DEEP GEOLOGIC NUCLEAR WASTE DISPOSAL – NO NEW TAXES

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ABSTRACT

To some, the perceived inability of the United States to dispose of high-level nuclear waste justifies a moratorium on expansion of nuclear power in this country. Instead, it is more an example of how science yields to social pressure, even on a subject as technical as nuclear waste. Most of the problems, however, stem from confusion on the part of the public and their elected officials, not from a lack of scientific knowledge. We know where to put nuclear waste, how to put it there, how much it will cost, and how well it will work. And it's all about the geology.

The President's Blue Ribbon Commission on America's Nuclear Future has drafted a number of recommendations addressing nuclear energy and waste issues (BRC 2011) and three recommendations, in particular, have set the stage for a new strategy to dispose of high-level nuclear waste and to manage spent nuclear fuel in the United States: 1) interim storage for spent nuclear fuel, 2) resumption of the site selection process for a second repository, and 3) a quasi-government entity to execute the program and take control of the Nuclear Waste Fund in order to do so. The first two recommendations allow removal and storage of spent fuel from reactor sites to be used in the future, and allows permanent disposal of actual waste, while the third controls cost and administration. The Nuclear Waste Policy Act of 1982 (NPWA 1982) provides the second repository different waste criteria, retrievability, and schedule, so massive salt returns as the candidate formation of choice. The cost (in 2007 dollars) of disposing of 83,000 metric tons of heavy metal (MTHM) high-level waste (HLW) is about \$83 billion (b) in volcanic tuff, \$29b in massive salt, and \$77b in crystalline rock. Only in salt is the annual revenue stream from the Nuclear Waste Fund more than sufficient to accomplish this program without additional taxes or rate hikes. The cost is determined primarily by the suitability of the geologic formation, i.e., how well it performs on its own for millions of years with little engineering assistance from humans. It is critical that the states most affected by this issue (WA, SC, ID, TN, NM and perhaps others) develop an independent multi-state agreement in order for a successful program to move forward. Federal approval would follow.

Unknown to most, the United States has a successful operating deep permanent geologic nuclear repository for high and low activity waste, called the Waste Isolation Pilot Plant (WIPP) near Carlsbad, New Mexico. Its success results from several factors, including an optimal geologic and physiographic setting, a strong scientific basis, early regional community support, frequent interactions among stakeholders at all stages of the process, long-term commitment from the upper management of the U.S. Department of Energy (DOE) over several administrations, strong New Mexico State involvement and oversight, and constant environmental monitoring from before nuclear waste was first emplaced in the WIPP underground (in 1999) to the present. WIPP is located in the massive bedded salts of the Salado Formation, whose geological, physical, chemical, redox, thermal, and creep-closure properties make it an ideal formation for long-term disposal, long-term in this case being greater than 200 million years. These properties also mean minimal engineering requirements as the rock does most of the work of isolating the waste. WIPP has been operating for twelve years, and as of this writing, has disposed of over 80,000 m^3 of nuclear weapons waste, called transuranic or TRU waste (>100 nCurie/g but <23 Curie/1000 cm^3) including some high-activity waste from reprocessing of spent fuel from old weapons reactors. All nuclear waste of any type from any source can be disposed in this formation better, safer and cheaper than in any other geologic formation.

NUCLEAR WASTE

The United States has about 80,000 tons each of spent nuclear fuel (SNF) and high-level nuclear waste (HLW) although the forms of each are quite different. SNF from reactors is in a solid form that is easily handled and easily stored in dry casks once it is removed from the cooling pools after about 5 years (Figure 1, courtesy of the Nuclear Energy Institute). HLW is in different liquid, sludge and solid forms in various containments such as the 90 million gallons stored in large tanks at Hanford, Savannah River and other DOE facilities. HLW needs to be solidified and packaged by various methods including grouting (cementing), vitrifying (glassification) or steam reforming (mineralization). When dewatered, solidified and repackaged, this HLW will have somewhat over 80,000 metric tons of heavy metals, referred to as MTHM. In addition to SNF and HLW, a minor amount of other wastes are

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included in the discussion of a deep geologic repository and include nuclear navy waste, weapons proliferation-related international waste, research materials and greater than Class C radioactive waste (GTCC). GTCC includes activated metals from decommissioned power plants, some sealed sources from the irradiation, medical and energy industries, and non-defense-related transuranic (TRU) waste.

However, spent nuclear fuel may not actually be waste since it can be re-used in various forms in present and future reactors, with or without additional reprocessing depending upon the reactor design. Since the economics of re-use is in question, SNF should be placed in an interim storage facility at the surface where it can be safely stored until needed, a conclusion agreed upon by the scientific community and the BRC. Whatever use is made of SNF, there will be eventual waste from it, even if it is disposed of ultimately without being re-used. So there will be a need for the final repository regardless of the future use of SNF. Interim storage truly is interim, and SNF, or its waste after re-use, will be disposed in a deep geologic repository at some point in time.

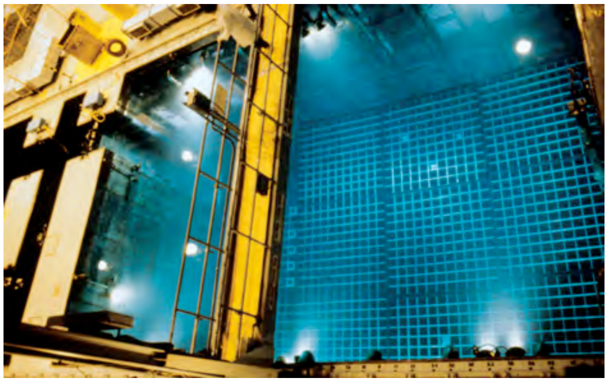

Fig. 1. (above) Wet storage of spent nuclear fuel in pools of water. When spent fuel is removed from the reactor it requires about five years in water to cool off and allow the short-lived radionuclides to decay away. It can then transferred to dry cask storage (below) until needed, e.g., burned in Generation IV or V fast reactors in the near-future.

On the other hand, HLW is waste that should be permanently disposed as soon as possible since it was generated primarily from reprocessing spent fuel from old weapons reactors and has no future value or use. The decision to co-mingle SNF and HLW administratively and physically in the same repository led to the concept of retrievability of the SNF, i.e., we might change our minds about throwing something so valuable away, so we should construct the repository so that we are be able to get only the SNF back out in 50 years or so. Unfortunately, retrievability makes a deep geologic permanent repository into a deep geologic interim storage facility that we attempt to engineer or morph into a deep geologic permanent repository after we retrieve the waste or decide to leave it in place. The engineering and logistics then becomes extremely important and costly. However, since SNF, or its waste after re-use, needs a repository in the long run, co-mingling the eventual waste may not be a problem in the manner it is presently considered, as there will not be a retrievability issue at that time. This is the problem that interim storage solves – SNF is not physically co-mingled during disposal of HLW.

The critical aspect about nuclear waste, unknown to the general public and their elected officials, is that there is not much of it. All the nuclear waste generated in the United States from its nuclear power fleet in the last 60 years can fit in a single soccer field.[3] Including all high-level defense waste in the U.S. more than doubles that but it still would fit in the field with some in the stadium. Compared to that, the over 400 million tons of solid waste and billion tons of CO_2 generated from coal-fired power plants each year is staggering. Even worse is the greater than 500 million tons of solid chemical and sanitary waste generated each year, and the 2 quadrillion gallons of water requiring waste treatment each year. These are large waste volumes that require thousands of disposal sites, if it is regulated at all. On the other hand, all of the nuclear waste generated in the United States in a thousand years could fit into one repository. Yes, it's bizarre material, but easy to handle and easy to dispose. *No one* has ever died in the U.S. from handling, transporting or disposing of nuclear waste, and *no one* has ever died in the U.S. at an operating nuclear power plant, a tribute to our technical, industrial and regulatory system. Because nuclear waste is sufficiently odd and long-lasting, scientific

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[3] *Using a light-water reactor assembly dimension of 21.5 cm x 21.5 cm, approximately 100,000 used assemblies, and a regulation soccer field of 100 x 60 meters*

opinion has long considered deep geologic burial to be the optimal method for permanent disposal (National Academy of Sciences, 1957; BRC 2011). The earth is the only system that can operate as expected for millions of years, and we understand geologic process sufficiently to be able to choose an optimal place to dispose of these materials.

OPTIMAL CHARACTERISTICS OF A GEOLOGIC REPOSITORY FOR NUCLEAR WASTE

Characteristics of a suitable geologic repository for the disposal of nuclear waste include the following favorable characteristics (McEwen 1995, EPRI 2006):

i. a simple hydrogeology,
ii. a simple geologic history,
iii. a tectonically interpretable area,
iv. isolation robustly assured for all types of wastes (no difficult or exotic processing needed),
v. minimal reliance on engineered barriers to avoid extravagant costs and long time extrapolations of models for certain types of performance,
vi. performance that is independent of the canister, i.e., canister and container requirements are only for transportation, handling and emplacement in the repository,
vii. a geographic region that has an existing and sufficient sociopolitical and economic infrastructure that can carry out operations without proximity to a potentially rapidly growing metropolis (unlikely to ever have dense human habitation near the site).

Two rock types that fit these characteristics are argillaceous rocks (claystones and shales) and bedded salts. Many studies have focused on argillaceous sites, particularly in Canada and Europe, with some strong technical arguments (Nuclear Energy Agency 2001); similarly for salt deposits (McEwen 1995, National Academy of Sciences 1970). The primary difference between salt and argillites is that, while both have extremely low permeability (the ability to conduct water and the contaminant dissolved in it), argillites have much higher porosity (the total amount of pore space, usually filled with water) and molecular diffusion coefficients (the ability of molecules and dissolved contaminants to “randomly walk” through the material independent of the flow of water. Massive salts have extremely low porosity and molecular diffusion coefficients as well as extremely low permeability. In fact, in massive salt, permeability and diffusion at the depths of a repository are vanishingly small, so nothing moves appreciably over millions of years. As an example, in the massive salt of the Delaware Basin spanning the borders of New Mexico and Texas, a half-mile below the surface it takes water, and any contaminants in it, a billion years to move an inch (Beauheim and Roberts 2002; Conca et al. 1993). Although salt deposits exist throughout the world (Zharkov 1984), many are not sufficiently massive, have too many clastic interbeds, are tectonically affected (faulted and folded), or are near population centers. Salt domes and interbedded salts are less optimal than massive bedded formations from a hydrologic standpoint, particularly within the United States where diapiric movement can exceed 1 mm/yr (McEwen 1995) and vertical spline fractures can act as hydraulic conduits. Still, there are many viable salt deposits in the U.S. and globally that meet these criteria (Zharkov 1984, Waughaugh & Urquhart 1983, Karalby 1983; see also Figure 5 below for the United States). The United States does not have optimal argillites for this purpose. It should be noted that volcanic tuffs, like those at Yucca Mountain, do not generally satisfy these criteria. The Yucca Mountain tuffs have a complicated dual-porosity hydrogeology, a complex geologic and tectonic history, and a heavy reliance on engineered barriers for the performance of a repository.

MASSIVE BEDDED SALT OF THE SALADO FORMATION

The Salado Formation in the Permian Basin of southeast New Mexico is one such formation that satisfies all of the above characteristics. The Salado Formation is a massive bedded salt deposit that has a simple hydrogeology with no dual-porosity. The Salado has had a simple geologic history and is in a tectonically quiet area. The Salado is a simple geologic unit exhibiting self-healing rock mechanical properties, such that the host rock cannot maintain open and connected fractures or pores, resulting in an overall hydraulic conductivity $\leq 10^{-14}$ m/s and diffusion coefficients $\leq 10^{-15}$ m^2/s (Beauheim & Roberts 2002, Conca *et al.* 1993). The unit provides performance that is independent of waste type, engineered barriers, and water content. The unit provides an environment that does not require long-term, or even short-term, survival of the canister. Container requirements are only for transportation and handling prior to emplacement. Geographically, there are many sites underlain by the Salado Formation that are remote from human habitation yet have sufficient socioeconomic infrastructure to support disposal operations.

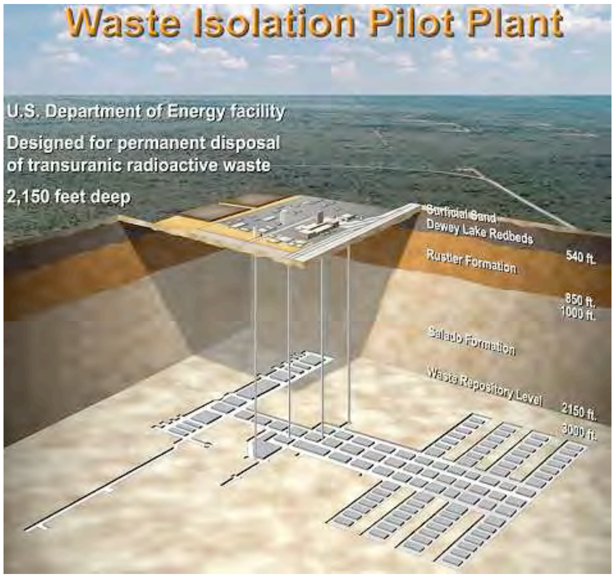

Fig. 2. The Waste Isolation Pilot Plant (WIPP), the only operating deep geologic nuclear waste repository, is located 700 meters (2,130 ft) below the surface in the massive salt of the Salado Formation, and has operating successfully since 1999.

If these properties and conditions sound familiar, it is because the Salado Formation is already host to an operating deep permanent geologic nuclear waste repository, called the Waste Isolation Pilot Plant, or WIPP, shown in Figure 2. WIPP, near Carlsbad, NM has been operating for over twelve years and, as of this writing, has disposed of over 80,000 m^3 of waste in over 100,000 containers, equivalent to about 400,000 fifty-five gallon drums, that have been delivered in 10,000 shipments from across the nation (Figures 3 and 4; http://www.wipp.energy.gov/). Massive salt was chosen by the National Academy of Sciences way back in 1957 as the best rock type for all nuclear waste (National Academy of Sciences and NRC. 1957) and that decision stands today. A small sixteen-square-mile portion of this salt in southeastern New Mexico was set aside in 1992 for permanent nuclear waste disposal and this became WIPP (Conca and Kirchner 2010). The repository is located one-half mile below the surface of the earth in the Salado Formation, a particularly massive and optimal member of these salt beds that has never been deformed, folded, faulted or otherwise had any disruptive geologic activity in 225 million years. The Salado only has 1% water, and that water is not mobile, but is trapped as small fluid inclusions of 225-million-old seawater that have not moved a millimeter in 225 million years (Griffith et al. 2008). The oldest intact biomolecules on Earth have been recovered from these inclusions (Griffith et al. 2008), the best performance indicator one could imagine. WIPP has been operating safely and efficiently for twelve years and when finished will have used up less than one square mile of the original sixteen of the total ten thousand (Conca et al. 2008; Conca and Kirchner 2010). The land set aside for WIPP could hold all the nuclear waste that the U.S. could produce in several hundred years.

However, WIPP is presently licensed and permitted *only* for defense-generated transuranic waste (TRU waste), basically bomb waste, that includes everything from low-activity to high-activity waste like recycled spent fuel waste from old weapons reactors. TRU waste is defined as having greater than 100 nanoCi/gram of alpha-emitting waste but less than 23 Ci/1000 cm^3). A curie (Ci) is a unit of radioactivity equal to 37 billion disintegrations per second from the nucleus. There are different types of radiation (alpha, beta and gamma) that penetrate to different distances (a piece of paper, a plate of glass, or three feet of concrete, respectively). Wastes containing different types have to be shielded to different degrees. Contact Handled waste (CH) has primarily alpha from the decay of transuranics (uranium, plutonium, americium, neptunium, etc.) so just a 55-gallon drum is more than enough shielding and one can put one's hand right on it.

Fig. 3. Over 10,000 nuclear waste drums and standard waste boxes filling 1 of 56 rooms to be filled at WIPP over a 20-year period. Over 30 rooms have been filled as of September 2011. Note the high-activity remote handled waste (RH) plunged into boreholes in the wall to the right and plugged, while the contact handled waste (CH) fills the bulk of the room. The technician shown is receiving about a tenth of the radiation dose that we receive at the Earth's surface, ironic since he is standing in front of the nuclear waste.

Remote Handled waste (RH) emits the more penetrating gamma, has surface exposures greater than 200 mrem/hr, so must be shielded and remotely handled. RH waste has an upper radioactivity limit of 23 Curie/1000 cm^3. These higher activities mostly result from gamma emissions from the decay of isotopes such as ^{137}Cs and ^{90}Sr/^{90}Y. This upper limit is similar to processed high-level waste such as high-level waste sludge or its treated form as vitrified glass. The RH waste is shielded, shipped in a 72B casket (Figure 4), and inserted remotely into a horizontal borehole in the disposal room wall (at left in Figure 3). These boreholes are single-drum-width in diameter and three drum-lengths deep with a shield plug, and are emplaced on 8-ft centers along the wall, similar geometrically to many international high-level waste disposal strategies. Disposing of this high-activity waste is relatively easy in WIPP. This restriction on WIPP to only defense-generated TRU waste was arbitrarily made in the 1970s and has nothing to do with the formation's ability to isolate any type of waste.

ENVIRONMENTAL MONITORING

From the standpoint of addressing operational and environmental risk, as well as public fear, WIPP has had extensive human health and environmental monitoring from six years before operations began to the present, with over 12 years of waste disposal operations. The New Mexico State University Carlsbad Environmental Monitoring and Research Center has been the independent monitoring facility for the area around WIPP since 1993 (www.cemcr.org). Levels of radiological and non-radiological analytes measured since operations began in 1999 have been within the range of baseline levels measured previously, and are within the ranges measured by other entities at the State and local levels since well before disposal phase operations began in 1999. Constituents and properties measured by the monitoring program include, but are not limited to, gross alpha/beta radiation, ^{133}Ba, ^{88}Y, ^{7}Be, ^{212}Bi, ^{213}Bi, ^{214}Bi, ^{144}Ce, ^{249}Cf, ^{57}Co, ^{60}Co, ^{134}Cs, ^{137}Cs, ^{152}Eu, ^{154}Eu, ^{40}K, ^{54}Mn, ^{233}Pa, ^{234m}Pa, ^{212}Pb, ^{214}Pb, ^{106}Rh, ^{125}Sb, ^{208}Tl, ^{228}Ac, ^{234}U, ^{235}U, ^{238}U, ^{230}Th, ^{232}Th, ^{228}Th, ^{234}Th, ^{241}Am, ^{238}Pu, ^{239,240}Pu, various volatile organic (VOCs) and solvents, and many inorganic constituents normally analyzed in waters, particularly RCRA constituents such as Pb and Cd. The public is invited to participate in the *in vivo* bioassay (whole body counting) program at CEMRC in the *Lie Down and Be Counted* program (Conca and Kirchner 2010) to see if they have any radioactivity in their bodies in addition to the natural radioactivity we all possess from eating food and breathing dust, e.g., ^{40}K, ^{232}Th, ^{235}U, ^{238}U, ^{137}Cs and ^{90}Sr. Based on the radiological analyses of monitoring samples completed to date for area residents and site workers, and for selected aerosols (dust), soils, sediments, drinking water and surface waters, there is no evidence of increases in radiological contaminants in the region of WIPP that could be attributed to releases from WIPP (Conca et al. 2008).

Fig. 4. High-activity remote handled nuclear waste, some of it from reprocessing of spent fuel from old weapons reactors, being transported to the WIPP site in New Mexico in a 72B cask. 10,000 shipments of nuclear waste to WIPP has never resulted in any release or harm to humans or the environment.

In addition to environmental monitoring, WIPP has addressed public concerns by developing a network of acceptable nuclear waste transportation routes throughout the United States, including many diversion routes around population centers, that is constantly monitored by satellite. WIPP's perfect safety record has gone a long way towards increased public acceptance and confidence. Finally, the issue of remoteness from population centers is handled well by the Salado Formation near WIPP, where the nearest towns are over 30 miles away (Carlsbad, Hobbs, Eunice, Otis and Loving, NM) and the nearest cities are well over 100 miles away (Roswell, NM and Midland, Lubbock and El Paso TX).

Therefore, nuclear waste is not the intractable problem once thought, and is much less of a problem than other energy-related wastes (Wright and Conca 2007). As will be discussed below, disposal of nuclear waste in the correct geology is not expensive, and is able to be covered completely by the existing nuclear waste fund into which all nuclear utilities presently must pay. Disposal in the wrong geology is very expensive.

RECOMMENDATIONS OF THE BLUE RIBBON COMMISSION

The BRC made many recommendations regarding the United States nuclear program in the areas of nuclear waste disposal, interim storage of spent fuel from nuclear power reactors, transportation and handling of nuclear waste, research and development needs for nuclear energy in the future, and how best to manage and implement these recommendations (BRC 2011). The BRC re-iterated the long-held decision by the scientific community that a deep geologic repository is the best option for permanent disposal of nuclear waste (BRC 2011). This discussion focuses on the most important recommendations to deep geologic disposal:

1. *Prompt efforts to develop, as expeditiously as possible, one or more consolidated interim storage facilities* as part of an integrated, comprehensive plan for managing the back end of the nuclear fuel cycle,
2. *Prompt efforts to develop, as expeditiously as possible, one or more permanent deep geological facilities for the safe disposal of spent fuel and high-level nuclear waste*, resuming the site selection process for a second repository that was put on hold in the 1987 Amendment to the NWPA, and
3. *A new, single-purpose organization to develop and implement a focused, integrated program for the transportation, storage, and disposal of nuclear waste in the United States*, and assure access by this entity to the balance in the Nuclear Waste Fund and to the revenues generated by annual nuclear waste fee payments.

The first recommendation above allows SNF to be separated from actual HLW. The second recommendation allows the selection of a second repository, and the third controls cost and removes the distracting activities of the Department from the focus of this mission, i.e., to solve the nation's nuclear waste problem and provide a resolution to the back end of the nuclear energy cycle. There is a history of success by this type of quasi-government entity, exemplified by the Tennessee Valley Authority (TVA).

In the Nuclear Waste Policy Act of 1982 (NPWA 1982), the second repository can have different waste criteria, retrievability, and schedule, so massive salt returns as the candidate formation of choice and the YMP continues as the candidate repository that addresses retrievability, a condition rendered not immediately important once the first recommendation for an interim storage facility for SNF is adopted. In this case, only one deep geologic repository is needed for HLW and it does not require long-term retrievability. If the BRCs recommendations are followed, then there is a clear path towards solving the nuclear waste problems in this country:

a. spent nuclear fuel is stored in a safe, simple surface facility(s) until needed
b. high-level waste is permanently disposed in a deep geologic repository
c. both facilities and their operations are funded completely by the existing balance, and future revenues of, the Nuclear Waste Fund plus committed DOE funding - no new taxes needed.

COSTS OF A NULCEAR REPOSITORY

Many estimates of costs have been developed for deep geologic nuclear waste disposal facilities in various rock types in various countries. The best-developed cost estimates come from:

1. the extensive work of the Yucca Mountain Program over the last 25 years, especially using Yucca Mt operations from 1990 to 2008, various Total System Life Cycle Cost estimates (TSLCC 2008) and information contained in the YMP license application,
2. the WIPP program over the last 32 years, particularly the last 12 years of WIPP operations when actual nuclear waste has been disposed in the deep geologic permanent repository (DOE 2004), and
3. GNEP cost studies for disposing of HLW from recycling SNF in generic salt and generic tuff repositories (DOE 2008).

The following discussion relies upon these estimates and previous work on generic repositories performed by DOE and other international repository programs, and commercial industrial mining practices. Assumptions for this discussion are for a generic repository, with a project period of 62 years, including interim storage for spent nuclear fuel and the permanent deep geologic disposal of 83,000 metric tons of heavy metal, high heat-generating, vitrified, non-retrievable high-level waste (DOE 2008) in either volcanic tuff, massive salt and crystalline rocks such as granite, basalt or metamorphics. Interim storage of SNF does not affect the repository programs, unless the sites are co-located for cost and shipping efficiencies. The cost of interim storage for SNF over this 62-year period, including the on-site storage at the generation sites until transfer, will be much less than for a repository although it strongly depends upon how the costs are shared between the utilities and the project, the rate of casking and transfer from reactor sites to storage site, and even the number of storage sites, whether a single centralized site or two to four regional sites (Hamal et al. 2011; Parkyn 2009; NAS 2006). To complete the discussion of high-level waste, storage and the expected liabilities on the Nuclear Waste Fund, we assume $13.5 billion for the interim storage program over 62 years. While absolute costs of these repositories depend upon many uncertain factors over the subsequent decades, the relative costs among the different repositories should stay more constant. The choice of 83,000 MTHM as the waste amount can also be adjusted upwards and the relative costs will not vary appreciably between the different rock types, although significant cost savings will occur by expanding an existing site as the pre-operational costs will not need to be repeated.

The duration of a nuclear waste disposal program is lengthy and includes more than just disposal operations. In general, for a generic repository in any rock type, the duration is made up of Site Screening and Selection (3 to 4 years), Site Characterization (3 to 9 years), Design and Licensing (5 to 7 years), Construction (6 to 8 years), Operations (35 to 40 years) and Closure (9 to 12 years), giving a total life cycle to the project in the neighborhood of 60 to 70 years (DOE 2008). The actual time is strongly dependent upon the rock type since that will determine the extent and difficulty of the mining operations and the engineering and waste form/handling/packaging requirements. The Yucca Mountain Project, which is still in the Design and Licensing phase, was in existence in 1982 but did not begin in earnest until 1987. The WIPP project was authorized by Congress in 1979 and began accepting nuclear waste in 1999. WIPP will complete disposal of the majority of its present permitted waste stream within the next six to eight years, although TRU waste will continue to trickle into the repository for many years, giving a project life span of about 50 years from start to almost finish (http://www.wipp.energy.gov/).

A life cycle of 62 years was chosen as the project life span to estimate costs for this generic repository. If Yucca Mountain, or a site within the Land Withdrawal Act boundary that presently hosts WIPP, is chosen as the actual repository, then these times (and subsequent costs) will be less than for their generic tuff or salt counterpart as significant funds and time have already been spent that can be leveraged to offset the final repository cost and schedule, much more so for WIPP than for YMP. Table 1 lists the costs in constant $2007 for generic repositories in the three rock types, broken down by major component (DOE 2008).

The significant cost reductions in a salt repository stem from the ease of mining, the simpler surface and subsurface facilities, the absence of extensive packaging and barriers, the simpler engineering, simpler transportation, and the ease of development and characterization. There are many salt deposits in the U.S. that are adequate for waste disposal purposes (Figure 5). Costs are significantly lower if the repository is placed at existing sites such as within the Land Withdrawal Act boundary that presently hosts WIPP (LWA) or at Yucca Mountain (YM).

However, these costs are not static or constant, but will occur over a 62-year period. Table 2 compares these costs to the future revenues in the Nuclear Waste Fund that presently has $24.1 billion in bank. Using a simple inflation of 2% with a Gausian spend-rate peaking during the disposal period, increases these costs to about $192 billion in volcanic tuff, $67 billion in massive salt, and $179 billion in crystalline rock. If the tuff repository is at Yucca Mt then the cost drops to about $163 billion. If the salt repository is placed within the Land Withdrawal Act boundaries that currently hosts WIPP, the cost drops to about $39 billion. Only in salt is the annual revenue stream from the Nuclear Waste Fund sufficient to accomplish this program without additional taxes or rate hikes, and will even have funds left over to carry out the SNF interim storage program, dispose of the eventual SNF re-use waste, and other nuclear-critical activities over this time frame including R&D efforts. Even if Congress continues to freeze the existing balance of the Nuclear Waste Fund for deficit-reduction purposes as it is doing now, the annual revenue stream alone is more than sufficient to carry out the entire nuclear waste program if the second repository is in salt.

Of course, there will be a DOE-funded component to this program separate from the NWF. Historically, the cost sharing allocation between government and commercial waste was 27.3% and 72.7%, respectively, but this does not truly represent the relative costs, and the emergence of a second repository, the avoidance of retrievability, interim storage and possible re-use of SNF, changes this dynamic. The States, the nuclear industry and the Federal Government will have to negotiate an equitable arrangement. Regardless of the final framework, salt will be the only formation that can be paid for with little or no new appropriations.

Table 1. Repository Costs (in millions constant $2007) for 83,000 MTHM of high-level waste.

Cost Component	*volcanic tuff*	*massive salt*	*crystalline*
Development and Characterization	9,488	800	11,006
Surface and Subsurface Facilities	24,053	7,187	27,901
Waste Package and Barriers/Shields	19,164	1,250	8,700
Performance Confirmation	3,273	926	3,797
Regulatory, Infrastructure and Mgmt. Support	4,687	2,030	5,436
Program Integration QA/QC, NRC, other	6,821	3,708	7,912
Transportation	9,434	7,000	6,500
Institutional Costs and Financial Assistance	6,604	6,604	6,604
TOTAL	$83,524	$29,505	$77,856
(at already developed sites)	(YM~$71,000)	(LWA~$17,500)	

Table 2. Nuclear Waste Fund Revenues versus Repository Cost Estimates (overnight and inflated)

Revenues	*(millions $2007)*	*Repository Costs for 83,000 MTHM (millions $2007)*		
Nuclear Waste Fund		volcanic tuff	bedded salt	crystalline
presently in bank	$24,100	$83,524	$29,505	$77,856
20% U.S. power generation from nuclear over 62 years provides revenues to the Fund		inflated costs using a simple 2%/annum with a high spend rate during the central operational period from years 17 to 52		
utilities/rate payer annual payments	~$770/yr			
annual interest	~$900/yr			
Accumulated NWF assets	**$131,000**	**$192,105**	**$67,861**	**$179,069**
(at already developed sites)		(YM $163,342)	(LWA $39,071)	
Estimated costs for generic SNF interim storage program		$13,500	$13,500	$13,500
Cumulative costs for a complete nuclear waste program		**$205,605**	**$81,361**	**$192,569**
(at already developed sites)		(YM $176,842)	(LWA $52,571)	

SOME SPECIFIC POLICY ACTIONS

Congress and the Administration should support the recommendations of the Blue Ribbon Commission on America's Nuclear Future, and make the necessary amendments to existing law that allow them to be implemented, that is, the Nuclear Waste Policy Act of 1982 and the Land Withdrawal Act of 1992, as later amended. In particular Congress should:

- support interim storage for spent nuclear fuel,
- support resumption of the site selection process for a second repository,
- support the formation of a quasi-government entity to execute the disposal and storage program and give it full control of the Nuclear Waste Fund, and

- support the completion of the Yucca Mountain license application review. The taxpayers paid for it, and it should be completed. It will take several years to complete the review and will calm the legal frenzy that is building in response to the project's demise. The license application itself will be viewed as scientifically reasonable, but completion does not equate to authorization to proceed. The choice of Yucca Mountain will be seen as not optimal, too expensive and no longer necessary given interim storage for SNF. However, completion of the application review, along with resumption of a second repository, provides flexibility and choices that allow the nation to move forward with a nuclear waste solution. A hard rock repository could even play a role in the nuclear program in the future, although a single salt repository can accommodate all of our nuclear waste needs for the foreseeable future.

At the same time, Washington State, South Carolina, New York, Maine, Idaho, Tennessee and whichever other states wish to participate, should partner with the State that has the most optimal salt deposit for nuclear waste disposal (Figure 5) such as New Mexico, and form a multi-state compact that proposes an equitable arrangement to carry out this program. Socialization of this proposal among the citizens of these states, tribes, local governments, the industry and other stakeholders would occur to develop a full proposal to the quasi-government entity that would include cost and schedule as well as acceptable agreements and regulatory obligations. This multi-state compact would then outline a proposal to the NRC, the Administration and to Congress that would be considered for ratification. Working out the details will take the bulk of this effort but the opportunity is set for a true forward motion in one of the most complex endeavors in our Nation's history.

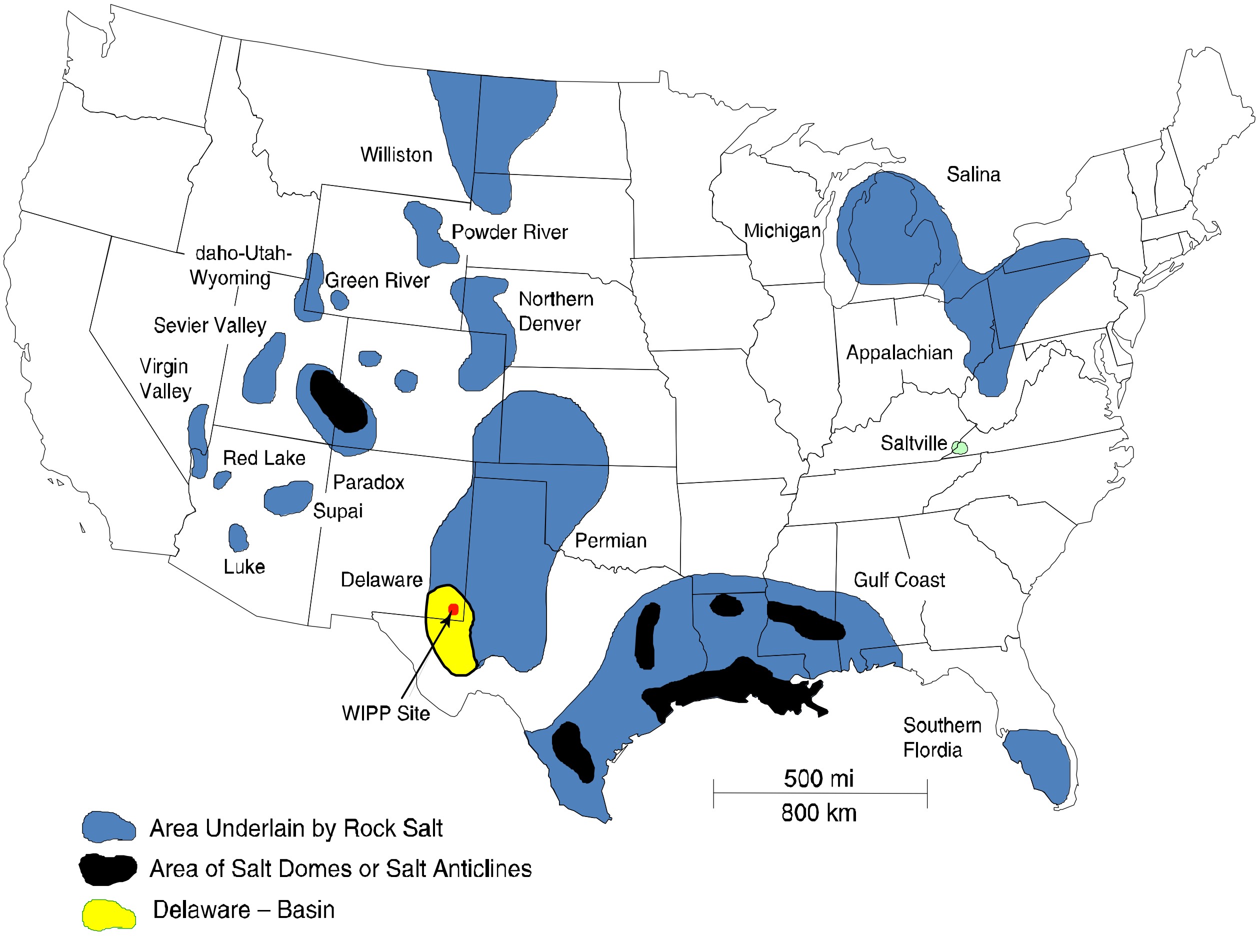

Fig. 5. Locations of salt deposits in the United States. The Delaware Basin salts (yellow) are the least tectonically deformed, are the thickest, and are at the most optimal depths for nuclear repository purposes.

CONCLUSIONS

Massive salt deposits, such as the Salado Formation near Carlsbad, New Mexico, offers a ready solution to the disposal of nuclear waste, a major impediment to solving our power generation and environmental needs in the next fifty years. This geologic unit is already host to permanently disposed nuclear waste at the WIPP site. The extensive scientific investigations of this unit, a perfect safety record over the 12 years of operation, and the disposal of higher-activity remote handled nuclear waste, demonstrate the capability of massive salt deposits, and of this type of operational environment, to handle nuclear waste of any type. The President's Blue Ribbon Commission on America's Nuclear Future has drafted a number of recommendations addressing nuclear energy and waste issues (BRC 2011) and three recommendations, in particular, have set the stage for a new strategy to dispose of high-level nuclear waste and to manage spent nuclear fuel within the United States: 1) interim storage for spent nuclear fuel, 2) resumption of the site selection process for a second repository, and 3) a quasi-government entity to execute the program and take control of the Nuclear Waste Fund in order to do so. The first two recommendations allow removal and storage of spent fuel from reactor sites to be used in the future, and allows permanent disposal of actual waste, while the third controls cost and administration. The Nuclear Waste Policy Act of 1982 (NPWA 1982) provides the second repository different waste criteria, retrievability, and schedule, so massive salt returns as the candidate formation of choice. The cost (in inflated 2007 dollars) of disposing of 83,000 metric tons of heavy metal (MTHM) high-level waste (HLW) over a 62-year project period is about \$192 billion in volcanic tuff, \$67 billion in massive salt, and \$179 billion in crystalline rock. If the salt repository is placed within the Land Withdrawal Act boundaries that currently hosts WIPP, the cost drops to about \$39 billion. Only in salt is the annual revenue stream from the Nuclear Waste Fund more than sufficient to accomplish this program without additional taxes or rate hikes, and will even have funds left over to carry out the entire SNF interim storage program and other nuclear-critical activities over this time frame. Even if Congress freezes the balance of the Nuclear Waste Fund for deficit-reduction purposes, the annual revenue stream alone is sufficient to carry out the entire program. It is critical that the states most affected by this issue (WA, SC, NY, ID, TN, IL and NM) develop an independent multi-state agreement in order for a successful program to move forward. Federal approval would follow.

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