The relation of benthic communities to radioactive waste disposal in the deep sea

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Abstract

One of the most difficult problem areas coupled with utilization of nuclear energy is radioactive waste disposal. A potentially realistic solution for high-level waste disposal is burial beneath the deep sea, where containment on the order of 10^6 years may be attainable. Several practical criteria suggest that mid-tectonic plate regions under central oceanic gyres are most promising as disposal sites.

While the intention is to completely isolate wastes from the biosphere, it is essential to learn what would be the result of accidental exposure of the benthos. Our modest available knowledge allows establishment of some hypotheses. Low benthic standing crop in conjunction with low turnover rates suggests that any effects other than possible mortality will be relatively slow. High diversity dependent on extreme environmental stability suggests both sensitivity to novel environmental distrubances and especially slow recovery rates. The cosmopolitan distribution of higher taxa within depth zones makes unlikely the disturbance of more than a small fraction of the total range of a basic community type. Species also seem to have broad distributions, minimizing the probability of extinctions.

Of equal importance is the question whether the deep benthic fauna would accelerate the return of radionuclides to man. While there exists a special epibenthic pelagic fauna, including taxa that feed on the benthos, which should constitute the first link in a food chain leading back up the water column, this pathway is likely to be tenuous. Horizontal mobility is probably also a minor pathway. Of greater concern is the possible metabolic solubilization of undesirable substances allowing transport by currents. However, other biological processes may cause precipitation of dissolved substances. Bioturbation will prolong exposure of deposited substances to the water interface, although it will also accelerate initial burial of particles settling from above.

Discussion

One of the most severe problems for mankind in the last quarter of the twentieth century will be a shortage of usable energy. It is probable that the solution to this problem will involve utilization of as many different sources as possible. Unfortunately, each type has disadvantages which must be tolerated or overcome. The benefit/cost dichotomy is particularly striking with nuclear power. This is a source of abundant, inexpensive energy, but because of its radioactivity, it is extremely dangerous to organisms unless carefully controlled.

As everyone knows from recent publicity, this disadvantage of nuclear energy has become critical because of the ever increasing amount of radioactive wastes. They must be isolated from the biosphere until their natural radioactive decay renders them harmless, but with some high-level wastes such as plutonium 239 or cesium 135, the half life may be hundreds of thousands of years. With these, the task of safe storage becomes formidable. Currently, solution to the problem of waste disposal is for the most part being held in abeyance by placing wastes in temporary storage, but clearly the ever increasing volume of these materials demands that a long-term solution be found. Many waste disposal techniques have been explored, including terrestrial geological respositories (salt beds and domes, shales, granites), polar ice caps, space, and the oceans.

Ocean disposal of substances has traditionally been popular. It has been inexpensive, and the oceans are such a vast sink that dilution renders most substances harmless until they decompose. However, for substances that degrade slowly, the oceans may be a poor receptacle. Even here, refractory substances may build up to unacceptable concentrations, particularly at the rate of supply that is sometimes achieved by fast-paced industrial societies. Nor is containment easy. Seawater is caustic to most substances, and oceanic circulation will transport undesirable materials from the most inaccessible regions. Because of such considerations, ocean disposal of dangerous substances has become increasingly unacceptable.

How then, is it possible to consider ocean disposal of high-level radioactive wastes seriously? Properly done, it may be possible to place radioactive wastes in parts of the seabed in a way that insures containment for acceptably long periods of time. This possibility is currently being studied actively in the United States by the Seabed Disposal Project, consisting of marine scientists from several academic institutions in cooperation with the Sandia Corporation, a contractor of the United States Department of Energy (1).

Several oceanic alternatives have been suggested, but the one receiving the project's most serious consideration is that properly packaged wastes be buried in the sediment of the ocean floor. Many criteria contribute to the determination of what geographic portion of the seabed might be most suitable: high geological stability, low biological productivity, minimal economic value, remoteness from mankind, adequately sized area, good climate, and possession of an embedding medium with excellent retention properties. On the basis of these criteria, the general class of sites currently deemed most promising are areas in the middle of geological plates and under central oceanic current gyres.

One such area that has received particularly intense study as a "type locality" is in the central North Pacific, approximately 900 km north of Hawaii. Here the bottom is a well oxidized red clay sprinkled with manganese nodules at a water depth of 5.5–6.0 km. Such clays have two properties that make them attractive from the present point of view.

First, they are so fine grained that their permeability to interstitial water is low. As a result, convective processes are essentially eliminated, and water movement is restricted to diffusion. Under these conditions, a dissolved ion, such as chloride, would require 10^6 years to move to the sediment surface from a burial depth of 100 meters (assuming a diffusion coefficient of 3×10^{-6} cm²/sec, which is an average value for deep-sea sediments) (2).

Second, such fine grains have very large surface areas per unit volume, enhancing the adsorbtion of metal ions onto their surfaces. This effect reduces the migration of heavy metals to rates considerably lower than would be the case if they were in solution. For example, preliminary evidence suggests that it would take strontium-90 30–250×10^6 years to migrate 100 meters (2).

Such slow rates of movement give hope that seabed emplacement is a realistic possibility for safe containment of high-level wastes with long half lives. However, these data constitute only a bare beginning of what must be learned before the potential of seabed emplacement can be adequately evaluated. For example, heat from the decaying wastes might reduce the containment properties of the sediment and provide a driving force for convective ion migration. Furthermore, disturbance resulting from emplacement might offer a channel for more rapid movement (3).

Considerable attention must also be given to biological aspects of the problem, because although the intention would be to contain the wastes so well that they would not reach the biosphere while they were hazardous, it would be prudent to recognize the possibility of an occasional accident which would release dangerous radionuclides into the ocean system. Concern about the interaction of radionuclides and the biosphere fall into two intergrading questions. To what extent will radionuclides damage the biosphere, and to what extent will organisms enhance the mobilization of those substances and thus speed their return to man? The following discussion will limit itself to a consideration of potential interactions involving benthic communities, which would constitute the first assemblage of organisms coming into contact with wastes leaking from or on the bottom (4). Our knowledge of these deep benthic communities is far from complete, but what is known allows the construction of a series of predictions that may be tested by future studies.

The central piece of available data which is relevant to the question of damage or alteration of the deep-sea community involves species diversity. As is well known now, these communities display a very large variety of species in any single area (5). The only factor with which consistant correlation has been made is the extremely high stability of environmental parameters (6). Although the precise way in which it exerts its influence is still a matter of much debate, environmental stability should minimize the likelihood of extinctions, thereby allowing community diversity to build up to high levels. Corollary to this is the high probability that deep-sea organisms are intolerant to environmental change. This prediction is based on the general body of observation that selective pressure does not cause evolutionary adaptation to conditions to which a species is not exposed. If this is the case, then one would expect the community to be quite sensitive to such novel environmental fluctuations as might be caused by man's activities. One would predict that the deep-sea community will suffer far more significant changes for a given disturbance than a comparable shallow-water one in which environmental fluctuation plays a dominant role.

Once the community is disturbed, its recovery is likely to be slow. This conclusion is based on what little is known of activity rates in the deep sea. Total community respiration per unit area of the bottom, as measured *in situ* with bell jar and oxygen electrode, is two to three orders of magnitude lower in the abyss than in shallow water (7, 8). Interestingly, a preliminary analysis of these same data on uptake per unit of wet-weight biomass of macrofauna shows no significant difference with depth, although in a different study, individual fish from bathyal depths used less oxygen per unit weight than did shallow-water counterparts (9).

Bacterial activity, as determined through substrate utilization under conditions where temperature and pressure were not allowed to deviate from that of the environment, is also lower in the deep sea than at lesser depths (10). However, scattered measurements by some other workers yield higher uptakes than the above (11, 12), so that the pattern of deep-sea microbial activity should not be considered settled.

There are also fragmentary data suggesting that metazoan growth rates are significantly lower in the deep sea. The tiny bivalve *Tindaria calistiformis* was measured to reach 100 years in age and not achieve sexual maturity until about fifty years (13). Other growth rates have been less extreme. The polychaetes *Capitella* sp. and *Heteromastus* sp. and the tunicate *Polycarpa delta* reached adulthood after less than 26 months in a recolinization experiment at 1760 meters depth (14). In the same study, the bivalve *Nucula cancellata* was nearly mature (Grassle, pers. comm.). Woodboring xylophagan bivalves had reached sexual maturity on wooden settling plates that had been in place for 104 days at 1830 meters depth (15). Although these last measurements show less extreme growth rates than for *Tindaria,* they are still lower than what one would find in shallow water.

Finally, the direct measurements of community recovery at 1760 meters in boxes of azoic sediment show rates that are orders of magnitude lower than in shallow water (14). These experiments do not measure the same sort of disturbance that would concern us in radioactive waste disposal, but they do give an indication of the community's lower resilience.

Soft bottoms of the oceanic abyss cover vast portions of the globe. Biogeographic studies have revealed that at a given depth, the fauna is remarkably similar throughout, at least with regard to supraspecific taxa. That is, genera and higher categories tend to be cosmopolitan. At abyssal depths, even species are likely to have ranges throughout single ocean basins, and frequently beyond. Thus, disturbance of a small area (which because of the vastness of oceans can be quite large by terrestrial standards) will affect only a small portion of the geographic distribution of the total community, or for the most part, even of individual species. If most species are indeed widely distributed, such disturbances are unlikely to result in species extinctions. Very little is known, however, about the zoogeography of rarer (i.e. most) deep-sea species, and they may well have much narrower geographic ranges. Disturbance of many small areas or of any large one is clearly a serious matter for rare and common species alike, and such considerations should play an important part in decisions about the geographic distribution of disposal sites.

So far we have discussed the effect of accidental leakage on the local community, and have predicted that the community would be damaged, that recovery would be slow, but that if it were localized, the damage might not be irreparable. The next task is to discuss the extent to which organisms might affect the movement of substances away from the site of leakage.

While very little is known about the radiochemistry of deep-water organisms (16), the ability of organisms in general to incorporate and sometimes concentrate radionuclides is well established. In order to minimize the rate of biogenic spread of such substances to other portions of the biosphere, particularly back to man, it would be desirable to place wastes where they would be exposed to as little biological activity as possible. The deep benthos under central gyre waters is an outstanding example of such conditions.

Surface waters in central gyres are regions of minimal oceanic primary productivity, and much of what nutrient substances begin to settle down through the several kilometer water column never reaches the bottom because of the cumulative attrition through such great depths. As a result, the deep benthos of central gyre waters displays the lowest standing crop of any major environment in the ocean. For macrofauna, faunal density is 30–250 individuals per square meter, which is two or three orders of magnitude less than what can be found in shallow waters (17, 18). Individual deep-sea benthic organisms tend to be smaller than those of shallow water (19) and therefore the difference in biomass between deep and shallow benthic communities is even greater. As already seen, weight-specific activity rates are also lower in the deep sea, further minimizing the magnitude of biogenic movement of materials from the bottom.

While activity rates may be low in the deep sea, there do indeed exist pathways which will move substances from the bottom. Studies with traps and baited cameras (20, 21, 22) have made us increasingly aware of a swimming fauna that is dependent on the bottom for at least a portion its existence. Some fish associated primarily with the bottom, however, have been caught surprisingly far up in the water column (23). The magnitude of this pathway for upward movement is unknown, although it is likely to be small, particularly at abyssal depths. Obviously, it would be desirable to select a disposal site which supports as few vertically migrating scavengers as possible.

A greater risk may accrue from the role of the benthic community in liberating substances into the water as soluble products of the metabolic activities. To the extent that any radionuclide is amenable to involvement in such pathways, it is available for worldwide transport via oceanic circulation. On the other hand, other metabolic pathways might equally well immobilize some radionuclides.

There is one other biological process which will have a significant effect on movement of radionuclides: bioturbation. In their daily activities, organisms mix the bottom sediment and circulate the interstitial water. In this way substances deposited at the surface will be mixed into the bottom and buried. Studies on the distribution of plutonium indicate that a substance deposited on the surface during the last few decades has already been mixed to a depth of over 10 cm (24). On the other hand, this same activity insures that any given particle will be returned to the surface over and over again thus prolonging the period during which it might be taken into the water column for transport. Thus, any predictions on the effect of the fauna on radionuclide movement are clearly equivocal. Biological processes exist which could enhance movement as well as retard it, and there is no *a priori* way of guaranteeing which will dominate.

The above discussion has outlined a variety of predictions on what might be the local biological consequences of accidental leakage of substances from nuclear wastes deposited in the seabed. Clearly these predictions must be regarded as tentative. Even leaving aside issues involving radionuclides, our knowledge of basic properties of deep-sea communities is disappointingly scant. Much more must be learned before we can make a statement about the outcome of deep-seabed nuclear waste disposal with a sufficient degree of confidence.

The study of deep-sea ecology is a rapidly expanding field, and there is much that can be done to improve significantly our understanding of deep-sea communities. It is unlikely, however, that we will ever understand the components of community structure and dynamics well enough to be able to predictively model in detail the outcome of the sort of perturbation that is under discussion here. Community processes are too complex to allow prediction through simple addition of component processes. This is not even possible in shallow water, where measurements are considerably easier.

Nor will it be possible to do sufficient laboratory studies on the reaction of various deep-sea organisms to the different radionuclides. The ability to maintain such sensitive organisms under adequately natural conditions does not exist, and this situation is unlikely to improve sufficiently in time to do much good. Data from shallow-water organisms will only have limited applicability to organisms from the abyss.

The situation leaves only one realistic way to evaluate the risks of leakage at the seabed. Properly conceived, field simulations of leakage could integrate the critical processes in a way that would yield the most urgently needed data. For example, they could reveal the local impact on the community, as well as the rates of radionuclide transfer within and out of the local system. The requisite manipulations and sampling techniques are fully within the realm of current technology. Until such experiments are performed, a proper cost-benefit analysis of seabed emplacement of radioactive wastes is impossible.

References

1. C. D. Hollister. 1977. The seabed option. Oceanus 20, 18–25.
2. G. R. Heath. 1977. Barriers to radioactive waste migration. Oceanus 20, 26–30.
3. A. J. Silva. 1977. Physical processes in deep-sea clays. Oceanus 20, 31–40.
4. R. R. Hessler, and P. A. Jumars. 1977. Abyssal communities and radioactive waste disposal. Oceanus 20, 41–46.
5. R. R. Hessler and H. L. Sanders. 1967. Faunal diversity in the deep sea. Deep-Sea Res. 14, 65–78.

6. H. L. Sanders. 1968. Marine benthic diversity: a comparative study. Amer. Natur. 102, 243–282.
7. K. L. Smith, Jr. and J. M. Teal. 1973. Deep-sea benthic community respiration: an *in situ* study at 1850 meters. Sci. 179, 282–283.
8. K. L. Smith, Jr. 1978. Benthic community respiration in the N. W. Atlantic: *in situ* measurements from 40 to 5200 meters. Mar. Biol. 47, 337–347.
9. K. L. Smith, Jr. and R. R. Hessler. 1974. Respiration of benthopelagic fishes: *in situ* measurements at 1230 meters. Sci. 184, 72–73.
10. H. J. Jannasch, C. O. Wirsen and C. D. Taylor. 1976. Undecompressed microbial populations from the deep sea. Appl. & Environ. Microbiol. 32, 360–367.
11. J. R. Schwarz, A. A. Yayanos and R. R. Colwell. 1976. Metabolic activities of the intestinal microflora of a deep-sea invertebrate. Appl. & Environ. Microbiol. 31, 46–48.
12. H. Seki, E. Wada, I. Koike and A. Hattori. 1974. Evidence of high organotrophic potentiality of bacteria in the deep ocean. Mar. Biol. 26, 1–4.
13. K. K. Turekian, J. K. Cochran, D. P. Kharkar, R. M. Cerrato, J. R. Vaisnys, H. L. Sanders, J. F. Grassle and J. A. Allen. 1975. The slow growth rate of a deep-sea clam determined by ^{228}Ra chronology. Proc. Natl. Acad. Sci. USA. 72, 2829–2832.
14. J. F. Grassle. 1977. Slow recolonization of deep-sea sediment. Nature 265, 618–619.
15. R. D. Turner. 1973. Wood-boring bivalves, opportunistic species in the deep sea. Sci. 180, 1377–1379.
16. A. G. Carey, Jr. 1972. Zinc-65 in benthic invertebrates off the Oregon coast. In: A. T. Pruter and D. L. Alverson (editors), The Columbia River Estuary and Adjacent Ocean Waters. Univ. Washington Press, Seattle, pp. 833–842.
17. H. L. Sanders, R. R. Hessler and G. R. Hampson. 1965. An introduction to the study of deep-sea benthic faunal assemblages along the Gay Head-Bermuda transect. Deep-Sea Res. 12, 845–867.
18. R. R. Hessler and P. A. Jumars. 1974. Abyssal community analysis from replicate box cores in the central North Pacific. Deep-Sea Res. 21, 185–209.
19. H. Thiel. 1975. The size structure of the deep-sea benthos. Int. Rev. ges. Hydrobiol. 60, 575–606.
20. J. D. Isaacs. 1969. The nature of oceanic life. Scient. Amer. 221, 146–162.
21. E. Schulenberger and R. R. Hessler. 1974. Scavenging abyssal benthic amphipods trapped under oligotrophic central North Pacific gyre waters. Mar. Biol. 16, 1–12.
22. J. D. Isaacs and R. A. Schwartzlose. 1975. Active animals of the deep-sea floor. Scient. Amer. 233, 84–91.
23. R. L. Haedrich and N. R. Henderson. 1974. Pelagic food of *Coryphaenoides armatus*, a deep benthic rattail. Deep-Sea Res. 21, 739–744.
24. V. T. Bowen, H. D. Livingston and J. C. Burke. 1976. Distribution of transuranium nuclides in sediment and biota of the North Atlantic Ocean. In Transuranium Nuclides in the Environment. Int. Atomic Energy Agency, SM-199/96. Vienna, pp. 107–120.