Addendum

Submitted by:
D. Roy Cullimore, Ph.D. R.M.
Droycon Bioconcepts Inc.,
315 Dewdney Avenue, Regina, Saskatchewan

A perspective on microbiological considerations in relation to the management methods outlined in the Nuclear Fuel Waste Act (NFWA) as well as other methods described in the NWMO November 2003 Discussion Document, "Asking the Right Questions".

> "The subsurface microbial community constitutes a large fraction of the Earth's biomass" (quoted from 1994 EOS, Transactions, American Geophysical Union, Volume 75, # 34. p395)

There is a common expression "Out of Sight, Out of Mind". Microorganisms can be considered as possible victims of a lack of recognition because they do not present an obvious presence by their structures and often generate subtle effects through their activities (unless they are virulent pathogens).

This submission addresses the NWMO November 2003 discussion document "Asking the Right Questions" primarily from the perspective of demonstrable and potential microbiological considerations. Specific statements in the document are addressed with prime concern relating to potential microbiological interactions.

Page 3 - To ensure a high measure of transparency in the NWMO's work

One prime factor is the potential interaction between the biosphere and the used nuclear fuel. In ensuring that there is a high degree of transparency in the NWMO's work, it is important that the extent and scale of the biosphere is fully appreciated. Today it is becoming well established that the biosphere extends well down into the geosphere to the limits controlled by the presence or absence of liquid water. Traditional concepts separated the geosphere as being virtually a sterile environment beneath the biosphere. This concept originates in a natural preoccupation with the surface biosphere and a biota limited to plants and animals. Today it has now become understood that biomass within the biosphere is dominated by microorganisms and that these dominate the subsurface biosphere into the geosphere and into the deep oceanic environments. If any environment being selected for storage or disposal contains a liquid form of water then there is a probability bordering on certainty that there will be potential interactions between the used nuclear fuel and the biosphere over the fullness of time. In creating a high level of transparency, the NWMO will need to critically evaluate the potential short- and long-term impact of any long term storage or disposal on the impacted elements of the biosphere. Impact may, at the simplest level, be viewed as causing death of some local microbial species, mutation and adaptation of others, and the potential for the survivors to accumulate and mobilize the radionuclides and stable trace elements contained within the used nuclear fuel.

Page 3 - Safely managing used nuclear fuel

Safety is a prime goal in all efficiently engineered and managed operations where there is potential risk to the workers and local communities. That safety concern persists until the work is done and the workers leave. Safety here has to have broader applications to cover communities (human, plant, animal and microbial) that were present before the beginning of the management process. Particularly challenging is the protection of the biosphere which means that, ideally, the used nuclear fuel has to have a containment envelope that is either so robust and durable that there can be no leakage of stored product or radiolytic emanations; or that the surrounding environment is so devoid of liquid water that there is no biological activity within that containment envelope. It is important to recognize this fact and design and operate accordingly.

Page 4 - It will set a benchmark for how we as a society will discharge our responsibility to manage the many wastes from the technologies we use to support our quality of life.

This process represents one of the most challenging responsibilities for society today since it represents a long term obligation to future generations. It becomes a benchmark in part because of the vast array of factors that come into play to ensure the safe management of the used nuclear fuel. In fulfilling this obligation there is a need to assure that protection is extended not just to society but also to the animal, plant and microbial species both known and yet to be discovered within the vastness of the biosphere. Technological challenges arise from the fact that these challenges cannot be simplified to a series of comfortable mathematical models but have to involve an effective inter-disciplinary approach that is mindful of all of the challenges without bias. Present day technologies have tended to be based on the "hard" sciences engrained in physics, chemistry and mathematics. Here the responsibility will be to effectively weigh all of the factors into a management scenario involving many generations into the future.

Page 4 - Understanding the dynamic interaction and tradeoffs between nature, technology and society over hundreds, if not thousands of years challenges both our ingenuity and our common commitment to find a solution.

Given the need for certainty of interactions between nature and technology and the potential risks to future generations, there is a need to ensure that full scale of the biosphere is recognized. The "commitment" to find a solution means not only ingenuity (that can be biased by the romancing of the notion) but also by a determined and unbiased approach to recognize the interactions, solve the dynamic processes, and undertake tradeoffs where these can be defended through comprehensive scientifically driven determinations. Perhaps the most significant challenge will be for the traditional disciplines to set aside their biases (based on a combination of ingrained dogmatisation and protectionist posturing) and recognize that we are all blended mixtures of ignorance, knowledge and prejudice. Indeed this will be a challenge.

Page 5 - We intend to mine the lessons of the past, to examine the present and imagine the future in our quest for answers.

From the perspective of the subsurface biosphere, the lessons of the past essentially ignore its relevance in favour of a geosphere that does not possess significant presences of life. There is a blossoming of research findings now on this part of the biosphere, which means through examining these activities a better understanding of the challenges that will have to be faced in the future. Imagination leading to discovery and the application is desperately needed to ensure long-term storage and effective management of the used nuclear fuel. This quest for answers will have to involve recognition of the many dynamic activities the microorganisms will undoubtedly play in the real world of storage and/or disposal. Dynamic events can range from corrosive processes working within the containment envelope aiding in the releases of the radionuclides, occlusive process to prevent their transport, bioaccumulative processes forming shields from radiolysis, gas and biocolloidal formation speeding up transport of the radionuclides through the water, biofilm, bioconcretious and slime formations retarding the escape of radionuclides through bioaccumulation, and mutation (stimulated by radiolysis) leading to the generation of strains of microorganisms that become adapted to the extreme environments created as a part of the storage and disposal of the used nuclear fuel.

Page 8 – Q-6. Human Health, Safety, and Well-being - Does the management approach ensure that people's health, safety, and well-being are maintained (or improved) now and over the long term?

Three critical components here are human health, safety and well-being. Health and safety are recognized within medical and regulatory processes. “Well being” on the other hand can be interpreted to mean “a state of being well, healthy, contented etc” (Oxford Concise Dictionary, 8th edition). Contented becomes the challenge since this is much more of an attitudinal state and more subject to outside influences. Society is becoming very sensitized to perceived risks exacerbated by recent terrorist attacks, outbreaks of “new” diseases such as SARS (severe acute respiratory syndrome). It is well known that radiolysis does increase mutagenesis in microorganisms. Should society become convinced that the occurrence of an undesirable event could be associated with storage or disposal facility for used nuclear fuel, there could be political ramifications. To prevent this, the method of used nuclear fuel management has to be demonstrably sufficiently robust and durable.

Page 8 - Q-8. Environmental Integrity - Does the management approach ensure the long-term integrity of the environment?

The key word here is “integrity” (defined as: 1. moral uprightness, honesty; or 2. wholeness, soundness; Concise Oxford Dictionary, 8th edition). Both definitions are relevant, the moral issues relate to the mature stewardship of the environment that needs to be done honestly without personal biases. These biases may restrict “looking at the big picture” that has to be done if a sense of wholeness is to be achieved and the premises have to be soundly based on good validatable science using demonstrable technologies. Beyond the challenges created by this lies the “long term” that is commonly defined in millennia for the storage and/or disposal of used nuclear fuel.

Science and technology today has been in the last two centuries preoccupied with speed, convenience and comfort rarely looking beyond two human generations. Today the impacts of human activity are becoming more evident through impacts perpetrated by society’s activities on the integrity of the environment. Only now is the idea of long term evaluations becoming appreciated. The storage and/or disposal of used nuclear fuel present such a challenge.

Used nuclear fuel management creates challenges to the associated science and technology through the need to: (1) establish confident projections of potential impacts extending over millennia; (2) develop an integrated approach that remains flexible and reactive to situations and avoids linearized thinking and denial of evidence; (3) avoid the inevitable loss of incentive and drive that is commonly a part of institutionalized projects; and (4) allow for a change in the decision-making matrix from one that is driven by politics and expediency to one that is logical and supportable by all parties. This has to be built on the spirit of horizontal collaboration with the achievement of a cohesiveness that ensures confidence in the final products (facilities for the environmentally safe storage and disposal of the used nuclear fuel) and services (long-term management of the storage facilities until all of the fuel has moved to final disposal).

Given that energy costs are steadily rising because of increasing demands and limited resources, it is probable that there will be new phase of nuclear powered electrical and/or hydrogen generating stations in the foreseeable future. Given the mandate of the NWMO, there may be sense in proposing changes in the siting of these stations with the premise of minimizing environmental impacts. Such changes could include the following basic premises: (1) nuclear fuel is mined, refined, managed, exploited, stored and disposed without the fuel leaving the domain of the generating agency; (2) the products (electricity and/or hydrogen) would leave the site after being generated; (3) the used nuclear fuel would be disposed within the mine from which the ore was mined for refining; (4) all operations as far as possible would be below grade; and (5) the environment within the potentially affected area would be subject to comprehensive and detailed base line evaluations to assure the long term utilization of the site for all phases of the exploitation of the resource and the development of the environmental management plan for long term implementation.

Page 12 - Each of the following methods must be the sole basis of at least one approach:

> **(a) deep geological disposal in the Canadian Shield, based on the concept described by Atomic Energy of Canada Limited in the Environmental Impact Statement on the Concept for Disposal of Canada's Nuclear Fuel Waste and taking into account the views of the environmental assessment panel set out in the Report of the Nuclear Fuel Waste Management and Disposal Concept Environmental Assessment Panel dated February 1998;**
> **(b) storage at nuclear reactor sites; and**
> **(c) centralized storage, either above or below ground.**

(a) While deep geological disposal had many attractive features, the present lack of appreciation of the interaction between the geosphere and the subsurface biosphere needs to be carefully addressed. Microorganisms that form the bulk of the biomass are capable of interacting with the containment envelope in a variety of positive and negative ways that need to be understood and exploited.
(b) Not subject to this review.
(c) Centralized storage should address options in a manner similar to the long-term storage of sulphur in Alberta. Here, the basic premise is block storage either

above grade (exposed to, or protected from, the elements), below grade but above the water table (semi-saturated) or below grade and below water table (saturated).

Page 16 - the predominant thinking in the international community regarding the long-term management of used nuclear fuel was that it was best buried and sealed deeply in stable geologic environments.

This predominant thinking predates the understanding of the importance of the subsurface biosphere in assuring a “stable geologic environment”. It has now become recognized that although the used nuclear fuel would have been buried and sealed in a deep geologic environment, the potential for microbiological factors leading to instability is a potentially significant factor that could also significantly affect travel times for escaping radionuclides from the confining environment.

Page 17 - With its emphasis on deep geological disposal, Canada was far from operating in isolation. Across the international community, many nations were investigating a solution offered by deep disposal in a stable geologic environment.

Traditional views of the geosphere as being divorced from the biosphere and physically relatively stable promoted this selection by the international community. Globally there was not at that time any deep understanding of the true extent of the subsurface biosphere.

Page 18 - From a technical perspective, the safety of the AECL concept has been adequately demonstrated for a conceptual stage of development, but not from a social perspective.

Technical perspective in this sense is a limited term addressing only addressable issues relating to engineering. There was not an adequate demonstration for the conceptual stage of the development because of the lack of recognition of some significant aspects of the concept. These include but are not limited to the inadequate recognition of the subsurface biosphere, assumptions about the physical stability of the proposed vault system and lack of appreciation for subsurface to surface interactions potentially involving biological factors.

Page 29 - If these contaminants move into groundwater, surface water, and/or air, and are then taken up by organisms, they can cause harm.

Movement through the ground water into surface waters and/or the air is most likely the time when the contaminants will be taken up by organisms. These organisms would in all probability be microorganisms with take up occurring extra-cellularly within the EPS in bound water. Uptake by the biota (plants and animals) is likely to occur at the surface in the soils and waters by ingestion (animals) and exchange (plants). Impacts can also occur in the ground water through mutagenesis and death amongst the carrying microorganisms.

Page 43 - To span the kind of time frame needed, the group explored four time horizons: 25 years (1 generation) into the future, 175 years (7 generations) into the future; 500 years (20 generations) into the future and 10,000 years (400 generations) into the future.

A span of this time length (10,000 years for the fourth horizon) goes beyond the ability for the scientific prediction of events with any accuracy. An example of this would be the prediction of future glaciation or global warming given our present knowledge base. For microorganisms that may generate six generations per year (as an example), the number of generations to 10,000 years would be 60,000. This would mean an even greater probability for the evolution of changes within the environments created by the emplacement of used nuclear fuel.

Page 62 Deep Geological Disposal.

Disposal is a method of isolating used nuclear fuel from humanity and the environment. It is conclusive and without the intention of retrieval or reuse. Deep geological disposal involves burying the used nuclear fuel deep underground. This method is currently favoured by many countries and by most international agencies. It would require transporting used fuel from interim storage facilities to a disposal facility (wherever it is located). The main challenge in effective disposal is to limit the potential for migration of radioactive and toxic contaminants away from the used nuclear fuel. The most worrisome migration process is through the groundwater flow system. Even if contaminants moved one metre per year – that still means the contaminant stream could be five kilometres long in 5,000 years, if ever the contaminants breached their containment barriers.

The term, “most worrisome migration process” for the movement of contaminants through the ground water flow system, is one of the Achilles heels in the whole process. Apart from extensive theoretical modelling based on simplified mathematical formulations, there is little developed understanding of the true nature of the migration process and the various forms of microbial interactions that do occur. This extends right through to the monitoring wells that are assumed to remain sterile and therefore can be used to take samples for chemical testing with impunity. Reality is that these monitoring wells do biofoul, generating imprecise data that can underestimate the position of the contaminant for a variety of plausible reasons.

Page 63 Industry has continued work on key issues around a deep geological repository in Canada. One design proposes that 324 fuel bundles would be contained in a steel inner vessel, which is surrounded by a copper outer shell. The fuel container would be encapsulated in bentonite self-sealing clay, which, in turn, would be packed in a buffer material, a dense backfill, and a light backfill. The container would be buried 500 – 1000 meters below the surface of the Canadian Shield.

Steel and copper are electrically dissimilar metals and if any water bridges these metals there is likely to be: (1) electrolytic corrosion; (2) generation of redox fronts; and focussed microbial activity leading to faster rates of corrosion depending upon the charge patterns that are generated. Copper is inhibitory to many microorganisms but if one of the acidic products of microbial fermentative activity reduce the surrounding pH then the copper may dissolve exposing the steel surface and creating very aggressive electrically active cells that will then perforate the steel. Bentonite as a “self-sealing clay” has value in single generation applications, but if saturated with water it can react with the dense backfill and then the lighter backfill through the activities of the microorganisms that are almost inevitable likely to be present. These activities may include the generation of gases leading to fracturing, instability in the clay and differential movement of the bentonite into the buffer material and vice versa. This design has a number of significant concerns from the microbiological perspective that should not be ignored.

Page 67. Emplacement in Deep Boreholes

Some countries, which must dispose of only small quantities of high-level waste, are looking at a method called “emplacement in deep boreholes.” In this method, solid packaged waste would be placed in deep boreholes drilled to depths of several kilometres, with diameters of typically less than one metre. The waste containers would be stacked in each borehole and would be separated from each other by a layer of bentonite or cement. The borehole would not be completely filled with waste: the top two kilometres would be sealed with materials such as bentonite, asphalt or concrete. Sweden, Finland and Russia, among others, have examined the deep borehole method as a possible alternative to a deep repository. Boreholes could be drilled both offshore and onshore in many types of rock, which broadens the number of possible disposal sites. Although proponents argue that related long-term risks to people and the environment would be very low, there are significant technical questions requiring further research.

A borehole is a conduit that has to be drilled down into the ground. This involves physical mechanical action that will cause fracturing. This conduit now passes down through lateral layers of ground water often of different chemistries and microbial flora. A result of this and the egress of oxygen from the surface now cause magnification of biological activity during a time when the containers are being stacked. While the borehole can be sealed, the sealant is not 100% nor does it extend into the fracture zones created by the drilling and loading of the borehole. Of the three sealants, bentonite is likely to swell through gas production where there is microbial activity, asphalt is likely to fracture creating open pathways (at the microbial level) and concrete may be corroded if acid producing bacteria are present and active in the reductive zones. The time frame is not the length of operating time for a mine (one or two generations commonly before abandonment) but considerably longer (e.g. by 200 times). This would mean more time for the microbial activity within and around the bore hole to impact on the security of repository. As an illustration, a water well can produce water reliably for 15 years of good quality and then in a short time period, of say only a year or two, the well degenerates now producing poor quality water until it then plugs up because of biofouling. That phenomenon is only now being recognized by the water industry as being a significant part of the maturation and failure of wells. Since the containers would also be generating heat this might cause convection currents to move up, in and around the borehole towards the surface. Technical questions that would need to be addressed are numerous and far reaching.

Page 68. Direct Injection.

This method involves injecting liquid radioactive waste directly into a layer of rock deep underground. The United States has used this method to dispose of liquid hazardous and low-level waste. The former Soviet Union has also used this method, to dispose of liquid high-level waste – at locations usually close to the waste generating sites. Direct injection requires detailed knowledge of subsurface geological conditions. It does not incorporate any man-made barriers. There would be no control of the injected material after disposal. Retrieval would be impossible. There are many technical unknowns that would require extensive research to be confident of the suitability of this method for a specified site.

Direct injection into a layer of rock has very significant microbiological implications. Since the rock is a layer with boundaries and likely to contain water and microorganisms, there is a probability of essentially uncontrolled movement of the waste over the life span of the facility. There is a danger that “out of sight, out of mind” and “dilution is the solution to pollution” were driving forces behind these earlier injections. Knowledge of “subsurface geological conditions” is too limiting in that it linearizes the process of investigation; “subsurface environmental conditions” would be more appropriate.

Page 68 Rock Melting.

In this method, liquid or solid waste is placed in an excavated cavity or a deep borehole. Heat generated by the waste would increase, melting the surrounding rock and dissolving the radionuclides in a growing sphere of molten material. As the rock cools, it would solidify and incorporate the radionuclides in the rock matrix, dispersing the waste throughout a larger volume of rock. In one variation of this method, heat-generating waste is placed in containers. When the rock melts around the containers, the waste is sealed in place. Research was carried out on this method in the late 1970s and early 1980s, when it progressed to the stage of engineering design. The design involved a shaft or borehole which led to an excavated cavity at a depth of two to five kilometres. It was postulated (but not demonstrated) that the waste would be immobilized in a volume of rock one thousand times larger than the original volume of waste.

This would kill the microorganisms in the direct impact zone (of the melting) but would create a thermal gradient that would cool over time. These thermal anomalies would cause some stress leading to fracturing in the encapsulating rock mass, which would saturate with water and form focal sites for the start of microbial activities that would move gradually into the cooling sphere of waste as it saturates with water. Microbial activities in this cooling mass may be stimulated by the higher temperatures leading to a faster growth in the biomass. Waste immobilization may be a temporary phenomenon if the microbial activity becomes sufficiently aggressive.

Page 69. Sub-Seabed Disposal

In this method, radioactive waste containers are buried in a suitable geological setting beneath the deep ocean floor. Sub-seabed disposal was investigated extensively in the 1980s, primarily under the auspices of the Seabed Working Group set up by the Nuclear Energy Agency (NEA) of the Organization for Economic Co-operation and Development (OECD). Canada participated in this group, along with the United States, the United Kingdom, Japan and several European countries. The sub-seabed disposal concept involves using missile-shaped canisters called "penetrators" to hold solid waste. The penetrators are dropped from ships, and bury themselves to a depth of a few metres or more in the sediments on the ocean

floor. The disposal sites would be ones where the sediments have a high capacity to absorb radionuclides, and where the water is a few kilometres deep. The idea behind the concept is that the waste form, inner canister, penetrator and sediments would provide sufficient protection to prevent the release of radionuclides into the ocean for thousands of years. When release finally does take place, it would occur very slowly and there would be substantial dilution.

While there can no doubt that the penetrators would strike the ocean floor and perhaps a few meters into the sediment before coming to rest what would happen after that is anybody's guess!! The seafloor sediment is commonly biologically very active dominated microbiologically by a range of bacteria often including sulphate reducing and various heterotrophic bacteria. Underpinning these organisms are methane producing bacteria that may extend for a 100 meters or more into the ocean floor. This option could be compared to slamming the penetrator into a prairie soil (the biomass would be similar in mass) and thinking there would be no consequences. The deep ocean is teeming with life and it would be irresponsible to believe that the penetrator would not be compromised and continue to slowly sink. Hydrogen sulphide would be produced and could start the process of electrolytic corrosion, acid producing heterotrophic bacteria could begin to generate acids, methane producing bacteria could destabilize the sediment (due to the methane and slimes being produced). This would mean that the mathematical model for ongoing descent of the penetrator would have no real value in predicting the risk, the penetrator may become corroded and release the contained radionuclides. These radionuclides would be bioaccumulated within the living sediment and move with the biomass into the surrounding environments including the ocean. Ocean sediment is a very essential and integrated part of the deep ocean biosphere. The only saving grace for this proposal is the eventual dilution factor over time, but if the radionuclides enter the oceanic food chain, this factor is not so significant.

Page 69 Disposal at Sea

This method consists of placing packaged waste on the bed of the deep ocean. The packaging would consist of canisters designed to last for a thousand years or more. The waste would be in a solid form that would release radionuclides into the ocean very slowly when the canisters fail. The site would be one where the water is a few kilometres deep, so that the waste would not be affected by human activity; there

would be substantial dilution of radionuclides before they reach the surface. Sea disposal was investigated by the NEA's Seabed Working Group, but not in the same detail as the sub-seabed disposal method. Sea disposal would be an extension of the 'sea dumping' method that was used until the early 1980s to dispose of solid low-level radioactive waste. It is now prohibited under international conventions.

Having dove down to the *RMS Titanic* three times (1996, 1998 and 2003) and observed the aggressive nature of microbial activity on the steels there, engineering a canister to slowly release radionuclides into the ocean environment would appear to be a significant challenge. While corrosion allowances can be made for the canister, once the canister is sited on the ocean floor then there are many factors that could affect the rate of corrosion particularly given that the deep-oceanic environment is very dynamic with a wide diversity of animal and microbial life. It would be reasonable to consider that the prohibition of the disposal of low-level radioactive waste should be extended to include high-level nuclear waste since the deep ocean is very much a part of the Earth's biosphere.

Page 70. Disposal in Ice Sheets

In this method, containers of heat-generating waste would be placed in very thick, stable ice sheets, such as those found in Greenland and Antarctica. Three possibilities have been suggested. In the "meltdown" concept, containers would melt the surrounding ice and be drawn deep into the ice sheet, where the ice would refreeze above the wastes, creating a thick barrier. In the "anchored emplacement" concept, containers would be attached to surface anchors that would limit the containers' penetration into the ice by melting at around 200-500 metres. This would allow for possible retrieval for several hundred years (before surface ice covers the anchors). In the "surface storage" concept, containers would be placed in a storage facility constructed on piers above the ice surface. As the piers sank, the facility would be jacked up to remain above the ice for perhaps a few hundred years. Then the entire facility would be allowed to sink into the ice sheet and be covered over.

Here the fundamental premise is presumably that the ice would be biologically inert and form a thick barrier. The assumption that ice would be suitable is based upon that fact that there would be no nutrients, no liquid water and too a low temperature for biological growth. The key word is “melt” which would convert solid water into liquid forms. Once liquid then there is a potential for microbial activity utilizing the nutrients entrapped within the ice and oxygen that has penetrated the ice. Whether this happens immediately (meltdown concept) or after the piers have sunk (surface storage concept); there would be a period with melt water around the containers. The form of microbiological activities would be a reflection of the nutrient loading within the ice contained melt zone. This microbial activity could cause the formation of biocolloidal matrices that would resist freezing and allow continued microbial activity down to at least $-10^{o}C$. The form of this activity would be primarily dependent upon the form and concentration of nutrients in the ice and the availability of oxygen. Lack of oxygen would create a greater challenge to the stored radionuclide containers through the generation of acids and hydrogen sulphide that could accelerate corrosive processes. At the same time significant gas (methane, carbon dioxide, nitrogen and hydrogen) production might cause fracturing and destabilization of the ice surrounding the sinking containers. Ice is also a part of the biosphere although not commonly recognized because the biota is passive when the ice is totally frozen.

Page 70. Disposal in Subduction Zones

This method was initially proposed in the 1980s. In theory, it involves placing waste in a subducting (or descending) plate of the earth’s crust. Subduction zones are always offshore, so this concept can be considered a variant of emplacement in the sea or beneath the seabed.

Microbiological challenges would emerge as the waste is moving down though the oceans floor sediments en route to the subduction zone. In that sense this option raises similar concerns to the use of the penetrator for sub ocean floor disposal. There remains some challenge relating to the confirmed existence of subduction zones beyond theoretical probabilities based upon current concepts of the manner in which continental drift has occurred. The only hard supporting evidence of subduction is that out from the areas of submarine trenches. Here, deep earthquakes can be plotted along lines (referred to as the Benioff zones). These lines go deeper away from the trenches and so these Benioff zones have been put forward as evidence that sea-floor material was diving into the trenches and pushing out deeper into the Earth along these lines as a part of the subductive processes. But there are other plausible explanations that need to be pursued before serious thought is given to assuring the validity of the premise before considering the utilization of a subduction disposal scenario

Page 70. Disposal in Space

This method would permanently remove radioactive waste from earth by ejecting it into outer space. Alternative destinations that have been considered include the sun, orbit around the sun, and ejection beyond the solar system. This method has been suggested for disposing of small amounts of the most toxic waste. This method has never been part of any major research and development program. Opposition to disposal in space has been reinforced by the Challenger and Columbia accidents.

There would appear to be no obvious microbiological concerns once the waste has been ejected and moved out of the Earth's orbit. Risk assessments of a launch failure or catastrophic re-entry are two issues that would render this option untenable.

Page 70. Dilution & Dispersion

The method would involve dissolving the fuel in acid, neutralizing the solution and discharging it slowly down a pipeline into the sea. The discharge site and rate would be such that radiation doses to people never exceed internationally-accepted limits. Another possibility would be to transport the fuel solution by tanker to the open ocean and release it there.

This proposal lacks any understanding of the fact that the oceans form the largest part of the biosphere and they are dynamic. "Dissolving the fuel in acid, neutralizing the solution and discharging it slowly down a pipeline into the sea" is an option if no considerations are given to the impact this discharge (slow discharge or fast dump) would have on the impacted biota. This discharge would presumably be in the trophic zone where there are very significant seasonal activities of plants, animals and microorganisms. Impacts would be related to the rate and location of the discharge but would cause a variety of effects even though the radiation would never exceed internationally accepted standards. Some expected effects would be: (1) bioaccumulation of the radionuclides by microbial consortia; (2) kill off of any species sensitive to any chemicals being discharged at the concentrations used; (3) accelerated rates of mutagenesis; (4) movement of the radionuclides into the food chain: and (5) bio-magnification of some of the radionuclides in the food chain as the ingestion sequence moves through the animals. It may be expected that the radionuclides would form into a “plume” (particularly when the fast dump technique is applied) with preferential concentration of the radionuclides wherever the organisms are concentrated within that plum zone. Dispersion is likely to be a phenomenon that is controlled by the surviving organisms (including microorganisms) within the impact plume. This would mean that there would not be a mathematically definable rate of dispersion that could be demonstrated through the effective routine practise of the art.