The Yucca Mountain Repository – Too Little, Too Late - 9005

Leif G. Eriksson
Consultant, Nuclear Waste Disposition
535 N. Interlachen Avenue, Unit #303, Winter Park, Florida 32789, USA

David L. Pentz
The Pentz Consulting Company, Inc.
4062 Beach Drive, Freeland, Washington 98249, USA

ABSTRACT

In 2008, the U.S. Department of Energy (USDOE) announced that the nation's first (and only pursued) deep geological disposal system (repository) for 70,000 metric tonnes of spent nuclear fuel (SNF) and other high-level radioactive waste (HLW) at the Yucca Mountain (YM) site in Nevada would:

1. Not be able to accommodate the projected stockpile of utility-generated SNF beyond 2010.
2. Open no earlier than in 2020, i.e., more than 22 years behind the statutory-mandated opening date.

In the meantime, the USDOE is legally obligated to compensate the utilities from January 31, 1998, until it takes title to the utilities' SNF. In 2005 when the YM SNF repository was projected to open in 2010, the utilities estimated that, depending upon how close to 2010 the YM repository opened, the "breach-of-contract" compensation could be in the range of between 100 billion and 300 billion U.S. dollars ($300B), which would exceed the 2008 projected life-cycle cost of $96B for the YM repository. It thus seems appropriate to look beyond the YM repository and call upon the U.S. Congress to promptly act and open new avenues allowing the USDOE to more timely and cost-effectively take title to both existing and pending SNF the current fleet of 104 reactors will generate through the next 60 years. Options for SNF arising from an additional 50 reactors should also be provided.

Based on our more than 60 years of combined involvement in nuclear waste management in the USA and abroad, we submit the following industrial-scale-proven, repository-related, nuclear-waste-management and disposition solutions for prompt Congressional consideration and action:

1. An increase in the disposal capacity (and perhaps mission) of the YM repository.
2. Prompt establishment of at least one large federal monitored retrievable storage (MRS) facility for utility-generated SNF.
3. Continued research in reprocessing options of existing and pending SNF with defined milestones.
4. Resurrection of a second repository program for both SNF and other long-lived radioactive waste requiring deep geological disposal.
5. Enable nuclear fuel leasing to a) lower the cost of U.S. utilities SNF waste management and b) ensure safe global expansion of commercial nuclear power.

If timely and diligently integrated into a holistic, total systems approach to nuclear energy/management policy, these solutions would accommodate currently-defined and projected national SNF-disposition needs over a planning horizon consistent with planned new nuclear power investments and a new national energy independence policy. They also embody major beneficial impacts on homeland security, the nuclear renaissance here and abroad, and ensure that nuclear proliferation risks are reduced and minimized. The planning horizon should extend for at least the next 60 years and also provide disposition solutions for other long-lived radioactive waste categories currently lacking domestic disposition solutions, including byproducts of both uranium enrichment and reprocessing.

INTRODUCTION

In 2008, the U.S. Department of Energy's (USDOE) made the following two announcements:

1. The nation's stockpile of utility-generated spent nuclear fuel (SNF) would exceed the current statutory capacity of the proposed Yucca Mountain (YM) repository in early 2010.
2. The YM repository would not open until at the earliest in 2020, which is a) an incremental delay of another 10 years and b) 22 years behind its statutory-mandated opening date of January 31, 1998.[1]

However, the current legislation does not allow the USDOE to pursue any other option for taking title to utility-generated SNF. The related financial consequences and homeland security risks are huge. In other words, time is of utmost importance. This paper thus outlines industrial-scale-proven SNF management and disposition solutions we believe could alleviate the near- and long-term challenges that are needed to be promptly addressed in a holistic total systems nuclear waste management perspective (Fig. 1) for a period that is a) consistent with the nature of nuclear power investments and b) compatible with a realistic time to site and construct all the necessary components of SNF management. The described solutions will either directly or indirectly affect the need for domestic disposal capacity for SNF, high-level radioactive waste (HLW), and other long-lived radioactive materials/derivatives requiring deep geological disposal. Furthermore, if the U.S. chooses to support the leasing of U.S.-enriched and -fabricated nuclear fuel to some foreign nations, this will influence the quantities of SNF and other long-lived highly-radioactive materials that need to be managed. It would also significantly contribute to the lowering of the disposal costs of domestically-generated SNF (and HLW). A section of this paper is therefore dedicated to nuclear fuel leasing to complete the total systems perspective. The classification system used for radioactive wastes in the USA is also concisely described under a subheading in the Background section because it differs markedly from the radioactive waste classification system recommended by the International Atomic Energy Agency (IAEA) that is used in most other countries.

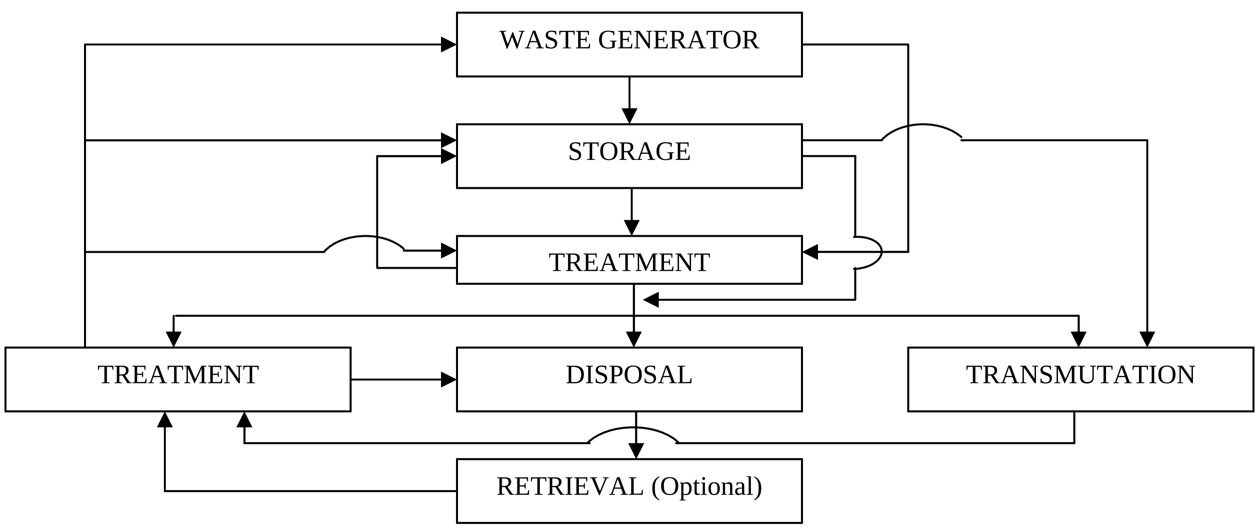

Fig. 1. Core components of a holistic national nuclear waste management program.[3]

Please note that the term "treatment" in Fig. 1 includes the terms "separation", "recycling", and "reprocessing", and neither "transmutation" nor "retrieval" is addressed in this paper. Furthermore, the term "reprocessing" is frequently used in the subsequent text for "recycling".

The reader is also advised that the opinions, comments, and recommendations presented in this paper are solely attributable to the authors.

BACKGROUND

The United States of America (USA or U.S.) has been a world-leader in both peaceful and destructive uses of the atom for more than 55 years. Furthermore, after a more than 25-year-long dormancy period, a rebirth and surge in the construction of new nuclear power plants (NPPs), also referred to as the nuclear renaissance, is projected. Critical components to the fruition of this nuclear renaissance are nuclear-industry confidence in the availability of: 1) affordable financing; and 2) at least one safe disposition path/ solution for both existing and future radioactive waste generated by the NPPs for a reasonably foreseeable future, e.g., which in our opinion is on the order of 60 years or longer. However, there are very few existing disposition paths for long-lived radioactive waste in the world today and the future of the global nuclear renaissance may hinge upon the leadership and radioactive waste management solutions in operation or being considered in the USA. Although NPPs generate several categories of radioactive waste, the focus in this paper is on the safe management and disposal of SNF due mainly to its current lack of an operating disposal facility; and the repeated delays in the projected opening of the nation's only current solution for safe disposal of SNF (~90%) and HLW (~10%); the deep geological repository pursued by the USDOE since 1976 at the YM site in Nevada (Fig. 2).

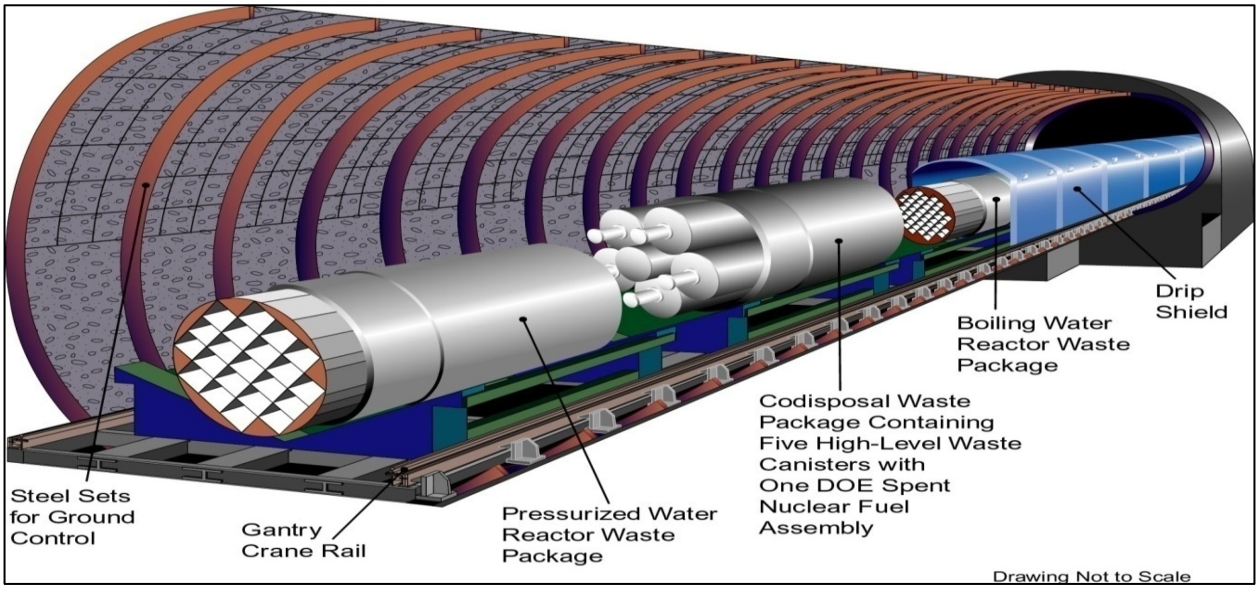

Fig. 2. Schematic illustration of a disposal tunnel in the Yucca Mountain SNF/HLW repository.

USA's Radioactive Waste Classification System

As illustrated in Fig. 3, the regulatory framework for the safe management and disposal of radioactive waste in the USA is based upon two main different waste streams, i.e., commercially- and government-generated, respectively, and related sets of regulations. Simply stated, the U.S. radioactive-waste classification system is fundamentally based on who the generator of the waste is and by the waste categories defined in the related regulatory framework, i.e., U.S. Nuclear Regulatory Commission (USNRC) regulations [e.g., 4-6] or USDOE Orders [7], respectively. The USDOE Orders only apply to radioactive wastes being managed, treated, stored or disposed at a federal site. In addition, all SNF and HLW to be disposed of at the YM site (Fig. 4) and all transuranic radioactive waste (TRU waste or TRUW) disposed of in the Waste Isolation Pilot Plant (WIPP) repository in New Mexico (Fig. 5) must meet environmental radiation protection standards promulgated by the U.S. Environmental Protection Agency (USEPA) [8, 9] but, whereas the YM standards are site-specific, the WIPP standards govern the rest of the USA. WIPP and a couple of "unique" U.S. waste categories are described below.

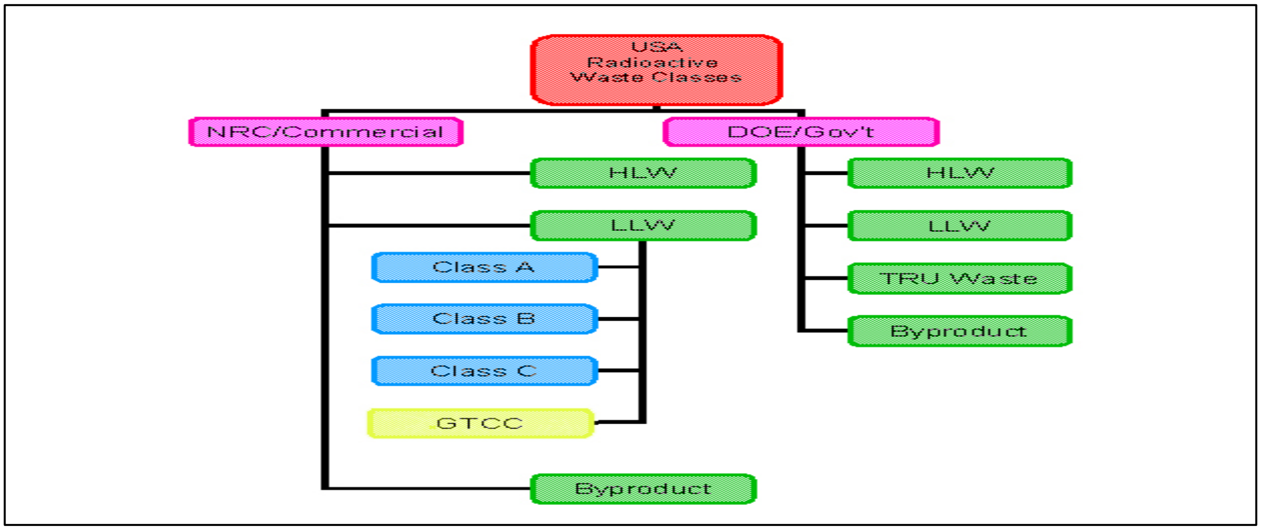

Fig. 3. Schematic illustration of the radioactive waste classification system used in the USA.

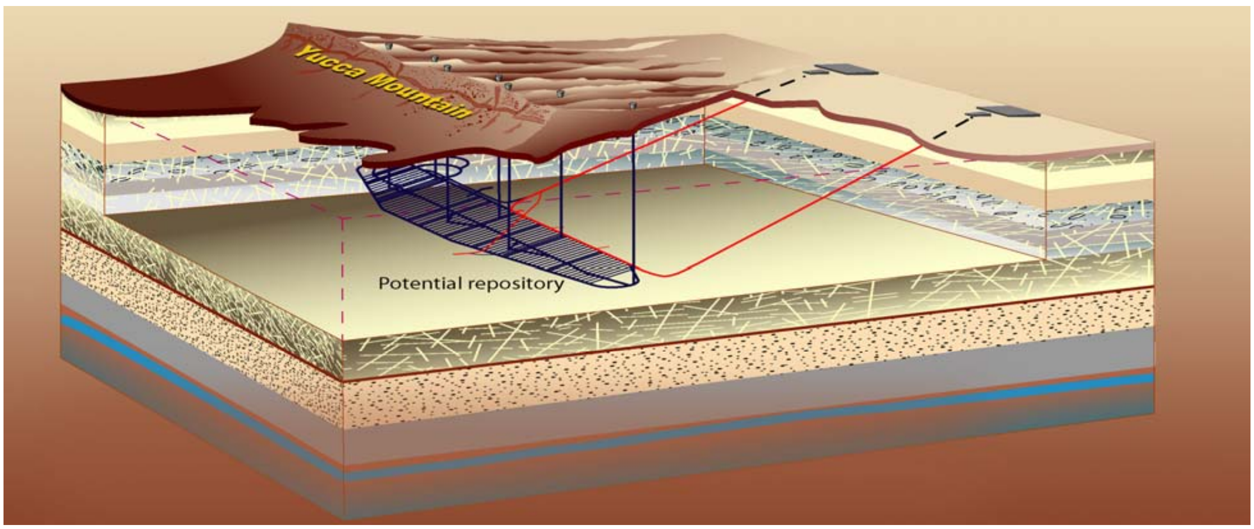

Fig.4. Schematic illustration of the layout of the candidate YM SNF/HLW repository (the underground research facility is shown in red).

The WIPP TRUW repository (Fig. 5) opened and has safely operated since March 26, 1999. It constitutes a global role model for how a repository for long-lived radioactive waste can be sited and developed in less than 25 years (1975-1999), provided it has adequate (= majority) local acceptance and political support.[e.g., 10, 11] TRUW is a unique federally-generated waste stream resulting from nuclear weapons production and research. It is a waste category rarely used outside of the USA that most closely resembles the long-lived low-level (LL-LLW) and long-lived intermediate-level radioactive waste categories (LL-ILW) defined by the IAEA. As illustrated under the USNRC-regulated/commercially-generated waste stream, there are the following four classes of LLW in the USA: A; B; C; and greater than Class C (GTCC).[5, 7] GTCC LLW is a unique U.S. waste category that also most closely resembles IAEA's LL-ILW category. The reason we are bringing up LLW here is that, whereas a disposal facility for federally-generated Class A-C LLW was licensed in Texas in January 2009, there is no disposal solution for commercially-generated GTCC LLW anywhere in the USA. In addition, 34 states also lack a disposal solution for commercially-generated Class B and Class C LLW.

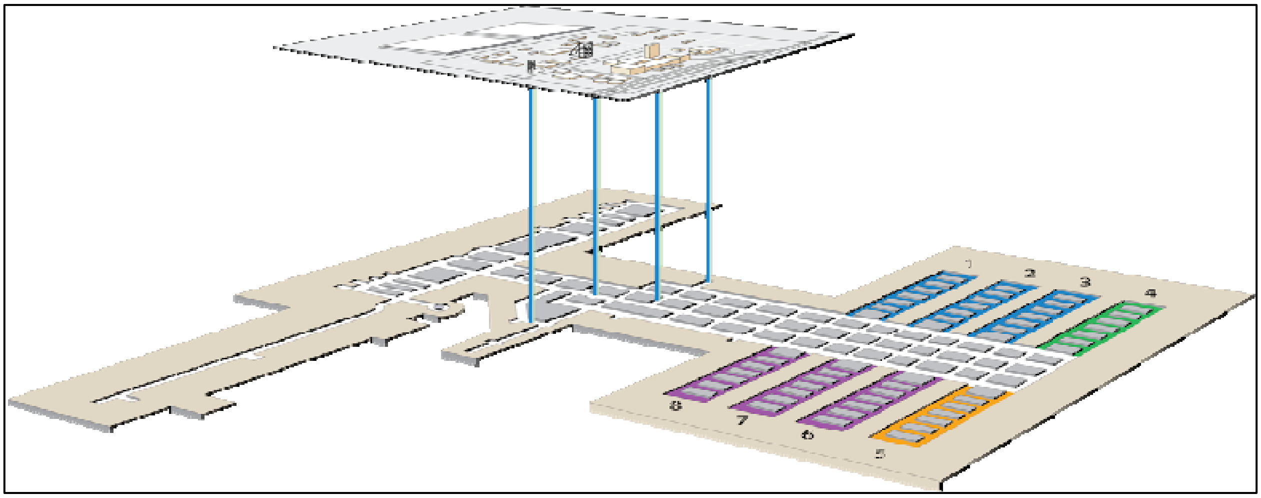

Fig. 5. Schematic illustration of the layout of the Waste Isolation Pilot Plant (WIPP) repository for safe disposal of up to 175,584 cubic meters of TRUW (the horizontal scale for the underground openings is exaggerated relative to that for the surface facilities). Panels 1-3 (shown in blue) have been filled and closed, panel 4 (shown in green) is being filled, panel 5 (shown in gold) is being developed, and panels 6-8 (in purple) remain to be developed. The underground openings shown to the left of and behind the four shafts constitute the adjoining underground research laboratory (URL), the North Experimental Facility, where in-situ tests were conducted until the late 1990s to establish the ability of the host rock (bedded salt) to isolate and contain TRUW and defense-generated HLW at ambient and elevated temperatures.[12]

Concise Chronological Overview of Select Milestones during the Evolution of the Yucca Mountain Candidate SNF/HLW Repository

The focus below is on milestones deemed by the authors to have significantly contributed to the current status of the YM SNF/HLW repository, *as remembered and/or perceived by the authors*.

In 1974, a prominent U.S. Geological Survey (USGS) earth scientist suggested that the dry tuff formations at the YM site in Nevada could be suitable for “storage” (= disposal) of long-lived radioactive materials.[13] The initial disposal concept was based on dry storage of simple waste canisters and heat would be allowed to dissipate through convection. (USDOE began the YM site investigation program in 1976.) In 1978, several prominent USGS scientists, including the author of the 1974 report, elaborated upon the 1974 report on the YM site expressing concerns about the potential adverse impacts on the host rock and complications to the safety analyses if the heat emanating from the disposed waste containers was high enough to generate steam [14], which it is in the current disposal concept.

In 1982, the U.S. Congress developed the Nuclear Waste Policy Act (NWPA). It was enacted, i.e., made a law, by the U.S. President in January 1983.[1] The NWPA directed the Secretary of Energy (the Secretary) to safely site, develop, open, operate, and decommission/close two deep geological disposal systems (repositories) for commercially(utility)-generated SNF. The first repository was to open no later than on January 31, 1998 and its total volume was not to exceed 70,000 metric tonnes of heavy metal or an equivalent amount of uranium (both referred to as MTU below) before the second repository had opened, which was to open approximately three years after the first repository. The NWPA also directed the Secretary to consider the option of developing an interim central monitored retrievable storage (MRS) facility for taking title to utility-generated SNF as expedient as practically possible. The MRS facility option was evaluated by and reported upon in 1989 [15] by a group of domestic experts and was subsequently deferred indefinitely by the then acting Secretary. The Secretary promptly established the ORWM within the USDOE to accomplish the federal SNF-management mission described in the NWPA. In the NWPA, the cost for the development of national disposition solutions for utility-generated SNF was covered by a tax on nuclear energy amounting to one cent per kilowatt, also referred to as one mill. This tax was to be paid into the Nuclear Waste Fund (NWF) by the nuclear utilities and any distribution out of the NWF was to be approved by the U.S. Congress. Consequently, the USDOE has to apply to the U.S. Congress more than one year in advance for its annual budget. Suffice it to mention here that the NWF had accrued approximately 31 billion U.S. dollars ($31B) of which approximately $11B had been allocated to the OCRWM program at the end of 2008 but t seldom, if ever, have the annual budgets requested for the OCRWM program following the establishment of the NWF 26 years ago reached the USDOE-requested amount.

In 1986, the USDOE commenced the construction of an underground research laboratory (URL) in the candidate repository host rock (volcanic tuff) at the YM site (Fig. 4). (It was subsequently used for a broad range of in-situ tests until it was closed in 2008.) In a February 1987 amendment to the NWPA (NWPAA),[2] the second repository program was deferred indefinitely and ongoing site characterization work at two of the then three candidate SNF-repository sites was terminated but neither the scheduled date for the opening nor the maximum volume of the nation's first SNF repository changed. The NWPAA also allowed the comingling of utility-generated SNF (~90%) and federal-government–generated SNF and other HLW (~10%). As followed, the YM site in Nevada became, and still is, the Secretary's only option for safe disposition of up to approximately 63,000 MTU of utility-generated SNF and up to approximately 7,000 MTU of federal-government/ defense-generated SNF and other HLW. However, the arbitrary constraint on the quantity of defense-related HLW that could be disposed in the YM repository had an unplanned consequence. It generated much higher costs related to the conditioning of the HLW in Hanford. If an active second repository program had existed, the baseline plan would have been substantially different from the current plan and at a lower project cost.

In 2002, the U.S. Congress and the President approved the YM site for the nation's first repository for SNF and HLW.

On June 3, 2008, the USDOE OCRWM submitted the Construction License Application (CLA) to the USNRC for the YM SNF/HLW repository for review and approval. On September 8, 2008, the USNRC accepted and docketed the CLA. The ensuing licensing review, even if uncontested, could take at least four years. Also in September 2008, the then Director of the OCRWM program announced that the USDOE recommended an expansion of the current statutory capacity of the YM repository. On December 9, 2008, the USDOE submitted two reports to the U.S. Congress; one on interim storage of approximately 2,800 MTU of SNF from ten decommissioned NPPs at nine sites and one on the need for a second repository. The Secretary subsequently suggested a deferral of the decision on a second repository. However, if the Congress decided that a second repository was needed, the report suggested the resurrection of the nine previously considered sites under the first repository program.

In summary, this short history demonstrates that making political decisions related to SNF management has suffered from a lack of comprehensive strategic risk analysis to help formulate the US policy. Arbitrary inclusions of constraints and lack of a requirement to update the U.S. Congress on the implications of new information that affects the mission and focus of U.S. policy is very evident.

Current Status of and Projected Challenges Facing SNF and HLW Disposition in the USA

The YM repository is the only current legal option for disposal of SNF and HLW in the USA, which means that the only currently available legal option for the USDOE is to extend the nuclear utilities' guardianship/ownership of its SNF. This, in combination with the repeated delays in the opening of the

YM repository, resulted in 41 utilities in 31 states successfully suing the USDOE in the late 1980s and several utilities have already been awarded significant “breach-of-contract” compensations. These and pending compensations, which were estimated by the utilities in 2005 to reach between $100B and $300B depending upon how close to 2010 the YM repository opened. This impending cost to the government will be an important driver in the U.S. Congress’s consideration of a new SNF policy. It will also influence the views of the utilities towards the future management of their liabilities. The nuclear utilities will seek a sustainable solution to SNF, which allows them continue to generate electricity and build new nuclear capacity when it is cost effective.

The most recently projected opening of the YM repository is at least 22 years behind its statutory-mandated opening date of January 31, 1998 and its current statutory disposal capacity would be at least 20,000 MTU less than the projected stockpile of SNF in 2020. Actually, a January 2009 Nuclear News article states that the current stockpile of SNF is 58,000 MTU, which would increase the 2020 “surplus” SNF stockpile to at least 30,000 MTU. It should be noted that both of these estimates are based a total annual generation of SNF of approximately 2,000 MTU (may be a low number in light of recent annual SNF generation being on the order of 2,400 MTU). This assumes the relicensing of most of the U.S. reactor fleet but none of the approximately 35 new reactors being planned. The USDOE is thus recommending an increase in the disposal capacity of the YM repository from 70,000 MTU to 130,000 MTU. A more than three times increase in the current disposal capacity, i.e., at least 210,000 MTU, has also been mentioned. However, if a 60 to 80 year reactor lifetime is considered and it is assumed that the U.S. reactor fleet was expanded to say 150 reactors and as reactors were decommissioned they would be replaced, then the capacity requirements for SNF management could range from 138,000 to 143,000 MTU by 2050 and 243,000 and 280,000MTU by 2050. The annual SNF-discharges could also reach 3,500 MTU per annum.

The historical global record suggests that the siting and development of an NPP and a deep geological repository for SNF/HLW will take at least 10 years and 30 years, respectively. As follows, even if another SNF repository program is started tomorrow, another repository would likely not be available until at the very earliest 2039. At that time and assuming no change to the utilities annual SNF generation rate, the total stockpile of utility-generated SNF would be on the order of at least 120,000 MTU, and perhaps even above 132,000 MTU. In addition, the general awareness and political majority opinion in the USA is that an increase in the current energy production is a prerequisite for the nation to a) remain a global financial leader and b) providing a high-level of quality of life to its residents.[e.g., 16] It is also commonly recognized that only nuclear power embodies the adequate clean-energy-generating power and power-output flexibility required for the projected energy needs. As follows, at the beginning of year 2040, the stockpile of utility-generated SNF requiring deep geological disposal is likely to be significantly more than the current stockpile of 58,000 MTU.

As discussed further below, the rate of increase in the stockpile of SNF can be reduced by reprocessing or be accommodated by either an expansion of the current disposal capacity of the YM repository and/or the development of another SNF repository. It should be noted that the PUREX recycling process currently used in the USA still has spent mixed-oxide (MOX) fuel and GTCC LLW that will be required to be disposed of at a future date. It should also be noted that other non-commercial-scale reprocessing technologies exist, e.g., UREX+, that do not separate the plutonium isotopes, which are of greatest proliferation concern. It should also be noted that USA has been conducting a program for reprocessing SNF under the Advanced Fuel Cycle Initiative (AFCI) since 2002. In February 2006, the Bush administration announced that recycling would be developed under a new effort, the Global Nuclear Energy Partnership (GNEP), which would incorporate AFCI as one of its activities. If the recycling research and development (R&D) program is successful and leads to deployment, GNEP would eventually require the USA to be an active participant in the community of nations that recycle SNF, because one aspect of GNEP is that some nations recycle SNF for other user nations. Two key technical objectives of GNEP are to develop, demonstrate and deploy:

- Advanced technologies for recycling of SNF that do not separate plutonium, with the goal over time of ceasing separation of plutonium and eventually eliminating excess stocks of civilian plutonium contained in the SNF and drawing down existing stocks of civilian SNF. Such advanced fuel cycle technologies would substantially reduce nuclear waste, simplify its disposition, and help to ensure the need for only one geologic repository in the USA through the end of this century.
- Advanced nuclear reactors that consume transuranic elements from recycled SNF.

Three facilities are key components of the GNEP program as currently planned: (1) a nuclear fuel recycling center, or centralized fuel treatment center (CFTC); (2) an advanced sodium-cooled burner reactor (ABR); a fast-neutron reactor; and (3) an advanced fuel cycle facility (AFCF). As suggested in 2007 [17], the adjoining YM site, Nevada Test Site (NTS), and, perhaps, the Nellis Air Force Range could serve as hosts for one or more of these facilities.

Experts selected and committees assembled by the National Academies/Institute of Medicine's National Research Council (NAS-NRC) have frequently reviewed the USDOE's nuclear energy R&D program.[e.g., 18, 19] In a 2008 report on the GNEP program,[19] all NAS-NRC committee members agreed that the GNEP program should be replaced by a less aggressive research program. However, the committee believed that a research program similar to the original AFCI was worth pursuing and that it should be paced by national needs, taking into account economics, technological readiness, national security, energy security, and other considerations. The committee also believed that the program should be sufficiently robust to provide useful technology options for a wide range of possible outcomes, including bringing together other appropriate divisions of USDOE and other federal agencies, representatives from industry and academia, and representatives from other nations well before any decisions are made on reprocessing technology.[19] It should be noted that the GNEP program currently has a zero base-funding plan.

INDUSTRIAL-SCALE-PROVEN SOLUTIONS TO CURRENT AND PROJECTED SPENT NUCLEAR FUEL MANAGEMENT CHALLENGES

In a 1996 NAS-NRC report, [18] the first sentence in the Introduction section reads:

> "The single most challenge facing the nuclear field (commercial and defense) is what to do with the nuclear waste."

In our assessment, very little has been accomplished since then to find or develop solutions that would close the nuclear fuel cycle. On the contrary, subsequent reductions in USDOE's requested annual budgets for the YM project have been instrumental to current project delays and life-cycle-cost increases.

A plausible SNF-disposition solution/path in the USA is deemed by many as vital to the advancement of the nuclear renaissance. However, again, even if the YM repository opens in 2020, it is not going to provide a long-term solution.

Based on our more than 60 years of combined periodic active involvement in radioactive waste management programs in the USA and abroad, we believe that current laws governing SNF management in the USA, [1, 2] are1) outdated, 2) unnecessarily stringent, and 3) may constitute an imminent threat to national security, the nuclear renaissance, and the economy/prosperity (quality of life), both in the USA and abroad. We therefore call upon the U.S. Congress to demand an urgent re-evaluation of the current SNF management legislation that takes into account the current realities as a precursor to new policy and legislation. A new holistic total systems national waste management policy (Fig. 1) must be founded on a technically based strategic review by the USDOE that includes the views of the utilities. This review should also consider the global realities of SNF management, particularly as they relate to nonproliferation. The recommendations from USDOE must therefore include the views of the U.S. State Department, and the National Security Council. This will enable a timely and cost effective policy that will take title to utility-generated SNF for at least the next 60 years. We thus respectfully submit for consideration the following four radioactive waste management and disposition solutions that we believe host a very-high probability of being able to gradually mitigate current and projected SNF management and disposition challenges, if timely and diligently integrated and implemented:

1. An increase in the SNF-disposal capacity of the YM repository.
2. The prompt development of a federal MRS facility for utility-generated SNF.
3. Reprocessing of existing and future SNF.
4. The resurrection of a second repository program.

A fifth repository-related issue of global importance, nuclear fuel leasing, is also addressed below under separate heading because the leasing of USA-generated nuclear fuel to foreign nations would require additional SNF-management and -disposal capacity in the USA. It may also require reprocessing capacity if it is cost effective.

Since each of the aforementioned five solutions requires both legislative and prompt actions to mitigate the most recent and any future delay or cancellation of the YM project, we call upon the U.S. Congress to promptly consider and act upon them to minimize the adverse impacts of the current and projected SNF-disposition needs. We also would like to stress that time is of utmost importance and we owe it to both current and future generations to establish a nuclear waste management policy that reaches well into the future. Based on our estimates of the time required for NPP (>10 years) and repository (>30 years) siting and development, we concluded that a national SNF-management and, by association, a national energy and waste management policy should reach out to a planning base of at least 60 years into the future to: a) accommodate the relicensing of existing reactors to their design life of 60 to 80 years, and b) a possible increase to the current fleet of104 reactors to approximately 150 reactors. Furthermore, the above solutions need to be looked upon as a total system because, if they are timely and properly integrated, they will enable significant time- and cost-savings, and would make the national radioactive waste management program much more robust and insensitive to further delays to the opening of the YM repository until sufficient repository capacity is available to assure the safe disposal of all SNF and HLW requiring deep geological disposal. It would also make the national nuclear waste management program more holistic (Fig. 1) and enhance homeland security and the energy independence of the USA.

Increasing the Disposal Capacity of the Yucca Mountain Repository

Although we support an increase in the disposal capacity of the YM repository as long as public safety is not compromised, we find it very difficult to envision that this would alleviate current SNF-disposition challenges and fiscal burdens. Furthermore, as illustrated below in Fig. 6, the current site is bounded by major fault systems and thus has limited space-expansion potential. The main options to accommodate more SNF/ HLW at the YM site are thus to either increase the canister/thermal loading per unit area, which in turn will drive up the near-field temperature and/or require modifications (numerical manipulations) of the current models and related codes, assumptions, and/or boundary conditions. We still share the concerns expressed by the USGS staff in 1978 [14] about the likely adverse impacts on rock characteristics and safety assessments that may be caused by greatly increasing the host rock temperature.[11] We are also concerned about other technical, financial, and political challenges facing the YM SNF/HLW repository and any numerical manipulations that may not gain the approval of the USNRC. As follows, we encourage the U.S. Congress to not consider an expansion of the disposal capacity of the YM repository as the only legislative action for mitigating current SNF-management challenges and recommend that the four additional solutions described in this paper also be considered and pursued. As indicated in the preceding text, SNF and HLW are not the only long-lived radioactive wastes in the USA currently lacking a disposal facility/solution. For example, a disposal solution for approximately 5,600 cubic meters/1.4 million sieverts of GTCC LLW is currently being explored by the USDOE's Office of Environmental Management (EM).[20] However, expanding the current YM repository SNF-disposal capacity and/or mission for this waste category is likely a much more time-consuming, costly, and uncertain solution than expanding the disposal capacity and mission of the WIPP TRUW repository.[21]

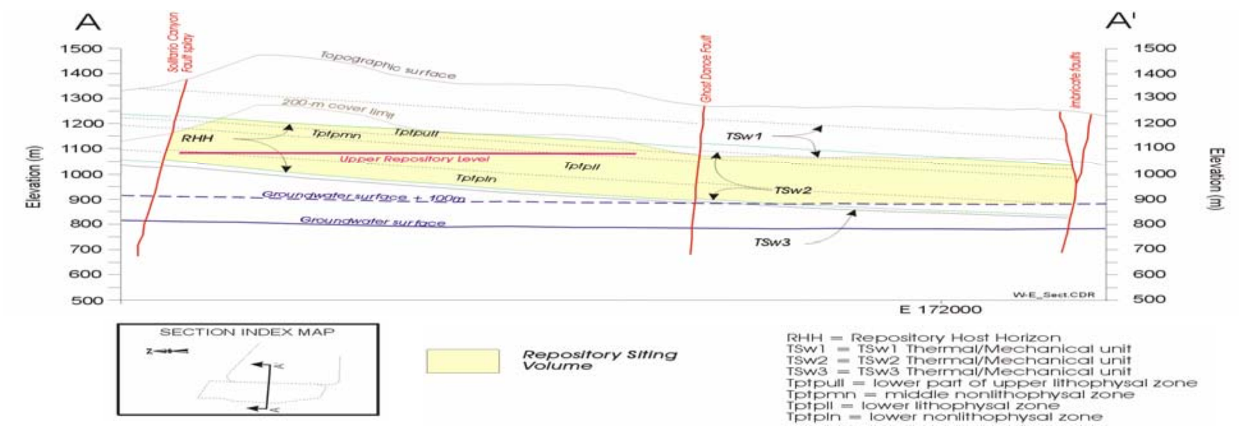

Fig. 6. E-W cross section through the Yucca Mountain candidate SNF/HLW-repository site (the red horizontal line depicts the repository and the red vertical lines depicts major faults).

Prompt Development of a Federal Storage Facility for Utility-Generated Spent Nuclear Fuel

The prompt development of at least one federal MRS facility with adequate capacity for accommodating the SNF resulting from at least 60 years of additional nuclear energy production is, by far, the most time- and cost-efficient way for USDOE to take title to the utility-generated SNF. Indeed, if promptly enacted by the U.S. President, this solution could probably be available almost a decade ahead of the currently projected opening of the YM SNF/HLW repository and would also mitigate the impacts of any further delay in the opening of the nation's first SNF repository. The USDOE submitted a report to the U.S. Congress on December 9, 2008, recommending the development of an interim storage facility for SNF from 10 decommissioned NPPs. This would be an excellent pilot project to gauge local acceptance because several different facility designs are already in operation. Actually, some nations have operated SNF storage facilities for more than 40 years and neither the technology/design nor facility safety should be an issue. Indeed, the Swedish MRS-facility (Clab) design (http://www.skb.se) is particularly attractive because it takes SNF which is only 12 to 15 months old thereby reducing the capital requirements of the Swedish reactors and associated operating utility costs for on-site pool storage and subsequent storage. Furthermore, any unscheduled release of radionuclides would be contained within the cavern hosting the SNF and, thus, not reach any member of the general public. Also, the subsurface facility and the stored SNF are virtually immune to damage from external force such as hurricanes, tornados, and explosives, and both ingress and egress to and from the SNF-storage caverns are through one shaft that is readily guarded, effectively controlled, and easily monitored. It should be recognized that storing the SNF is only a temporary solution. The Swedish example does, however, demonstrate the economic and safety values of total system thinking. Furthermore, past domestic experience strongly suggests that sound science is imperative to the cost-effective design and licensing of an SNF-management facility and local acceptance will govern its timely and cost-effective siting and development.

Reprocessing of Spent Nuclear Fuel

Up to the present, the U.S. has restricted the consideration of SNF management as an environmental issue. The international nonproliferation aspects of the safe expansion of commercial nuclear power require that the current U.S. policy should be expanded to include examination of additional storage, treatment, and disposal requirements generated from an U.S.-based nuclear fuel leasing initiative as well as what could be provided by partnering countries. Conceivably, the USA would need to develop the technologies and processes required for reprocessing the nation's SNF and perhaps other similar radioactive residues from the uranium enrichment cycle, to establish the homeland security and nonproliferation level required for domestic protection, which also would solidify and sustain USA's role as a global leader in nonproliferation. Reprocessing is a key component to any nation or group of nations engaged in nuclear fuel leasing as a means to safeguards against proliferation. It would also significantly reduce the volume of long-lived radioactive materials requiring deep geological disposal.

France, Britain, Russia, India, and Japan currently reprocess SNF. Commercial reprocessing of SNF based on the PUREX technology has been conducted for several decades and is presently conducted on an industrial scale in e.g., France (La Hague), Japan (Rokkashomura), and the United Kingdom (Sellafield). There has never been commercial reprocessing in the U.S.; however, domestic reprocessing was available at one time at the Barnwell reprocessing plant in South Carolina but this plant was left without a license or mission by the Carter administration in 1977.[19] The Carter administration also signed the Nuclear Nonproliferation Treaty in 1978, which included major restrictions on reprocessing. In short, very little has been done in the USA since then to advance either aqueous or non-aqueous (pyrochemical) reprocessing technologies/methods to an industrial scale until the GNEP was introduced by the Bush administration in the early 2000s. However, the GNEP initiative is facing strong scientific and political opposition in the U.S. Congress despite abundant foreign verifications that reprocessing can be done safely on an industrial scale.

Reprocessing is a proven industrial-scale option to extend the use of a limited natural resource; uranium. More than one reprocessing technology exists and at least two based on the PUREX technology are in daily use today on an industrial scale in friendly countries such as THOR in the UK and UP3 in France and shortly in Japan. Furthermore, research and development (R&D) are being conducted in the USA to develop industrial-scale reprocessing technologies that would to enhance the protection against diversion of weapons- useable-grade materials. The USDOE is currently examining two methods for recycling nuclear fuel that do not isolate plutonium: UREX+ (a collection of methods); and pyroprocessing. While the UREX+ processes work with oxide fuels, pyroprocessing deals with metallic fuels or oxide fuels, with an additional processing step to reduce the oxide to metal. With oxides, the pyrochemical reduction (PYROX) process is being developed for treatment of Generation IV oxide fuels.

For these and many of the other reasons described in this paper, we believe that reprocessing should become an integral component of a long-term total systems nuclear waste management policy. It should be noted that experience in the UK and France has shown that the development of a new reprocessing facility in the U.S could take at least 13 years. A related issue is thus whether to promptly establish the proven PUREX technology to create MOX on a commercial basis or to continue to R&D any of the UREX+ technologies and at what pace. An optimal solution might be to use existing domestic PUREX capabilities until one of the UREX+ technologies is developed on an industrial scale. However, before allowing the PUREX approach to deployed, there must be agreement from the responsible nonproliferation entities in the U.S. government that this fuel cycle step is acceptable. Once this is established, then the commercial basis must be confirmed with the utilities. Furthermore, liabilities and ownerships need to also be established in advance. Also, all applicable foreign experiences should be reviewed and incorporated, as appropriate, in a timely way that ensures appropriate safety assurance in licensing, construction, and operation.

Resurrection of a Second Repository Program

As mentioned frequently above, the nation's current legislative framework governing SNF disposal will render the still pending disposal solution at the YM site inadequate no later than 2010. As also mentioned above, the USDOE submitted a report on December 9, 2008, to the U.S. Congress recommending the pursuit of a second repository. Whereas we in principle support this general recommendation, we are surprised and concerned about the lack of institutional memory leading to the recommendation that the search for a second repository should focus on the YM site plus the other eight potential sites that were found less suitable than the YM site in the 1987 site selection process for the first repository. If one assumes that the previous screening process was adequate, there is no "site-suitability" reason to follow this path beyond the two other candidate sites; the Deaf Smith Canyon site in Texas (rock salt) and the Hanford Reservation site in Washington (basalt). There are, however, very strong environmental and political reasons to not pursue the Deaf Smith Canyon site again. For example, it sits on top of the state's largest groundwater aquifer, the Ogallala. Furthermore, based on the experiences gained during the recent approximately 4½ year long licensing process for two LLW (Fig. 3) landfills in Texas, the likelihood that the state would be a willing host of an SNF/HLW repository is very low. Instead, if U.S. government were to re-start the search for a second repository, we strongly recommend following the very successful, time- and cost-saving Finnish approach, which is to take an initial look at what has been done elsewhere in the world and assess how much of that available experience can be utilized to advantage. In other words, if we are going to do it again, we should use existing knowledge and experience to advantage including the approaches to repository siting (and total system thinking) successfully employed in Sweden and Finland.

Based on our combined 60 years of involvement and monitoring of SNF management and repository developments around the world, including involvement in six of the nine sites suggested by the USDOE for consideration plus the WIPP site, plus two of the regions previously considered for a second repository, four attributes that stand out as extraordinarily important for a timely and cost-effective siting, licensing, and opening of an SNF repository are:

1. A voluntary host community/sovereign nation and state.
2. A repository host rock that has been previously characterized and that has an extensive database and mature/validated numerical codes and models.
3. A repository design that is pursued by others.
4. A repository site (and design) that can be modeled with a high degree of confidence and, preferably, require few engineered barriers to meet long-term USEPA radiation protection criteria.

Based on the last three criteria, a low-temperature repository in a thick, laterally extensive, undisturbed unit of rock salt (e.g., WIPP), argillaceous ("clay") rocks (e.g., Mol in Belgium, Buhre in France, and Mont Terri in Switzerland) and igneous (granitic/crystalline) rocks (e.g., Olkiluoto in Finland, Forsmark and Laxemar in Sweden, and Grimsel in Switzerland) appears particularly promising starting points. The following evaluations should, however, precede a defensible decision to pursue a second SNF repository:

1. Will currently available or imminently pending large-scale industrial processes be available and able to reduce the amount of existing SNF and that projected for at least another 60 years.
2. If and when will the YM repository open.

As mentioned above, PUREX-based reprocessing is the only currently-available, large-scale industrial process for reducing the amount of long-lived radioisotopes in SNF requiring deep geological disposal. In addition, absent an expansion of the YM repository and reprocessing, a second SNF repository would be the only currently feasible solution to accommodate the disposal capacity required for direct disposal of the SNF generated in the USA beyond 2010. The main issue to us, however, is whether the YM SNF/

HLW repository will ever open because, as mentioned in the BACKGROUND section, the local opposition is very strong and it has vocal champions with great influence in the U.S. Congress. Even if reprocessing becomes available, it will not suffice for closing the nuclear fuel cycle if the YM repository is terminated because, regardless of how we treat the SNF, there will always be long-lived radionuclides requiring deep geological disposal. In addition, another repository will likely be needed in the USA for other existing waste categories requiring deep geological disposal such as e.g., GTCC LLW (= ~LL-ILW). Also, as evidenced in e.g., Sweden, the siting, development, licensing, and opening of a repository for SNF/HLW may take at least 30 years even in a welcoming community. *The timely decision on whether or not to develop a second repository is thus of utmost importance but should not be done without also integrating the nation's need for disposal capacity for the other long-lived radioactive materials/residues resulting from uranium enrichment and reprocessing during the next 60 years.*

Nuclear Fuel Leasing

The U.S. as well as many other countries are currently witnessing a large increase in the interest in new NPPs. The IAEA has reported that it has been contacted by over 50 nations about developing nuclear power, which is substantially greater than the current group of 41 nations. If over the next 40 to 50 years the developing countries are to make real progress in their targets to allow their populations to gradually achieve the standard of living, which nations like our enjoy, then they must have affordable, reliable and controllable/flexible energy. Furthermore, the safe advance in the percentage of electrical power from nuclear power, currently about 16%, is an essential part of the fight to reduce carbon emissions. Actually, even maintaining the current percentage as the projected demand increases with time due to increased population and clean-energy suggests that the world may need to at least double the number of reactors over the next forty to fifty years.[e.g., 16] However, this increase in NPPs and, perhaps more so, new nation's developing NPPs cannot be permitted to happen without significantly improved global systems ensuring that no nation developing an NPP will be able to also develop nuclear weapons. The recent examples of North Korea, Iran, Libya and Syria, and the actions of A.Q. Khan and his associates and other nations during the past 40 years have demonstrated that diversion of technology and sensitive equipment have occurred despite the efforts to the contrary by the IAEA. The only way to protect against this scenario is by leasing nuclear fuel to developing nations who want to build new NPPs. This "insurance" process could also be expanded to nations that have very limited nuclear-generating capacity and therefore no economic basis for long-term SNF management and disposal. In summary, the current nuclear fuel cycle is not secure from diversion of source material for nuclear weapons, whereas, strictly controlled, nuclear fuel leasing is a very powerful tool to ensure highest attainable safeguards and control against nuclear proliferation and, at the same time, boost nuclear power generation around the world.

We therefore believe that nuclear fuel leasing must be an instrumental component of a successful U.S. nonproliferation strategy to safeguard against clandestine diversion of potential source materials for nuclear weapons or radiological dispersion devices, i.e., "dirty bombs". Leasing nuclear fuel can be simply defined as the process of supplying nuclear fuel designed for a particular reactor and then taking it back at some pre-determined time after it has been removed from the reactor. Actually, nuclear fuel leasing is already an essential part of USA's nonproliferation strategy. The U.S. government conducted a highly enriched fuel supply program for foreign research reactors for many years. It then instituted a take back program for the spent highly-enriched uranium (HEU) for disposition in the USA. The U.S. government provided this service under the "Atoms for Peace" initiative for many foreign research reactors throughout the world for many years and about 16 MTU in 15,000 assemblies are currently stored at the Savannah River Site (SRS), which is included in the amount of federally-generated SNF/HLW the USDOE intends to commingle with utility-generated SNF in the YM SNF/HLW repository. This process was in effect a fuel leasing program. However, nuclear fuel leasing cannot be sustainable for the commercial nuclear power industry unless there is a market component to incorporate the financial transaction. This cannot be restricted to the supply of nuclear fuel it must also include charging for the “back-end” component. This inevitably means a public private partnership with sponsoring of nuclear fuel leasing nations that can agree in partnership to take ultimate responsibility for the resulting SNF or its derivatives, e.g., HLW and other long-lived residues/derivatives such as GTCC LLW/LL-ILW. There must also be some aspects of competition to provide a basis for a market. Inevitably, this will include the availability and cost of disposal sites. Those sites that can safely dispose of nuclear wastes that require no or minimal engineered barriers will be cheaper to characterize, license, and construct.[22] Conversely, nuclear fuel leasing provides an apparent means to drastically lower the cost for the otherwise huge domestic expenses embodied in the siting, development, and licensing of an SNF repository. Considering a second repository in the U.S. is therefore not just a domestic policy consideration, which includes state burden equity – not all in one place – it is also part of a necessary review of SNF management in the USA and through fuel leasing a necessary component of a U.S. foreign policy review because it is inextricably linked to nonproliferation.

Regardless of what is done with regards to uranium enrichment and reprocessing, and the development of new reactors, some nations must take ultimate responsibility for the safe disposal of the nuclear waste products if nuclear fuel leasing is to occur. We believe the USA is a very strong candidate to become one of these nations. The U.S. government should thus form strategic partnerships/alliances with countries that presently dominate either the supply of uranium or known uranium-ore reserves, or have or plan to build safe nuclear fuel enrichment and/or SNF reprocessing facilities, and have long-standing experience in SNF management to optimize the control of potential source materials for nuclear weapons, i.e., the nuclear fuel, SNF and other HLW. For example, the U.S. could form a partnership with the main suppliers of uranium (Australia, Canada, and Kazakhstan) and the countries providing enrichment to secure the front end of the fuel cycle and agree to take indefinite responsibility for the disposition of the resulting SNF. This is the only way that expansion of nuclear energy can take place without the risk of diversion of source material for nuclear weapons and other warfare and terrorist uses.

It should be noted that if the U.S. nuclear energy and SNF policy were to include: accepting ultimate responsibility for U.S.-leased light water reactor (LWR) fuel; enabling the leasing entity to establish a market basis for bundling the front end fresh nuclear fuel supply with a complete early take-back service; this could be the basis for a significant reduction in the cost for U.S. utilities SNF management and the U.S. government. The amount that U.S. nuclear fuel leasing could reduce the domestic costs could be significant depending upon the overall strategy for SNF management in the USA. It should therefore also be noted that 14 European countries have resolved to set up an European Repository Development Organization (ERDO) to collaborate on nuclear waste disposal. The 14 countries backing the proposal are: Austria, Bulgaria, Czech Republic, Denmark, Estonia, Ireland, Italy, Latvia, Lithuania, Netherlands, Poland, Romania, Slovakia, and Slovenia. The proposal for a "staged, adaptive implementation strategy" for an ERDO results from the EC-sponsored Strategic Action Plan for Implementation of European Regional Repositories (SAPIERR) Project. The SAPIERR project is in line with proposals from the IAEA, Russia, and the USA (with GNEP) for multilateral cooperation in the fuel cycle in order to enhance global security. Shared repositories for HLW are an important element of this.

SUMMARY

In the U.S., the federal government is responsible for safe disposal of the long-lived radioactive waste resulting from energy and weapons production, including SNF generated by commercial NPPs. In 1982, the U.S. Congress agreed upon a national program for the safe disposition of utility-generated SNF that was signed into law by the U.S. President in 1983.[1] This piece of legislation, i.e., the NWPA, directed the Secretary to 1) take title to utility-generated SNF “as expedient as practically possible” and 2) begin receiving and disposing it in a deep geological repository no later than January 31, 1988. The maximum amount of SNF that could be disposed of in the first repository before a second repository had opened was 70,000 MTU. The NWPA also directed the Secretary to pursue the development of a second repository on a schedule lagging the first repository schedule by approximately three years and consider the option of developing an MRS facility for taking title to utility-generated SNF as expedient as practically possible. Both the second repository and the MRS were subsequently postponed indefinitely leaving the first repository as the only path forward for the USDOE to take title to utility-generated SNF.

The development and opening of the nation's only current potential SNF and HLW disposal solution, the YM repository site in Nevada, is at least 22 years behind the current statutory schedule and would be too small for the existing stockpile of SNF ten years before it may open. To remedy the current shortage of SNF/HLW disposal capacity, the USDOE recommends an at least 60,000 MTU increase in the disposal capacity of the YM repository. For these, as well as for the nonproliferation concerns and other reasons described and discussed in this paper, we submit that the U.S. policy related to SNF management should be reviewed and revised, and the following five feasible interdependent solutions; all requiring legislative action, should be promptly considered and acted upon by the U.S. Congress after a supportable evaluation by the USDOE that includes sustainability, economics, nonproliferation and public health risks:

1. An increase in the disposal capacity (and perhaps mission) of the YM repository.
2. Prompt establishment of at least one large federal monitored retrievable storage (MRS) facility for utility-generated SNF.
3. Reprocessing of existing and pending SNF.
4. Resurrection of a second repository program.
5. U.S. nuclear fuel leasing.

We believe that each of these solutions to various degrees would enhance continued national industry/ economic growth, promote and sustain the nuclear renaissance, enhance homeland security, and reduce the risks associated with other nations developing their own fuel cycle facilities. For example, the prompt establishment of a large federal MRS facility for SNF would mitigate any additional delays in the opening of the nation's first SNF repository and make SNF-management in the USA both less problematic and less costly, until sufficient repository capacity is available to assure the safe disposal of all SNF and HLW. Nuclear fuel leasing would provide a substantial financial contribution to the development and opening of an SNF repository. We also believe that these actions will play an essential part in enabling U.S. energy independence and reducing the risk associated with investing in new NPPs and substantially remove the risks and huge costs associated with the U.S. government not taking title to the utilities SNF until at the very earliest in 2020. However, *no single solution proposed above will suffice for the safe management of the SNF* (or other HLW and GTCC LLW/LL-ILW) already generated or projected to be generated during the next 60 years. A holistic total systems nuclear waste management approach is needed and should be promptly initiated by the U.S. Congress.

In closing, as a food for thoughts, we would like to repeat Rear Admiral Hyman R. Rickover's closing comment in a presentation at a Banquet of the Annual Scientific Assembly of the Minnesota State Medical Association in St. Paul, Minnesota, on May 14, 1957:

> "High-energy consumption has always been a prerequisite of political power. The tendency is for political power to be concentrated in an ever-smaller number of countries. Ultimately, the nation which controls the largest energy resources will become dominant. If we give thought to the problem of energy resources, if we act wisely and in time to conserve what we have and prepare well for necessary future changes, we shall insure this dominant position for our own country."

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