From Banned to Allowed: Pathway to Sub-seabed HLW Repositories – 16279

Craig L. Porter, P.E.
Jetseal Engineering & Technical Services, LLC: *craig@jetsealengineering.com*

ABSTRACT

For many countries the disposal of high-level radioactive waste (HLW) has been delayed due to a number of factors including the Not-In-My-Backyard (NIMBY) syndrome. Sub-seabed disposal has no NIMBY concerns since the disposal facilities utilize sediments underlying approximately 4000 meters of international waters. The technical feasibility of the concept was demonstrated during a 12-year joint effort of over 200 researchers from 10 different countries. Social pressures to keep the oceans off-limits to most disposal activities resulted in termination of the coordinated international effort. However, the treaty banning the concept mandated a 25-year review frequency covering the latest scientific and technical information germane to the activity. An effort is underway to supply information to the signatories of the treaty, in their native languages, so they can make a fully-informed decision -- whether or not to approve an amendment that would allow sub-seabed disposal *if* determined to be protective of human health and the environment *and* permitted in accordance with guidelines provided by the International Atomic Energy Agency (IAEA). The information highlights the environmental and safety aspects of the disposal concept within a sensible global stewardship framework. With an amended treaty to allow sub-seabed HLW repositories, the global outlook for nuclear waste disposal would be altered dramatically: the number of potential disposal facilities scattered around the world could be reduced from over sixty land-based to approximately six (three land-based, three sub-seabed).

INTRODUCTION

Nuclear generated electricity first occurred in 1951 near Arco, Idaho. Since that time there has evolved a "clear and unequivocal understanding that each country is ethically and legally responsible for its own wastes, therefore the default position is that all nuclear wastes will be disposed of in each of the 50 or so countries concerned".[1] Combining that understanding with renewed interest in nuclear power and the international consensus that deep geological disposal is the preferred disposal method, eventually yields a scenario represented by Figure 1.

A key tenet of the nuclear safety culture is a questioning attitude. By questioning the prevailing understandings that are leading us to the situation illustrated by Figure 1, it is possible to arrive at a more environmentally responsible solution – one which has a few international repositories located as far away as possible from population centers and the land-based resources needed for sustaining humans. By minimizing the number of repositories which must be safeguarded over a long period, the ultimate goals of nuclear non-proliferation are more reliably achieved. By locating the minimum number of repositories in areas under international jurisdiction, the uncertainty of long-term security is greatly minimized.

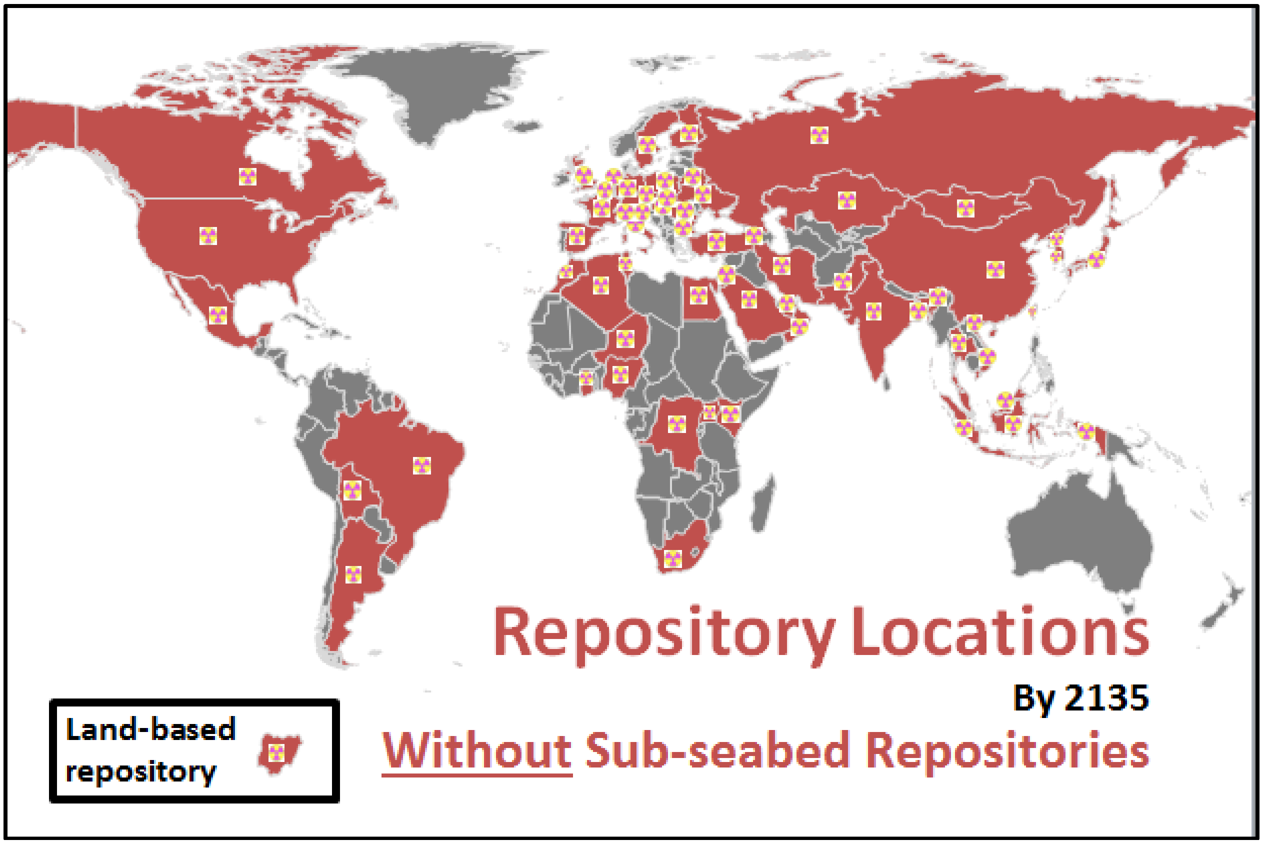

Figure 1 - Countries destined to host a land-based HLW repository

Using the past as an indicator of the future, one would expect that national boundaries will continue to change from century to century, while the recognition of international waters would be expected to remain unchanged as it has for thousands of years.

Figure 2 represents a plausible alternative scenario for HLW repository locations by the year 2135. To achieve such a scenario an international treaty would need to be amended to allow sub-seabed disposal of HLW *if* determined to be protective of human health and the environment *and* permitted in accordance with guidelines provided by the International Atomic Energy Agency (IAEA).

The plausibility and pathway to the scenario illustrated by Figure 2 is the main focus of this paper. Presented are both the rationale and the detailed path forward that supports the expectation that sub-seabed repositories could be operational within ten years after the treaty is amended, at a cost far below that of land-based counterparts. Consequently, any country for which the projected operational date for their land-based disposal facility is beyond 2030, would most likely opt to utilize an international sub-seabed repository.

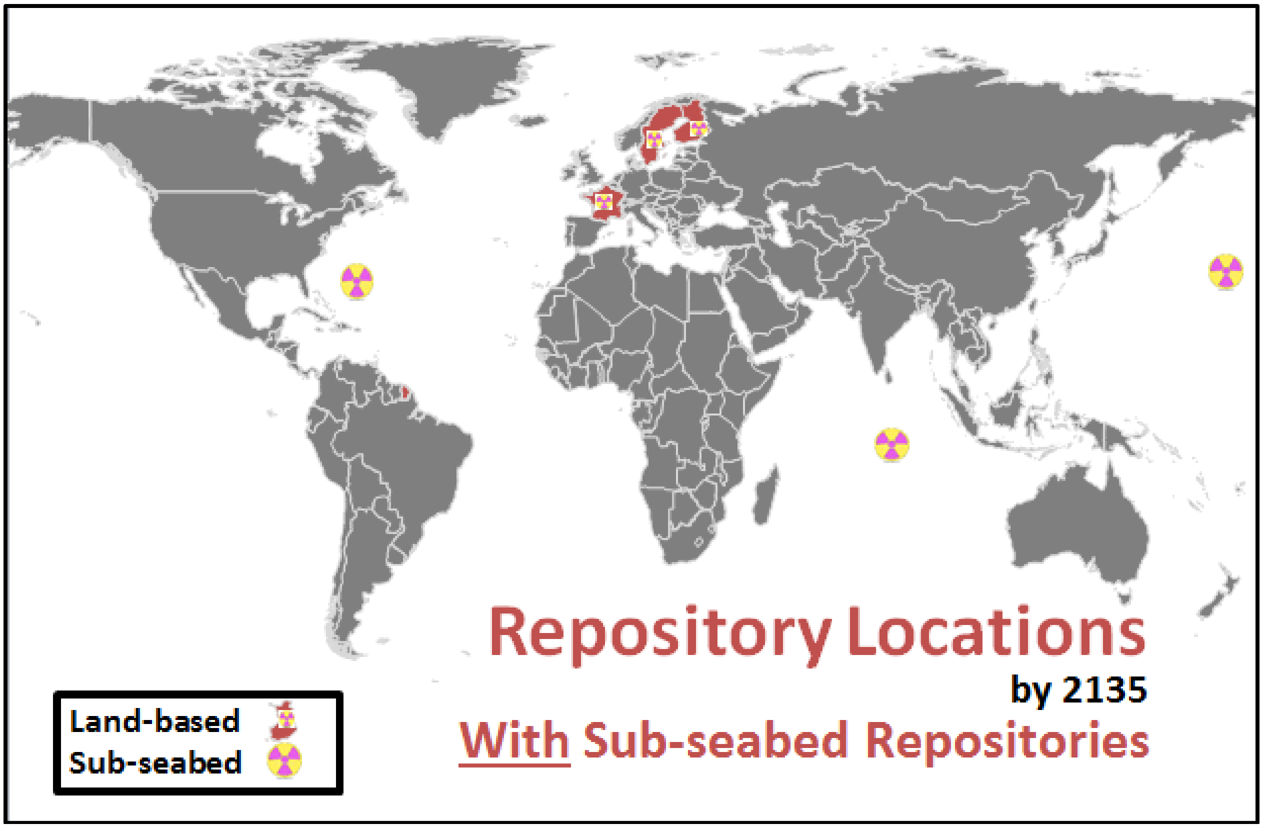

Figure 2 - HLW Repository Scenario with Sub-seabed Locations

TREATY BACKGROUND

The disposal of radioactive waste by "dumping" in the sea is currently 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 [2], 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 eight years, the average number of attendees has been forty-two. Consequently, at least 29 countries will be needed to for an amendment to pass. This contrasts with the normal amendment process for international treaties which requires explicit acceptance of two-thirds of all the *signatories*. There are currently 90 and 46 signatories of the London Convention and London Protocol, respectively [3].

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…".[4] The interval for the first 25 year review period effectively concludes during 2018. The most recent consultative session of the LCLP reviewed the work plan for the scientific review[5]. The plan is summarized in Table 1.

Task	Performing Group	Date
1. Circulate draft outline of literature review report	Scientific Groups	Oct2015
2. Circulate outline of literature review report	Governing bodies	Oct2015
3. Complete draft of literature review…proposed conclusions	Scientific Groups	Nov2016
4. Decide whether additional studies are needed **OR** that "no amendment" will be pursued	Governing bodies	Nov2016
5. Repeat tasks 1-4 until no additional studies are identified	Scientific Groups Governing bodies	Feb2019

Table 1 - Proposed LCLP Work Plan for 25-year Scientific Review of All Radioactive Waste and Other Radioactive Matter

Based on the potential for a "no amendment" decision to be made as early as November 2016, it is imperative that the strategy proposed herein be timed to either preclude an early decision or be prepared for a decisive vote.

The 1996 London Protocol (LP) takes a precautionary approach by banning all activities other than those explicitly approved in Annex I. The legal and programmatic path for adding approved activities to Annex I is well established. The most recent addition illustrates an achievable timeline. 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.

TREATY AMENDMENT STRATEGY

The overall strategy is to first preclude an early "no amendment" decision and then to present the proposed amendment for a vote only after the required number of attendees has indicated their support in private meetings. Who to meet with, what to present, how to present it, and when to present it, are the critical components of the strategy.

Who – The key is to recruit a core of supportive member states to sponsor and champion the required change to the London Protocol treaty. Top on the list would be Japan. Due to land-based siting stalemates in Japan, the industry ministry announced on December 11, 2015 that it will consider the feasibility of burying high-level radioactive waste from nuclear power plants under the seabed[6]. The next highest priority will be given to those member states with emerging nuclear programs. For this effort the regular attendees of the annual consultative gatherings have been prioritized into three groups:

1. Small or emerging nations that have or are aspiring to have a nuclear program (14 currently in this category).
2. Major countries that have operating nuclear power plants and plans for a geological repository in the distant future, beyond 2030 (14).
3. Small countries with remote regions or remote island nations (8).

To counter those regular attendees that do not have any nuclear plans or have operating plants and will have their own geological repository by 2030 and thus would have no incentive to vote in favor of the amendment, additional countries would need to be recruited to attend the consultative session. The perfect outcome would be if all 64 of the member states of the Priority 1, 2 and 3 countries were persuaded to attend the consultative session and vote in favor of the amendment. Priority will be given to countries emerging into the nuclear arena since they will benefit the most from an international repository. One indicator of such countries is the schedule of the Integrated Nuclear Infrastructure Review (INIR) team of the IAEA. The team recently reported on their eight-day mission to review infrastructure development for a nuclear power program in Morocco [7]. Other embarking countries that have utilized the INIR service are Bangladesh, Belarus, Indonesia, Kenya, Nigeria, Poland, Thailand, Turkey, the United Arab Emirates, and Vietnam. Each of these countries would benefit from the availability of an international HLW repository as opposed to siting one within their own borders. All eleven of these embarking countries are either signatories of the LCLP treaty or have recently been attending the consultative sessions as observers.

What and How – Critical to the recruitment effort is assembling a portfolio of concise, informative, educational materials, including short informational videos. In preparation for the private meetings a series of focused informational videos will be developed and translated into the six official languages of the International Maritime Organization. Those languages are Arabic, Chinese (Mandarin), English, French, Russian, and Spanish. It would be advantageous for each of the Priority 1, 2 and 3 countries to have the materials in their native tongue. If sufficient funds are committed for this portion of the effort, additional translations would occur in Portuguese, Farsi, Italian, Polish, Ukranian, Dutch, Japanese, Korean, German, Marshallese, Filipino, and Bislama. Three focus areas have been identified for the videos and accompanying literature.

Before the three focus areas are discussed it is important to understand that everything presented is couched in terms of supporting a very specific amendment to Annex I. The specific wording would only allow precise placement of penetrators containing HLW canisters into sub-seabed sediments. This is necessary to clearly separate this effort from previous practices of “dumping” radioactive waste into the oceans. An exhaustive analysis of the successful effort to ban all oceanic disposal of radioactive waste explored how it was successful even though “scientists and powerful states” strongly opposed the ban and there was a “lack of scientific evidence of damage to humans and the marine environment from ocean dumping of radwaste…”[8]. The ban was successful because the opponents were able to influence a broad audience with simple, strong metaphors and images: a “dying ocean” cause by “dumping”. With the “dumping” image it was easy to make a big issue out of transboundary transport and the difficulty of monitoring compliance. The "dumping" image was also well suited to the argument that retrieval was not possible if risk assessments changed in the future. Eventually the public support for the ban became so overwhelming that the powerful states that strongly opposed the ban: Britain, France, Japan, and the United States, agreed to terminate the practice. By eliminating the "dumping" image from the rhetoric, many of the most effective tools previously used by those that are expected to oppose the amendment will be rendered nearly useless.

The first video focus area is the generic premise of using the oceans vs. land or air for disposing of the waste products of mankind. It will be patterned after a classic treatise authored by the late C. L. Osterberg, that provides a compelling argument in favor of appropriate use of the oceans[9]. Mr. Charles Osterberg was a well-respected oceanographer who served as the director of the International Laboratory of Marine Radioactivity in Monaco from 1976 to 1979. He recognized the great carrying-capacity of the oceans, which occupy more than 70% of the earth's surface, to efficiently process and neutralize certain waste products of mankind. The land, the air, and the oceans are each capable of efficiently processing and neutralizing a certain level of wastes. For example, terrestrial based microbes efficiently neutralize human sewage in a well-designed septic system. Wastes which readily oxidize into carbon dioxide and water are well suited to discharge into the atmosphere, although the build-up of carbon dioxide has become controversial. The main take-away from the video is that it is not environmentally responsible to limit our disposal options for radioactive waste to only the land upon which we reside. To be good stewards of the earth we need to consider the earth in its entirety as we address the waste disposal challenges of mankind. This short video (~10 minutes) sets the stage for the other videos.

The second informational video will specifically cover international sub-seabed repositories for high-level radioactive waste. The ultimate goal is to present a convincing, easily understood argument that such repositories are needed and would be protective of human health and the marine environment. Key elements to present include: current state of the land-based HLW disposal approach and how it will eventually lead to the scenario represented by Figure 1; ocean site screening process, putting the results of the radiological assessment into perspective for the general public, a description of the overall process, simple summary of research already conducted, long-term isolation ability of the sub-seabed sediments, and retrievability of the waste packages.

The envisioned storyline of this 15-20 minute video is:

> *For over 50 years the high-level and spent fuel component of the waste products from nuclear research and development have been stored for eventual permanent disposal. National governments have assumed the responsibility of developing the final resting place for these wastes, collectively referred to as high-level radioactive waste (HLW). Most major nuclear powers are in various stages of developing national land-based deep geologic repositories. Finland and Sweden are the closest to opening their*

facilities with expected openings in 2023 and 2025, respectively[10]. Most other major countries have repository opening forecasts 15 to 60 years in the future. In general, the national efforts have been plagued with so many delays and cost estimate increases that the HLW issue is considered the Achilles heel of the nuclear industry. Efforts to develop regional or international solutions have not fared any better, largely due to the Not-In-My-Back-Yard (NIMBY) syndrome. The use of sub-seabed repositories is taking a different approach, an approach not driven by politics but by technical simplicity that translates into efficiency, both from an implementation standpoint and a cost standpoint. The approach eliminates the NIMBY variable by siting international repositories in sub-seabed sediments underlying international waters. In order to ensure the repository is protective of human health and the environment, the site screening process starts by identifying locations that are as far away from population centers as possible (show satellite map of the earth at night where the lights represent the population centers). Next show a yellow line snaking thru the oceans representing locations farthest from humans. Note that polar regions are excluded for a variety of reasons other than distance from population centers. The yellow line disappears anywhere one of the following criteria (driving rationale) is met:

1. *Ocean depth less than 4000 meters (no food chain – deepest diving fish goes to 3000 meters)*
2. *Not within international water (no NIMBY syndrome)*
3. *Mineral nodules located below (minimize human intrusion)*
4. *Known petroleum reserves located below (minimize human intrusion)*
5. *Deep ocean trench located below (minimize human intrusion, research interest conflicts, geologically active)*
6. *Passes over communication lines or pipelines (minimize human intrusion)*
7. *Passes over famous ship wrecks (minimize human intrusion)*
8. *Passes over sea mounts (geologically active area)*
9. *Passes over major fault zones (geologically active area)*
10. *Passes over major shipping lanes (minimize human intrusion)*
11. *Passes over major fisheries (minimize human intrusion)*

The yellow line becomes green whenever it:

1. *Passes over a section of "blue ocean" where the chlorophyll levels are below 0.1 mg/m3. (minimize environmental impacts since biological life is at a minimum)*
2. *Passes over abyssal plains or hills (geologic stability; thick, uniform sediment layers – minimize migration)*
3. *The brightest green represents where the maximum number of criteria are met and feathers into fainter green shades where the chlorophyll levels are higher. As the different criteria are graphically represented the rationale for the criteria would be presented.*

Graphically illustrate the simple, mature disposal concept highlighting the following:

- *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 to propel penetrators 30 to 70 meters into the sub-seabed sediments (released from the moon pool of a specially designed ship).*
- *Uses the natural properties of the sediment "ooze" to backfill behind the penetrators.*
- *"Hires" Mother Nature to provide the security for the facility – the deposition rate of sediments is greater than the migration rate of most of the radionuclides, thus they never escape the facility.*
- *The back-up security in the unlikely event of an "escapee" is provided by Mother Nature as well – the volume of the ocean provides a dilution effect that keeps any radionuclide concentration several thousand times below natural background levels – thus being protective of human health and the environment.*
- *Utilizes research that is nearly complete with over 14 years of coordinated effort between 200+ researchers from over 10 different countries[11].*
- *Pursued as private-enterprise endeavor.*
- *Avoids the NIMBY syndrome – located below international waters.*
- *Maximizes use of existing, well-proven transportation mechanisms for SNF/HLW.*

Contrast via graphics the dramatic cost-savings available to national budgets considering the estimated cost of the service would be $200/kg compared to $600/kg to $2400/kg for land-based repositories.

Connect the elements of the radiological risk assessment to the above features to demonstrate how the evaluation of many of the assessment criteria are either eliminated or greatly simplified by the concept – supporting the conclusion that it is protective of human health and the marine environment. Graphically put the results of the radiological assessment into perspective with natural background doses (base case peak dose: $3x10^5$ times smaller than background doses)[12].

Conclude by emphasizing the earth-wise stewardship this approach represents by transitioning from Figure 1 to Figure 2.

The final short video (~10 minutes) will address the advantages to small countries of small modular reactors (SMRs). The important point for smaller nations, island nations, and nations with remote areas, is the fact that SMRs, which are needed by this group, are not economically viable for them because the waste disposal liability is open ended. With international sub-seabed repositories the cost becomes fixed at an attractive enough rate that some vendors will include disposal in the price and market the SMRs on a "buy, burn, and return" basis. In other words, a small island nation could purchase a small reactor that supplies power continually for 20, 30, 60 years (depending on the vendor). At end of life the vendor removes it as an entire module (just as it was installed) and handles the disposal of the waste via the contract with a sub-seabed repository that was tendered at the time the SMR was sold. The small island nation never shoulders that liability.

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 (EFN)*, organized in 1996 currently has chapters in over 65 countries and continues to grow at a steady rate[13]. Both the international president of EFN and the president of EFN-USA have agreed to cooperate on this effort.

The well-managed effort and message must keep in mind that in the latter 1980s there was a shift away from a recognition of the "assimilative capacity of the oceans" and the accepted use of "dispose and dilute" to the precautionary principle governed by the concept of "isolate and contain"[14]. Sub-seabed repositories for HLW are consistent with the isolate and contain approach of the precautionary principle. Compared to their land-based counterparts they would be more isolated and long-term containment is more assured.

In order to go beyond the private meetings with the selected member states, the overall effort will need to use environmentalists, scientists, and the mass media in order to raise the public awareness and increase the visibility of this global environmental issue. The videos and other educational materials will be available for access via the internet for use by all in the global coalition.

When – Working backward from the potential November 2016 "no amendment" consideration, it is imperative that the specific Annex I proposal be on the agenda so that the "no amendment" option is tabled. An alternate approach would be to provide a Contracting Party with information regarding additional studies that should be reviewed before a "no amendment" vote could be recommended. This should be easy to do since the proposed literature review list did not include two important categories. There is no mention of the numerous studies that have been completed and are continuing regarding what has been dubbed, "the largest accidental release of radiation to oceans in history"[15]. To be complete the literature review should include studies related to the "further research" areas identified by the Seabed Working Group following the 12-year comprehensive effort to assess the feasibility of disposal of high-level radioactive waste into the seabed[16]. Due to the multi-lingual requirement for the meetings of the Contracting Parties, any items proposed for consideration in the November meeting must be submitted by June. Once the "no amendment" option is tabled this effort will need to closely monitor the progress of the additional studies review so the support for the desired amendment wording for Annex I is in place.

CONCLUSION

By following the strategy detailed above, an amended treaty to allow sub-seabed HLW repositories is achievable before 2019. This would allow private industry to pursue permitting of such international HLW repositories. With such repositories available before 2028, the global outlook for nuclear waste disposal would be altered dramatically. Instead of spent fuel and other HLW being stored on an interim basis at hundreds of reactor sites around the world while awaiting sixty-plus national land-based deep geological repositories to become operational, the number of potential disposal facilities scattered around the world would be reduced from over sixty to approximately six. The three countries that are on track for an operational repository before 2030, Finland, Sweden, and France would most likely have land-based national repositories. With the first international HLW repository in the Atlantic operational by 2028, at a fraction of the cost of the average national land-based repository, most other countries would opt to utilize one of the three international HLW repositories that would be permitted to support the demand - one each in the Atlantic, Pacific, and Indian Oceans.

REFERENCES

1. World Nuclear Association, *International Nuclear Waste Disposal Concepts*, (updated March 2015), http://www.world-nuclear. org/info/Nuclear-Fuel-Cycle/Nuclear-Wastes/International-Nuclear-Waste-Disposal-Concepts/.
2. http://www.imo.org/About/Pages/FAQs.aspx
3. International Maritime Organization, “Status of Conventions as of 13 October 2015”, excel spreadsheet downloaded from http://www.imo.org/en/About/ Conventions/StatusOfConventions/Pages/Default.aspx
4. International Maritime Organization, “1996 Protocol to the Convention on the Prevention of Marine Pollution by Dumping of Wastes and Other Matter, 1972” Annex I, paragraph 3. (as amended in 2006).
5. International Maritime Organization, “MATTERS RELATED TO THE MANAGEMENT OF RADIOACTIVE WASTES, Proposed work plan for the 25-year scientific review of all radioactive wastes and other radioactive matter”, LC 37/10/1, (5Aug2015).
6. THE ASAHI SHIMBUN December 12, 2015, accessed via http://nuclearpower.einnews.com/article/301508834/OEKZdL5tWyay9ize
7. https://www.iaea.org/newscenter/pressreleases/iaea-reviews-morocco%E2%80%99s-nuclear-power-infrastructure-development (27Oct2015).
8. LASSE RINGIUS, Radioactive Waste Disposal at Sea, Public Ideas, Transnational Policy Entrepreneurs, and Environmental Regimes, pp.4-5, The MIT Press Cambridge, Massachusetts, (2001).
9. C. L. Osterberg, “Why Not in the Oceans?”, *IAEA Bulletin*, Vol. 24, No. 2 (1982).
10. IHLRWM 2015 Opening Plenary – I, “International Implementation of Used Fuel and HLW Disposal”, ANS Conference, Charleston, SC (April 12-16, 2015).

11. Nuclear Energy Agency (NEA), “Feasibility of Disposal of High-Level Radioactive Waste into the Seabed”. Vol. 1-8., Paris, Organization for Economic Cooperation and Development (1988).
12. Ibid., Vol. 2, “Radiological Assessment”, pp 10-13.
13. Obtained from “Members” link on the Environmentalist for Nuclear (ENF) website, http://www.ecolo.org
14. LASSE RINGIUS, Radioactive Waste Disposal at Sea, Public Ideas, Transnational Policy Entrepreneurs, and Environmental Regimes, pg.149, The MIT Press Cambridge, Massachusetts, (2001)
15. Woods Hole Oceanographic Institution, “Fukushima Radiation”, http://www.whoi.edu/main/topic/fukushima-radiation
16. Nuclear Energy Agency (NEA), “Feasibility of Disposal of High-Level Radioactive Waste into the Seabed”. Vol. 1. “Overview of Research and Conclusions”, pg. 61, Paris, Organization for Economic Cooperation and Development (1988)