COMING TO AN OCEAN FAR FROM YOU—SUB-SEABED REPOSITORIES

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Blue Ocean Repositories, LLC is a private-enterprise partnership that is being formed to develop sub-seabed repositories for high-level radioactive waste (HLW). Today's confluence of circumstances provides the perfect window of opportunity for resurrecting such an endeavor. Twelve years of coordinated research between 200 scientists from 10 different nations is summarized and provides the basis for the effort. Follow-up research is addressed, along with a strategic path forward. Support is provided for the contention that implementation within ten years is in the realm of possibility – and at a fraction of the cost of the average mined repository being pursued by most national governments. Characterized sites, located in sediments below 4000+ meters of international waters, are discussed. The repositories, available to all countries, regardless of the size of their nuclear program, will not suffer from the NIMBY syndrome that has mired many efforts to site HLW disposal facilities. Mitigation for the major roadblock to this disposal option, the fact that it is presently banned by international treaty, is presented. An argument is offered to dispel skeptics' fears and show that sufficient evidence exists to demonstrate that a sub-seabed repository is protective of human health and the environment and can be permitted.

I. WINDOW OF OPPORTUNITY

Electricity was first generated from nuclear energy in 1951 near Arco, Idaho. Since that time, management of the wastes generated from nuclear research and power generation has become the Achilles' heel of the industry.[1] In response to the anti-nuclear assertion that dealing with nuclear wastes is an unresolved problem, the World Nuclear Association (WNA) responds with the following:

> In all countries using nuclear energy there are well established procedures for storing, managing and transporting such wastes, funded from electricity users. Wastes are contained and managed, not released. Storage is safe and secure, plans are well in hand for eventual disposal.[2]

I.A. Delays and Cost Increases

Eventual disposal of HLW has become such a moving target in the United States (US), that the Nuclear Regulatory Commission (NRC) was instructed by the courts to consider (for its Waste Confidence Rulemaking) that a HLW disposal facility may never be built. It is widely acknowledged that most national programs are "far behind their original schedules".[3] Special commissions are officially recommending that national repository development programs use "flexible deadlines and continual program reinvention to secure success".[4, 5] Over 70 lawsuits have been filed by utilities in the US over the federal government's failure to open a repository.

The US program, used only as an example, is representative of the general world-wide picture. Table I summarizes the forecast history of countries with significant quantities of HLW in storage.

TABLE I. HLW Disposal Facility Availability Forecasts[a]

Country	Initial, Amended, Updated…
USA	1998, 2010, 2020, 2048
Finland	2020, 2022
Switzerland	2020, no sooner than 2040
Sweden	2023, 2025, 2029
Germany	2025, 2035
France	2025
Canada	2025, No sooner than 2035
Japan	2035, 2040
Belgium	After 2035, not before 2080
Russia	Decision on what to do by 2025
South Korea	2050
Spain	After 60yrs of interim storage
China	2050
United Kingdom	Late 2050s, 2075

a. Information extracted primarily from www.world-nuclear.org or media announcements

Cost increases are naturally connected to slipping schedules and preliminary plans. The US is again a good example to illustrate this since its history/plans are well documented and now cover both scenarios. The 1982 Nuclear Waste Policy Act (NWPA) and subsequent amendments mandated that the federal government provide for the disposal of spent nuclear fuel (SNF) and

HLW. Included among the various provisions was an authorization for the Department of Energy (DOE) to enter into contracts with utilities for federal removal of SNF from reactor sites. Federal removal, beginning by 1998, was in return for a fee on utilities' sales of nuclear generated electricity. For fuel used prior to the 1983 implementation of the standard contract, the DOE assessed a flat fee based on burnup. In terms of 2014 dollars the fee ranged from $200/kg to $450/kg.[6] Three decades later the current cost estimate ranges from $200/kg to nearly $2000/kg.[7] These latter numbers are considered highly uncertain and speculative since they are now based on concepts rather than detailed designs.

The US is not alone. Sweden announced last year that it is proposing almost doubling the fee that the Swedish nuclear industry must pay into its Nuclear Waste Fund in 2015.[8] The proposed fee is 4.0 öre per kilowatt hour of nuclear power produced, an 82% increase over the current rate of 2.2 öre/kWh, which increased 220% in 2011 from the original 1.0 öre/kWh fee.[9]

From a business perspective the HLW disposal market can be characterized as one with buyers eager for a solution, with a limited number of suppliers that are not meeting the demand. Now is the time for a cost-effective, timely solution to be offered. A commercial sub-seabed repository for the international community is such a solution.

I.B. Customers Searching for Alternatives

Early in 2014 the DOE announced it was reevaluating its policy of using commercial facilities to dispose of its radioactive waste.[10] Prior policy was limited to the single criteria of cost. The department now recognizes that there may be other factors that would make the use of a commercial facility preferable. With one-quarter of the world's operating reactors, the US represents a significant portion of the SNF/HLW customer base.

In October of 2013 South Korea formed a special commission - the Public Engagement Commission on Spent Nuclear Fuel Management.[11] This commission is comprised of 13 nuclear experts, professors, city council members and an official from a private environmental watchdog group. They were tasked with seeking advice from experts and plausible breakthrough ideas. Their report was due by the end of 2014.

The United Arab Emirates (UEA) is part of a sizable group of countries that are categorized as emerging into the nuclear power realm. They are typically smaller countries or countries with electric demands that can be met with only a few nuclear power plants. Consequently, pursuing a national repository would be cost prohibitive. Regional alliances or international repositories are considered to be the best alternative for this group. The UEA is thus pursuing a "dual-track" strategy of developing a national storage and disposal program in parallel with exploring regional and international options.[12]

I.C. Banned by International Treaty

It is true that disposing of radioactive waste by "dumping" in the sea is prohibited by international treaty. The 1972 Convention on the Prevention of Marine Pollution by Dumping of Wastes and Other Matter (London Convention) initially addressed the subject. In 1996, the "London Protocol" was adopted to further modernize the London Convention and, eventually, replace it. This is all under the auspices of the International Maritime Organization (IMO).

However, the combined treaties (LCLP) are subject to amendment and, in the case of radioactive waste, also subject to a mandated periodic review based on the latest scientific and technical information. As explained in the FAQ section of the IMO website[13], most technical conventions adopted since the early 1970s have incorporated a process known as "tacit acceptance". The tacit acceptance procedure means that amendments enter into force on a set date unless they are specifically rejected by a specified number of countries. Such amendments require approval of two-thirds of the *attendees* of special consultative sessions. For the combined LCLP annual consultative sessions over the last seven years the average number of attendees has been forty-one. This contrasts with the normal amendment process for international treaties which requires explicit acceptance of two-thirds of the *signatories*. There are currently 87 and 45 signatories of the London Convention and London Protocol, respectively.[14]

Specifically regarding radioactive waste, the LCLP provides that, "within 25 years of 20 February 1994, and at each 25 year interval thereafter, Contracting Parties shall complete a scientific study relating to all radioactive wastes…, taking into account such other factors as Contracting Parties consider appropriate and shall review the prohibition on dumping of such substances…".[15] The interval for the first 25 year review period effectively concludes during 2018. So now is certainly the time to bring forth relevant studies and recruit member states such as the UEA to sponsor and champion an amendment.

I.D. Growing Demand for an International Solution

In a 2010 report by the International Atomic Energy Agency (IAEA) it was reported that some sixty-five countries without nuclear power plants "are expressing interest in, considering, or actively planning for nuclear power".[16] Each country will be developing a national policy for dealing with its nuclear waste. Such policies will necessarily include regional or international options since most of the countries could not afford to develop a dedicated national disposal facility. When these are added to the handful of countries serious about developing their own national HLW disposal facility, the vast majority of countries using nuclear power could benefit from an international solution.

At the request of several of its member states, the IAEA produced a 1998 TECDOC outlining the important factors to be taken into account in developing multinational disposal options for nuclear waste. An updated report was issued in 2004 and its conclusions included that:

(1) Multinational repositories can enhance global safety and security by making timely disposal options available to a wider range of countries. For some Member States, multinational repositories are a necessity…

(2) The global advantages of multinational repositories are clear and the benefits can be significant for all parties, if they are shared equitably…

(6) The high ratio of fixed to variable costs for a repository ensures that considerable economies of scale will apply.

(7) Transport of nuclear material is so safe that the distances resulting from a multinational repository will not have a significant impact on public health.[17]

The confluence of delayed national programs, increased interest in an international solution, and the approaching re-evaluation period for the treaty banning sub-seabed disposal of HLW makes now the perfect window of opportunity for pursuing sub-seabed disposal.

II. RESURRECTED SOLUTION

The first question to address is whether the sub-seabed disposal option is worth the effort it will take to pursue it. At least one Nobel laureate thinks so. Henry Kendall – a Nobel laureate in physics, a professor at Massachusetts Institute of Technology, and co-founder of the Union of Concerned Scientists calls sub-seabed disposal a "sweet solution" and a "winner," labeling it the best of the alternatives from a technical standpoint.[18]

To understand why it is termed the "best of the alternatives from a technical standpoint" one must consider the overall objective of waste management – to protect human health and the environment. The dose rate to the *maximally exposed individual* is the ultimate measure of the human aspect of the objective. Minimizing the dose to individuals or the population at large is best achieved by sequestering the source as far away as possible from population centers. Given that criteria alone, the ideal repository location would be in the oceans. Couple that with minimizing the possibility of radionuclides entering the food chain, and the ideal repository location would be deeper than 3000 meters (depth to which whales are known to dive for food).[19] Factor in protecting the environment and the best location is pushed into the sub-seabed oozes where microbes reside only in the top 10 centimeters. Refining the criteria further to minimize future intrusion requires the location to not be in the vicinity of mineral reserves or near areas of research interest, such as deep ocean trenches. Taking all the criteria together, the abyssal plains and abyssal hills of the deep ocean regions are a perfect match. To further solidify the "best of the alternatives" standing, the abyssal plains and hills are some of the most geologically stable regions on the earth as evidenced by millions of years' worth of undisturbed sediment deposition.

Recognition of the superior standing of sub-seabed disposal from a technical perspective has been consistent from its inception in the 1970s. The 1981 DOE Record of Decision for disposal of commercially generated radioactive waste included sub-seabed disposal as an option that should continue to be funded.[20] However, continued research was terminated as a "matter of international policy".[21] As recent as 2011 it was noted that radionuclide doses from sub-seabed disposal were often lower and subject to less uncertainty than repositories on land.[22] Various efforts to pursue sub-seabed disposal over the years have languished because they have been dependent upon national funding and policy decisions, which can change 180 degrees within election cycles. By divorcing this effort from government funding and allowing the market forces to govern SNF owners' decisions, the probability of timely implementation is increased. Government involvement will still be necessary. In some cases national governments are the customer. In other cases national governments are like the guard at a gated-community – controlling access to the ultimate customer, the private utilities, through regulation and policy. Each scenario will require a coordinated effort of stakeholders to ensure the regulatory and political environment is favorable.

II.A. More than a Decade of Coordinated Research

Before active research was terminated in the late 1980s, over a decade of coordinated research was conducted. Approximately 200 scientists and engineers from 10 countries, plus the Commission of European Communities, actively participated in the Seabed Working Group (SWG). The SWG was tasked with assessing the safety and engineering feasibility of seabed disposal. Specific task groups were formed to conduct research and studies in the following areas:[23]

Site Assessments Engineering Studies
Near Field Research Sediment Barrier
Physical & Biological Oceanography
Radiological Assessment

Closely coordinated laboratory and field research programs were undertaken. The following three key questions guided the efforts toward thoroughly assessing the feasibility and long-term safety of the sub-seabed disposal concept:

1. Are there locations in the oceans which have the geologic stability and barrier properties suitable for disposal?
2. Is it possible to implant waste-filled canisters in the seabed sediments and what effect does this have on the barrier properties of the system?
3. What are the radiological consequences of seabed burial?

Including the overview volume, eight volumes were published in 1988, representing the state-of-the-art on seabed disposal at that time.

II.B. Summary of Research

To answer the first question a set of site selection guidelines was developed. Three factors were considered most significant:

1. the study areas must have predictable characteristics in time and space to ensure long-term stability,
2. the study areas must be geologically stable, and
3. the sedimentary formation should have characteristics that make it an effective barrier to the release of radionuclides.[24]

These guidelines were used first to screen candidate sites and then to guide characterization efforts on selected sites. Other factors were also considered such as "use avoidance", i.e., to avoid areas where potential uses might lead to human intrusion. Examples of such uses are mineral and energy exploration, commercial fisheries, scientific research and installation of communications structures.

Numerous sites in the Pacific and the Atlantic passed the initial screening process and then fifteen sites were selected for detailed characterization studies. Based on the results of the geosciences studies it was concluded that within two of the 15 study areas, "sites may be found that will satisfy the geosciences requirements for a sub-seabed high-level waste repository location."[25] It should be noted that the level of site characterization could support the expected requirements of a permit application.

The main focus of the engineering task force was to perform design studies of emplacement systems, including detailed life-cycle cost estimates, and to evaluate operational reliability. The two emplacement concepts that were studied in detail included emplacing a 450-meter column of waste packages into predrilled holes 750 meters deep. The second method utilized gravity to drive penetrators launched from a disposal ship to precisely embed waste packages about 50 meters below the seafloor. Laboratory tests and field trials were run. The engineering task group sponsored three dedicated ocean exercises to study penetrator behavior and hole closure phenomena, launching some 125 penetrators over the course of the studies. The detailed life-cycle studies estimated the disposal costs (in 2014 dollars) to be ~\$70/kg for the penetrator option and ~\$160/kg for drilled emplacement.[26] The overall opinion was that "disposal methods and equipment can be developed that will meet international requirements for public safety, reliability, disposal rate, and cost."[27]

Answering the third question was the combined focus of the remaining task groups. The Near Field, Sediment Barrier, Physical Oceanography, and Biological Oceanography task groups identified processes that affect the behavior of wastes in a seabed repository. Data was assembled on geologic formations, sediment properties, ocean circulation, etc., that were necessary to run the models utilized by the Radiological Assessment Task Group. The Biological Oceanography Task Group concluded in its 200 page report that:

1. No biological factors have been identified which would preclude the option of disposal of high-level radioactive wastes into the deep sea,…
3. The principal role of biological processes is primarily that of retarding the upward transport of radionuclides…
5. That dose rates to the deep-sea fauna would be at or below background levels of radiation and thus unlikely to be detrimental at a population level.[28]

Numerous laboratory investigations were conducted with sediment cores from the studied sites. Four significant findings resulted:

1. The deep sea sediments studied would provide a very effective barrier to the migration of 11 of the 15 critical elements in HLW…
2. Although the critical elements C, I, Se, and Tc are not removed from solution to a significant extent…the escape of significant quantities of these elements would nevertheless be delayed for a period on the order of 10^4 years…because of the time required for diffusion…
3. In most cases, the mineralogy and redox state of the sediments studied…did not have a significant effect…on the distribution ratios and effective diffusion coefficients…
4. The radionuclide distribution ratios and effective diffusion coefficients measured for deep-sea sediments are generally comparable to those measured for continental geologic formations.[29]

The near field research focused on three interactions that fed into the radiological assessment, 1) canister corrosion, 2) waste form leaching, and 3) thermal effects from the waste packages. Corrosion rates were determined for the titanium and carbon steel materials used in the waste packages in order to determine the corrosion allowances needed to meet the 1000 year waste package integrity requirement. Leaching studies were limited to the borosilicate glass matrix resulting from European vitrification activities. The results, which were considered preliminary, demonstrated that after an initial period of fast linear corrosion, the attack slows down noticeably. This behavior was observed in sea water and expected in the sediment tests once they are conducted over a longer period of time.[30] In general, the results of the thermal effects testing demonstrated negligible impact to the radiological assessment.

Consistent with the approach for land-based geologic repositories, the radiological assessment considered three types of scenarios – normal (base case) scenario, abnormal or accidental scenarios, and human intrusion/error scenarios. The base case considered a disposal area 22x22 km that received 10^5 metric tons of HLW glass, embedded into the sediments to a depth of 50 meters. The method of embedment was via gravity driven penetrators. Both deterministic and stochastic methodologies were followed. "The calculations were made simultaneously and independently by different institutions in several countries…This made possible a large number of intercomparisons and verification studies, increasing the confidence in the quality of the results."[31] Since the results did not vary significantly between sites the assessment was not considered site specific. The bottom line was that this disposal option could be radiologically a very safe option (base case peak dose: $3x10^5$ times smaller than background doses). It was noted that, since in many cases, conservative assumptions or data were used, it is expected that future research would yield even lower doses. An example of such a conservative assumption was the assumption that the sediment thickness above the waste package remained constant. However, for the base case, "the phenomenon most likely to occur is sedimentation and, in practice, it may very well happen that the rate of sedimentation exceeds the rate of transport by diffusion, so that most nuclides will, in reality, never be released to the ocean."[32]

II.C. Remaining Research

The composite conclusions from the subject research noted that, "Although the general feasibility of seabed disposal has been established, further research in the following areas would be needed before actual schemes could be implemented…"[33] Six general areas were addressed with the detailed plans in the respective volumes of the 8-volume report:

- Sediments – pore water migration; hole closure; role of faults and layered sediments
- Chemical speciation of radionuclides in the sediments near the waste package
- Ocean mixing studies relative to transportation accident scenarios
- Deep-sea biological activity/pathways
- Engineering aspects of transportation
- Field or laboratory validation of the models used in the assessment

Some of the research has been accomplished in the intervening twenty-five years. Obviously, today's ocean circulation modeling capabilities, which parallel the exponential growth in computing power (see Figure 1) are orders-of-magnitude more advanced than in the 1980s.

This endeavor favors precise placement with gravity-driven penetrators. Consequently, additional penetrator testing is needed. This will be coupled with in-situ corrosion studies and demonstration of retrievability. Permitting the facility as a repository with demonstrated retrieval is essential for two reasons. First, it provides "insurance" against the unlikely event that monitoring indicates failure of the repository. The second reason is driven by the fact that SNF is a financial asset for the business. Once the price of uranium reaches a certain threshold it becomes profitable to reprocess the retrieved SNF, sell the fuel, and re-dispose of the HLW. If retrieval proves to be too challenging with the penetrator approach, then the focus will be shifted to the drilled emplacement method.

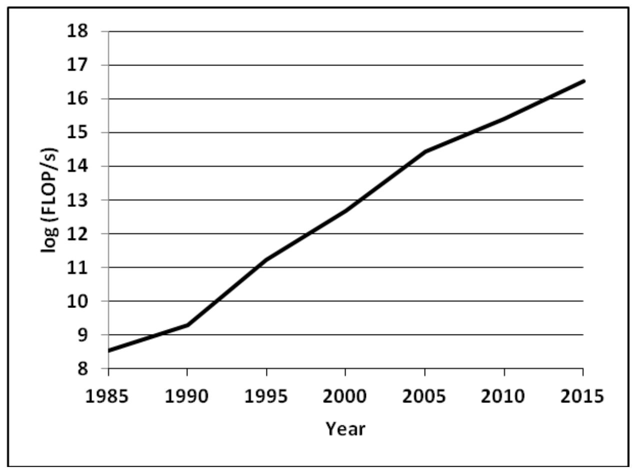

Fig. 1. Exponential growth in computing power since sub-seabed disposal modeling in late 1980's.

Additional sediment studies and waste packaging studies, along with the transportation issue are covered as part of the *Strategic Partners* discussion below.

III. PATH TO SUCCESS

To successfully carryon from the foundational work of the 1980s, the further research will need to be conducted in parallel with other critical tasks. Each task needs to be approached from a rational, business standpoint, with the ultimate mission in mind. For example, even though there is additional research that needs to be performed, it may not need to be completed before the permit application process begins. Likewise, the research does not have to be conclusive – it just needs to support the goal with the requisite level of confidence.

A comprehensive business plan has been developed that includes coverage of:

- Legal Analysis and Permitting Strategy
- Industry Analysis
- Research and Development
- Market Analysis and Marketing Plan
- Business Model
- Repository Operation & Monitoring
- Competition Assessment
- Financial Plan and Analysis
- Strategic Partnering
- Risk Analysis and Mitigations

Due to the constraints of this limited paper, the following covers only the top-of-the-waves of three areas critical to the success of this endeavor.

III.A. Simplified Business Model

Phase I will keep the business start-up as simple as possible. The initial service offered to the customers will be limited to receiving and emplacing waste canisters that are ready to be transferred from the reusable transportation cask into the penetrators at the ship. The customer will be required to load the SNF (assemblies or consolidated rods – customer choice) and the HLW into canisters that meet the specifications required by the penetrator design, seal weld the canisters, load the canisters into reusable transportation casks and transport them to the waiting ship. A single repository will be permitted in the Atlantic Ocean. This will simplify licensing and permitting activities and minimize the startup capital required. Concurrent activities will be conducted to support Phases II and III. These activities will include site characterization studies in the Pacific Ocean and site screening research in the Indian Ocean.

Phase II will focus on permitting a repository in the Pacific Ocean and expanding the services to Atlantic basin customers. Some customers will not have the facilities to consolidate SNF and prepare canisters. With the expanded services developed as part of Phase II, these customers would only be responsible for loading the spent fuel assemblies into the transportation casks. Blue Ocean Repositories would assume ownership at that point and be responsible for the transportation to a portside facility for consolidation and canister prep. Phase II will therefore require licensing by the respective nations where these portside facilities are located. While the Pacific site is being permitted, the Indian Ocean site will be characterized in preparation for permitting as part of Phase III.

Phase III will resemble Phase II with the respective activities shifted to the Indian Ocean for permitting and the Pacific basin countries for portside facility construction and licensing. Whenever the spot price of uranium justifies it, penetrators containing the applicable SNF types will be retrieved and reprocessed. The canisters will be designed to keep this option available for centuries.

III.B. Strategic Partners

Based on the business model there are four major areas that would benefit from a strategic partnership alliance. This alliance could be either a direct partnership or a subcontracted arrangement.

Transportation of SNF and HLW has been conducted safely, both over land and over water, for decades. By maximizing the use of, either via a partnership or subcontracted services, experienced providers of these services, implementing a sub-seabed repository will be streamlined.

Many potential customers have unique waste streams. For example, the Idaho National Laboratory (INL) has a significant quantity of HLW in the form of calcined solids. Per agreement with the State of Idaho, such waste must be readied for transport out of the State by 2035 or significant fines will be assessed.[34] Through a teaming arrangement the INL could conduct leaching and migration studies with sediments provided from the repository site characterization phase. The data could then be included in the radiological assessment. If warranted by the results, the calcined solids could be packaged directly in canisters. This would eliminate further processing via the hot-isostatic pressing or cold crucible induction melting that is currently being studied by the INL.

Partnering with institutions that have expertise in needed areas will serve to further streamline the implementation of this solution to the HLW disposal problem. For instance, China is completing construction of a national deep-sea base patterned after Woods Hole Oceanographic Institute. The State Oceanographic Administration indicated that part of the research activities will be to, "strengthen monitoring of radioactivity in international public waters, set up an early warning system for radioactivity in the West Pacific, and report the information to governments at all levels."[35] This dovetails nicely with the need for a baseline radiological survey of the Pacific and Indian Ocean repository sites and periodic monitoring to ensure they perform as predicted.

International firms experienced in the design, construction, licensing, and commissioning of terminal port facilities is another area targeted for strategic partnerships. Eventually, portside waste processing facilities will be needed throughout numerous countries to service the regional needs of the growing world-wide nuclear industry.

Inquiries have been tendered in each of these areas and discussions are underway. However, agreements have not been finalized.

Another area with potential that has not been pursued yet would be an alliance with a small modular reactor (SMR) vendor. Such a partnership would provide the SMR vendor with a fixed price for disposal so that they could market their SMR on a "buy, burn, and return" basis. The market place could thus be expanded to small island nations and other remote locations that have limited ability to assume the nuclear waste disposal liability.

III.C. Risk Mitigation

The greatest risk to this endeavor – the fact that it is a banned activity via international treaty – is mitigated by following the pattern set by CO_2 sequestration under the seabed. The 1996 London Protocol (LP) takes a precautionary approach by banning all activities other than those explicitly approved in Annex I. The LP entered into force on 24 Mar 2006. In November of 2006 the LP Contracting Parties adopted an amendment to Annex I to regulate CO_2 sequestration below the seabeds. One-hundred days later the amendment went into force. The relevant guidelines were developed and have been adopted by the Parties. Within seven years after the Annex I change, 3 pilot projects had been permitted.

It is fortunate that the legal and programmatic precedent has already been set. *If* a similar timeline along the same path could be followed, the first sub-seabed repository could be permitted within 10 years.

Expanding upon this critical link to the success of this endeavor, it is acknowledged that the public perception of radioactive waste management is much different than the public perception of CO_2 sequestration. Indeed, some of the most vocal and active coalitions in support of limiting greenhouse gases are also the ones protesting anything associated with nuclear power. That is exactly why a well-managed effort and message is necessary – a message that includes input from the growing number of environmental groups that are supportive of nuclear power. One such group, *Environmentalist for Nuclear Energy*, organized in 1996 currently has chapters in over 65 countries and continues to grow at a steady rate.[36]

Key to managing the message is assembling a portfolio of concise, informative, educational materials in the official languages of the signatories of the LCLP, including short informational videos. Particular focus will be given to those member states with emerging nuclear programs. The goal is to assemble a core of supportive member states to sponsor and champion the required Annex I change. The marketing effort will greatly benefit from these same materials assembled to manage the message.

Other attempts to permit regional or international HLW disposal facilities have died because of societal pressures – not technical challenges. Common to all such failures was the *Not In My Backyard* syndrome (NIMBY). This effort will not suffer a similar fate because it is in *everybody's backyard*. The repositories are specifically sited in international waters. The risks are shared equitably and *everybody* has a say in the management of the shared risks through the IMO.

IV. CONCLUSIONS

The current SNF/HLW disposal landscape consists of major countries that have universally made it the responsibility of their respective national governments to provide for disposal. This has been the case for over 50 years and progress has been agonizingly slow in pursuit of a "consensus" approach of land-based deep geologic repositories. Numerous promised repository openings have slipped indefinitely. Smaller countries are attempting to form regional alliances or are just waiting for an international repository to become available. In short, the utilities are quickly losing faith in their respective governments' ability to provide the solution and the national governments are repeatedly embarrassed by the need to delay a promised opening and increase the estimated cost of disposal. A window of opportunity currently exists for a private-enterprise to offer a cost-effective, timely, international solution to the HLW disposal dilemma.

The mission of the commercial effort is to provide, in a timely and cost-effective manner, sub-seabed HLW repositories to the international community. The service will be cost-effective and timely because of its simplicity:

- Utilizes sites prepared by Mother Nature over millions of years – located in truly "oceanic desert" areas (abyssal plains more than 4000 meters below the ocean surface).
- Uses gravity propelled penetrators to precisely emplace waste packages 30 to 70 meters into the sub-seabed sediments.
- Uses the natural properties of the sediment "ooze" to backfill behind the penetrators and prevent migration of most radionuclides.
- Uses Mother Nature to provide the security for the facility on three fronts: 1) the deposition rate of sediments is greater than the migration rate of most of the radionuclides, thus they never escape the facility, 2) Ocean volume provides back-up protection through dilution and 3) Remote location ensures nuclear non-proliferation protection.
- Research is nearly complete with over 12 years

of coordinated effort between 200+ researchers from over 10 different countries.

- Driven by private-enterprise.
- A truly international solution (no NIMBY)
- Cost-effective: Estimated breakeven cost is a fraction of the cost of national efforts.
- Legal and programmatic fast track for international permitting has already been plowed by CO_2 sequestration.
- Waste packages are retrievable for centuries.

This truly is a "sweet solution" and will prove to be a winner for the nuclear industry and the world.

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