Spent Fuel Disposal

Success vs. Failure

A Comparison of the Swedish and U.S. Repository Programs

The spent fuel disposal programs of Sweden and the United States have distinctly different statuses and expected futures. The author examines some perceived root causes for these.

By Leif G. Eriksson

During the past three decades, the national programs for safe deep geological disposal of spent fuel in Sweden (www.skb.se) and in the United States (www.ocrwm.doe.gov) have been the most advanced and scrutinized spent fuel repository programs in the world. Both programs experienced milestone events in 2009 that affected their respective status and future. However, whereas the future of the Swedish repository program remains very promising at the end of 2009, the U.S. disposal program is on indefinite hold and potentially faces a 23-plus-year reversal that could also adversely overflow into Homeland Security areas and could also affect the nuclear renaissance in the United States as well as in many other countries. In simple terms, the current political and public attitudes in Sweden could be characterized as "please come to my backyard" and in the United States as "do not dare to come to my state."

This concise comparative overview of core components of these two programs, subject to additional analyses, can be strategically and beneficially adopted or avoided to advantage both in the U.S. and abroad. It also serves to illustrate that the prevailing national political will, which is time-dependent, ultimately governs the progress and cost of all spent fuel disposal programs. Based on the author's periodic involvements and continuous monitoring of both the Swedish and U.S. repository programs since 1978, the following four "universal" repository program constituents were selected to highlight some perceived major root causes of the status and perilous future of the U.S. disposal program as of the end of 2009:

- Legal and regulatory frameworks.
- Organizational structure.

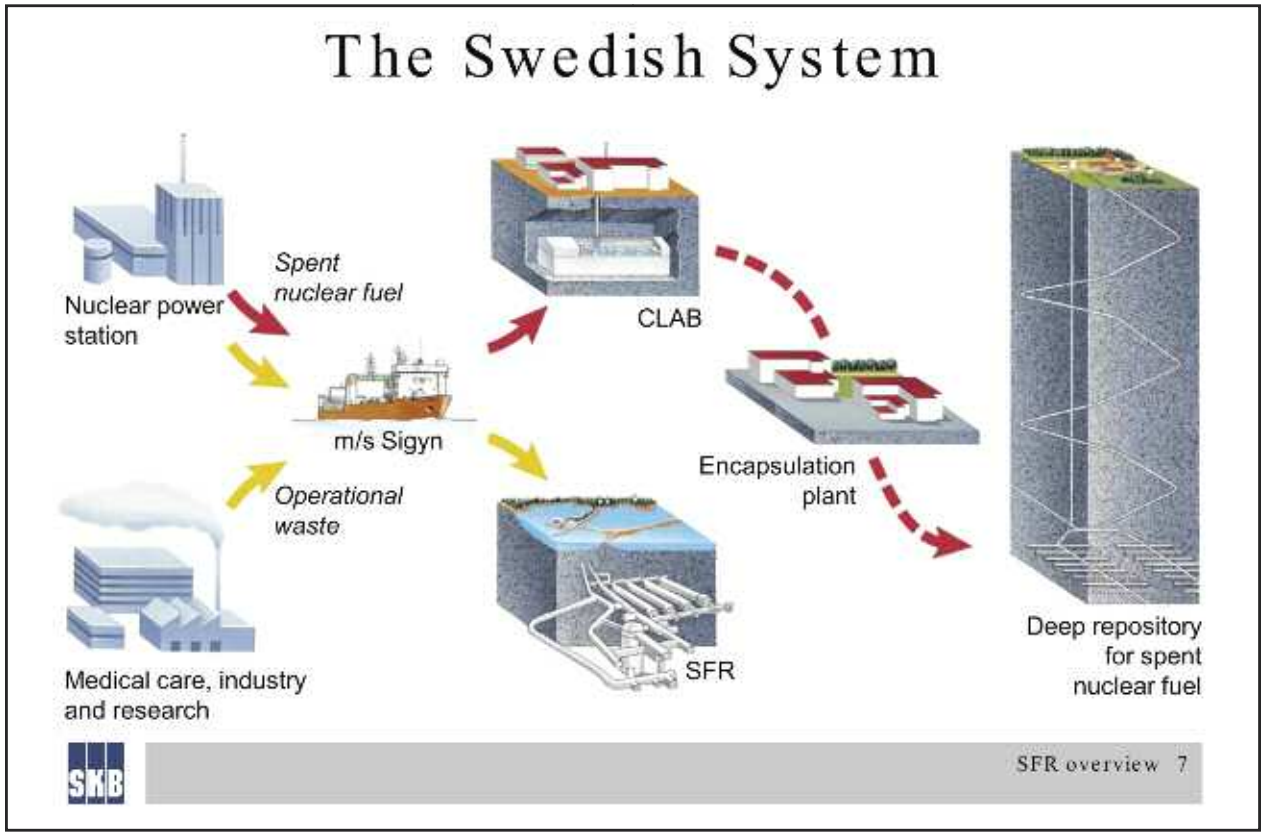

Fig. 1. Schematic illustration of core components of the Swedish nuclear waste management and disposal program/system. (Illustration courtesy of SKB.)
Key: CLAB = A central facility for long-term (30–40 years) storage of spent fuel, which opened in 1985.
SFR = A repository for long-lived low- (LLW) and intermediate-level (ILW) radioactive waste, also referred to as operational waste; opened in 1988.
Dark arrows depict spent fuel. Light arrows depict LLW and ILW. Solid arrows lead to operating facilities.
Dashed line and arrow lead to planned facilities, both projected to open for trial operation in 2023 and regular operation in 2025.

- Siting approach.
- Design concept.

Even though the U.S. repository would have to accommodate at least ten times more spent fuel than the Swedish repository, this difference is neither a root cause of current problems nor does it negate the suggested remedies.

Current Statuses

The U.S. program for the safe management and disposal of spent fuel comprises the following two sequential phases: storage by the generator and disposal by the government. In February 2009, the energy section of the Obama administration's fiscal year 2010 budget priorities outline concluded, "The Yucca Mountain program will be scaled back to those costs necessary to answer inquiries from the Nuclear Regulatory Commission, while the Administration devises a new strategy toward nuclear waste disposal."[1] It was subsequently indicated that this strategy may result in the abandonment of the nation's proposed spent fuel repository site at Yucca Mountain in Nevada,[2] forfeiting the more than 34 years and $13 billion invested to date in the site. At the end of 2009, the Yucca Mountain program, which was already almost 12 years behind schedule and projected to not open for another 7–10 years, was placed on indefinite hold, with no alternative spent fuel storage or disposal option available or being pursued. The pertinacious lack of will by Congress to address the spent fuel disposal issue during the past 12 years seems to me to be one of the two primary root causes of the current status of the U.S. spent fuel repository program, the other being the pestilent performance of the implementing organization, the U.S. Department of Energy's Office of Civilian Radioactive Waste Management (OCRWM, www.ocrwm.doe.gov).

The Swedish government, on the other hand, has been an active participant in the spent fuel disposal program from the outset and has been in favor of direct disposal of spent fuel in a deep geological repository since 1978. The major components of the Swedish program/system for safe management and disposal of all domestically generated nuclear waste are shown in Fig. 1. The Swedish Nuclear Fuel and Waste Management Co. (SKB) develops and operates these components on behalf of the owners of the country's nuclear power plants. At the end of 2009, the only elements of the full repository program remaining to be licensed and opened were the encapsulation plant and the repository. SKB submitted a permit application for the encapsulation plant in November 2006. In June 2009, SKB recommended that Sweden's first repository be built at the Forsmark site in the municipality of Östhammar. SKB also announced that pending a timely

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approval of this site by the Swedish government and Östhammar, the related permit application and environmental impact statement would be submitted in the second half of 2010, as well as related documents for the central storage facility (CLAB) and the pending encapsulation plant. Both the encapsulation plant and the repository are projected to open for trial operation in 2023 and for regular operation in 2025.

In summation, Sweden is currently expected to have a fully integrated nuclear waste management and disposal program/system in place in 2025. Furthermore, CLAB will have ample excess storage capacity, thereby mitigating any potential delay(s) to the opening of the encapsulation plant or the repository.

Legal and Regulatory Frameworks

In the United States

The Nuclear Waste Policy Act of 1982 (NWPA)[3] is the current cornerstone of the U.S. legal and regulatory framework for safe disposal of spent fuel. It directed the secretary of energy to enter into contracts (known as the Standard Contract) with the nuclear utilities for the acceptance and safe disposal of their spent fuel. The Standard Contract states that in return for the fees paid into the Nuclear Waste Fund by these utilities' ratepayers, the DOE will (1) take title to and safely dispose of spent fuel covered by the contract as expeditiously as practicable and (2) commence operation of a spent fuel repository no later than January 31, 1998. The OCRWM was established within the DOE in 1983 to develop and operate the facilities required for fulfilling these obligations. The NWPA also limited the capacity of the first repository to 70 000 metric tons of uranium (MTU) until a second repository was in operation. Subsequently, Congress approved the commingling of utility-generated spent fuel and government-generated spent fuel and other high-level radioactive waste and terminated the second repository program.

In 1987, Congress amended the NWPA (NWPAA)[4] to expedite the search for the nation's first spent fuel/HLW repository, directing the secretary of energy to consider only the Yucca Mountain site in Nevada and to abort studies on two other candidate sites. The governor of Nevada promptly submitted a notice of disapproval, which Congress overrode. Nevada has strongly and successfully opposed the Yucca Mountain repository ever since. This siting approach of ignoring and/or disregarding the opinion of the directly affected parties is a long-standing major root cause of the current status and uncertain future of the Yucca Mountain repository.

In June 2008, OCRWM submitted a construction license application to the NRC for a 70 000 MTU spent fuel/HLW repository at the Yucca Mountain site, of which 63 000 MTU was to be utility-generated spent fuel. Seven months later, in December 2008, the secretary of energy advised Congress that the projected stockpile of spent fuel and HLW would exceed the statutory limit of the Yucca Mountain repository in 2010 and recommended that it be increased. He also suggested that in the event the capacity of the Yucca Mountain repository was not adequately increased, "the most efficient path to identifying potential sites for a second repository would be to start with the other sites and areas that were under consideration for either the first or second repository before the Amendments Act was passed."[5] However, the secretary of energy did not mention the option for saving time and money by also evaluating and taking advantage of lessons learned by other repository programs during the past 23 years, including the domestic Waste Isolation Pilot Plant (WIPP) repository (www.wipp.ws, see Fig. 2), which had been safely operated by the DOE for more than 10 years.

Among many negative domino effects of the current state of the U.S. spent fuel/HLW management program and, in particular, the potential termination of the Yucca Mountain repository, the adverse impacts on Homeland Security issues and on the nuclear renaissance in the United States and abroad stand out. For example, in the absence of a reasonably plausible U.S. spent fuel/HLW disposal solution, the NRC's nuclear waste confidence rule, which is critical to both the licensing of a new plant and the license renewal of existing plants, might need revisions and repromulgation. This process involves public hearings and a court ruling in the most litigious country in the world and could take several years, during which time the related licensing and renewal processes could be brought to a virtual halt.

In addition, abandoning the Yucca Mountain program prior to the NRC's pending ruling on the construction license application would pit politics against science, safety, and existing law by preempting the authority currently vested by law in the NRC and the U.S. Environmental

Protection Agency (EPA) to promulgate and oversee compliance with the nation's regulations and standards for the licensing of nuclear facilities.

While advocates of fuel reprocessing have been energized by the decision to place the Yucca Mountain repository on indefinite hold, it should be recognized that reprocessing would not obviate the need for a geological repository. It would, however, provide the political advantage of an interim destination for the utilities' spent fuel.[2] It would also provide the advantage of reducing the volume of long-lived radioactive waste requiring deep geological disposal, and, if the waste is stored again, the option to reduce either the time-dependent thermal output of the waste at the time of disposal or the area needed for disposal.

At the end of 2008, the utilities had been assessed more than $31 billion (U.S.) in Nuclear Waste Fund fees. The failure of the DOE to comply with the terms of the Standard Contract has been the subject of litigation between the DOE and the utilities. The utilities won and are now entitled to breach-of-contract compensations until such time as the DOE complies with the terms of the Standard Contract. While the amount of damages is contingent on both when the DOE takes title to the utilities' spent fuel and who makes the cost assessment, in 2002 the estimated amount due to the utilities, if the repository would open in 2010 as once scheduled, ranged from some $10 billion to nearly $300 billion. Following the repository program's being placed on hold in 2009, and possibly being abandoned—which, in turn, could affect the validity of the NRC's nuclear waste confidence rule—several utilities have requested relief from the Nuclear Waste Fund fee until there is a reasonably plausible solution. In any fiscally responsible society and accountable organization, these conditions would constitute a major impetus for promptly evaluating organizational improvements and legal modifications. Indeed, based on the current track records of the U.S., Swedish, and Finnish (www.posiva.fi) spent fuel repository programs, there are very strong indications that both the citizens and the utilities in the United States would be much better off if the utilities were responsible for the safe disposal of their spent fuel.

Another major root cause of the current Yucca Mountain program difficulties grew from the NRC site-specific licensing regulation for Yucca Mountain[6] and related EPA environmental radiation protection standards,[7] put forth after more than 25 years of site investigations. They conveyed a very strong message to the general public and others not directly involved or politically or financially dependent upon the OCRWM program that the Yucca Mountain site could not comply with the previous nationwide NRC and EPA regulations[8,9] and that the new regulations did not provide the same level of protection/safety as did the old regulations. These conclusions were reinforced, first, by the WIPP repository (see Fig. 2) having already (in 1998) demonstrated the attainability of the level of postclosure protection/safety prescribed by the EPA[9]; second, by the removal of the 1000-year upper limit for postclosure reliance on the waste canister in the new NRC regulation; and, third, by the evolution of the initial Yucca Mountain disposal concept, which is elaborated upon later in this article.

In fairness, it should be acknowledged that the *Code of Federal Regulations* (CFR) Title 40, Part 197, extended the postclosure period to be projected in the repository system safety/performance assessments from 10 000 years to 1 million years, which at first sight may convey a message of increased safety. However, almost everyone outside the small group of brilliant mathematicians, statisticians, physicists, and other numerically gifted individuals conducting the safety/performance assessments already had difficulties in comprehending and accepting the results for the 10 000-year-long period. The 990 000-year extension made it even more difficult for members of the general public to understand and to accept the results. Indeed, it may have fostered perceptions that code and model developments and the related calculations were being conducted by a small group of numerically enshrined/entrapped individuals with little or no relevant hands-on experience, and the results were merely reflecting numerical hallucinations. As discussed later, perception becomes reality unless the recipient fully understands the message or trusts the messenger.

In Sweden

The Stipulations Act of 1977, the Financing Act of 1981, the Nuclear Activities Act of 1984, and the Environmental Code of 1998 are the legal cornerstones of nuclear waste management and disposal in Sweden. The Stipulations Act required reactor owners to produce an account of "absolutely safe" disposal of spent fuel. At that time, Sweden planned to reprocess its spent fuel, which is no

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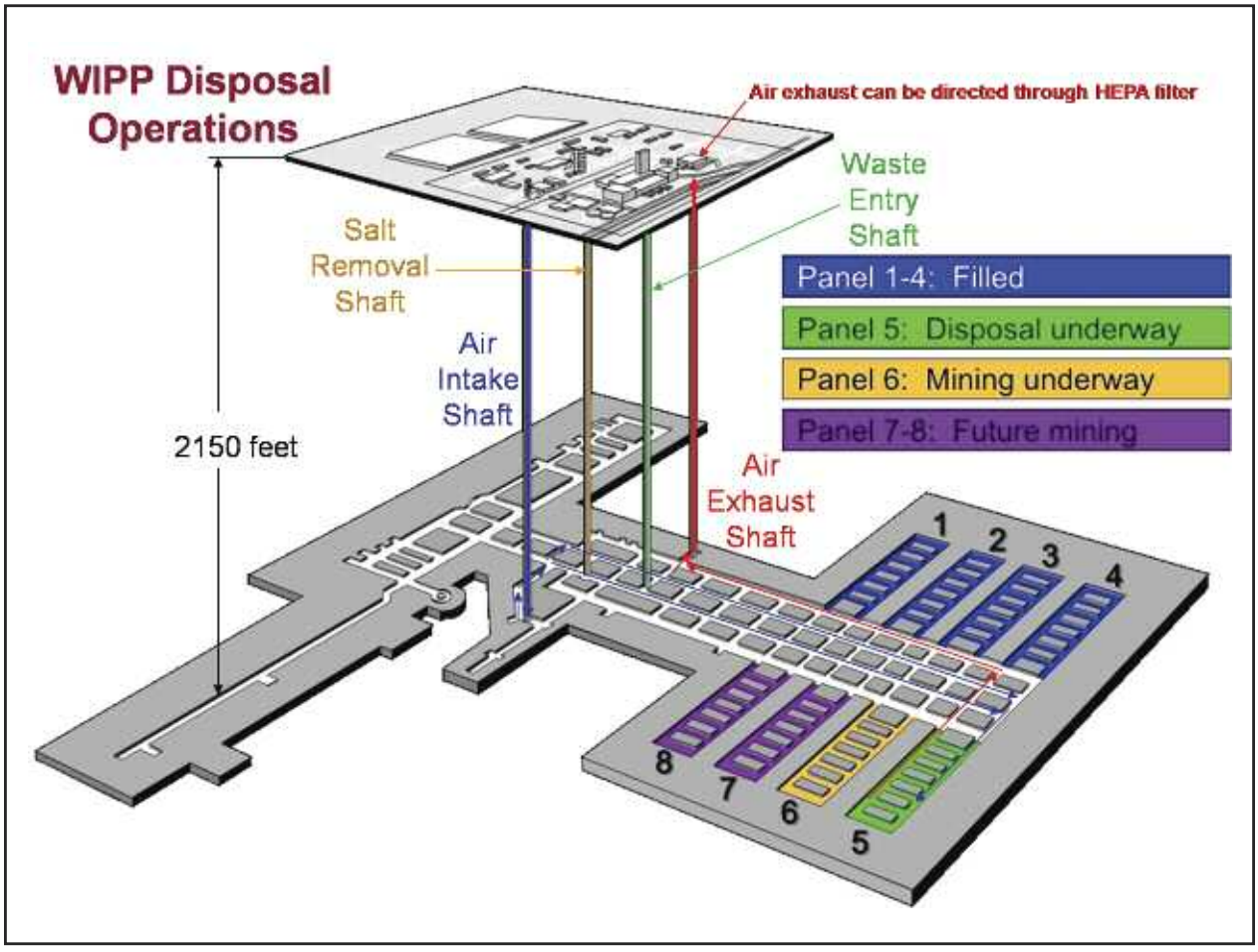

Fig. 2. Schematic illustration of the layout and current status of the WIPP transuranic waste repository. (The tunnels left of the air exhaust shaft, also referred to as the North Experimental Area, have been used since the late 1970s for full-scale transuranic waste, spent fuel, and HLW tests.)

longer the preferred option. Rather, the preferred Swedish option during the past 32 years has been direct disposal of the spent fuel, with the long-term (30–40 years) interim spent fuel storage component added in 1983. The Financing Act clarified how the costs for radioactive waste disposal were to be allocated and how the nuclear industry should pay fees into a domestic nuclear waste fund. The Nuclear Activities Act also required the utilities to submit a report on the progress of its research, development, and demonstration (RD&D) work every three years. The RD&D report is prepared by the SKB on behalf of the utilities and submitted to the regulator for review and distribution to affected parties. To date, SKB has prepared eight such reports that have served as the basis for its dialogue with the communities considered for hosting the spent fuel repository, the regulators, the National Council for Nuclear Waste, and other interested parties. The Environmental Code required the utilities to provide an environmental impact assessment for the repository site, the use of "best available technology," and the evaluation of alternative disposal method designs, including an appendix containing all received comments and SKB's related comments. Two inherent advantages of this legislative framework relative to that currently in effect in the United States are that (1) SKB is shielded from temporary political and ideological agendas and (2) the utilities can control the cost of the spent fuel management program as well as the pace of the disposal program.

Comparison

One perceived root cause of the current status of the OCRWM program is the pervasive distrust in the OCRWM because there is no legal or regulatory requirement for it to be transparent and periodically lay its long-term plans on the table and consider and timely respond to feedback from affected and interested parties. The DOE does, however, submit annual budget requests to Congress based on the pending program, but, with few exceptions, Congress has usually directed the DOE to accomplish the proposed program at a lower cost (a major setup for failure), which has contributed to the DOE's failure to comply with the terms of the Standard Contract.

Three distinct organizational structure differences between the implementing organizations for spent fuel disposal in the United States and Sweden are their respective "ownership," their upper-management staffing procedures, and confidence and trust among the general public and other parties not directly involved in or financially or politically affected by the respective program.

SKB is a private company, fully owned and controlled by the owners of Sweden's nuclear power plants, including the Swedish State Power Board (Vattenfall) as well as foreign owners, whereas OCRWM is a politically controlled federal agency. The upper management positions in SKB are staffed with career nuclear energy and waste management professionals, as are several seats on the SKB's board

of directors. In contrast, the director of OCRWM and the positions above her/him, including that of the secretary of energy, are staffed by politically selected and appointed individuals who, typically, have very little, if any, previous experience in nuclear waste management or disposal, and may serve only four years (one presidential term). Consequently, the upper management of SKB benefits from institutional memory, ample relevant experience, and accountability, but this may not always be the case with the DOE and OCRWM. Indeed, comparing the respective 30-year-long track records and the current statuses and expected futures of the two programs strongly suggests that the organizational structure in the United States would be improved by transferring the responsibility and cost for the siting, development, and operation of future commercial spent fuel disposal solutions and the control of the related financing mechanism to the nuclear utilities.

Three other perceived benefits of utility ownership are improved leadership, increased trust in the messenger,[10] and a more conventional fiscal accountability concept. Case in point: the OCRWM program is already 12 years behind its contractual obligations and projecting at least another seven-year delay, the related statutory obligation for safeguarding the spent fuel has by default been unilaterally transferred to the utilities with considerable adverse economic impacts to the ratepayers and taxpayers, and no one within the DOE has been held accountable to date. The DOE's, as well as its contractors', long-standing accountability and award concepts seem to be based upon applying for as much funding as possible, being awarded less than requested, spending it all regardless of accomplishments, attributing lack of progress to funding deficits, and applying for more funds the next year.

Siting Approaches

The cornerstone of the Swedish siting approach since 1992 has been to consider only voluntary communities where the majority of the residents favor hosting the nation's spent fuel repository. On the other hand, the U.S. siting approach over the past 27 years has been to look at several host rocks, without regard to the opinions of the host communities or the majority of their affected residents. In simple terms, the U.S. siting approach to date may be described as a congressionally directed steamrolling of the affected communities, its residents, and its elected representatives. As experienced in the past by repository programs around the world, including the United States, France (www.andra.fr), Switzerland (www.nagra.ch), Sweden, and the United Kingdom (www.dna.co.uk), this approach carries a very high probability of failure.

One main benefit resulting from the voluntary repository host approach employed in Sweden is that the major repository-related issues are primarily handled in a timely and professional manner by the candidate host communities and SKB. This relationship has eliminated almost all the free-for-all, long-distance, often self-serving ideological and political grandstanding that has adversely affected the progress and the costs of the U.S. spent fuel disposal program during the past three decades. Indeed, this U.S. approach is the primary root cause of widespread past and current local and national opposition to the Yucca Mountain repository, as well as to several of the previously considered sites, areas, and regions the previous energy secretary recommended as starting points in the search for another repository site.[5]

Two related contributors to the current status and perilous future of the Yucca Mountain repository program are the selection in 1987 (under the NWPAA) of a site with a globally unique repository host rock and the subsequently increased thermal loading of the host rock. These virtually eliminated the option and benefit of collaborating and exchanging state-of-the-art scientific and engineering information with other repository programs and required the OCRWM program to single-handedly develop, test, and validate time-consuming and costly beyond-the state-of-the-art, one-of-a-kind disposal concepts, codes, and models.[11]

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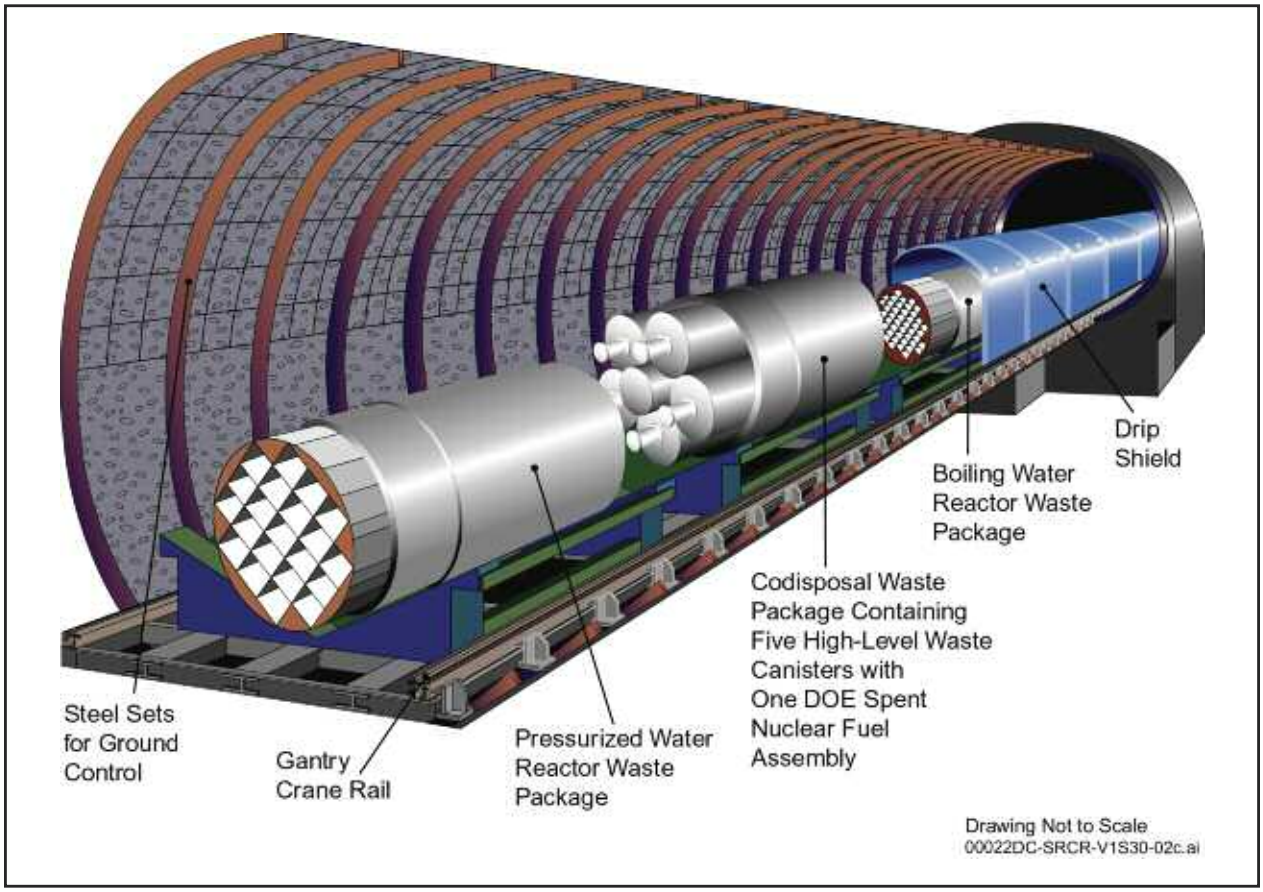

Fig. 3. Schematic illustration of the current disposal room design at the Yucca Mountain site.

Disposal Concepts

Although disposal concepts pursued in the United States and Sweden differ significantly, one important point to be made before addressing these differences is that the fundamental objective of any repository design, operation, and performance is to demonstrate compliance with applicable laws and regulations. In other words, any repository concept/design meeting applicable laws and regulations is, by definition, adequately safe, provided of course that these laws and regulations have been framed so as to provide adequate protection for the public and the environment.

One distinct difference between the two disposal concepts is that the Yucca Mountain repository would be located in the vadose zone (contains sink and pore water but is not fully saturated), well above the regional groundwater table, while the Swedish repository would be located well below the regional groundwater table. As illustrated in Figs. 3 and 4, the related disposal room designs differ considerably.

Another perceived root cause to the current perilous status of the Yucca Mountain repository is the evolutionary history of the disposal concept. In the 1970s, the proposed disposal concept was to place the spent fuel in a dry underground environment and then let it cool by convection with virtually no other engineered barrier system than the waste container (at that time the room, tunnel, and shaft seals were not considered to be engineered barriers). Based on the ensuing site characterization of the Yucca Mountain site, the currently proposed design concept (Fig. 3) is significantly more complicated and expensive. For example, the state-of-the-art drip shield alone, shown in Fig. 3, is projected to cost approximately $16 billion.

Another differing component of the current disposal concepts of critical importance to the validation, understanding, and acceptance of the postclosure safety/performance assessments is the magnitude and duration of the thermal pulse induced into the engineered barrier system components surrounding the spent fuel and into the host rock. The thermal pulse induced by the spent fuel emplaced in the Swedish repository will be below the prevailing vaporization point of the surrounding groundwater at all times. At the Yucca Mountain site, the spent fuel will be used to induce a thermal pulse that will establish a thermal gradient in the host rock that, in turn, will generate steam curtains driving moisture away from the emplaced spent fuel and HLW. This state-of-the-art "steam curtain" concept severely complicates the already Einsteinian challenge of attempting to assign numerical values to prevailing features, events, and processes in the inherently inhomogeneous geological setting and then quantitatively projecting their evolution for 1 million years at the Yucca Mountain site. The Yucca Mountain steam-curtain concept will, however, reduce the horizontal area needed for disposal at the Yucca Mountain site relative to the Swedish disposal concept. It was initially perceived as a brilliant concept for accommodating 70 000 MTU at a site with limited areal extent.[11] In other words, the thermal loading of a repository embodies a trade-off option between reducing the horizontal area required for waste disposal and increasing the

complexity and uncertainty in the safety/performance assessments.

Notwithstanding the 1-million-year-long safety/performance assessment period's inherent formidable intellectual challenge, it is not currently seen as a major root cause of the current status or uncertain future of the Yucca Mountain site. The length of that period does, however, impose a high premium on "trust in the messenger,"[10] which *is* a perceived root cause of the current status of the Yucca Mountain site that also could affect the future of the OCRWM program, because the safety/performance assessments are the fundamental yardsticks for approving or rejecting the construction license application, as well as the pending waste receipt license application.

Unfortunately, in the United States there is an entrenched public lack of trust in the government. Fueling that mistrust, at the end of 2009 the projected opening of the nation's first repository was at least 19 years behind schedule, and no other option has been actively promoted or pursued during the past 12 years that would alleviate this status and/or the related financial breach-of-contract obligations to the utilities. Furthermore, pending the NRC's ruling on the Yucca Mountain construction license application, only a few select "licensing" individuals at or hired by the OCRWM are allowed to communicate with affected and interested parties. As follows, there is no apparent reason for local residents and other members of the public to engender any confidence or trust in the DOE or the OCRWM if transparency is not an integral component of the OCRWM program.

A Path Forward?

In closing, once upon a time, the U.S. and the Swedish spent fuel repositories were projected to open in January 1998 and in 2017, respectively, but similar to all other national (and regional) spent fuel disposal programs, they have experienced roller-coaster rides adversely affecting cost, schedule, and public and political confidence and support. However, while the Swedish program appeared to be near the end of the ride at the end of 2009, the U.S. program, after several detours on the political merry-go-round, seems to be stuck on a giant political Ferris wheel that will certainly delay the previously projected (2017–2020) opening of the Yucca Mountain repository and *might* result in a 23-year-plus extension of the current 50-plus-year ride.

In addition to the Swedish program, other national repository programs, including that for WIPP, have had significantly greater success in accomplishing their milestones and avoiding cost increases than has the OCRWM program. For example, the "voluntary-host-community, majority-of-resident-support" siting approach has proven its long-term benefits at WIPP and in Finland, France, and Sweden. On the other hand, the current U.S. and similar nonvoluntary-host siting approaches already have led to terminal failures in many countries, including but not limited to Canada, France, Sweden, Switzerland, and the United Kingdom.[12, 13] In other words, all of these countries have seen and benefited from lessons learned domestically and/or abroad, whereas the United States has not despite already having proven the successful outcome of the voluntary approach at WIPP, where strong local support effectively negated vociferous long-distance opposition.

The following four proven remedies could mitigate the perilous future and escalating costs of the U.S. spent fuel and HLW disposal program:

- Transfer the responsibility for safe disposal of commercial spent fuel to the utilities, which would unify the nation's management and disposal of commercial spent fuel under one industry entity that would work with rather than for the ever-changing political community. The safe disposal of government-generated spent fuel and HLW (and greater-than-Class C low-level radioactive waste) would remain the DOE's responsibility and leave

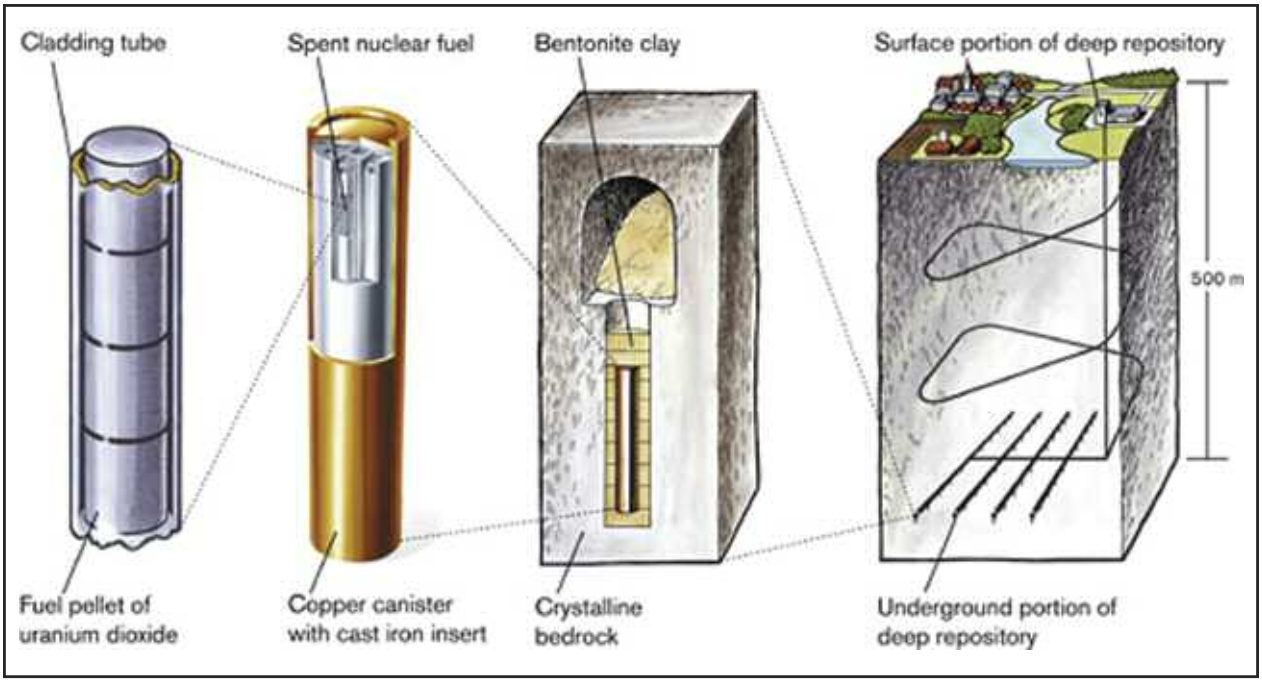

Fig. 4. Schematic illustration of the Swedish SKB-3V disposal concept (500 m = ~ 1640 ft). (Illustration courtesy of SKB.)

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the DOE with the following three cost-effective solutions: (1) a much smaller "defense-waste-only" repository at the Yucca Mountain site and/or (2) an expanded mission of the WIPP repository/site and/or (3) buying disposal space in a commercial repository.

- Promulgate and implement nationwide NRC and EPA licensing regulations.
- Employ a siting approach based on voluntary host communities where the majority of the residents are in favor of hosting a repository in their "backyard."
- Establish at least one federal central storage facility to accommodate the multiyear legal process required for the three previous remedies and any required modification to the NRC nuclear waste confidence rule.

However, all of these remedies require either amendments of current or enactment of new laws. As follows, the future of the United States' spent fuel management program currently rests upon the shoulders of the Congress, as does the restoration of the United States' standing as a global leader in nuclear waste management.

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Leif G. Eriksson is a retired nuclear waste undertaker. This article is based on his periodic involvements in and continuous monitoring of the U.S. and Swedish repository programs since 1978. They include more than 10 years of direct involvement in each of the U.S.'s two deep geological repository programs for safe disposal of long-lived radioactive waste, the National Waste Terminal Storage/OCRWM and WIPP programs; related periodic status reports since 1985 to the International Association for Engineering Geology on the main challenges facing these programs and potential solutions thereto; and five independent reviews of the Swedish spent fuel disposal program—three for the Swedish Government and two for one of the two candidate repository host municipalities. Eriksson can be reached at nukewastedisp@gmail.com.