RISK ASSESSMENT OF OCEANIC DISPOSAL OF LOW-LEVEL RADIOACTIVE WASTE

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INTRODUCTION

Ocean dumping of radioactive waste has been a source of serious concern. In many countries, programs for ocean disposal have met serious resistance, sometimes bordering on hysteria, from various public and political groups. In the USA, no ocean disposal activities have been conducted for the past several years. As has been the case in many technological areas, the levels of perceived risk associated with ocean dumping are far different than risk levels determined by objective analysis. A likely basis for the high level of perceived risk lies in the premise that any amount of radioactivity added to the ocean constitutes an unacceptable hazard. Were this premise valid, mankind might long since have succumbed to the effects of the natural radioactivity which has always existed in the ocean and far exceeds the quantities or effects that could result from well-planned oceanic radwaste disposal.

This paper reviews some of the results of an unfunded study conducted by the authors under the auspices of the Northern California Section of the American Nuclear Society. During the summer and fall of 1980, a considerable amount of political activity and media coverage was directed toward stimulating public anxiety regarding the possible health consequences of past radioactive waste disposal at the Farallon Island dumpsite located in the Pacific Ocean about twelve miles from the city of San Francisco. This dumping occurred during and following World War II up to about 1970. The disposal program has been described in WASH-734[1] and several subsequent reports.[2] Largely as a result of the 1980 publicity campaign, concern was aroused to the extent that many people feared eating seafood caught off the Pacific coast.

To determine whether such fears had a rational foundation, we performed a risk assessment to study the concept and place in perspective the overall hazard which might result from oceanic disposal of low-level radioactive waste. In particular, we have applied risk assessment methodology to evaluate conditions at the Farallon Island dumpsite. This paper reviews some of the salient insights derived from our study.

ON CONTAINER INTEGRITY

Historical records reveal that the waste dumped at the Farallon site was contained largely in 55 gallon drums. Much concern was expressed in news coverage that these drums were leaking "deadly radioactivity" into the ocean waters where it could disperse and find its way into food chains.

A seriously mistaken impression given in media coverage was that the leaking or totally unsealed waste containers observed at the dumpsite constitute an error or miscalculation of some sort on the part of responsible officials at the time the dumping occurred.

Even forty years ago scientists were well aware of the corrosive properties of seawater. From our investigations, we found that there was, in fact, no intent or belief that the barrels and other containers would not leak. The concept was that, considering the dispersive capacity of the ocean, the total quantities of radioactive material disposed simply were not sufficient to constitute a significant hazard.

With regard to the alternative waste disposal philosophies of "dilute and disperse" versus "concentrate and contain," it should be noted that ocean disposal uses both principles to advantage. Since the intent of oceanic disposal is to provide both isolation from the immediate human environment and a huge medium for dispersal in the event of release from the dump site, it is apparent that in either case the public health is protected.

As previously noted, the waste packages were never intended to be leakproof. Their major function was to hold the waste until it reached the ocean floor. Any subsequent leakage would be naturally dispersed by normal oceanic processes such that no significant hazard could result. For example current international guidelines for sea disposal of radioactive waste[3] state:

> "The container shall be made sufficiently strong or pliable to remain intact and retain its contents under the pressure encountered <u>during descent to the sea floor</u>."

PERSPECTIVE ON NATURAL RADIOACTIVITY

A rational approach to placing the severity of potential hazard in perspective is to relate it to that due to naturally occurring radioactivity.

Nature has placed considerable quantities of toxic and radioactive material in seawater, including such radionuclides as Uranium (10^{-3} ppm), Radium (10^{-10} ppm) and Potassium-40 (.05 ppm). If we consider only the seawater column roughly defined by the Farallon dumpsite (10,000 km^2, 1.0 km deep) we have defined a volume of 10^{13} cubic meters. Considering only the Radium content, we would expect a total inventory in this volume of 1000 grams of this naturally occurring radionuclide. Via ingestion pathways (which are the predominant route for human exposure in this case), this amount of Radium is equivalent in toxicity to, for example, 3 tons (170,000 ci) of Plutonium-239.

A similar perspective is obtained from considering the naturally occurring Radium present in the sediments (10,000 km^2 x 2 meter depth) contained in the Farallon dumpsite. The radium content in these sediments amounts to 6700 grams. This quantity of radium is equivalent in ingestion toxicity to 26.8 tons (1,675,000 Ci) of Pu-239.

According to WASH-734,[1] the total inventory of all radionuclides in the Farallon dumpsite is estimated to be 14,000 Ci, of which only 30 Ci consists of long lived alpha activity. If all 30 curies were Plutonium-239 (a very pessimistic assumption) or even if all 14,000 curies were Plutonium (a completely absurd assumption), the hazard would still be trivial compared to the naturally occurring Radium in the same area. It should also be noted that the Radium follows roughly the same exposure pathways and behaves similarly to the transuranic elements toxicologically and in its potential for bioaccumulation.

The column of water defined by the Farallon dumpsite (10^4 km^3) contains quantities of naturally occurring radionuclides which make the radioactive waste trivial in comparison, from either a radioactivity or hazard viewpoint. Table I lists these natural radionuclides, along with their mass, radioactivity and Toxicity Index. The Toxicity Index is a simple measure of potential hazard expressed as the volume of water required to dilute a given quantity of a toxic or radioactive material to acceptable public drinking water standards.

Table I Some Naturally Occurring Radionuclides in 10,000 km^3 of Average Seawater (Estimated Volume of Farallon dumpsite water column)

Radionuclide	Mass (Tons)	Radioactivity (ci)	Toxicity Index (m^3)
Uranium-238	10^4	3×10^3	3×10^6
Radium-226	10^{-3}	10^3	1×10^1
Potassium-40	5 x 103	3×10^6	3×10^8(a)

(a) Based on computed dose factor for K-40 relative to K-42.

Further, it should be noted that the toxicity of the naturally occurring radionuclides is orders of magnitude lower than that of certain naturally-occurring, nonradioactive toxic components of seawater. Table II presents the Toxicity Index for several of these nonradioactive toxic constitutents,together with the Uranium and Radium for comparison. Thus, the waste toxicity is insignificant in comparison with the toxicity of the local natural radioactivity; and this, in turn, is insignificant compared to the nonradioactive toxic material. (Also, note that the toxicity of these nonradioactive materials will persist forever.)

Table II Total Toxicity of Seawater Components in 10,000 km^3

Element	Mass (grams)	Toxicity Index* (m^3)
Selenium	4×10^{10}	4×10^{12}
Arsenic	3×10^{10}	6×10^{11}
Lead	4×10^{10}	8×10^{11}
Barium	5×10^{10}	5×10^{11}
Mercury	3×10^{8}	2×10^{11}
Silver	1.5×10^{9}	3×10^{10}
Uranium	1×10^{10}	3×10^{6}
Radium	1×10^{3}	1×10^{10}

*Computed as the volume of water required to dilute inventory to EPA drinking water standards.

RADIOACTIVITY IN FISH

Another insight on relative hazard may be gained from a comparison with the natural radioactivity of fish. According to Bennett,[5] fish in the average San Francisco diet contain a Radium-226 concentration of 0.26 pci/kg. (Fish in the average New York City diet contain 0.89 pci/kg.) This is simply due to the natural occurrence of Radium in oceanic waters.

Comparing MPC's, it can be shown that one picocurie (pci) of Radium-226 is equivalent in ingestion toxicity to 170 picocuries of Plutonium-239. Therefore, the "hazard" due to eating fish in San Francisco, simply due to its natural Radium-226 content, is equivalent to its having a plutonium "burden" of 44 pci/kg.

The maximum value for plutonium content of fish at the Farallon site in the muscle tissue or edible flesh that was actually observed and measured was 0.008 ± 0.003 pci/kg.[6] From this perspective it can be concluded that the maximum hazard from plutonium in fish from the Farallon dumpsite is a factor of 5500 less than that due to naturally occurring radium in the same fish. Note again that radium is just one of many naturally occurring radionuclides in the marine environment.

To place the measurement in further perspective, consider the natural radium content of other food products. Since, curie for curie, radium is 170 times more toxic than plutonium via ingestion, the equivalent plutonium toxicities of everyday food products can be easily computed. For example, Brazil nuts, due to their natural radium content, have an equivalent plutonium concentration of 2,400,000 pCi/kg. Placed in this perspective, a one ounce serving of Brazil nuts is equivalent in terms of radiotoxicity to the plutonium content of 18 million pounds of fish as sampled at the Farallons. The consumption of Brazil nuts should not be a particular hazard when done in moderation. It is likely that the hazard due to their caloric content would exceed that due to their radioactivity. Other foods have less radiotoxicity than Brazil nuts, but at the same time, are far more radiotoxic than Farallon fish. Compared to the .008 pCi/kg of measured plutonium in fish muscle, the following plutonium equivalents (based upon radium content) are interesting:

Peanut Butter	20,000 pCi/kg
Grapes	5,000 pCi/kg
Peas	1,000 pCi/kg
Carrots	1,000 pCi/kg
Bread	500 pCi/kg
Potatoes	200 pCi/kg
Beef	140 pCi/kg
Pork	140 pCi/kg
Cheese/eggs	170 pCi/kg
Fish (average San Francisco diet)	44 pCi/kg

GENERAL CONSIDERATIONS

Using conservative (pessimistic) assumptions, it can be calculated that if all the world's electricity were generated only by nuclear power for the next 100 years (10^8 MW_e-Yr) and if all of the resultant waste Plutonium-239 were uniformly distributed throughout the world's oceans, the net ingestion radiotoxicity of the seawater would increase by a factor of only 8×10^{-10} above that due to the existing Radium-226. It might also be noted that although the plutonium would decay very slowly (half-life 24,000 years) the radium level would remain stable for billions of years since it would remain in secular equilibrium with the oceanic uranium content. Since oceanic radium contributes only a minor fraction (1.0%) of man's background radiation dose, it might be concluded that, even under the most pessimistic conditions, the marginal added dose due to oceanic plutonium would be negligible under any reasonable condition. This is particularly true considering that radium concentrates in biological foodchains to a somewhat greater extent than does plutonium.

An assessment by B. L. Cohen of potential consequences of ocean dumping of stabilized high-level radioactive waste also indicates resultant dose levels well below background.[7] These calculations are based on an assumption of uniform distribution of dissolved radioactivity. The question of whether such an assumption is indeed conservative has been studied. Considering the phenomena involved, it is apparent that if distribution of dissolved radioactivity were not uniform, then it would be above average in some areas and below in others. The high concentration areas would necesarily be in the vicinity of the "source" or dumping area. If we are at all prudent, these dump sites would be selected to be remote from shorelines, populations, or areas of significant biological activity. If this is the case, it follows that effects on man would be well below those which could result if the distribution were uniform. It would, therefore, appear that an assumption of uniform mixing reflects a "worst case" and is indeed conservative.

CONCLUSION

From our assessment of potential risk due to oceanic disposal of radioactive waste, it can be concluded that the widespread concern over this practice is unwarranted. A subsequent study by the GAO confirms this conclusion.[8] It is certainly unfortunate that ocean dumping has attained such an adverse political image since, from an overall public health standpoint, it appears to be one of the safest alternatives for radioactive waste disposal. It certainly deserves serious, objective, and intelligently designed investigation.

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