Salt Rock - the 60-Year-Old Prodigy Host Rock for Consent-Based Disposal of Long-Lived Radioactive Waste - 16010

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ABSTRACT

The USA's HLW-disposal program has been on hold since 2010 pending enabling legislation for its only candidate HLW-repository since 1987 at the Yucca Mountain site in Nevada and/or other, "consent-based", HLW-disposition solutions. Related projections in 2008 and 2012 suggested they might open 9-12 years and 35 years after being adequately enabled, respectively. In 2014, domestic HLW arisings exceeded the capacity of the candidate repository by >4,000 metric tons (MT) and they were projected to grow by 2,000-2,300 MT/year. One or more new HLW repositories are thus highly-likely in the future. In the meantime, ***the DOE should make every effort to promptly take title to civilian-generated HLW by other means***.

Historical evidence in the USA and abroad during the past 30+ years shows that all HLW-repository siting and development schedules and costs are governed by the inherent, intricate, relationships and related domino effects of the:

1. Maturity/robustness of the disposal concept;
2. Related levels of relevant domestic repository-sciences/engineering expertise, data, institutional knowledge, and applicable regulations;
3. Abundance and "ease" of physical access to potentially-suitable host-rock sites;
4. "Trust" in the implementing and regulating organizations;
5. Timely resolution of inevitable contentions and lawsuits;
6. Facility-host-acceptance level;
7. Timely and adequate enabling legislation, and therefore, *ultimately*, by
8. Prevailing POLITICAL WILL.

Based upon their respective status at the end of 2015, *salt rock still offers the most, but not the only, promising path forward for new, mined, HLW repositories in the USA, and ~5-km-deep boreholes offer the most-promising disposal-solution for small HLW containers/packages/pellets*.

INTRODUCTION

At the end of 2015, the USA's only candidate high-level radioactive waste (HLW)[a] - repository since 1987 at the Yucca Mountain (YM) site in Nevada (Figure 1) [1-2] had been on hold since 2010 [3], pending enabling legislation for it and/or the consent-based siting and development (S&D) strategy for new HLW-disposition (storage and disposal) facilities recommended by the Blue Ribbon Commission on America's Nuclear Future (BRC) in January 2012 [4]. The focus of this paper is the

[a] Although the definitions for UNF, SNF, and HLW differ in the USA and among countries, as used herein, the term HLW may include none, one, or both of them, as well as only one of U.S. civilian- (CHLW) and defense-generated (DHLW) HLW.

timely and cost-effective S&D of at least one new, "consent-based", HLW repository based upon the following three main boundary conditions:

1. The December 2008 recommendation by then Secretary of Energy (Secretary) to the U.S. President and Congress [5] to start a new HLW-repository-siting program based on the sites evaluated under the Nuclear Waste Policy Act of 1982 (NWPA) [1] and abandoned by the Nuclear Waste Policy Amendments Act of 1987 (NWPAA) [2] that left only the YM site (Figures 1 and 2).
2. The author's active involvement in, monitoring of, and reporting on long-lived radioactive waste management and -disposition programs in the USA and abroad since 1978 [e.g., 6-20].
3. Potentially-suitable, domestically-abundant, rock types and mature, *global*, HLW-disposal concepts and their respective repository host rock at the end of 2015 deemed particularly promising to gaining and sustaining *majority local acceptance* of a <u>new</u> HLW repository host rock[b].

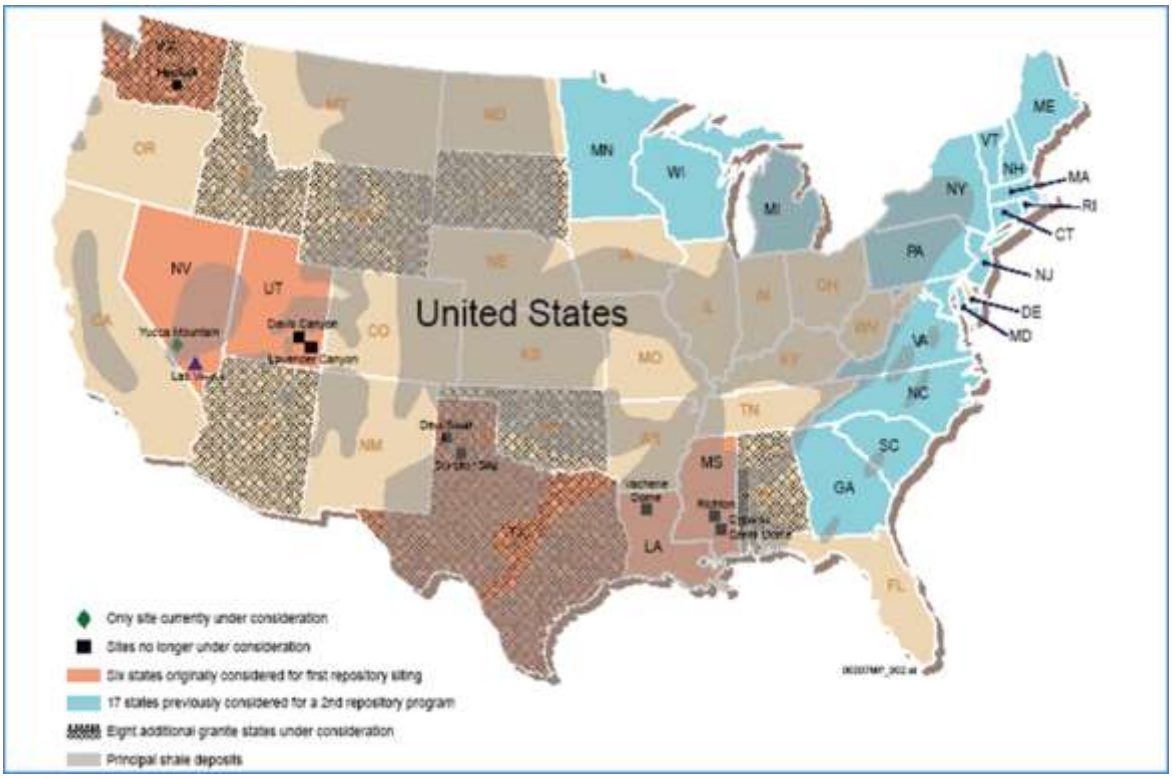

Fig. 1. Locations of the Yucca Mountain site and other sites, areas, and regions in the contiguous USA considered for HLW-disposal since 1982[c].

[b] Although Belgium, Japan, and Switzerland have comparatively mature HLW-repository programs, including long-standing underground research laboratories, evaluating "clay", they are not included herein, due to their repository being either situated close to the surface, in soil material, i.e., over-consolidated clay, or not scheduled to open before 2030.
[c] The repository host rocks considered in the six states shown in orange were: basalt in WA; welded tuff/ignimbrite in NV; bedded salt in UT and TX, and domal salt in LA and MS. The second repository program (blue states) focused on igneous/crystalline rocks, also referred to as "granite". But "shale" was not a rock type evaluated under the NWA [1]).

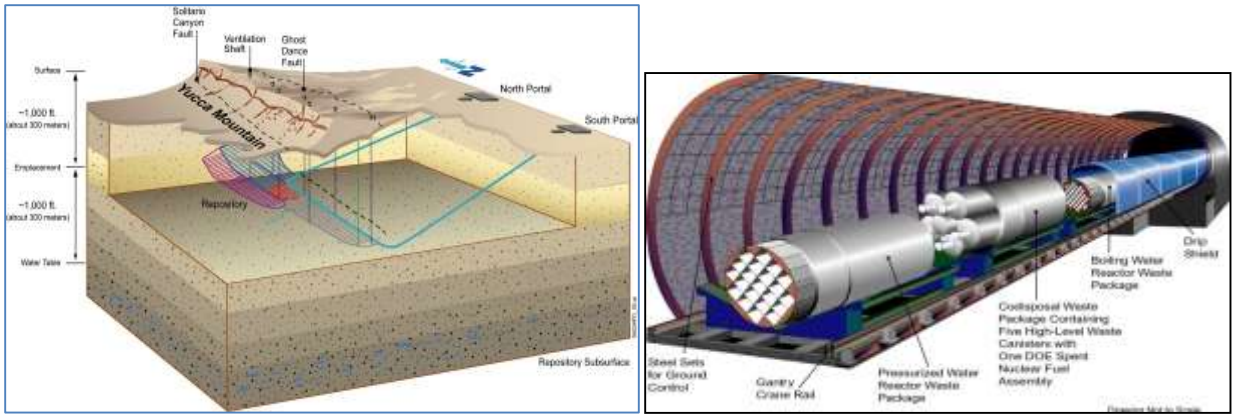

Fig. 2. Schematic illustration of the layouts of the Yucca Mountain HLW repository and its existing access tunnels and URL niches (left) and (right) the disposal-room and in-room HLW-emplacement concept.

Main observations, opinions, conclusions, and recommendations herein are typically accompanied by one or more Arabic numbers within brackets [1-36] that refer to the same-numbered data sources listed in full in the REFERENCE section. Internet links to some data sources are also provided within brackets in the text.

BACKGROUND

In 1957, following a 1955 conference, a U.S. National Academy of Sciences-National Research Council report on land disposal of **liquid** HLW concluded [21]:

A. *"Radioactive waste can be disposed of safely in a variety of ways and at a large number of sites in the United States."*
B. *"Disposal in cavities mined in salt beds and salt domes is suggested as the possibility promising the most practical immediate solution of the problem."*
C. *"Disposal could be greatly simplified if the waste could be gotten into solid form of relatively insoluble character."*

In March 1999, a deep geologic repository in *bedded salt* for up to 175,584 m^3 of solid-form, long-lived transuranic radioactive waste (TRUW), opened at the Waste Isolation Pilot Plant (WIPP) site in New Mexico (Figures 3 and 4) [e.g., 11-16]. But all other searches for a mined HLW repository in salt rock had been abandoned in stages by the end of 1987, as had those in all other rock types shown on Figure 1, except a thick sequence of volcanic ash layers at the YM site in Nevada [2]. The NWPA [1] limits the disposal capacity of the USA's first HLW repository to 70,000 metric tons (MT) of HLW [1]; subsequently projected to comprise ~ 90% commercially– (CHLW) and ~ 10% defense-generated (DHLW) HLW. As shown on Figure 2, the YM HLW repository would be situated in an ~ 100-m thick welded-tuff/ignimbrite located in the vadose zone ~ 300 m below the ground surface and above the regional groundwater table [e.g., 8,16,21]. Its construction license application (CLA) was submitted in June 2008 [22], but, similar to the U.S. Department of Energy (DOE), the U.S. Nuclear Regulatory Commission (NRC) has not been allocated funds since 2011 to complete the review of the CLA. The NRC's preliminary review did not identify any disqualifying condition.

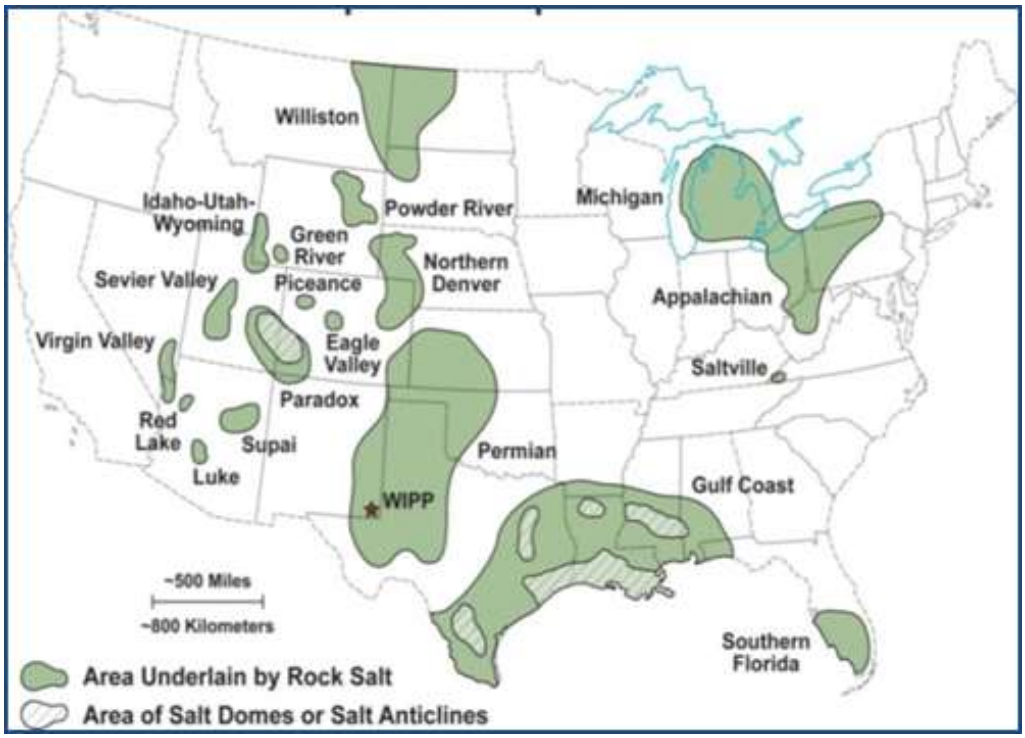

Fig. 3. Locations of the WIPP TRUW-repository site and major salt-rock deposits in the USA.

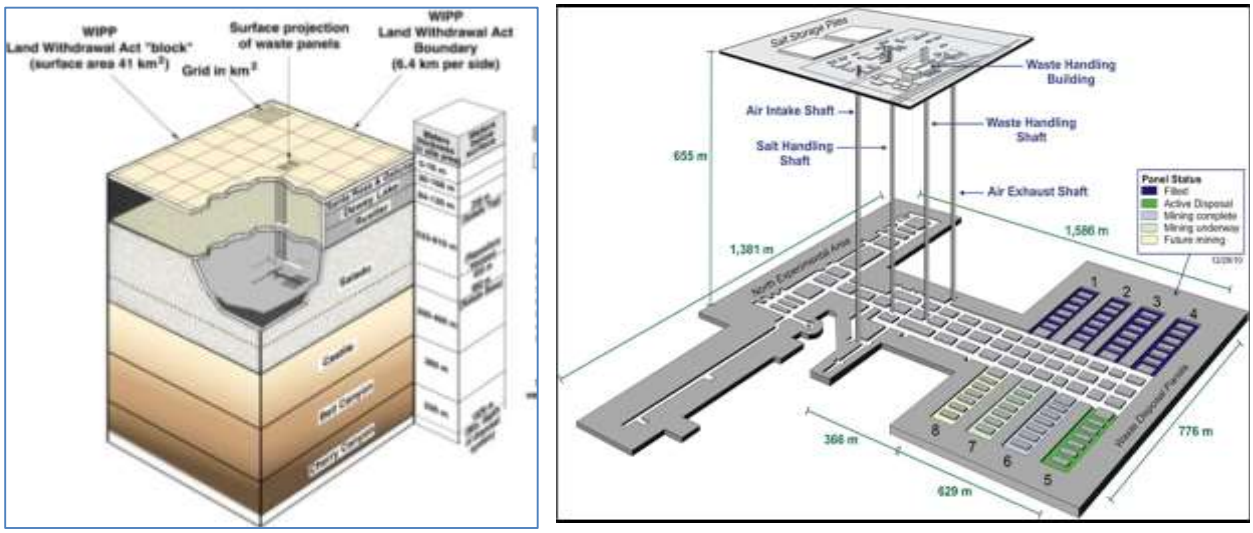

Fig. 4. Schematic (not to scale) illustrations of the 75 km^3 geosphere set aside for the WIPP disposal system (left) and the layouts of the underground repository, the shaft pillar, and the North Experimental Area (URL).

In October 2014, the DOE recommended separate disposal paths for CHLW and DHLW [23], and its Office of Nuclear Energy (NE) is already evaluating deep borehole disposal (DBD) of DHLW at the end of 2015, adding uncertainty and complicating the projection of future HLW-disposal paths/options.

DESCRIPTIONS AND DISCUSSIONS

As schematically illustrated above on Figures 1-4, a large number of sites, areas, and regions in the USA with different rock types have been evaluated for geological disposal since the enactment of the NWPA in January 1983 [1] for their respective suitability to host a safe, mined, HLW-disposal solution. The ensuing descriptions and discussions begin with the author's understanding of the status of and prospect for HLW-disposal in the USA at the end of 2015, followed by those in the countries currently projected to open the worlds' three first HLW repository, i.e., Finland in 2023 (http://www.posiva.fi), France in 2025 (http://www.andra.fr), and Sweden in 2027 (http://www.skb.se. Concise descriptions of a few lessons learned in Finland and Sweden deemed particularly promising to expediting a future, consent-based, HLW-repository S&D process in the USA, if timely adopted, adapted, and funded are also presented. A summary of the author's main concerns about starting a new HLW-repository-siting program based solely upon the abandoned sites recommend by the then Secretary in 2008 [5] concludes the descriptions and discussions.

HLW-Disposal Status and Prospects in the USA at the End of 2015

Following in quasi-chronological order are descriptions and discussions of recent events and lessons-learned in the USA and abroad deemed to govern the status of and/or future prospects for HLW disposal in the USA at the end of 2015:

A. ***In January 2012,*** the BRC recommended a new national strategy/policy for the back end of the nuclear fuel cycle based upon eight "Key Elements" [4]. However, pursuant to directions received from the Obama administration, the BRC neither addressed the suitability nor the future of the YM site.
B. ***In January 2013***, the then Secretary presented the Obama administration's BRC-related, 14-page, strategy [24]. It included, *unexplained*, projections that the USA's first "consent-based": a) Consolidated CHLW-storage facility would open *"by 2025"; and b)* CHLW-disposal facility would open *"by 2048"*.
C. ***Three rulings; one in 2012*** [25] ***and two in 2013*** [26-27], by the U.S. Court of Appeals for the District of Columbia Circuit (the A-Curt) included:
    1. Rulings the NRC and the U.S President were in violation with applicable law by stopping the CLA-review and the development of the YM HLW repository in 2010, respectively, and to continue evaluating and developing it until new legislation to the contrary had been enacted.
    2. References in [27] to the Secretary's 2013 strategy [24] as *"truly pie in the sky"* and *"the strategy is based on assumptions directly contrary to law."*
D. ***Two virtually-identical efforts; one in June 2013 (S.1240-IS)*** [28] ***and one in March 2015 (S.854-IS)*** [29], had been made in the U.S. Senate to enact enabling legislation for the S&D of one or more, new, consent-based, HLW-disposition facilities by a new organizational structure, but ***none of them had been enabled or enacted by the end of 2015***. As understood by the author, two paradigms proposed in S.854-IS deemed of particular importance to the S&D of new HLW repositories are:
    1. A new organizational structure in the Executive Branch, referred to as the Nuclear Waste Management Administration (NWMA) and comprised by the Nuclear Waste Administrator (NWA) and the Nuclear Waste Oversight Board

(NWOB) would take over the HLW-disposition responsibilities assigned to the "Secretary" in the NWPA [1].

2. Consent-based S&D by the NWMA of one or more HLW-disposal facilities.

As shown in TABLE I and elaborated upon in another WM2016 paper [30], the upper-managers of the NWA and the 5 members of the NWOB would be solely selected and appointed by the U.S. President with the advice and consent of the U.S. Senate. Figuratively speaking, the new organizational structure proposed in S.854-IS may be likened to leaving the old pig locked up and letting it starve to death, and replacing it with a piglet that has no life-experience, its legs tied together, and a ring through its nose with a golden chain connecting it to the White House and the Senate.

TABLE I. Independent Agencies in the Executive Branch and Related Positions and Terms of Service Proposed in S.854-IS [29].

Agency	Position	Selected and Appointed by	Term Limit
Nuclear Waste Administration (NWA)	Administrator	U.S. President and U.S. Senate	6 years[a]
	Deputy Administrator	U.S. President and U.S. Senate	6 years[a]
	Inspector General	U.S. President and U.S. Senate	No Limit
	General Counsel	The Administrator	No Limit
	Financial Officer	The Administrator	No Limit
	<4 Assistant Administrators	The Administrator	No Limit
	? Clerical staff	(TBD)	(TBD)
Nuclear Waste Oversight Board[b] (NWOB)	Member #1[c]	U.S. President and U.S. Senate	1 year[d]
	Member #2[c]	U.S. President and U.S. Senate	2 years[d]
	Member #3[c]	U.S. President and U.S. Senate	3 years[d]
	Member #4[c]	U.S. President and U.S. Senate	4 years[d]
	Member #5[c]	U.S. President and U.S. Senate	5 years[d]
	Executive Secretary	The Oversight Board	No Limit
	<11 Clerical staff	The Oversight Board	No Limit

[a] *May serve more than 1 term.*

[b] *The U.S. President designates the Chair of the Nuclear Waste Oversight Board.*

[c] *Not more than 3 members of the Nuclear Waste Oversight Board may be members of the same political party.* But *"3 members of the Oversight Board shall constitute a quorum for the purpose of doing business."*

[d] *A member of the Oversight Board may be reappointed for an additional term by the President, by and with the advice and consent of the Senate.*

E. ***An October 2014 DOE report*** [23] included the following Section 8(a) of the NWPA [1] compliant, yet groundbreaking, recommendations:
   1. *"This report, therefore, recommends that DOE pursues options for disposal of DOE-managed HLW from defense activities and some thermally cooler DOE-managed SNF, potentially including cooler naval SNF, separately from disposal of commercial SNF and HLW."*
   2. "*This report also recommends that DOE retain the flexibility to consider options for disposal of smaller DOE-managed waste forms in deep boreholes rather than in a mined geologic repository."*

F. ***At the end of 2014***, the Nuclear Energy Institute (NEI) projected the amount of HLW destined for deep geological disposal exceeded the legal disposal capacity of the YM HLW repository [1-2,16] by 4,258 MT, and it would continue to increase at an annual rate of 2,000-2,300 MT until the government began disposing it [https://en.wikipedia.org/wiki/Nuclear_Energy_Institute]. As illustrated on Figure 5, ***at the end of 2001***, there were already 131 sites in 39 states storing HLW destined for deep geological disposal. The number of sites storing HLW has likely increased during the ensuing 15 years and would likely continue to increase in the absence of an operating HLW repository.

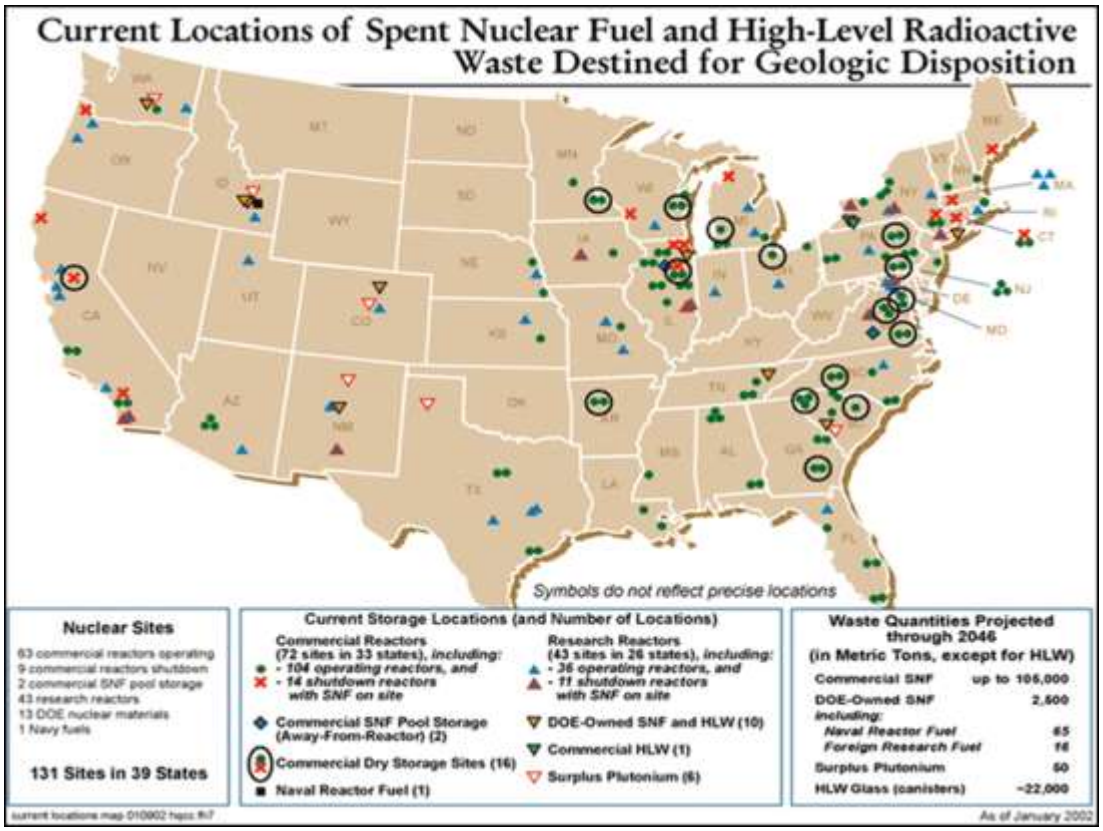

Fig. 5. Locations of 131 sites in 39 states storing HLW destined for deep geological disposal in January 2002.

Due to continually diminishing CHLW-storage capacity at the nation's Nuclear Power Plant sites, some nuclear utilities had already begun repackaging CHLW in dry-storage-containers (DSCs) and moving them to dry storage pads.

Clearly, more DSCs will be needed in the future, because the amount of CHLW was projected by the nuclear utilities in 2014 to continue to grow at an annual rate of 2,000 - 2,300 MT under their custodianship until the DOE begins taking title to it. Also, the DSCs shown on Figure 6 are 1.7 m in diameter, 4.72-5.38 m high, and weigh 49.2 MT, but they may not be the biggest or heaviest DSCs at the time a HLW repository opens. Contingent upon the size and/or weight of a given DSC, its transportation and emplacement options may be limited, unless it is re-opened and the HLW is repackaged in smaller and lighter containers; actions exposing workers and near-field environments to additional radiation risks and resulting in additional costs. Alternatively, the DSC may have to be transported on rail or on water, rather than by truck, to its off-site storage and disposal location. The DSC could also be limited to in-room emplacement (Figure 2) and require an inclined tunnel from the surface down to the emplacement location. A tunnel that would be at least six times longer than a shaft, penetrating and disturbing a larger portion of the geosphere.

Fig. 6. One type of dry-storage containers (DSCs) for HLW in the USA.

At the end of 2015, the USA's HLW-repository program was still on hold and its future was uncertain. Put simply, it seems to be caught in a tug of war between the U.S. President (= Executive Branch) and the Senate on one side with the House of Representatives on the other side as the anchors. In addition, further increasing the uncertainty, is that, despite the 2012 BRC [4]and the 2013 [28] and 2015 [29] Senate recommendations, the HLW-disposal program may be removed from the federal government. In the meantime, it seems as if the DOE is trying to gain control over the "consent-based" siting process by scheduling a kick-off meeting on this topic in January 2016. But regardless of the aforementioned turf battles, it is a virtual certainty that "consent" will govern the S&D of future HLW–disposition facilities [e.g., 4,24,29]. However, as opined in the accompanying WM2016 paper [29] and in other papers [e.g., 17-20], ***consent*** *is qualitative term that needs to be defined both as to who's consent is needed and how to measure it before it is written into law to minimize the historical time-consuming and costly debates, contentions, and law suits.*

HLW-Disposal Status and Prospects in the Finland, France, and Sweden at the End of 2015 and Lessons Learned in Finland and Sweden.

At the end of 2015, Finland, France, and Sweden are projected to open their respective first HLW-repository in 2023, 2025, and 2027. The HLW-repository host rocks are basement igneous/crystalline rocks, commonly referred as "granite", in Finland and Sweden, and argillite/mudstone, commonly referred to as "clay", in France.

Key features and lessons learned in the Finnish and Swedish programs [4,7,17, 31-33] that could increase initial acceptance among the directly affected parties (DAPs), and save time and cost to a new S&D process for HLW-repositories are:

1. They have long-standing, *fully-integrated, nuclear waste management programs* that are *successfully funded by the domestic nuclear utilities,* and managed by a jointly owned company; Posiva in Finland and SKB in Sweden. Whereas the government does not have a say in the planning or implementation of the day-to-day operations, it still has both the first and final say, because it approves both the proposed and final disposition solutions. These decisions are in large part based upon the recommendations provided by the respective domestic regulators and the legal entities involved. For example, on ***12 November 2015***, the Finnish government approved the construction license for Finland's HLW repository on the Olkiluoto Peninsula and the Swedish regulator, the Swedish Radiation Safety Authority (SSM) (http://www.stralsakerhetsmyndigheten.se) had advised the Swedish Congress on the need for increasing the Nuclear Waste Fund rate charged the nuclear utilities, which was accepted in 2015. SSM also advised the Congress and others on 17 November 2015 that it agreed with the SKB on the selection of Forsmark in the Municipality of Östhammar as the "best" final candidate sites for the Swedish HLW repository.
2. In the 1980s, Finland ***adopted*** the vertical HLW-emplacement version of the Swedish KBS-3 concept (KBS-3V) shown on Figure 7 and related lessons learned in the then more advanced Swedish HLW-repository program. It then ***adapted*** it to domestic conditions and also continued to collaborate with Sweden, enabling jointly-focused and cost effective research, development, and demonstrations, in turn, increasing public acceptance in both countries. Both programs currently benefit from >60% support in their respective "final" HLW-repository-host-communities, i.e., Eurajoki in Finland, and Östhammar in Sweden.
3. During the past 25+ years, their prospective HLW-repository-host communities have had a definitive say in the S&D and licensing processes, including veto right [7,17-20,31-33]. In Sweden, they have also been provided financial resources to retain their own group of local and subject-matter experts [17-20].
4. Both the Finnish and the Swedish HLW-repository S&D programs have experienced delays and cost-increases*, as have all other national HLW-repository-siting programs*. But no other nation has experienced delays of the duration (>29 years) or cost increases of the magnitude experienced hitherto in the USA, which brings to attention a couple of past root causes to these set-backs that also must be addressed and mitigated in a future, consent-based, HLW-repository-siting program:

a. Majority acceptance in facility-host entities, including sovereign nations, must be verified before potential and candidate site locations are announced and selected, respectively.
b. Majority acceptance and support must be maintained in potential and candidate facility-host entities throughout the S&D process.
c. The implementing organization must be trusted by the facility-hosts.
d. The applicable regulations cannot be tailor-made to a given site.

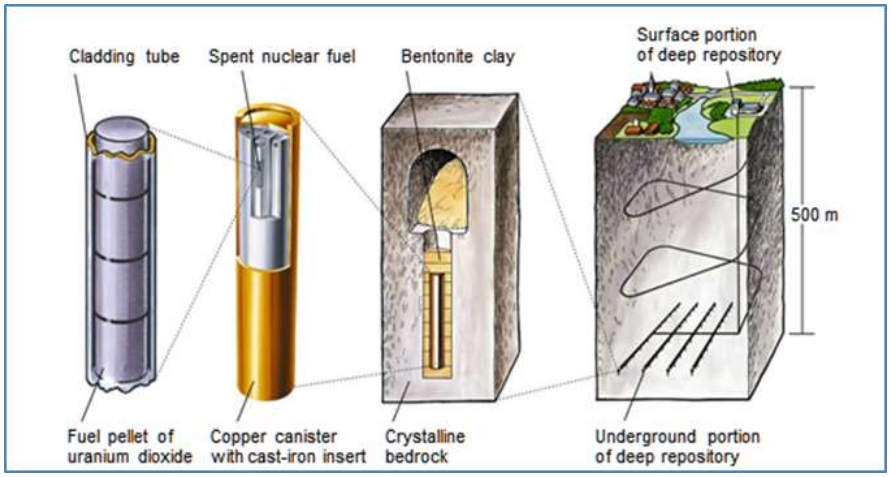

Fig. 7. Schematic illustration of the KBS-3V HLW-disposal concept.

Main Author Concerns at the End of 2015 About Starting a New HLW-Repository Siting Program Solely Based on the Sites Abandoned by 1988.

Concisely described and discussed below are conditions not addressed in the Secretary's 2008 report [5] deemed by the author to be particularly important to the timely and cost-effective S&D of a new HLW repository in the USA. They are based upon his multi-year direct involvement in the basalt site on the Hanford Reservation (BWIP) that included the construction of and in-situ-tests in an underground research laboratory (URL) [6], the evaluation of the three domal salt sites (Cyprus Creek, Richton and Vacherie), and one of the two "granite" regions shown on Figure 1, and >11 years of post-1992 involvement in the WIPP site (Figures 3 and 4) that included its 1998 certification, and 1999 opening [11-15].

1. *The local support and opposition in the respective host states and municipalities and among other DAPs at the time these sites were abandoned or any other reason for their respective abandonment.* To the best of the author's recollection, all seven salt-rock sites shown on Figure 1 were opposed locally at the time they were abandoned. For example, ***the candidate Deaf Smith County HLW repository was situated under one of the largest aquifers in the USA***, ***the Ogallala***, which had raised considerable local, state, and adjoining-states concerns. Also, even if local acceptance was not a decisive criterion before 1988, it most definitely has become one in the USA at the end of 2015, as well as in many other countries, e.g., Canada, Germany, Sweden, Switzerland, and the U.K. Put simply, it is now the basic criterion for S&D of new HLW-disposition facilities proposed in the USA since 2012 [e.g., 4,24,29, 31-33].

2. *The 2008 status of the related domestic-state of repository geosciences and geoengineering expertise, data, and lessons learned for any of the proposed starter sites*. To the best of the author's recollection ***the only two abandoned sites having exploratory boreholes extending down to the respectively proposed repository level/depth were the BWIP and the Deaf Smith County sites*** (Figure 1), of which ***only BWIP had designed, conducted, and analyzed, large-scale, in-situ tests in an operating URL*** [6]. But, in order for people to be able to work in the proposed ***BWIP-***repository for more than a couple of hours, a refrigeration plant would be needed, due to the ***high ambient temperature***. Also, many of the retrieved basalt cores exhibited extensive, "spontaneous", post-retrieval, disking. ***Core-disking*** is indicative of very-high differential (deviatoric) principal stresses that will affect the size, shape, and stability of man-made openings located in such rock portions. These portions would likely require structural support to ensure worker safety and disposal-hole stability. ***Whether the aforementioned, as well as any other, site-specific data can be found for the aborted sites 30 years or more after they were abandoned remains an issue*** based on the author's mid-1990 experiences, when both the author and his counterpart project manager at Battelle Memorial Institute (BMI) independently failed to locate data and records pertaining to the "Core Aging Study" on salt rock cores conducted and reported on by the Earth Technology Corporation in support of the USA's HLW-repository program in mid-1980.
3. *The ravages of time since 1987 on domestic availability of relevant and, in particular, state-of-the–art, repository-sciences/engineering expertise and data*. Optimistically assuming the siting of a new HLW repository commences in 2018, ***30 years would have passed since the USA was engaged in a domestic, site-specific, characterization for a HLW-repository other than in the volcanic ash layers at the YM site and the salt beds at the WIPP site*** [e.g., 34]. The ***related natural attrition*** will inevitably make domestic professionals with relevant repository-sciences and -geoengineering education and hands-on experiences, in other rock types much scarcer, if even available.

As follows, ***this author sees no apparent advantage in solely reviving and evaluating the sites recommended by the then Secretary in 2008*** [5].

MAIN OBSERVATIONS, CONCLUSIONS, AND RECOMMENDATIONS

At the end of 2015, the USA's beleaguered HLW-disposal program had been on hold since 2010 and its future was uncertain, because, contingent upon pending legislation, the USA may have one or more legal paths forward for HLW disposal to choose from. However, whereas continuing developing the YM HLW repository can be accomplished by allocating additional funds under existing laws [1-2], the S&D of any other HLW-disposal solution would require the enactment of new law(s) and, likely, new regulations. Also, the legislation proposed in S.854-IS for the S&D of new HLW-disposition systems [29] differs significantly from and partially overlaps and conflicts with the current legislation for the YM HLW repository [1-2,30].

Based upon the historical record, the political will has been inadequate since before 1 February 1998 to enact and enable legislation addressing/mitigating existing and

projected challenges. It will likely remain inadequate or vetoed throughout and, perhaps, beyond the reign of the current administration. But, for reasons very conclusive to the author, one day in the future, by default, disaster, or Homeland Security reasons or to honor international commitments and obligations [e.g., 35], enough nationally-elected representatives will step up to the plate and face the job-security/re-election challenge embodied in enacting enabling legislation facilitating safe and secure disposition of existing and a substantial portion of its pending HLW. In the meantime, ***a measureable, preferably quantitative, definition of "consent-based"*** S&D could save both time and money. Other conditions also deserving attention before a law for consent-based S&D of new HLW-dispositions is enacted include:

1. At the end of 2015, the statutory-mandated, no-later-than-31 January-1998, opening of the YM HLW repository [1] was already > 17 years overdue. Federal-tax payers therefore pay "breach of contract" penalties to the nuclear utilities, currently amounting to ~ $500 M per year, on behalf of the government *until it takes title to CHLW*. The total amount of the "breach of contract" penalties was estimated by the nuclear utilities in 2014 to reach $30.6 billion in 2028. As follows, ***time is of essence to the federal-tax payers. It could also still be of essence to the USA's international reputation and standings.***
2. Pursuant to existing law [1], the Secretary, i.e., the government, has had the option since January 1983 to store and thereby take title to up to 1,900 MT CHLW. But, although the DOE Office of Environmental Management (EM) has safely stored DHLW on several government-owned and –operated sites since early 1940, it still does not store any CHLW on any of them. As indicated by the September 2015 House Bill H.3643 [36], the DOE may be given the option to also take title to CHLW stored on a privately-owned and –operated site. However, in light of where existing HLW-storage-facilities and -experience resides at the end of 2015, ***it seems much easier, less time-consuming, and more logical and secure to amend the NWPA and increase the amount of CHLW that can be stored on government-owned and –operated sites***, even if they don't currently host a HLW storage facility. Indeed, the prompt opening of one or more large, expandable, CHLW-storage facilities on government-owned and –operated sites in jurisdictional entities willing to host them could drastically expedite the government taking title to 1,900 MT CHLW. In the meantime, a storage capacity increase could be pursued whilst the search for one or more new HLW-disposal solutions takes place. A large, expandable, operating CHLW-storage facility would be particularly valuable if the YM HLW repository program remains stuck in its current political quagmire or fails to comply with applicable regulations or is terminated by law in the future.
3. Notwithstanding a large number of sites in the USA have been considered for safe disposal of HLW since 1983, few of them were subjected to site-specific investigations extending down to and below the proposed repository elevation and related performance and safety assessments/analyses (PSAs). Also, only volcanic ash sequences and bedded salt formations have been investigated and evaluated during the past 28 years. Furthermore, ***even if it has been done for other rock types in the past, due to the ravages of time, relevant data, models, and repository-sciences and –geoengineering experts may be***

scarce and in some cases not-to-be-found on other HLW-repository host-rocks than those at the YM and the WIPP sites, i.e., welded tuff/ignimbrite and bedded salt, respectively.

4. The YM HLW repository has faced hitherto insurmountable political opposition since 1988 and, even if it survives both current and pending contentions, socio-political and legal challenges, and applicable licensing requirements, the limited vertical and horizontal extents of its host rock might limit a future increase in its disposal-capacity, unless the thermal loading per unit area is increased, which, in turn, would cause very-challenging domino effects [9-10,16,19] if the distance to the compliance point is not increased again [16,20]. Furthermore, *adequately-thick and –laterally-extensive volcanic ash layers with suitable material properties are very scarce in the USA*. As follows, ***vitrified ash layers do not seem to be promising prospects for a new HLW repository***.
5. In contrast, as illustrated on Figure 3, *thick, laterally-extensive salt-rock deposits are abundant in the USA, among which the WIPP site and other areas with adequately thick, and laterally-extensive salt rock are particularly promising paths forward based on available domestic data and state-of-the-art expertise*. Actually, the WIPP site was evaluated for HLW disposal by Sandia National Laboratories (SNL) from 1975 well into 1990 [e.g., 8, 11-15,34] on behalf of another DOE office, i.e., EM, than that evaluating the suitability of the sites abandoned by 1988, i.e., the 2011-dissolved Office of Civilian Radioactive Waste Management (OCRWM), which could explain why the WIPP site was not included in the 2008 recommendations [5]. Be that as it may be, the historical record for WIPP since 1975 strongly suggests a carefully-sited repository in bedded salt will contain and isolate long-lived radioactive waste even under very-unrealistic, statistically-based, straight-lined, hypothetical, very-low-probability, human-intrusion, scenarios with less than 1/3 of the maximum distance allowed between the perimeter of the waste and the regulatory control points (5 km) than that allowed at the YM site (> 15 km). Also, the results of the tests conducted in support of the aforementioned Core Aging Study on domal salt cores strongly indicated that even under confined, climatically-controlled, conditions, with time, rock salt experiences micro-cracking, stress relaxation, and increased permeability/hydraulic conductivity. This may sound bad, but it simply means that ***rock salt data used in PSAs based on old salt cores likely depict worse than the prevailing conditions***.

Peeking at what the rest of the world is doing, the repository-host rocks in the most mature/advanced foreign HLW-disposal programs at the end of 2015 were:

1. ***"Granite"*** in Finland and Sweden, i.e., ***basement igneous/crystalline rocks***.
2. ***Sedimentary rocks*** in France composed predominantly of indurated clay particles and commonly referred to as "argillite/mudstone" and "clay".
3. ***Salt domes/anticlines*** in Germany. Despite a recent hold on the continued development of the Gorleben HLW-repository to allow other rock types to be evaluated, German scientists have conducted and analyzed a suite of state-of-the-art tests on salt and continue to collaborate with WIPP and SNL scientists.

In summation, when the domestic state-of-the-art in each of the aforementioned three rock types are also duly accounted for, the overriding conclusion is that ***salt***

rock is still by far the most promising host rock for safe disposal of both large amounts and large packages of long-lived radioactive waste, due to:

1. The abundance of large salt deposits in the USA.
2. The inherent material characteristic of salt.
3. The domestic abundance of relevant state-of-the-art data, experts and experiences. In particular, those gained, maintained, and being continually updated since 1975 at and adjacent to the WIPP site (Figures 3 and 4).
4. SNL's long-standing and still ongoing international collaborations with German HLW-disposal experts.
5. The already expressed willingness of one state with significant salt rock deposits to consider hosting a HLW repository.

However, when the uncertain future of the USA's HLW disposal program is added, for multiple-reasons, ***at the end of 2015, the still most pressing federal-tax payer issue to resolve is means to transfer the title of CHLW to the DOE.***

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