cases there may be a milestone where an item is being fabricated, maintenance is being performed on a facility, or a document is being issued through a formal document control process where it specifically calls out a formal review of the document. In these cases, documentation (e.g., inspection report, maintenance request, work planning package documentation or the documented review of the issued document through the document control process) of the completion of the activity along with the Document Cover Sheet is sufficient to demonstrate achieving the milestone. QRL for such milestones may also be marked N/A in the work package provided the work package clearly specifies the requirement to use the Document Cover Sheet and provide supporting documentation.*

# Task Order 22 – Engineering and Technical Support, Deep Borehole Field Test: AREVA Summary Review Report

## RPT-3014934-000

## Prepared by: AREVA Federal Services LLC

**REVISION LOG**

| Rev. | Date | Affected Pages | Revision Description |
|---|---|---|---|
| 0 | 01/18/16 | All | Initial Issue |
| | | | |

# DISCLAIMER

# TABLE OF CONTENTS

# LIST OF FIGURES

# LIST OF TABLES

# LIST OF ACRONYMS

| | |
|---|---|
| A&AS | Advisory and Assistance Services |
| AFS | AREVA Federal Services |
| ANSI | American National Standards Institute |
| API | American Petroleum Institute |
| ASME | American Society of Mechanical Engineers |
| B&PV | Boiler and Pressure Vessel |
| BOP | Blowout Preventer |
| C | Celsius |
| CBH | Characterization Borehole |
| CFR | Code of Federal Regulations |
| CT | Coiled Tubing |
| DAF | Dynamic Amplification Factor |
| DBD | Deep Borehole Disposal |
| DBFT | Deep Borehole Field Test |
| DBH | Deep Borehole |
| $D_c$ | Canister Diameter |
| $D_h$ | Hydraulic Diameter |
| DOE | Department of Energy |
| EIS | Environmental Impact Statement |
| EPA | Environmental Protection Agency |
| eqn | Equation |
| EZ | Emplacement Zone |
| f | friction factor |
| FoS | Factor of Safety |

| | |
|---|---|
| ft | feet |
| FT | Field Test |
| FTB | Field Test Borehole |
| g | gravity |
| GE | General Electric |
| HazOp | Hazardous Operations |
| HIC | High Integrity Container |
| HLW | High Level Waste |
| ID | Inside Diameter |
| IL | Impact Limiter |
| in | inch |
| $K_{form}$ | loss coefficient |
| km | kilometer |
| ksi | kilo pound per square inch |
| l | length of waste package |
| lb | pound |
| MUA | Multi-attribute Utility Analysis |
| N/A | not applicable |
| NE | Nuclear Energy |
| NEPA | National Environmental Protection Act |
| NRC | Nuclear Regulatory Commission |
| OD | Outside Diameter |
| $P_{cr}$ | Critical load |
| PLC | Programmable Logic Controller |
| psi | Pounds per square inch |

| | |
|---|---|
| QA | Quality Assurance |
| R&D | Research and Development |
| ROM | Rough Order of Magnitude |
| RPT | Report |
| $S_m$ | Design stress intensity |
| SME | Subject Matter Expert |
| SNF | Spent Nuclear Fuel |
| SNL | Sandia National Laboratories |
| SRR | Summary Review Report |
| $S_u$ | Minimum material ultimate strength |
| $S_y$ | Material yield strength |
| TBD | To Be Determined |
| TIG | Tungsten Inert Gas (welding type) |
| UC | Universal Canisters |
| U.S. | United States |
| $V_{ratio}$ | velocity ratio |
| $v_t$ | terminal velocity |
| WESF | Waste Encapsulation Storage Facility |
| WP | Waste Package |
| $\rho_c$ | density of canister |
| $\rho_f$ | density of fluid |

# Executive Summary

Under Task Order 22 of the industry Advisory and Assistance Services (A&AS) Contract to the Department of Energy (DOE) DE-NE0000291, AREVA has been tasked with providing assistance with engineering, analysis, cost estimating, and design support of a system for disposal of radioactive wastes in deep boreholes (without the use of radioactive waste). As part of this task order, AREVA was requested, through a letter of technical direction, to evaluate Sandia National Laboratory's (SNL's) waste package borehole emplacement system concept recommendation using input from DOE and SNL. This summary review report (SRR) documents this evaluation, with its focus on the primary input document titled: "Deep Borehole Field Test Specifications/M2FT-15SN0817091" Rev. 1 [1], hereafter referred to as the "M2 report." The M2 report focuses on the conceptual design development for the Deep Borehole Field Test (DBFT), mainly the test waste packages (WPs) and the system for demonstrating emplacement and retrieval of those packages in the Field Test Borehole (FTB). This SRR follows the same outline as the M2 report, which allows for easy correlation between AREVA's review comments, discussion, potential proposed alternatives, and path forward with information established in the M2 report. AREVA's assessment focused on three primary elements of the M2 report: the conceptual design of the WPs proposed for deep borehole disposal (DBD), the mode of emplacement of the WP into DBD, and the conceptual design of the DBFT.

AREVA concurs with the M2 report's selection of the wireline emplacement mode specifically over the drill-string emplacement mode and generically over alternative emplacement modes. Table 5-1 of this SRR compares the pros and cons of each emplacement mode considered viable for DBD. The primary positive characteristics of the wireline emplacement mode include: (1) considered a mature technology; (2) operations are relatively simple; (3) probability of a radiological release due to off-normal events are relatively low; (4) costs are relatively low; and (5) maintenance activities are relatively simple. The primary drawback associated with the wireline emplacement mode for DBD is the number of emplacement trips-in to the borehole, which results in a relatively higher probability for a drop event. Fortunately, the WPs can be engineered with impact limiters that will minimize the likelihood of a breach of the WP due to a drop.

The WP designs presented in the M2 report appear to be focused on compatibility with the drill-string emplacement mode (e.g., the threaded connections). With the recommendation that the wireline emplacement mode be utilized for the DBFT, some changes may be warranted to these WPs. For example, the development of a WP release connection that is more reliable than the currently credited connection, which is considered to have a high failure probability, and the integration of an impact limiter into its design.

The M2 report states the engineering demonstration of the DBFT will occur in the FTB over a 4-year period. AREVA recommends development and testing of the WP emplacement handling equipment occur separately (but concurrently, if not earlier) from the FTB at a mock-up facility. The separation of this activity would prevent schedule interference between the science and engineering thrusts of the project. Performing tests in a mock-up facility would allow additional control and observation compared to the FTB. The mock-up facility could also be utilized as a training facility for future operations. Terminal velocity and impact limiter testing would require the FTB for testing, since these areas would be difficult to reproduce in a limited depth mock-up.

Although only at the end of the conceptual stage of design development, DBD appears to be a viable solution for some waste forms produced by the nuclear industry. However, regulatory requirements have yet to be established for pre- and post-closure performance of DBD and should be established as soon as possible. Some of the main areas of focus from a regulatory perspective include: (1) establishing acceptable performance requirements for the long-term behavior of DBD; (2) determining acceptable borehole abandonment criteria; (3) establishing retrievability requirements; (4) developing a consensus on the factor of safety (FoS) for the emplacement mode and WP; and (5) establishing safety and safeguards performance requirements for DBD. Although conservative requirements have been utilized to provide the foundation for the conceptual design of DBD, regulatory requirements and feedback are necessary to confirm recommendations made herein and to ensure the long-term performance of DBD is acceptable.

The combination of the M2 report and this SRR is intended to facilitate the completion of the conceptual design for DBD for the Cs and Sr capsules and calcined waste forms. Using the conceptual design, preliminary design activities (the second stage of a three-stage process described in the M2 report) can proceed and the DBFT utilized to support, demonstrate, and confirm engineering elements of this design.

# 1.0 Introduction

## *Scope and Purpose of Review*

The scope of this report is to provide a summary review of the "Deep Borehole Field Test Specifications/M2FT-15SN0817091" Rev 1 [1], herein referred as the "M2 report," as prepared by SNL. The purpose of this SRR is to provide an evaluation of the conceptual design of the WP borehole emplacement systems (i.e., emplacement mode, WP design, etc.) presented within the M2 report and either concur with the identified recommendation on the preferred emplacement system in the report or identify an appropriate alternative(s).

The scope of this SRR, consistent with the scope of the M2 report, is limited to the emplacement of Cs/Sr capsules and calcined waste forms into the DBD; no spent nuclear fuel (SNF) or high level waste (HLW) forms are considered at this time, but it is noted these waste forms could be considered later.

The combination of the M2 report and this SRR is intended to lead to the completion of the conceptual design for DBD, for the Cs/Sr capsules and calcined waste forms. Using the conceptual design, preliminary design activities (the second stage of a three-stage process described in the M2 report) can proceed and the DBFT utilized to support, demonstrate, and confirm *engineering* elements of this design.

## *Overview of Review*

This SRR is organized into eight major sections. Table 1-1 provides an overview of each section.

TABLE 1-1: OVERVIEW OF REVIEW

| Section | Brief Overview |
|---|---|
| Section 1.0 | • Scope and Purpose<br>• Overview of Review |
| Section 2.0 | • Review of Basis of DBFT Design<br>• Review of DBD Safety Case<br>• Review of Disposal System Architecture<br>• Review of Requirements for Disposal System and DBFT<br>• Specific Discussion on the FoS<br>• Review of Design Assumptions<br>• Table Listing of TBDs in M2 Report<br>• Specific Discussion on Potentially Challenging Design Assumptions<br>• Review of Waste Disposal Concepts (Perforated Casing, Impact Limiter Design/ Terminal Velocity, Position on Proposed Disposal Operations and Discussion on Emplacement Options Wireline/Drill-String/Coil Tubing/Free Fall/Conveyance Liner) |
| Section 3.0 | • Review of DBFT Conceptual Design Description<br>• Review of Waste Package Concept<br>• Waste Package Functions in the DBFT<br>• AREVA Experience with Threaded Connections<br>• Comments on Emplacement and Retrieval<br>• Insights/Innovations to Conceptual Design Questions |

| Section | Brief Overview |
|---|---|
| | • Verification of Applicability to Disposal Case of Items in M2 Specification Tables 3-1 and 3-2 |
| Section 4.0 | • Review of Supporting Engineering Analyses<br>• Comments on Waste Package Stress Analysis<br>• Review of Terminal Sinking Velocity<br>• Comments on Impact Limiters<br>• Review of Energy Needed for Package Breach<br>• Review of Thermal Hydrology Analysis |
| Section 5.0 | • Review of Engineering Design Selection Study<br>• Approach and Methodology<br>• Alternatives Evaluated<br>• Review of Objectives and Performance Measures<br>• Review of Uncertainties<br>• Review of Initial Analysis<br>• Review of Deep Borehole Field Test Specifications, Appendix C – Normal and Off-Normal Cost Estimates for Design Selection Study<br>• DBFT Cost Estimate Considerations<br>• DBD Cost Estimate Review<br>• Table of Pros and Cons of Emplacement Modes<br>• Sensitivity Analyses |
| Section 6.0 | • Summary and Recommendations<br>• Emplacement Mode Review and Recommendations<br>• Conceptual Waste Package Design Review and Recommendations<br>• Conceptual Design of the DBFT Review and Recommendations |
| Section 7.0 | • DBFT Scope Recommendations<br>• DBFT Recommendations Independent of Emplacement Mode Choice<br>• DBFT Recommendations for the Drill-String Emplacement Mode<br>• DBFT Recommendations for the Wireline Emplacement Mode |
| Section 8.0 | • References |
| Attachment A | • Editorial Comments on Report<br>• Additional Technical Comments on Report |

# 2.0 Review of Basis of DBFT Design

Section 2 of the M2 report provides technical information about the DBD concept, the emplacement method options, and the requirements and assumptions proposed to support the next stage of the design process (i.e., preliminary design). The sub-sections of this section of the report cover the DBD safety case (pre-closure and post-closure), the proposed system architecture, the functional and operational requirements for the disposal system and the DBFT, the design assumptions for the disposal system and the DBFT, the options for WP emplacement, the reference waste disposal concept, and some disposal system conceptual design questions. AREVA's review of this section of the M2 report is focused on our areas of expertise, which include the equipment, such as the WP and the shipping and transfer casks, and the thermal and shielding analyses performed for the WP located above and within the borehole. Details related to the drill rig components, wireline equipment, and borehole and casing design are not within AREVA's area of expertise; hence, comments made concerning these items are of a limited nature. These comments, or the lack of comments, should not be interpreted as an endorsement or a disapproval of these portions of the design and are primarily provided to address potential interface issues with items in the design AREVA is familiar with.

## 2.1 Review of DBD Safety Case

### *Summary of Section*

The risks associated with the safety case for DBD were split into those associated with pre-closure and those associated with post-closure. The key elements of the post-closure safety case are related to long-term isolation of the deep geologic environment, whereas those for the pre-closure safety case include surface handling and possible abnormal events that could lead to a WP breach within and above the emplacement zone. The post-closure safety case is dependent on natural barriers, such as thermally driven fluid flow and effectiveness of the seals. The pre-closure safety case is dependent on all waste handling activities prior to post-closure. The focus of the AREVA review was on the pre-closure safety case and includes evaluation of the emplacement concepts, potential shielding issues, licensed highway transportation cask, onsite transfer cask, WP impact limiter (IL) design, WP terminal velocity, impact energy in the borehole, and equivalent air drop above or outside of borehole. AREVA concurs with favoring operational safety objectives including safely emplacing WPs in the disposal zone given the extent of waste isolation performance credited to natural barriers as summarized in Section 2.1 of the M2 report.

### *AREVA Review Comments, Discussion, Proposed Alternatives, and Path Forward:*

AREVA agrees that the pre-closure safety case should be supported by engineering design studies and testing of important components of the DBD system. Important elements of the pre-closure safety case are identified as the surface handling equipment and procedures, WP integrity during emplacement operations prior to borehole sealing, and the emplacement configuration and procedures. Pre-closure radiological risks are identified for both normal conditions and off-normal conditions. AREVA agrees that radiation exposure during normal conditions is limited to workers, whereas for off-normal conditions worker radiation exposure and surface contamination caused by WP breach could result. In addition to the off-normal conditions identified in the M2 report, AREVA believes an airborne contamination event could result from a breached WP above the borehole. Planning for airborne contamination caused by a breached WP will be required for DBD, unless the design is modified to prevent this release. For the DBFT, with its absence of radiological material, no planning for an airborne release is necessary, but if engineering features have been implemented for DBD to prevent or mitigate the consequences of this drop scenario, then those features may require demonstration at the DBFT. Furthermore, the cost impacts associated with these features must be considered in the overall design. However, these drop scenarios in air are considered fairly independent of emplacement mode and hence, will not significantly differentiate one mode from another.

With respect to safety, a case can be made regarding the advantage the wireline emplacement method has over the drill-string emplacement method, as at some point of the operation, the drill-string method will have up to 40 WPs staged within the top portion of the borehole, suspended above the borehole prior to emplacement; whereas the wireline method will have at most 1 WP staged and suspended above the borehole. Therefore, the source term is 40 times greater for the drill-string method over the wireline method and hence, the consequence of a multiple-breached WP scenario involving these WPs (and potentially additional WPs already emplaced in DBD) is potentially significantly greater than the worst-case breach scenario associated with the wireline method.

Finally, with respect to post-closure, AREVA agrees in principle with the isolation concepts applied to post-closure for DBD, but defers to subject matter experts (SMEs) in this area. AREVA does note that regulations for post-closure DBD are identified as TBD in Section 2.4 and hence, identifies the risk that the current design for post-closure may be inadequate. However, the self-imposed design criteria for this disposal approach, as identified in Section 2.4, are restrictive and should either satisfy future regulatory performance requirements or provide an appropriate path towards successfully satisfying them.

## 2.2 Review of Disposal System Architecture

### *Summary of Section*

Section 2.2 of the M2 report provides the system architecture in outline form for DBD and for waste packaging, handling, and emplacement, primarily through a listing of subsystems in Tables 2-1 and 2-2 of the M2 report. For emplacement, architecture for both the wireline and drill-string methods are presented, even though only one will be selected for the DBFT.

### *AREVA Review Comments, Discussion, Proposed Alternatives, and Path Forward:*

AREVA agrees with the proposed system architecture presented in Tables 2-1 and 2-2, which include items applicable to wireline, drill-string, or both emplacement methods. Both tables are in outline form and as noted in the M2 report "are as a starting point for future design development, functional analysis, project management, and risk analysis activities." The following specific comments are provided for Section 2.2 and Tables 2-1 and 2-2:

- Additional equipment may be required to mitigate a potential WP drop scenario in air. For the drill-string, a possible drop scenario exists in the basement area when attempting to lower a WP from the shipping cask down to the next WP or instrumentation package staged below in the basement. For the wireline, a similar drop scenario exists when lowering the WP down to the blowout preventer (BOP), but since an IL will likely already be attached onto the WP, additional mitigation may not be required.

- Resources permitting, AREVA suggests installing a fiber optic cable along the outside of the casing. The fiber optic cable would provide real-time temperature monitoring of the casing, potentially every 3 ft. Furthermore, this cable could be used to monitor descent or verify location of WPs for all emplacement modes [2].

## 2.3 Review of Requirements for Disposal System and DBFT

### *Summary of Section*

Section 2.3 of the M2 report presents design requirements and controlled assumptions for the WP, handling and emplacement system as part of the DBFT. Parallel sets of requirements for both DBD and the DBFT are presented, where technically possible. The information in this section includes functional and operating requirements for handling and emplacement/retrieval equipment, performance criteria, WP design and emplacement requirements, borehole construction requirements, and sealing requirements. Assumptions are included if they could affect engineering design. Design solutions are avoided in the requirements discussion.

The current project technical baseline is identified in documents cited in the M2 report, which provide the basic description of the DBFT and DBD. A similar basis is provided for the prototype WPs developed for the DBFT. This information will be updated as the design advances and as non-technical requirements and criteria are developed (e.g., safety, health, security, etc.).

Requirements from the M2 report are presented in Table 2-3 and controlled assumptions are included in Table 2-4. In addition, to be determined (TBD) information is identified throughout this section of the M2 report with nine primary reasons provided for the assignment of these TBDs. Table 2-2 of this SRR contains a comprehensive list of TBDs that have been both explicitly and implicitly identified.

### *AREVA Review Comments, Discussion, Proposed Alternatives, and Path Forward:*

The following specific comments are provided for Section 2.3 of the M2 report:

- Section 2.3.2: Radiological Protection Requirements states that actual WP handling operations will make use of shielding, but for the DBFT such shielding may be simulated. In order to mimic/simulate those shielded operations at the DBFT, the extent of shielding necessary to protect personnel should be determined in advance.

- Table 2-3: contains a TBD for the "Safeguards and Security Requirements" that are not captured in Section 2.3.3. Recommend deleting all text from Section 2.3.3 except for the first sentence and adding a TBD. If not deleting this text, then need to revise it considering the unnecessary need for self-protection of Cs/Sr capsules, as this material is not special nuclear material requiring protection per 10CFR73. Additionally, the material regarding self-protection is somewhat speculative as it depends on, for example, how long a waste form has been decayed and how much self-shielding the waste form provides.

- Section 2.3.6: unclear why "nuclear criticality" needs to be specifically called out for speculative future activities. Recommend either deleting or placing "for example" at the beginning of the sentence (criticality may not be the only concern).
- Section 2.3.9: on page 2-10, the first sentence of the first full paragraph, clarify the implication of "If waste packages are lowered a few at a time on a wireline," since the operation of the wireline was understood as "one" at a time. Also, clarify the main impact of doglegs if any created during borehole construction on this emplacement method.
- Section 2.3.9: define "flush" as used by the drilling industry or other suitable standard.
- Section 2.3.9: it is stated that a slotted or perforated liner will be used for the disposal boreholes but not for the DBFT boreholes; however, this statement is inconsistent with other portions of the M2 report (e.g., Figure 2-2 on page 2-27, Section 2.6.2 on page 2-30), which identify the liner as probably being perforated in the disposal zone. Without a slotted/perforated liner in the DBFT disposal zone (for the FTB), the terminal velocity would be slower than with a perforated liner and therefore drop testing of test WPs would not correctly represent a drop in the actual disposal zone borehole.

  This may not be important to the overall design process, as drop testing may be bounded by drops in air from operations above the borehole (note that the drop orientation for a drop in air may not necessarily be on end and must be investigated). Nevertheless, AREVA recommends the M2 report be updated to consistently address this point and also recommends including perforated casing in the EZ of the DBFT (for the FTB) as described in option d) on page 2-29 of the M2 report. This would allow for an increase in the terminal velocity, simulation of drop conditions into the borehole, and, if needed, demonstration of sealing technologies. Additionally, perforated casing in the EZ will allow for DBFT insertion times to be assessed.
- Section 2.3.10: note the overpack internal length of 5 m is not compatible with the Cs/Sr Waste Encapsulation Storage Facility (WESF). Suggest coordinating the compatibility of the WP length with activities upstream of the borehole, noting the length of the WP also affects the dimensional layout of the equipment within the basement of the drill-string option.
- Section 2.3.10: note that the self-emplacement method would be performed if WP IL testing were performed in the DBFT (in the FTB).
- Section 2.3.10: suggest adding a TBD to determine mechanical loads for WP design.
- Section 2.3.10: note that WP leakage could be tested using a hyperbaric test facility rather than at the DBFT. A custom hyperbaric test vessel could be built to replicate high-temperature environments and saline/sour fluids, or use of existing hyperbaric testing resources could be pursued.
- Section 2.3.10: this section notes that WP containment is required through all phases of disposal operations, until the borehole is sealed and packages will be inspected for damage and leakage after the conclusion of the DBFT emplacement/retrieval operations. Recommend defining the containment requirements, including a required leakage rate

and testing methods. These requirements are likely major drivers for WP design and need to be defined early in the development of the program.

- Section 2.3.11: suggest including a discussion or criteria for the stuck WP condition (e.g., if stuck in the EZ, then leave the WP in place, but if stuck above the EZ, then remove the WP along with the casing, as necessary). Currently, there is some discussion regarding the stuck package in Appendix B-3 and Appendix C, but the discussion regarding the strategy and consequences should be added to Section 2.3.11.
- Section 2.3.11: indicates that the fluid level in the borehole must be closely monitored and this will be accomplished using mud ports at the wellhead. Figure 2-4 of the M2 report indicates the mud handling equipment in the basement is located above the BOP stack. The anticipated fluid level should be indicated here. If the fluid level were above the BOPs, then the BOPs would be submerged during normal operation and would be difficult to inspect. If the fluid level is below the BOPs, then additional valves will be required to keep the mud handling lines flooded between the two levels.

In summary, AREVA agrees with the requirements identified in Sections 2.3.1 through 2.3.13, but has some reservations on the validity of the proposed DBFT WP emplacement testing program, since the TBD requirements are anticipated to have an impact on final DBD design. As an alternative to the DBFT, emplacement development could be performed in a mock-up test facility (additional details related to this facility are identified below).

### *Specific Discussion on the Factor of Safety (FoS):*

The M2 report "has assumed a minimum design FoS for mechanical analyses of the waste packages." Although this assumed value appears to be adequate, it does not adequately address the various failure modes (e.g., buckling that a WP may experience in a DBD environment). For these other failure modes, different FoSs should be applied, depending on the loading conditions.

A good reference for the handling and disposal of radioactive materials is Section III of the American Society of Mechanical Engineers (ASME) Boiler and Pressure Vessel (B&PV) Code [3], which was specifically created for the design and construction of nuclear power plants. Additionally, NRC-licensed transportation packages under 10CFR71 typically utilized portions of the ASME B&PV Code in design and fabrication. Structural areas covered for a transportation package, and directly applicable to a WP containment boundary, include: buckling, external pressure, free drop impact, crush, compression, heat, and deep immersion. Each structural load case applies a different FoS, as defined by Section III of the ASME B&PV code.

Under the ASME Code, the allowable stresses are based on the maximum shear stress theory. This theory states that yielding of the material will begin whenever the maximum shear stress in a mechanical element becomes equal to the maximum shear stress in a tensile-test specimen when that specimen begins to yield. Based on this premise, the ASME B&PV Code has specified the basic allowable stress for materials as the design stress intensity, $S_m$. The stress intensity is equal to twice the maximum shear stress and is equal to the largest algebraic difference between any two of the three principle stresses. In general, design stress intensity is approximately equal to two-thirds of the material yield strength, $S_y$, at room temperature for ductile materials. All other stress limits for various conditions are based on the design stress intensity for normal, off-normal, and accident conditions. For each of these conditions, different stress limits are applicable, which results in different FoSs. An example of the various stress limits that are applied to a containment boundary are provided in Table 2-1. AREVA recommends these stress limits be utilized for the DBD WPs.

TABLE 2-1: CONTAINMENT STRUCTURE ALLOWABLE STRESS LIMITS

| Stress Category | Normal Conditions | Off-Normal/Accident Conditions |
|---|---|---|
| General Primary Membrane Stress Intensity | $S_m$ | Lesser of: $2.4S_m$ $0.7S_u$ |
| Local Primary Membrane Stress Intensity | $1.5S_m$ | Lesser of: $3.6S_m$ $S_u$ |
| Primary Membrane + Bending Stress Intensity | $1.5S_m$ | Lesser of: $3.6S_m$ $S_u$ |
| Range of Primary + Secondary Stress Intensity | $3.0S_m$ | Not Applicable |
| Pure Shear Stress | $0.6S_m$ | $0.42S_u$ |
| Buckling | Per ASME Code Case N-284<br>• FoS for Normal Conditions: 2.00<br>• FoS for Accident Conditions: 1.34 | |

Refer to "Subsection NB Class 1 Components" Chapter 6.0 of reference [3] for a more thorough review.

One final recommendation is for the licensee of DBD to interact with the regulator as soon as possible in order to establish a common understanding on FoSs. An example of a concern that may need to be addressed includes identification of two potential FoSs applied to the wireline: one to prevent a drop in air in an orientation the IL may not be able to protect the WP and one to minimize the probability of a drop in fluid within the borehole where the IL will prevent damage to the WP (with the impact of the wireline on top of it).

## 2.4 Review of Design Assumptions

### *Summary of Section*

Section 2.4 of the M2 report covered the various assumptions used to design DBD and elements of the DBFT including: waste forms to be disposed, depth of the borehole, number of WPs in a drill-string, minimum and maximum density of the fluid in the borehole, dogleg severity, maximum weight of a WP, WP wall thickness, and the buoyancy of the WP.

### *AREVA Review Comments, Discussion, Proposed Alternatives, and Path Forward:*

AREVA reviewed this section (and the remainder of the M2 report) to independently confirm the controlled assumptions documented in Table 2-3, Table 2-4, and Section 2.4 were comprehensive in nature. These tables and section did capture the majority of the TBD information, however there is some implicit TBD information contained in Section 2.0 of the M2 report that the tables did not mention. Table 2-2 in this SRR was independently created from a review of the M2 report for TBD information. This table includes a brief description of the TBD, the applicable work scope affected, and AREVA's review of the resolution path. The TBD numbering has been assigned for document review purposes only. This list focused primarily on the TBDs and assumptions that affect the preliminary design basis for follow-on design activities, especially in the area of the emplacement mode and packaging concepts.

## TABLE 2-2: M2 REPORT TBDs AND AREVA COMMENTS

| Summary of Document Information | | | | | AREVA Review & Comments | | |
|---|---|---|---|---|---|---|---|
| TBD No. | Section | Description | Work Scope Affected | Working Assumption Basis / Resolution Path for DBFT | Comments on Assumption Basis / Resolution Path for DBFT | Review of TBD Impact on Emplacement Mode | Proposed Resolution Path for Radioactive Waste Disposal |
| TBD -01 | §2.3.1 & Table 2-3 | For waste disposal activities, a broader framework would be used in design, encompassing radiological exposure and dose, nuclear criticality, nuclear QA, and so on. The particulars of such a program are beyond the scope of the DBFT, and are TBD. | Waste Disposal Only | 10CFR20: Standards for Protection Against Radiation. | AREVA review concurs with approach for DBFT | No impact on emplacement mode, as regulations are assumed to impact both modes equally | Work with appropriate regulatory bodies to define regulatory requirements for DBD.<br>This rulemaking will have an impact on the complexity of any waste handling facilities and equipment, and associated cost. |
| TBD -02 | §2.3.3 & Table 2-3 | Safeguards and security requirements for DBD of radioactive waste are TBD. | Waste Disposal Only | Not required | AREVA review concurs with approach for DBFT | Yes, as safeguards may require extra measures for drill strings hanging at the top if not emplaced in an immediate timeframe (e.g., safeguarded isolation). | Work with appropriate regulatory bodies to define safeguards and security requirements for DBDI. |
| TBD -03 | §2.3.4 & Table 2-3 | QA requirements for DBD radioactive waste disposal are TBD. | All deep bore holes drilled | The Used Fuel Disposition R&D program QA requirements | AREVA review concurs with approach for DBFT | No | Work with appropriate regulatory bodies to define QA |

| Summary of Document Information | | | | | AREVA Review & Comments | | |
|---|---|---|---|---|---|---|---|
| TBD No. | Section | Description | Work Scope Affected | Working Assumption Basis / Resolution Path for DBFT | Comments on Assumption Basis / Resolution Path for DBFT | Review of TBD Impact on Emplacement Mode | Proposed Resolution Path for Radioactive Waste Disposal |
| | | | | will be used (Quality Rigor Level 3). As such, any data collected from the DBFT will not necessarily be used for future waste disposal licensing. | | | requirements for DBD. |
| TBD -04 | §2.3.5 & Table 2-3 | NEPA – The National Environmental Protection Act is applicable to borehole disposal activities but specific details are TBD. | FTB and Waste Disposal | The type of NEPA assessment (e.g., categorical exclusion or EIS) will be determined and implemented prior to initiating field activities for the CBH and FTB. | AREVA review concurs with approach for DBFT | Yes, environmental impact of accident/upset conditions may be different for each emplacement mode | Assume 10CFR51 is applicable; this requires an EIS to be issued. |
| TBD -05 | §2.3.5 & Table 2-3 | Waste disposal boreholes may be classified as injection wells in accordance with 40CFR144, but the applicability of this regulation to future DBD projects is | All deep boreholes drilled | It is assumed that the 40CFR144 is not applicable to the DBFT. | AREVA review concurs with approach for DBFT | No impact | Work with appropriate regulatory bodies to define regulatory requirements for DBD.<br>This rule making could have an |

| Summary of Document Information | | | | | AREVA Review & Comments | | |
|---|---|---|---|---|---|---|---|
| TBD No. | Section | Description | Work Scope Affected | Working Assumption Basis / Resolution Path for DBFT | Comments on Assumption Basis / Resolution Path for DBFT | Review of TBD Impact on Emplacement Mode | Proposed Resolution Path for Radioactive Waste Disposal |
| | | TBD. | | | | | impact on the complexity of any waste handling facilities and equipment, and associated cost |
| TBD -06 | §2.3.6 & Table 2-3 | Disposal activities will be performed in a manner consistent with long-term waste isolation, in accordance with a safety strategy that depends on the waste type and site-specific factors, and is TBD. | Waste Disposal Only | The assumed safety strategy is to prevent package breach until the borehole is sealed. | AREVA review concurs with the conservative approach for DBFT, but notes this resolution path may be over-burdensome to satisfy and result in an overly conservative design. | Yes, both emplacement modes would need to conform to the safety strategy. | The overall safety strategy for the long-term waste isolation will need to be determined after waste type and site-specific factors are defined. |
| TBD -07 | §2.3.7 & Table 2-3 | Operational requirements for radioactive waste disposal operations are TBD. | Waste Disposal Only | Not required | AREVA review concurs with identification of TBD | No | Work with appropriate regulatory bodies to define operational requirements. |
| TBD -08 | §2.3.8 & Table 2-3 | Allow for characterization of the hydro geologic setting from the surface to total depth, including the overburden, seal zone, and disposal | CBH, FTB, and Waste Disposal | Drilling and construction of the CBHs and FTBs shall be conducted to allow characterization of the hydro | AREVA review concurs with approach for DBFT | No | The type of data to be collected and sampling requirements will need to be specified.<br>This decision is expected to be based on the DBFT |

| Summary of Document Information | | | | | AREVA Review & Comments | | |
|---|---|---|---|---|---|---|---|
| **TBD No.** | **Section** | **Description** | **Work Scope Affected** | **Working Assumption Basis / Resolution Path for DBFT** | **Comments on Assumption Basis / Resolution Path for DBFT** | **Review of TBD Impact on Emplacement Mode** | **Proposed Resolution Path for Radioactive Waste Disposal** |
| | | zone. For future waste disposal boreholes, this requirement is focused on any confirmatory data to be collected, the nature of which is TBD. | | geologic setting. | | | results and the performance requirements placed on the isolation barrier. |
| TBD -09 | §2.3.8 & Table 2-3 | Design requirement for ensuring that the service life is at least 10 years is TBD. | FTB and Waste Disposal Only | Service lifetime of the CBHs and FTBs shall be 10 years, considering casing corrosion, creep, and other significant time-dependent processes. | AREVA believes the 10-year service life should be reassessed as more data is available on time-dependent degradation processes in the downhole environment. | No | The actual designed service life for DBD will be reassessed based on the DBFT results. (Related to TBD-16) |
| TBD -10 | §2.3.9, Table 2-3 & Table 2-4 | Maximum dogleg severity for the waste disposal boreholes is TBD. | FTB and Waste Disposal | A maximum dogleg severity was specified for the DBFT as 3° per 100 ft. | AREVA review concurs since this is justified by drilling expert opinion. | Depends on the type of dogleg and the condition of the casing, therefore the impact on emplacement mode is unknown. | The estimate will be confirmed by experience and data from the DBFT and supporting calculations. |
| TBD -11 | §2.3.9 & +Table 2- | The need for directional drilling for | FTB and Waste | Directional drilling will only | AREVA review concurs with | Yes | This will be developed based on |

| Summary of Document Information | | | | | AREVA Review & Comments | | |
|---|---|---|---|---|---|---|---|
| TBD No. | Section | Description | Work Scope Affected | Working Assumption Basis / Resolution Path for DBFT | Comments on Assumption Basis / Resolution Path for DBFT | Review of TBD Impact on Emplacement Mode | Proposed Resolution Path for Radioactive Waste Disposal |
| | 4 | disposal boreholes is TBD, and may depend on emplacement method. | Disposal | be required if standard non-directional drilling is not able to achieve the straightness requirements of the borehole. This will be determined by the company selected to drill the borehole. | approach for DBFT | | experience and data from the DBFT. |
| TBD -12 | §2.3.9, §2.3.10 & Table 2-3 | Requirements for managing thermal expansion in a heater test or other temperature changes in the CBHs and FTBs are TBD. | CBH and FTB | The design of the emplacement zone should account for the potential of a heater test equivalent to a Cs/Sr WP. | AREVA review concurs with approach for DBFT. | No | This will be developed based on experience and data identified from the DBFT. |
| TBD -13 | §2.3.10 | The actual package length is up to 5m. | FTB and Waste Disposal | The package length is assumed to be up to 5m long. | Package compatibility with upstream waste owners is beyond the scope of DBFT. Future DBD operations can adapt to specific WP lengths required for | The test package length selected for DBFT will be compatible with the emplacement mode utilized. | Beyond the scope for DBFT activities |

| Summary of Document Information | | | | | AREVA Review & Comments | | |
|---|---|---|---|---|---|---|---|
| TBD No. | Section | Description | Work Scope Affected | Working Assumption Basis / Resolution Path for DBFT | Comments on Assumption Basis / Resolution Path for DBFT | Review of TBD Impact on Emplacement Mode | Proposed Resolution Path for Radioactive Waste Disposal |
| | | | | | upstream waste owners. | | |
| TBD -14 | §2.3.10 & Table 2-3 | Disposal WP radial clearance is TBD. | FTB and Waste Disposal | The current conceptual design uses a 0.7-inch radial gap. | Will be determined by analysis of the package sticking, maximum velocity, and borehole liner geometry. | Yes, terminal velocity depends on the radial clearance for both emplacement modes. | This will be developed based on experience and data identified from the DBFT. |
| TBD -15 | §2.3.10, §2.4, Table 2-3, & Table 2-4 | The maximum pressure for actual WPs is TBD because it depends on the properties of the so-called emplacement mud, and how it is introduced.<br><br>WPs, including the waste load, shall have negative buoyancy in borehole fluid (density TBD).<br><br>The minimum borehole fluid density is assumed to be that of pure water (density TBD).<br><br>The maximum borehole fluid | FTB and Waste Disposal | The DBFT and test packages will be evaluated using the bounding maximum and minimum fluid density of 1.3 and 1.0 × density of water, respectively. | AREVA review agrees, this should be confirmed with actual measurement before the DBFT package placement tests with the selected emplacement fluid.<br><br>This will evaluate the formation of concentrated brines in the basement whose densities exceed 1.3 × the density of water.<br><br>Temporary higher density emplacement fluids (>1.3) could be installed to limit | Yes, maximum borehole fluid density will affect buoyancy hydrostatic pressure, and terminal velocity for both wireline and drill-string methods. | The actual borehole fluid density will be determined by experience and identified from the DBFT. |

| Summary of Document Information | | | | | AREVA Review & Comments | | |
|---|---|---|---|---|---|---|---|
| **TBD No.** | **Section** | **Description** | **Work Scope Affected** | **Working Assumption Basis / Resolution Path for DBFT** | **Comments on Assumption Basis / Resolution Path for DBFT** | **Review of TBD Impact on Emplacement Mode** | **Proposed Resolution Path for Radioactive Waste Disposal** |
| | | density for DBD is TBD. | | | or mitigate terminal velocity, then replaced later for sealing purposes, but increased hydrostatic pressure would also result. | | |
| TBD -16 | §2.3.10 & Table 2-3 | For actual waste disposal over packs (if used) and WPs, the design safety factor is TBD. | FTB and Waste Disposal | An FoS of 2 will be used per the requirements document for normal conditions. Off-normal conditions will be evaluated separately. | Document the basis for this FoS. Suggest using a consensus standard as the basis for the WP design as done for licensed transport and storage packages under 10CFR71/72. Also suggest citing the lifting standard by which the Tuffline® wireline is rated (it is not rated using a FoS of 2). | Yes, all methods will be affected by the WP weight, which is a function of the FoS. | Work with appropriate regulatory bodies to obtain approval for use of FoS. This will also be a function of associated risk (i.e., TBD-17). FoS on the wireline may be subject to a consensus lifting standard used in the nuclear industry. |
| TBD -17 | §2.3.10 & Table 2-3 | The maximum test package temperature in the FTB is TBD. | FTB | Assumed maximum temperature is 170°C in the | The assumed temperature appears conservative and | None | Not required |

| Summary of Document Information | | | | | AREVA Review & Comments | | |
|---|---|---|---|---|---|---|---|
| TBD No. | Section | Description | Work Scope Affected | Working Assumption Basis / Resolution Path for DBFT | Comments on Assumption Basis / Resolution Path for DBFT | Review of TBD Impact on Emplacement Mode | Proposed Resolution Path for Radioactive Waste Disposal |
| | | | | FTB. | is based on a geothermal gradient of 30°C/km and a mean annual surface temperature of 20°C. | | |
| TBD -18 | Deleted | | | | | | |
| TBD -19 | §2.3.10 | Containment longevity may be required after the borehole is sealed depending on the disposal environment, waste radionuclide half-life, and other characteristics. The extent of which is TBD. | Waste Disposal Only | These considerations do not apply to DBFT test WPs, which will be retrieved immediately. | AREVA review concurs with approach for DBFT | No | Work with appropriate regulatory bodies to define regulatory requirements including containment longevity for DBD. |
| TBD -20 | §2.3.10, §2.4 & Table 2-4 | Leakage control requirements for WPs during operations are TBD. | DBFT and Waste Disposal | For DBFT, test packages shall at a minimum, prevent leakage of borehole fluid into the packages during repeated emplacement | Waste packages can be designed and fabricated to accommodate leakage rates that could range by several orders of magnitude, (i.e. down to $10^{-3}$ for | The leakage rate is independent of emplacement mode. | Work with appropriate regulatory bodies to obtain approval for leakage or containment requirements for WPs used in DBD. |

| Summary of Document Information | | | | | AREVA Review & Comments | | |
|---|---|---|---|---|---|---|---|
| TBD No. | Section | Description | Work Scope Affected | Working Assumption Basis / Resolution Path for DBFT | Comments on Assumption Basis / Resolution Path for DBFT | Review of TBD Impact on Emplacement Mode | Proposed Resolution Path for Radioactive Waste Disposal |
| | | | | and retrieval testing operations. For DBD, waste packages shall prevent leakage to the requirements of the waste form disposed. | water compared to $10^{-7}$ for helium molecules). Test packages may use a less stringent leakage definition for DBFT due to no radioactive materials planned for the test. Inspection (e.g., prior to demonstration) and leak detection (e.g. after emplacement testing in the FTB) should be well defined and cost effective. | | |
| TBD -21 | §2.3.11 & Table 2-3 | The circumstances necessitating retrieval of WPs for DBD is out of scope for DBFT.. | Waste Disposal Only | For the DBFT retrieval means that packages are emplaced, released, then reattached and hoisted from the borehole. | AREVA review concurs with approach for DBFT | Yes, retrieval of packages required with either emplacement mode may be a challenge for one mode over another. | Retrievability for DBD is beyond the scope of DBFT activities and will need future regulatory performance criteria. |
| TBD -22 | §2.3.11 & Table 2-3 | The need for wellhead BOP equipment in waste | All deep boreholes | Test WP emplacement and retrieval | The BOP equipment should be designed to | Yes, either emplacement mode will be | Assume BOP equipment will be |

| Summary of Document Information | | | | | AREVA Review & Comments | | |
|---|---|---|---|---|---|---|---|
| **TBD No.** | **Section** | **Description** | **Work Scope Affected** | **Working Assumption Basis / Resolution Path for DBFT** | **Comments on Assumption Basis / Resolution Path for DBFT** | **Review of TBD Impact on Emplacement Mode** | **Proposed Resolution Path for Radioactive Waste Disposal** |
| | | disposal boreholes is TBD. | drilled. | equipment will be designed to function with or without BOPs in place on the FTB wellhead. | avoid breaching a WP or severing the drill pipe or wireline. | affected as provisions will need to be made for accommodating a drill-string suspended over the borehole or the presence of a wireline through the BOP. | required.<br>Design the BOP and the BOP controls to ensure protection of WP, drill-string, and/or wireline. |
| TBD -23 | §2.4 & Table 2-4 | Waste forms to be considered in a future DBD waste disposal system are TBD. | Waste Disposal Only | The assumed waste forms to be considered include DOE-owned granular HLW materials, vitrified HLW, HLW in sealed capsules, and SNF. No radiological material will be used in the DBFT. | No comments | The waste form will have no effect on the emplacement mode used for DBFT | Resolution path for DBD is out of scope for DBFT and will depend on regulatory performance criteria. |
| TBD -24 | §2.4 & Table 2-4 | Borehole total depth for borehole disposal of radioactive waste is TBD. | Waste Disposal Only | Stated DBFT requirement of 5 km. | AREVA review concurs with approach for DBFT. | Yes, either since this affects the ambient pressure (TBD-15). | This will be developed based on experience and data from the DBFT.<br>This may also require regulatory |

| Summary of Document Information | | | | | AREVA Review & Comments | | |
|---|---|---|---|---|---|---|---|
| TBD No. | Section | Description | Work Scope Affected | Working Assumption Basis / Resolution Path for DBFT | Comments on Assumption Basis / Resolution Path for DBFT | Review of TBD Impact on Emplacement Mode | Proposed Resolution Path for Radioactive Waste Disposal |
| | | | | | | | performance requirements to justify the borehole total depth. |
| TBD -25 | §2.4 & Table 2-4 | The DBFT will not involve demonstration of waste package storage at the borehole site. | Waste Disposal Only | No onsite storage of packages is assumed for the DBFT. The maximum throughput of 1 package per day is also assumed for the cost-risk model comparison. | Accept assumption for DBFT purpose. | The storage assumption will have no impact on emplacement mode for DBFT | Actual disposal operations are beyond the scope of the DBFT. |
| TBD -26 | Table 2-4 | Long-term control and ownership of sites for DBD(s) are TBD. | FTB and Waste Disposal | Assume DBFT site is owned by DOE until all testing is complete. Then the test site would be turned back over to another owner. | AREVA review concurs with approach for DBFT. | None | Work with appropriate government bodies to define the ownership requirements for DBD. |
| TBD -27 | §2.4 | Maximum and minimum weight of disposal WPs is TBD. | Waste Disposal | For DBFT, the maximum weight for a reference-size test package is given in the M2 | Suggest tabulating the parameters that may affect the test package weight (e.g. wireline weight | Yes, the maximum package weight affects both emplacement modes. | Work with appropriate regulatory bodies to define the regulatory requirements for FoS. |

| Summary of Document Information | | | | | AREVA Review & Comments | | |
|---|---|---|---|---|---|---|---|
| TBD No. | Section | Description | Work Scope Affected | Working Assumption Basis / Resolution Path for DBFT | Comments on Assumption Basis / Resolution Path for DBFT | Review of TBD Impact on Emplacement Mode | Proposed Resolution Path for Radioactive Waste Disposal |
| | | | | report based on disposal of DOE-owned granular waste and Cs/Sr capsules. | and strength, FoS used on handling loads, connection weight, instrumentation weight, dynamic loading, etc.) See also TBD-31. | | |
| TBD -28 | §2.6.2 | The emplacement zone fluid viscosity. | Waste Disposal | Grout injection for waste emplacement is not planned. | This will need to be studied and determined before and during the DBFT. Demonstrating that the packages can be emplaced in the high viscosity fluid in the emplacement zone is an important aspect for the viability of DBD. | Yes, maximum borehole fluid viscosity will affect the decent rates of the WPs. | The actual borehole emplacement fluid properties will be determined by experience and data from the DBFT. |
| TBD -29 | §2.6.4 (drill-string only) | The mechanical details of the transfer carrier are TBD. | FTB and Waste Disposal | None | Once the emplacement method is established, surface operations will need to be detailed and equipment designed to optimize | None foreseen, only used for drill-string. | If used, this equipment will be developed based on experience and data from the DBFT. |

| Summary of Document Information | | | | | AREVA Review & Comments | | |
|---|---|---|---|---|---|---|---|
| TBD No. | Section | Description | Work Scope Affected | Working Assumption Basis / Resolution Path for DBFT | Comments on Assumption Basis / Resolution Path for DBFT | Review of TBD Impact on Emplacement Mode | Proposed Resolution Path for Radioactive Waste Disposal |
| | | | | | operations and perform them safely. | | |
| TBD -30 | §2.6.6 | The feasible sink rate for wireline emplacement is TBD. | FTB and Waste Disposal | Assuming a sink rate of 1.7 ft/s for wireline emplacement. | This should be part of the FTB data collected and considered together with TBD-15. | Yes, the maximum velocity is a determining factor for wireline mode, impacting the design of the IL. | If wireline is used, this data will be collected from the DBFT. |
| TBD -31 | §2.6.5 | The weight of the cable head and any additional logging tools and subs used on the WP is TBD. | Waste Disposal Only | A path forward is not explicitly stated. | Additional lifted components such as cable connection and logging tools reduce the available capacity of the wireline to support the WP with safety margin (i.e., FoS). The maximum assumed design weight for these items based on the selection of the wireline emplacement mode needs to be established to size the ILs and verify the FoS for the | Yes, wireline is near capacity with a single package and with existing FoS. If a higher FoS is required by the regulator, then wireline process may not be viable. | If used, this equipment will be developed based on experience and data from the DBFT and coordination with the regulator to verify acceptable FoS for wireline. |

| Summary of Document Information | | | | | AREVA Review & Comments | | |
|---|---|---|---|---|---|---|---|
| **TBD No.** | **Section** | **Description** | **Work Scope Affected** | **Working Assumption Basis / Resolution Path for DBFT** | **Comments on Assumption Basis / Resolution Path for DBFT** | **Review of TBD Impact on Emplacement Mode** | **Proposed Resolution Path for Radioactive Waste Disposal** |
| | | | | | wireline is met. See also TBD-27 | | |
| TBD -32 | §2.6.7 | The chemical environment the package must survive in-situ for 10 years is TBD. | Waste Disposal Only | Assume the packages may be exposed to significant concentrations of chloride, Na, Ca, and possibly Mg ions. | This should be part of the FTB data collected. | Yes, if the maximum weight assigned to the packages increases as a result. | The environment needs to be determined before a final WP material can be selected for performance under an external pressure of 9,600 psi for 10 years. Chemical environment data should be collected during the DBFT. |
| TBD -33 | Table 3-1 | The amount of damage the drill rig functions could induce on a WP during the emplacement processes at the surface is TBD. | FTB and Waste Disposal | Drill rig functions will be fully simulated, for demonstrating drill-string emplacement. Automated equipment (iron roughneck, power slips, and tongs) will be evaluated for damage to test packages. | AREVA agrees with approach. | Yes | If used, this equipment will be developed based on experience and data from the DBFT. |
| TBD -34 | §4.2 | The terminal velocity of the different WP(s) and drill | FTB and Waste Disposal | A path forward is not stated. | This should be studied in detail with the slotted/ | Yes, this would affect emplacement | This will be developed using data and analysis |

| Summary of Document Information | | | | | AREVA Review & Comments | | |
|---|---|---|---|---|---|---|---|
| **TBD No.** | **Section** | **Description** | **Work Scope Affected** | **Working Assumption Basis / Resolution Path for DBFT** | **Comments on Assumption Basis / Resolution Path for DBFT** | **Review of TBD Impact on Emplacement Mode** | **Proposed Resolution Path for Radioactive Waste Disposal** |
| | | strings is TBD. | | | perforated casing design and actual emplacement fluid properties. | speeds and inherent safety of the different designs | from the DBFT. |
| TBD -35 | §4.5 | The time frame for actual disposal is TBD. | Waste Disposal Only | Emplacement was assumed for thermal analysis estimates to be in 2020. | AREVA agrees with the timeframe for emplacement. | No | N/A |
| TBD -36 | §4.5 | The permeability of the borehole and surrounding disturbed rock zone is TBD. | Waste Disposal Only | The permeability of the borehole and the surrounding disturbed rock zone (within a cross-sectional area of 1 $m^2$) was increased by a factor of 10 to account for increased permeability in the disturbed rock zone and degradation of borehole seals. | AREVA does not have the expertise to either confirm or disagree with this approach. However, this should be part of the studies conducted on the FTB. | No | This will be developed using data and analysis from the DBFT. |
| TBD -37 | §4.5 | The actual temperature at the bottom of the borehole is TBD. | FTB and Waste Disposal | The temperature at the bottom of the borehole is fixed at 160°C. | Please provide basis for this input/assumption. | No | This will be developed using data and analysis from the DBFT. |

| Summary of Document Information | | | | | AREVA Review & Comments | | |
|---|---|---|---|---|---|---|---|
| TBD No. | Section | Description | Work Scope Affected | Working Assumption Basis / Resolution Path for DBFT | Comments on Assumption Basis / Resolution Path for DBFT | Review of TBD Impact on Emplacement Mode | Proposed Resolution Path for Radioactive Waste Disposal |
| TBD -38 | §4.5 | The actual geothermal temperature gradient is TBD | FTB and Waste Disposal | The temperature boundary conditions represent an average geothermal gradient of 25°C /km. | Provide basis for this input/assumption. | No | This will be developed using data and analysis from the DBFT. |
| TBD -39 | Table 5-1 | Flexibility to accommodate an uncertain future may include criteria related toretrievability and/or reversibility to modify the disposal approach in response to technical, policy, and/or regulatory changes. | Waste Disposal Only | No retrievability requirements are applicable to the DBFT. | AREVA agrees that this is a reasonable assumption for DBFT. | No, these criteria do not differentiate among emplacement modes. | Beyond the scope of the DBFT and will require regulatory performance requirements. |
| TBD -40 | Section 5.0 | Failure rates of equipment borehole casings are TBD. | FBT and Waste Disposal | The failure rates were estimated by an expert panel described in Appendix A. | AREVA agrees and believes further investigation is merited by SMEs. | Yes | A detailed failure analysis of the actual equipment to be used with waste disposal will be created for the licensing of any DBD. |
| TBD | Section 2.4 and | WP strings are limited to 40 WPs, | FTB and Waste | No supporting plugs in the | AREVA agrees with the | Limit applies to both | Additional testing and analysis should |

| Summary of Document Information | | | | | AREVA Review & Comments | | |
|---|---|---|---|---|---|---|---|
| **TBD No.** | **Section** | **Description** | **Work Scope Affected** | **Working Assumption Basis / Resolution Path for DBFT** | **Comments on Assumption Basis / Resolution Path for DBFT** | **Review of TBD Impact on Emplacement Mode** | **Proposed Resolution Path for Radioactive Waste Disposal** |
| -41 | Table 2-4 | consistent with the reference design. | Disposal | FTB, therefore package string is limited to 40 WPs for FTB. | assumption. | emplacement modes. | be performed on supporting borehole plugs to verify capacity to support multiple WP strings. |
| TBD -42 | Section 2.4 | Overburden is assumed to be sediments that could be overpressured and exceed the casing external pressure limit. | FTB and Waste Disposal | Condition to cause overpressure is unlikely given the geologic setting selected for waste disposal. | AREVA agrees and believes further investigation is merited by SMEs. | Applies to both emplacement modes. | Additional testing and analysis should be performed to verify the overburden is not overpressurised. |
| TBD -43 | N/A | Corrosion rate and hydrogen generation of materials in the borehole. | FTB and Waste Disposal | Assume the DBFT can be performed despite existence of corrosion and hydrogen and will be used to gather data. | AREVA agrees and believes further investigation is merited by SMEs. | Applies to both emplacement modes. | Additional testing and analysis should be performed to determine bounding values to be used for DBD. |
| TBD -44 | N/A | WPs are required to have threaded connections at both ends. | FTB and Waste Disposal | Threaded connections are assumed to be merited on the WP regardless of emplacement mode selected to allow for IL, instrument | AREVA agrees with having threaded connections on each end of the WP as it provides flexibility for future activities. | Yes | Once the design of the WP and emplacement mode mature, it should be evident whether or not threaded connections on each end of the WP are necessary. |

| Summary of Document Information | | | | | AREVA Review & Comments | | |
|---|---|---|---|---|---|---|---|
| TBD No. | Section | Description | Work Scope Affected | Working Assumption Basis / Resolution Path for DBFT | Comments on Assumption Basis / Resolution Path for DBFT | Review of TBD Impact on Emplacement Mode | Proposed Resolution Path for Radioactive Waste Disposal |
| | | | | packages, etc. to be connected to WP. | | | |

*Specific Discussion on Potentially Challenging Design Assumptions:*

Several design assumptions could potentially be challenging to solve in regards to the WP design and emplacement method. The following issues for the DBFT are identified:

**Package Terminal Velocity (see TBD-34):** This is a critical value for assuring the safety of the DBD for either emplacement mode. This may require substantial analysis and testing before and during the DBFT. This analysis is also highly coupled with other design inputs such as the package diameter, package weight, package length, emplacement fluid properties, and casing design (i.e. perforations). Many of these inputs are currently identified as TBD in the above table.

**Method of Retrieval (see TBD-21):** Retrieval of stuck waste packages is beyond the scope for the DBFT. Demonstrating casing removal with stuck waste packages is beyond the scope for DBFT. The DBFT will include emplacement and retrieval of non-stuck test packages to confirm initial feasibility of the DBD concept.

## 2.5 Review of Waste Disposal Concepts

This section of this SRR diverts from the contents within the M2 report. The following topics are discussed in this section:

- Perforated casing
- IL design/terminal velocity
- Position on proposed disposal operations
- Discussion on emplacement options wireline/drill-string/coil tubing/free fall/conveyance liner
- Drill-string basement discussion
- Emplacement rate discussion
- WP design recommendation
- Emplacement connection recommendation
- Position on proposed enhancements

*Perforated Casing*

Mitigating the drop of a 40 WP drill string with drill pipe begins with the design of the borehole EZ. The terminal velocity is controlled by the hydraulic diameter, which is the difference in diameters between the borehole or casing ID and the WP outside diameter (OD). The M2 report describes various design options for the perforated casing in the EZ. Option d), page 2-29 of the M2 report, includes filling the entire disposal zone guidance casing annulus with cement and the casing is then cleaned out and filled with emplacement fluid. Option d) effectively minimizes the hydraulic diameter for the perforated casing design and the resulting terminal velocity of a dropped 40 WP drill string with drill pipe is minimized (see Section 4.2 for further analysis). An IL stroke of less than 6 ft could potentially be utilized with the 40 WP drill string with the option d) casing construction.

A dropped 4.5-inch diameter drill pipe string without the attached WP would have a large hydraulic diameter and the resulting terminal velocity and impact energy would likely result in a breached WP. A potential mitigation technique for a dropped drill pipe string would include attaching several dummy WPs to the end of the drill pipe string. The dummy WPs would have large ODs to limit the terminal velocity and include features for impact absorption. Potentially, several dummy WPs connected together could be used to mitigate a dropped drill pipe string. The dummy WP would include the J-slot connection or other features for connecting and releasing the WPs.

The wireline method would also benefit by using the option d) casing construction for the same reasons above.

Another potential mitigation approach for a dropped WP within the borehole would be to consider an increase in the density of the emplacement fluid beyond 1.3 x water proposed for the FTB. A fluid such as the Baker Hughes HPHT Drilling Fluid PYRO-DRILL$^{SM}$ has a density up to 19.4 lb/gal compared to pure water density of 8.3 lb/gal or approximately 2.3 times pure water. Determining terminal velocity using the equations from Bates et al. [4] with higher fluid densities indicates that slower terminal velocities will result.

### *Impact Limiter Design/Terminal Velocity*

Since test WP emplacement mode testing can occur in both the CBH and the FTB, then separate test WPs with corresponding IL designs will be required for the two different borehole diameters. Below are a few design differences to consider:

- In order to achieve similar terminal velocities for both the CBH and the FTB, the radial clearances will likely have to be adjusted for each borehole diameter. Unfortunately, adjusting the radial clearance will also affect the emplacement performance of the WP without becoming stuck in the casing. Further study will likely be required to prioritize the desire for achieving terminal velocity and corresponding IL performance or the emplacement performance within a bounding dogleg casing. It is unlikely that both performance parameters could be checked within the same borehole.
- Difference of IL design between CBH (8.5” diameter) and FTB (17” diameter)
- For the drill-string, assume no limiter is installed since they would have negligible effect in a borehole drop and would take up valuable EZ volume; therefore, only a diameter difference must be considered for the WP design at this time.
- For the wireline, initial estimates on the IL reveal that a drop in air outside the borehole is bounding over a free drop within the borehole fluid. Despite the bounding air drop case, the terminal velocity within the borehole fluid would need to be verified for the wireline case. The terminal velocity, and corresponding limiter performance, is dependent on the borehole diameter and WP radial clearance, thus separate limiter designs will be required for both the smaller CBH and larger FTB.

### *Position on Proposed Disposal Operations:*

Transportation Cask:

The disposal operations describe a system using a purpose-built Type B shipping cask and purpose-built truck-trailer. The Climax transport cask referenced was not certified as a Type B shipping cask, but it provides a good example of a transfer cask that could be used in conjunction with a Type B shipping cask.

The primary purpose of the Type B shipping cask is to provide shielding and confinement as well as impact, puncture, and thermal protection for its special form contents during transport under both normal and accident conditions. Adding features such as slide doors and penetrations through the containment boundary would likely require further study to develop custom seals that would remain leak tight containment following drop, puncture, and thermal testing.

Hard Stops:

The cask operations include using hard stops to prevent the WPs from being lifted out of the shielded cask, but programmable logic could be used to prevent the inadvertent lifting event and prevent an overload situation within the load path of the WP.

### *Discussion on Emplacement Options Wireline/Drill-String/Coil Tubing/Free Fall/Conveyance Liner:*

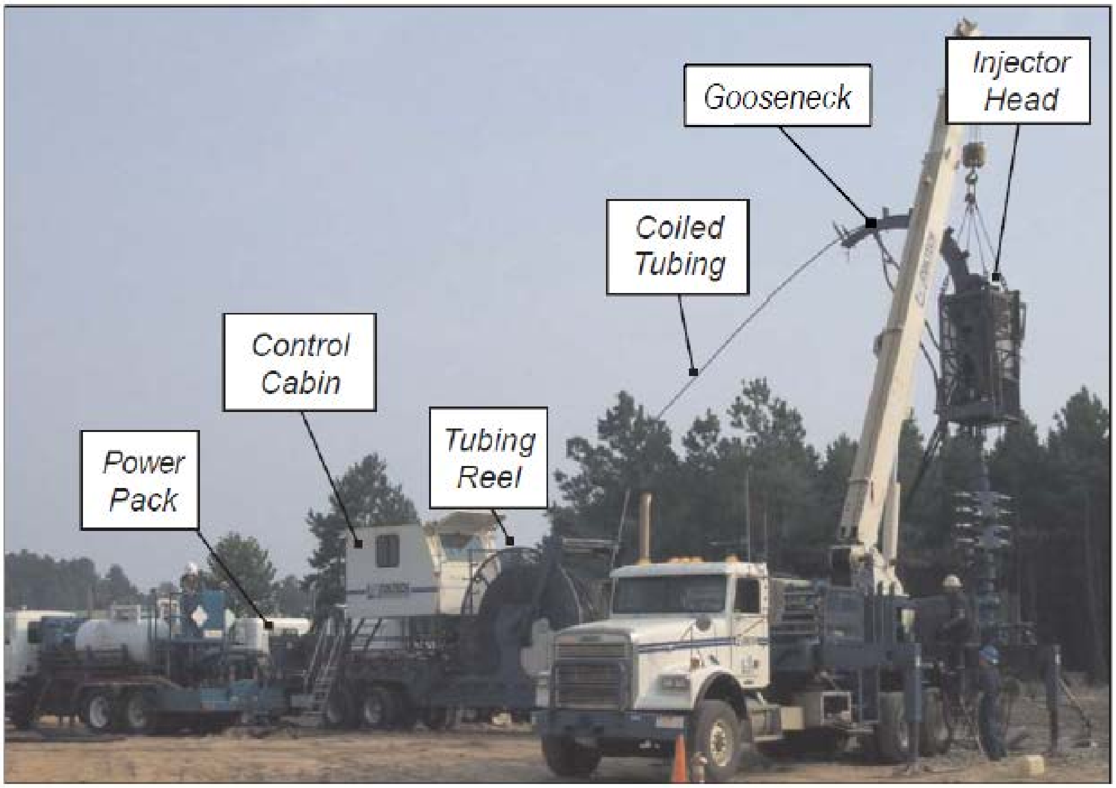
The following discussion is provided as an overview of all the emplacement modes considered in this SRR. Only highlights or comments of the drill-string and wireline are included since they are already covered in depth in the M2 report.

- The drill-string option includes the risk of suspending the heavy drill string over the WPs in the borehole and thus having the potential energy to breach the WPs in the event of a drill-string handling mishap. The impact energy for the wireline is much less than the drill-string emplacement option, because only one WP is emplaced per trip-in and, since the wireline is flexible (not a rigid structure), one expects that it will slowly coil onto itself gradually releasing a low impact energy onto the WPs; thereby avoiding breaching a WP.
- **Self-emplacement**: The free fall or self-emplacement option is similar to the wireline option. The same equipment is required for both, a wireline logging and a borehole ring gage would be tripped-in and -out of the borehole prior to every package emplacement in order to verify the emplacement location and the condition of the casing. There would be no time savings with the free fall method if the assumed delivery limit of one WP per day remained. The free fall or self-emplacement method would not require the release mechanism and the inherent risk of a release mechanism failure would be eliminated along with the minor cost savings that would be realized without the release mechanism. Self-emplacement would be coincidently tested during the IL test to be performed for the DBFT, since free fall of the WP in the emplacement fluid would be required for limiter testing.
- **Coil Tubing**: A typical Coiled Tubing (CT) unit includes several key components. (See Figure 2-1 corresponding to the description below):
    1. A CT reel to store and transport the CT string: a CT string is a long continuous length of pipe made from high strength steel, low-alloy flat strip rolled into tube and resistance seam welded and wound on a spool. Typical strengths range from

55 to 120 ksi. Chrome and titanium alloys are also available. Diameters range from 0.75 in to 4.5 in and lengths of 20,000 ft are common.

2. Injector head to provide tractive effort to push or pull the CT string in and out of the well.
3. The control cabin where the operator controls and monitors the operations.
4. Power pack that generated the hydraulic and pneumatic power required by the well equipment.

FIGURE 2-1: TRAILER MOUNTED CT UNIT AND CRANE [COURTESY ICOTA (5)]




The continuous tubing passes over a gooseneck structure and through an injector head before insertion into the well-control equipment typically consisting of a stuffing box (dynamic seal), riser, and BOP stack on top of the wellhead.

Electrical conductors can be added to the CT to provide power and control to electronically operated tools. The electrical conductor is typically installed into the CT by attaching a pig connector to the end of the conductor cable and then pumping and feeding the conductor through the CT similar to a piston moving in a cylinder. At the reel end of the tubing, the conductor passes through a pressure bulkhead into the axle and to a rotating connection called a collector ring where an electrical plug allows connection to controls or the electrical logging device. At the downhole end of the CT, a termination is placed to allow mechanical and electrical connections to the removable logging tools; ports are included that allow pumping of fluids or gases downhole.

Advantages to CT process include:

- Compared to drill-string emplacement mode, this CT is quick to mobilize, has lower costs, and can expedite operations as there is no need to stop and connect threaded joints or store/retrieve pipe sections.
- Reasonably high load capacities for deeper vertical and high angle reach compared with wireline (stranded cable around electrical conductors) and slick line (solid stranded non-electric cable).
- Although it is unlikely to be needed for DBFT, CT operations can work under pressure in “live” wells without having to “kill” (e.g., placing a column of heavy fluid into a well bore in order to prevent the flow of reservoir fluids out at the surface) the well.
- CT also provides the unique capability to pump fluids through the tubing at any time regardless of position in a well or direction of travel. These operating features are due to the inherent capabilities of the injector head and stuffing box equipment.
- Provision for data or power cables inside CT strings facilitates well logging, downhole monitoring or control, directional drilling, and electrical submersible pump installations.
- CT provides the capability of operation in non-vertical wellbores.

Disadvantages to CT process include [6]:

- CT has a limited life due to low cycle fatigue resulting from repeated plastic bending caused by each trip-in and -out of the well. The CT experiences three plastic bending operations while tripping down the hole, first while unwinding from the tubing reel, second while going over the gooseneck, and third when the tubing is straightened again in the injector head and down the well hole. Tripping-out of the well causes three additional plastic bend operations in reverse order to tripping-in. There are field monitoring equipment and software programs available to keep track of bend cycles, pressure, and axial loadings at various tubing length sections and estimating remaining life of the tubing string, allowing the operator to avoid fracture due to repeated bending [7].
- Repair of the tubing is difficult and is typically done using Tungsten Inert Gas (TIG) welding procedures. The best repair weld has no more than 50% of the fatigue life of the virgin tubing. [8]

In addition to the CT disadvantages mentioned above, some other disadvantages include:

- Release mechanism similar to the wireline would have to be developed for the WPs.
- A shielding structure capable of supporting the WP transfer cask would have to be added between the injector head and the BOP stack.

- Multiple package loading would require a shielded structure housing tongs and slips to allow connecting the packages using API threads.
- Multiple packages connected together have the inherent risk of higher source loading.

In summary, the CT emplacement mode appears to not have an advantage over the wireline emplacement mode for WP emplacement into DBD, although it appears to be utilized for the seal plug cementing process as described in the M2 report. The lifting capacity of the tubing is greater than the wireline, but the longevity is much shorter. Multiple WPs could be supported by the CT option compared to the wireline, but multiple packages would require an additional shielded structure to mate the packages together and with the limited assumption of delivery of one package per day, will not improve the emplacement throughput for DBD. In addition to complete the emplacement of 400 WPs into DBD, multiple replacements of the entire CT string would be expected. The anticipated replacement time for a drum of CT is TBD assuming the conductor cable and end fittings are included with the CT inventory on site. A large drum diameter is also required for the CT and trying to reach a potentially remote site with this large drum may be problematic without the building of a robust infrastructure to the site and in addition, hauling this large drum over the highway could require special permitting.

- **Conveyance liner emplacement mode**: The conveyance liner consists of a tubular pipe with a ported bottom end approximately 900 ft in length to support up to 40 WPs. The conveyance liner would be temporarily supported near the top of the borehole (on a hanger or possibly using the lowest BOP) allowing a wireline to stack the WPs inside the liner one at a time without connecting them together. Once the WPs are loaded into the conveyance liner, the drill rig would attach to the conveyance liner with a J-slot type sub-connection and lift up slightly while the temporary conveyance liner support would be released. The drill rig would then lower the conveyance liner down to the emplacement zone using multiple drill pipes. The process would be repeated using multiple conveyance liners with up to 40 WPs each until all 400 WPs are emplaced [2].
    - Advantages include:
        - Fewer trips required.
        - Additional drop protection potentially built into conveyance liner (more robust structure).
        - Individual waste package connections not required (although a release mechanism for each conveyance liner would be needed).
    - Disadvantages include:
        - Larger borehole diameter required (> 17 in.) to make room for the conveyance liner tubing (or could reduce WP diameter).
        - Development of a hanger to support the liner near the top of the borehole.
        - J-slot connection required.
        - Additional corrosion and hydrogen gas generation from liner.

- Shielded basement type structure required to load and support conveyance liner.
- Release mechanism for conveyance liner.
- Concentrated source loading near surface prior to emplacement.
- Likelihood of high package breach potential for string related drops is not changed.

*Recommendations/Issues with Basement Concept:*

- Issue associated with performing maintenance with drill-string present.

  Performing maintenance without the drill string present would not present a radiation exposure problem.

- Issue associated with handling of contaminated emplacement fluid/mud due to breach.

  Contaminated emplacement fluid could be handled using shielded mud surge tank, shielded sump pump, and shielded mud lines. Additional portable shielded storage tanks could be brought in to allow locating the contaminated mud to a different location.

- Ability to perform emergency repairs in radiation environment (i.e., how conceptually should basement be set-up?).

One of the challenges associated with the drill-string option is how to repair handling equipment in the basement area when a WP(s) containing radioactive waste becomes stuck there. The radiation from the WP(s) would prevent personnel access unless shielded.

One alternative would be to design the basement as a hot cell with manipulator arms extending into the basement area for use to repair the broken equipment. A separate viewing room could be located adjacent to one of the basement walls allowing operator access to the manipulator arms. Oil rig equipment such as the tongs and slips utilized in the basement area would require redesign to allow remote installation/replacement using the manipulator arms. Redundant slips would be required within the basement to allow support of the drill string during replacement of the broken set. The basement ceiling could include access covers to allow equipment to be lifted in or out using an overhead hoist.

Another alternative might include temporary shielding around the WP(s) whereas permanent shielding would likely increase the WP(s) diameter beyond the borehole diameter.

Lastly, another alternative would locate the basement above grade allowing substantial spacing for hot cell-like components to be installed outside of the basement. However this option would raise the rig and other equipment significantly higher, making it more difficult to operate and potentially vulnerable to natural phenomena.

Future study will be required to determine how the BOP(s) could be repaired while a stuck WP remains inside the BOP or if redesign is required to accommodate remote repair or replacement.

For the DBFT, there would be no radiation and off-the-shelf rig equipment could be utilized for initial proof of concept. An order of magnitude increase in design complexity is expected for the actual WP handling; the remote operations and radiation shielding required will drastically change the handling equipment design and operation for DBD. The DBFT will not be representative for DBD if these details are omitted.

### *Recommendation on Emplacement Rate Discussions:*

If a separate transfer cask is utilized in addition to the Type B shipping package, and if multiple WPs are included in the Type B shipping package, then >1 WP per day rate could be achieved. Therefore, overall timesavings for all emplacement options is possible.

### *Recommendations on WP Design:*

The following table identifies pro and con features for use as a summary review.

TABLE 2-3: WASTE PACKAGE DESIGN PROS AND CONS

| **Flask-type Design (Options 1 and 3)** | **Internal-flush Design (Options 2 and 4)** |
|---|---|
| Pros | |
| • Uses conventional American Petroleum Institute (API) threads (drill string only)<br>• Joints designed for repeated assembly/disassembly (drill-string only)<br>• Provides a smooth exterior surface<br>• Relative ease of manufacturing<br>• Due to the fill port, friction welding could occur before loading allowing for post-weld heat treatment | • No welds in the axial load path<br>• Joints provide better seal for external pressure (drill string only)<br>• Large opening diameter can accommodate canistered waste |
| Cons | |
| • Requires pipe dope<br>• Smaller waste diameter (bigger factor for SNF than for bulk waste)<br>• Welds in the axial load path<br>• Threaded fill port would require O-rings and bolt torqueing/evaluation for containment<br>• Fill port would require testing for containment | • Would require a custom mill run based on material selection<br>• Top and bottom plugs are welded inside the end fitting requiring special welding and weld inspection equipment<br>• No easy way to verify leak tightness |

See Section 2.3 for discussion on FoS.

- Insights on IL design:
  - Refer to Section 4.3 for detailed comments for the IL design
- Alternative packaging materials/metallurgy:
  - AREVA technical personnel have previously developed and licensed metallic disposal containers to comply with the structural stability requirements of 10CFR61 for land disposal of Classes B and C radioactive wastes. High integrity containers (HICs) are one method that is acceptable to provide structural stability, as discussed in the NRC's Technical Position on Waste Form, Revision 1 [20]. The document specified a minimum design life of 300 years for structural stability. The HIC design considers both the corrosive and chemical effects of the

waste contents and the disposal environment. To meet these structural and corrosive requirements, a specific duplex stainless steel, Ferralium Alloy 255, was selected over other corrosion-resistant metals for the metallic HIC design.

- For the proposed DBD, the WPs, which are required to maintain the containment function for a minimum of 10 years, will be emplaced into a more corrosive and severe environment in the crystalline rock than the HIC disposal environments. However, some structural, corrosion-resistant materials that may be suitable for WPs in this disposal environment include:
  - Ferralium Alloy 255
  - Hastelloy C-22 alloys or Inconel® alloy 22
  - Hastelloy® N alloy
  - Incoloy alloys
  - Monel alloys
- In order to determine the best material for DBD, test coupons of selected materials could be placed in the emplacement zone of the CBH and/or the DBFT holes for extended periods of time. Exposure of the materials to the disposal environment will provide valuable data to support the final designs of the WPs for DBD.
- Finally, an alternative to selecting an acceptable corrosion-resistant material (but potentially expensive) is to make the wall thicker of an alternative (cheaper) material. This would have to be balanced against the spatial limitations of the borehole and waste materials to be disposed in a WP.

- Consider corrosion rate and hydrogen production after disposal due to the deep borehole environment as identified in TBD-43.
- Performance goals are reasonable (39 WPs placed above, high-pressure environment, no post-closure performance credit).

### *Recommendation on Emplacement Mechanisms and Connections:*

Comment on page 2-42 for emplacement Step 37: the 15,000 ft long 4½-inch diameter drill pipe will shrink in length by approximately 12¾ ft (per below shrinkage estimate) when the weight of the package string transfers to the bottom of the borehole and the remaining drill string weight is supported by the rig. Determining the precise drill pipe elevation required for the J-slot disengagement will be difficult due to the 12¾ ft stretch. The discussion of this pipe shrinkage should be included in the M2 report to contrast the increased difficulty compared to the wireline option.

Shrinkage Estimate: $\Delta L = \frac{P \times L}{A \times E}$

Where:

P=154,000 lbs (buoyant weight of 40 package string in pure water)

L = 180,000 in (15,000 ft)

A = 6.28 $in^2$ (cross-sectional area of 4 ½” drill pipe using OD = 4.5 in, ID = 3.5 in)

E = 30,000,000 psi (approximate modulus of elasticity for steel)

Alternate Approach 1: A connection enhancement for the J-slot might be to develop a 20 ft long telescoping cylinder with a hexagonal shaped cylindrical rod for transmitting torque that could accommodate a 20 ft rig lowering over shoot. The end of the hexagonal rod could accommodate the J-slot connector while the butt end of the cylinder would have the threaded box end for attaching to the drill string. A load cell within the cylinder or the rig could detect the weight change or movement of the cylindrical rod and stop the lowering process thereby preventing the weight of the drill string from bearing on the WP string. The same device could be used to lower the bridge and cement plugs.

Alternate Approach 2: Design a release mechanism similar to the wireline that would be larger to accommodate supporting 40 WPs. The connection could potentially be battery powered if conductor cable were not available for use with the drill pipe.

Recommendation for the wireline WP connection: obtain a device similar to the GE Oil and Gas "Addressable Downhole Release (ADR002)" [9].

### *Position on Proposed Enhancements:*

AREVA agrees with the proposed enhancements listed in Section 2.7.1 and recommends the following:

- Using a transfer cask with slide doors along with a Type B shipping container without slide doors thereby reducing the effort and cost required to obtain NRC license for the shipping container.
- Section 2.6.4 (page 2-40), under handling steps, the second to last paragraph notes "could be optimized for safety and control". AREVA agrees that this is conceptual at this point and that programmable logic controller (PLC) type controls would be added for safety and control.
- AREVA agrees with the crush box enhancement as described for the drill string on page 2-49 that could be used to absorb the load surge through the package string.
- The wireline WPs will require individual ILs to be installed either prior to shipping or following delivery to the disposal site. The hot cell designed for the purpose of installing the IL should be relatively simple, and the disposal site would be more flexible if located there rather than the facility from which they were shipped, and the Type B shipping package would be smaller if installed later at the disposal site.
- The shield plug integral to the WP will require verification of shielding for the purpose intended prior to DBD, and would be desired for the FTB for simulation as well.
- Section 2.7.2 item p) proposes the use of a conveyance casing. As discussed in Section 2.5 of this SRR, the conveyance casing requires a larger borehole diameter, but feasibility of a larger borehole may not be known until after the FTB, and should not be considered until that time.
- Note the reference SFT-Climax cask with sliding doors was not certified as Type B shipping cask (page 2-31 of the M2 report).

- The primary purpose of the Type B shipping cask is to provide shielding and confinement as well as impact, puncture, and thermal protection for its contents during transport under both normal and accident conditions. Experience has shown that maintaining containment following a required 30 ft drop test with cask features such as slide doors is extremely difficult to achieve.
- An alternate approach is to design both a typical Type B shipping cask without slide doors and a separate transfer cask with sliding doors for the borehole handling operations. The Type B shipping cask would be designed for transporting WPs to the disposal site, and would meet the requirements of 10CFR71, which requires surviving a 30 ft drop test, preparation of a Safety Analysis Report and subsequent review and compliance approval by the NRC. The transfer cask with sliding doors and hinged top would be exempt from the 10CFR71 requirements but would be limited for use at the waste disposal location. This approach is recommended by AREVA.
- The SFT-Climax transport cask referenced in the M2 report serves as a good example of a transfer cask that could be used in conjunction with a Type B shipping cask. A semi-portable transfer station would be designed to assist the shielded movement of the WP from the Type B shipping cask into the transfer cask.

# 3.0 Review of DBFT Conceptual Design Description

This section of the M2 report provides a description of the DBFT and provides clarification to the scope of the DBFT and how it differs from the disposal system. Included is a discussion of the borehole drilling and construction, test package concepts, test package emplacement and retrieval, and unresolved conceptual design questions.

### *Review of Waste Package Concept:*

The WP designs are discussed in detail in Section 2.6, *Review of Waste Concepts*, of the M2 report and are reviewed in Section 2 of this report. In this section, the system architecture associated with the WP is discussed including: 1) the WP function(s) in the DBFT, 2) options to improve WP interfaces, and 3) related experience with threaded connections in similar environments.

### *Waste Package Functions in the DBFT:*

The test WP can be used to demonstrate the following in the DBFT:

- Waste Package Design

  As discussed in Section 3.2 of the M2 report, multiple WP designs may be used in the DBFT (if resources permit) to demonstrate design features and to help in selection of a WP design for the disposal borehole.

  Prototype testing will provide valuable feedback for the function of each design tested. For drill-string emplacement, a string of 40 test packages should be fabricated that includes (at a minimum) fully prototypic WPs at the top and bottom of the string. Intermittent packages could be simplified to save cost and could consist of just the outer shell (to test wall thickness design under test loading) and threaded interfaces (to test connection design). If used, simplified prototypic packages should be designed with necessary ballast to equal the loaded package weight. For wireline emplacement, only a small number of prototypic packages would be required to test the design. The number of packages would depend on the testing plan and should accommodate air free drop testing or down-hole drop testing if required.

  The testing of multiple WP designs using the same emplacement method would be largely beneficial in the selection of the preferred design. The performance of both designs could be directly compared after testing. However, the time to perform multiple test sequences and the cost of doing so may preclude testing multiple package designs.

- Above Ground Operations

  The DBFT will demonstrate the use of a WP to interface with emplacement equipment for DBD insertion. The emplacement equipment used will be somewhat simplified, as described in Section 3.3 of the M2 report, but will still provide valuable operational experience in handling the WPs above ground.

- Emplacement method(s)

  The emplacement method selected for the DBFT will be tested to insert the WP design(s) into DBD.

- Interface requirements

  The WP must be shown to correctly interface with the transportation cask (or transfer cask if used), above ground operations, emplacement equipment, and other WPs (for drill-string emplacement).

- Containment

  The WP design will be tested to demonstrate containment before and after being inserted into DBD. This will require pre- and post-emplacement helium leak testing. Leak test requirements have yet to be defined.

- Fabrication techniques/friction weld method

  Fabrication of test WPs will provide good insight into fabrication processes and techniques. The proposed friction welding on the WPs can be tested and procedures can be developed. Problems and challenges can be addressed such that final package construction is well defined and proven.

### *AREVA Experience with Threaded Connections:*

During hot operations any malfunctioning equipment near the package, any cross thread event, would all have to be solved/fixed using remote robotic equipment if a loaded package were present. This could cause a significant cost increase over the wireline method.

The required use of pipe dope to use API threads requires a custom designed machine to apply the pipe dope remotely (due to the expected high radiation environment during actual HLW disposal). This is another machine/step that could fail and end up with an incorrectly assembled waste string and highlights yet another need for specialty equipment by the drill-string emplacement method that complicates the placement due to the potential difficulty of getting all the alignments reset when moving from borehole to borehole.

### *Comments on Emplacement and Retrieval:*

The emplacement and retrieval options are presented and discussed in Section 2.0. The emplacement mode selected will be deployed for the DBFT as discussed in Table 3.1 of the M2 report. Both the wireline and drill-string methods (if selected) will be fully simulated. AREVA believes that a full simulation is appropriate and justified for the DBFT. The full simulation needs to demonstrate: surface operations (including use of temporary shielding); emplacement mode rigging, trip-in, and trip-out operations; WP containment during at depth placement over several months; and retrieval operations. Furthermore, the DBFT needs to simulate the design of DBD to the extent possible to ensure collected data and results are representative of future disposal activities. If, for example, perforated casing is not used in the DBFT disposal zone, non-realistic results for insertion times and velocities would be attained and downhole drop testing of WPs, if performed, would not correctly represent a disposal borehole due to a slower terminal velocity.

### *Insights/Innovations to Conceptual Design Questions:*

The design of the DBFT will include BOPs until it is clear that they will not be required by permitting authorities (page 3-6 of the M2 report, see also TBD-22):

- According to the drill-string system architecture, the third or lowest BOP in the stack called the "elevator ram" is used for supporting the WP string during connection of a subsequent WP or drill pipe. A circular shear key within the elevator ram clamps engage a groove located near the base of the WP to provide vertical restraint. A basement slip device using wedging serrated teeth is used to provide redundant vertical support at the top end of the WP. Because of the redundant systems involved, the elevator ram will require system interlocks with the basement slips along with the rig hoist device supporting the drill pipe above. The operation of the elevator ram will have to be sequenced to open prior to raising the waste string slightly in order to release the basement slips and pipe slips located above. The first and second BOPs in the stack will have to be locked out while the WP is in the basement. A PLC would easily control the interlocks required for the basement and rig equipment.

*Verification of Applicability to Disposal Case of Items in M2 Specification Tables 3-1 and 3-2:*

For the WP design, it is intended that the same packaging design concepts for the disposal WP are used for the test WP to be used at the DBFT. It should be added that this includes material specification and fabrication techniques. Much can be learned from prototype testing of the WP and the design and fabrication techniques can be refined and optimized for the disposal system.

The instrumentation package is listed as not being required for the DBFT. However, as noted in Table 3-1 of the M2 report, instrumentation should be included in the DBFT to measure acceleration loading on package. This will help to determine the package loading environment and provide input in the evaluation of any package damage observed post emplacement and/or may also allow for a reduction in the conservatism included in the design of the WP if the design conditions are not as severe as preliminarily identified.

The DBFT should test a prototypic WP. The prototypic WP should be tested with all the features planned for use in the disposal system. The current design for wireline emplacement includes an IL for the WP. Section 4.0 of this SRR includes more details on the IL design. AREVA recommends for the DBFT dropping an instrumented wireline test package to verify the maximum terminal velocity and the performance of the impact mitigation device. This test provides the opportunity to accurately measure the terminal velocities both above the disposal zone and within the disposal zone where the impact of the perforations in the casing can be quantified (separate effects testing is merited for this velocity as well—potentially with a scaled system). The DBFT or mock-up facility could also include IL testing such as free air drop testing.

The current design for drill-string emplacement includes the possibility of using a crush box at the bottom of each string that prevents a load surge through the package string. The possibility of an IL for the drill-string is discussed in Section 4.0. If an IL is planned for the drill string it should be tested during the DBFT in a manner similar to that described for the wireline in the previous paragraph.

Shielding that is tested using a mock-up should be fully defined in terms of size and required space. Operations need to be completed with the actual space allowance present for the disposal system.

The basement concept will be included in a minimized form if drill-string emplacement mode is to be utilized. AREVA recommends if the basement should be needed, that it should be designed, built, and operated for remote handling to demonstrate that the drill-string emplacement method is feasible under potential radiological disposal conditions. There are potential significant engineering challenges introduced to the surface operations due to the need for remote handling activities. It is suggested that these challenges be vetted out in the DBFT. Additionally, AREVA proposes that the basement equipment and systems could be installed above ground with an increase in platform height. This may save costs, while still providing a test of equipment and handling processes, and allow for transfer of this equipment from borehole to borehole. Drawbacks of situating the basement above grade include the need to raise the drill rig by another 30 ft (the rig floor would be about 60 ft off the ground) and the need to hoist the transfer cask, under the drill rig, by the height of the basement structure. These potential complications may eliminate any cost savings.

The casing will not be removed from the FTB or CBH unless done as a follow-on activity. Considering that casing will be removed for the disposal borehole and boreholes of this diameter have not been completed to the depth required for this activity in the past, it would be useful to demonstrate the operation as part of the DBFT. This is especially relevant since it is stated in the M2 report that casing removal can be difficult. If past experience with removing casing has been documented, it should be referenced. If casing removal was practiced, procedures for removal and for handling stuck casing could be developed that would mitigate risks associated with the disposable borehole, including identifying the need for hot cell-like facilities for handling the WP under these conditions.

Surface transport, transfer fixtures, handling equipment, and radiation protection mock-ups should not be considered essential to the scope of the DBFT. Those items should be considered essential for demonstration and/or testing, but a separate location with a shallow borehole mock-up could be utilized instead of the DBFT. This would potentially lower the cost and complexity of testing these items at the remote DBFT site. This off-DBFT-site testing would serve as a platform for operational lessons that would be incorporated into any preliminary DBD design and risk assessment after the DBFT is complete. This site could also serve any future needs to demonstrate remote recoveries from minor and major events.

# 4.0 Review of Supporting Engineering Analyses

## 4.1 Comments on Waste Package Stress Analysis

This section of the report provides stress analysis for the WP designs described in Section 2.6.7 of the M2 report.

### *Stress Analysis for Options 1-4:*

Stress analysis of the four WP designs is provided in Section 4.1 of the M2 report. The analysis used SolidWorks Simulation® finite element software to calculate stress in the WP body. Results for each WP are presented separately with a brief description of the load application and resulting stress results. The von Mises stress criterion is used and the von Mises stress is compared to the material yield strength.

The WPs are loaded by the downhole hydrostatic pressure (9,600 psi is used to bound the 9,540 psi pressure calculated in Section 2.3.10 of the M2 report) and by axial compressive force (applied as a surface pressure) due to a drill string of 40 WPs. The tensile force is stated in Section 2.6.7 of the M2 report as 154,000 lbs.

The results of the finite element stress analysis for WP Options 1 through 4 appear reasonable based on the loading conditions and the model geometry. As the conceptual design evolves into the prototype/demonstration design for the DBFT, the following recommendations should be considered:

- Evaluate WPs at a bounding temperature.
- Use a denser mesh with a minimum of four elements through any wall thickness.
- The groove at the weld connection will not be present after friction welding and should be removed.
- The WP designs may need to be modified to meet the required 2.0 FoS.
- Use close-ups or adjusted stress ranges to clearly present model stress results.

The WPs are currently evaluated at nominal temperature. The report does note that an increased temperature will reduce the material yield strength and alter the results. However, the report should be revised to say that the yield strength will be reduced to 87% of the nominal temperature value. It is recommended that a bounding temperature be selected and used for the WP stress analysis. The results at room temperature are not bounding and are non-conservative.

The WPs are meshed using tetrahedral elements with a large mesh density and one element through the package wall. Due to the coarse mesh, there are not enough elements modeled to capture bending stresses at the interface between the pipe and more rigid end components or at the weld groove. This is non-conservative and is not sufficient to evaluate the concept adequately for preliminary review. Common industry practice (based on AREVA's experience with previously NRC licensed cask designs) recommends that at least four elements are used through a package wall so that the effects of bending can be correctly modeled. This also allows for stress linearization through a package wall, which can reduce local maximum stress. Eight node quadrilateral elements are usually recommended for package finite element analysis (due to large deformation); however, for the conceptual design tetrahedral elements are adequate.

The models of the Option 1 and Option 3 packages include a groove at the connection weld location. Per Section 2.6.7 of the M2 report, the packages are to be welded using a friction welding technique. This technique results in complete penetration of the connecting metal surfaces and additional metal flows out to create a circumferential protrusion on both the outside and inside of the package wall. Typically, the external protrusion is machined down to create a flush surface. (A complete penetration weld in the containment boundary is the standard for current NRC-licensed transportation and storage packages.) Therefore, the model of the package should not include a groove at the weld connection; unless a groove is a required feature of the WP that will be present after welding. This small modeling change will have a significant effect on the WP response to multiple WPs dropped in Section 4.4 of the M2 report. This could affect the results of the number of WPs that could be safely lowered on the drill string.

The FoS provided by the analysis results does not meet the requirements of Section 2.3.10 of the M2 report. The minimum FoS is 1.9 for the Option 1 design. Using the yield strength temperature reduction of 87% would lower this to 1.65. This is less than the required FoS of 2. The packaging concept may need to consider thicker walls, smaller diameter, or a different material to meet the minimum required FoS. See Section 2.3 for a discussion of the recommended FoS.

The published figures do not provide a precise stress result. The color range provided by SolidWorks Simulation® does not clearly define the maximum stress in the package. For example, the Option 1 results in Figure 4-1 of the M2 report show a range in the green of 66.75 ksi to 41.81 ksi. From Figure 4-1 of the M2 report, it is not clear that the maximum stress was reported in the report. A close up of the location of maximum stress will provide more clarity, or the range/color settings in Simulation® could be adjusted to guarantee the maximum values are being reported.

### *Effect of Axial Stresses on Collapse Pressure of the Package:*

The packages were evaluated for geometric stability (buckling) based on the external pressure and axial force. Equations from the API Bulletin 5C3 are provided and the collapse pressure is calculated for package tubular sections. Both 11 in (10.75 in OD) and 5 in (5-in OD) tubes are analyzed. The tubes are loaded by external pressure, axial force, and bending due to borehole curvature. Material properties for P-110 steel at room temperature are used.

The results of the collapse pressure evaluation are reasonable. As the conceptual design matures, the following recommendations should be considered:

- Evaluate packages at a bounding temperature.
- Provide clarity to analysis approach/methodology.
- For clarity, the results should be contrasted against the allowable limits.

The evaluation was performed using material properties at nominal temperature. It is recommended that the analysis be performed at the maximum bounding temperature to provide bounding results.

It is not clear how the evaluation was performed or which of the three failure criteria (i.e., yield strength, combined yield strength and tension, and bending) were used to obtain the collapse pressure results in Table 4-1 of the M2 report. The equation terms are not defined and multiple failure criteria are provided which leads to confusion. The table of results could be presented with a brief description. Supporting equations are not necessary, but if provided, they should be easily followed/understood. It is recommended that this section be revised for clarity as the conceptual design matures.

The results presented in Figure 4-7 of the M2 report show that curvature of the guidance casing will have a minimal effect on the collapse strength of the tubular portion of the packaging. (Per Table 2-4 a maximum curvature of 3 degrees per 100 ft is allowed. Based on the results of Figure 4-7, this would result in a collapse pressure reduction of approximately 1.5% for 5.0-inch casing and less than 1% for 10.75-inch casing.) For clarity the required/allowed dogleg severity should be listed and a cross-reference to Table 2-4 of the M2 report should be provided.

## 4.2 Review of Terminal Sinking Velocity

A discussion of the calculated terminal velocity is provided in Section 4.2 of the M2 report. The terminal velocity was calculated earlier by Bates et al. [4] as 8 ft/sec for a larger diameter WP (13.4 in) with a larger radial clearance (0.93 in) and using water as the emplacement fluid. The maximum weight of the reference-size package was used. Perforated casing was not considered.

Section 4.2 of the M2 report uses a larger radial clearance than the current design. The package outside diameter is 10.75 in (from Section 2.6.7 of the M2 report) and the drift diameter of the guidance liner is 12.459 in (from Table 2-5 of the M2 report). The radial clearance is:

$$\frac{12.459 - 10.75}{2} = 0.855 \, inches$$

This value is smaller than the report value of 0.93 in, so the terminal velocity of 8 ft/sec is conservative. This difference is addressed in the report. The report also points out that using the viscosity of water is conservative compared to the viscosity of the emplacement fluid, which will be higher.

The terminal sinking velocity calculation does not consider a perforated liner in the disposal zone. The presence of the perforated liner would increase the drop velocity and, therefore, the results as presented may be non-conservative depending on the size and number of perforations in the liner. Due to heat restrictions, discussed in Section 2.3.9 of the M2 report, a perforated liner is projected to be used in the disposal borehole. The calculation for the terminal velocity should model the most conservative or bounding case and therefore should include the perforated liner.

A terminal velocity of 8 ft/s is equivalent to a package falling in air during handling from a height of approximately:

$$h = v^2/2g = (8\,ft/s)^2/2(32.2\ ft/s^2) = 1\,ft$$

Therefore, any drop of a single package on the surface of greater than approximately 1 foot should be bounding over any drop in-hole if the slotted casing has a negligible effect.

To study the effect of perforated casing, the terminal velocity for a single larger diameter package can be estimated using the original equations developed by Bates et al. [4] in the emplacement zone. Due to the casing being perforated, if it is assumed that the displaced water could freely flow into the larger 17-in diameter borehole in the crystalline rock, then (taking out the guidance casing thickness) the hydraulic diameter can be determined to be 5-in and the ratio of the fluid velocity in the annulus compared to the package velocity (Eqn. 4-3 of Bates et al. [4]) to be 0.87 (for a 10.75-in diameter canister). The closed boundary terminal velocity can be established using equation 4-4 from Bates et al. [4] to be approximately 20 ft/s given: a fluid density of 81.1 $lb_m/ft^3$, a package length of 18.5 ft, a loss coefficient (from Bates et al. [4]) of 1.5, and a friction factor of 0.027 (from the Swamee-Jain Correlation with a assumed surface roughness of 0.03 inches). This terminal velocity is equivalent to a package falling 6 feet in air during handling. Therefore, any drop of a single package on the surface of greater than approximately 6 feet should be bounding over any in-hole drop if the casing is "significantly" perforated. This assessment should be confirmed with additional modeling and testing to ensure that Equation 4-4 of Bates et al. [4] is still valid under lower velocity ratio values ($V_{ratio} < 1$).

The terminal velocity of the drill string is not evaluated in the M2 report. For the purpose of supporting the evaluation of the drill-string emplacement method in this report, both the terminal velocity in the non-perforated and perforated casing is estimated considering the same methodology described above. The only major difference from the analysis of a single package is the density of the waste string, which is conservatively estimated to be 1065.8 $lb/ft^3$ by assuming the weight of the small diameter drill string is lumped into the density of the 40 package waste string.

The hydraulic diameter of the waste string in the un-perforated casing is 1.4 in (2 times the 0.7-in radial gap stated in Section 2.6.6 of the M2 report), which results in a volume ratio of 3.605. The terminal velocity of the waste string in the un-perforated casing can then be estimated from Equation 4-4 of Bates et al. [4] to be approximately 15 ft/s given: a fluid density of 81.1 $lb_m/ft^3$, a waste string length of 740 ft, a loss coefficient (from Bates et al. [4]) of 1.5, and a friction factor of 0.0167 (from the Swamee-Jain Correlation with a assumed surface roughness of 0.0015 in).

Similarly, the terminal velocity estimated for the drill string in the emplacement zone with perforated casing (using the same volume ratio and hydraulic diameter established above for the single package) is predicted to be approximately 60 ft/s given: a fluid density of 81.1 $lb_m/ft^3$, a package waste string length of 740 ft, a loss coefficient (from Bates et al. [4]) of 1.5, and a friction factor of 0.026 (from the Swamee-Jain Correlation with a assumed surface roughness of 0.03 in).

This scoping assessment should be confirmed with more advanced analytical modeling and testing to ensure that Equation 4-4 of Bates et al. [4] is still valid under lower velocity ratio values ($V_{ratio} < 1$). It also serves to show that the design, analysis, and testing of the package(s) descending through the perforated casing is critical to the deep borehole disposal concept.

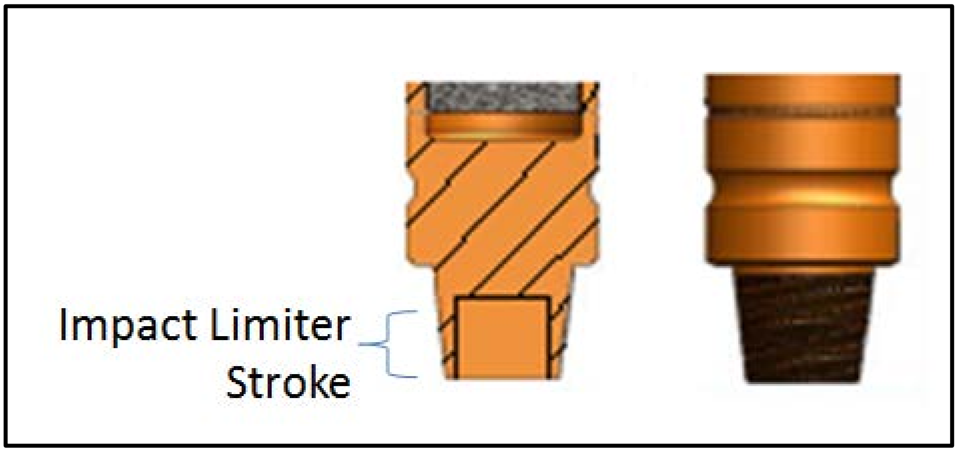
## 4.3 Comments on Impact Limiters

The required crushing stroke of an IL is evaluated in Section 4.3 of the M2 report. The calculation is based on a linear energy-balance using the terminal velocity listed in Section 4.2 of the M2 report. The IL is assumed to be used for a single package inserted by wireline.

The conservation of energy methodology is routinely used in impact mitigation scoping and is an appropriate method for this application. As the IL design evolves into the prototype/demonstration design for the DBFT, the following recommendations should be considered:

- The energy absorbing material proposed is Hexcel Tube-Core® (assumed to be aluminum honeycomb). There are a number of issues with using aluminum honeycomb for this application. The open-celled structure will be full of drill mud which will inhibit its function. Alternatively, if the aluminum honeycomb is encapsulated in a shell it would have to be strong enough to resist the 9,600 psi external pressure and the honeycomb would not buckle at low acceleration levels as predicted. The effect of the emplacement fluid on the aluminum honeycomb crush curve would need to be qualified and proven. The effect of the high temperature environment (predicted to be 170 °C) on the honeycomb organic adhesive is also a concern. The adhesive may also have hydrogen radiolysis issues during transport.
- It is recommended that requirements be added for the IL to define its function. These requirements could include: the IL shall not prevent retrieval of the package below it (the IL should not deform the lift point below it excessively), the IL should not expand radially to fill the casing, and the IL needs to perform in and out of the borehole (be able to function in air or in an emplacement fluid environment).
- The basis for using yield as the acceptance criteria for the package stress during the impact needs to be justified. It could be argued that the ultimate stress or 3.6 $S_m$ should be used per ASME Section III, Div. 1, Subsection NB [11] (following the guidance of Reg. Guide 7.11 [12] and NUREG-3854 [13]). See the discussion on FoS in Section 2.3
- The acceleration estimate made in Section 4.2, indicates that an 8 ft/s drop in an emplacement fluid environment is equivalent to an approximately 1-foot drop in air and a 20 ft/s drop in an emplacement fluid environment (estimated for perforated casing) is equivalent to an approximately 6-foot drop in air. A free drop in air of greater than 6 feet can occur in the system, similar to the off-normal event described in Appendix B.1 of the M2 report. This off-normal event occurs as a result of interlock errors, which will allow the WP to fall through the lower cask doors and impact on the closed blind ram on top of the well head. This scenario is by far the bounding impact scenario for the exposed waste container inside or outside the bore hole.
- The WP designs are very robust. Some preliminary assessments suggest the packages could survive an excess of 200 g without losing containment.
- The weld chamfer shown on the package will not be present after friction welding and should be removed from figures and analytical models.
- An IL could be designed to target an acceleration of 50g while stopping the package with about 0.7 inches of stroke. The IL could be designed to be a part of the lower package fitting as shown below. Another option would be to use a short thin walled tube welded to the bottom of the forging with bleed holes to allow the mud to flow out.

FIGURE 4-1: IMPACT LIMITER STROKE




The M2 report considers an IL option for single packages emplaced using a wireline. The feasibility of an IL design to mitigate the drop of 40 packages emplaced using a drill-string is estimated as follows:

> The force to buckle a WP if another package were to fall on it is assumed to make a WP irretrievable (using Euler column with pinned connections). This assessment is used as an estimate only; it is understood that because of the constrained environment of the WP inside the casing, complete buckling may not occur before the WP contacts the surrounding casing. The critical load can be estimated to be 2,209,667 lb based on: the elastic modulus of the package material of $30 \times 10^6$ psi (assumed for the 110 ksi material, this is a nominal value used in Shigley [14] for steel), the second moment of inertia of 367.8 $in^4$ for a 10.75 inch OD package, and the length of the package of 222 inches (18.5 ft per Section 2.6.7 of the M2 report).
>
> The maximum weight (static) the package could see is 468,000 lbs (per Section 2.6.4 of the M2 report). This means that the onset of elastic buckling would occur if the g-level exceeded 2.1 g assuming a dynamic amplification factor (DAF) of 2.0 (very rigid system per NUREG-3966 [15]) and no safety factor to elastic buckling. If there were no IL, the lower end of the WP (impacting end) would be a solid steel surface with approximately 6-in diameter (scaled from Figure 2-14 of the M2 report). Assuming that the steel would flow at a stress just above yield and not work harden (120 ksi) and applying the combined weight of the WPs and the drill pipe, a g level of 7.2 g would result.
>
> Therefore, an IL may be required so that package yielding does not occur <u>during normal operations</u> including emplacement at the bottom of the borehole.
>
> Any impact mitigation for an <u>off-normal condition</u> would be a significant undertaking due to the large variance in kinetic energy for all the different drop scenarios. If the IL is sized for a 468,000 lb load, it would react very stiffly to a lower load (such as a 150,000 lb section of dropped drill pipe traveling at its terminal velocity) and create a large impact load. The worst-case kinetic energy is based on the terminal velocity of the dropped pipe string that is dependent on the drop height and the mass of the dropped pipe.

A potential solution is a design concept that utilizes a longer, softer IL - sized to avoid the smallest axial force that causes damage and then made long enough to stop the worst-case impact kinetic energy without stroking out. With the low allowed accelerations, the ILs might be required to be significantly long to avoid breach.

An estimate for 450,000 lbs dropping 900 feet is used to estimate the terminal velocity of the drill-string pipe and 40 WPs. A more accurate assessment would need to be performed using a non-linear dynamic impact program such as LS-DYNA to design an actual IL, however at this stage of the design an estimate is considered appropriate for simple scoping purposes.

The maximum terminal velocity of the drill string was established in Section 4.2 to be approximately 60 ft/sec. This assessment conservatively used water properties and lumped the mass of the drill string pipe into the WP string, since the WP string has the limiting annular flow area. The drag on the drill-string itself was assumed to be negligible in this approach. Using this terminal velocity (60 ft/sec) and mass (450,000 lbs), a kinetic energy of approximately 25,155,280 ft-lb can be established. If the IL was designed to crush under a compressive load of 700,000 lbs (rounded from the load applied to Figure 4-11 of the M2 report that maintains containment), then this would require an IL stroke of 35-feet. However, the IL would be at least three times this long assuming a 30% allowable crush material. Designing an IL of this length would be a significant design challenge and would require extensive research and development. It would also consume a significant portion of the emplacement zone and hence, would unlikely be utilized.

However, if the perforations in the emplacement section of the casing were minimized, such that the terminal velocity was closer to the non-perforated velocity of 15 ft/s, then the kinetic energy would be much lower (approximately 1,572,205 ft-lb). If the IL was again designed to crush under a compressive load of 700,000 lb (rounded from the load applied to Figure 4-11 of the M2 report that maintains containment), then this would require a stroke of 2.2-feet. However, the IL would be about three times longer than this assuming a 30% allowable crush material. Therefore, it is feasible that the system could be designed to avoid a breach if dropped.

These preliminary evaluations above demonstrate that design, analysis, and testing of the WP(s) descending through the perforated casing is critical to the DBD concept.

## 4.4 Review of Energy Needed for Package Breach

A calculation to determine the effect of a falling package (from wireline emplacement) striking a stationary WP at the bottom of the borehole is provided in Section 4.4 of the M2 report. The effect of the lowest package in a string of packages (drill pipe emplacement) falling on the bottom is also evaluated. Using a simple fragility analysis, the difference in potential damage resulting from a single package drop and a drop of a string of packages is evaluated and compared to the WP material yield strength.

The conservation of energy methodology is routinely used in impact mitigation scoping and is an appropriate method for this application. The axial load due to a package(s) drop is applied eccentrically over a 40-degree sector on the face of the top of the WP. This is a reasonable estimate for scoping activities, but the actual loading and affected area will depend on the design of the bottom of the WP and/or the design of the IL (if used). The current design of the bottom of the WP would result in contact to a larger area of the top of the WP than modeled and hence, the contact area used in the M2 report appears to be conservative.

There should be a dynamic load factor (per NUREG/CR-3966[15] and identified as DAF) applied to the analysis to eliminate the non-conservatism of a quasi-static model for impact loading on WP containment. A factor of 2 is recommended to avoid any disputes about non-conservatism in the model.

The model includes grooves at the top and bottom weld locations. As discussed in Section 4.1, the model of the package should not include a groove at the weld connection, unless a groove is a required feature of the package that will be present after welding. If it is a required feature, a location change away from the weld heat affected zone should be considered. Removing the groove from the model would remove the “stress concentration” discussed in the M2 report and could have a significant effect on the results presented in Figure 4-11 through Figure 4-14 of the M2 report. This could change the number of packages that could be safely lowered on the drill string.

The basis for using yield as the acceptance criteria for the package stress during the impact will need to be justified for the WP to be deployed in the DBD. Consideration of an argument based on the ultimate stress or 3.6 $S_m$ per ASME Section III, Div. 1, Subsection NB [11] (following the guidance of Reg. Guide 7.11 [12] and NUREG-3854 [13]) should be considered for the WP.

The maximum stress provided in Figure 4-8 and Figure 4-9 of the M2 report should be defined in the text for clarity.

## 4.5 Review of Thermal Hydrology Analysis

The thermal-hydrology simulations of Section 4.5 of the M2 report evaluate a single borehole for cesium and strontium WP disposal with either a 2-capsule or 6-capsule WP. The summary is presented with modeling details and simulation results. The simulation results include temperatures at selected depths and the vertical groundwater flux at a selected depth over a period of 100,000 years. The results of the thermal hydrology calculations appear reasonable.

After the DBFT is completed and the design evolves into the prototype/demonstration design for the DBFT, the following analytical recommendations should be considered (note that these recommendations are out-of-scope for the DBFT):

- The selection of the heat load is discussed, but it is never explicitly stated. The discussion with Figure 4-15 of the M2 report seems to imply that the cesium “or” the strontium heat load is used. It should be clarified if the heat load is based on all the weighted average thermal output of cesium and/or strontium capsules.
- The length and some details about the 2-capsule WP (or disposal over pack) were discussed, but the length of the 6-capsule WP is assumed but not provided. The number of capsules included in the model should be stated along with the overall length of the train, and the spacing between capsules. The heat load distribution (e.g., constant) over the length of the package train should be discussed.
- It is not clear what the mesh size is around the bore hole and the WP. The mesh density needs to be fine enough to capture the temperatures of the borehole and WP materials.

- The relation of permeability variation is different from that used in Arnold and Hadgu (2013) [14] for modeling nuclear fuel disposal. It has a lower porosity for the crystalline basement rocks. A justification should be provided for this change.
- Increasing the permeability of the borehole and surrounding disturbed rock zone is reasonable, but the justification for the factor of 10 needs to be provided. A basis or reference for this factor would help clarify this. Also, the effect on porosity and thermal conductivity should be discussed including: how the thermal conductivity of the crystalline basement rock changes with depth throughout the model and how the thermal conductivity of the crystalline basement rock compares to the overburden values.
- It is stated that groundwater salinity stratification was not included in the model. A sensitivity analysis was included in Arnold and Hadgu (2013) [16] to address this. It may be beneficial to reference that sensitivity analysis as a justification for the omission of the groundwater salinity stratification.
- Add a brief justification or reference for the average geothermal gradient that the bottom boundary condition is based on and how this affects the initial temperature of the model.
- The text discusses a maximum temperature rise of 50°C for the 2-capsule analysis and references Figure 4-16 of the M2 report for this value. But Figure 4-16 shows a maximum temperature rise of about 25 to 30°C over the initial temperature. The 50°C rise is actually a 50°C decrease to the final steady-state temperatures. The text also discusses a maximum temperature rise of 125°C for the 6-capsule analysis and references Figure 4-18 of the M2 report for this value. But Figure 4-18 shows a maximum temperature rise of about 70°C over the initial temperature. There is about a 150°C decrease to the final steady-state temperatures. The correct maximum temperature rise for both cases should be provided that matches the referenced figures.
- A fixed temperature of 160°C is used as the bottom boundary condition. Please provide justification for how 170°C for the package design is conservative in Section 2.3.10. Recommend using 200°C to bound any non-conservativeness in the thermal model.
- The temperatures for the simulations at steady-state (about 1,000 to 100,000 years) in Figures 4-16 and 4-18 of the M2 report are lower than the 25°C/km temperature gradient should allow for. It is reasonable to expect that the temperature of the borehole region should return to the initial linear gradient when the decay heat of the packages becomes insignificant. This discrepancy should be discussed.
- The 6-capsule case has a larger water flux than found for the 2-capsule case. The total heat load should be the same for both cases so a similar vertical groundwater flux would be expected. Is the higher water flux most likely due to the size of the borehole, the greater depth of burial, or the concentration of the cesium/strontium capsule heat load? Or is it that since these are at different depths they may not be directly comparable.
- Finally, the connection between the ground water flux at this depth and the movement or release of radioactive material to the surface should be discussed or referenced to another section.

# 5.0 Review of Engineering Design Selection Study

Section 5 of the M2 report describes a study performed to support the selection of one of the emplacement modes for WPs for the DBFT described in Section 2.6.7 of the report (i.e., WPs for Cs/Sr capsules and/or bulk granular waste). The sub-sections of this section of the report discuss the evaluation approach and method used to evaluate emplacement and handling approaches, the inputs utilized in this evaluation, and the initial results and sensitivity of the results to select inputs. The level of conciseness of the results from the selected evaluation method depends primarily on the level of detail of the proposed operations associated with the emplacement and handling activities, which are described in Sections 2.6.3, 2.6.4, and 2.6.5, and the performance criteria (not requirements), which are described in Sections 2.3.8 and 2.3.11. The results of this study establish that the wireline emplacement mode is cheaper to implement and less likely to result in a radiological release than the drill-string emplacement mode, but the drill-string mode is more likely than the wireline mode to result in incident free emplacement of the 400 WPs for a single borehole. Based on AREVA's assessment of these results and consideration of additional factors (e.g., non-routine maintenance activities), AREVA recommends the wireline emplacement mode over the drill-string emplacement mode.

## 5.1 Approach and Methodology

### *Summary of Section:*

The approach and methodology used to select the emplacement mode and handling concept for the DBFT are described in this section. The selected tools include decision analysis and multi-attribute utility analysis (MUA) based on their transparent, rational, and defensible analysis that is easy to explain and communicate. The MUA also allows for identification and consideration of design modifications that may improve the performance of an evaluated mode. In addition, the use of uncertainty and sensitivity analyses are captured in this approach, which identify the impacts to the results of parameters with larger uncertainties and also the sensitive nature of the results to changes in important parameters. Finally, a review of the expert panel assembled to support this approach is provided.

### *AREVA Review Comments, Discussion, Proposed Alternatives, and Path Forward:*

The utilized approach and methodology are reasonable for evaluating the two emplacement modes (wireline and drill-string), which do not significantly differentiate themselves from one another (i.e., many of the operations performed for these two emplacement modes are common with one another). Furthermore, due to the conceptual nature of the proposed emplacement modes, the ability of this approach to allow for identification and consideration of design modifications, that potentially can improve a conceptual emplacement mode, provide it an advantage over alternative approaches, such as Hazardous Operations (HazOp) or What-If evaluations [10]. These alternative approaches work ideally with mature designs and operations and hence, are not as suitable for distinguishing the advantages of one emplacement mode over another. The ability to include uncertainty and sensitivity analyses using the MUA provides another benefit of selecting this evaluation method over alternatives.

The expert panel elicited to provide "a broader perspective to the analysis" and "to help quantify the risks of each mode" certainly was an idea with merit and produced meaningful feedback to this approach. The diverse nature of this panel was also beneficial, although having only one expert in the drilling field may lead to myopic results in this area, especially considering other panelists may have had no or only limited knowledge of the drilling field. In addition, without regulatory performance requirements to abide by (e.g., public consequence limits), the performance criteria identified to be utilized during this elicitation (no leaks, no drops, or failing to retrieve them from the DBFT) will likely have resulted in a conservative assessment. Although these criteria are likely bounding of any future regulatory requirements, they may be difficult to satisfy, result in an expensive design, and/or lead to elimination of a design that may meet regulatory requirements but not these potentially more restrictive criteria.

As a path forward, AREVA recommends using the DBFT to perform mock-up test package handling and emplacement operations to advance the conceptual design described in this report. Specifically, simulation of all normal operations from receipt of the test package to emplacement in the bottom of the borehole should be performed during the DBFT, including the use of temporary shielding if expected to be needed for normal operations and the use of a gauge ring to verify borehole characteristics prior to test package emplacement. Since each borehole may have unique characteristics (e.g., dogleg severity), testing using the gauge ring prior to every emplacement activity is considered imperative to promoting successful emplacements (as opposed to repetitive emplacement and retrieval cycles of a test package).

Based on the results of this report, focus should also be on the rigging activities for the test package as this will be one of the more vulnerable portions of the activity to initiating off-normal hazards (e.g., drop events). By identifying the step-by-step normal operations involved with handling and emplacement activities of a WP, a more detailed analysis (e.g., HazOp) can be performed on the emplacement modes which can be used to refine the event and fault trees included in this report. Furthermore, by mocking-up these operations and analyzing them through analyses such as a HazOp, design improvements can be made which may reduce: the risk of an off-normal event, exposure to operators, inefficiency of operations, and potential off-normal consequences.

AREVA also recommends using the DBFT to examine all potential maintenance activities, both routine (regularly scheduled) and non-routine (irregularly scheduled), associated with handling and emplacement activities for a WP. One of the primary concerns AREVA has with the proposed drill-string emplacement mode is associated with performing maintenance activities when WPs are suspended in the basement area below the surface. Since the dose rate from potential WPs to be emplaced in DBD are likely to result in unacceptable exposure to personnel per 10CFR20, access to this basement would be limited when a WP(s) is present and hence, maintenance would likely be limited to automated equipment (hot cell-like). The DBFT would provide the opportunity to design and mock-up this equipment in the basement, if the drill-string emplacement mode is to be considered for use by the DBFT.

Finally, AREVA recommends, resource permitting, using the DBFT or a mock-up facility to inform potential off-normal reactionary and recovery activities. Specifically, the DBFT should examine: the impact of the closure of the BOP to potential emplacement modes and the WP, the impact to the WP and the casing as a result of the WP and drill pipe, if present, having been dropped into the borehole, and the potential for fishing out a WP(s) and the impact of various fishing methods on the WP. The need for the BOP to isolate the borehole environment from the surface environment to prevent the escape of pressure from the borehole requires a valve or ram-like closure device which could damage wireline, drill pipe, and/or WP traveling through it at the time of closure. Hence, AREVA recommends that the DBFT be used to examine the ability of the designed BOP to prevent damaging the WP and wireline or drill pipe upon closure of this device (e.g., by limiting the force applied to the closure device), while maintaining the necessary isolation. In addition, the DBFT can be used to characterize potential impacts of dropped test packages to both the borehole casing and test package itself by dropping a test package and wireline or drill-string (as appropriate) into a borehole after having first characterized the casing. After the drop event, the test package and casing would be inspected for damage, which would potentially allow for confirmation of, or improvement to, test package design features (e.g., ILs) and/or selection of emplacement mode. Furthermore, this would provide the opportunity to fish for a test package and examine the effectiveness of potential fishing techniques and/or establish improvements to test package designs to improve the ability to fish them out. AREVA recommends that the DBFT, if possible, be utilized to drop a test package into a borehole. This would allow characterization of damage to a test package and the borehole casing and the ability to examine potential fishing approaches to recovering a test package.

## 5.2 Alternatives Evaluated

### *Summary of Section:*

This section identified the two primary emplacement modes evaluated in the report (i.e., drill-string and wireline) and the potential differences between these modes. Key assumptions are identified as all elements of the design have been selected other than emplacement, thus only the emplacement mode needs to be selected and only those aspects of the emplacement modes that are different from one another require evaluation (e.g., all operations up to the movement of the WP to the top of the borehole and all operations after emplacement of the last WP in a borehole are considered the same for both emplacement modes and hence, do not require evaluation).

The main differences between the emplacement modes that were relevant to this analysis included: the use of ILs; the use of downhole instrumentation during emplacement activities; and the number of WPs emplaced during a "trip." This last difference establishes the number of trips into the borehole, the number of connections needed to be made between WPs prior to an emplacement, and the weight of an emplacement, which impact the probability of a drop and the consequences of a drop.

### *AREVA Review Comments, Discussion, Path Forward, and Proposed Alternatives:*

The two emplacement modes (i.e., wireline and drill-string) presented in this section represent two of the primary methods for emplacement of the WPs into DBD, with the uncontrolled free-fall or gravity emplacement mode not included. In addition, two other modes were mentioned at the Nuclear Waste Technical Review Board meeting held October 20 and 21, 2015 in Washington, DC: conveyance liner and CT. The CT emplacement mode is essentially a drill-string or a wireline emplacement mode with the drill pipe replaced with CT or with the wireline replaced with CT, respectively. In either case, the following review and assessment will apply to the replacement of the drill-string or the wireline with CT. The conveyance liner emplacement mode was not mentioned in the report, but a table in Section 5.5 of this review includes a summary of the pros and cons of utilizing this emplacement mode relative to the other emplacement modes. AREVA suggests a more comprehensive list of emplacement modes be incorporated into this section of the report to acknowledge their consideration.

In addition, consideration of emplacement of different quantities of WPs at a single time than currently considered for the wireline (1 WP) and the drill-string (40 WPs) emplacement modes should be included in this portion of the report to acknowledge the potential sensitivity of the results to this parameter (as investigated in Section 5.6.3 of the report). The emplacement of different numbers of WPs per trip-in to the borehole could overcome (or further impose) some of the limitations identified in the following sections (e.g., number of trips-in to the borehole).

This section should also include the caveat that the assessment performed in the following section will produce results based on, and consistent with, the level of design detail provided in Section 2. Since this level of design is considered "conceptual," the results produced from this assessment should also be identified as "conceptual" and hence, their use should be limited to, for example, a relative comparison of the conceptual design of two emplacement modes (i.e., do not consider their use in a regulatory license application).

## 5.3 Review of Objectives and Performance Measures

### *Summary of Section:*

This section established objectives and performance measures to be used in the evaluation of the different emplacement modes. The objectives were developed from lists of objectives utilized in prior nuclear waste management related evaluations and were pared down based on those relevant to the emplacement mode (as summarized in Table 5-1 of the M2 report). The performance measures ("metrics") were developed for each relevant objective as a means to quantify the objective and allow for assessment by technical experts and for relative comparison between emplacement modes.

### *AREVA Review Comments, Discussion, Path Forward, and Proposed Alternatives:*

The list of objectives considered for use in comparing emplacement modes is comprehensive; however, there are a couple of additional considerations that AREVA believes should be identified as relevant to the evaluation of the emplacement modes compared in this assessment. Under the *Health and Safety Impacts*, a consideration potentially relevant to the assessment is the impact of potential maintenance activities on worker exposures and/or the need to include remotely operated equipment to allow for performance of maintenance activities that cannot be performed by operators due to high dose rates. This could directly impact the health of workers and the costs of the emplacement mode and indirectly impact the safety of the emplacement mode if, for example, a remotely operated system is utilized that creates additional/new hazards (e.g., fire).

Under *Costs*, it states that "All other costs are the same for all emplacement modes, including costs for transportation of wastes to the site…" which assumes the WPs for the emplacement modes are essentially identically designed. This may not be the case if, for example, ILs need to be incorporated into one design that results in the requirement for a larger cask system. The extent of this impact on the total cost is likely to be minor, but depends on completion of the WP design. Furthermore, as noted in the prior paragraph, the costs may be impacted if maintenance activities require remote operations to be deployed. This would not only increase the capital costs, to account for the remotely operated equipment, but also costs associated with operations and mock-ups of the remote systems that would be necessary to allow for optimization of the design and training on the remotely operated equipment. The costs associated with this remotely operated system are expected to have a non-negligible impact on the overall cost of the emplacement mode.

For the *Ability to Meet Waste Acceptance Criteria*, the implicit assumption utilized under this objective is that the waste acceptance criteria at this stage of development of the borehole disposal system is limited to the wastes described in Section 2.6.7 of the report (i.e., Cs/Sr capsules and bulk granular waste). Other wastes that may be disposed of in DBD in the future have not been currently evaluated for disposal and are outside the scope of the DBFT and hence, their impact on the emplacement mode is not considered in this assessment and would require separate assessments.

A minor comment related to the Objective *Flexibility to Accommodate an Uncertain Future* is if retrievability is considered a future criterion. Under this case the timeframe for recovery may be significantly shorter for the drill-string emplacement mode, as multiple WPs could be recovered at one time provided the surface facility is designed for this activity, over the wireline emplacement mode, which would require each WP to be separately recovered.

For the *Social and Economic Impacts*, the two emplacement modes evaluated in this assessment do not evaluate differently under this objective, however the free fall emplacement mode mentioned elsewhere in this report may evaluate differently under this objective. This is because public anxiety is likely to be greater for an uncontrolled emplacement mode over the considered controlled emplacement modes currently evaluated in this report.

Finally, although all the listed objectives and their relevance to the evaluation of the emplacement mode are comprehensive, ultimately there is no explicit regulation for disposal of wastes in DBDs. Fortunately, the conservative assessment of these objectives as summarized in Table 5-1 of the M2 report (e.g., yes/no radiological release measure), should result in satisfying any future regulatory requirement with one potential exception: the allowing for the disposal of a stuck drill string above the emplacement zone with a commitment to long term monitoring. AREVA does not believe regulations will allow for HLW to be allowed to be disposed above the emplacement zone. With the potential for a strongly corrosive environment to exist in the borehole, allowing HLW to be disposed of above the emplacement zone is likely an unacceptable regulatory risk, as the long-term isolation of the HLW cannot be demonstrated. Furthermore, long term monitoring will identify when containment of the HLW by the borehole has been breached, but does not necessarily allow for effective mitigating actions to prevent contamination of the surrounding environment by the HLW, although it could enact mitigating actions.

As a path forward, AREVA will include an assessment of these additional considerations on the emplacement mode in the following review sections. For the DBFT, consideration should be made for redesigning the basement, if used, for the drill-string emplacement mode to incorporate the ability to remotely perform maintenance activities in the presence of a waste string waiting emplacement and to remotely recover a WP fished from DBD (with or without the casing). This redesign could include replacing the basement with a surface facility (hot cell-like) that allows for maintenance to be performed during a drill-string emplacement. This facility could be mocked-up somewhere other than at the DBFT for demonstration purposes.

## 5.4 Review of Uncertainties

### *Summary of Section:*

This section identified three uncertainties which could impact the evaluation of the emplacement modes: (1) uncertainty associated with operations occurring as planned; (2) uncertainty about costs, timing, and occupational safety associated with normal operations; and (3) uncertainty about radiological releases, occupational safety risks, and/or increases in the time or costs required to complete the disposal process.

A hazard analysis (per Appendix B of the M2 report) was performed to identify the unplanned operations that could lead to off-normal events important to the performance of DBD and the likelihood of these occurrences. This hazard analysis identified four primary failures that could lead to breaching a WP during emplacement activities. Figures 5-2 and 5-3 of the M2 report provide event trees summarizing the sequence of events that occur after any of these off-normal failures.

Appendix C of the M2 report provided cost estimates for each emplacement mode under normal operations. These costs are dominated by the costs of the drill rig or wireline unit and since these costs are time dependent, the total time of emplacement is the most important factor impacting the total costs. The emplacement time is currently assumed the same between the emplacement modes due to the limited receipt of one WP per day to the site.

Five primary outcomes were established as a result of the event tree analyses: (1) one or more WPs breached above the disposal zone; (2) one or more WPs breached within the disposal zone; (3) a WP is unbreached but possibly damaged in the disposal zone; (4) one or more WPs become stuck within the disposal zone; and (5) one or more WPs become stuck above the disposal zone. Estimates for the costs and durations required to respond to each outcome are established in Appendix C of the M2 report.

### *AREVA Review Comments, Discussion, Path Forward, and Proposed Alternatives:*

The uncertainties identified in this section are representative of those associated with the operations evaluated in this assessment for the wireline and drill-string emplacement modes. One area that needs further assessment involves the need for performing maintenance on equipment in areas where dose rates may be high, such as when a slip gets stuck with one or more WPs containing Cs/Sr capsules suspended in the basement area during a drill-string emplacement activity. Under the current design for the basement, a worker would need access to the basement to perform a maintenance activity and given the high dose rate, this would lead to a higher dose to the worker. There are multiple options to remedy this issue including: increasing the shielding on the WPs, providing remotely operated equipment to perform these operations, and/or providing additional shielding in the basement around the equipment and/or the WP to minimize worker exposure during these activities.

Another area requiring further evaluation includes events around the BOP including: (1) the dropping of the WP in air on to the solid surface of a closed BOP prior to being lowered into the borehole and (2) the crushing of a WP due to the closing of the BOP as the WP is lowered through this device. Based on some preliminary estimates (drop height dependent), a free drop in air of the WP(s) on to a solid surface likely bounds the drop of a WP into DBD full of solution/fluid (per terminal velocity), see Section 4 of this review for this assessment.

Furthermore, since these events occur above, at, or near the surface of the borehole, the distance to off-site dose receptors is shorter than for drops into boreholes and since these events occur in air as opposed to solution/fluid, the airborne release will not be suppressed/filtered. Thus, these types of air-drops potentially result in a further increase in the consequences to off-site dose receptors. Hence these events should be included in Table 5-2.

Comments on Figure 5-2 include: (1) there appears to be no difference if a WP breaches in the disposal zone or above it during a drop from the top, verify this is accurate (alternatively verify "WP drops from top" will always result in the WP reaching the disposal zone and if it breaches, the breach would be in the disposal zone); (2) consider including a separate event tree for the WP drop from the top in air onto a hard surface such as on to a closed BOP; (3) verify the implicit assumption that if fishing results in a WP drop, then this drop will be into the disposal zone; (4) verify for outcome "C2" that a wireline (not a WP) can be fished out; and (5) there should be some probability (other than 0) of a breach for a WP dropped into the borehole due to something such as a failed weld or material flaw.

Comments on Figure 5-3 include: (1) the 100% probability of a WP breach upon drop of a drill-string is likely an accurate value when the whole drill-string (40 WPs and drill-string piping) is dropped at one time, but would expect a lower probability if a single or few WPs are dropped, without drill-string piping following it into the borehole (similar to wireline drop event); (2) the breach probability of a WP should also depend on the drop height (i.e., a drop of one foot may not breach a WP); (3) a drop of the WP in air onto a hard surface such as a closed BOP should be identified as a separate event tree; and (4) verify for outcome "C2" that drill string pipe (not a WP) can be fished out. These are details likely better teased out in a more detailed hazard analysis (looking at the actual causes of a drop) and hence are not needed at this time and likely do not change the results, but caveats could be added to the text to reflect the conservative nature of the assessed drops.

In Section 5.4.3, outcomes A2 and E2 are identified as one or more WPs not successfully fished, and instead left in place above the disposal zone (A2 for a breached WP and E2 for an initially intact WP). AREVA believes these outcomes are not an acceptable end state because: (1) the WP(s) could be stuck at a depth where it could leak into a medium that would be unacceptable to the public/regulator (e.g., drinking water aquifer); (2) the WP is currently only designed for 10 years in the borehole and hence, a leak from it under the corrosive conditions found in the borehole may be considered inevitable; and (3) the monitors credited for this event would only detect if/when the leakage occurs and at this point there really is not a recovery mode (too late to recover the package), although other mitigating activities could be initiated upon detection (e.g., circulation of borehole fluids). AREVA understands these are potential outcomes of an emplacement activity and hence need to be evaluated, however AREVA recommends that outcomes A2 and E2 not be allowed to be final end states. If the WP cannot be fished/removed from the borehole, then it should be mandatory for the casing with the stuck WP to be removed (if this is a successful means for recovery). AREVA considers a WP stuck and "disposed" of in place above the disposal zone as an unacceptable end state.

The Appendix B hazard analysis performs a preliminary level assessment of the conceptual design described in the M2 report. A more detailed assessment will be necessary as more details of the design are identified and the design matures towards a level necessary for licensing. At this conceptual stage of design, engineering improvements to either emplacement mode can still be implemented to improve their overall performance. Hence the benefit of performing this hazard analysis at this time, along with a preliminary cost assessment, is to identify vulnerabilities of each conceptual emplacement mode design and then identify potential engineering solutions for these vulnerabilities. If these solutions are deemed cost-effective, then they can be implemented into the design and thereby reduce the vulnerability.

Due to the preliminary nature of this assessment, AREVA suggests that the specific numerical values for the probabilities/likelihoods listed in the M2 report be limited to the Appendix. The probabilities/likelihoods identified or listed in the main body of the report should be referred to as *relative likelihoods* or *relative probabilities* to ensure the understanding that the probabilities/likelihoods are not absolute or concisely derived or values to be used as a licensing basis.[1] The calculated probabilities/likelihoods in this report for the emplacement modes are based on a set of input values that are consistent relative to one another and likely within an order of magnitude of actual values; hence, providing a representative method for comparison. To establish probability/likelihood values needed for a licensing basis (outside the scope of the DBFT), the fault trees in Appendix B will need to be worked to more detail (i.e., component level) and applicable and verifiable failure data will be required. Additional comments on this Appendix are provided below.

The Appendix C cost calculations for the drill-string should include the need for thicker walled WPs, remotely operated equipment in the basement, and/or shielding around the WPs to allow for maintenance activities to occur when WPs may be present in the basement. Although these are not likely to reach the level of costs associated with the drill rig, the potential need for a mock-up of this basement, either at the DBFT or as a separately designed facility, will add to both capital and training costs for the drill-string emplacement mode. The focus on the mean cost difference between the options is the appropriate parameter to be compared, as opposed to absolute costs. Additional comments on this Appendix are provided below.

Finally, as noted earlier, the mode of transportation can impact the results of this assessment. For example, if multiple WPs can be transported to the DBD site at one time then the time for emplacement could be reduced, with the potential reduction in time for the drill-string emplacement mode being greater than for the wireline emplacement mode. This reduction in time results in a direct reduction in costs to both emplacement modes, potentially favoring one over another, and hence, should be considered in a sensitivity analysis.

As a path forward, AREVA recommends examining in more detail the impact on worker safety and on facility cost of maintenance activities in the basement for the drill-string emplacement mode when WPs are present. The conceptual design of the basement at this time does not appear to account for performing maintenance activities if WPs are present. Although this does pose an issue, engineering solutions exist that can resolve this issue (e.g., provide additional shielding or include remotely operated equipment to perform actions). AREVA also suggests that the hazard analysis and the cost estimate be updated as the design matures, as the current version of the

[1] For example, in the first paragraph of Section 5.4.1 replace "(b) quantify the likelihood of occurrence of each of those events" with "(b) quantify the *relative* likelihood of occurrence of each of those events".

hazard analysis and cost estimate are intended to compare the two considered waste emplacement modes and not provide probabilities utilized for licensing activities.

## 5.5 Review of Initial Analysis

### *Summary of Section:*

This subsection of the M2 report details the results from the preliminary assessment discussed in the prior subsection. Failure probabilities were calculated in Appendix B from fault trees and the rolled-up values are presented in Table 5-3. These failure probabilities were calculated using approximate basic event probabilities as listed in Table 5-4, which themselves were often produced based on insights offered by the panel described in Appendix A. As identified throughout this section of the M2 report, the basic event probabilities were developed "as an alternative to detailed assessment or development of individual failure rates for each individual event." These failure rates were subsequently characterized as falling into one of the following three categories with a basis provided for each: higher frequency of failure (> $10^{-3}$/trip), human error rates, and lower frequency of failure (< $10^{-4}$/trip). In addition to the failure rates, probabilities for the event branches in the event trees were identified in Table 5-5 with a basis provided for the value (primarily based on inputs from the elicitation panel).

The costs established in Appendix C were then incorporated into the model to establish relative cost impacts per emplacement mode and event tree outcome. Table 5-6 summarizes whether or not the event tree outcome results in a radiological release, the incremental increase in time over the normal emplacement duration, and the incremental cost increase over the normal emplacement costs.

Results are established using the failure and event probabilities along with the impact of each outcome on the performance metrics to determine the drill-string emplacement mode has a higher incremental cost relative to the wireline emplacement mode. Furthermore, although the likelihood of having an incident free emplacement of 400 WPs in the borehole using the drill-string emplacement mode is lower than for wireline, the drill-string emplacement mode is also more likely to result in a radiological release than is the wireline emplacement mode. Table 5-7 provides a summary of the "initial" results.

Finally, the drivers of the "initial" results are identified for the most likely off-normal outcomes for each emplacement mode. For the drill-string, drop of a WP drill string from the top is the dominant failure probability ($4.1 \times 10^{-3}$) and for the wireline, the drop of one WP during the trip-in is the dominant failure probability ($2.2 \times 10^{-2}$). The relatively high likelihood for an unbreached WP dropped in the disposal zone for the wireline emplacement mode is due to the high number of trips-in to the DBD (400) for this emplacement mode.

### *AREVA Review Comments, Discussion, Path Forward, and Proposed Alternatives:*

Based on the initial inputs provided in this assessment, the resulting event probabilities in Table 5-7 of the M2 report are reasonable and provide a means to allow for comparison between the wireline and drill-string emplacement modes. Although the impact of natural phenomenon (e.g., seismic) are not captured in this assessment, which could result in initiating event frequencies larger than those established for identified off-normal events, sites suitable for DBD are expected to be stable and hence emplacement is expected to be negligibly impacted by natural phenomenon at these sites. The calculated probabilities are only suited for pair-wise comparison and not for use in an absolute-sense (e.g., as part of a licensing basis).The results in Table 5-7 should be identified as "per borehole" to avoid any confusion with "per WP," "per drill-string," etc.

As noted throughout the M2 report, the results presented are of a preliminary nature and detailed fault trees and event trees will be required for licensing purposes. To this end, the following comments are made for each of the fault trees presented in Appendix B, which in turn provide the results listed in Table 5-3 and hence, may impact them accordingly.

- Figure B-1 (dropping WP from surface using wireline emplacement):
    - Suggest removing "to EZ" in top level of the tree, as the fault tree below it does not distinguish between drops into or above the EZ (disposal zone) and it is unclear if a WP dropped from the surface cannot become stuck on the way down
    - In the second level of the tree, the three events should be:
        - "Waste Package Drops from Surface without Wireline"
        - "Waste Package Drops from Surface with Wireline due to Headframe Failure"
        - "Waste Package Drops from Surface with Wireline due to Wireline/Rigging Failure"
    - The second block defined above should capture events related to the failure of the headframe system, which may benefit from insights provided in NUREG-0612 [17] and NUREG-0554 [18], which are related to identifying failure mechanisms associated with a single failure-proof crane
    - Since the design of the safety controls (interlocks) are "proposed" and other features are being considered for incorporation into the design, additional evaluation of these control systems/features are merited once they have been formally included in the design
    - The cut-set for this fault tree is dominated by the over-tensioning event and this appears to be conservative, however there are a couple of concerns that need to be addressed to verify this:
        - Given the environment in the borehole appears to be corrosive (brine solution at high temperature), the resistance of the wireline and associated rigging (e.g., connecting device from the wireline to the WP) to corroding in this environment must be confirmed to be negligible.
        - The probability of failure of various components of the headframe (e.g., winch drive failure, winch brake failure, winch interlock failure, etc.) should be compared against failure rates and failure mechanisms identified in NUREG-0554 [18] and NUREG-0612 [17] to ensure all the credible failure/fault scenarios have been identified and the utilized probabilities are conservative.
- Figure B-2 (dropping WP during trip-in using wireline emplacement):

  - Suggest removing "to EZ" in top level of the tree, as the fault tree below it does not distinguish between drops into or above the EZ (disposal zone) and it is unclear if a WP dropped during the trip-in cannot become stuck on the way down
  - In the second level of the tree, there should be two events:
    - "Waste Package Drops during Trip-in due to Headframe/Spooling-Device Failure"
    - "Waste Package Drops during Trip-in due to Wireline/Rigging Failure"
  - The existing fault tree from the second level down should be placed under the wireline/rigging failure listed above
  - A fault tree for failure of the headframe/spooling-device should be created consistent with the guidance identified in NUREG-0554 [18] and NUREG-0612 [17]
  - The cut-set for this fault tree is dominated by a wireline break caused by a wireline becoming un-tensioned during the trip-in (WP hung up in borehole or wireline fed into borehole at too high a rate) and then the WP suddenly descends into the borehole at a rate that causes the wireline to become over-tensioned and break, which appears to be conservative but a couple of concerns need to be addressed to verify this:
    - Given the environment in the borehole appears to be corrosive (brine solution at high temperature), the resistance of the wireline and associated rigging (e.g., connecting device from the wireline to the WP) to corroding in this environment must be confirmed to be negligible (not captured in fault tree, but discussed briefly in text)
    - The probability of failure of various components of the headframe/ spooling-device that could lead to a drop during a trip-in need to be included in the fault tree (utilizing failure rates and failure mechanisms identified in NUREG-0554 [18] and NUREG-0612 [17]) to ensure all the credible failure/fault scenarios have been identified and the utilized probabilities are conservative
    - The probability of a wireline break due to this over-tension event appears to be dependent on the rate of descent of the WP into the borehole, need to verify the rate of descent selected for the wireline trip-in does not increase this probability (noted that a sensitivity analysis was performed in the report on this parameter, but in a manner that assumed the utilized value was bounding)

- Figure B-3 (WP getting stuck during trip-in using wireline emplacement):
  - Under "WP stuck on debris":
    - Could split "Debris from working above borehole" into two fault trees: (1) the existing tree <u>or</u> (2) "Debris falls into borehole from worker activity (1E-5)" <u>and</u> "Gauge ring fails to catch fallen debris into borehole (1E-5)." This would cover the condition if worker debris fell into borehole prior to sending

gauge in for inspection, but its probability is 3 orders of magnitude less than (1) and hence its addition will not impact the final result.

    - "Other debris" is somewhat nebulously defined in this report and has a probability of occurrence essentially equivalent to the "Cement Debris" portion of the fault tree, but the "Cement Debris" allows for credit of the gauge ring. Suggest crediting the gauge ring for "Other Debris" as well or alternatively including under "Cement Debris" and "Other Debris": (1) credit for the gauge ring <u>or</u> (2) credit for the limited duration "cement debris" or "other debris" could accumulate between the gauge ring inspection and the WP emplacement. Also this "other debris" should consider a dependency on the size of the perforated casing located in the disposal zone.

  - The cut-set for this fault tree is dominated by the cement and other debris events and this appears to be conservative because, as noted above, the "other debris" appears to be overly conservatively handled by not crediting the gauge ring for capturing this debris. However, in the absence of capturing the potential impact of the seismic event (site specific characteristic) as a cause for casing collapse, it is uncertain if the established overall value for getting stuck during the trip-in is conservative, although sites suitable for DBD are expected to be stable.

- Figure B-4 (dropping wireline onto WP during trip-out using wireline emplacement):
  - Comments on this figure are similar to those for Figure B-2, namely:
    - Suggest splitting event tree below top level into "Wireline/Rigging Failure leads to wireline and/or attached tools to drop onto waste package" and "Headframe/Spooling-Device Failure leads to wireline and/or attached tools to drop onto waste package"
    - A fault tree for failure of the headframe/spooling-device should be created considering the guidance identified in NUREG-0554 [18] and NUREG-0612 [17] (e.g., consider the potential of a wireline failure due to misalignment during back-spooling [different tension level than when lowering WP into borehole] which may crimp wireline or have it caught in or near the winch drum and torqued to breaking point)
    - Given the environment in the borehole appears to be highly corrosive (brine solution at high temperature), the resistance of the wireline to corroding in this environment must be confirmed to be negligible or captured in the failure data utilized in this fault tree

  - Minimally need to clarify that the "cable head accidental release" portion of this fault tree will result in a drop of attached tools onto the WP, suggest placing this portion of the fault tree under the aforementioned fault tree for "Wireline/Rigging Failure leads to wireline and/or attached tools to drop onto waste package"

  - There is no dominant cut-set for this fault tree (unlike for the trip-in fault tree) and this is a reasonable result for a relatively unlikely drop event for a minimally load bearing wireline on the trip-out

- Figure B-5 (dropping WP string from surface using drill-string emplacement):
  - "Rigging Failure" should be moved from under the portion of the fault tree associated with "Drawwork not attached to WP string" to the portion of the fault tree associated with "Drawwork attached to WP string" as this is a failure mechanism associated with a WP string still connected to the draw work
  - In addition to the "Drawworks runaway" and the "Rigging Failure", there should be a failure associated with the line from the draw work to the WP string included under "Drawwork attached to WP string", although this is expected to be a low probability event
  - The cut-set for this fault tree is dominated by the "rigging failure" and this is conservative relative to the other failure events identified in this fault tree (by approximately two orders of magnitude), however there are a couple of concerns that need to be addressed to verify this:
    - As aforementioned, the effect of the corrosive environment within the borehole on the rigging must be confirmed to be either captured in the utilized failure data or shown to be negligible
    - To resolve issues associated with potential need for worker access to the basement area when WPs are present (e.g., to perform mechanical repair and maintenance activities), the report notes the system may need to be engineered for "self-recovery," in which case failure mechanisms associated with this design modification need to be identified and incorporated into this fault tree
    - In addition, considering this fault tree produces the highest failure probability for the drill-string emplacement mode and there are two orders of magnitude difference between the highest and next highest failure probabilities, consider reducing the probability of occurrence of rigging failure (e.g., redundant rigging and/or multiple independent checks of appropriate rigging connection) to reduce the overall failure probability
    - There may also be an opportunity to remove some features designed to reduce the failure probability of other branches in this tree that are several orders of magnitude below the dominant branch (e.g., under "WP grips fail" the "System interlock failure" could be removed from the design [not recommended] or the design to prevent inadvertent opening of the basement slips or elevator ram could be simplified [increasing the failure probability, but still maintaining the overall probability of this branch less than the dominant failure probability associated with the rigging]), this is considered leveling the risk

- Figure B-6 (dropping WP string during trip-in using drill-string emplacement):

  - Establishing the fault tree for the trip-in using the drill-string emplacement method is difficult without a list of operating steps for the lowering of the drill string into the borehole.
  - The failure probability associated with "WP string released prematurely" is listed as $10^{-6}$ per trip in Table 5-4, but is identified as $10^{-5}$ per trip in this figure. Since there is no justification for the value, it is unclear which value should be utilized and/or is appropriate. Furthermore, the lack of a description for this activity makes it uncertain if this failure is caused by mechanical failure and/or human error, however the failure probability is indicative of mechanical failure (would be higher if human error were involved). AREVA's suggestion is to expand this branch of the fault tree to justify the failure probability as produced by mechanical and/or human failure.
- The cut-set for this fault tree is dominated by an elevator failure with a failure probability of $10^{-6}$ per pipe stand (as identified in Table 5-4 and described on page B-9), which is conservative relative to the other failure probabilities calculated in this fault tree. Figure B-7 (WP/drill string getting stuck during trip-in using drill-string emplacement):
  - The left-hand side of this fault tree under "WP stuck on debris" is identical to the one in Figure B-3 and hence, comments that applied to that portion of the fault tree apply to this figure.
  - The cut-set for this fault tree is dominated by the casing collapse scenario and this appears to be conservative because the failure probability of the lead package in a WP string to detect the collapsed casing is 0.1 per trip due primarily to telemetry failure.
- Figure B-8 (dropping the pipe string onto WP during trip-out using drill-string emplacement):
  - Unlike the comment under Figure B-6 where 40 WPs were part of the pipe string, the two orders of magnitude lower failure rates (higher reliabilities) associated with the inadvertent opening of the rig slips and pipe ram used for the pipe stand over failure rates for the basement slips and elevator ram used for the WPs appear to be appropriately designated.
  - The cut-set for this fault tree is dominated by an elevator failure with a failure probability of $10^{-6}$ per pipe stand (as identified in Table 5-4), which is conservative relative to the other failure probabilities calculated in this fault tree, but the following concern needs to be addressed to verify this:
    - Given the environment in the borehole appears to be corrosive (brine solution at high temperature), the resistance of the pipe stand to corroding in this environment must be confirmed to be negligible (not captured in fault tree) and in addition, the potential impact to the pipe stand (including the threads) of the higher thermal temperature at the bottom of the borehole and the thermal gradient upon tripping-out of the borehole must be confirmed to be

negligible to the failure probabilities of the pipe stand components (not captured in fault tree).

In addition, this overall assessment did not examine the impact of natural phenomena (specifically the seismic event) on the fault and event trees developed for these two emplacement modes. Depending on the specific site utilized, the likelihood of some natural phenomena are comparable to some of the failure rates utilized to produce the probabilities listed in Table 5-7 and hence, events initiated by natural phenomena (e.g., casing failure) may impact these probabilities. However sites suitable for DBD are expected to be stable and in order to evaluate the impact of natural phenomena on this assessment either bounding or site specific initiating frequencies and criteria would be required; since there currently is no specific site and use of bounding criteria will likely lead to an over-conservative assessment, the suggested path forward is to examine these fault and event trees once a site has been selected for the DBFT to verify no tangible impact occurs. Consider the following in this assessment: (1) identification of the impacts of natural phenomena on the existing failure mechanisms for emplacement; (2) identification of any new events and/or faults to the emplacement modes created by the natural phenomena; (3) quantification of the impact of natural phenomena on the probabilities listed in Table 5-7; and (4) establish if an alternative emplacement mode should be selected over the one recommended by this assessment. Since the natural phenomena are likely to impact both of the emplacement modes in similar manners and sites suitable for DBD are expected to be stable, the expectation is that there will not be a change in the recommendation.

The event probabilities listed in Table 5-5 appear to be reasonable; however, there are some concerns related to the last three entries in the table. As noted in the review of the prior section, AREVA does not believe regulations will allow a WP stuck above the emplacement zone to be disposed of in this region. The potentially corrosive environment in the borehole will likely ensure the WP cannot provide long-term isolation of its contents and the lack of crystalline basement rock tightly fitting around this portion of the casing in the borehole will likely ensure the borehole cannot be assured of providing the necessary long term isolation needed for its contents. Thus, AREVA recommends that the value for this term be identified as 0.

The time and cost values listed in Table 5-6 provide a reasonable initial assessment of these parameters. As noted above, AREVA deems outcomes A2 and E2 as unacceptable end states for a WP (i.e., stuck and left in place above the emplacement zone) and hence, recommend their deletion as an acceptable end state. In addition, Table 5-6 includes data for outcomes A1, A2, A3, B2, and E4 for the drill-string emplacement mode, but the event tree for this emplacement mode (Figure 5-3) does not show these outcomes as possible, so some clarification is needed on how costs were established for these outcomes.

### *Review of Deep Borehole Field Test Specifications, Appendix C – Normal and Off-Normal Cost Estimates for Design Selection Study:*

The following section provides an evaluation of the *Deep Borehole Field Test Specifications* (FCRD-UFD-2015-000132 Rev. 1), Appendix C titled "Normal and Off-Normal Cost Estimate for Design Selection Study". As specific cost details are not provided for review including equipment and labor rate structures, resource loadings, and escalation and market conditions, an evaluation of the Rough Order of Magnitude (ROM) estimate values is not provided. Instead, the following discussion provides a review of cost impacts for the DBFT as a result of design considerations presented elsewhere in this report, and additional cost considerations for future DBD operations. Some considerations discussed below have associated discussions within other sections of this report (and will be referenced as such) and some stand on their own strictly as prudent considerations.

### *DBFT Cost Estimate Considerations:*

It should be noted that an estimate specifically for the DBFT has not been provided; however, design considerations for the DBFT discussed elsewhere in this report have associated cost impact considerations. This subsection reviews the cost impacts of those DBFT design considerations. A specific ROM is not provided as no specific rate structure was provided in Appendix C for the DBD cost estimate and if DBFT cost impacts are to be estimated, the confidential rate structures from recently received proposals for the execution of the DBFT should be utilized.

DBFT cost estimate considerations are presented as: a) considerations impacting the final design cost of the DBFT; b) considerations impacting the normal operations of the DBFT, and; c) considerations impacting the off-normal operations of the DBFT. The following items impact the final design cost of the DBFT as stated elsewhere in this document and should be included in the scope of the DBFT in order for the DBFT to be representative of future DBD waste placement operations:

- Cost impacts related to the design completion of the FTB and casing structure
  - As a perforated casing is likely to be used in DBD, it should also be considered for use in the FTB as it has implications on WP emplacement velocities and potential drop testing of ILs. As a result, civil structural analysis will likely be required for the perforated casing emplacement zone and its supporting design if it differs from conventional non-perforated borehole casing used in the FTB (Report Section 4.2). The potential cost impact for the civil structural analysis is estimated to range from 100 to 200% of current structural analysis cost for use of the currently specified non-perforated casing cost (assuming civil structural analysis is performed on the conventional non-perforated casing).
  - The FTB emplacement zone solution/working fluid chemistry should be characterized to support final material selection for the future WP(s) (reference Section 7.1, item 7.1).
  - The emplacement mud properties should be measured to validate any analytical terminal velocity studies performed. This includes viscosity, density, chemistry, and particulate size ranges (reference Section 7.1, item 7.1.b).
  - The temperature in the emplacement zone and the temperature gradient should be measured to support any thermal-hydraulic analytical studies performed (reference Section 7.1, item 7.1.c).
  - Surface transport, transfer fixtures, handling equipment, and radiation protection mockups and other related equipment necessary for the transport and material handling of canisters of waste materials for disposal should be considered essential for demonstration and/or testing at a separate location with a shallow borehole mock-up (Reference Section 3.0, subsection “Verification of

applicability to disposal case of items in M2 Specification Tables 3-1 and 3-2", and page Section 7.1.f). By the use of a mock-up facility, the DBFT would be able to provide necessary site licensing activities with applicable and proven experience as well as a valid data needed in order to license application RFIs. The site could also serve the future training needs of DBD operations personnel without overly complicating the DBFT or DBD sites(s). Additionally, the mock-up location can provide for trouble shooting and interface logistics of material handling in a controlled environment while providing a reduction in risk to the start-up of actual operations at the DBD site. Finally, timing of testing and mock-up operations can occur during a broad window from before actual site mobilization at the DBFT site to immediately before the operational readiness review of the DBD site operations. As no estimated cost for these items or activities have been addressed in Appendix C of the M2 Specification, there is no cost data available for comparison. However, the cost of such a mockup and training facility should reduce related DBD start-up risk register contingency amounts enough to offset the cost of the facility.

- Although not the recommended mode for WP emplacement for DBD, if the drill-string emplacement mode is to be demonstrated at the DBFT, then the following items are recommended for inclusion into the scope of the DBFT (Reference Section 7.2):
  - The "shielded basement";
  - Repeated remote assembly and disassembly of test packages;
  - The packaging release mechanism should be tested under the maximum expected loading conditions.
- If the wireline emplacement mode is to be demonstrated at the DBFT, then the following items are recommended for inclusion into the scope of the DBFT (Reference Section 7.3):
  - Recommend dropping a wireline test package (this test could be combined with the IL testing described in Section 7.1.e.);
  - Recommend a free drop of a single package to assess the bounding damage to the test package;
  - Surface drop testing of a test package for the maximum expected handling height.

Cost estimates for these items and operations can be can be derived from the estimated cost of the cycling a WP for emplacement during wireline emplacement operations provided in Appendix C of the M2 report.

- Test package testing considered incomplete for DBFT
  - Testing of the test package utilized in the DBFT needs to be representative of the physical characteristics of the future WP to be utilized for the DBD with identical bounding temperatures, load factors, sizes, weights, buoyancies, IL designs, and package connections (reference Section 2.5, sub-section on "Recommendations

on WP design", Section 4.1, Section 4.3, Section 7.1.d, and Section 7.1.e). The potential cost impact for the test package is estimated to range from 0 to 50% more for the DBFT WP to be tested, dependent upon the final specifications and codes applied to the WP. Cost impacts from the necessary analyses and instrumentation required to support the additional testing is very hard to define as it is not known what analysis is included in the DBFT scope of work for the future WP; however, specific quotes for engineering analysis, instrumentation and material testing can be easily obtained once a preliminary future WP design is determined.

- Normal Operations
    - The FTB emplacement zone solution/working fluid chemistry should be characterized to support final material selection for the future WP(s) design (reference Section 7.1, item 7.1.).
    - The emplacement mud properties should be measured to validate any analytical terminal velocity studies performed. This includes viscosity, density, chemistry, and particulate size ranges (reference Section 7.1, item 7.1.b).
    - The temperature in the emplacement zone and the temperature gradient should be measured to support any thermal-hydraulic analytical studies performed (reference Section 7.1, item 7.1.c).

All other attributes of the DBFT would be considered as Normal Conditions as no radiological materials are utilized in the DBFT.

- Off-Normal Operations

  AREVA believes that consideration of the DBFT for Off-Normal Operations is proof of a workable and licensable concept for DBD operations. As a result, the below off-normal considerations should be considered as potential cost impacts to the DBFT.

    - It is conceivable that the straightness of the CB or FTB are not within acceptable limits due to geological conditions, contractor effectiveness, equipment effectiveness, or a combination of these conditions. This would be considered an off-normal condition of the drilling process. A resulting remedy could be:
        - Research, support and incorporate equipment upgrades due to insufficient technology utilized by the drilling contractor. This remedy would have some cost and schedule impacts, but is dependent upon the willingness of the drilling contractor. The cost impact could range from an additional zero to 50% dependent upon the contractual arrangements with the drilling contractor and availability of necessary equipment to the drilling contractor (as some needed technological equipment may have limited availability to specific drilling contractors).
    - The support of additional off-normal testing including:
        - Stuck test package below DZ
        - Stuck test package above DZ
        - Dropped test package – no breach

    - Fishing operations testing
  - Simulate retrieval of dropped/breached test package
    - Fishing operations testing with additional test package and operational waste evaluation performed
  - Breached test package below DZ – same as above
  - Breached test package above DZ – same as above

The estimated cost for including these short-duration testing operations can be derived from the M2 report, Section c.2.3 titled “DBD Cost Estimates – Off-Normal Outcomes”.

### *DBD Cost Estimate Review:*

Although insufficient detailed information is available for evaluation of DBD waste emplacement operational costs, the evaluation of off-normal conditions does seem sufficient in the M2 report, Appendix C. However, those tasked to provide and /or support DBD operations should ensure that the following list of potential cost impacts have been fully considered:

- Increase of required rad-worker training requirements after an off-normal condition occurs
- Potential increase in worker security clearance requirements dependent on waste form and non-proliferation rating of waste form
- Transport of WPs, transfer casks and handling equipment to site
  - Equipment likely to be different depending on drill-string or wireline emplacement method; therefore, resulting cost estimate different for drill-string vs. wireline emplacement method
- Procurement and transportation of WP handling and necessary shielding for loading facility
  - Different WP dependent on drill-string or wireline emplacement method
    - Should also include appropriate WP IL
  - Learning curves applied to production of WPs and ILs
- Obtaining regulatory permits
  - NRC
  - State
  - Permits needed for site and permits needed for operations
  - Potential impact of development and/or revision of regulatory and public standards
  - Typically, decontamination and radiological facilities must already be present and workers trained in operations for obtaining necessary radiological license(s)
- DBD Design considerations

  - Concrete design of the well head basement or above ground shielding (along with equipment for future retrieval operations) would likely require additional analysis to support the anticipated handling equipment
    - Remote operations
    - Remote maintenance
    - Worker protection
    - Worker training for operations
    - Equipment testing and training for use does not need to occur at DBFT site; can occur at WP loading site (DOE site)
  - Additional BOP requirements which would then impact the basement or emplacement equipment design
  - Potential design requirement for hyperbolic test vessel to perform WP pressure testing
  - Specific considerations for the drill-string option
    - Determining interfaces (if any) between the drill rig and WP handling equipment
    - Design completion of custom drill rig equipment (if any)
    - Separate WP IL designs required for both the CBH and DBD borehole
    - Design completion of the release device
    - Separate WP concepts (flask-type and internal-flush type)
  - Specific influences to the wireline option
    - Design completion of the release device
- Equipment rental not likely during DBD operations as potential for contaminated equipment is high; therefore, will have to purchase all equipment at mobilization of either method
  - If equipment can be rented/leased, likely not at comparable market rates and likely well-used with high maintenance and repair requirements
    - Operations schedule impacts
    - Worker dose impacts
  - Rented equipment likely not state-of-the-art; may impact operations requirements
    - Borehole straightness
    - Speed of operations may be negatively impacted
  - Lead times and cost of equipment to be purchased increases with high demand in market
  - Lead time of coil tubing equipment high for equipment purchase at all times; due to demand, likely to be cheaper to buy than rent

    - Lead-time likely to be very long impacting start-up capital and internal cost-of-money

- Normal Operations
  - DOE estimate acceptable
- Off-Normal Operations additional considerations
  - Schedule impacts after off-normal condition occurs
    - Regulatory downtime likely underestimated by 25 to 50%
    - Cost of waste disposal for breached packages and handling equipment not clearly defined in Appendix C estimate
    - Increased rad-worker training as a result of breached WP and potentially contaminated equipment
    - Increased routine D&D during routine operations
    - Increased equipment D&D during routine maintenance activities
    - Increase of equipment D&D, survey, material handling, packaging, transportation preparation
  - Cost impacts after off-normal condition occurs
    - Related cost impacts for above schedule impacts
    - Waste disposal transportation of waste from off-normal condition; rad-waste disposal sites limited and likely further away
    - Equipment packaging for disposal more expensive
    - If equipment purchased, less cost impact from equipment being idle and re-mobilization, and potential for re-imbursement at higher market value
  - In case of WP breach, contaminated borehole fluid initially removed likely to never meet acceptance profile at disposal site unless highly diluted in liquid or solid form; therefore, anticipate greatly larger disposal volume than 3X and use water based fluids for ease in solidification

### *Emplacement Mode Analysis*

The initial results from this analysis comparing the wireline emplacement mode to the drill-string emplacement mode shown in Table 5-7 are reasonable and provide a means for comparing these two emplacement modes against one another. As noted in the report, the results from this table indicate the following:

- The drill-string emplacement mode has a higher probability of incident-free emplacement for the 400 WPs of a borehole, due principally to fewer trips-in (10) relative to the wireline emplacement mode (400)
- The drill-string emplacement mode has a higher probability of a radiation release as a result of an emplacement activity, due principally to drop events involving a drill string that includes WPs and the WPs breaching upon impact

- The wireline emplacement mode has a higher probability of a WP becoming stuck and left in the borehole above the emplacement zone (Outcomes A2 and E2)
- The expected value of costs for the wireline emplacement mode ($22.8M) are less than for the drill-string emplacement mode ($42.0M)

Considering these results the wireline emplacement mode appears to have a more favorable relative rating than the drill-string emplacement mode. Furthermore, as noted above, the concern regarding the needed design changes to accommodate remote maintenance/repair activities in the basement used for the drill-string emplacement mode when WPs are present, may further complicate the operation (as well as increase the cost) during the drill-string emplacement mode. Thus, AREVA considers the wireline emplacement mode the more favored approach to placing the WPs into the borehole.

A similar conclusion can be reached from the following table which compares the pros and cons of these two emplacement modes, as well as several alternative emplacement modes not specifically investigated in the M2 report.

TABLE 5-1: PROS AND CONS OF EMPLACEMENT MODES

| Emplacement Option Pros and Cons | | |
|---|---|---|
| **Emplacement Mode** | **Pros** | **Cons** |
| **Wireline** | • Developed technology<br>• Relatively simple borehole loading operations<br>• Electrically capable<br>• Rapid mobilization<br>• Minimal source loading near the surface<br>• ILs with short stroke could mitigate dropped WP<br>• Release/retrieval mechanism could be developed from existing technology<br>• Smaller shielded structure above ground<br>• Single package less likely to get stuck<br>• Emplacement descent approximately 6 hrs<br>• Lower breached package potential | • A stuck WP may need to be recovered with drill pipe introducing the same hazards associated with the drill pipe<br>• Wireline susceptible to damage and failure from repeated use<br>• Multiple emplacement trips required |
| **Drill-string** | • Developed technology customized for specific use<br>• High lift capacity for potential stuck packages<br>• ILs with long stroke could potentially mitigate dropped WP | • Lengthy mobilization construction<br>• Not electrically capable<br>• Multiple safety interlocks required due to complex redundant operations<br>• Redundant lift components |

| Emplacement Option Pros and Cons | | |
|---|---|---|
| **Emplacement Mode** | **Pros** | **Cons** |
| | string<br>• Fewer emplacement trips required due to conveyance of multiple packages (30 to 40) emplaced per trip | required to prevent accidental drops<br>• Slow mobilization<br>• Highest source loading near the surface<br>• Complex shielded basement structure required for package string connections<br>• Possible hot cell required for maintenance/replacement of basement equipment<br>• Higher package breach potential due to accidental drill string drop<br>• Release/retrieval mechanism could be difficult because of heavy drill pipe string<br>• Lengthy package string more likely to get stuck<br>• Complicated borehole loading operations |
| **Free fall/Self-emplacement** | • Simple, no borehole release mechanism<br>• Rapid mobilization<br>• Minimal source loading near the surface<br>• ILs with short stroke<br>• Single package less likely to get stuck<br>• Lowest cost | • Difficult safety perception (uncontrolled descent)<br>• Use of IL required for safe emplacement<br>• Wireline logging required to verify emplacement<br>• A stuck WP may need to be recovered with drill pipe introducing the same hazards associated with the drill pipe |
| **Coiled Tubing** | • Minimal source loading near the surface<br>• Fast trip time<br>• Reduced personnel requirements<br>• Can be fitted with internal electrical and/or hydraulic conduits for downhole power and communication tools<br>• Push and pull capable<br>• WP connection could be electrically controlled similar to wireline<br>• Single package less likely to get stuck | • Frequent tubing string replacement required due to bending (yielding) of tubing every trip<br>• Specialized equipment required for inspection of coil string and computing life expectancy<br>• Custom designed shielded structure between injector and BOP required for WP/tubing connection<br>• Complicated borehole loading operation<br>• Multiple emplacement trips |

| Emplacement Option Pros and Cons | | |
|---|---|---|
| **Emplacement Mode** | **Pros** | **Cons** |
| | • Lower breached package potential | required<br>• A stuck WP may need to be recovered with drill pipe introducing the same hazards associated with the drill pipe |
| **Conveyance Liner** | • Fewer emplacement trips required due to conveyance of multiple packages (10 to 20) emplaced per trip<br>• Package connections not required due to simple stacking in conveyance<br>• Liner would offer some protection to WPs from drill pipe string and reduce the chance of a breached package | • Larger borehole diameter required (> 17 in.) to accommodate additional conveyance liner<br>• Shielded basement type structure required to load and support conveyance liner<br>• Drill rig required for heavy lift<br>• Release mechanism for conveyance liner or trap door required<br>• Concentrated source loading near surface<br>• Additional corrosion/hydrogen gas generation if conveyance liner is left in borehole, or more complicated design if trap door is required to release WPs<br>• Complicated borehole loading operations<br>• Does not change the likelihood of two of the three types of drill-string drops that have high potential to breach packages |

Some additional comments on the results from this report:

- Establish if washover pipe could be used as an alternative method to retrieve a WP or WP string that has become stuck in a borehole
- To reduce the potential for getting stuck during a wireline emplacement, consider increasing the weight of a WP by, for example, increasing its length, using a heavier packaging material, including more waste items in the WP, etc. and the impact to:
    - The reduced buoyancy of the WP
    - Transportation and interim storage activities prior to disposal
    - The wireline thickness (accounting for the FoS)
    - Loading of the WP

  - IL design
- To reduce the failure probability for the drill-string emplacement mode as a result of failed casing, consider creating a mock-up test to examine the telemetry from the lead WP, which would be detecting the collapsed casing (could be tested using the DBFT)
- Development of a WP release connection that is more reliable than the currently credited connection, which is considered to have a high failure probability
- For outcomes crediting the successful fishing of a stuck WP from the borehole, consider the potential impact of the pressure change if the WP is considered breached and brought to the surface for recovery

## 5.6 Sensitivity Analyses

*Summary of Section:*

This section describes the sensitivity analyses performed to explore the impacts to the results in Table 5-7 as a result of changes to four event probabilities, seven failure probabilities, the number of WPs in a WP string, and the number of safety controls. Specifically, the impacts were examined to assess if the results in Table 5-7, which lead to the preference of the wireline emplacement mode over the drill-string emplacement mode, could be sufficiently changed to reverse this preference. Appendix D includes the details for each of the sensitivity analyses.

The sensitivity to the following four event probabilities was examined: location of where the WPs get stuck (above or within the disposal zone), the success rate for removing a stuck WP(s), the likelihood of breaching a WP while attempting to fish or remove a stuck WP(s), and the likelihood of breaching a WP due to a drop event. The results indicated a relative insensitivity to the impact of changing the location of where the WP(s) gets stuck and the success rate for removing a stuck WP(s). However, the results from changing the likelihood of breaching a WP while attempting to fish or remove a stuck WP(s) and the likelihood of breaching a WP(s) due to a drop event indicated some degree of sensitivity to these event probabilities. An increase of between 15% and 20% to the likelihood of breaching a WP during fishing for the wireline emplacement mode was necessary to get a risk comparable to the drill-string emplacement mode (but the costs for wireline emplacement were still significantly lower than for drill-string emplacement). An even more dramatic change to the likelihood of breaching a WP due to a drop event was necessary to get comparable risk values between the emplacement modes (but the costs for wireline emplacement were still significantly lower than for drill-string emplacement).

The sensitivity to the following seven failure probabilities was examined: the probability that a human error leads to a failure, the frequency of human error, the probability of a dynamic over-tension failure, the failure rate of a safety control (interlock) system, the probability of becoming stuck by debris in the borehole, the probability of rigging failure, and the frequency of casing collapse. Results were established to be relatively insensitive to the probability that a human error leads to a failure, the frequency of human error, the failure rate of a safety control (interlock) system, and the frequency of the casing collapse. By decreasing the probability of a dynamic over-tension failure, the likelihood of emplacing WPs by the wireline emplacement mode moderately improves. The wireline emplacement mode results are highly sensitive to the probability of a WP becoming stuck by debris in the borehole since this is related to the only breach mechanism of this emplacement mode; however even a 10-fold increase in this probability does not cause the overall probability of a radiation release to exceed that of the drill-string emplacement mode (the costs will still favor the wireline emplacement mode). The drill-string emplacement mode is also sensitive to the probability of rigging failure, where any increase in this probability will result in an increase in the probability of a radiation release and hence highlighting the importance of this parameter to this emplacement mode.

The sensitivity of the results to a decrease in the number of WPs in a WP string for drill-string emplacement is shown to be relatively minor, as a reduction in WPs will reduce the probability of a release per trip but would be counter-balanced by the increased number of trips to emplace the total number of WPs in the borehole to result in a net increase in the probability of release per borehole.

Finally, the impact of the number of safety control (interlock) systems on the wireline emplacement mode failure probabilities was examined. Table 5-8 presents the findings for each failure event calculated in Appendix B with the full set of interlocks, no interlocks, and interlocks with an increased failure rate. Table 5-9 summarizes the likelihood, as a function of different levels of safety controls, of dropping, sticking, and breaching a test package during a demonstration of 9 or 60 packages.

*AREVA Review Comments, Discussion, Path Forward, and Proposed Alternatives:*

The sensitivity analyses performed in this report is very beneficial because it determines which parameters are important and unimportant to establishing the probabilities in Table 5-7 that influence the assessment for the preferred emplacement mode. By establishing the important parameters, additional resources can be placed on determining a more concise value or range of values for each of these parameters, whereas fewer resources need to be extended towards establishing concise values for the unimportant parameters. However, to ensure the proper parameters have been identified as important, a sensitivity analysis will have had to been performed on that parameter. Considering the failures that dominated (i.e., the cut-sets) each of the fault trees in Appendix B, sensitivity analyses were performed for each of these dominant failures with the exception of the elevator failure. The elevator failure dominated the drill-string emplacement mode fault trees for the dropping of the WP drill string during the trip-in (Figure B-6) and for the dropping of the drill pipe during the trip-out (Figure B-8). Hence, AREVA suggests performing a sensitivity analysis (as part of S-F3) for the probability of failure for the elevator as this parameter significantly impacts results for the drill-string emplacement mode. However, since the justification provided on page B-9 of the M2 report (none provided in Table 5-4) indicates the failure rate for the elevator used in the fault trees is conservative, this sensitivity analysis is likely to examine only further reductions in this failure rate and hence, will not identify any adverse trends.

The sensitivity analysis performed for human errors (S-F2) only examined the impact of decreasing the frequency of human errors and found “the results are insensitive to these changes,” which is to be expected as human errors were not part of any of the dominant cut-sets for the fault trees. So essentially, an inconsequential failure rate was made further inconsequential by this decrease in frequency. Since frequencies associated with human errors often are associated with having large error bars, the sensitivity analysis would have been expected to also increase the frequency of human error to examine the impact on these results. AREVA suggests including the impact of an increase in the frequency of human error in this sensitivity analysis to verify the insensitivity of the results to this parameter.

Similarly, the sensitivity analysis performed for the over-tension probability (S-F3) for the wireline emplacement mode only analyzed for a decrease in this probability. Since this probability is part of a dominant cut-set from the trip-in fault tree (Figure B-2), an increase in this probability is expected to further adversely impact the results. By not performing the sensitivity analysis for an increased probability, the implicit assumption is the value listed in Table 5-4 is the bounding high value. AREVA suggests examining the impact of an increased over-tension probability considering potential descent rate and other factors specific to boreholes that can influence this probability or justifying the established value as bounding.

The sensitivity of the results to the likelihood of rigging failure to the results of the drill-string emplacement mode indicate: (1) the need for a robust rig; (2) verification the utilized likelihood in the analyses is representative of the existing rigging design; and (3) the potential need for redundant rigging. AREVA suggests details of the rig design be identified or developed, as appropriate, to verify the robustness of the design and to ensure the likelihood of failure is representative of the value utilized in this report ($10^{-5}$ per WP).

Table D-7 in Appendix D has empty cells for the “Drop Trip-In,” “Get Stuck,” and “Drop Trip Out” where results of the sensitivity analyses were expected to be established. Without these values, the impact of the analyzed parameters on the results cannot be confirmed for these sensitivity analyses for the drill-string emplacement mode and hence, the assessments made in the body of the report not confirmed. AREVA suggests the results for these analyses be incorporated into this table.

Finally, as noted several times above, AREVA does not believe outcomes A2 or E2 will be acceptable end states for the WP(s) (i.e., stuck and left in place above the emplacement zone) and hence, recommend examining the sensitivity of the results to the removal of these options (i.e., their probability is equal to zero). That is, establish additional features and/or actions that make the probability of “disposal” of a WP above the emplacement zone negligible.

# 6.0 Summary and Recommendations

This SRR provides an independent review and assessment of the "Deep Borehole Field Test Specifications/M2FT-15SN0817091" Rev 1 [1], referred throughout the SRR as the M2 report, with focus on three primary elements of the M2 report:

(1) The mode of emplacement for the WPs to be disposed into the deep borehole with validation of the findings of the M2 report on the selection of the wireline emplacement mode;

(2) The conceptual design of the WPs proposed for DBD with particular emphasis on the supporting engineering analyses related to the designing of the ILs for these WPs; and

(3) The conceptual design of the DBFT with a focus on identifying activities of the DBFT important to supporting the designing of the WP and to implementing the wireline emplacement mode.

The emplacement mode review and recommendation is intentionally covered first in the following summary so that the focus of the review and recommendations for the WP conceptual design and the DBFT will be on those aspects supporting the wireline emplacement mode. Review and recommendations associated with the other emplacement modes covered in the M2 report are discussed in the body of this SRR, but are not summarized in this section. In addition, detailed comments and recommendations on sections of the M2 report are also included in the body of this SRR.

The combination of the M2 report and this SRR is intended to lead to the completion of the conceptual design for DBD for the Cs and Sr capsules and calcined waste forms. Using the conceptual design, preliminary design activities (the second stage of a three-stage process described in the M2 report) can proceed and the DBFT utilized to support, demonstrate, and confirm *engineering* elements of this design.

## 6.1 Emplacement Mode Review and Recommendations

AREVA concurs with the M2 report's selection of the wireline emplacement mode specifically over the drill-string emplacement mode and generically over alternative emplacement modes. Table 5-1 compared the pros and cons of each emplacement mode considered in this SRR. The primary positive characteristics of the wireline emplacement mode include: (1) considered a mature technology (e.g., successfully utilized at the Climax SNF test); (2) operations are relatively simple (e.g., compare the drill-string operations in Section 2.6.4 of M2 report versus the wireline operations in Section 2.6.5); (3) probability of a radiological release due to off-normal events is relatively low (e.g., contrast wireline and drill-string probabilities in Table 5-7 of the M2 report); (4) costs are relatively low (e.g., contrast costs presented in Section 5.5.3 of the M2 report between the drill-string and wireline emplacement modes); and (5) maintenance activities are relatively simple (e.g., contrast against drill-string emplacement mode, which may require remotely operated equipment).

The primary drawback associated with the wireline emplacement mode for DBD is the number of emplacement trips-in to the borehole (one per WP) relative to the drill-string and conveyance casing emplacement modes. This larger number of trips-in to the borehole results in a higher probability of a drop event (e.g., Table 5-7 of the M2 report shows the relative drop probabilities for drops during trips-in for the wireline and drill-string emplacement modes). Fortunately, the WPs can be engineered with ILs that minimize the likelihood of a breach of the WP due to a drop. So although this drawback increases the probability of an event, the risk of the event is likely to be very low as the consequences are likely to be prevented by the IL. Including an IL may, however, require modification of the shipping cask to accommodate the IL and/or receipt handling operations to allow remote installation of the IL. Neither of these activities are expected to reduce the safety or reliability of the wireline emplacement mode nor measurably increase the costs of the wireline emplacement mode.

Results presented in the M2 report from the fault and event trees provide a quantitative assessment of the wireline and drill-string emplacement modes, which allows for a relative comparison of these emplacement modes. As noted in the M2 report and confirmed by this SRR, the results favor the wireline emplacement mode. Furthermore, sensitivity analyses performed on the critical inputs to these events and fault trees did not significantly change the outcome of the results and did not change the recommendation for the wireline emplacement mode. This overall assessment did not consider the impact of natural phenomena (specifically the seismic event), although sites suitable for DBD are expected to be stable and hence, the impact is likely negligible.

The advantages of the wireline emplacement mode over the drill-string (and other) emplacement modes with respect to safety, reliability, and the cost of emplacement, result in the recommendation of the use of this mode of emplacement at the DBFT. One caveat to this recommendation is that without regulatory performance requirements (e.g., public consequence limits), there is a degree of uncertainty about the acceptability of this emplacement mode and potentially other emplacement modes. There may be outcomes associated with specific off-normal emplacement activities that may not meet future regulatory requirements. For example, as noted in this SRR, for the wireline and drill-string emplacement modes, AREVA does not believe leaving a WP stuck in the borehole above the EZ (outcomes A2 and E2) is an acceptable end state from a regulatory position. Fortunately, in this case, there appears to be means of removing the WP from the borehole (e.g., by removing the casing with the WP in it), but there may be other outcomes challenged by future regulatory performance requirements.

## 6.2 Conceptual Waste Package Design Review and Recommendations

The WP designs presented in the M2 report appear to be focused on compatibility with the drill-string emplacement mode and with the recommendation that the wireline emplacement mode be utilized for the DBFT; some changes may be warranted to these WPs. For example, the development of a WP release connection that is more reliable than the currently credited connection, which is considered to have a high failure probability. Inclusion of an integral IL may also be beneficial, as it could reduce potential surface operations associated with connecting an IL to a WP (however not necessary as long as a threaded WP design is maintained).

Important parameters to the design of a WP and its IL for DBD that are likely to be verified by the DBFT include: (1) the design of perforations/slots of the disposal zone casing; (2) properties of the fluid in the borehole; and (3) temperature of the EZ. With selection of the wireline emplacement mode, ILs may be required to prevent a breach of a WP in case of a drop into the borehole and the design of these ILs are dependent on establishing a terminal velocity, which is dependent on all three of these parameters. Furthermore, selection of the WP material depends on the fluid properties and temperature within the borehole. Thus, although the conceptual design of the WPs presented in the M2 report appear acceptable, AREVA recommends the DBFT be used to collect data for these parameters to inform/verify the preliminary design of the WPs.

Although not part of the scope of the DBFT, AREVA notes that the design of the test package should be proximate to the design of the future WP and that the design of the future WP consider compatibility with potential upstream activities. Designing the test package in this manner should ensure project continuity and production of results meaningful/representative of potential future WP emplacement activities.

## 6.3 Conceptual Design of the DBFT Review and Recommendations

The following recommendations for the DBFT were identified during the course of the review:

- Emplacement operations above the borehole using the wireline emplacement mode should be mocked-up to the extent possible to reflect those that will be performed at an actual disposal site.
    - Namely a test WP should be utilized at the DBFT to allow simulation of wireline emplacement activities from receipt of the WP to emplacement in the bottom of the borehole, including the use of temporary (simulated) shielding.
    - This simulation will allow for the identification of potential vulnerabilities to the worker and provide opportunities to improve and/or streamline activities, including those particularly susceptible to causing a safety issue during emplacement (e.g., WP rigging activities).
- Identification of credible WP breach scenarios, beyond those analyzed in the M2 report, should be analyzed for at the DBFT to establish if there are other credible drop and/or crush scenarios that may not occur within the fluids of the borehole and could lead to consequences greater than those considered in the M2 report.
    - For example, consider the potential for the drop of a WP on to a BOP during an emplacement activity, establishing the drop distance, the extent of yield/rigidity provided by the drop surface, the ability of the WP to withstand the drop, the potential consequences of a breached WP, and the potential features needed to mitigate the consequences.
    - Similarly, consider the ability of the BOP to crush the WP if closed as a WP were being lowered through it, establishing the extent of a credible breach, the potential consequences of this breach, and the potential features needed to mitigate the consequences. Ideally the BOP is designed to provide insufficient load to crush a WP making this exercise unnecessary.
- Examining the ability to recover a test package from the DBFT including:
    - The fishing out of a test package from the DBFT using various methods to establish those with the most success and those with the least probability of damaging a WP.

- Performing test package drop scenarios in the DBFT, which includes ensuring the casing of the DBFT reflects the casing to be utilized in actual disposal boreholes and the fluid in the borehole is representative of that expected in actual disposal boreholes.
  - The DBFT needs to include perforated or slotted casing in the EZ, so that the drop of a test WP into the borehole produces results representative of a disposal borehole, which includes increased terminal velocities in the EZ.
  - The DBFT needs to include fluid within the borehole that is expected to be representative of the fluid to be used in an actual disposal borehole, so that the drop of a test WP into the borehole produces results representative of a disposal borehole, which includes the fluid viscosity impact on the terminal velocities throughout the borehole.
  - Recommend mock-up testing (not at the DBFT) be performed in advance of a drop test at the DBFT to establish the impact of perforated or slotted casing on terminal velocity of a test WP (potentially through the use of a scaled-down test package). This testing would confirm analytical modeling of the impact of perforated or slotted casing on the terminal velocity.
  - The objective of this drop test is to demonstrate the ability of the test WP, with its IL, to withstand credible drop scenarios.

# 7.0 DBFT Scope Recommendations

AREVA has reviewed the M2 report and recommends that the following features of the conceptual/ preliminary design for the deep borehole be tested during the DBFT phase. This testing would assist in verifying design inputs for future design work and provide data for some of the TBDs identified in Section 2.5 of this SRR.

## 7.1 DBFT Recommendations Independent of Emplacement Mode Choice

The following items are recommended for incorporation into the scope of the DBFT independent of the emplacement mode chosen:

a) The EZ solution/working fluid chemistry should be characterized to support and verify material selection for the WP(s).

b) The emplacement mud properties should be measured to validate/confirm any analytical terminal velocity studies performed. This includes viscosity, density, chemistry, and particulate size ranges.

c) The temperature in the EZ and the temperature gradient should be measured to support any thermal-hydraulic analytical studies performed.

d) The DBFT test WP should use outer dimensions and weight that prototypic of WP features planned for disposal use. The test package could be fabricated from a lower cost material where the results can be analyzed and serve as a basis for demonstrating/verifying a 10-year life in the borehole environment.

e) Any impact mitigation devices on the test packages (e.g., ILs) should be tested during the DBFT. Any drop testing should use internally instrumented test packages to inform future work on WP designs and validate analytical fluid models. (Note: this is not a performance or qualification test, but a benchmark for future design work.)

f) Surface transport, transfer fixtures, handling equipment, and radiation protection mockups should not be considered essential to the scope of the DBFT. However, these items should be considered essential for demonstration and/or testing at a separate location with a shallow borehole mock-up. This would lower the cost and complexity of testing these items at the DBFT site. This off-DBFT-site testing would serve as a platform for operational lessons that would be incorporated into any preliminary DBD design and risk assessment after the DBFT is complete. This site could also serve any future needs to demonstrate remote recoveries from minor and major events remotely.

g) The DBFT should be conducted and executed in a manner consistent with the existing and/or anticipated EPA and NRC regulations.

## 7.2 DBFT Recommendations for the Drill-String Emplacement Mode

Although not the recommended mode for WP emplacement for DBD, if the drill-string emplacement mode is to be demonstrated at the DBFT, then the following items are recommended for inclusion into the scope of the DBFT:

a) The “shielded basement” should be designed, built, and operated for remote handling to demonstrate that the drill-string emplacement mode is feasible under anticipated radiological disposal conditions. There are challenges introduced to the surface operations due to potential remote handling requirements needed for the emplacement of radioactive wastes. These challenges should be vetted during the DBFT stage, perhaps at a separate test facility.

b) Repeated remote assembly and disassembly of test packages is considered essential to the demonstration of the viability of the drill-string emplacement mode. This could be done under the scope of the DBFT but not necessarily at the borehole site.

c) The packaging release mechanism should be tested under the maximum expected loading conditions. This test could be conducted at the DBFT site or a separate facility.

## 7.3 DBFT Recommendations for the Wireline Emplacement Mode

If the wireline emplacement mode is to be demonstrated at the DBFT, then the following items are recommended for inclusion into the scope of the DBFT:

a) Recommend free dropping a wireline test package to test the maximum terminal velocity and impact mitigation device performance in the borehole. This way it stays attached to the wireline and gives a method to accurately measure the descent velocity without remote sensors. This test could be combined with the IL testing described in 7.1.e.

b) Recommend a free drop of a single package to assess the bounding damage to the test package.

c) As part of the package design development, recommend surface drop testing of a test package for the maximum expected handling height. It should be noted the actual drop may also depend on the regulation basis document created in 7.1.g.

d) Develop detailed design and mockup test of above-grade handling system for both emplacement and potential retrieval operations. This should be a simpler version of a) under the drill-string emplacement method in Section 7.2.

# 8.0 References


1. Sandia National Laboratories (SNL), *Deep Borehole Field Test Specifications/M2FT-15SN0817091*, September 2015.
2. Mark MacGlashan, Panel 2, *DBH Disposal Technical Workshop*, US NWTRB Workshop, Washington DC, October 2015.
3. ASME, *Companion Guide to the ASME Boiler and Pressure Vessel Code, 4th Edition, 2012*, ed. K.R. Rao.
4. Bates, E.A., M.J. Driscoll and J. Buongiorno, "Drop-in Concept for DBH Canister Emplacement," *Proc. Intl. High-Level Radioactive Waste Mgmt. Conf.*, Albuquerque, NM. April 10-14, 2011, American Nuclear Society, Chicago, IL.
5. International Coiled Tubing Association, *An Introduction to Coiled Tubing History, Applications, and Benefits*, http://www.global-tubing.com/pdf/ICoTA_Intro_to_CoiledTubing.pdf.
6. Arnold, B.W., P.V. Brady, S.J. Bauer, C. Herrick, S. Pye and J. Finger, *Reference Design and Operations for DBH Disposal of High-Level Radioactive Waste.* SAND2011-6749. Albuquerque, NM: SNL, 2011.
7. Steven M. Tipton, *Why Coiled Tubing Fails and How to Avoid Failure on Your Job in Your Well*, Society of Petroleum Engineers, Distinguished Lecturer Program, http://www.spe.org/dl/docs/2010/StevenTipton.pdf, 2010.
8. Schlumberger, *Monitoring and Managing Coiled Tubing Integrity*, Oilfield Review 27, no. 1 (May 2015) Copyright © 2015 Schlumberger, Download pdf at: http://www.slb.com/resources/oilfield_review/en/2015/or2015_may.aspx.
9. General Electric Company, *Addressable Downhole Release (ADR002)*, GE Oil & Gas. (August 2015). Copyright © 2015 General Electric Company. Download pdf at: https://www.geoilandgas.com/sites/geog.dev.local/files/gea31930_addressable_downhole_release_adr002_r3_0.pdf
10. American Institute of Chemical Engineers, *Guidelines for Hazard Evaluation Procedures*, April 1995.
11. American Society of Mechanical Engineers (ASME) Boiler and Pressure Vessel Code, Section III, *Rules for Construction of Nuclear Facility Components*, Division 1 – Subsection NB, *Class 1 Components*.
12. U.S. Nuclear Regulatory Commission, Regulatory Guide 7.11, *Fracture Toughness Criteria of Base Material for Ferritic Steel Shipping Cask Containment Vessels with a Maximum Wall Thickness of 4 Inches (0.1 m)*, June 1991.
13. L. E. Fischer, W. Lai, *Fabrication Criteria for Shipping Containers*, NUREG/CR–3854, UCRL–53544, U.S. Nuclear Regulatory Commission, March 1985.
14. Joseph Shigley, Charles Mischke, Mechanical Engineering Design, 5th Edition, McGraw-Hill, 2002.

15. T.A. Nelson and R. C. Chun, Methods for Impact Analysis of Shipping Casks, NUREG/CR 3966, UCID–20639, U.S. Nuclear Regulatory Commission, November 1987.

16. Arnold, B. and T. Hadgu, "Thermal-hydrologic modeling of a DBH disposal system." *Proceedings of the 14th International High-Level Radioactive Waste Management Conference.* April 28-May 2, 2013. Albuquerque, NM.

17. U.S. Nuclear Regulatory Commission, H. George, *Control of Heavy Loads at Nuclear Power Plants*, NUREG-0612, July 1980.

18. U.S. Nuclear Regulatory Commission, L. Porse, *Single-Failure-Proof Cranes for Nuclear Power Plants*, NUREG-0554, May 1979.

19. C.J. Simiele, L.T. Blackford, D. Levinskas, J. Lavender, J.L. Pennock, S.R. Godrey, L.D. West, WM2014 Conference, March 2-6, 2014, Phoenix, Arizona, USA, "Improving Safety and Emergency Preparedness for Storage of Cs/Sr Capsules from Lessons Learned From Fukushima Events – 14022, CH2M HILL Plateau Remediation Company.

20. U.S. Nuclear Regulatory Commission, *Technical Position on Waste Form*, Revision 1, January 1991.

# Attachment A: Editorial and Additional Technical Comments on Report

| AREVA Editorial Comments | | | | | | | |
|---|---|---|---|---|---|---|---|
| # | Section | Report Page | DBFT | DBD | Wire | Drill | Comment |
| 1 | Acronyms & Abbreviations | xi | | | | | 1) CCL used on page 2-4 should be defined in this list.<br>2) KBS used on page 2-25 should be defined in this list. |
| 2 | General | | | | | | Throughout the M2 report, a waste package without radioactive contents appears to be identified in several different ways: test WP, dummy WP, and prototype WP. Verify the use of these descriptors is intentional (i.e., do they represent 3 different WPs?) and verify they are appropriately used throughout the report. |
| 3 | 1.1 | 1-1 | X | | X | X | In the report, the reference DBD concept is discussed. When the reference design is first introduced, it should be explicitly explained and a reference to the supporting documents should be provided. |
| 4 | 1.1 | 1-1 | | | | | This section begins with "This report documents conceptual design development" whereas the title identifies the report as providing "Test Specifications", unclear if title is correct. |
| 5 | 1.3 | 1-3 | X | | X | X | Consider using the words “demonstrate the initial” in lieu of “confirm the”. |
| 6 | 1.3 | 1-3 | X | | X | X | If the field test is to be used to support licensing of the process in the future in the US, the relationship with the regulators needs to be stated up front. |
| 7 | 1.3.1 | 1-3 | X | | X | X | First Paragraph: Section 1.3.1 of the M2 report describes the scope of the DBFT. It would be useful to expand the “Borehole Drilling and Construction” subsection to include a clear description of the characterization hole and field test borehole. |
| 8 | 1.3.4 | 1-5 | X | | X | X | Consider inserting the words “*designed for and conducted in the smaller diameter CB*” in place of “*conducted in the CB*”. Note that separate package designs would be required for using differing borehole diameters and may result in multiple design parameters that may or may not be scalable. |
| 9 | 2.1 | 2-2 | | X | X | X | Section 2.1 of the report discusses radiological risks associated with off-normal conditions. The risk of worker radiation exposure and surface contamination are said to be caused by a package breach following an accident, such as dropping a waste package/pipe string, or by waste package recovery after a package(s) becomes stuck. This discussion appears to state that a package will breach from recovery operations. Based on the proposed package designs, although there is risk of breach associated with package recovery, a package recovery operation does not guarantee that a breach occurs. |
| 10 | Table 2-1 | 2-3 | | X | X | X | Need to specify the waste form(s) this waste package is designed for (Cs/Sr capsules and not SNF) |

| AREVA Editorial Comments | | | | | | | |
|---|---|---|---|---|---|---|---|
| # | Section | Report Page | DBFT | DBD | Wire | Drill | Comment |
| 11 | 2.3.1 | 2-7 | X | | X | X | Due to the nature of drilling operations, OSHA has not been effectively applied in drilling operations. What would the basis be for stating a more stringent program, such as what is found at DOE sites, could be effectively applied and still be able to use proven technology? |
| 12 | 2.3.4 | 2-7 | X | | X | X | Are these references applicable on a non-Sandia/DOE site? |
| 13 | 2.3.7 | 2-9 | X | X | X | X | Unclear why the last paragraph was added to this section. Recommend moving. |
| 14 | 2.3.10 | 2-11 | | X | X | X | Need to clarify if the 11-inch limit is the OD or ID of the waste package. |
| 15 | 2.3.10 | 2-12 | | X | X | X | The small diameter of the canisters will result in a small ID, and hence, a very small volume of waste per canister. |
| 16 | 2.3.10 | 2-12 | | X | X | | Why then is not free drop being consider as a viable option for emplacement? |
| 17 | 2.3.10 | 2-12 | | X | X | X | A smooth surface could trap debris between the WP and the borehole wall whereas vertical grooves around the surface of the WP could provide a debris pathway and prevent the WP from being stuck. Tests could be performed to verify any performance improvement. |
| 18 | 2.3.10 | 2-12 | | X | X | X | What are the tolerances for the waste package diameters? |
| 19 | 2.3.10 | 2-12 | | X | X | X | To design a waste package, these loads need to be defined. |
| 20 | 2.3.10 | 2-12 | X | X | X | X | Assume leakage is defined as water leaking back into the package for the DBFT. Water leakage from the borehole into the WP may not be a bounding case. Actual waste disposal activities would require radioactive containment requirements that are more stringent. |
| 21 | 2.3.13 | 2-14 | X | | X | X | What are “these requirements”? |
| 22 | 2.4 | 2-15 | X | | X | X | Package Design Requirement: test package failure – includes any detected containment breach or leakage. Add requirement to TBD-09. |
| 23 | 2.4 | 2-15 | X | | X | X | The cost and risk factors associated with the “drop-in” method should be presented in this report. |
| 24 | 2.4 | 2-16 | | X | X | X | Add New TBD-xx indicating the maximum tooling weight expected to be suspended along with the WP. |
| 25 | 2.4 | 2-16 | X | X | X | X | In Section 2.4 of the report, the bounding waste package weight is calculated using an OD of 11 inches, a wall thickness of 1.2 inches, and a length of 18.5 ft. The waste contents are assumed to be 367 pressurized water reactor (PWR) rods at 2.39 kg/rod. This number of |

| AREVA Editorial Comments | | | | | | | |
|---|---|---|---|---|---|---|---|
| # | Section | Report Page | DBFT | DBD | Wire | Drill | Comment |
| | | | | | | | rods appears to be low considering the geometric constraints of the waste package. The package ID is 11-2(1.2) = 8.6 inches. A conservatively small PWR fuel rod has a cladding diameter of 0.36 inches (W17 × 17 OFA). From these values, it can be determined that 440 PWR fuel rods would fit within the 8.6 inch package inner diameter. The waste package weight can be adjusted based on the weight per rod provided in the report: 440-367=73 additional rods that will fit in the package, 73 rods × 2.39 kg/rod = 174 kg or 385 lbs. The bounding package weight could be as high as 5,005 lbs. Of course; the weight per rod could be less for a smaller sized fuel rod. |
| 26 | Table 2-3 | 2-20 | X | | X | X | Subsection 2.3.10: The DBFT requirement is that test packages perform at test package temperatures of up to 170 °C. How is this verified? There are no planned heating tests specified for the DBFT so would it be more accurate to state that waste packages shall be designed for temperatures up to 170 °C. |
| 27 | Table 2-3 | 2-22 | X | | X | X | Subsection 2.3.11 Field Test Well head Preventer - recommend BOP be included in the DBFT to ensure demonstration of emplacement method(s) with BOP in place can be performed. |
| 28 | Table 2-3 | 2-22 | X | | X | X | Subsection 2.3.12, Seal Permeability: Over what period of time is the specified permeability applicable? In time, seals may shrink away from the walls. |
| 29 | Table 2-4 | 2-24 | X | | X | X | Demonstrating Disposal of Waste Forms: To truly do this demonstration, the handling facilities of the waste package and transfer from the transport package to the borehole needs to be demonstrated. This may not mean that the demonstration facility is needed at the borehole site, but should be mocked up at some location, such as at a DOE facility, so issues and operational opportunities can be worked out to provide an adequate basis for estimating the costs for the emplacement method. |
| 30 | 2.6 | General | | | | | The terminology listed in Figure 2-2 is not completely consistent with the terminology utilized in the text. For example:<br>1) On Pages 2-28 and 2-29, "guidance casing" is utilized and appears to be identified in Figure 2-2 as "Slotted guidance liner".<br>2) On Page 2-28, "intermediate liner" is utilized and appears to be identified in Figure 2-2 as "Upper Crystalline Basement Casing".<br>3) On Page 2-28, "lower 13-3/8 inch casing" is utilized and appears to be identified in Figure 2-2 as "Guidance tieback casing". |
| 31 | Fig. 2-2 | 2-27 | X | | X | X | Clarification required: How is the guidance casing connected to the guidance liner? What maintains the guidance casing concentric with the guidance tieback casing? How is the |

AREVA Editorial Comments

| # | Section | Report Page | DBFT | DBD | Wire | Drill | Comment |
|---|---|---|---|---|---|---|---|
| | | | | | | | port collar utilized? |
| 32 | 2.6.1 | 2-28 | X | | | | Terminology in first paragraph after Table 2-5 does not appear to match the terminology in Figure 2-2 (e.g., "intermediate liner" vs. "Upper Crystalline basement casing") |
| 33 | 2.6.3 | 2-31 | | X | X | X | Text: The cask will also have permanently fixed range-limiting pins…<br>Comment: An event involving the use of these range limiting pins would result in a Stop Work condition because the pins would be in an indeterminate condition and would have to be replaced.<br>An alternate method would be to use a logic controller on the hoist controls to limit the hoist grapple height once engaged. Optical or laser sensors could be mounted above the cask that would provide input to the controller. The sensors could be wired to “fail safe” whereby if the sensor failed the hoist raise function would be disabled and the waste package could not be raised above the cask. |
| 34 | 2.6.3 | 2-31 | | X | X | X | Text: The purpose-built shipping cask will be a hollow, right circular cylinder with doors on each end that can be operated remotely by connection to an external power supply. These doors could be electrically operated with worm gear drives. The doors will have locking pins or bolts that restrain the doors in either the open or closed position (important for wireline emplacement as discussed below).<br><br>Comment: It is not clear what is meant here. Would this be a hinged door, a knife gate style door? Depending on the concept, this might pose significant design challenges on a Type B cask. |
| 35 | 2.6.3 | 2-31 | | X | | X | Fifth Paragraph: Using radial restraint bolts at the lower end of the cask would be difficult to incorporate with the containment function in the cask. Also, the bolts could potentially damage the waste package.<br><br>An alternate method would be to place a removable short gripping tool on top of the cask that would grip onto the upper portion of the WP and provide the restraint torque required for installing the drill pipe or adapter. |
| 36 | Fig. 2-3 | 2-33 | | X | | X | It is unclear where the "iron roughneck" is utilized; identify where it is located in Figure 2-3. |
| 37 | Fig. 2-4 | 2-34 | | X | | X | Comment: Has this type of connection ever been demonstrated before at 10,000 ft depth? There is a significant risk for stuck waste packages if this connection is not designed to allow easy passage of packages assuming a misalignment during construction. |

| AREVA Editorial Comments | | | | | | | |
|---|---|---|---|---|---|---|---|
| # | Section | Report Page | DBFT | DBD | Wire | Drill | Comment |
| 38 | Fig. 2-4 | 2-34 | | X | | X | The packages could contain over 100,000 Ci of Cs-137 by our estimates. The dose in the basement would most likely preclude anyone from accessing the area for the entire emplacement period without significant permanent biological shielding in actual waste disposal. So the system, if developed for actual use, would need to operate without personnel intervention. All operations would need to be performed remotely. |
| 39 | Fig. 2-4 | 2-34 | | X | | X | This is part of the challenge is to design a system where all repairs can be made either remotely or by removing various components to work on it. This will be of particular concern for both emplacement systems for a stuck package that needs to be removed by pulling the casing. As I have been commenting on this project, a very key element is the design of the borehole head handling equipment and required shielding. It is the old problem if you make it easy to work around and accessible for remote handling, e.g., robots, etc., it is difficult to shield . If you shield, it then it is difficult to make it easily repairable. The opportunity lies in defining all the requirements (dose to workers and public, emplacement, speed, cost, etc.) and than try to optimize the system. All of these points need to be designed and fabricated at least in a mockup form and tested. This mockup could also be used to train personnel. This could be done in parallel with the field test at a separate location. Another restriction would probably be to make it all modular so it could be easily transferred from borehole location-to-borehole location. Also consideration should be given to maybe have a secondary shield that could be brought in to allow work on the primary handling system. Containment considerations need addressing as well in case of breach during these operations. |
| 40 | 2.6.4 | 2-35 | | X | | X | First Paragraph, Last Sentence: Using the receiving collar and basement ceiling to resist the inadvertent upward pull of the rig hoist forces a release of the breakaway sub and the package string to drop. Just a slight contact with the receiving collar could result in damaged parts breaking off later and falling into the borehole.<br><br>An alternate method would be to use a logic controller on the hoist controls to limit the hoist and package height once engaged. Optical or laser sensors could be mounted above the cask that would provide input to the controller. The sensors could be wired to “fail safe” whereby if the sensor failed the hoist raise function would be disabled and the waste package could not be raised above the cask. |
| 41 | 2.6.4 | 2-35 | | X | | X | Second Paragraph: Add figure showing the breakaway sub. Add a figure of the J-slot connection, and tooling if used here. |
| 42 | 2.6.4 | 2-40 | | X | | X | Emplacement Step 9: Is the instrument package wireless? If not wireless, how are the |

| AREVA Editorial Comments | | | | | | | |
|---|---|---|---|---|---|---|---|
| # | Section | Report Page | DBFT | DBD | Wire | Drill | Comment |
| | | | | | | | electrical connections for the instrument package made? |
| 43 | 2.6.4 | 2-42 | | X | | X | Emplacement Step 37: The 15,000 ft long 4-1/2" diameter drill pipe will shrink in length approximately 17.5 ft. when the weight of the package string transfers to the bottom of the borehole and the remaining drill string weight is supported by the rig. Determining the precise drill pipe elevation required for the J-slot disengagement will be difficult. The risk analysis should include this difficulty as compared to the wireline. Another issue would be retrieval of the WP string if the J-slot becomes damaged.<br>Alternate approach: A connection enhancement might be to develop a 20 ft. long telescope cylinder with hexagon shaped cylinder rod for transmitting torque that could accommodate a 20 ft. rig lowering over shoot. The end of the hex rod could accommodate the J-slot connector while the butt end of the cylinder would have the threaded box end for attaching to the drill string. A load cell within the cylinder or the rig could detect the weight change or movement of the cylinder rod and stop the lowering process thereby preventing the weight of the drill string from bearing on the waste package string. The same device could be used to lower the bridge and cement plugs. |
| 44 | 2.6.5 | 2-42 | | X | X | | Wireline Emplacement Option: Add figure showing the interface of the waste package to the release connection. |
| 45 | 2.6.6 | 2-47 | | X | X | X | Text: Note that if slotted casing is used in the disposal zone, the waste package terminal velocity could be significantly greater.<br>Comment: Why not tabulate the velocity using the viscous-open boundary that Bates developed to give bounding velocity? (Equation 4-9 of Bates, A DROP-IN CONCEPT FOR DEEP BOREHOLE CANISTER EMPLACEMENT, 2011). |
| 46 | 2.6.7 | 2-49 | | X | X | X | Package String or Stack Weight: The rig hook load is to be controlled but there is no discussion describing how that is accomplished. |
| 47 | 2.6.7 | 2-52 | | X | X | X | Option 1, Last Paragraph: Does the collar feature machined on the upper end plug for gripping the package exclude the package from being gripped elsewhere? Are the slips designed for the collar diameter or the smaller drill pipe diameter? Provide a figure showing the interface of the Option 1 package with the rig handling equipment. |
| 48 | 2.6.7 | 2-52 | | X | X | X | Text: A chamfer is included on the inboard end of each end plug so that the massive plug does not interfere with friction welding by acting as a heat sink.<br>Comment: Disagree with this design. There should not be a groove in the waste package containment boundary since is this severely reduces the robustness of the waste package design. The package response to accident conditions is an input to the emplacement |

| AREVA Editorial Comments | | | | | | | |
|---|---|---|---|---|---|---|---|
| # | Section | Report Page | DBFT | DBD | Wire | Drill | Comment |
| | | | | | | | method selection.<br>Is this required currently for other API friction welding operations? If so, the friction welding process results in a full penetraion weld with an upset in the final as-welded design, and no groove. |
| 49 | Fig. 2-14 | 2-53 | | X | X | X | Suggest showing the welded cover plate installed over the fill port plug. |
| 50 | 2.6.7 | 2-54 | | X | X | X | Text: 2)… makeup of pipe thread joints requires pipe dope;<br>Comment: Agree; this is a clear disadvantage since this would require the threads to be coated with pipe dope at the DBFT. During actual disposal, this would require the pipe dope to be applied remotely right before assembly. If drill-string was selected this step should be considered to be demonstrated remotely as-if this was a hot operation. |
| 51 | 2.6.7 | 2-54 | | X | X | X | Text: …the external upset increases OD by 0.23 inches beyond the 11-inch diameter requirement (Section 2.3).<br>Comment: This same disadvantage is also true for Options 1, correct? Please clarify. |
| 52 | 2.6.7 | 2-56 | | X | X | X | Comment: Is the gray item shown around the Cs/Sr capsules the centralizer? Please label the figures for clarity. |
| 53 | 2.6.7 | 2-56 | | X | X | X | Text: Disadvantages include: 1) welds in the axial load path; 2) makeup of pipe thread joints requires pipe dope; and 3) use of an external collar at the upper end (for drill-string emplacement) impacts radial clearance.<br>Comment: An additional disadvantage over Option 4 is the limited usefulness due to the small fill port opening. The usefulness of the fill port diameter also may be further limited by the OD of the optional thin-wall canister over the waste capsules. |
| 54 | 2.6.7 | 2-56 | | X | X | X | Text: …external-flush casing requires the addition of external collars for drill-string emplacement, which could increase the maximum OD beyond the 5-inch maximum diameter requirement…<br>Comment: Please show required external collar in Figure 2-20 for clarity since the intended audience could be outside the drilling community. If these external collars are a separate item, how are they installed remotely on the waste string during drill line emplacement? This step would be critical to the safe operation of the drill string during waste emplacement, and should be demonstrated that it can be done remotely with no personnel intervention. |
| 55 | 2.6.7 | 2-56 | | | | | Reference to Figure 2-17 should be Figure 2-19. Also, why do the capsules change from red in Figure 2-18 to yellow in Figure 2-19? Similarly on the previous page (p. 2-55) |

| AREVA Editorial Comments | | | | | | | |
|---|---|---|---|---|---|---|---|
| # | Section | Report Page | DBFT | DBD | Wire | Drill | Comment |
| | | | | | | | reference to Figure 2-16 should be Figure 2-18 or 2-19. |
| 56 | 2.6.7 | 2-58 | X | X | X | X | Recommend adding of holes to top of latch/fishing neck to allow mud to squirt out if impacted by above package |
| 57 | 2.6.8 | 2-59 | X | | X | | Second Paragraph, Last Sentence: The risk analysis assumes a double-release device was used. This devise will require further testing to verify the risk analysis assumption. |
| 58 | 2.7.1 | 2-63 | | X | | X | Text: Re-design power tongs with self-clearing mechanism for lock-up.<br>Comment: Not sure what is meant by “self-clearing.” Is this the ability to unthread and detach cross threaded packages? |
| 59 | 2.7.1 | 2-63 | | X | | X | Step gg: This step may not be consistent with the “double-release device” assumed in Section 2.6.8, last sentence, third to last paragraph. |
| 60 | 2.7.2 | 2-64 | | | | | For item l), replace "setting" with "sitting".<br>For item p), change "lower" to "lowered" at end of page. |
| 61 | 2.7.2 | 2-64 | X | | | X | Step j) Text: Use packages with API pipe thread connections, not casing threads, to the extent possible to lower the likelihood of cross-threading.<br>Comment: Disagree with approach; the required use of pipe dope to use API threads requires another custom designed machine to apply the pipe dope remotely (due to the expected high radiation environment during actual HLW disposal). This is just another machine/step that could fail and end up with incorrectly assembled waste string. |
| 62 | References | 2-65 | | | | | Verify comments from review of earlier documents cited in this section are captured in this report. |
| 63 | 3.2 | 3-1 | X | | X | X | Test packages should be detailed enough to be able to demonstrate closure technology and handling requirements. If not actually used, it would allow a clear definition of remote equipment that may be required to close and test the package. Also, the package would help identify and design the required handling equipment, at the loading area, in transport, and placement over the borehole head. |
| 64 | 3.4 | 3-4 | | | | | For item o), replace "setting" with "sitting". |
| 65 | 4.2 | 4-8 | | X | X | X | How much (related to "Note that if slotted casing is used in the disposal zone, the waste package terminal velocity could be greater")? |
| 66 | 4.2 | 4-8 | | X | X | X | What is the impact to the terminal sinking velocity of a free falling WP is banging against |

| AREVA Editorial Comments | | | | | | | |
|---|---|---|---|---|---|---|---|
| # | Section | Report Page | DBFT | DBD | Wire | Drill | Comment |
| | | | | | | | the casing? Will the casing also be impacted? |
| 67 | 4.3 | 4-9 | | X | X | X | Why not more discussion on free drop placement? |
| 68 | 4.5 | 4-15 | | X | | | Recommend removing the year 2020 and instead, replace with an assumed decay duration. |
| 69 | References | 4-21 | | | | | Verify comments from review of earlier documents cited in this section are captured in this report. |
| 70 | 5. | 5-1 | X | | X | X | • Please consider adding definitions for drilling terminology. This will increase the clarity of the section. (e.g., replace “tripping-in” with “traveling-in.”) Tripping may have the connotation of an alarm tripping or a failsafe tripping for those readers outside of the drilling industry).<br>• Please consider using the word “options” rather than “alternatives” when describing the design options for emplacement mode. This was confusing to a first time reviewer of the document since it left the reviewer wondering “alternative to what pre-existing emplacement method?”<br>• It would be beneficial to have a summary statement at the end of the section. |
| 71 | Fig. 5-1 | 5-2 | X | | X | X | This figure appears to be saying that the evaluation is to demonstrate one method may be better than the other. It does not address whether both are acceptable or both are unacceptable. There is no acceptance criteria for which to judge it by. |
| 72 | 5.1 | 5-1 | X | | X | X | A brief definition of MUA would be helpful. As a general comment, brief definitions of oil field drilling terms would be helpful. |
| 73 | 5.4.1 | 5-8 | X | X | X | X | Not actually providing a absolute quantification of the likelihood, but a relative likelihood only good for comparing against one another |
| 74 | Table 5-2 | 5-9 | X | X | X | X | Missing drop events of the WP in air (e.g., onto the BOP) |
| 75 | Figure 5-2 | 5-10 | | | X | | There should be some likelihood of failure of WP after a drop event due to, for example, a manufacturing defect |
| 76 | Figure 5-2 | 5-10 | | | X | | The "Breach conditions reached" that lead to outcomes E4 and B2, are they due to a drop event? |
| 77 | Figure 5-2 | 5-10 | | | | | Missing "EZ" after "Above" for "Where Stuck?" near the center of the figure. |
| 78 | Figure 5-3 | 5-11 | | | | X | Doesn't the potential for breach of those vessels due to a drop depend on the height they |

| AREVA Editorial Comments | | | | | | | |
|---|---|---|---|---|---|---|---|
| # | Section | Report Page | DBFT | DBD | Wire | Drill | Comment |
| | | | | | | | are dropped from? |
| 79 | 5.4.3 | 5-12 | X | X | X | X | Aren't outcomes A2 and A3 associated with "breached WPs"? Add "breached" in front of "WPs" for outcome A2 and A3. |
| 80 | 5.4.3 | 5-13 | | | | | Revise E4 to "One WP drops into DZ during fishing; no breach occurs" (only applies to wireline emplacement mode and hence, only 1 WP involved and unclear if WP actually drops to "bottom of DZ" as currently written). |
| 81 | Table 5-4 | 5-15 | X | X | X | | Shouldn't there be an "X" located under "WP Stuck" for the Wireline method under "Operator fails to notice or respond to signal that casing has collapsed"? On Page 5-18, make "results" singular for ""Other" debris in borehole sufficient to result in WP stick" |
| 82 | Table 5-5 | 5-23 | X | X | X | | Add a TBD to the end of the "Initial Value and Basis" for "Breach conditions reached as the result of a drop (wireline)".<br>Second row last sentence, replace "were" with "where".<br>Third row fourth sentence, replace "remaining" with "remains".<br>Fifth row first sentence, replace "is" with "if". |
| 83 | 5.5.4 | 5-24 | | | | | Add "of" before "400 WPs" in 2nd sentence of 1st paragraph.<br>Add "relative" before "probability of that failure" in the last sentence on the page. |
| 84 | Table 5-7 | 5-25 | X | X | X | X | Recommend normalizing the probabilities against one another as the values should be relative to one another and not discrete values |
| 85 | 5.6.1 | 5-27 | | | | | For S3, replace "Table 5-3" with "Table 5-5".<br>Replace "four of the key event" with "seven failure" in first sentence of first paragraph. |
| 86 | 5.6.1 | 5-26 thru 5-27 | X | | X | X | Include any additional information from Appendix D, Section D-1 in this section and provide a summary write-up in Section D-1 in the Appendix D. This information would eliminate the possibly of any confusion generated by having the same discussions in two areas of this report. |
| 87 | 5.6.2 | 5-27 thru 5-29 | X | | X | X | Include any additional information from Appendix D, Section D-2 in this section, and provide a summary write-up in Section D-2 in the Appendix D. This information would eliminate the possibly of any confusion generated by having the same discussions in two areas of this report. |
| 88 | Table 5-9 | 5-31 | X | X | X | X | Are the last two rows in this report also in terms of percentages as the 1st two rows? |

| AREVA Editorial Comments | | | | | | | |
|---|---|---|---|---|---|---|---|
| # | Section | Report Page | DBFT | DBD | Wire | Drill | Comment |
| 89 | References | 5-31 to 5-32 | | | | | Verify comments from review of earlier documents cited in this section are captured in this report. |
| 90 | 6.1 | 6-1 | X | | X | X | This alternative method ("drop method") needs to be discussed more positively and remain as an option to be further evaluated in the DBFT. |
| 91 | 6.1 | 6-1 | X | | X | X | The drop method needs to be evaluated in the field also since it is effective, and in the worst case, it would bound the dropped package concerns from the wireline placement. |
| 92 | 6.1 | 6-2 | X | | X | X | This "*if the same cask is used for transportation and transfer to the borehole*" can be demonstrated under a separate program at a different location. |
| 93 | 6.2 | 6-3 | | | | | Under Results, replace "(Table 6-1)" with "(see Table 5-6 and Section 5.5.3)" in the last paragraph. |
| 94 | 6.2 | 6-3 | X | | X | X | Should remind the reader once again that these are only RELATIVE costs since the estimate does not include the total costs of handling, transportation, packaging, etc., that applies to both systems. |
| 95 | 6.3 | 6-5 | X | | X | | Some basic package design (e.g., dummy package) should be tested, i.e., like the final test would to be to drop a package and test recover capabilities. This could validate the drop in method as a viable alternative as well as bound the results of a drop package. Also demonstrates fishing technology. |
| 96 | Fig. 6-1 | 6-7 | X | | X | X | This figure needs to be clarified. The title states that the wireline related items are highlighted yet there are items in a number of the activities that are wireline related that are not highlighted. |
| 97 | General | N/A | | X | X | X | The drop of a waste package from the cask onto the closed blind ram on the well head or suspended waste string needs to be considered. |
| 98 | General | N/A | | X | X | X | The Yucca Mtn. “rigging failure probability” should be applied to both emplacement modes in a consistent manner for an unbiased evaluation of these emplacement methods. |
| 99 | General | N/A | | X | X | X | Need to indicate preliminary nature of the identified fault trees without the presence of detailed operating procedures and results are preliminary in nature as well due to preliminary nature of fault trees and preliminary nature of utilized failure data. |
| 100 | B.1 | B-1 | X | X | X | X | Other surface drop issues include: rigging failure (crane), connection failure (WP), wire failure, crane failure |

| AREVA Editorial Comments | | | | | | | |
|---|---|---|---|---|---|---|---|
| # | Section | Report Page | DBFT | DBD | Wire | Drill | Comment |
| 101 | B.1 | B-2 | | X | X | | Text: A wireline could also break if the cask doors, or a ram on the well head, is closed inadvertently onto the cable. The safety control (interlock) system would be relied on to disable door or ram actuation during the trip-in, subject to override in the event of a well control emergency.<br>Comment: Did they apply the human error probability to the manual override of the ram actuation that could cause a drop? I am thinking of the lessons learned from Chernobyl and Three Mile Island accidents when the operators used manual overrides to overcome engineered safety barriers/systems to either initiate or acerbate the accident. |
| 102 | B.1 | B-2 | | X | X | | If there is the potential for enhanced failure due to cold weather, then either need to capture in failure rate or identify an admin control/tech spec limit against making transfers when that cold. |
| 103 | B.1 | B-3 | | X | X | | Text: However, whereas limiters are made from soft, compliant materials, they should be designed conservatively with tapers, cowling, etc., so they cannot catch on the casing or its components, deform, and cause the package to become stuck.<br>Comment: This state should be reviewed in light of the impact limiter comments in Section 4. |
| 104 | Table B-1 | B-4 | | X | X | | Text: Drop packages while assembling WP string<br>Comment: Is this dropping a package being placed onto the suspended string? Will this cause the string to be dropped into the borehole? There are two possible outcomes:<br>• Package dropped ruptures on the waste string being supported by the power slip.<br>• Package dropped causes the string below to be dropped into the borehole. |
| 105 | B.1 | B-4 | X | X | X | X | There are lots of descriptors used throughout this section identifying failure rates (e.g., "rare"), recommend limiting to a few concise fairly well defined terms or relative comparative terms. |
| 106 | B.2 | B-9 | | X | | X | Text: Whereas the probability of rigging failure leading to drop in nuclear facilities has been estimated at $10^{-4}$ per lift (e.g., this is typical for preclosure safety analysis in the Yucca Mountain license application), drops are much less common on drilling rigs and workover rigs. These rigs are numerous, they are relatively mature engineered systems, and they perform many thousands of repeated lifts with failure frequency on the order of $10^{-6}$. For handling waste packages the panel adopted $10^{-5}$ acknowledging that nuclear regulations could apply.<br>Comment: This analysis is unclear. Please clarify the following in the report:<br>• What operational equipment in the drill line is considered in the “rigging”? |

| AREVA Editorial Comments | | | | | | | |
|---|---|---|---|---|---|---|---|
| # | Section | Report Page | DBFT | DBD | Wire | Drill | Comment |
| | | | | | | | • Does the rigging include the failure of the power slip holding the string? If not, the probability that a drop drill pipe segment or waste package causes the power slip holding the string to fail (this should be an AND on the $10^{-5}$ per lift criteria).<br>• Why wasn't this $10^{-4}$ failure per lift statement considered for the wireline approach? What is included in this "rigging" for Yucca Mtn., and should it be applied to the wireline if it is applied to the drill string rigging?<br>This is where the $10^{-4}$ Yucca failure probability per lift would be compared to. This would increase the failure probability an order of magnitude over what is presented in Figures B-2 and B-4.<br>This would make a significant effect on the discussion in Chapter 5. |
| 107 | C.1 | C-1 | | X | X | X | Costs for licensing and security are not included. |
| 108 | C.1.1 | C-1 | | X | X | X | Not only the cost of the rig, but also operation and security of the site as well. Active sites have high hotel occupancy rates. |
| 109 | C.1.2 | C-2 | | X | X | X | If it gets contaminated or even potentially contaminated, one would be will be buying it anyway. This is a potentially hidden but large cost of the drill-string option. |
| 110 | Table C-1 | C-4 | | X | X | X | Unclear why the "One-Time Costs" for the drill-string and wireline options are so close considering the drill-string requires a pretty significant basement whereas the wireline does not |
| 111 | C.2.1 | C-5 | | | | | Replace "(Table 1)" with "(Table C-2)" in first paragraph.<br>Replace "is" with "are" in the first sentence of the section. |
| 112 | C.2.1 | C-5 | | X | X | X | Add a brief statement tying this section to the information provided in Section 5.4.3. |
| 113 | C.2.1 | C-6 | | X | X | X | This sentence "Once the equipment is operator-owned,..." doesn't make sense (1st paragraph). |
| 114 | C.3 | C-14 | | X | X | X | Remove extra "4." under Response Facilities.<br>A "shielded hot cell" is likely not necessary for the wastes currently considered for disposal |
| 115 | Table D-13 | D-18 | | X | X | X | Is this radiation release or radioactive material contamination release? Table needs to be revised to ensure clarity of what is being concluded. |
| 116 | General | General | | X | X | X | For consistency, it would be helpful if the full report was reviewed by a technical editor. |
| 117 | General | General | | X | X | X | There is much information on drilling in this report but it would be very helpful if there was |

| AREVA Editorial Comments | | | | | | | |
|---|---|---|---|---|---|---|---|
| # | Section | Report Page | DBFT | DBD | Wire | Drill | Comment |
| | | | | | | | an appendix containing a short primer on oil drilling. |
| 118 | Intro | D-1 | | X | X | X | 2nd Paragraph of the introduction: It is stated that the expressions disposal zone (DZ) and emplacement zone (EZ) are used interchangeably. Knowing this, it is still confusing when one sees EZ in Figure D-1 and Figure D-2 and then when reviewing Table D-1, one sees the DZ designation. |
| 119 | D.1 | D-1 | | X | X | X | 3rd Bullet: Table 2 should be Table D-2 / W_breach_fish should be Fish_breach / Case S3s should be Case S3a |
| 120 | D.1 | D-1 | | X | X | X | Generally the description given in D-1 Sensitivity to Event Probabilities is understandable in describing Figures D-1 and D-2 and Tables D-1 thru D-5. Much of this event probabilities information is covered in Section 5.6.1, and it would be best to cover everything about sensitivity to event probabilities in Section 5 and have a brief one to two statement summary in this appendix, tying to the Tables and Figures. |
| 121 | D.1 | D-5 thru D-8 | | X | X | X | It would be convenient to have a table listing a brief one statement identification of the Outcomes listed in Section 5.4.3. For example: A1: Breached WPs fished and removed / C2: The drill pipe or wireline also drops and must be fished/removed. A table with this outcome information eliminates paging back and forth when studying the tables. |
| 122 | D.1 | D-8 | | | | | Add "the" in front of "sensitivity analyses" in the 3rd sentence of the first paragraph. Close parenthetical at end of first paragraph on page. |
| 123 | D.2 | D-8 thru D-10 | | X | X | X | This provides a good description of the various types of sensitivity to failures. Suggest using more reference listings when referring to references listed at the end of each section and when referring to other sections of this report. |
| 124 | D.2 | D-8 thru D-10 | | X | X | X | Provide any additional information contained in this section and place in Section 5.6.2. Then provide a brief one to two statement summary in this appendix tying to the Tables and Figures. |

| Additional AREVA Technical Comments | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| # | Section | Report Page | CBH | DBFT | DBD | Wire | Drill | Comment |
| 1 | 1.3.2 | 1-4 | | X | | X | X | Section 1.3.2 of the report describes Objectives for the DBFT. The FTB diameter is listed as 17 inches with a depth of 5 km. However, there is no description of the characterization borehole diameter or depth. This should be added to clearly define the testing program. |
| 2 | 1.3.3 | 1-5 | X | X | | X | X | This subsection is missing from the document. Is this omission a misnumbering of sections error, or is there a §1.3.3 that was left out of the document? |
| 3 | 1.3.5 | 1-5 | X | X | | | | Change the words "will contracted" to "will *be* contracted". |
| 4 | 2.1 | 2-1 | | | X | | | Delete "in" from following sentence "*The most likely postclosure risks are related to thermally driven fluid flow and the effectiveness of the seals system, as evaluated in by Brady et al. (2009).*" |
| 5 | Table 2-1 | 2-3 | | | X | | | Under the "Applicability Discussion" for "Shielded Transfer Cask", "used" should not be past tense. |
| 6 | Table 2-1 | 2-4 | | | X | X | | What is CCL? |
| 7 | Table 2-1 | 2-5 | | | X | X | | Why is there no monitoring for the casing condition under the wireline emplacement method? |
| 8 | 2.3.9 | 2-9 | | | | | | First paragraph has some dimensions listed in terms of metric and English units, but does so inconsistently. |
| 9 | 2.3.10 | 2-11 | | | X | X | X | The report states that Hoag (2006) proposed a radial clearance of 0.9 inches for packages with a 13-3/8 inch diameter. Is this the casing ID not the package OD? Also, the drift diameter is state to be 12.49 inches for 13-3/8 inch ID casing. This value should be 12.459 inches to match Table 2-2. A cross-reference to Table 2-2 should be added for clarity. |
| 10 | 2.3.10 | 2-12 | | | X | X | X | The peak temperature rise of 100 °C does not appear to match the value from Section 4.5. |
| 11 | 2.3.10 | 2-12 | X | X | | X | X | The report states that the maximum test waste package temperature will be 170 °C. This value should be cross-referenced to a prior report or to Section 4.4. |
| 12 | 2.4 | 2-16 | X | X | X | X | X | Track Assumption: maximum package dry weight of 4,620 lb. |
| 13 | Table 2-3 | 2-18 | X | X | | X | X | Subsection 2.3.7, Operating Requirements: Add description that tooling may be attached to the WP during emplacement and adds approximately 2,000 lb to the |

| Additional AREVA Technical Comments | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| # | Section | Report Page | CBH | DBFT | DBD | Wire | Drill | Comment |
| | | | | | | | | suspended weight. |
| 14 | 2.6.2 | 2-29 | X | X | | | | "characteristics" should not be plural in the first full sentence on this page. |
| 15 | 2.6.3 | 2-30 | X | X | | | | Missing "of" after "Selection" in last paragraph. |
| 16 | 2.6.3 | 2-31 | X | X | | | | Missing "the" after "… would be" in the last sentence of the second to last paragraph on the page. |
| 17 | 2.6.4 | 2-40 | | | X | | X | Emplacement Step 2: Provide the reference location for the breakaway subtext. |
| 18 | 2.6.4 | 2-40 | | | X | | | Emplacement Step 2: The sentence states "see text", what text?<br>Replace "see text" with reference to section of report where material can be found. |
| 19 | 2.6.7 | 2-51 | | | X | X | X | First Bullet: The maximum package diameter is listed as 11 inches. However, on Page 2-54, the external upset diameter is listed as 11.23 inches. |
| 20 | 2.6.7 | 2-54 | | | | | | Delete first "and" from last sentence of first paragraph on the page.<br>Delete repeated "of" from last sentence of second paragraph on the page. |
| 21 | 2.6.7 | 2-56 | | | | | | Second paragraph replace "Figure 2-17" with "Figure 2-19".<br>Delete 1st "and" from last sentence of third paragraph on the page. |
| 22 | 2.7.1 | 2-62 | | | X | X | | Define or clarify the word "strip" |
| 23 | 2.7.2 | 2-64 | | X | | | X | Step n) Text: Store package strings in the upper part of the borehole, i.e., like a “kill string” in development wells, during string assembly (keep the string cool, and allow worker access to the basement for maintenance).<br>Comment: Please elaborate on how this would be achieved to document the approach for the DBFT. Would this require more surface operations? How would this operational change affect the failure probability documented in Chapter 5? |
| 24 | 3.4 | 3-2 | X | X | | | | No questions were raised in Section 2.7 as identified in this section. |
| 25 | 4.1 | 4-1 | | | | | | Delete repeated "are" in 1st sentence of section.<br>Reference to Section 2.4 in first paragraph should be Section 2.3.10. |
| 26 | 4.1 | 4-5, 4-6 | | | | | | Define terms in equations. |
| 27 | 5.1.1 | 5-1 | | | | | | Add "and" between "each alternative" and "the objectives" to the 2nd sentence of the 4th paragraph on the page.<br>Add a comma between "decision-maker preferences" and "the relative importance" |

| Additional AREVA Technical Comments | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| # | Section | Report Page | CBH | DBFT | DBD | Wire | Drill | Comment |
| | | | | | | | | to the 3rd sentence of the 4th paragraph on the page. |
| 28 | Fig. 5-1 | 5-2 | X | X | | | | Delete the "and" from the fourth step (blue) on the figure (starting with "(If necessary)") after "multiple metrics". |
| 29 | 5.2 | 5-4 | X | X | | X | X | Suggest title change to "Emplacement Mode Design Aspects Evaluated". |
| 30 | 5.1 | 5-1 | X | X | | X | X | The Keeney, 1982 reference was not listed in the References for Section 5. As a general comment, it would be helpful to list the chapter, section and/or paragraph of references when appropriate. |
| 31 | Table 5-1 | 5-7 | | | | | | Delete "much" from the 2nd column on the row associated with "Flexibility to Accommodate an Uncertain Future". |
| 32 | 5.4 | 5-8 | X | X | X | | X | An uncertainty not evaluated but should be considered is the necessity to perform maintenance operations or some other reason for entry into the basement while a drill string is present, as this will distinguish an advantage for wireline emplacement over drill-string |
| 33 | 5.4.1 | 5-9 | | | X | X | X | Add "the" in front of "figures" in the last sentence of the 3rd paragraph on the page. |
| 34 | 5.4.2 | 5-11 | | | X | X | X | Make package plural in the 3rd sentence of the 2nd paragraph on the page. |
| 35 | Table 5-3 | 5-14 | | | X | X | X | Add asterisks to the end of each of the rows that end with "per WP string". |
| 36 | Table 5-6 | 5-23 | | | X | X | X | Switch the drill-string and wireline columns with one another for consistency with future tables.<br>To make consistent with Table 5-7, place results for wireline to left of drill-string or vice-versa in Table 5-7. |
| 37 | Table 5-7 | 5-25 | | | X | X | X | Identify results as "per borehole" |
| 38 | 5.6.1 | 5-26 | | | X | X | X | For S1, replace "Table 5-2" with "Table 5-5".<br>For S1, replace "… identified. The represent the…" with "… identified that represent the…".<br>For S2, replace "that" with "than" on last line of page. |
| 39 | 5.6.2 | 5-28 | | | X | X | X | For S-F3, replace "sensitivity" with "sensitive" in the first sentence of the second paragraph.<br>For S-F3, replace "changes" with "chances" in the second sentence of the second paragraph. |

| Additional AREVA Technical Comments | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| # | Section | Report Page | CBH | DBFT | DBD | Wire | Drill | Comment |
| 40 | 6.1 | 6-1 | X | X | | X | X | Verify the citation of other section numbers in this section (e.g., 1st paragraph sites "Sections 5 and 6" which should appear to be "Sections 4 and 5").<br>Replace "Sections 5 and 6" with "Section 5" in the 1st paragraph.<br>Under Requirements and Assumptions, replace "It is" with "They are" and "is" with "are" in the last sentence. |
| 41 | 6.2 | 6-2 | X | X | | X | X | Under Methodology, add "of" between "events" and "importance" in the second sentence. |
| 42 | Table 6-1 | 6-3 | X | X | | X | X | Do we need $ sign here ("Expected value of costs…")? |
| 43 | 6.2 | 6-4 | X | X | | X | X | Make "analysis" plural (i.e., "analyses") in last paragraph on this page. |
| 44 | B.1 | B-2 | | | X | X | X | Delete "using" in first sentence of first full paragraph on this page. |
| 45 | B.2 | B-9 | | | X | X | X | The failure frequencies listed in the second paragraph should all be identified as "per lift". |
| 46 | B.2 | B-10 | | | X | X | X | In the fifth full paragraph on this page, "be" is missing between "to" and "a" in the second sentence.<br>Second and forth paragraphs under "Waste Packages Get Stuck (Figure B-7)", there is an inconsistency related to the most likely cause of a string becoming stuck. |
| 47 | B.2 | B-11 | | | X | X | X | Delete the second use of "failure" in the last sentence on the page. |
| 48 | C.1.3 | C-3 | | | X | X | X | Delete "are" from the third sentence of the last paragraph.<br>Replace "they" with "the" in the third sentence of the second paragraph of this section. |
| 49 | Table C-1 | C-4 | | | X | X | X | Why is the "Project duration" 430 days? |
| 50 | C.2 | C-5 | | | X | X | X | The reference to (Table 1) is not clear as to where in the report this is located. Is it Table C-1? |