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A Single Global Small-User Nuclear Repository - 9085

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ABSTRACT

Global energy partnerships in nuclear power, proposed by France, Russia, U.S. and England, seek to address the proliferation issue by controlling fuel production and nuclear materials, removing the need for each country to develop enrichment, fabrication, recycling or disposal capabilities. Several of the large generator countries such as France, the U.S., Japan, S. Korea, Russia, the U.K., China and India, all have plans for deep geologic repositories because they anticipate sufficient waste over the next century to justify the expense of a repository. However, countries having, or planning, less than five reactors, such as Egypt, Iran, Indonesia, Brazil and about 30 other countries, will not have sufficient waste generation, or a favorable geologic site, to justify the economic and environmental issues of developing their own repository. The Salado salt formation in New Mexico, set aside for nuclear waste disposal within the 16 square-mile area by the Land Withdrawal Act of 1992, is the most optimal geologic formation for the permanent disposal of any nuclear waste and is easily able to host all of the commercial nuclear waste that will be generated in the next thousand years. The U.S. commercial nuclear waste needs presently surpass all others, and will for the foreseeable future. Hosting the relatively small amount of waste from these small-user nations will add little to U.S. waste stream while the cost/benefit analysis from the standpoint of operations, safety, geology, cost and proliferation is overwhelmingly positive for developing such a global repository. Oceanic and overland transportation, high-level disposal logistics and costs from several programs, including WIPP, have demonstrated that the operation would pay for itself from international user fees with no U.S. taxpayer dollars required and still save the world about $400 billion over 100 years. The ethical considerations alone are compelling.

INTRODUCTION

The magnitude of humanity's energy needs requires that we embrace a multitude of various energy sources and applications in order to achieve a sustainable energy production that will allow the world economy to grow without intermittent shortages, security vulnerabilities, extreme costs or environmental degradation (Wright and Conca, 2007). Using best-estimate population growth and global energy consumption projections (United Nations 2004), world population will exceed 9 billion before 2050 and energy consumption could top 40 trillion kW-hrs/year (Figure 1, and Deutch & Moniz 2006). With determined conservation and efficiency programs, cultural changes and new construction strategies, this might be reduced to 30 trillion kW-hrs/year (Energy Information Administration, 2007; Stix 2006). Ambitious proposals to replace conventional fossil fuel (coal, oil and gas) power generation by alternative energy sources hope to drop the percentage of fossil fuel use by half from its present two-thirds to one-third (Figure 2). Unfortunately, because of the huge growth in consumption, a third of 30 trillion kW-hrs/year is 9.8 trillion kW-hrs/year, which is the same absolute amount of fossil fuel used today (Figure 1). Therefore, the other two-thirds, or 20 trillion kW-hrs/year, must come from non-fossil fuel sources.

If half of that comes from alternative non-nuclear, non-hydroelectric sources (an increase of 3000%), then nuclear still needs to increase by a factor of four worldwide to compensate (over 1500 ~1200 MW Gen III reactors). Many of the reasons nuclear energy did not expand after 1970 in North America and elsewhere (proliferation, capital costs, operational risks, waste disposal, and public fear) are no longer the insurmountable challenges they once were (Wright and Conca 2007). Standardizing units, removing punitive financing and regulatory delays, providing loan guarantees and streamlining the permitting process, cuts costs dramatically. Even so, for nuclear to produce 10 trillion kW-hrs/yr by 2040 will require investments upwards of $8 trillion. The same power production from renewables will require about $9 trillion, and simply fueling existing fossil fuel plants to produce 10 trillion kW-hrs/yr from now to 2040 will require over $20 trillion depending upon fossil fuel cost projections. However, if nuclear and renewables fail to significantly exceed 5 trillion kW-hrs/yr by 2040, then fueling fossil costs will exceed $50 trillion between now and 2040.

Because nuclear and renewable costs are mainly up front, they appear larger than for fossil fuel, but the continuous need to fuel fossil fuel plants with increasingly costly fuel quickly overwhelms any reasonable projections of nuclear and renewable costs. In other words, as costly as the almost $20 trillion investments in nuclear and renewable over the next 30 years will be, not investing in nuclear and renewable to this degree will cost much more in the long run.

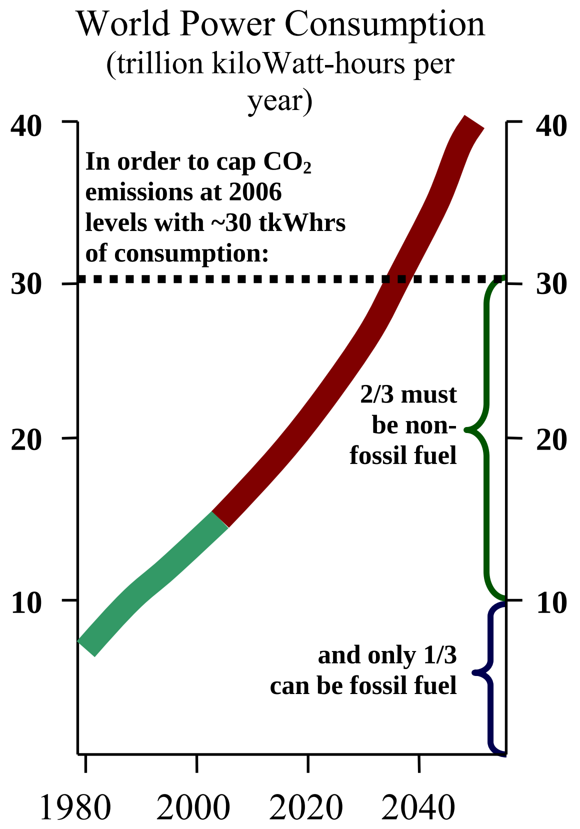

Fig. 1. World energy consumption from 1980 projected to 2050. It is imperative that thia levels at about 30 trillion kW-hrs/year in order to be able to cap CO_2 emissions at present levels. After Deutch & Moniz (2006).

While most of this investment in nuclear will occur in large-generating countries like China, India and the U.S., many smaller countries will build only a few reactors, perhaps less than five 1,200 MW reactor-equivalents. The fuel requirements and waste streams generated will be fairly small, certainly not justifying an entire fuel cycle from enriching to geologic disposal. This small-user nation characteristic is the driving force behind various global nuclear energy partnership strategies, such as GNEP in the U.S. or GNPI in Russia, and multiple-country repository concepts and world nuclear fuel banks in Europe (McCombie 2007). In these types of nuclear energy partnerships, nuclear fuel is provided to non-nuclear-capable countries by nuclear countries thereby removing the necessity of non-nuclear countries from developing their own enrichment capabilities that can be used to produce weapons-grade material. Since the fuel costs are much lower than the O&M costs of nuclear power (23% fuel vs. 77% O&M), unlike coal (78% fuel vs. 22% O&M) or gas (91% fuel vs. 9% O&M), this makes economic sense (OECD 2005, NEI 2006). If the small-user country does enrich or dispose, then nuclear materials are greatly controlled, reducing proliferation risks.

The production of sufficient nuclear fuel by a few large nuclear nations for many small-user nations involves tricky logistical, economic, diplomatic and technical planning especially if recycling of spent fuel is part of the plan. But the storage and subsequent deep geologic disposal of the waste from the small-user nations is not difficult at all scientifically, technically or economically, only politically.

NUCLEAR WASTE DISPOSAL IN AN IDEAL DEEP GEOLOGIC FORMATION

The critical aspect about nuclear waste unknown to the public and public officials is that there is not much of it. All the spent fuel generated in the United States in the last 60 years can fit on a single soccer field (assuming a PWR assembly dimension of 21.5 cm x 21.5 cm, approximately 100,000 used assemblies, and a regulation soccer field of 100 x 60 yards). Therefore, all the nuclear waste generated in the United States in a thousand years can fit into one repository. If only one repository is needed, then that repository should be as ideal as possible

Characteristics of a suitable geological repository for the disposal of nuclear waste includes 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 vitrification or reforming necessary),
v. minimal reliance on engineered barriers to avoid long time extrapolation 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 the first several hundred years of peak temperature after emplacement in a repository, and
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 human habitation anywhere near the site).

The Salado Formation in the Permian Basin of southeast New Mexico is a geologic formation that satisfies all of the above characteristics to a degree not matched by any other formation in the world, although other adequate formations do exist (Nuclear Energy Agency 2001; McEwen 1995; National Academy of Sciences 1970). The Salado Formation is a massive bedded salt deposit that has a simple hydrogeology with no dual-porosity or multi-component properties. The Salado has had a simple geologic history and is in a tectonically quiet area. The Salado is a simple geologic unit exhibiting optimal thermal properties (K_τ ~ 9 kcal/m/hr/deg @ 200°C), unconnected porosities of only 1%, and rheological properties that, under the 150 bar geostatic pressure, allow rapid creep closure of all openings. These self-healing rock mechanical properties mean that the rock cannot maintain open and connected fractures or pores, resulting in overall hydraulic conductivities $\leq 10^{-14}$ m/s (Beauheim & Roberts 2002) and diffusion coefficients $\leq 10^{-15}$ m^2/s (Beauheim & Roberts 2002, Conca *et al.* 1993). The presence of 230-million-year-old seawater still trapped in the salt as fluid inclusions and as intergranular water has long been known, but recently Permian macrobiomolecules of bacterial husks, cellulosics and DNA strands exceeding 12,000 base pairs, have been found to be pervasive in the ubiquitous fluid inclusions (Griffith et al 2008). The persistence of these biomolecules illustrates that almost nothing has happened to this formation in 200 million years – no volcanism, tectonics or diagenesis, sufficiently rapid burial for removal from cosmic-ray degradation but never deep enough burial for heating above the denaturing temperature (> 41°C), and almost no naturally-occurring radioactive materials (>99% NaCl).

Therefore, the Salado formation in this area at this depth 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 pre-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.

If these properties and conditions sound familiar, it is because the Salado Formation is already host to an operating deep geologic nuclear waste repository, called the Waste Isolation Pilot Plant, or WIPP, shown in Figure 2. WIPP, near Carlsbad, New Mexico has been operating for almost ten years, since 1999, and as of this writing, has disposed of about 60,000 m^3 of waste in over 100,000 containers, equivalent to about 300,000 fifty-five gallon drums of defense transuranic waste (Figure 3, see also http://www.wipp.energy.gov).

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

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. Almost 25 rooms have been filled as of June 2008. Note the higher activity remote handled waste plunged into boreholes in the wall to the right and plugged with four feet metal-wrapped cement.

Beginning in January 2007, WIPP began accepting waste containing radionuclides that emit more penetrating gamma radiation, referred to as Remote Handled (RH) waste. RH waste has surface exposures greater than 200 mrem/hr, so must be shielded and remotely handled. It still must have transuranic activity concentrations greater than 100 nanocuries per gram of waste, but the upper limit is 23 Curie/liter. 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, essentially recycled defense spent fuel. 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 right 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. Another unique feature of the Salado is the ease, safety and low-cost of mining operations in this relatively soft rock versus the hard rock of many proposed high-level repositories.

An important issue relating to disposal of recycle waste, or any high-thermal waste, in the Salado Formation is the presence of fluid inclusions in the salt. The extremely low water content in the salt exists primarily as fluid inclusions of brine and brine along grain boundaries. Fluid inclusions have been studied extensively with respect to high activity waste disposal because inclusions can migrate under a significant thermal gradient, e.g., 1.5°C/cm, by dissolution of salt on the up-gradient side and re-precipitation on the down-gradient side (Roedder 1984). This process encourages brine to migrate towards the waste. In most international high-level waste programs, this has been viewed as a problem because the canisters and any engineered barriers are required to survive intact anywhere from 10,000 to 100,000 years and interactions with brine, however small the

Fig. 4. Remote Handled nuclear waste (>100 nanoCi/gram of waste but <23 Ci/liter), some of it from reprocessing of spent fuel, being transported to the WIPP site in New Mexico in a 72B cask.

volumes, could be detrimental to canister performance. However, in the Salado Formation, the canister does not need to survive after emplacement, there is no need for engineered barriers, and a halo of increased water content within or around the disturbed rock zone is of no consequence from a repository performance standpoint.

In addition, after fluid inclusions have migrated and the salt has recrystallized behind them, the hydraulic conductivity is still $< 10^{-14}$ m/s and the diffusion coefficient is even lower because of the lowered water content (Conca *et al.* 1993). In fact, at WIPP, the performance assessment assumes a repository with various amounts of water inundation probabilistically distributed, from dry to completely flooded, with completely breached and corroded containers. Therefore, fluid inclusion migration is not an issue for nuclear waste disposal in the Salado Formation (McEwen 1995; Beauheim and Roberts 2002).

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, ten years after waste disposal operations (CEMRC 2007). The New Mexico State University Carlsbad Environmental Monitoring and Research Center (CEMRC), located in Carlsbad, NM, has been the independent monitoring facility for the area around WIPP from 1993 to the present (www.cemcr.org). Constituents measured by the monitoring program in various environmental media include gross alpha/beta, ^{7}Be, ^{212}Bi, ^{213}Bi, ^{214}Bi, ^{144}Ce, ^{249}Cf, ^{60}Co, ^{134}Cs, ^{137}Cs, ^{152}Eu, ^{154}Eu, ^{40}K, ^{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, ^{241}Am, ^{238}Pu, ^{239,240}Pu, various VOCs, and many inorganic constituents normally analyzed in waters, particularly RCRA constituents. The *in vivo* bioassay (whole body counting) program at CEMRC performs direct bioassays which include transuranium elements via L x-ray in lungs, ^{241}Am, ^{234}Th, ^{235}U, fission and activation products in lungs including ^{54}Mn, ^{58}Co, ^{60}Co and ^{144}Ce, and fission and activation products in total body including ^{134}Cs and ^{137}Cs (and ^{57}Co, ^{88}Y and ^{133}Ba). Based on the radiological analyses of monitoring samples completed to date for area residents and site workers, and for selected aerosols, soils, sediments, drinking water and surface waters, there is no evidence of increases in radiological contaminants in the region of WIPP that can be attributed to WIPP operations. 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 operations began in 1999.

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. WIPP's phenomenal safety record has gone a long way towards increased public acceptance and confidence in the nuclear industry. Public surveys show that regional community acceptance is about 93% which is even larger than the overall 74% favorability rating of nuclear energy nationwide (Bisconti 2008). This results from the length of time WIPP has operated without significant safety or environmental incidents. Such a safety record has also caused public acceptance of other nuclear operations in the area such as the recent construction initiative of a nearby uranium enrichment facility by URENCO. Finally, the issue of remoteness from population centers is handled very 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, the Salado formation is demonstrably the most optimal site in the world for nuclear waste disposal. It then becomes an ethical issue when deciding where to place the small amount of nuclear waste from the small-user nations. Forcing each to dispose of their own waste forces construction of many disposal sites with less-than-optimal to poor characteristics spread throughout the world, causing dramatically increased environmental risk, huge unnecessary costs and increased proliferation risks. Since the volume of waste from the small-user nations is relatively small compared to the large-user nations, it makes economic and environmental sense to combine all this waste at one site. And that one site should be the best site available. Since the Salado is already disposing of similar waste, and has much more capacity than needed even within the small area set aside for this purpose, it is unethical and foolish not to place this waste in the Salado formation within the Land Withdrawal Boundary.

ECONOMICS OF A SINGLE GLOBAL SMALL-USER REPOSITORY

Other groups and researchers have discussed the possibility of centralizing waste disposal in one or a few locations as a way of reducing costs and environmental issues, addressing proliferation concerns and taking advantage of the best sites geologically. Neil Chapman and Charles McCombie in particular, along with the ARIUS project (www.arius-world.org) have championed this concept for years (Chapman and McCombie 2008). WIPP's execution over ten years provides documented, robust cost data for disposing of nuclear waste of all types, and can be used to calculate the cost-effectiveness of a single small-user repository in the Salado. The mining operations in this relatively soft rock were easily adapted from the potash mining over the last century in the KCl layers above the massive NaCl of the repository. The use of off-the-shelf equipment, well-established procedures, an already-fully-trained work force and simple inexpensive containers requiring no longevity after emplacement, allows the WIPP operations to be extremely cost-effective compared to other proposed nuclear disposal sites. Annual operating costs of about $230 million over that last ten years, which include disposing of RH waste, are an order of magnitude less than any other proposed nuclear disposal site. Adding further waste volume from commercial waste or international sources, whether involving recycling or not, will not significantly change the overall economics, and the economy of scale means better cost benefits. Even the transportation issues have been solved, on land by WIPP itself, and by sea with the Japanese and Isreali IAEA/U.S. transoceanic shipping programs.

Since the U.S. has much more waste than all the anticipated small-user nations combined (assuming about 100 new reactors), the costs of adding that waste stream can be scaled up easily, and would not exceed $100 billion over 50 years, even assuming an order of magnitude cost increase for handling spent fuel or recycled waste. Perusing and combining recent cost projections for international disposal programs (IAEA 2008), an estimate for disposing of the small-user nation waste from 100 new reactors in many different sites around the world would exceed $500 billion. From the standpoint of environmental impacts, disposing of waste in many second- or third-rate locations is wrong and increases the likelihood of adverse impacts millions of times. Since the deomstrated performance period for the Salado is in the hundreds of millions of years, it is unethical not to combine this waste with our own. Because the worldwide cost savings is so large, a reasonable waste handling fee can be charged to each small-user nation, say $2 billion per 1200-MW reactor per 50 years, providing sufficient funds to handle this external waste plus all of our own, resulting in no U.S. taxpayer dollars needed for nuclear waste disposal in this country, and still saving the world hundreds of billions of dollars. The nuclear waste fund could then be used for R&D in areas we desperately need, e.g., recycling technologies and future reactor development. Also, there is no rush to dispose, so spent fuel could be stored at the site for decades while the decisions and the technologies for recycling are decided and developed. Or not. Then, whatever waste does require permanent geologic disposal will be easily and quickly emplaced in the Salado at the time. If such a solution is not implemented, the much higher costs of the potential proliferation issues alone could well be shouldered by the U.S. taxpayer regardless.

NON-PROLIFERATION ADVANTAGES OF A SINGLE GLOBAL SMALL-USER REPOSITORY

The rise in global nuclear power requires that we complete the entire nuclear fuel cycle (Figure 5). However, addressing the proliferation issue requires tight control on the fuel cycle. So while we shouldn't mind that Iran has a nuclear power plant, we are concerned that they have an enrichment facility. The large generator countries such as France, the U.S., Japan, S. Korea, Russia, the U.K., China and India, arguably need and can afford to have the entire cycle, but small-user nations do not have the resources or the need to have more than one or two parts of the cycle. Since half of all uranium deposits in the world are in developing countries, it is hard to argue they should not mine them as the economic oportunities are too great to ignore, as was seen recently by Jordan's discovery of large uranium deposits in that country. Together with building and operating a nuclear plant, these are obvious parts of the cycle all should engage in if possible. But the amount of fuel needed and the small amount of waste generated do not justify the entire cycle for these small-user nations. This is the economic basis for global partnerships. The proliferation advantages of these partnerships are just another advantage and flows from the economics, not from a confrontational stand of the large generator nations.

From the waste standpoint, Chapman and McCombie point out that the proliferation risks are increased if the number of disposal sites increases without regard, and if there is a neglect of the security risks associated with the back end of the fuel cycle (McCombie et al., 2008). According to McCombie and Chapman, the security concerns associated with fuel-cycle wastes are those of fissile materials being used for weapons production by proliferating States or of other radioactive materials from the cycle being used in acts of terrorism or war. These risks fall into four categories:

- Diversion of fissile materials separated during civil reprocessing of spent fuel,
- Clandestine reprocessing of spent fuel to produce weapons materials,
- Disruption of waste storage facilities in acts of terrorism or war, and
- Diversion of radioactive wastes with the intention of dispersion and contamination.

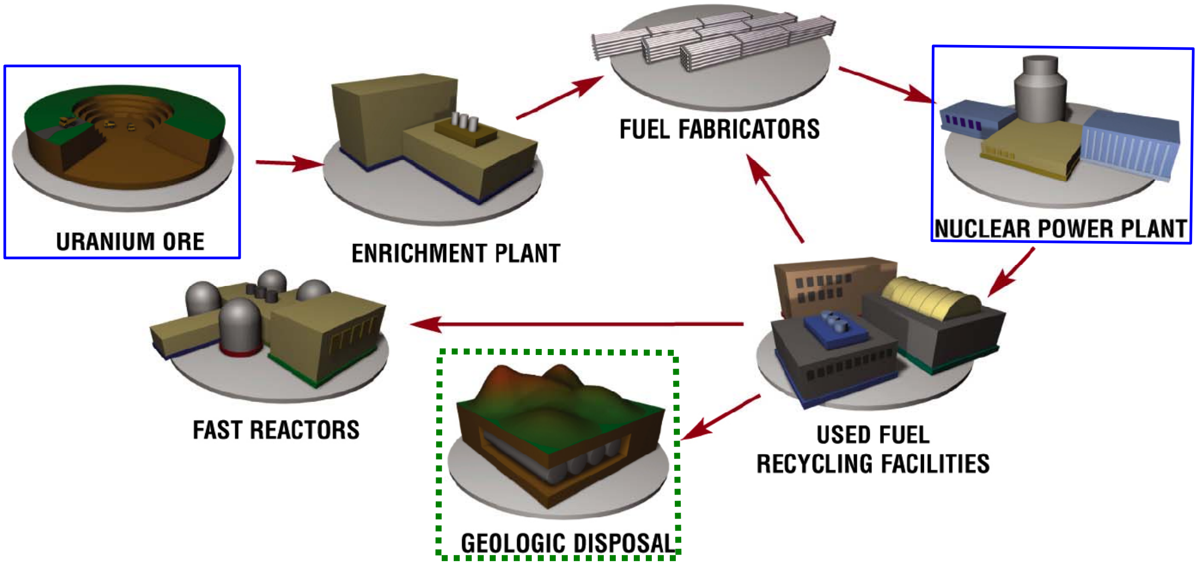

Fig. 5. The nuclear fuel cycle, the entirety of which will probably occur in all large generator nations (France, the U.S., Japan, S. Korea, Russia, the U.K., China and India), but with small-user nation steps outlined in solid lines and the small-user repository in the U.S. outlined in a dotted line [after NEI].

While spent fuel alone does not guarantee a weapon, and is itself a poor candidate material for dirty bombs (Conca and Reynolds 2007), the existence of many small countries having a small amount of spent fuel with little ability to dispose or otherwise handle the spent fuel causes pressure for these nations to find easy ways to rid themselves of it. Controlling nuclear materials of all types is essential to non-proliferation, and taking control of spent fuel from small user nations is the easiest way to prevent this particular type of proliferation vector, the vector most likely to result from the spread of peaceful nuclear power throughout the world. Having a cost-effective option in a stable provider nation with full transparency in full compliance with non-proliferation treaties and agreements is the safest option for all small-user nations and the world at large. But, while proliferation is the concern, economics should be the driver.

CONCLUSIONS

The massive salt deposits of the Salado Formation near Carlsbad, New Mexico, offer a ready solution to the disposal of nuclear waste from any source, including spent fuel and/or recycle or reprocess waste. These wastes are a major impediment to solving the global power generation and environmental needs in the next century, especially as many small nations are planning or starting a nuclear power program with no ability to dispose or otherwise disposition spent fuel and other nuclear waste. The Salado salt is already host to permanently disposed nuclear waste at the WIPP site. The extensive scientific investigations of this unit, a perfect safety record over ten years of operation, the recent disposal of higher-activity remote handled nuclear waste, and the semi-infinite capacity of this unit in this region, demonstrate the capability of this formation to handle any and all nuclear waste. Adding the small amount of additional nuclear waste over the next century from the operations of small-user nations having less than five reactors is an easy, cost-effective way to expand nuclear power worldwide without increasing the risk of weapons proliferation.

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