# Status of HLW Disposal in the USA and Rational, Progressive, Paths Forward Based upon Lessons Learned in the USA and Abroad since 1973 - 15103

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## ABSTRACT

The development of the USA's only *candidate* (since 1987) HLW-repository at the Yucca Mountain (YM) site, Nevada, was halted by the Obama administration in 2009. Four years later, the Obama administration proposed a new strategy for the back end of the nuclear fuel cycle that would open a ***consent-based*** HLW repository "by 2048". At the end of 2014, both the YM HLW repository and the new HLW-disposition (storage and disposal) strategy remain on hold due to lack of enabling legislation.

With this as background, and based upon our active involvement in, monitoring of, and reporting on HLW management programs in the USA and abroad since 1973, we submit that:

1. Politics, political will, and legal actions and outcomes will continue to govern progress.
2. Public acceptance and sustained support (PASS) may influence politics and political will.
3. PASS is time-dependent and governed by:
    a. Ideologies;
    b. Perceived benefits and risks;
    c. Level and equity of radiation protection provided by applicable regulations;
    d. Perceived robustness/safety of the proposed disposition concept; and
    e. Perceived credibility and competency vested in the involved organizations and their respective leaders (= **TRUST**).

We therefore recommend that the USA concurrently pursues at least two, "centralized" HLW-storage and -disposal solutions based upon best-available relevant knowledge and majority-PASS at facility-host locations. Furthermore, safe(r) and more secure disposal of defense/government-generated HLW could probably commence at least 15 years earlier than "by 2048" in/at:

1. The YM repository/site.
2. The WIPP repository/site.
3. "Local" deep boreholes.

## INTRODUCTION AND BACKGROUND

At the end of 2014, the future of nuclear energy in the USA is more closely tied to *public acceptance and sustained support* (PASS) of safe and secure disposition (storage and disposal) solutions for the resulting long-lived radioactive residuals/isotopes (LL-RR) than it has ever been [1,2,3]. However, while a broad range of safe and secure LL-RR-storage solutions exist in the USA (Figure 1) and abroad, the 2023 projected opening of the world's first disposal solution for HLW[1] in Finland is still eight years away. As described in the subsequent text, such an event was at least 9, but more likely 13, years away in the USA. Actually, despite more than 55 years of effort [4], the opening of the USA's first HLW repository could

[1] Although their respective legal definition differs in the USA, in this paper, the acronym HLW includes used nuclear fuel (UNF) and spent nuclear fuel (SNF), but it does not include any other LL-RR, such as transuranic radioactive waste (TRUW) or intermediate-level radioactive waste (ILW).

be more than 35 years away [2] contingent upon the content and the time of enactment of the pending enabling legislation required to take action on one or both:

- Continue licensing of the Yucca Mountain (YM) site in Nevada (Figures 2 and 3) [5,6], which was declared "not workable" in 2009 by the Obama administration [7] and then aborted in 2010 (http://en.wikipedia.org/wiki/Yucca_Mountain_nuclear_waste_repository); and/or
- Implement the new DOE strategy for the management of HLW proposed by the Obama administration in January 2013 [2].


For the purposes of the forward projections made in this paper, we assumed enabling legislation would be enacted for both of them by the end of 2015 and that it would then take another year to establish one or more implementing organizations and consent-based siting procedures. In other words, 2017 would be $T_0$.

Fig. 1. Non-government-operated storage sites for commercial HLW in the USA (= 83 sites in 34 states). (Please note that ~ 30 government-owned/operated storage sites are not shown on the figure.)

In the following paragraphs , we have identified and commented upon a few selected root causes of the 55+ years [4] of failures to site, develop, and open "central" storage and disposal facilities for HLW generated by commercial (CHLW) and defense/government (DHLW) related activities [5,6]. These and other root causes are also addressed in greater detail in another WM2015 paper [8] and in a WM2013 paper [9]. Whereas both of these papers focus on the quantitative definition of the qualitative term "***consent-based***", this paper focuses on solutions that might allow a HLW repository in the USA to open before 2048. The underlying themes for all three papers are: time (= $) is of the essence; we know how to safely site LL-RR repositories (Figures 2-4) and dispose of it (Figure 4); and ***the growing elephant in the room, fed by lack of political will, is the increasing volume of HLW requiring ultimate disposal.***

Our subsequent discussions include projections on the future of HLW disposition in the USA based upon our long (40+ years) involvement in and monitoring of radioactive waste management programs in the USA and abroad. The following three disposal concepts are discussed: 1) Deep geological disposal (DGD); 2) Deep mine/repository disposal (DMD); and 3) deep borehole disposal (DBD). Both the DMD concept and the DBD concept are DGD solutions/systems (DGDSs).

Our initial focus is on the following two fundamental HLW-disposal issues, but it includes peripheral views on the status of several mature HLW-management and -disposal programs and issues abroad:

1. How did the USA's HLW-disposal program get to where it is currently?

2. What can be done in the future based upon the lessons learned in the USA and abroad during the past 40+ years to avoid or minimize past adverse impacts on the schedules and costs for HLW-repositories in the USA?

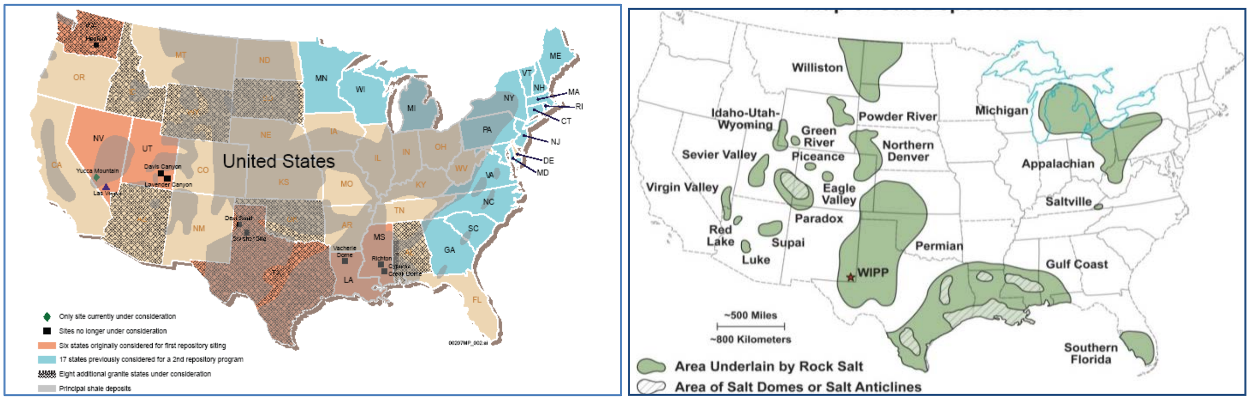


Fig. 2. Schematic illustration of locations of sites, areas, regions, states and some of the rock types (the right figure shows rock salt) evaluated prior to 1987 for suitability to host a U.S. HLW repository.

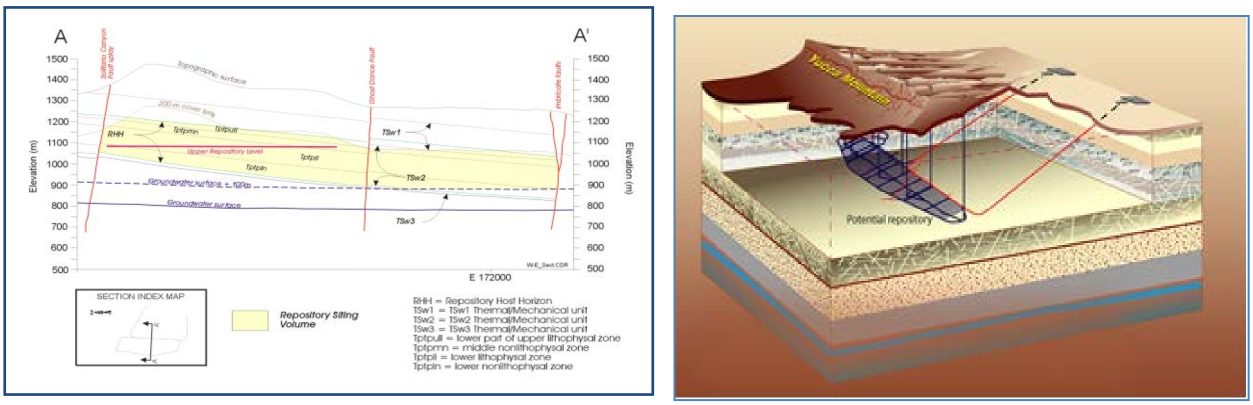


Fig. 3. Schematic illustrations of the stratigraphy and the repository location in a west-east cross section (to the left) and the proposed layout for the USA's only candidate HLW-repository since 1987 at the Yucca Mountain site in Nevada (Figure 2 shows its location). Layout tunnels shown in red have already been constructed and used for full-scale in-situ test, but they were closed in 2008.

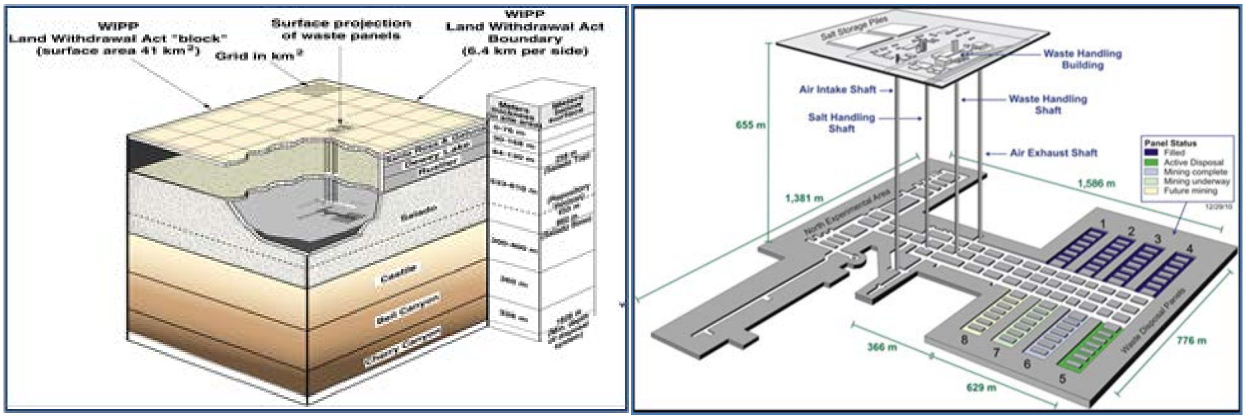


Fig. 4. Schematic illustrations (to the left) of the 41 km$^2$ (4x4 miles) controlled area and its current 1.6 km (6,000 feet) depth limit at the WIPP site, and (to the right) of the TRUW-repository and its adjoining four shafts and underground research facility (URF); the North Experimental Area. At the end of 2014, panel 1 through 6 had been filled, panel 7 was partially filled, panel 8 was partially mined, and 91,000 m$^3$ of TRUW had been disposed of in the WIPP repository.

**Main Events Contributing to the End of 2014 Status of the USA's HLW-disposal Program**

The following annotated chronological summary of post-1982 domestic events is deemed by the authors to be of particular importance to the current status and potential future of HLW disposition in the USA:

- In January 1983, the U.S. Secretary of Energy (the Secretary) was directed by the Nuclear Waste Policy Act of 1982 (NWPA) to open its first HLW repository no later than 31 January 1998 [5]. At that time, it was more than 10 years earlier than any other country was scheduled to have an operating HLW repository.
- While States with sites under consideration for a HLW repository were promised the "right of refusal" of the HLW repository, in December 1987, the Secretary was directed by an Amendment to the NWPA (NWPAA) to only evaluate the YM site for the nation's first HLW repository and to terminate all other HLW-repository-siting activities within 90 days [6]. Under strong opposition (pressured by Las Vegas casino interests), Nevada promptly rejected the selection of the YM site, but its rejection was overruled by the U.S. Congress in 2002.
- In December 2008, the YM HLW repository schedule was revised with a projected opening date no earlier than 2017, but more likely 2020 [12]. At that time, it would still open earlier than any other countries HLW repository.
- In February 2009, the Obama administration announced its intention to abort the YM HLW-repository project [7].
- In January 2010, the Obama administration appointed a Blue Ribbon Commission on America's Nuclear Future (BRC) to evaluate domestic and foreign nuclear waste management policies and programs and then recommend a new U.S. policy for the back end of the nuclear fuel cycle within 24 months. The BRC was also directed that it was not to serve as a siting body [1]. Accordingly, it did not evaluate the YM or any other location as a potential site for the disposal of HLW [1].
- In March 2010, the Secretary provided a motion to the U.S. Nuclear Regulatory Commission (NRC) for withdrawal of the June 2008 construction license application (CLA) for a 70,000 metric tonnes repository at the YM site (Figures 2 and 3) containing ~63,000 metric tonnes of CHLW and ~7,000 metric tonnes of DHLW. The NRC rejected the motion, and its legality and the Obama administration's related termination of the YM HLW-repository project were promptly challenged in court by several directly affected parties (DAPs) and interest groups.

- In January 2012, he BRC presented its recommendations on a new strategy/policy for HLW management and disposal in the USA [1]. Again, it did not address the YM HLW repository site.
- In January 2013, the Secretary/DOE released a 14-page report purportedly based upon the BRC recommendations. It projected that a new HLW repository would open "by 2048" [2], which would be at least 20 years later than the 2023, 2025, and 2027 opening dates projected at that time for the Finnish (http://www.posiva.fi), French (http://www.andra.fr), and Swedish (http://www.skb.se) HLW-repositories, respectively.
- In June 2013, a Bill (S.1240-SI) [3], referred to as the "Nuclear Waste Administration Act of 2013" (NWAA), was introduced in the U.S. Senate to:
    - *"Establish a new nuclear waste management organization"* … *"to discharge the responsibility of the Federal Government to provide for the permanent disposal of "nuclear waste*[2]";
    - *"Establish a new consensual process for the siting of nuclear-waste management facilities"*;
    - *"Provide for centralized storage of nuclear waste pending the completion of a repository"*; and
    - "Ensure adequate funding for managing nuclear waste, *and for other purposes*."

  However, the NWAA will not be implementable until after it has been passed by the U.S. Congress and then signed by the U.S. President, and, of course, have been adequately funded.
- In August 2013, the U.S. Court of Appeals for the District of Columbia Circuit (the A Court) ruled [13] on the legal challenges to the Obama administrations 2010 attempts to terminate the YM HLW program that *neither the U.S. President nor a federal agency could unilaterally reject or deviate from a statutory mandate without prior approval by the U.S. Congress*.
- In November 2013, the A Court ruled on another lawsuit [14] that the strategy proposed in January 2013 for the siting and development of a new HLW repository was a *"pie in the sky"* proposal, and directed the Secretary to relieve the nuclear utilities from paying annual fees into the Nuclear Waste Fund (NWF) [14] until the DOE was able to take title to their CHLW.
- On 16 May 2014, the fee payments into the NWF were halted.
- At the end of 2014, the status of HLW management in the USA was as follows:
    - More than 76,000 metric tonnes of HLW were stored at > 100 sites in > 40 states;
    - The CHLW stockpiles will continue to increase at an annual rate of ~ 2,000 metric tonnes until they are depleted by treatment and/or disposal solutions;
    - The YM HLW repository was the USA's only legal HLW-disposal option; but it remained on hold pending enabling legislation;
    - The new HLW-management and -disposition strategy proposed by the Obama administration in January 2013 [2] was also on hold pending enabling legislation;
    - The nuclear utilities were not required to pay into the NWF until the DOE is able to take title to their CHLW, or has a credible plan or facility for storing or disposing it; but
    - The annual penalties being paid to the nuclear utilities since 1 February 1998 due to DOE's failure to timely dispose of or take title to its HLW will continue until the DOE takes title to the CHLW.

## DESCRIPTIONS, DISCUSSIONS, CONCLUSIONS AND RECOMMENDATIONS

From our perspective, it is important that the primary reasons (root causes) for the 2014 status must be understood so as to illuminate the potential keys to future progress, because we believe that critique without one or more potential solutions is not constructive. Also, although we assumed that both the YM and the Obama-administration-proposed HLW repository would survive and that all legal, regulatory, and

[2] Although several laws cited in S.1240-SI refer to HLW and other LL-RR, S.1240-SI is not clear on the nuclear waste categories it applies to, because it extensively uses the generic term "nuclear waste".

financial instruments, and organizational structures needed for their respective implementation could be in place by the end of 2016, this very-likely will not be the case. For example, utilization of the YM HLW repository project might be foreclosed due to the long-standing, very-strong, political opposition it has at the state level. However, in light of the extensive knowledge already acquired and the financial investment already made in the YM site, *we don't think the very substantial financial and scientific investments should be so easily or completely forfeited.* Therefore, we are also outlining potential alternative utilizations of the YM site in the subsequent text.

**Fundamental Challenges to and the Path Forward for Opening a HLW Repository in the USA**

The disposal of all LL-RR involves state of the art repository-sciences and -engineering concepts, features, events, and processes (FEPs), and non-related nuclear events that often lead to decisions being made based upon fears and a related desire to promptly eliminate them [8]. Based upon our active involvement in the consent-based Swedish HLW-repository program since 1978 and the consent-based WIPP-repository project since 1993, we would like to emphasize the importance of the proponent's spokespeople having the requisite relevant experience, credentials, reputation, and credibility to be trusted on issues beyond the comprehension of the recipient(s). They must also be able and willing to present the information in contexts and terms readily understood by laypeople [15-18]. We believe this is most effectively done in public meetings where the members of the audience can ask for clarifications in real time, because, there will still be grey areas that need to be addressed. A related cornerstone is the receiving party's perception or understanding of the credibility of the presenter/communicator/messenger. Simply stated, information received from a friend or a source deemed to possess the desired knowledge and integrity often trumps the information received from an unknown person with an impressive title and/or education.

A long-recognized root cause in the USA is the wide-spread reluctance among the elected representatives, their supporters and staffs, and people with political ambitions, to champion or support a HLW repository due to the perceived risks (short-term and long-term) and related re-election, job security, and election risks, respectively. However, as demonstrated in France and Sweden, this long-standing tide can be turned when the majority of the DAPs become fully informed of repository scientific performance and relevant public health risks. They can in fact become supportive of hosting a HLW-repository, because, logically, it would then be counterproductive to the election and/or the re-election of their elected representatives to oppose it.

**The Proposed Nuclear Waste Administration Act of 2013 (NWAA) of 27 July 2013 (S.1240-SI)**

S.1240-SI was the first political action at the national level to establish a path forward for the enactment and enabling of the recommendations provided by the BRC in January 2012 [1], and the related HLW-disposition strategy envisioned by the Obama administration in January 2013 [3]. However, all of these documents were released prior to the August 2013 ruling by the A Court [13] that revived the prospect for the YM HLW repository. The A Court ruling means that the U.S. Congress must take another look at if and how it wants to shape the future of HLW-disposition in the USA.

The U.S. President, who must sign or veto the proposed enabling legislation, has been on record since early 2009 of opposing the continued development of the YM HLW repository. As a result, the most convenient and expeditious option for the U.S. Congress at this time is to approve S.1240-SI and then amend the NWPA again to continue or eliminate the YM HLW repository project. However, as explained in another WM2015 paper [8], as initially written, S.1240-SI failed to incorporate several fundamental lessons-learned in the USA and abroad on how to conduct a successful, consent-based, siting of a DGDS for LL-RR. It is, therefore, deemed highly-likely that, *as initially written, S.1240-SI will delay rather than advance progress on future new HLW-storage and -disposal solutions due in large part to its lack of timely active and meaningful, DAP involvement in the planning and decision-making* *processes*. It could, however, represent a politically irresistible concept similar to the 1985 "geologic-media diversification" concept that resulted in three candidate repository sites in different geologic media, i.e., basalt, rock salt, and tuff, and the abandonment of six rock salt sites.

Another historical HLW-disposal concept that has received renewed attention and interest during the past five years in the USA and abroad, although not addressed in S.1240-SI, is DBD [19]. It could be a promising concept for localized disposal of limited quantities of HLW, based on generic predictive modeling results. This option embodies a reduction in HLW-handling and -transportation risks and cost, but it lacks the empirical database and site-specific analyses required for implementation that are abundant for the HLW-repository concept. The DBD concept will also require the promulgation of new, time-consuming, HLW-disposal and environmental radiation protection criteria/standards. In principle, we support the continued evaluation of the DBD concept, but we do not consider it a mature, near-term, solution for safe and secure disposal of large quantities of HLW at this time. Nonetheless, on paper [19], the DBD concept appears virtually ideal for disposal of small quantities of LL-RR at existing generator and storage sites, and should receive appropriate local consideration.

### Best-Available Repository-Sciences and -Engineering Knowledge

In our evaluation, we applied the term "best-available" as encompassing the current "state-of-the-art". A related pre-requisite was the existence of a comprehensive data base that included full-scale, in-situ, tests in the intended host-rock formation, encompassing specially-designed tests conducted in an underground research facility/laboratory (URF/URL). A listing of URFs/URLs and their respective host-country and repository host media is provided in Table I (http://en.wikipedia.org/wiki/Deep_geological_repository).

TABLE I. Countries Hosting or Having Hosted URFs and URLs at the end of 2014.

| Country | URF/URL name | Location | Host Media | Depth | Status |
|---|---|---|---|---|---|
| Belgium | HADES | Mol | plastic clay | 223 m | in operation 1982 |
| Canada | Pinawa | Pinawa | granite | 420 m | 1990-2006 (closed) |
| Finland | Onkalo | Olkiluoto | granite | 400 m | in operation 2004 |
| France | Bure | Meuse district | mudstone | 500 m | in operation 1999 |
| Japan | Horonobe | Horonobe | sedimentary rock | 500 m | under construction |
| Japan | Mizunami | Mizunami | granite | 1000 m | under construction |
| Korea | Korea Underground Research Tunnel (KURT) | Daejeon | granite | 80 m | in operation 2006 |
| Sweden[a] | Äspö | Oskarshamn | granite | 450 m | in operation 1995 |
| Switzerland | Grimsel | Grimsel Pass | granite | 450 m | in operation 1984 |
| Switzerland | Mont Terri | Mont Terri | claystone | 300 m | in operation 1996 |
| USA[b] | Yucca Mountain (Figures 2 and 3) | Nye County | welded tuff, ignimbrite | 200+ m | 1997-2008 |

[a] Prior to1995, international HLW-disposal RD&D in *crystalline/igneous ("granitic") rocks* had been conducted for two decades in a dedicated portion of an abandoned iron mine at Stripa.

[b] Prior to 1987, the USA also had conducted deep underground HLW-in-situ tests in the Climax *granite* formation on the Nevada Nuclear Safety Site, in a near-surface facility in *basalt* located in the Gable Mountain on the Hanford Reservation in the state of Washington [20], and in *rock salt* at the WIPP site in New Mexico [21], and in several domal-salt mines in Louisiana.

Due to the fact that the USA has only conducted, full-scale, in-situ, HLW-related RD&D in tuff and salt since 1987, the current state-of-the-art repository-sciences and -engineering expertise and experiences in other repository host-rocks are to be found in other countries. At this time, the seven most advanced/mature HLW-repository programs in terms of repository sciences and engineering are to be found in Belgium, Finland, France, Germany, Sweden, Switzerland, and the USA. Summarized below are our views about the current status and prospects of these seven programs in alphabetical order.

**Belgium -** Has evaluated an *over-consolidated clay* (soil) formation, the Boom clay, at Mohl-Dessel for more than 30 years, in which it continues to operate a URF. The construction of the Belgian HLW repository is projected to begin in 2050 **(**http://www.eu-decom.be/contacts/belgium/ondrafniras.htm). We deem it unlikely that over-consolidated clay would be considered in the USA in light of the abundance of other repository-host media.

**Finland -** Has evaluated *crystalline/igneous ("granitic") Pre-Cambrian basement rocks* for more than 30 years. Posiva Oy (http://www.posiva.fi) is responsible for the siting, licensing and safe and secure development and operation of the required centralized HLW-disposal facility. Posiva is also responsible for the safe, secure, and timely transportation of the HLW from the two domestic NPP sites with operating nuclear reactors; namely at Loviisa (close to the Russian border) and at Olkiluoto (at the coastline of the Baltic Sea), to the appropriate disposition facilities. The HLW-generators are responsible for storing it until the HLW repository can receive it. At the end of 2014, Posiva operates the Onkalo URF at the depth and location of the intended HLW repository, which is ***projected to open in 2023***. The related data bases and experiences, in combination with those of Sweden's, constitute the state-of-the-art databases and experiences on DMD of HLW in crystalline rocks. This joint-state-of-the-art "ownership" is founded upon the joint use during the past 20 years of the KBS-3 disposal concept and related collaborative research and development (R&D) efforts; *a borderless collaborative approach highly recommended by the authors*.

**France -** Has evaluated several different HLW-repository host-rock types during the past 40 years. Andra (http://www.andra.fr) is responsible for the siting, licensing and safe and secure development and operation of the required centralized HLW-disposal facility. During the past 20 years, the focus has been on *a clay-rich, lithified, sedimentary rock (argillite/mudstone/claystone) formation* in the Meuse and the Haute Marne districts, in which it currently operates a URF at Bure in the Meuse district (Table I). The French repository (Cigéo), which will contain both long-lived intermediate-level (LL-ILW) and HLW, is currently ***projected to open in 2025***. The related data bases and experiences, in combination with those of Switzerland's, constitute the state-of-the-art databases and experiences on DMD of HLW in sedimentary rocks. However, they may not be applicable to shale, which was one of the potential repository host rocks considered in the USA prior to 1983 (Figure 2).

**Germany -** Has also evaluated different rock types during the past 40 years, but the focus during the past 30+ years has been on a salt anticline at Gorleben. Although no safety issues preventing its safe use have been identified hitherto, the evaluation and development of the Gorleben HLW-repository was halted between 2002 and 2012, and then halted again in 2013 to accommodate a political re-evaluation of other HLW-repository host rocks. As a result, *neither the final host rock nor the projected opening of Germany's first HLW repository has been identified at the end of 2014.* Notwithstanding the holds on the Gorleben HLW repository, the state-of-the-art HLW-repository sciences and engineering expertise in many rock salt areas are still vested in Germany. The Science Advisor on the WIPP project since 1975, Sandia National Laboratories (SNL), has collaborated closely with German repository scientists for more than 25 years, so the nexus for the state-of-the-art HLW-repository collaboration already exists.

**Sweden -** Has evaluated *crystalline/igneous ("granitic") Pre-Cambrian basement rocks* for more than 40 years. The Swedish Nuclear Fuel and Waste Management Company (SKB) (http://www.skb.se), which is owned by the nuclear utilities operating Sweden's four NPPs, is responsible for the siting, licensing and safe and secure development and operation of the required disposition facilities. During the past 23 years, *the HLW-repository siting process was limited to voluntary host-communities*, and the detailed site investigations were limited to two communities in 2002; namely, Oskarshamn and Östhammar. In 2010, SKB recommended and the Swedish government approved a site adjacent to the Forsmark NPP site with three operating reactors in the municipality of Östhammar for the development of the nation's first HLW repository. The municipality of Oskarshamn was selected to host the nation's only HLW-encapsulation facility (Cink). At that time, the municipality of Östhammar already hosted the nation's only (underground) disposal system for short- lived LLW and ILW (the SFR) and the municipality of Oskarshamn already hosted an NPP site with three operating nuclear reactors, a second-generation URF at Äspö, a long-term, underground , monitored-retrievable, HLW-storage facility (Clab), and the HLW-encapsulation laboratory (Inka). Similar to Finland, Sweden has a fully integrated nuclear waste management program that also includes the state-of-the-art on consent-based siting of nuclear facilities in several locations. *The Swedish HLW repository is currently projected to open in 2027*.

**Switzerland** - Spent fuel (SNF) from the Swiss NPPs and vitrified fission product solutions from reprocessing will be disposed of in a HLW repository. It will also have tunnels for LL-ILW and is projected to be operational around 2050. As shown in Table I, Switzerland has operated a URF in *crystalline/igneous rocks* at Grimsel since 1982, but its HLW-repository focus during the past 20 years has been on sedimentary rocks that included full-scale, in-situ, tests in *claystone* in the Mont Terri URF.

**USA** - As indicated on Figure 2, the USA has evaluated a broad range of potentially-suitable HLW-repository host rocks and locations during the past 60 years. The aforementioned evaluations included Columbia Basin *basalt* intrusions and flows at the Hanford Reservation in the state of Washington, *crystalline/igneous (”granitic”) rocks* in two large regions in the eastern portion of the USA, *lithified sedimentary rocks* (e.g., shale) across the USA, *bedded and diapiric/domal rock salt* across the USA, and *volcanic effusive/ash layers* (e.g., *welded tuff/ignimbrite*) at the YM site in Nevada (Figures 2 and 3). As listed in Table I and its two footnotes, some of the aforementioned surface-based evaluations were augmented by full-scale-in-situ teats in an URF/URL.

## Consent-Based Siting

With regards to consent-based siting and development of HLW-repositories, at the end of 2014, Finland, France, and Sweden are the furthest advanced nations. However, when it comes to consent-based siting of a DMD for LL-RR, the WIPP repository in New Mexico, USA, is still the leader by more than 35 years. Based upon our global observations and experiences, we believe that *majority PASS among the DAPs is an imperative pre-requisite for a societally-equitable siting, development, and operation of future HLW-storage and -disposal facilities in a democratic country*. However, as discussed further in other places in this paper, the term *“consent-based”* used in the 2012 BRC report [2] and in the Obama administration's 2013 strategy [3], as well as the term *“consensual”* used in the June 27, 2013 Senate Bill (S.1240-SI) [3], which currently govern the siting of a new HLW repository in the USA, are qualitative terms (catch-phrases) that need to be defined in measurable terms to serve a constructive purpose.

As discussed in our WM2013 paper [9] and in another WM2015 paper [8], the term/concept “consent-based”, as well as its qualitative derivatives, need to be more clearly defined as to whose consent is needed and what constitutes “consent” (> 50%?), to serve any meaningful purpose in making progress on the siting of new HLW-storage and -disposal facilities in the USA. Without it, the term/concept “consent-based” will surely remain a fertile target for prolonged public and judicial arguments to delay the siting and opening of the USA's first centralized HLW-storage and -disposal solutions. For example, notwithstanding that the host county (Nye) for the YM site and six adjacent counties are willing to host the HLW repository (http://en.wikipedia.org/wiki/Yucca_Mountain_nuclear_waste_repository), its opening has been successfully opposed and delayed since 1987 by the state, ignored by the U.S. Congress, and disregarded by several U.S. Presidents. The primary related root cause is the U.S.

Congress' failure to maintain support for opening the YM subsequent to its site selection approval in the face of strengthened political opposition in Nevada, and the support of that position by the Obama administration. This, in turn, raises the following sociopolitical issue: ***whom, besides the designated regulator(s), should have the final say in accepting or rejecting a HLW repository location?***

As discussed in the aforementioned WM2013 [9] paper, we believe the legal residents in the facility-host community, also referred to as the DAPs, to be the primary decision makers on whether or not to host a HLW-disposition facility, i.e., a bottoms-up, rather than a top-down decision-making process. Likewise, the legal residents adjacent to the proposed HLW-transportation routes should be the primary decision makers on the acceptability of those routes and related transportation risks [9].

**Projections about HLW-disposal Solutions in the USA**

At this time, the USA's HLW-disposition programs are still on hold pending enabling legislation formulated as a result of the BRC report. Our most optimistic, yet speculative, projection is as follows:

1. The enabling legislation will be enacted no later than at the end of 2015.
2. It will then take at least another year to establish and populate the implementing organizations and to write the new siting criteria required pursuant to S.1240-SI.

Based upon this projected scenario, if the YM HLW-repository survives the pending legislation, the 2017-2020 opening dates suggested for it in the December 2008 report [12] would be delayed at least seven years and the "by 2048" opening of the hypothetical HLW-repository proposed by the Obama administration in January 2013 [2] would be delayed at least four years. Therefore, the YM HLW repository could mathematically open as early as in 2024, but more likely in 2027, whereas the HLW repository proposed by the Obama administration in January 2013 [2] would open "by 2052".

There are, however, options based on "best-available technology" that could expedite the opening of a HLW repository in the USA. For example, the DOE released a noteworthy report in October 2014 [25] that outlined the benefits of establishing separate disposal solutions for CHLW and DHLW. Two of the anticipated benefits were that such a separation would greatly simplify disposal and advance the opening date for the DHLW repository relative to the "by 2048" opening date projected in January 2013 [2].

In our opinion, additional time and cost-savings would conceivably be possible if either the mission of the WIPP repository was expanded to also facilitate disposal of DHLW or if the mission of the YM HLW repository was limited to DHLW. For example, several statements by the NRC through December 2014 on four of the five volumes of the DOE's 3 June 2008 license application to construct a 70,000 metric tonnes HLW repository at the YM site, strongly suggest that it can safely accommodate up to 63,000 metric tonnes of CHLW and 7,000 metric tonnes of DHLW under the site-specific disposal regulations [26,27]. Since, DHLW is both much smaller in total volume and less "thermally-hostile" to the near-field environment than CHLW, logically, it should not raise the same post-closure-safety and health issues or concerns as those related to the commingled CHLW and DHLW.

The historical record shows that the YM HLW-repository concept was accepted and supported in Nevada until it was prematurely mandated as the one and only option for the disposal of HLW in 1987. Conceivably, a drastic reduction in the amount of HLW that would be disposed of, its more benign thermal characteristics and the commencement of the search for a consent-based CHLW-repository site could be compelling reasons for Nevada to reconsider its current position and contribute to the partial resolution of a significant national problem/obligation. After all, the YM site already represents a rate- and tax-payer investment during the past 30 years alone on the order of 16 billion U.S. dollars ($16B) that deserves serious consideration before it is abandoned. Such consideration can include a changed mission. In our opinion, long-term storage of commingled HLW and disposal of DHLW are the two most viable options to ensure that rate- and tax-payers get some return on their investments, and also improve the USA's standings in the international radioactive waste management and non-proliferation communities.

The DBD concept could also advance the disposal of both DHLW and CHLW, but, unfortunately we don't think it would do much, if anything, to increase public confidence in the disposal of HLW in large man-made/mined underground openings, i.e., repositories.

**Can WIPP Replace the Yucca Mountain Repository?**

In Dr. Frank L. Parker's November 4, 1999, Plenary Session presentation at the National Academies Workshop on "*Disposition of High-Level Radioactive Waste Through Geological Isolation: Development, Current Status, and Technical and Policy Challenges*", he chronicled the repository successes of the time with WIPP's March 26, 1989 opening and the DOE decision to vigorously pursue the licensing and opening of the YM HLW repository (Figures 2 and 3). The subsequent delays to the opening and successful attempts by the Obama administration, begun in 2009, to abandon the YM HLW repository, have brought forward the question whether WIPP could *replace* it? Given the current laws at the end of 2014, i.e., the NWPA of 1982 [5], as amended in 1987 [6], and the WIPP Land Withdrawal Act of 1993 (LWA) [22], as amended in 1997 [23], ***the short answer is still an unambiguous no***.

Clearly, laws can be amended or replaced, provided there is a political will in the U.S. Congress to do so and the U.S. President will not veto them. But the Obama administration's track record through 2014 on the YM site is discouraging. The legality of the USA's first HLW repository site was reinforced in the August 2013 [13] and November 2013 [14] rulings by the A Court. The August ruling also affirmed that the U.S. President could not unilaterally change or disobey a statutory mandate without prior consent of the U.S. Congress. It is, therefore, deemed important that the U.S. Senate demonstrated political will in June 2013 [3] to replace the current statutory-mandated implementing organization of the USA's HLW-disposition program, and also institute a new, "consensual", siting process for future HLW-disposal and -storage facilities. With regards to the siting of a new HLW repository, assuming that:

a). The future, consent-based-siting, process for HLW-disposal facilities will be based upon relevant, state-of-the-art, domestic repository-science and -engineering experiences in safe and secure disposal of LL-RR; and
b). Time, money, and local support will be important criteria in the future; then

the WIPP repository would be by far the most promising option for a successful HLW-repository program with rock salt being a close second. The following are the main underpinnings for these conclusions:

- The only two repository host rocks pursued since 1987 in the USA and thus credibly can claim state-of-the-art repository science- and engineering knowledge are *rock salt* and *unsaturated tuff*.
- The domestic availability of rock salt formations with large lateral extents and, in particular, thicknesses is much more abundant than that of unsaturated tuff.
- No other nation has found tuff of interest to host a LL-RR disposal system, whereas several other nations, most prominently Germany, have pursued rock salt. Indeed, Germany continues to evaluate rock salt and possesses some of the state-of the art in disposal of heat-generating waste.
- All rock properties vary directionally in space and also react differently to both human-imposed and naturally-imposed changes. When it comes to the human induced impacts of HLW, the National Academy of Sciences – Natural Research Council concluded in 1957 that rock salt was the most promising host rock for a HLW-repository [4]. Subsequent R&D in the USA and abroad has emphatically corroborated this conclusion [e.g., 10,11,14].

- Nevada has opposed the development of the YM HLW repository since 1987, whereas New Mexico and residents adjacent to the WIPP site have supported it since 1972, when it was first proposed as a HLW-repository.
- The WIPP site has been evaluated for safe disposal of LL-RR since 1973. That evaluation includes more than 15 years of full-scale in-situ tests in the North Experimental Area (Figure 4) to establish the prevailing rock salt's response to HLW-disposal, before the TRUW repository opened in 1999. These in-situ tests were preceded, succeeded, and augmented by surface-based data acquisition well below the Salado Formation (Figure 4) that included extensive off-site laboratory tests and detailed analyses of rock salt by the WIPP Science Advisor, SNL, with a keen eye on both TRUW and HLW disposal. Between 1973 and 1983, the Umtra-Cowden portion of the Salado Formation located ~ 135m (~ 450 feet) below the TRUW-disposal horizon at a depth of ~ 820 m (~ 2,690 ft) below the ground surface was the designated HLW-disposal horizon. SNL also developed, updated, and maintained the related algorithms, codes and models used for stochastically evaluating prevailing rock mass conditions and then superimposing a wide range of FEPs during the 10,000-year-long post-closure period.
- In May 1998, the U.S. Environmental Protection Agency (EPA) certified that the proposed WIPP TRUW repository complied with all applicable post-closure environmental radiation protection standards [28]. The EPA has since corroborated this ruling three times. On a side note, the TRUW-disposal operations were halted in February 2014 and may remain on hold until 2018 following an underground truck fire on 5 February and the unrelated release of a small amount of radionuclides on 14 February requiring remediation and the review and update of off-site and on-site waste-handling procedures.
- Both of the aforementioned events were due to human and operational errors and failures; one off-site and one on-site. It is therefore important to recognize that neither of them negates rock salt's excellent radionuclide containment and isolation characteristics [4], nor do they diminish the viability of disposing TRUW at WIPP or HLW in rock salt. In fact, they inadvertently demonstrated the proof of concept by containing and isolating most of the released radionuclides within the underground facility despite the underground ventilation system's attempt to suck them out of the repository. However, the longer it takes for WIPP to re-open, the greater is the risk that the entire disposal concept will be compromised in the eyes of the public.

Notwithstanding the overwhelming evidence that rock salt is the most promising host rock for HLW-disposal, and that the WIPP site is the most promising consent-based option at this time, expanding the WIPP mission to include HLW involves complex legal and regulatory challenges that will delay and might even prevent its expanded mission. In this regard, our concerns are influenced by the following:

1. Neither the EPA nor the DOE is the main regulator for disposal of HLW; the NRC has that responsibility under current law. The U.S. Congress would thus have to reconcile how HLW could be added to the current WIPP mission, pass the enabling legislation, and present that solution to the U.S. President, for approval or veto.
2. The EPA-standards governing the WIPP site are very different from those governing the YM site. For example, the WIPP standards include periodically-updated, bore-hole-density-criteria per unit area based upon non-sustainable assumptions that could exclude HLW disposal. Of particular concern is that the most recent, very high, drilling rates for natural hydrocarbon resources, mainly oil and gas, in the region have to remain linear for the entire 10,000-year post-closure period in the repository performance and risk/dose analyses. In reality, none of the extracted natural hydrocarbon resources are renewable and the current drilling rates are therefore, by necessity, going to decline with time. An extension of the post-closure period at WIPP to 1,000,000 years as it is at the YM HLW repository would exacerbate this concern.
3. The controlled area at the WIPP site is (only) 41.4 $km^2$ (16 $mi^2$) and the shortest distance between the current perimeter of the underground facility (repository) and the accessible environment is

(only) 2.4 km (3.6 mi). Furthermore, it is currently surrounded by either the U.S. Bureau of Land Management or privately-owned or -leased land that limits a lateral expansion, at least for a considerable period of time. Therefore, the prospects for a prompt expansion of the horizontal footprint of the WIPP site or the WIPP repository are not viewed as promising.

4. The DOE agreed with the state of New Mexico in 1982 to limit the depth of the WIPP disposal system to 1,828 m (6,000 ft). An appreciable expansion of the disposal capacity in the near term, whether for TRUW or HLW, would thus be more promising at another, either shallower (TRUW only) or deeper elevation within the current controlled area (Figure 4). In terms of HLW-disposal, the Umtra-Cowden horizon in the Salado formation is deemed very promising based on available data, existing modelling capability, and domestic subject-matter expertise.

However, even without the use of the WIPP site, we still believe that rock salt represents by far the most promising alternative path forward for a new HLW repository. On that note, we would like to mention that there are at least five other locations in the New Mexico portion of the Delaware Basin that could host an HLW repository.

The most apparent disadvantage of establishing a new repository site in New Mexico, as opposed to expanding the WIPP site/mission, is the additional time and costs required for infrastructure development, site characterization, and public and political interactions. But, based on the historical record during the past 50 years, the other side of the coin is that the time and cost required to develop an HLW repository site in a state with a long-standing nuclear history and with the surrounding population already very familiar with the concept and potential consequences of deep geological disposal of LL-RR, is very likely several years, perhaps decades, shorter than if a new HLW-repository site was to be developed in a state lacking or being short on this experience. This is especially true if it is in another host-rock in another state willing to host an HLW repository. The time and cost savings would be even greater if the elected representatives in a potential host state are against the development of a local HLW repository. As illustrated in Nevada, host community acceptance and support there during the past 18 years have not been enough to sway state politics. However, the 2014 elections changed the national political fabric that might lead to future policy changes at local, state, and/or national levels. Conceivably, or perhaps ideally, such changes could include the revival of Nevada's pre-1987 support of the YM HLW repository site and the U.S. Congress' will to effect a solution to this significant national problem by devising and enabling a rational, fully-integrated, national HLW management and disposal program.

In summation, we clearly believe that the WIPP mission could and should be expanded. But, for reasons summarized herein (as well as for reasons not summarized herein due to publication-space limitations), we recommend such an expansion initially focuses on DHLW, rather than CHLW. DHLW is significantly less challenging to add to the current waste inventory in terms of both ownership and inherent waste characteristics than CHLW would be.

## SUMMARY OF CONLUSIONS AND RECOMMENDATIONS

Following are our main conclusions (C):

C-1. Given the documented status and findings from multiple URL and HLW repository programs in many countries (Table I), the state of the art for repository-sciences, -engineering, and -licensing standards are fully and sufficiently established to enable the defensible opening of safe, and effective repositories for both CHLW and DHLW in four major groups of rock, namely:
   a. Evaporites (e.g., bedded and diapiric/domal rock salt);
   b. Lithified volcanic ash (e.g., welded tuff);
   c. Sedimentary and low-grade metamorphic rocks (e.g., mudstone. claystone, and argillite); and

d. Igneous/crystalline rocks (e.g., gneiss and granite).

As indicated in Table I, it also exists in soil (e.g., over-consolidated clay).

C-2. The U.S. HLW repository program has applied state-of-the-art science, engineering and licensing expertise to the siting and design of the YM HLW repository for its approval and operations since 2001 [26,27]. But, it was prematurely foreclosed in 2010 during the licensing process, despite being supported by the repository-host county and six adjacent counties.

C-3. The USA's repeated failures to demonstrate progress and political leadership in safe and secure disposition of HLW to the rest of the world for more than 15 years has and will continue to erode its standing as a leader and credible spokesperson in the international radioactive waste management and non-proliferation communities. This will persist until this trend is reversed and actual progress is made.

C-4. Existing HLW stockpiles already exceed the legal disposal capacity of the YM HLW repository. Another large-capacity HLW repository would thus provide assurance that adequate disposal capacity is available whether or not the YM HLW repository survives the pending legislation.

Following are our main recommendations (R):

R-1. Enabling legislation supportive of quantifiable or quantitative, consent-based, siting criteria should be introduced, passed, and implemented by the U.S Congress and the Obama administration in 2015.

R-2. Quick actions to consider an expansion of WIPP's mission to include DHLW should be vigorously pursued.

R-3. The applicability of the YM site for centralized storage of UNF and HLW should be evaluated and actions should be initiated to license the facility for that purpose.

R-4. Given the national extent and international acceptability of bedded salt formations for HLW disposal, consideration of siting a new HLW repository for both CHLW and DHLW should be a priority of the new U.S. Congress and the Obama administration.

Let's all address the enormous "Elephant in the Room" that while we meet and collaborate here once again on the nation's nuclear waste issues , the volume of HLW and UNF continues to grow to adding to associated costs and risks awaiting a rationalized repository solution. This problem of a continually growing quantity of CHLW, DHLW, and other LL-RR requiring deep geological disposal deserves our immediate attention; it will not go away nor fix itself. *Let's all collectively engage to solve this problem by taking advantage of the lessons learned in the USA and abroad during the past 40 years, and by pursuing the options posing the most promising outcomes. It is a long-overdue responsibility of this generation and we have the scientific and engineering knowledge to do it safely.*

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