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Towards a Defensible Safety Case for Deep Geologic Disposal of DOE HLW and DOE SNF in Bedded Salt

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TOWARDS A DEFENSIBLE SAFETY CASE FOR DEEP GEOLOGIC DISPOSAL OF DOE HLW AND DOE SNF IN BEDDED SALT

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ABSTRACT

The primary objective of this study is to investigate the feasibility and utility of developing a defensible safety case for disposal of United States Department of Energy (U.S. DOE) high-level waste (HLW) and DOE spent nuclear fuel (SNF) in a conceptual deep geologic repository that is assumed to be located in a bedded salt formation of the Delaware Basin. A *safety case* is a formal compilation of evidence, analyses, and arguments that substantiate and demonstrate the safety of a proposed or conceptual repository. A safety case also provides the necessary structure for organizing and synthesizing existing knowledge in order to help DOE prioritize its future research and development (R&D) activities. We conclude that a defensible initial safety case for potential licensing could be readily compiled by capitalizing on the extensive technical basis that exists from prior work on the Waste Isolation Pilot Plant (WIPP), work on other repository development programs, and the work published through international efforts in salt repository programs such as in Germany.

It should be emphasized that the DOE has not made any decisions regarding the disposition of DOE HLW and DOE SNF. This study provides additional information that could be used to inform DOE‘s decision making regarding management of this waste. Furthermore, the safety case discussed herein is not intended to either site a repository in the Delaware Basin or preclude siting in other media at other locations. Rather, this study simply presents an approach for accelerated development of a safety case for a potential DOE HLW and DOE SNF repository using the currently available technical basis for bedded salt. This approach includes a summary of the regulatory environment relevant to disposal of DOE HLW and DOE SNF in a deep geologic repository, the key elements of a safety case, the evolution of the safety case through the successive phases of repository development and licensing, and the existing technical basis that could be used to substantiate the safety of a geologic repository if it were to be sited in the Delaware Basin. We also discuss the potential role of an underground research laboratory (URL).

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ACRONYMS

CBFO	Carlsbad Field Office
CCA	Compliance Certification Application
DOE	Department of Energy
EBS	Engineered Barrier System
EIS	Environmental Impact Statement
EPA	Environmental Protection Agency
FEPs	Features, Events, and Processes
HLW	High-Level Waste
LWR	Light Water Reactor
NEA	Nuclear Energy Agency
NEPA	National Environmental Policy Act
NRC	National Research Council
NWPA	Nuclear Waste Policy Act
NWTRB	Nuclear Waste Technical Review Board
PA	Performance Assessment
PoS	Postclosure Safety
PrS	Preclosure Safety
QA	Quality Assurance
R&D	Research and Development
RD	Repository Design
RH	Remotely Handled
SC	Site Characterization
SNF	Spent Nuclear Fuel
SNL	Sandia National Laboratories
SS	Site Selection
TMI	Three Mile Island
TRU	Transuranic
URL	Underground Research Laboratory
U.S.	United States
U.S. NRC	U.S. Nuclear Regulatory Commission
WIPP	Waste Isolation Pilot Plant
YMP	Yucca Mountain Project

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1.0 INTRODUCTION

The primary objective of this study is to investigate the feasibility and utility of developing a defensible safety case for disposal of United States Department of Energy (U.S. DOE) high-level radioactive waste (HLW)[1] and DOE spent nuclear fuel (SNF)[2] in a potential deep geologic repository if it were to be sited in bedded salt formations of the Delaware Basin. A *safety case* is an integrated collection of evidence, analyses, and other qualitative and quantitative arguments used to demonstrate the safety of the repository. Investigating the feasibility and value of developing a defensible safety case for DOE HLW and DOE SNF at this time based on existing technical information is motivated by the fact that the previously existing pathway for disposal (Yucca Mountain) has been halted. The emphasis of this study is on DOE HLW and DOE SNF, in part because of its limited economic value as an energy resource, but also to further the development of geologic repository science and engineering, while the Nation endeavors to reach a consensus on the disposition of commercial SNF (BRC 2012).

The development of any geologic repository will take place over a period of years and will generally include the following phases: site selection and characterization (including facility design), licensing, construction, operation, closure, and postclosure (NRC 2003, Sec. 3.1). However, as noted by the Nuclear Energy Agency (NEA 2004): ―An initial safety case can be established early in the course of a repository project. The safety case becomes, however, more comprehensive and rigorous as a result of work carried out, experience gained and information obtained throughout the project…" The key point here is that the rigor needed is already in large part available for an initial safety case in bedded salt due to the amount of work previously related to waste disposal in salt, both domestically and internationally. Thus, if a repository were to be sited in Delaware Basin bedded salt, the initial safety case could be strong and equivalent in level of detail and rigor to what could be expected of a safety case at a later phase of a repository program in another geologic medium and/or location. That is, many of the major elements of a safety case could be addressed with existing technical bases and experience from prior salt repository work.

Lessons learned from DOE‘s experience on the Waste Isolation Pilot Plant (WIPP)[3] and Yucca Mountain Project (YMP), and collaborations with the German salt repository program, are applied here and add confidence to the conclusion that a defensible initial safety case can be developed at the present time using the available technical basis. This experience includes many key aspects of repository development, operations, and safety assessment, including repository and seal system design, preclosure safety analysis, and application of performance assessment

[1] ―High-level radioactive waste (HLW)" is defined as in the Nuclear Waste Policy Act, Sec. 2: ―highly radioactive material resulting from the reprocessing of spent nuclear fuel..."

[2] ―Spent nuclear fuel (SNF)" is defined as in the Nuclear Waste Policy Act, Sec. 2: ―fuel that has been withdrawn from a nuclear reactor following irradiation..."

[3] The Waste Isolation Pilot Plant is a DOE waste disposal facility designed to safely isolate defense-related transuranic (TRU) waste from people and the environment. Waste temporarily stored at sites around the country is shipped to WIPP and permanently disposed in rooms mined out of a bedded salt formation 2,150 feet below the surface. WIPP, which began waste disposal operations in 1999, is located 26 miles outside of Carlsbad, NM.

(PA) methodology (Cranwell et al. 1987; DOE 1996; DOE 2008; DOE 2011a). Also, even if the eventual site of a DOE repository is located outside of the Delaware Basin, but still in bedded salt, the relevance of the WIPP experience and other technical bases would nonetheless be significant.

There is much value for DOE in developing the safety case described herein. Potential benefits include leveraging previous investments and lessons learned at WIPP to potentially reduce future repository development costs, enhancing the ability to effectively plan for a salt repository and its licensing, and possibly shortening the schedule for such a repository. A safety case will provide the necessary structure for organizing and synthesizing existing salt repository science and identifying any issues and gaps pertaining to safe disposal of heat-generating nuclear waste in salt. This safety case synthesis will help DOE to plan its future research and development (R&D) activities for improving the defensibility of the safety case using a risk-informed approach, based in part on performance assessment modeling. Future activities, if deemed necessary, to increase the confidence in the arguments that form the basis of the safety case, may include a limited set of additional laboratory, field, and/or site investigations to reduce uncertainties in the events, processes, and properties associated with the evolution of heat-generating waste emplaced in salt.

The outline of this paper is as follows. The regulatory basis relevant to a DOE HLW/SNF repository is discussed in Section 2. Section 3 describes the general concept of a safety case, its phased development, and the major elements that compose a safety case. Section 4 summarizes the existing technical basis, including existing site characterization information, which supports development of a safety case for bedded salt; a basic design concept for a DOE HLW/SNF repository in bedded salt; an overview of the characteristics of DOE HLW and DOE SNF legacy waste; and the methodology and existing analyses for safety assessments before and after repository closure. Section 5 presents the motivation for an underground research laboratory (URL), which would be useful for building additional understanding and confidence in the safety case. Section 6 provides the conclusions of this study. Finally, Appendix A gives a more detailed outline of the elements of a safety case and Appendix B offers a more detailed outline of the existing technical information and understanding regarding the key elements of the safety case for disposal of DOE HLW and DOE SNF in bedded salt.

2.0 REGULATORY BASIS FOR A DOE HLW/SNF DEEP GEOLOGIC REPOSITORY

The safety standards and implementing regulations governing development of a geologic repository are the important bases for judging the safety of a conceptual DOE HLW/SNF geologic repository. The site-specific Environmental Protection Agency (EPA) and U.S. Nuclear Regulatory Commission (U.S. NRC) regulations for Yucca Mountain, 40 CFR 197 and 10 CFR 63, are not applicable to a separate DOE HLW/SNF repository, but existing EPA and U.S. NRC regulations for disposal of high-level radioactive wastes in geologic repositories remain in effect, i.e., 40 CFR 191 and 10 CFR 60. However, these existing regulations would likely be superseded for a DOE HLW/SNF repository, since they were developed almost 30 years ago and are not consistent with the more recent thinking on regulating geologic repositories that embraces a risk-informed, performance-based approach (U.S. NRC 2004), such as that represented in the site-specific regulations for Yucca Mountain. Despite this uncertainty regarding applicable safety standards, a robust safety case can still be developed based on either the existing standards (40 CFR 191 and 10 CFR 60) or on generic standards that incorporate dose or risk metrics recognized internationally to be important to establishing repository safety. Examples of the latter are compiled in Bailey et al. (2011, Sec. 6.2), e.g., the French requirement that the dose rate should be less than 0.25mSv/yr. With respect to the existing U.S. standards (10 CFR 60, Subpart E), Section 4 of this report describes some of the waste package materials that could be used to meet the existing subsystem requirement for the waste package at 10 CFR 60.113 (―substantially complete" containment for not less than 300 years nor more than 1,000 years after permanent closure of the repository).

Another important regulatory issue that influences the safety case is the specific waste inventory to be disposed in a DOE HLW/SNF repository (BRC 2011; BRC Staff 2011). The safety case described herein assumes that the inventory would be a ―non-NWPA" inventory consistent with Sec. 8(c) of the Nuclear Waste Policy Act (NWPA 1987)[4] and would be based on one of the inventories considered by Carter et al. (2012).[5] There were five repository cases in Carter et al. (2012, Table 2-1), comprising four different inventories: Savannah River HLW only (Case 1); all DOE HLW (Cases 2 and 3); all DOE HLW plus DOE SNF (Case 4); and all DOE HLW, DOE SNF, plus Naval reactor SNF (Case 5).[6]

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[4] The NWPA Sec. 8(c) states that ―The provisions of this Act shall apply with respect to any repository not used exclusively for the disposal of high-level radioactive waste or spent nuclear fuel resulting from atomic energy defense activities, research and development activities of the Secretary, or both." (also see NWPA, Sec. 101).

[5] Some inventory owned and managed by DOE is not included in Carter et al. (2012), such as 275 HLW canisters from the West Valley, NY reprocessing facility; damaged Three Mile Island (TMI) spent fuel; and Fort St. Vrain spent fuel. Because these wastes are related to commercial energy production, it is not clear if these wastes are part of the non-NWPA waste inventory mentioned above that could be disposed of in a facility dedicated ―exclusively" to atomic energy defense activities and DOE R&D activities (BRC Staff 2011).

[6] The inventory used for ―Case 5" in Carter et al. (2012) includes most of the HLW and SNF managed by DOE (see exceptions in previous footnote), as well as naval reactor spent fuel. If this inventory were assumed for the safety case, repackaging of naval fuel canisters into smaller packages may be required, in order to allow transfer of packages from the surface to the underground using existing shaft-hoist technology. (Note also that Cases 2 and 3 have identical inventories—all DOE HLW—but differ only in the assumed location of the repository.)

If DOE decides to ultimately pursue the development of a deep geologic repository for disposal of DOE HLW and DOE SNF, other requirements may have to be satisfied, such as the National Environmental Policy Act (NEPA) (40 CFR 1500-1508). A NEPA-mandated Environmental Impact Statement (EIS) for a repository, if it were to be sited in the Delaware Basin, could be developed by leveraging the EIS for WIPP (DOE 1997) and much of the technical basis identified in the present study.

Finally, the WIPP Land Withdrawal Act, Public Law 102-579 (as amended by Public Law 104-201, Section 12) does not allow for the disposal of HLW or SNF at the WIPP site. However, the Salado bedded salts of the Delaware Basin are extensive in southeast New Mexico, implying that most of the technical basis developed for the WIPP site can be used at other potential salt repository sites in the Delaware Basin.

3.0 SAFETY CASE CONCEPT

The Nuclear Waste Technical Review Board (NWTRB 2011, Section 4.4) has suggested that the U.S. repository program would benefit from international work (NEA 1999; NEA 2004; NEA 2008; IAEA 2011) regarding ―what a safety case should look like and how a national program might advance it," and has called the international work ―innovative" and ―path-breaking." A *safety case* is an integrated collection of evidence, analyses, and other qualitative and quantitative arguments used to demonstrate the safety of the repository. Two of its major roles are as a management tool to guide the work of the implementer (e.g., DOE) through the various phases of repository development and to communicate the understanding of safety to a broad audience of stakeholders (NRC 2003). With regard to the former, because of various technical uncertainties associated with a complex one-of-a-kind repository project, the safety understanding and basis evolves through time. The safety case provides the framework to assist in prioritizing the technical work in the next phase of development, in order to reduce these uncertainties and to enhance the confidence in safety. This will be in the context of various defined decision points that may or may not result in construction and operation of the repository. As noted by the Nuclear Energy Agency (NEA 2004, p. 7):

> ―Adetailed safety case, presented in the form of a structured set of documents, is typically required at major decision points in repository planning and implementation, including decisions that require the granting of licenses. A license to operate, close, and in most cases even to begin construction of a facility, will be granted only if the developer has produced a safety case that is accepted by the regulator as demonstrating compliance with applicable standards and requirements."

With regard to the role of the safety case in the communication of safety arguments to a diverse group of stakeholders, the National Research Council's Committee on Principles and Operational Strategies for Staged Repository Systems (NRC 2003, p. 126) has stated:

> ―The safety case is also used to develop a program with features such as robustness and conservatism and to convince the implementer itself[7], the regulator, stakeholders, and the general public that there is a sensible and defensible set of arguments showing that the repository will be safe. The safety case includes a broad and understandable (to stakeholders and the general public) explanation of how safety is achieved and a similar discussion of the uncertainties that result from limitations in the scientific understanding of system behavior."

As mentioned in the previous section, the current and applicable regulations for any new geologic repository, including a DOE HLW/SNF repository, are subject to being superseded as part of the development of the nation's policy for managing the back end of the fuel cycle. However, the purpose of the safety case would not be to replace or expand upon requirements of the licensing process, but rather to make the rationale for decisions about the facility accessible and understandable to the public and to a wider range of decision makers (e.g., Congress; state and local governments) beyond the regulatory experts who already have the technical expertise to make judgments about safety. Much of the safety rationale can be developed prior to the

[7] In the present study the ―implementer" would be the Department of Energy.

finalization of new regulations (if applicable), based on past DOE repository experience (Yucca Mountain and WIPP), as well as on commonly proposed safety indicators and metrics in the international arena (e.g., Becker et al. 2002). Thus, regardless of the presence or absence of either general or site-specific regulatory guidance, the safety case structure and concept, as described here, is the recommended vehicle for articulating and communicating the safety of a DOE HLW/SNF repository.

3.1 Elements of the Safety Case

Although the scope of a safety case, and the definitions and terminology used therein, differ somewhat across the various international programs (Schneider et al. 2011; Bailey et al. 2011; NEA 2009; NEA 2004), they all have the same goal of understanding and substantiating the safety of a disposal system. In this study, the major elements of the safety case are patterned after the NEA postclosure safety case (NEA 2004), but include aspects of preclosure safety (see Appendix A for additional detail):

- *Statement of Purpose*. Describes the current stage or decision point within the program against which the current strength of the safety case is to be judged.
- *Safety Strategy*. This is the high-level approach adopted for achieving safe disposal, and includes (a) an overall management strategy, (b) a siting and design strategy, and (c) an assessment strategy. Two important principles of the safety strategy are (1) public and stakeholder involvement in key aspects of siting, design, and assessment and (2) alignment of the safety case with the existing legal and regulatory framework.
- *Site Characterization and Repository Design*. This contains key portions of the *assessment basis* that is described in some safety case concepts (NEA 2004), and includes a description of (a) the primary characteristics and features of the repository site, (b) the location and layout of the repository, (c) a description of the engineered barriers, and (d) a discussion of how the engineered and natural barriers (i.e., the multiple-barrier concept) will function synergistically. In the earliest phases of the repository program it includes the site selection process and associated selection criteria/guidelines.
- *Preclosure and Postclosure Safety Evaluation*. This includes a quantitative safety assessment of potential radiological consequences associated with a range of possible evolutions of the system over time, i.e., for a range of scenarios, both before and after repository closure. It also includes qualitative arguments related to the intrinsic robustness of the site and design, insights gained from the behavior of natural and anthropogenic analogues, and sensitivity and uncertainty analyses to quantify key remaining uncertainties, which may be addressed with future R&D, if necessary.
- *Statement of Confidence and Synthesis of Evidence*. The statement of confidence is based on a synthesis of safety arguments and analyses, and includes a discussion of completeness to ensure that no important issues have been overlooked in the safety case. The statement of confidence recognizes the existence of any open issues and residual uncertainties, and perspectives about how they can be addressed in the next phase(s) of repository development, if they are considered to be important to establishing safety.

The postclosure *safety assessment*, which in the U.S. program and regulations is generally referred to as the postclosure *performance assessment* (e.g., see 40 CFR 191, the currently applicable standard for all geologic repositories in the U.S. other than Yucca Mountain and the standard under which WIPP is certified), is a key part of the safety case. As stated by the NWTRB (2011, p. 53): ―Performance assessment is arguably the most important part of the safety case...” Performance assessment is primarily focused on a quantitative evaluation of postclosure safety through a systematic analysis of repository performance and a comparison of this performance with quantitative design requirements and safety standards, along with an estimation of how quantifiable uncertainties might affect repository performance. Such an assessment requires conceptual and computational models that include the relevant features, events, and processes (FEPs) that are or could be important to safety.

The knowledge base for performance assessments in the U.S. is extensive. For example, PA methodology has been used successfully to certify the WIPP repository and to develop the Yucca Mountain license application, and has been applied to many other waste disposal projects in the U.S. and internationally, beginning in the 1970s (Meacham et al. 2011). This methodology is directly applicable now for estimating the potential performance of a DOE HLW/SNF repository in bedded salt against relevant safety criteria (see Section 2).

Demonstrating confidence in preclosure safety is also an important element of the safety case and includes transportation safety and operational safety. These aspects of preclosure safety should be described and analyzed in a safety case, and made available to decision makers and the public as transportation and disposal systems mature. Transportation of SNF and HLW, potential transportation routes, potential risks of transporting SNF and HLW, and potential transportation accidents and consequences should be described and evaluated. Operational safety should include a description of surface facilities and their operation, a description of the preclosure *safety assessment* methodology, and an assessment of potential occupational and public health and safety. The preclosure safety assessment identifies the potential natural and operational hazards for the preclosure period; assesses potential initiating events and event sequences and their consequences; and identifies the structures, systems, and components (SSCs) and procedural safety controls intended to prevent or reduce the probability of an event sequence or mitigate the consequences of an event sequence, should it occur (DOE 2008, Chapter 1).

3.2 Phased Development of the Safety Case

The development of a geologic repository will take place over a period of years and will generally include the following phases: site selection and characterization (including facility design), licensing, construction, operation, closure, and postclosure (NRC 2003). The relationship between the phases of repository development and the evolution of the safety case is illustrated in Figure 1. Typical phases and decision points in the development of a repository are shown across the top of the figure, while key elements of the safety case are shown along the side. As the repository program evolves from siting to licensing to closure, the required level of completeness and rigor increases and the associated safety case becomes more detailed with the addition of more data from site characterization, repository design, and safety assessment activities. These three key activities combine to form an iterative process wherein the safety assessment from one phase feeds site characterization and design at the next phase. Public and other stakeholder participation are important in each phase, before proceeding to the next phase of development.

With respect to the staged repository development shown in Figure 1, because of the existing salt information basis from the WIPP repository and internationally, it is possible to accelerate the development of a defensible safety case for the site selection to licensing phases for a repository of DOE HLW/SNF in bedded salt. This safety case will not only provide decision makers and stakeholders with a concise summary of existing technical information mapped to the elements of the safety case, but also the basis for beginning the process of licensing and conducting public and regulator interactions. It will also provide a basis for identifying and prioritizing those activities necessary to finalize the safety case and license application.

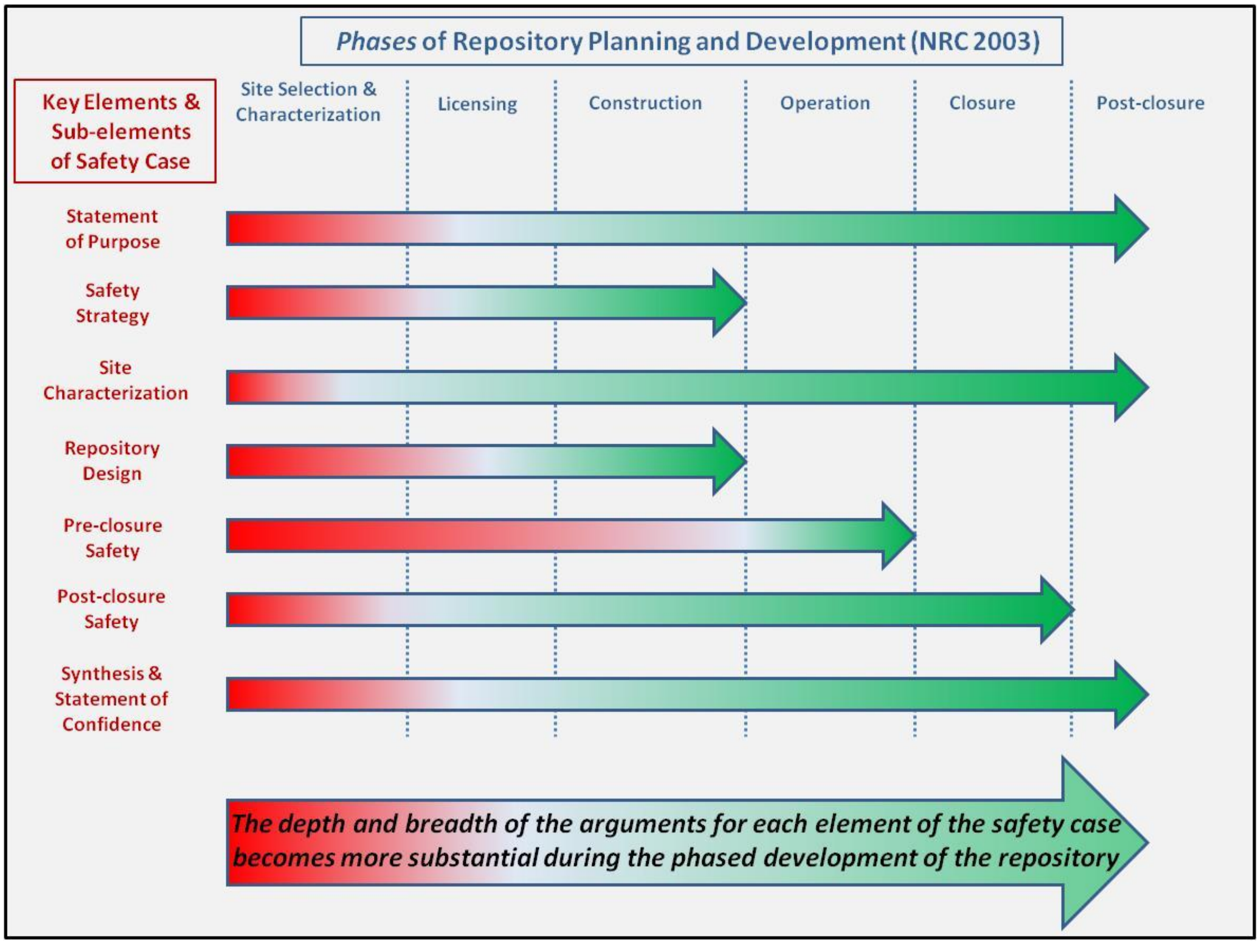

Figure 1. Evolution of the Safety Case as Part of a Phased Approach to Repository Development.

4.0 EXISTING TECHNICAL BASES FOR A SALT REPOSITORY

The concept of radioactive waste disposal in salt was recognized by the National Academy of Sciences as early as 1957 when they identified salt as the most promising method for high-level waste disposal (NRC 1957). An operational radioactive waste disposal facility for defense-generated transuranic (TRU) waste (WIPP) has since been sited in the Delaware Basin of Southeast New Mexico in the U.S., demonstrating this concept. Lessons learned from siting and operating this facility can be used to support the development of an HLW/SNF disposal facility in salt, particularly since the original design concepts and siting requirements for WIPP were based on the intent to dispose of HLW in addition to TRU waste (Weart 1975; Powers et al. 1978, p. 2-9).

Disposal of DOE HLW/SNF in a suitable salt formation is attractive because the material is essentially impermeable, self-sealing, thermally conductive, and a significant experience base exists from earlier studies. A salt repository could potentially achieve complete containment, with no releases to the environment in undisturbed scenarios for as long as the region is geologically stable (Hansen and Leigh 2011). This complete containment goal could be further supported if it were decided to site a repository in the areally extensive and thick sequence of bedded salt and associated evaporites in the Delaware Basin, a sub-element of the Permian Basin of Southeast New Mexico and West Texas. However, it should be noted that phenomena caused by heat from HLW and SNF could add some potentially beneficial and/or detrimental FEPs that are not necessarily important for the significantly cooler TRU waste that is disposed at WIPP. This consideration also applies to FEPs related to the physical and chemical characteristics of DOE HLW and DOE SNF, since these characteristics are likely to be appreciably different than TRU waste. In addition, site-specific considerations and differences in the disposal concept, container types, and performance period could give rise to potentially important FEPs. Further, new human intrusion FEPs may need to be considered because of the different characteristics of DOE HLW/SNF. Overall, a FEPs analysis would be required in order to move forward with a safety case, and many of the FEPs screening results performed for WIPP will still be applicable.

A specific example of a potentially detrimental FEP that was determined to be unimportant for TRU waste, which may be important for heat-generating waste like HLW and SNF, is the reaction of acidic brines with metal waste containers. Acid-producing reactions were found to occur in a WIPP-representative brine subjected to elevated temperatures (Molecke 1983) implying that, if an acidic brine was available in sufficient quantity under repository conditions, it could be potentially detrimental to waste container performance. In fact, DOE has recently funded studies of waste container material performance to provide information applicable to a potential salt repository for SNF or HLW (Bryan et al. 2011). Corrosion-resistant materials such as Ti 99.8-Pd and TiCode-12 exhibit very low uniform corrosion rates that would allow isolation of wastes within the container, if needed, for several hundreds to thousands of years depending on container thickness. However, additional work may be needed to determine conditions under which such materials can be used without crevice corrosion. Alternatively, thick carbon steel containers, which appear not to be susceptible to localized corrosion (Bryan et al. 2011), may provide waste isolation for a sufficient period of time after repository closure.

As an example of site-specific FEPs that should be considered if a repository were to be sited in the Delaware Basin, the potential impact of karst processes on repository performance would need to be evaluated depending on the site location and regulatory compliance period, since these processes are prevalent in some regions of the Permian Basin, including the Delaware Basin (Johnson 2008).

The remainder of this section reviews the existing technical and knowledge bases if a repository for disposing nuclear waste were to be sited in Delaware Basin bedded salt, relying heavily on current and previous site investigations and *in-situ* experiments conducted both at the WIPP defense TRU waste repository and internationally. This knowledge base substantiates a strong argument that much of a safety case would be complete for a conceptual DOE HLW/SNF repository in Delaware Basin bedded salt. The technical basis reviewed in this section specifically includes (1) the extensive hydrogeological, geochemical, thermo-mechanical, and other technical data that has been collected from the WIPP site and surrounding area to evaluate the site‘s suitability as a host for a radioactive waste repository; (2) the well-known characteristics of the waste inventory; (3) the U.S. and international experience in developing and operating salt repositories and the flexibility in design afforded by disposal in salt; and (4) and the application of current PA methodology to the evaluation of salt repository performance.

Figure 2 shows the categories of information needed for the safety case and indicates that this information is available now to build an initial safety case if a repository for DOE HLW/SNF disposal were to be sited in Delaware Basin bedded salt. Confidence statements are provided for each of the main categories of technical information needed for a safety case in this salt formation. Supporting references for each category in Figure 2 are identified in Appendix B.

Site Selection Bases

SS DOE Has Proven Methods and Sufficient Technical, Environmental, and Socioeconomic Information to Select a Repository Site for DOE HLW/SNF in Delaware Basin Bedded Salt.

SS 1 Proven methods from previous site screening studies, e.g., for commercial HLW/SNF and TRU waste, are applicable for a DOE HLW/SNF waste repository

SS 2 The hydrogeological, geochemical, thermomechanical, and geophysical properties of Delaware Basin bedded salt have been extensively characterized as a result of site characterization at WIPP and can be used as a basis for siting a DOE HLW/SNF waste repository

SS 3 The natural environment (including flora and fauna) and potential disruptions to that environment have been extensively investigated as part of the WIPP EIS and that information can be used as a basis for siting a DOE HLW/SNF waste repository

SS 4 Natural resources extracted for commercial purposes and the effect of those activities on repository performance have been extensively investigated as part of the WIPP PA. That knowledhge can be used to inform the siting of a DOE HLW/SNF waste repository

SS 5 Socioeconomic impacts (e.g., effect on population centers) have been studied extensively as part of the WIPP EIS and that information can be used as a basis for siting a DOE HLW/SNF waste repository

Site Characterization Bases

SC DOE Has Sufficient Hydrogeological, Geochemical, Thermomechanical, and Geophysical Information about Bedded Salt in the Delaware Basin to Provide an Assessment Basis for a DOE HLW/SNF Waste Repository

SC 1 Hydrogeologic information about the Delaware basin gathered in support of WIPP can be applied to a DOE HLW/SNF repository in Delaware Basin bedded salt

SC 2 Geochemical information about the Delaware Basin gathered in support of WIPP can be applied to a DOE HLW/SNF repository in Delaware Basin bedded salt

SC 3 Thermomechanical information about the Delaware Basin gathered in support of WIPP can be applied to a DOE HLW/SNF repository in Delaware Basin bedded salt

SC 4 Geophysical information about the Delaware Basin gathered in support of WIPP can be applied to a DOE HLW/SNF repository in Delaware Basin bedded salt

Repository Design Bases

RD DOE Has a Number of Suitable Designs That Could Be Used for a DOE HLW/SNF Waste Repository in Delaware Basin Bedded Salt

RD 1 Because of previous work on a geologic repository for HLW/SNF, volumes, waste forms, and packages for DOE HLW/SNF are adequately known

RD 2 A recent design concept (generic salt repository design) for HLW is a new disposal concept based on lessons learned from the WIPP, Asse, and Morsleben and can be used in the safety case for disposal of DOE HLW/SNF Waste in Delaware Basin Bedded Salt

RD 3 The shaft sealing system designed for WIPP, which has been reviewed and certified by EPA, can be used in the safety case for disposal of DOE HLW/SNF Waste in Delaware Basin Bedded Salt

Pre-Closure Safety Bases

PrS DOE Can Demonstrate Pre-closure Safety for a DOE HLW/SNF Waste Repository in Delaware Basin Bedded Salt

PrS 1 DOE Can Demonstrate Transportation Safety for a DOE HLW/SNF Waste Repository in Delaware Basin Bedded Salt

PrS 2 DOE Can Demonstrate Safe Packaging and Handling Procedures for a DOE HLW/SNF Waste Repository in Delaware Basin Bedded Salt

PrS 3 DOE Can Demonstrate Mining Safety for a DOE HLW/SNF Waste Repository in Delaware Basin Bedded Salt

PrS 4 DOE Can Demonstrate Operational Safety for a DOE HLW/SNF Repository in Delaware Basin Bedded Salt

Post-Closure Safety Bases

PoS DOE Can Demonstrate Long-term Safety for a DOE HLW/SNF Waste Repository in Delaware Basin Bedded Salt

PoS 1 Results from previous long-term performance evaluations indicate the safety of disposal in Delaware Basin Bedded Salt both for TRU waste and for HLW

PoS 2 FEPs Screening and Scenario Development from WIPP are applicable with only slight modification to a DOE HLW/SNF repository in Delaware Basin Bedded Salt

PoS 3 Modeling capabilities for long-term safety assessments are mature and can be applied with only minor modifications to a DOE HLW/SNF repository in Delaware Basin Bedded Salt

PoS 4 Consideration of uncertainty in safety assessments is a mature science and can be applied to a DOE HLW/SNF repository in Delaware Basin Bedded Salt

PoS 5 Future research and development activities in a URL will enable relevant uncertainties to be reduced or even avoided

PoS 6 Quality assurance procedures have been well tested on previous repository programs and will bolster confidence in the long-term safety assessment for a DOE HLW/SNF repository in Delaware Basin Bedded Salt

Figure 2. Summary of Technical Bases Supporting the Safety Case for a DOE HLW and DOE SNF Geologic Repository in Delaware Basin Bedded Salt (Supporting Technical Bases for each Category, such as "SS," are Identified in Appendix B).

4.1 Site Selection

During the site selection process, the organization responsible for repository siting and development investigates one or more sites to determine suitability with respect to various screening criteria and guidelines (NRC 2003). Preliminary site investigations, including deep drilling or mining excavation, will produce a variety of technical data, including geologic, hydrologic, geochemical, geophysical, and thermo-mechanical data at the candidate sites. In addition to technical data, other data related to guidelines for health and safety, environmental, socioeconomic, and economic considerations (Keeney 1980) should be gathered during the siting process.

These types of criteria were used during the WIPP site selection process, and can be used to inform any future site selection of a DOE HLW/SNF repository. In particular, the WIPP site selection was conducted ―utilizing siting factors appropriate for a high-level waste repository in order to provide as much flexibility for future options as possible.” (Weart 1978a) Thus, even though the WIPP Land Withdrawal Act (WIPP 1992) later precluded the use of WIPP as an HLW repository, the original site selection process developed for bedded salt during the WIPP planning and siting phase could be used to inform the siting of a DOE HLW/SNF repository elsewhere, if it were to be sited in the Delaware Basin.

At early stages of site selection, both the geologic media (e.g., salt, shale, or granite) and the location or setting (e.g., salt domes or bedded salt) are part of the down-selection process. At later stages, after a specific medium and/or setting is established, the criteria become specific to the medium and setting. Oak Ridge National Laboratory and the U.S. Geological Survey decided in the early 1970s that a repository in bedded salt of the northern portion of the Delaware Basin would be suitable for radioactive waste (Griswold 1977, p. 10; Powers et al. 1978, Sec. 2.3.1; Rechard 2000). Once this was determined, more specific siting criteria were applied to help site an exact repository location, including (Powers et al. 1978, Sec. 2.3.6):

- *Geology criterion*. Includes the following factors: topography, depth, thickness, lateral extent, lithology, stratigraphy, structure, and erosion
- *Hydrology criterion*. Includes the following factors: surface waters, aquifers, dissolution, subsidence, hydrologic transport, climatic fluctuations, and man-made penetrations
- *Tectonic stability criterion*. Includes the following factors: seismic activity, faulting/fracturing, salt flow/anticlines, diapirism, regional stability, igneous activity, and geothermal gradient
- *Physico-chemical compatibility criterion*. Includes the following factors: fluid content, thermal properties, mechanical properties, chemical properties/mineralogy, radiation effects, permeability, nuclide mobility
- *Economic/social compatibility criterion*. Includes the following factors: natural resources, man-made penetrations, transportation, accessibility, land jurisdiction, population density, ecological effects, and sociological impacts

A more specific implementation of these criteria, such as ―a minimum depth to suitable salt of 1,000 ft,” led to the choice of the Los Medaños region as the best site for the WIPP TRU waste repository (Griswold 1977; Weart 1978a; Powers et al. 1978). Since that time, much work has been done on the characterization of the land surface, particularly with respect to the flora and fauna present in the Delaware Basin. With that work as a basis, the WIPP Disposal Phase Final EIS (DOE 1997) discussed potential environmental impacts from the construction and operation of the facility, including impacts to flora and fauna. No significant environmental impacts were identified. Furthermore, any realized impacts have been manageable, as demonstrated by the construction and operation of WIPP. Thus, for development of a safety case for licensing a repository, were it to be sited in the Delaware Basin, DOE could confidently assume that potential environmental impacts to flora and fauna will be minimal.

The nature and extent of commercially mined natural resources in the Delaware Basin, like oil, natural gas, and potash, are also known (DOE 2009, Appendix DATA) and have been addressed both in the WIPP EIS (DOE 1980 and 1997) and in the many performance assessments and compliance/recertification applications developed for WIPP (SNL 1990, SNL 1991, SNL 1992, DOE 1996, DOE 2004, DOE 2009). This compendium of information indicates that while extraction of natural resources for commercial purposes will likely continue in the presence of the existing and any future radioactive waste repository located in the bedded salt formation of the Delaware Basin, the dual use of this regional area is workable and can be managed so that repository performance would not be adversely affected.

Finally, socioeconomic impacts have been studied extensively as part of the WIPP EIS and that information could be used as a basis for siting a DOE HLW/SNF waste repository elsewhere in the Delaware Basin. Potential and actual impacts to potentially exposed individuals due to the existence and operation of the WIPP have been determined and reported in various WIPP documents, including the WIPP EIS, the WIPP Compliance Certification Application (CCA), and the WIPP Annual Site Environment Report (see Appendix B).

The foregoing siting basis for WIPP and other, similar criteria and associated factors could be used if a repository for DOE HLW/SNF were to be sited in the Delaware Basin. In addition, the methodology from other site-screening studies for radioactive waste, e.g., for commercial HLW/SNF (Merkhofer and Keeney 1987), is applicable to decisions about siting a DOE HLW/SNF repository.

4.2 Site Characterization

The WIPP site is located 26 miles (42 kilometers) east of Carlsbad, New Mexico, in Eddy County. The WIPP disposal horizon is located within a rock salt deposit known as the Salado Formation at a depth of 2,150 feet (650 meters) below the ground surface. The Salado Formation is used by example herein to represent the host rock stratigraphy for the safety case, and consists mainly of halite, with interbeds of sulfate and other evaporite minerals (DOE 1996; Ch. 2). It would not be necessary to specify the exact location of the repository in the Salado because the Salado is regionally extensive and runs continuously underneath the land surface of the Delaware Basin, ranging in depth from about 455 to 915 meters, with a thickness of approximately 610 meters in the vicinity of the WIPP site (Powers et al. 1978).

The region surrounding the WIPP site has been studied extensively for many years. Geophysical logs, cores, basic data reports, geochemical sampling and testing, and hydrological testing and analyses are reported by the DOE and Sandia National Laboratories (SNL) in numerous public documents (DOE 1996, Ch. 2; also see Appendix B). Numerous additional studies have also been conducted by DOE and SNL since the initial WIPP certification. Many of these documents could form the technical basis for a safety case for a DOE HLW/SNF repository were it to be sited in Delaware Basin bedded salt (see DOE 2004; DOE 2009; Hansen and Leigh 2011 and references therein).

The geology of southeastern New Mexico has also been discussed or described extensively in professional journals or technical documents from many different sources other than DOE and SNL, primarily because of the exploration of both potash and hydrocarbon deposits in the region. These types of articles are another source of site characterization information for a possible Delaware Basin repository site. Elements of the geology presented in such sources have been the subject of specific DOE-sponsored studies (DOE 1996, Ch. 2).

4.3 Repository Design and Waste Characteristics

As mentioned by Hansen and Leigh (2011), a salt repository can be engineered to accommodate a broad spectrum of waste volumes, types, and decay heat. The engineered barrier system (EBS) design and repository layout are less dependent on emplaced waste characteristics than in other media because of the robustness of the natural barrier, i.e., the impermeability of salt and its ability to encapsulate the waste after disposal, thereby lessening the dependency of the safety case on the functioning of engineered barriers and the waste container.

4.3.1 DOE HLW/SNF Waste Characteristics

DOE nuclear waste materials that need to be permanently disposed, including HLW and SNF, have been well characterized (DOE 2002; DOE 2008) and would be further evaluated during the development of this safety case. HLW is generated by the reprocessing of SNF. DOE SNF was primarily generated by DOE production reactors, but also includes naval SNF. The majority of the DOE HLW and DOE SNF is currently stored at three DOE sites: Hanford, Savannah River, and the Idaho National Laboratory.

DOE SNF generated in production reactors supported weapons and other isotope production programs. An example of SNF existing today from production reactors is the N-Reactor fuel stored at the Hanford site. Radionuclide inventories for DOE SNF vary widely depending on the history and fuel design. Projections for the number of SNF canisters that would need to be disposed of vary depending on the fuel types, treatment and packaging arrangements and may possibly be a function of the repository design (DOE 2008; Carter et al. 2012).

HLW is generated from DOE SNF by mixing with a combination of silica sand and other constituents or with glass-forming chemicals that are melted together and poured into stainless steel canisters. Once the material solidifies, the canister is sealed. A loaded, sealed HLW canister and its contents constitute the final, to be disposed, waste form. Well over 20,000 canisters would have to be disposed in various sizes with a range of canister inventories and heat generation rates depending on where the HLW originated and its age (DOE 2002; DOE 2008; Carter et al. 2012).

As described in Section 2, some DOE HLW/SNF is of commercial origin (e.g., damaged TMI SNF) and will not initially be considered in the safety case described herein, but its volume and characteristics are not sufficiently different to affect the confidence basis in a DOE HLW/SNF repository safety case, if it were to be included later.

4.3.2 Repository Design

A mine layout for HLW and SNF disposal in salt can be quite flexible (Hansen and Leigh, 2011). For example, the concept of operations utilized at WIPP includes stacking of contact-handled (CH) waste on the floor and horizontal disposal of remotely handled (RH) waste in boreholes in pillars. Initial designs for WIPP considered placement of HLW in vertical boreholes in the floor of the repository. Internationally, Germany has taken a leading role in underground waste disposal in rock salt formations with two repositories, one in a former salt mine (Asse) in north-central Germany that was operated between 1967 and 1978, and another in the Bartensleben salt mine in Morsleben, Germany that was used from 1972–1998. The Asse mine was also used as a research facility for a number of years. The feasibility of both borehole and drift disposal concepts has been demonstrated by about 30 years of testing in the Asse mine (Brewitz and Rothfuchs 2007).[8] Although no country has a repository for HLW in salt, the previous experiments and disposal demonstrations attest to the flexibility of the concept of disposal operations.

The safety case outlined in this paper could start with the recent design concept for a defense waste salt repository (Carter et al., 2012) that was derived from a conceptual salt repository study for recycled commercial light water reactor (LWR) fuel in a hypothetical closed fuel cycle (Carter et al., 2011). The waste in the original study (Carter et al., 2011) was assumed to be generated by a conventional recycling facility which recovers uranium (U) and plutonium (Pu) for reuse and produces a vitrified high-level waste containing the high decay heat radionuclides. The repository design concept for this conceptual salt repository for commercial HLW was based on lessons learned from the WIPP, Asse, and Morsleben. The underground geometric layout consists of panels with individual rooms containing a series of alcoves. This configuration allows emplacement of HLW waste in the alcoves, with the main room functioning as an access corridor. The disposal strategy assumes placement of one canister at the end of each alcove to be covered by crushed salt backfill for radiation shielding of personnel accessing adjacent alcoves. By providing spacing between adjacent canisters the areal heat loading of the salt is controlled. It is assumed that the thermal loading will accelerate closure of the alcoves and rooms due to salt creep.

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[8] It should be noted that the Asse mine is currently being decommissioned as a radioactive waste repository (BfS 2012). This is primarily a result of two detrimental factors: mechanical instability and brine influx. In particular, contrary to the WIPP site or to a new DOE HLW/SNF repository, the Asse site was not originally developed as a waste repository but as a potash mine, beginning in 1909. Therefore, care was not taken to ensure appropriate thickness for the repository horizon, and in some places the overlying rock (the source of brine influx) is within 5 meters of mine chambers. Some radioactive contaminated liquid is also found in the mine, due to poor isolation practices and spills during emplacement activities (but not due to the current influx of salt-saturated fluid—about 12 m^3/day). Three options for decommissioning are being considered: complete retrieval of radioactive waste with above-ground interim storage, relocation of waste to new and deeper chambers in the mine and backfilling the new waste chambers with concrete, or concrete backfilling of the mine and stabilizing the waste in its current location.

Defense-related and other DOE waste generally has a much lower heat load than the commercial HLW assumed in Carter et al. (2011). Evaluation of the DOE waste inventory in Carter et al. (2012) revealed that the vast majority of the packages would be less than 100 watts each, which allows a much more efficient underground emplacement approach. Alcove emplacement of individual waste packages is not required. Instead, an in-room disposal approach was proposed, with variable spacing, to accommodate waste packages with varying heat loads. Most waste packages are closely spaced, with a minimum spacing of 1 foot between canisters (3 feet centerline spacing) to allow for a run-of-mine salt backfill and to ensure packages are not displaced from their intended location as additional waste packages are emplaced. Thermal calculations demonstrated that a maximum temperature of 95°C could be assured for DOE HLW waste packages, even in a densely packed disposal scenario, while a temperature of less than 250°C could be maintained for DOE SNF waste packages by appropriate spacing and/or repackaging.

Regarding waste package/container design, as described in Section 4.0, the DOE has funded studies of waste container material (Bryan et al. 2011). Corrosion-resistant materials such as Ti 99.8-Pd and TiCode-12 exhibit very low uniform corrosion rates that would allow isolation of wastes within the container, if needed, for several hundreds to thousands of years depending on container thickness. However, additional work may be needed to determine conditions under which such materials can be used without experiencing localized corrosion. Alternatively, thick carbon steel (corrosion-allowance) containers could be used, which appear not to be susceptible to localized corrosion (Bryan et al. 2011).

Another important component of salt repository design is the shaft sealing system. The shaft sealing system designed for WIPP, which has been reviewed and certified by EPA, would be the starting point for a salt repository safety case. Any modifications to the WIPP seal design envisioned for a repository for DOE HLW/SNF were it to be sited in Delaware Basin bedded salt would enhance the basic functions for which the WIPP shaft seal system was designed, namely:

- Limit waste constituents reaching regulatory boundaries
- Restrict formation water flow through the seal system
- Use materials possessing mechanical and chemical compatibility
- Protect against structural failure of system components
- Limit subsidence and prevent accidental entry
- Utilize available construction methods and materials

Thus, the DOE could have high confidence that the shaft seal system for a repository containing DOE HLW/SNF will meet requirements associated with repository system performance.

4.4 Preclosure Safety

The analysis of safety before repository closure is a mature science based on a systematic examination of the site, the design, and the potential initiating events caused by underlying hazards (DOE 2008). An initiating event is a departure from normal operation that triggers an event sequence. A preclosure safety analysis will consist of internal and external initiating event identification, event sequence analysis, radiological dose and consequence analysis, and criticality analysis. In this case of disposal in bedded salt the analysis will be supported by data from real packaging, transportation and operational experiences. In particular, operational information gained from experience at WIPP, the Asse mine, and Morsleben can all be inputs to an assessment of safety before closure.

Probably the most relevant information from ongoing WIPP operations includes safe waste packaging/handling at the generator sites, safe transportation practices while moving waste from the generator site to the disposal site, and safe mining practices at the disposal site (DOE 2011a). In addition, experience and analyses gained over the lifetime of the Yucca Mountain Project, specifically related to packaging and transportation of HLW/SNF and the potential vulnerability of waste packages (DOE 2008, see Chapter 1, Repository Safety Before Permanent Closure), can also be used in preclosure safety analyses.

Conceptual design information for the repository design discussed in the previous section could be used to identify initiating events and to conduct preliminary event sequence analyses. Representative waste containers, rather than those of specific designs or specific suppliers, can be analyzed for their failure potential associated with these event sequences. In addition, a range of container dimensions and materials can be considered within the set of representative preclosure safety analyses for the safety case. Conceptual design information on locations and amounts of radioactive material at various locations in the repository could be used in performing consequence and criticality analyses.

Additional site information relevant to a preclosure safety analysis for a conceptual Delaware Basin repository site, such as wind patterns, precipitation, environmental conditions and impacts, are available from the latest WIPP Annual Site Environmental Report (DOE 2011b) and the WIPP EIS (DOE 1997).

4.5 Postclosure Safety

An assessment of repository safety after closure addresses the ability of a site and repository facility to meet safety standards and to provide for the safety functions of the engineered and/or geological components, e.g., containment by engineered and natural barriers or reduction in the rate of movement of radionuclides in the engineered and natural barriers (cf. 10 CFR 63.2 & 40 CFR 191.13/14). A complete safety assessment includes quantification of the long-term, postclosure performance of the repository, analysis of the associated uncertainties in this prediction of performance, and comparison with the relevant design requirements and safety standards.

Figure 3 illustrates the steps in the performance assessment (PA) methodology that was used successfully to certify the WIPP defense TRU waste repository (DOE 1996) and develop the Yucca Mountain License Application (DOE 2008), and has been applied to many other waste disposal projects, dating back to the 1970s (Meacham et al. 2011). This same methodology could be readily applied in an assessment of safety after repository closure for a bedded salt repository for DOE HLW/SNF if it were to be sited in the Delaware basin. The PA methodology shown in Figure 3 organizes a variety of types of information that build confidence in postclosure system safety, including (1) the underlying technical bases for the safety assessment models (a component of the *assessment basis* in some safety case concepts, e.g., NEA 2004), (2) the scenario and FEPs analysis that ensure a comprehensive assessment of postclosure performance, (3) a quantitative and qualitative description of barrier capability (which promotes the defense-in-depth concept), and (4) uncertainty and sensitivity analyses that help quantify where additional information is needed for the next stage of repository development.

Because the conceptual repository proposed in this study is assumed to be located in bedded salt similar to WIPP, many of the FEPs and associated analyses used for the WIPP PA will be applicable, but subject to some modifications and additions, as mentioned in Section 4 above. For example, the phenomena caused by heat from HLW and SNF would add some FEPs, since TRU waste disposed in WIPP is significantly cooler. In addition, the physical and chemical characteristics of HLW are likely to be appreciably different than TRU waste. Therefore, the waste-related and repository FEPs would need to be reviewed. Additionally, there could be differences in the disposal concept, container types, and performance period. There could also be differences in the natural system FEPs depending on the actual location of the HLW and SNF repository, but for the safety case outlined here it will be assumed that the natural system is similar to WIPP. Finally, because FEPs are grouped to construct scenarios for analysis of performance and safety, and because the applicable set of FEPs will be somewhat modified from the set used for WIPP, the appropriate PA scenarios may be different from those included in the WIPP CCA, as well.

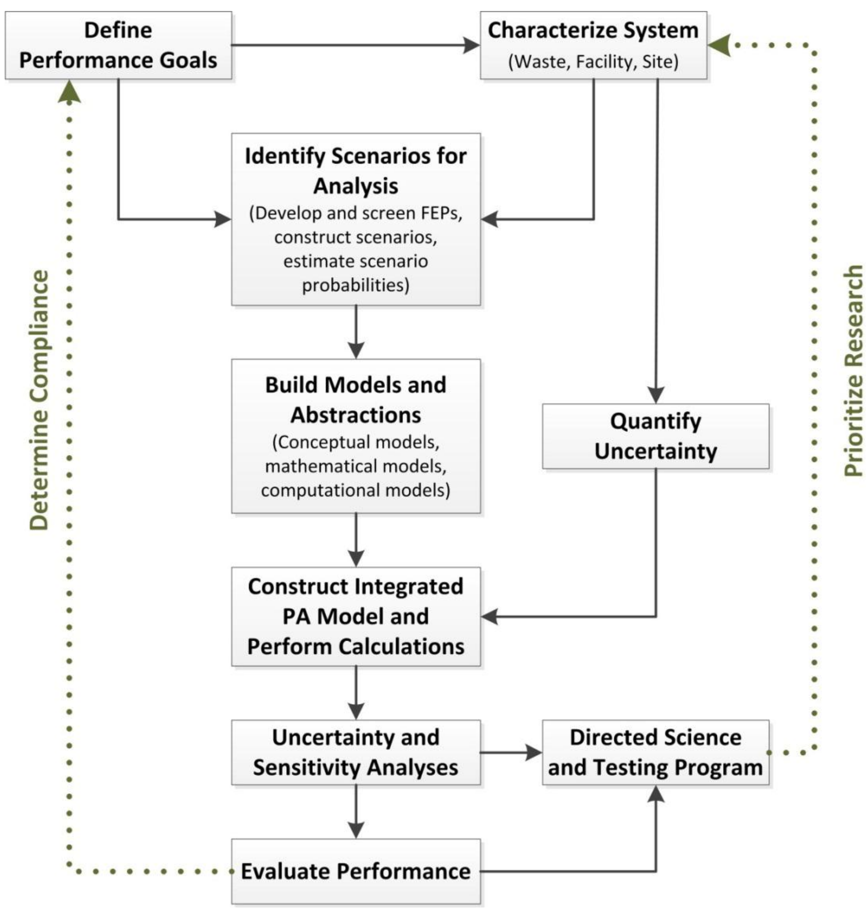

Figure 3. Performance Assessment Methodology (from Meacham et al. 2011).

The advancements in performance assessment for WIPP[9] and other new modeling capabilities, such as the effects of heat on salt (Clayton and Gable 2009, Stone et al., 2010), as well as the existing knowledge base associated with WIPP FEPs, could be used to inform and perform a safety assessment for a DOE HLW/SNF repository. Results from previous postclosure safety assessments provide confidence in the safety of disposal in the Delaware Basin bedded salt, both for TRU waste and for HLW (Weart 1978a & b; also see Appendix B Section PoSC-1 of this report.)

Another key consideration in the assessment of postclosure safety is the identification and analysis of uncertainties that have the potential to undermine the understanding of the degree of safety the system offers. Consideration of uncertainty in the evaluation of safety after repository closure is a well-developed science (see Appendix B, Section PoS-4) that categorizes uncertainty into two major types: uncertainty related to the inherent randomness of the problem (such as random external events that affect safety, e.g., seismicity) and uncertainty related to lack of measurement data (such as the uncertain composition of the current inventory of spent fuel and high-level waste). The former type of inherent or irreducible uncertainty is often called *aleatory* uncertainty and the latter type of measurement or reducible uncertainty is often called *epistemic* uncertainty (Helton et al., 1998). Epistemic uncertainties can be reduced by data-gathering methods, including additional site characterization, design studies, fabrication and other demonstration tests, and other experiments both in the laboratory and in underground test facilities.

Sensitivity analyses from the postclosure safety assessment provide the basis for defining the types of tests and studies needed to reduce epistemic uncertainty and for assigning priorities for further R&D work in the next stage of repository development. This is a key feature of the PA methodology, as indicated in Figure 3, which results from the iterative nature of the process wherein the current performance assessment informs the research and development agenda necessary for the next phase of system characterization, design, and/or implementation. In particular, the PA methodology shown in Figure 3 does not simply encompass evaluations of repository performance and regulatory compliance, which is a more traditional definition of PA. In early stages of repository development, as disposal at a particular site or with a particular design concept is being considered, the methodology includes analyses that inform the decision maker about what is important for repository performance and what, if any, “data gaps” would need to be filled. This iterative principle has been applied to several very different disposal concepts that advanced to licensing: WIPP (DOE 1996), Yucca Mountain (DOE 2008), and Greater Confinement Disposal (Cochran et al. 2011). As recommended by the Nuclear Waste Technical Review Board (NWTRB 2011, p. 53): “Future repository programs should use probabilistic performance assessments throughout the life of a program to help set priorities among site-characterization activities, i.e., to guide the research portfolio.”

Finally, as mentioned in Section 3.1, with regard to the elements of the safety case concept, anthropogenic and geologic analogues provide necessary insight into the safety of permanent nuclear waste disposal and bolster the case for long-term, postclosure safety. In the case of salt,

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[9] WIPP performance assessments have been conducted for the initial CCA in 1996 (DOE 1996) and repeated in 2004 (DOE 2004) and 2009 (DOE 2009).

anthropogenic analogues derive from over 7,000 years of salt excavation by mankind and wide use of salt formations, including for storage of fluid hydrocarbons. The analogue references cited in Hansen and Leigh (2011, Section 1.4) summarize the qualitative evidence that salt formations have the capacity to contain a wide variety of severe conditions permanently (e.g., the effects of seismicity or volcanism).

4.6 Quality Assurance

One important and necessary aspect of each element of the safety case is quality assurance (QA). All elements of repository development must be properly planned, implemented, and documented, such that the technical basis for the safety case is repeatable, transparent, and traceable. All nuclear programs, including radioactive waste disposal facilities, follow strict QA guidelines. The DOE Carlsbad Field Office (CBFO) Quality Assurance Program Document (QAPD) establishes and describes the QA program requirements that apply to the WIPP programs and projects managed by the DOE (DOE 2010). These requirements are applicable to site characterization, general collection of data for PA, PA software and models, expert judgment activities, waste characterization, and environmental monitoring. It is expected that any DOE HLW/SNF facility would follow similar QA requirements. Since the safety case elements developed for WIPP would be similar to those of DOE HLW/SNF facility, many elements of the WIPP QA program should be applicable.

5.0 UNDERGROUND RESEARCH LABORATORY

The safety case supports all aspects of disposal concept development and provides a framework for identifying and prioritizing work in those areas where further understanding is needed to build confidence and ensure the safety of the geological facility. An underground research laboratory (URL), such as the one being proposed at WIPP, could be used to build additional confidence in those areas that would be better examined at a large scale, such as aspects of different design options regarding ventilation and cooling systems, operational efficiency, and safety. Examining coupled physical and chemical processes at a field scale can also help reduce residual uncertainty in these processes because they would be examined at a scale close to the actual scale of a repository.

It should be emphasized that a field-scale disposal demonstration is not needed at this time to initiate a strong safety case for disposal of DOE HLW and DOE SNF if it were to be sited in Delaware Basin bedded salt. However, if it is ultimately determined that a URL is desirable for building additional confidence for the safety case, then field testing should be directed at reducing uncertainties and to addressing those technical issues that may become the focus of interveners in the licensing proceedings. These focused research activities in a URL must be “risk-informed” in a systematic fashion by the current version of the safety case and any associated performance assessment analyses, such as uncertainty and sensitivity analyses which determine the parameters and processes that most affect repository performance. Thus, any test activity potentially used to support licensing should be assigned a priority based on how much it builds confidence in the safety case and reduces uncertainties.

Finally, it is important that a technical management and assessment structure be put in place prior to any testing in a URL. Such a structure would first consider the overall testing needs and preferred arrangements of the URL consistent with the safety case. This would lead to identification and prioritization of demonstration and testing activities and establish their functional and operational requirements. Sequencing of tests and demonstrations, test-to-test interference, data acquisition systems, synergism between and among tests, and the method for evolving from initial tests (say of a single disposal demonstration) to a long-term URL of use to the international salt science community, all need to be addressed prior to any underground testing.

6.0 CONCLUSIONS

Based on the wealth of existing technical information and the multiple performance assessment iterations at WIPP, a defensible safety case can be developed expeditiously for a geologic repository for DOE HLW and DOE SNF waste if it were to be sited in Delaware Basin bedded salt. This conclusion is derived from the following factors:

- The Nation has an extensive knowledge base in salt repository science that indicates that salt is a suitable disposal medium for radioactive waste; this basis stems from prior work on WIPP, work on other repository development programs, and the work published through international efforts in salt repository programs such as in Germany
- Performance assessment (PA) methodology for nuclear waste disposal has been developed, matured, and applied successfully in the certification of WIPP
- DOE has the experience to develop the safety case and associated licensing basis:
  - Managed and developed the WIPP Compliance Certification
  - Managed and developed the Safety Analysis Report and License Application for Yucca Mountain
  - Is actively involved in international safety case projects
- DOE has the experience needed for the construction and operation of a repository:
  - Managed materials and wastes within EPA, U.S. NRC, and DOE regulatory frameworks
  - Transported SNF between sites
  - Developed and operated a geologic repository (WIPP)

The potential benefits of developing a safety case include leveraging previous investments in WIPP to reduce future new repository costs, enhancing the ability to effectively plan for a repository and its licensing, and possibly expediting a schedule for a repository. A safety case will provide the necessary structure for organizing and synthesizing existing salt repository science and identifying any issues and gaps pertaining to safe disposal of DOE HLW and DOE SNF in bedded salt. The safety case synthesis will help DOE to plan its future R&D activities for investigating salt disposal using a risk-informed approach that prioritizes test activities that include laboratory, field, and underground investigations.

It should be emphasized that the DOE has not made any decisions regarding the disposition of DOE HLW and DOE SNF and is presently studying options. This study provides additional information that could be used to inform DOE‘s decision making regarding management of this waste. Furthermore, the safety case discussed herein is not intended to either site a repository in the Delaware Basin or preclude siting in other media at other locations. Rather, this study simply presents an approach for accelerated development of a safety case for a potential DOE HLW and DOE SNF repository using the presently available technical basis for bedded salt if it were to be sited in the Delaware Basin. Experience gained from development of this safety case will also be beneficial if a DOE waste repository is sited outside of the Delaware Basin in either bedded or domal salt.

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APPENDIX A: ELEMENTS OF THE SAFETY CASE CONCEPT

The five elements of the safety case, as defined in Section 3, can be described in more detail as follows (NEA 2004; Van Luik et al. 2011):

- A clear *statement of purpose* is required to set the context of the safety case relative to the decision it is informing. This includes an outline of the program and the current stage (see Figure A-1) or decision point within the program against which the safety case is used to inform. This will set the context in which the defensibility of the safety case and the importance of remaining uncertainties can be judged. It also provides the context for evaluating system performance. Although the current applicable regulatory performance goals given in 40 CFR 191 and 10 CFR 60 may be superseded, one can envision goals and safety indicators similar to those that exist for other repository programs (Bailey et al. 2011). These types of performance goals and indicators can be used at early stages for focusing the safety assessment analyses towards informing future R&D. In later stages of the program, such as the licensing phase, the system performance will be compared directly to whatever safety metrics are prescribed in the regulations.
- The *safety strategy* is the high-level approach adopted for achieving safe disposal, and includes (a) an overall management strategy, (b) a siting and design strategy, and (c) an assessment strategy. Two important principles of the safety strategy are (1) public and stakeholder involvement in key aspects of siting, design, and assessment and (2) alignment of the safety case with the existing legal and regulatory framework. The safety strategy must be sufficiently flexible to cope with unexpected site features or technical difficulties and uncertainties that may be encountered, as well as to take advantage of advances in scientific understanding and engineering techniques, as the project progresses. The siting and design strategy is generally based on principles that favor robustness and minimize uncertainty, including the use of the multi-barrier concept. Similarly, the assessment strategy must ensure that safety assessments capture, describe, and analyze uncertainties that are relevant to safety, and investigate their effects.
- *Site Characterization and Repository Design* contains many parts of the *assessment basis* element of the safety case concept commonly used internationally (NEA 2004), and includes a description of (a) the primary characteristics and features of the repository site and how they will interact with waste degradation and migration processes, (b) the location and layout of the repository (or criteria by which the location and layout will be determined), (c) a description of the engineered barriers and how they will be constructed and emplaced, and (d) a discussion of how the engineered and natural barriers (i.e., the multiple-barrier concept) will function synergistically. The descriptions should be based on existing scientific and technical information and understanding, and include plans for reducing existing uncertainty in this technical and scientific basis. The foregoing description should be centered on the characterization of those safety-bearing components or features of the repository that are ―important to waste isolation” (cf. 10 CFR 63). Site characterization and repository design evolves into implementation after a regulatory decision to authorize construction, when the development then

proceeds to the construction phase (Figure 1). In the earliest phases of the repository program it includes the site selection process and associated selection criteria/guidelines.

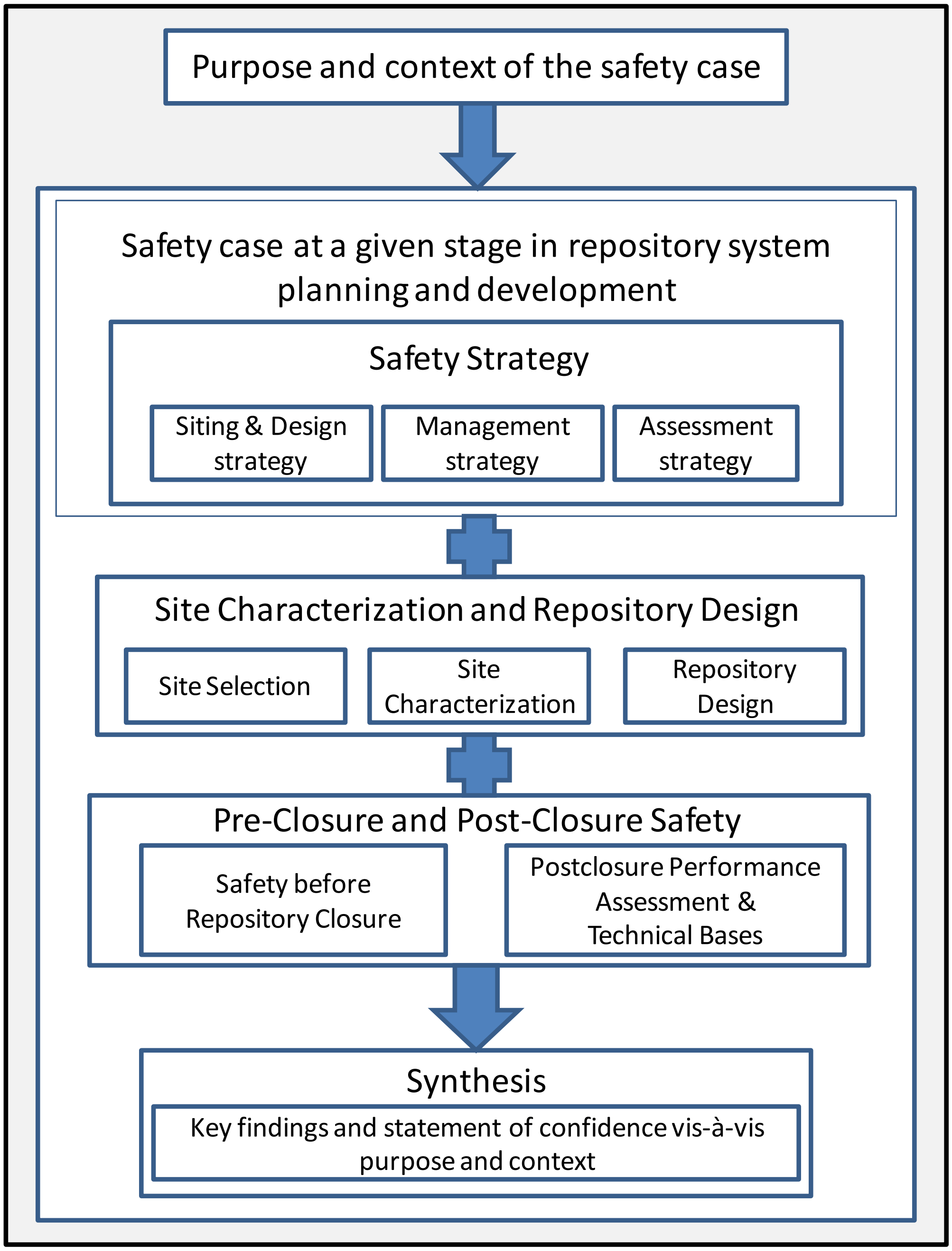

Figure A-1. An Overview of the Elements of a Safety Case (modified from NEA 2004, Fig. 1).

- The *evaluation of preclosure and postclosure safety* provides a quantitative assessment (―safety assessment") of potential radiological consequences for a range of scenarios both before and after closure. This requires a methodological approach to evaluating the numerous processes, features and other technical issues against a set of safety criteria and metrics. Most national regulations give safety criteria in terms of dose and/or risk metrics, and the evaluation of these safety metrics appears prominently in safety or licensing cases that are intended for regulatory review. The evaluation of safety includes both preclosure and postclosure safety analyses, and generally uses sensitivity and uncertainty analyses to determine those uncertain phenomena to which the safety metrics are most sensitive. Another component of the safety analysis is the *modeling basis*, which includes the methods of analysis, computer codes and models, and databases that are currently available to support the numerical modeling of the evolution of the disposal system and the quantification of its performance (NEA 2004), as well as the QA framework by which the computer models and codes are validated and verified. Other evidence and arguments that support the system safety analyses include (a) the intrinsic quality and robustness of the site and the design, (b) insights gained from the study of natural and man-made analogues to the repository components, (c) a strategy to manage and address the key residual uncertainties identified by the uncertainty and sensitivity analyses, and (d) a performance confirmation program to monitor the repository for a period of time after the waste has been emplaced.

- A *statement of confidence* is required to justify a positive decision to proceed to the next phase of planning or implementation. It is based on a *synthesis* of the analyses and arguments developed and the supporting evidence gathered, and includes a discussion of completeness to ensure that all important issues have been addressed. The statement of confidence recognizes the existence of open issues and residual uncertainties, and perspectives about how they can be addressed in the next phase(s), if they are determined to be important to safety. The audience of the safety case must decide whether it believes the reasoning that is presented is adequate, and on that basis whether it shares the confidence of the safety case author.

APPENDIX B: SUPPORTING BIBLIOGRAPHY FOR EXISTING TECHNICAL BASES FOR A SALT REPOSITORY

This appendix provides a supporting bibliography for Section 4 of this document. The references cited below are organized according to the subsection titles from Section 4 and, in particular, to the categories listed in Figure 2 (i.e., SS, SC, RD, PrS and PoS).

Site Selection for WIPP (SS)

Site selection was conducted in a broad sense for salt and to a greater degree for WIPP, utilizing siting factors appropriate for a radioactive waste repository. These included the evaluation of ecology, socioeconomics, geology, hydrology, seismic and igneous activity, geomechanical, geochemical, and thermodynamic properties of salt, and a collection of general science activities not easily categorized in the previously mentioned disciplines. In determining the transition from siting activities to site characterization activities, 1981 was selected as the transition point between site selection and site characterization because it represents the year that construction of the shafts and underground was initiated.

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Preclosure Safety (PrS) Basis – Safety Before Permanent Closure

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Postclosure Safety (PoS) Basis – Safety After Repository Closure

This section provides postclosure safety references, which discuss long-term, postclosure performance of the WIPP repository and analysis of the associated uncertainties, along with a comparison to the regulatory standards.

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- Volume 2: Technical Basis, SAND92-0700/2
- Volume 3: Model Parameters, SAND92-0700/3
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References to the Primary WIPP PA Codes:

User‘s Manual for BRAGFLO, Version 6.0 (ERMS 545016) SECOTP2D – Performs single or multiple component radionuclide transport in fractured or granular aquifers.

User‘s Manual for SECOTP2D, Version 1.41 (ERMS 245734) CUTTING_S – Calculates the quantity of material (in m^3) brought to the surface from a radioactive waste disposal repository as a consequence of an inadvertent human intrusion through drilling.

User‘s Manual for CUTTING_S, Version 6.0 (ERMS 537039) CCDFGF – (Cumulative Complementary Distribution Function). Assembles the release estimates from all other components of the WIPP PA system to generate cumulative complementary distribution functions (CCDFs) of releases using Monte Carlo procedures.

User‘s Manual for CCDFGF, Version 7.0 (ERMS 55046) NUTS – (NUclide Transport). A multidimensional, multicomponent radioactive material contaminant transport, single-porosity (SP), dual-porosity (DP), and dual-permeability (DPM) finite-difference simulator that simulates first-order radioactive chain decay during radioactive material transport.

User‘s Manual for NUTS, Version 2.05 (ERMS 246002) DRSPALL – Calculates the volume of waste subject to material failure and transport to the surface during an inadvertent drilling intrusion into WIPP repository.

User‘s Manual for DRSPALL, Version 1.10 (ERMS 533151) PANEL – Takes the source term data and computes the source term for the elements needed. PANEL also takes brine flow and repository volume data and computes the amount of mobilized radioisotopes that leave the repository.

User‘s Manual for PANEL, Version 4.02 (ERMS 526652) JAS3D – A three-dimensional finite element program designed to solve large quasi-static nonlinear mechanics problems.

User‘s Manual for JAS3D, Version 2.4.C-WIPP (ERMS 545609) EQ3/6 – A software package for modeling geochemical problems involving fluid-mineral interactions and/or solution-mineral equilibria in aqueous systems.

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