SUBDUCTION FOR PERMANENT DISPOSAL OF LONG-LIVED HIGHLY RADIOACTIVE NUCLEAR WASTE

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Abstract

Subduction, the slow natural submersion of oceanic plates beneath continental plates of the earth, seems an ideal approach for permanent disposal of highly radioactive nuclear waste. A single borehole drilled into the Juan de Fuca plate off Vancouver Island, 3 ft in diameter and 1 km deep, would cost $21 million, and would only be half-filled with the spent uranium fuel produced in Canada in one year, less so with true waste, with ample space for cladding and capping. The deposited waste would then submerge at 5cm/year with the plate underneath the North American continent, untouched for millions of years.

1. Introduction

One of the major stumbling blocks to general public acceptance of the use of nuclear power generation as a viable alternative to the burning of fossil fuels is the apparent lack of methods for safe disposal of long-lived, highly radioactive nuclear waste created as a bi-product of nuclear fission. The report [1] by the Nuclear Waste Management Organization (NWMO) ‘Choosing a Way Forward: The Future Management of Canada’s Used Nuclear Fuel’ states: “… used nuclear fuel poses a hazard which needs to be managed for one million years or more” [1, p. 344]. Current thoughts in nations that are accumulating nuclear waste from power plants or from production of nuclear weapons, or both, are focused virtually entirely on nuclear waste disposal on land in deep geological repositories within stable geological formations consisting of granite, sedimentary rock, or clay formations [1, pp. 360ff].

In Canada, the NWMO was asked to study three options for disposal, as laid out in the Nuclear Fuel Waste Act of 2002, section 12.(2) [1, p. 334]: 1) deep geological disposal in the Canadian Shield, 2) storage at nuclear reactor sites, and 3) centralized storage, either above or below ground. Their recommendation was an amalgam of all three options in an “adaptive phased management” approach, with an eventual final closing of the deep geological repository and decommissioning of the surface facilities [1].

The study of options other than the above-mentioned three was not within the direct mandate of the NWMO, although a cursory examination of waste elimination by reprocessing, partitioning and transmutation was carried out. These methods were rejected as being not economically viable at all, or not commercially feasible at present [1, p. 386]. Other methods of disposal, none of which have been pursued by nuclear power states, were considered to be of limited interest [1, p. 389], and rejected as being contrary to international conventions or as having insufficient proof-of-concept.

Among the methods with insufficient proof-of-concept was the use of subduction of oceanic plates for disposal of nuclear waste. This approach is examined here and compared in part to final disposal in the Canadian Shield.

The present examination of the potential use of subduction shows that a) subduction is a feasible solution for the safe and permanent disposal of nuclear waste, that b) it is possible with current technology, c) it is economically viable, d) it is paid for up front by the current users with no negative legacy for future generations, and e) it will not contaminate the continental or oceanic biosphere. Moreover, compared to other regions in the world, Canada's geology off its west coast is uniquely suited for this approach.

The discussion below touches on each of these points, providing the theoretical underpinnings for the use of subduction as an ideal and possibly uniquely Canadian approach to the disposal of highly radioactive long-lived nuclear waste.

To make the examination tractable, the focus here has been only on the final aspect, the placement of highly radioactive waste into the subducting oceanic plate itself. Except for the use of subduction for final disposal, pre-disposal approaches are identical to those outlined by the NWMO report [1]. Also, the assumption in the calculations here, in parallel with the NWMO study, has been that the spent uranium fuel would not be reprocessed. Reclamation of the 98% unused uranium-238 and of other fissile or fertile actinides in the spent uranium fuel for further use in energy extraction would of course be advantageous and would reduce the current volume of hazardous long-lived material for permanent disposal by any method.

2. Concept of subduction for nuclear waste disposal in Canada

Subduction is the slow submersion of one of the earth's tectonic plates underneath another. This process most often takes place at continental edges, where an oceanic plate of the earth's crust submerses under the continental plate of lesser density.

Oceanic crustal plates have been created for millions of years from the earth's molten magma that upwells and solidifies at mid-ocean ridges. The crustal plates travel at speeds of up to 15 cm per year across the ocean floor and finally submerge or "subduct" underneath continental crusts and eventually re-melt in the hot magma. In Canada, the Juan de Fuca plate, at an ocean depth of about 2.5 km, subducts under the North American continental plate at the Cascadia subduction zone approximately 100 to 150 km off the west coast of Vancouver Island (Fig.1), travelling with a speed relative to the continent of 4.5 cm per year, or 45 km in one million years [2].

This natural process offers an ideal way of disposing of very hazardous nuclear waste, permanently and safely, without the need or possibility of further human intervention. If long-lived highly radioactive nuclear waste were to be inserted and sealed inside deep boreholes in this solid oceanic crust (the oceanic lithosphere) at the subduction zones near the continental margins, this waste would be carried underneath the continental crust, and in the process be covered further by an ever-increasing thickness of sediment, accretion layers and continental crust for millions of years (Fig. 1). As the locked-in deposits travel with the slowly descending oceanic plate, the radioactivity of the nuclear waste in the sealed deposits decays well removed from the human and oceanic biosphere. In Canada's case, the Juan de Fuca plate is already 40 km deep, covered by the North American continental crust, by the time it crosses underneath the centre of Vancouver Island after 2 to 3 million years [2].

The Juan de Fuca plate continues on a downward slope, melting into the earth's magma after about 6 million years. Only at this time, 6 million years hence, would any exceedingly long-lived isotopes mixed with the magma be in a location where they could by chance become part of the upwelling lava expelled by potential volcanic action in the Garibaldi arc of mountains in British Columbia, about 300 km east of the subduction zone.

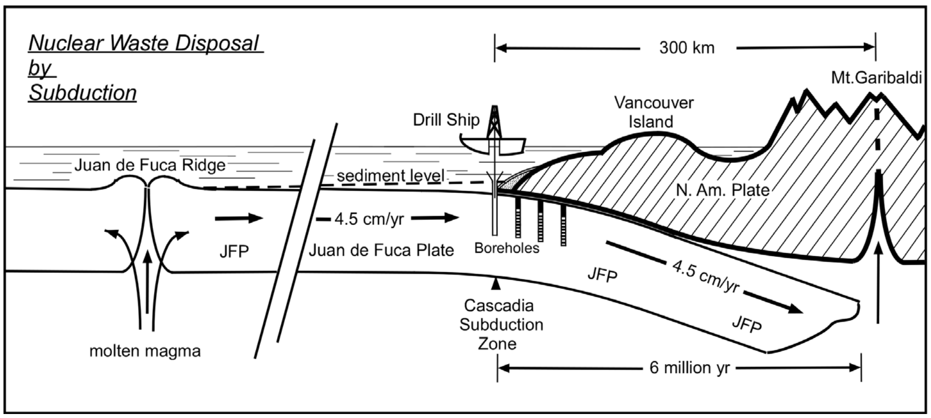

Figure 1. Schematic of concept of high-level nuclear waste disposal by subduction. Drawing is not to scale.

3. Boreholes -- technical feasibility, absolute and relative cost

Boreholes have been drilled into the ocean floor both for scientific and commercial purposes. Drilling for oil has resulted in boreholes with lengths of well over 5 km, some even including changes in directions underground (under-ocean floor) while drilling. Information from Earth Science Australia indicates that, in ocean drilling for oil, the diameters of drill bits run from a current maximum of 36 inches down to 8.5 inches [3].

Using GPS navigation and sophisticated systems of manoeuvring screw propellers, drill ships can maintain and reproduce their position above a drill site to well within one meter. Under the threat of high waves, or for economic or scientific reasons, they can retract the string of drill pipes, and return later to reinsert the drill string in the same borehole. (This latter capability is a major advance since the 1977 Hare Report on "The Management of Canada's Nuclear Waste" [4], which rejected the use of ocean-floor boreholes due to "the difficulties of relocating over the hole in case of severe storms", but suggested that "Canada should at least keep abreast of developments".)

Ocean drilling in general draws on two technologies. One uses a “riser” concept, the other, less expensive variety, does not. In the riser conception a steel pipe casing is constructed from the ship to the ocean floor. Drilling activity is confined in the casing, and re-usable drilling mud, sand, rock, rock cores for analysis, etc. are raised to ship level to be carried away for ocean or non-ocean deposition elsewhere. The other drilling technique does not have such a riser; mud, sand, and rock other than cores used for analysis, are deposited outside the drilling hole on the ocean floor.

To investigate the technical and financial feasibility of creating deep boreholes of useful diameters for potential nuclear waste disposal, an inquiry was made into the cost of the Japanese “riser” ship CHIKYU, the most modern to date, to drill a borehole 36 inches in diameter and 1000 m deep into the ocean floor in the Juan de Fuca Plate at an ocean depth of 2500 m. The response was that such a task would take 30 days and would cost US $21 million [5]. Non-riser drilling would be less expensive, as would a borehole of a smaller diameter. If a greater depth is desirable, the above drill costs indicate that each additional depth of 50 m would cost about US $1 million.

Using the example above, a borehole with a diameter of 36 inches (0.914 m) and a depth of 1000 m would result in an available volume of 657 cubic meters. In comparison, for the year 2007, Canada’s total annual volume of spent uranium oxide at a density of 8.3 g/cc in an estimated 125,000 fuel bundles [1, p.395] is 288 cubic meters. Such a volume of uranium oxide would fill the borehole to a height of only 440 m, leaving a 560 m height to accommodate the volume of containers of the spent fuel and for suitable clays and cements to seal the borehole.

However, as stated earlier, spent nuclear fuel from Canadian reactors contains more than 98 % uranium-238, which is fissile with fast neutrons and or can be converted into fissile fuel for thermal neutrons, and so has great potential for further energy production. The spent fuel also contains thermally fissile actinides such as uranium-235 and plutonium-239. Therefore true high level nuclear waste, consisting only of fission products, would have a volume much smaller than the spent uranium oxide from current Canadian reactors.

The $21 million cost of drilling such a borehole might appear to be high on first look. However, this cost is a very small fraction of the value of the electricity produced annually by Canada’s nuclear reactors. With a yield of 1 MW-year of electricity for 6.25 bundles of fuel, or 120 kg of uranium oxide [1, p. 351], the 125,000 bundles of fuel used currently in one year would have produced 20,000 MW-years of electricity. At an estimated 8 cents/kWh that the consumer pays, this electrical energy yields gross revenues of $14 billion. Thus the additional price of the above borehole, to dispose of the annual output of spent fuel nuclear waste, is only 0.15% of the gross revenue, or 1 cent for every $6.65 charged to the consumer for electricity produced by nuclear power.

The NWMO report indicates that up to the end of 2004 there were 1,869,163 fuel bundles in storage or in reactors [1, p.350]. To dispose of all of the spent fuel in these bundles via subduction would require 15 such boreholes as above, at a drilling cost of 2.25% of the current gross income from nuclear electricity for only a single year.

4. Containers and transportation

Current designs for containers of spent fuel bundles call for canisters about 2 ft in diameter and about 6 ft in length, made of titanium or possibly copper-clad steel. Whether this size or this material would be optimal for in-borehole deposition would remain to be determined. It may be that the borehole diameter chosen should fit an optimal container, or an optimal container should be designed to fit the most economical borehole dimensions. No containers for true nuclear waste, the fission products separated from the spent fuel, have been designed, since such extraction is not being considered at this time.

Transport of nuclear waste by land for disposal in boreholes is no different than in other disposal scenarios [1]. Containers on railway carriages have been successfully tested for retention of their integrity under various accident conditions. Since transport would cross more provincial boundaries than it does now, and since deposition in boreholes is offshore, it would be necessary to persuade affected provinces and the federal government of the safety and efficacy of this method of nuclear waste disposal.

Transport by ship to borehole sites should provide no great additional problems. However, recovery of nuclear waste containers in case of an accidental sinking should be considered. Perhaps for this part of the transport journey containers should fitted with homing devices and with suitable grappling fixtures for retrieval cables that could be attached using currently available ROVs (remotely operated vehicles).

5. Deposition into boreholes

Containers of appropriate size loaded with highly radioactive nuclear waste could be lowered through the casing of the “riser” drilling procedure from the drill ship, or from a specially designed less expensive vessel, directly into the borehole, which itself may be completely or partially cased. This procedure would effectively isolate the containers from the surrounding ocean biosphere during deposition into the oceanic lithosphere, and circumvent objections to deposition even temporarily into the ocean surround.

If a “riser’ approach is not used for drilling, then the containers would be lowered into the borehole by way of currently used entry funnels. Such funnels are situated at the entrance of boreholes to facilitate insertion and retraction of drill strings (pipes), the placement of instrument packages, and to aid in the temporary sealing of boreholes during interrupted drilling operations. Such interruptions are planned or are forced on such operations for scientific, economic or meteorological reasons.

Once a borehole is filled to what is considered capacity, the remaining upper length of the borehole in the ocean crust (lithosphere) beneath the sedimentary layers should be filled and sealed with appropriate absorbing clays, grout (non-shrink cement) or other suitable capping materials. Further barriers to radiation would occur naturally with time as the oceanic plate moves into thicker deposits of sediments, accretion layers, and finally under the North American continental plate (Fig.1).

6. Failure at depth/basalt permeability/Canadian Shield comparison

One of the apprehensions with any closed repository for long-lived highly radioactive waste is the possibility of containment failure "early" after deposition, which for long-lived isotopes could be thousands of years. The prime concern with containment failure is the prospect of radioactivity entering the biosphere via groundwater aquifers or other aqueous seepage. A comparison below between the characteristics of the oceanic crust and of the Canadian Shield seems to argue in favour of the subduction approach for nuclear waste disposal.

6.1 Oceanic crust

The oceanic lithosphere below the sedimentary layer is considered to be anhydrous [6] with water contents measured in the parts per million.

Laboratory measurements of the permeability of different basalts (ocean crust material) to water under pressure have indicated values of 10^{-22} m^2 to 10^{-17} m^2 [7], with Juan de Fuca basalt having a permeability of 3.0×10^{-19} m^2 [8]. Direct measurements *in situ* in the Costa Rica Rift inside different length-portions of pressurized, packer-plugged boreholes [7] indicated that below 250 m into the basalt (260 m to 1010 m) the overall permeability was 1.7×10^{-17} m^2, despite potential porosities and fractured textures over a length of 700 m, and that it decreased further to 5×10^{-18} m^2 at depths of 960 to 1270 m.

Important for potential mobility of radioactivity from failed containers is a measure of water flow in such strata. Fisher [7, p.150] stated that a flow of several millimetres per year was measured in basalt with a permeability of 10^{-13} to 10^{-14} m^2 near the surface of the crust. Therefore a permeability of 10^{-17} m^2 at depths below 250 m, as indicated above, should reflect a water flow of several millimetres in 1000 years, or several meters in 1 million years.

Given these parameters, failure of any containment vessels in the sealed borehole, early, or even after many years, should not result in leakage of radioactivity into the anhydrous surround, or worse, into an aquifer leading into an oceanic biosphere, and certainly not into a continental biosphere.

6.2 Canadian Shield

In the Candian Shield water transport by natural seepage from the surface to horizontal mine tunnels at a depth of 1300 m, measured over a 20-year period, indicates that the mean transit time over this distance was only 23 years in the early period after drift (tunnel) construction in 1979 [9]. The flow quickened to about 17 years two decades later. In another experiment, more like the measurements made in ocean boreholes, Jensen [10] measured water flow between boreholes 10 to 50 m apart at 260 m depth in the Lac du Bonnet batholith in the Canadian Shield near Pinawa. Under unit pressure gradient the water transit time between these boreholes was only about 6 days. Both of these sets of measurements indicate that waterflow in the strata of the Canadian Shield at 260 m and below is many orders of magnitude faster than flow measured below 250 m in the lithosphere of the ocean crust. The proposed deep geological repositories in the Canadian Shield are planned for a depth of 500–1000 m [1, p.26]. For any containment failure at these depths, the measured 20-year transit times for water seepage in the Canadian Shield, should be cause for reflection on the possible radioactive contamination of the habitat of a future generation of Canadians and of Canadian flora and fauna, by seepage of dissolved isotopes to the surface or into an aquifer.

7. Potential borehole locations

An examination of the geological characteristics of the Juan de Fuca plate leads to the conclusion that the most advantageous sites for potential boreholes for nuclear waste deposition would be on the northern portion of the Cascadia subduction zone. This region encompasses about 100 km of the subduction zone running south-south-east from the terminus of the zone at the Nootka fault line (near borehole "Nootka Fault" at 49.1°N, 127.5°W to borehole "CAS-04B" at 48.3°N, 127.1°W [11]). It is approximate 70 to 100 km off the central Pacific coast of Vancouver Island from Nootka Sound south-east.

The geological reasons for this choice are two-fold. Firstly, near the northern edge of the Juan de Fuca plate the rate of motion and of subduction is largest, about 4.5 cm per year; it decreases continuously to 2.9 cm per year at the southern extreme of the subduction zone, 1500 km to the south [2]. Thus waste deposits in boreholes in the northern region would move more quickly underneath the cover of an increasing layer of continental crust.

Secondly, the sedimentation layer overlying the basaltic ocean crust is likely thinner here than in other locations, for two reasons: a) The mid-ocean ridge, the Juan de Fuca ridge, where the Juan de Fuca plate is created (Fig.1), is closer here than at other locations of the subduction zone, with the consequence that the plate in this regions is younger than in other regions of the zone. Less time was therefore available for settling out of suspended matter onto the oceanic crust in this part of the ocean. b) There is no major river outlet in this region, as opposed to the south end of Vancouver Island and the Strait of Juan de Fuca where the Fraser River outflow brings continental run-off and silt out onto the plate. Therefore the drilling of a borehole in this northern region would likely traverse a thinner sedimentation layer, hitting the solid basalt lithosphere more quickly, and so be less costly.

8. Earthquakes and volcanic actions

Subduction of oceanic plates is in general associated with earthquakes and with volcanic activity. Since both phenomena have potentially calamitous consequences, any proposal of the use of subduction for disposal of long-lived highly radioactive nuclear waste must address these two powerful natural forces. However, an examination of relevant data associated with these events suggests that neither earthquakes nor volcanic action preclude the success of this disposal concept.

Subduction, or the sliding of an oceanic plate of the earth past and underneath a continental plate, is in general not a smooth, well-oiled phenomenon, but often occurs in a stick-slip manner. A temporary locking together of plate contact regions causes a compression in both plates and an accumulation of strain, often with a measurable uplifting of the lighter, granitic continental plate. With sufficient build-up of stress forces, the locked contact is broken, permitting a relative motion between the plates and a release of the strain. The effect is an earthquake, with the rearrangement of the continental crust, and a subsidence of the uplift.

The confrontation of equal and opposite forces at the locked zone between the two plates has unequal consequences. The lighter granitic composition of the continental plate is more friable. The heavier basalt of the oceanic plate has a greater compressive strength, a greater shear strength, and a higher elastic limit. The ultimate response to the increasing stress force in both interlocked plates, caused by continued motion of the oceanic plate, is a failure in shear in the granite with greater or lesser thrust faulting of the continental plate, and a release of the locked interface.

Since the compressive stress was still below the higher elastic limit of the basaltic oceanic plate, this plate suffers virtually no consequences other than expansion in the plane of the plate, manifest as forward and downward motion, i.e. subduction. Few faults, if any, are seen in seismic reflection images below the continuously well-defined smooth top of the ocean plate [12]. This is remarkable even after the series of major earthquakes that seem to have occurred in the geologic history of the Juan de Fuca plate at intervals of 570-590 years, with the last being in 1700 [13]. Moreover, the interface itself does not expand and mix the rocks of both plates: recent core samples from boreholes across the boundary between the subducting Philippine plate and the overlying Eurasian plate indicate that at depth "*the critical zone*" of relative motion "*is a sequence of several discrete thin layers only a few centimetres thick*" [14].

These observations together suggest that a borehole in the Juan de Fuca plate would likely not be cracked and disrupted by shear displacement, since the basaltic plate does not appear to fracture on locking and on being strained prior to earthquakes, nor on release during such events. The borehole should deform elastically with the oceanic plate over the length of the borehole, as new compressive and shear strain accumulates. During this time the load of individual stacked canisters within the borehole would easily flex like a beaded necklace without failure of the individual canisters, and then return to the original position on release of the strain after each earthquake. The very top of the borehole at the oceanic plate boundary surface may be sheared during strain release and relative movement of the plates, as suggested by the Philippine/Eurasian plate interface core samples [14], but this would be of no serious consequence, since the top region of the proposed repository borehole should be packed only with inert sealing material for several hundred meters. There may be evidence for such an elastic response, or against it, from seismic data being accumulated in boreholes existing at present for scientific or commercial purposes; I have not yet found such data. Nevertheless, it seems plausible that neither earthquakes nor gradual accumulations of strain in the oceanic crust would compromise the integrity of nuclear disposal boreholes in the basalt of the Juan de Fuca plate.

The concern that volcanic action may release deposited highly radioactive nuclear waste into the biosphere must also be addressed. Volcanic activity associated with subduction takes place in a geographic belt that defines the approximate position of the edge of the subducting plate where it is deep enough and hot enough to melt in the earth's magma (Fig.1). The subduction zone into which repository boreholes are envisioned to be placed is approximately 300 km west of the belt of potentially active volcanoes in the Garibaldi volcanic arc of British Columbia and the Cascade volcanic arc of the north west coast of the United States. At the rate of plate travel of 4.5 cm per year, or 45 km in 1 million years, the repository boreholes travelling within the subducting plate would arrive underneath this region of the continent in well over 6 million years. Thus only a fraction of the very longest-lived radioactive isotopes would still exhibit activity. Moreover, should the subducting plate be deep enough to have reached its melting temperature of 1300°C in the magma of the earth, any titanium container still intact would not melt (Ti melting temperature is 1660°C), and any U_3O_8 would convert to UO_2 with a melting temperature of 2878°C. A UO_2 lump, at a density of 10.96 g/cc compared to a magma density of 3.3 g/cc, would sink deeper into the viscous magma of the earth, likely crushed together with the cladding and container material. Even if it were uplifted at this time by molten lava during volcanic action, its radioactivity would present very little danger to the environment, since it would have decayed to the level in unprocessed uranium ore [1, p.341].

Thus neither earthquakes nor volcanic actions pose an impediment to the success of the use of subduction for high-level nuclear waste disposal.

9. International conventions

A potential legal hurdle to placement of nuclear waste into boreholes in the oceanic crust could be the London Convention of 1972 on prevention of marine pollution, to which Canada is a signatory [15]. It is slated for re-examination and renewal in 2017. The Convention prohibits dumping of any kind of waste at sea. Nevertheless, the NWMO report does not classify the use of subduction as contravening international conventions [1, p. 389], suggesting that placement deep into the sub-ocean floor may not be considered dumping.

10. Consideration by other countries

Subduction as a means of disposal of highly radioactive waste has not been in the mainstream thoughts of other countries that have active nuclear industries. A consideration of the geology surrounding these states makes it obvious why methods other than subduction have of necessity been of prime importance. Russia and European states with nuclear power plants have no subduction zones off their coasts. Moreover, subducting trenches off Japan, off the Aleutian Islands, off Chile, and off Puerto Rico are all at depths of 7 km or more, making them currently inaccessible [16]. At present the Japanese drill ship CHIKYU has drilled into an ocean depth of 4 km [14], but has not been able to reach the 7 to 8 km depth of the Japan Trench. Thus a proof-of-concept for subduction could not be expected from other countries.

This means that Canada is in a unique geographic and geological situation. Before subducting, the Juan de Fuca plate, at an ocean depth of about 2.5 km and a distance of about 100 km off Vancouver Island, has the most accessible subducting zone in the world, easily within Canada's exclusive economic zone of 200 miles.

11. Associated studies

If further studies were required to assuage concerns of the ultimate safety of the use of subduction, they might be carried out at appropriate sites in the Juan de Fuca plate. This plate is being studied for other reasons in the "NEPTUNE" project (**N**orth-**E**ast **P**acific **T**ime-series **U**ndersea **N**etworked **E**xperiments), a venture on which the US government is spending some $300 million and Canada about $112 million in the northern part of the plate [17, 18]. A small diameter borehole 1km or more into the basalt layer may permit the measurement of any still-outstanding characteristics of potential concern. Such measurements would likely fit into the scientific thrusts that are part of the NEPTUNE project. One relevant site might be south-southwest of Nootka Island, with an existing borehole designated as "CAS-04B" in the NEPTUNE Canada Workshop [11].

12. Conclusion

Subduction, the slow submersion of oceanic plates of the earth underneath the lighter continental crust, has been proposed here as an ideal vehicle for the safe and permanent disposal of Canada's long-lived, highly radioactive nuclear waste. Such nuclear waste, placed and sealed in deep boreholes in the solid oceanic lithosphere of the Juan de Fuca plate at the northern end of the Cascadia subduction zone, would submerse with the oceanic plate underneath the North American continental plate off the coast of Vancouver Island. With time, the waste would be covered by ever-increasing thickness of sediment, of accretion layers, and of continental crust as it traveled away from oceanic and continental biospheres for well over 6 million years. The time span easily meets the requirement of waste management for 1 million years or more [1, p. 344], and does so safely away from accidental or deliberate human interference. The approach is fundamentally different from depositing such waste in stationary deep geological repositories on land or in non-moving, non-subducting portions of the ocean floor, where at some future date failure of containment may contaminate the local environment and make it potentially unsuited to sustain life.

The subduction approach can be realized with today's technology. It is surprisingly cost-effective, with the cost of one borehole, which can take Canada's total annual nuclear waste, being only 0.15% of the gross revenue of the electricity produced for one year's worth of spent nuclear fuel. Moreover, the cost is borne up-front, by today's users of the energy and today's creators of the waste, with no negative legacy for future generations in terms of financial burdens or in terms of potential contamination of their biosphere.

Canada is in a unique position geologically to implement the subduction approach to nuclear waste disposal, since the Cascadia subduction zone off our west coast, at a depth of only 2.5 km, is the most accessible in the world. All other oceanic subduction trenches occur at depths of 7 km or deeper. Thus Canada can lead the world in the safe disposal of long-lived, highly radioactive nuclear waste. Moreover, a successful demonstration of this technology should lead to a much greater acceptance of nuclear power as a safe, "green" alternative to the burning of fossil fuels for the many industrial, commercial, and private processes that require heat or electricity. Likewise, proof of the safety of this method of disposal might lead to the development of a profitable international nuclear waste repository whose sites are continually renewed by tectonic plate movement.

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