EMPLACEMENT MODE HAZARD IDENTIFICATION AND ANALYSIS

Fuel Cycle Research & Development

Prepared for
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EXECUTIVE SUMMARY

This report documents the activities of Pacific Northwest National Laboratory (PNNL) in support of Task 4 "Emplacement Mode Hazard Identification and Analysis" of Work Package "FT-15SN081709 Borehole Test Design." PNNL staff members performed work in the following three areas:

- Researched industry data on the nature and frequency of accidents with wireline/slickline and drill-string operations.
- Assisted in identifying hazards associated with all the emplacement options (e.g., borehole collapse) and with each option separately (e.g., wireline fouling or improper tubing joint connection).
- Provided subject matter experts for review of the design study.

The search of published oil industry information identified potential sources of reliability data at the level of individual equipment (pumps and valves, for example) but no significant published information at a summary level useful in the first stages of a conceptual design. A PNNL subject matter expert participated in the review of the preliminary design. Several drilling experts provided rough failure probabilities based on their personal work or knowledge of general industry practice, but none of them were able to identify any summary-level published failure probabilities.

PNNL also assisted in identifying the hazards for two competing modes of waste emplacement, drill string emplacement and wireline emplacement. The hazards were identified using waste package emplacement process steps[1] and expressed as fault trees. This work resulted in a preliminary fault tree for the wireline emplacement mode developed using the Saphire software[2].

[1] Cochran JR and EL Hardin. 2015. *Handling and Emplacement Options for Deep Borehole Disposal Conceptual Design*. Revision 9, SAND2015-6218, Sandia National Laboratories, Albuquerque, New Mexico.
[2] Smith CL and ST Wood. 2011. *Systems Analysis Programs for Hands-on Integrated Reliability Evaluations (Saphire) Version 8. Volume 1: Overview and Summary*. NUREG/CR-7039, Vol. 1, Idaho National Laboratory, Idaho Falls, Idaho.

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EMPLACEMENT MODE HAZARD IDENTIFICATION AND ANALYSIS

1. INTRODUCTION

The U.S. Department of Energy (DOE), Office of Nuclear Energy is investigating deep borehole disposal as one alternative for the disposal of high-activity waste, along with research and development (R&D) for mined repositories in salt, granite, and clay, as part of the Fuel Cycle Technologies (FCT) Program, Office of Used Nuclear Fuel Disposition (UFD) R&D. The deep borehole disposal is consistent with the Blue Ribbon Commission on America's Nuclear Future (BRC 2012) recommendation to help resolve current uncertainties about deep borehole disposal and to allow for a more comprehensive evaluation of the potential practicality of licensing and deploying this approach.

The Deep Borehole Field Test (DBFT) (SNL 2014) is designed to develop the logistics and advance the technical basis for the siting and implementation of a deep borehole disposal facility. The DBFT will be used to validate proof of concept and has three purposes:

- Evaluation of the capability for drilling and construction of deep, large-diameter boreholes
- Downhole scientific analyses to assess hydrogeochemical conditions that control waste stability and containment
- Engineering analysis to assess the viability and safety of deep borehole canister emplacement.

The Work Package "FT-15SN081709 Borehole Test Design" for fiscal year (FY) 2015 supports the DBFT with the following work scope over approximately 4 years: design, fabricate, test, and demonstrate a system for safe and effective emplacement and retrieval of mockup waste canisters in deep boreholes. This design will be based on consideration of a fully operational disposal system, with simplifications appropriate for a demonstration project. FY 2015 activities will initiate design, and Sandia National Laboratories will produce a major milestone report: M2FT-15SN081709 – *Deep Borehole Field Test Specifications* (09/15/15).

Important objectives for the report and supporting activities include:

- Select the mode of emplacing canisters in disposal boreholes (wireline/slickline, coiled tubing, drill string, or drop-in).
- Identify design requirements and interfaces for coordinating design of waste canisters with DOE Office of Environmental Management.
- Form a team from national laboratory staff members and a new engineering services support contractor to proceed with design.

Work Package "FT-15SN081709 Borehole Test Design" has ten tasks that span a range of activities. These tasks include: 1) draft design requirements for DBFT engineering demonstration, 2) draft deep borehole disposal and field test description, 3) handling and emplacement options for design study, 4) emplacement mode hazard identification and analysis, 5) methodology recommendation for emplacement mode design study, 6) shielding and transportation analysis, 7) design study results and demonstration specifications, 8) waste thermo-hydro-mechanical analysis for deep borehole disposal, 9) canister static and dynamic analysis, and 10) draft borehole disposal canister specifications.

PNNL personnel contributed only to task 4, which has the following scope:

- Identify the hazards associated with all the options (e.g., borehole collapse) and with each option separately (e.g., wireline fouling or improper tubing joint connection).
- Specify measures to be used to minimize risk (e.g., frequent caliber logs).
- Research industry data on the nature and frequency of accidents with wireline/slickline and drill-string operations.
- Evaluate fishing operations in terms of the most likely accidents, fishing methods most likely to be used, and the likelihood of canister breach.

This report will be used to brief subject-matter experts for the design study, and will be used in whole or part in the conceptual design report.

2. SUPPORT ACTIVITIES

Pacific Northwest National Laboratory (PNNL) staff members supported activities in the following three areas:

- Research industry data on the nature and frequency of accidents with wireline/slickline and drill-string operations.
- Identify the hazards associated with all the options (e.g., borehole collapse) and with each option separately (e.g., wireline fouling or improper tubing joint connection).
- Provide subject-matter experts for review of the design study.

2.1 Research Industry Data

Most accidents or failures in complex engineered systems are not caused by a single incident of equipment malfunction or operator failure but from a chain of events or failures. The system may be as simple as a pipeline compressor station (Moore and Brun 2007) or the drilling platform involved in the huge oil spill in the Gulf of Mexico (National Commission on the BP Deepwater Horizon Oil Spill and Offshore Drilling 2011). The published literature was reviewed for information on failure modes and frequencies of well logging operations and emplacement of equipment in wells. Several of the published references reviewed in this task were initially identified by David Sevougian of Sandia National Laboratories.

Human errors can contribute to engineered system failures. Extensive research into the reasons for human errors for nuclear power plants led to the U.S. Nuclear Regulatory Commission- (NRC-) approved Standardized Plant Analysis Risk-Human Reliability Analysis (SPAR-H) method (Gertman et al. 2005). This method has recommended failure probabilities for actions or reviews by humans that can be applied even in the conceptual design stage of a project.

Two recent books (Calixto 2013; Davorin et al. 2014) present a variety of techniques on oil and gas reliability engineering and risk analysis for preventing hazardous situations. Both books cite hundreds of primary references, some of which were reviewed, but none of them provided primary failure data at the level of the primary events in the fault trees discussed in Section 2.2. PNNL staff members searched a large number of abstracts on the OnePetro (2015) website maintained by the Society for Petroleum Engineers. PNNL also used search engines and enlisted the help of its technical library for the literature search.

The literature search resulted in complete lack of summary-level published data applicable to this problem, other than the rates for human error. PNNL also consulted a number of drilling experts (see Section 2.3) with respect to failure probabilities. Several experts provided rough failure probabilities based on their personal work or knowledge of general industry practice, but none were able to identify any published failure probabilities.

In general, the basic events in the fault trees in Section 2.2 could be considered intermediate events. For example, a basic event in Section 2.2 is a hoist failure in lowering a waste package with the wireline emplacement mode. However, the hoist failure could be caused by a rigging failure, a wireline drum brake failure, or one of several other mechanical problems with the hoist.

If the basic events in the fault tree were further refined, a number of databases of failure rates are potentially applicable to this problem. Although equipment functions have been determined, specific equipment has not been identified at this point in the conceptual design, thus the database data are of limited use. A list of oil industry databases is available (Akhmedjanov 2001). Other databases specific to the nuclear industry are identified in the design information for the terminated Yucca Mountain facility.

Two databases containing information on equipment failure rates possibly of use in later phases of this work are Offshore and Onshore Reliability Data (OREDA 2015) and Government Industry Data Exchange Program (GIDEP 2015). OREDA is sponsored by nine oil companies with worldwide operations. OREDA collects and exchanges reliability data among the participating companies and is a forum for coordination and management of reliability data in the oil and gas industry. GIDEP is a cooperative activity between government and industry participants seeking to reduce or eliminate expenditures of resources by sharing technical information essential during research, design, development, production and operational phases of systems, facilities and equipment. Both of these databases have restrictive access policies.

2.2 Hazards Identification

PNNL assisted in identifying the hazards for two competing modes of waste emplacement, drill string emplacement and wireline emplacement (Cochran and Hardin 2015). One of the purposes of the activity was to compare the hazards of the different emplacement modes. Thus, the hazards identification focused on the differences between the emplacement modes. The comparison starts with a completed borehole ready for waste emplacement and a shipping cask holding a waste package bolted to the drilling platform.

A failure, in terms of this comparison, means that waste packages were removed from the shipping cask, but they were not properly placed in the emplacement zone of the borehole. However, emplacement failures where the waste packages can be returned undamaged to a shipping cask are not considered potentially hazardous events. Hazardous events include dropping a waste package in the borehole, dropping something on a waste package during emplacement operations or after it is emplaced, or getting the waste package stuck in the borehole. Hazards identification includes a qualitative assessment whether a failed operation has the possibility to rupture a waste package, but it does not include a radiological assessment because of ruptured waste packages.

The general approach to defining the hazards was the use of a fault tree (Vesely et al. 1981). A fault tree is a top-down analysis of undesired states of a system, where the undesired state can occur through the combination of lower level events. For example, an undesired state might be dropping a waste package during the emplacement process. This state could hypothetically occur if a waste package is hoisted over the emplacement hole and then an operator inadvertently initiates release of the hoisting mechanism at the wrong time. The hazard identification included discussion of a series of mechanical or computer-controlled interlocks that could be included to prevent undesired activities.

Fault trees can generally be conceptualized as consisting of basic events, intermediate events, and top level events. Basic events are such things as a pump failure, a break in a wire, or a human mistake. Failure probabilities are assigned to all basic events, and only to basic events. Intermediate events are combinations of basic events. Failure probabilities of intermediate events are calculated from the combination of basic events that lead to the intermediate event. Finally, a top-level event is defined as a combination of basic and/or intermediate events.

Development of the fault tree starts with consideration of the things that can go wrong after the shipping cask has been secured to the receiving collar at the borehole site. Thirteen separate steps are identified in the process of removing individual waste packages from the shipping cask and lowering them to the emplacement interval by wireline (Cochrad and Hardin 2015). In general, intermediate fault states can result if a waste package is dropped, if the waste package gets stuck in the borehole at the wrong location, or if something is dropped on the waste package.

The Saphire software (Smith and Wood 2011) was used in the analysis. This software is accepted by the NRC for fault tree and event tree analysis. A fault tree analysis is a top down failure analysis in which an undesired system states are analyzed using Boolean logic to combine a series of lower-level events. An event tree analysis is based on binary logic, in which an event either has or has not happened or a component has or has not failed. It is useful in evaluating the consequences arising from a failure or undesired event.

A preliminary fault tree for wireline emplacement of waste packages developed by PNNL is shown in Figure 2-1. Basic events are shown in boxes with light blue shading and intermediate- and top-level events are shown using solid blue shading.

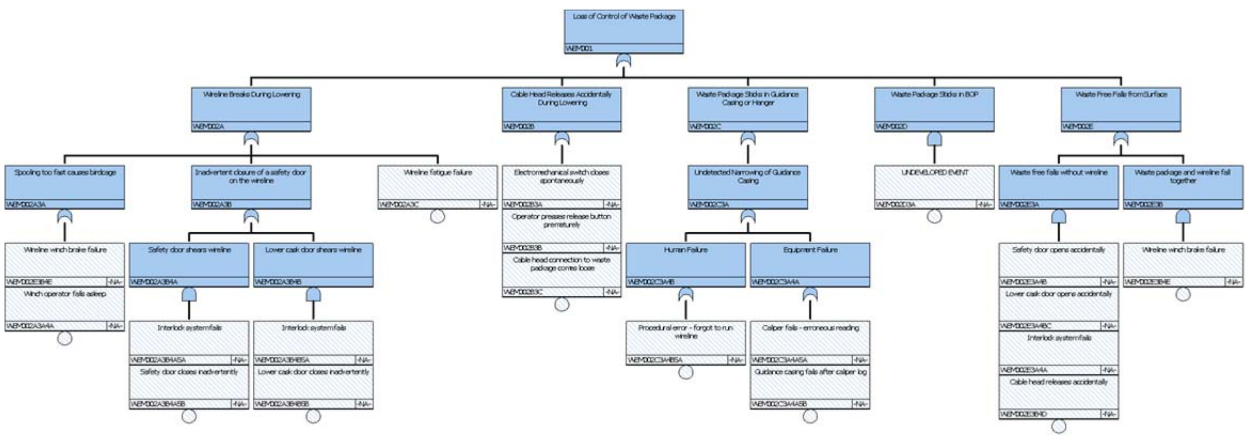

Figure 2-1. Preliminary Fault Tree for Wireline Emplacement of Waste Packages

Unfortunately, almost no data on failure probabilities are published at the level of detail in the fault tree shown in Figure 2-1. The preliminary fault tree was updated by SNL staff members, and the failure probabilities were developed by SNL using a panel of drilling and waste containment experts.

2.3 Expert Review

The methodology for selecting between drill-string emplacement and wireline emplacement (Jenni and Hardin 2015) includes having a panel of experts review preliminary fault trees Cochran and Hardin 2015) for emplacement failure modes. Frank Spane of PNNL has extensive experience in well logging and he served on the panel of experts that performed the review. The review panel members and their affiliations were the following: Doug Blankenship (SNL), John Finger (Consultant), Mark MacGlashan (Consultant), Frank Spane (PNNL), and Nelson Tusberg (Leitner-Poma).

The panel members reviewed the fault trees for both wireline and drill string emplacement modes over a three day period. Extensive discussions of the waste package handling steps by panel members resulted in modification of the descriptions of several emplacement failure modes and addition of some new failure modes. In addition, the panel members suggested a number of modifications to the sequence of recovery actions that might be attempted when a waste package is dropped or becomes stuck during emplacement activities.

As noted in Section 2.1, little information is published on the probability or frequency of failure modes. Expert panel members provided estimates of the probability of occurrence of basic failure events in the fault trees based on decades of experience in the industry. The estimates were complete enough by the end of the review to calculate the probability of occurrence for each of the intermediate and top level fault states.

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