Burial of Radioactive Waste under the Seabed

Although the notion troubles some environmentalists, the disposing of nuclear refuse within oceanic sediments merits consideration

by Charles D. Hollister and Steven Nadis

On the floor of the deep oceans, poised in the middle of the larger tectonic plates, lie vast mudflats that might appear, at first glance, to constitute some of the least valuable real estate on the planet. The rocky crust underlying these "abyssal plains" is blanketed by a sedimentary layer, hundreds of meters thick, composed of clays that resemble dark chocolate and have the consistency of peanut butter. Bereft of plant life and sparsely populated with fauna, these regions are relatively unproductive from a biological standpoint and largely devoid of mineral wealth.

Yet they may prove to be of tremendous worth, offering a solution to two problems that have bedeviled humankind since the dawn of the nuclear age: these neglected suboceanic formations might provide a permanent resting place for high-level radioactive wastes and a burial ground for the radioactive materials removed from nuclear bombs. Although the disposal of radioactive wastes and the sequestering of material from nuclear weapons pose different challenges and exigencies, the two tasks could have a common solution: burial below the seabed.

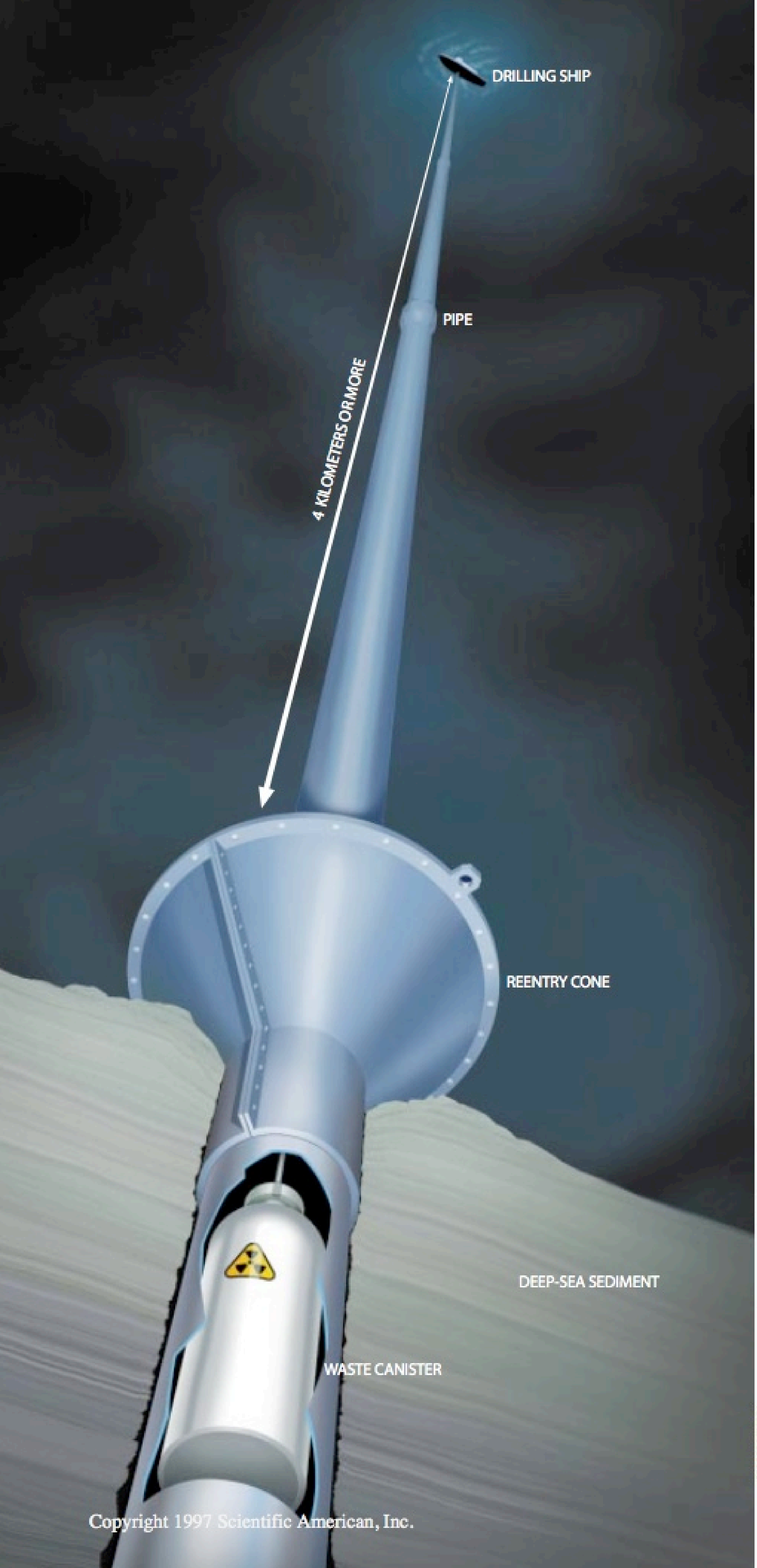
High-level radioactive wastes—in the form of spent fuel rods packed into pools at commercial nuclear power plants or as toxic slurries housed in tanks and drums at various facilities built for the production of nuclear weapons—have been accumulating for more than half a century, with no permanent disposal method yet demonstrated. For instance, in the U.S. there are now more than 30,000 metric tons of spent fuel stored at nuclear power plants, and the amount grows by about 2,000 metric tons a year. With the nuclear waste repository under development at Yucca Mountain, Nev., now mired in controversy and not expected to open before 2015 at the earliest [see "Can Nuclear Waste Be Stored Safely at Yucca Mountain?" by Chris G. Whipple; Scientific American, June 1996], pressure is mounting to put this material somewhere.

The disposition of excess plutonium and uranium taken from decommissioned nuclear weapons is an even more pressing issue, given the crisis that might ensue if such material were to fall into the wrong hands. The U.S. and Russia have each accumulated more than 100 metric tons of weapons-grade plutonium, and each country should have at least 50 metric tons of excess plutonium, plus hundreds of tons of highly enriched uranium, left over from dismantled nuclear weapons. Preventing terrorists or "rogue states" from acquiring this material is, obviously, a grave concern, given that a metric ton of plutonium could be used to make hundreds of warheads, the precise number depending on the size of the bomb and the ingenuity of the designer.

The Clinton administration has endorsed two separate methods for ridding the nation of this dangerous legacy. Both entail significant technical, economic and political uncertainties. One scheme calls for the surplus weapons plutonium to be mixed with radioactive wastes and molded into a special type of glass (a process called vitrification) or, perhaps, ceramic for subsequent burial at a site yet to be chosen. The glass or ceramic would immobilize the radioactive atoms (to prevent them from seeping into the surrounding environment) and would make deliberate extraction of the plutonium difficult. But the matrix material does not shield against the radiation, so vitrified wastes would still remain quite hazardous before disposal. Moving ahead with vitrification in the U.S. has required construction of a new processing plant, situated near Aiken, S.C. Assuming this facility performs at its intended capacity, each day it will produce just one modest cylinder of glass containing about 20 or so kilograms of plutonium. The projected cost is $1.4 million for each of these glassy logs. And after that considerable expense and effort, someone still has to dispose of the highly radioactive products of this elaborate factory.

The second option would be to combine the recovered plutonium with uranium oxide to create a "mixed oxide" fuel for commercial reactors—although most nuclear power plants in the U.S. would require substantial modification before they could run on such a blend. This alternative measure of consuming mixed-oxide fuels at commercial power plants is technically feasible but nonetheless controversial. Such activities

STEEL PIPE, lowered from a ship on the surface, would be used to drill holes in the deep-sea muds and, later, convey nuclear waste containers for permanent burial—according to the plan envisioned. Mud pumped into the borehole would then seal the nuclear refuse within the clay-rich undersea formation, effectively isolating the radioactive materials.



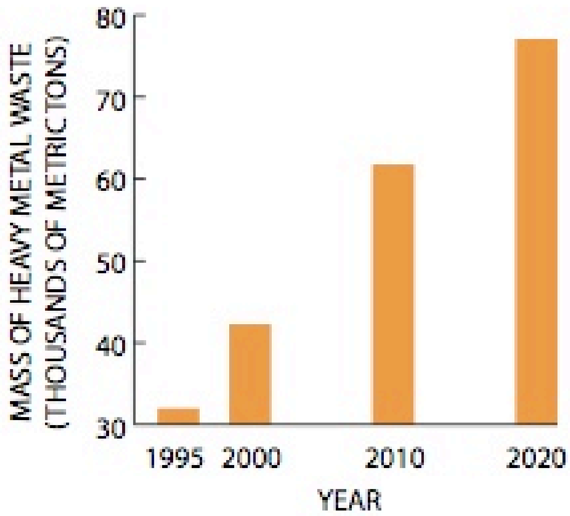
GEORGE RETSECK

would blur the traditional separation between military and civilian nuclear programs and demand heightened security, particularly at mixed-oxide fabrication plants (of which none currently exist in the U.S.), where material suitable for building a nuclear bomb might be stolen. And in the end, mixed-oxide reactors would produce other types of radioactive waste. Hence, neither of the schemes planned for disposing of material from nuclear weapons is entirely satisfactory.

Pressing Problems

For the past 15 years, the operators of nuclear power plants in the U.S. have been paying the Department of Energy in advance for the eventual storage or disposal of their wastes. Even though there is no place yet available to put this radioactive refuse, the courts have ordered the DOE to meet its contractual obligations and begin accepting expended fuel rods from nuclear utilities this year. It is not at all clear what the DOE will do with these materials. One plan supported by the U.S. Senate is to build a temporary storage facility in Nevada near the Yucca Mountain site, but President Bill Clinton opposes this stopgap measure. In any event, the mounting pressure to take some action increases the likelihood of hasty, ill-considered judgments. The best course, in our opinion, would be to do nothing too drastic for now; immediate action should be limited to putting the spent fuel currently residing in cooling ponds into dry storage as needed and trying to stabilize the leaks in high-level-waste containers at weapons sites, while scientists and engineers thoroughly investigate all reasonable means for permanent disposal.

Although some ambitious thinkers have suggested that nuclear waste might one day be launched into space and from there cast into the sun, most people who have studied the problem agree that safety and economy demand that the waste be put permanently underground. Curiously, the search for a suitable nuclear graveyard has been confined almost exclusively to sites on the continents, despite the fact that geologic formations below the world's oceans, which cover some 70 percent of the planet's surface, may offer even greater potential. The disposal of nuclear weapons and wastes below the seabed should not be confused with disposal in the deep-



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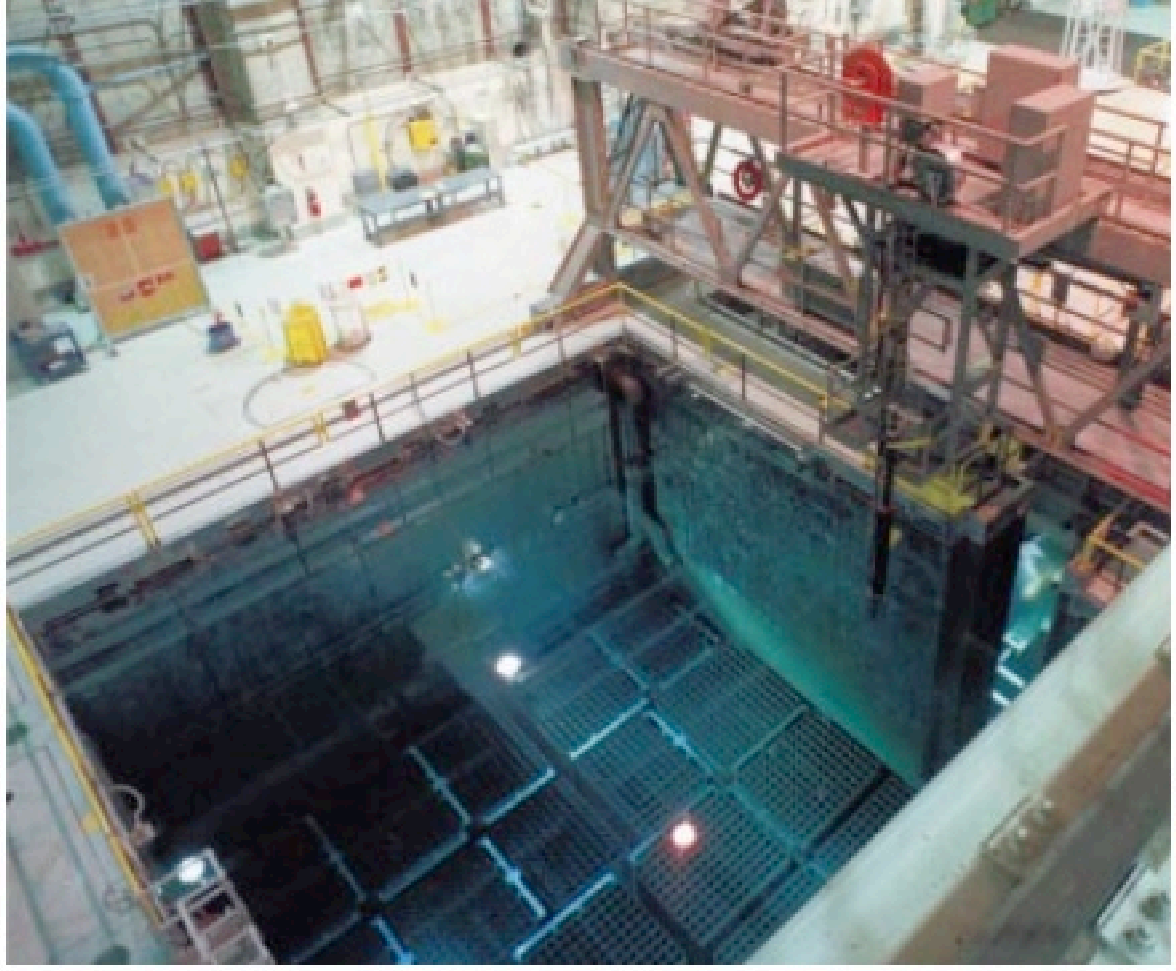

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SPENT REACTOR FUEL will more than double in quantity in the U.S. by the year 2020, even if no new nuclear power plants are built, according to estimates of the Department of Energy (*graph*). Because no procedures for permanent disposal are yet established, the spent nuclear fuel is now stored temporarily at the reactor sites, often in cooling ponds (*above*).

ocean trenches formed at the juncture of two tectonic plates—a risky proposition that would involve depositing waste canisters into some of the most geologically unpredictable places on the earth, with great uncertainty as to where the material would finally reside.

Subseabed disposal, in contrast, would utilize some of the world's most stable and predictable terrain, with radioactive waste or nuclear materials from warheads "surgically" implanted in the middle of oceanic tectonic plates. Selecting sites for disposal that are far from plate boundaries would minimize chances of disruption by volcanoes, earthquakes, crustal shifts and other seismic activity. Many studies by marine scientists have identified broad zones in the Atlantic and Pacific that have remained geologically inert for tens of millions of years. What is more, the clay-rich muds that would entomb the radioactive materials have intrinsically favorable characteristics: low permeability to water, a high adsorption capacity for these dangerous elements and a natural plasticity that enables the ooze to seal up any cracks or rifts that might develop around a waste container. So the exact form of the wastes (for example, whether they are vitrified or not) does not affect the feasibility of this approach. No geologic formations on land are known to offer all these favorable properties.

It is also important to note that disposal would not be in the oceans, per se, but rather in the sediments below. Placing nuclear waste canisters hundreds of meters underneath the floor of the deep ocean (which is, itself, some five or so kilometers below the sea surface) could be accomplished using standard deep-sea drilling techniques. The next step—backfilling to seal and pack the boreholes—is also a routine practice. This technology has proved itself through decades of use by the petroleum industry to probe the continental shelves and, more recently, by members of the Ocean Drilling Program, an international consortium of scientific researchers, to explore deeper locales.

We envision a specialized team of drillers creating boreholes in the abyssal muds and clays at carefully selected locations. These cylindrical shafts, some tens to hundreds of meters deep, would probably be spaced several hundred meters apart to allow for easy maneuvering. Individual canisters, housing plutonium or other radioactive wastes, would then be lowered by cable into the holes. The canisters would be stacked vertically but separated by 20 or more meters of mud, which could be pumped into the hole after each canister was emplaced.

As is the case for disposal within Yucca Mountain, the waste canisters themselves would last a few thousand years at most. Under the seabed, however, the muddy clays, which cling tenaciously to plutonium and many other radioactive elements, would prevent these substances from seeping into the waters above. Experiments conducted as part of an international research program concluded that plutonium (and other transuranic elements) buried in the clays would not migrate more than a few meters from a breached canister after even 100,000 years. The rates of migration for uranium and some other radioactive waste elements need yet to be properly determined. Still, their burial several tens to 100 meters or more into the sediments would most likely buy enough time for the radioactivity of all the waste either to decay or to dissipate to levels below those found naturally in seawater.

The Seabed Working Group, as the now defunct research program was called, consisted of 200 investigators from 10 countries. Led by the U.S. and sponsored by the Nuclear Energy Agency of the Organization for Economic Cooperation and Development, the project ran from 1976 to 1986 at a total cost of about $120 million. This program was an outgrowth of a smaller effort at Sandia National Laboratories that was initiated in response to a suggestion by one of the authors (Hollister), who conceived of the idea of subseabed disposal in 1973.

As part of the international program, scientists extracted core samples of the seabed and made preliminary environmental observations at about half a dozen sites in the northern Atlantic and Pacific oceans. The collected sediments showed an uninterrupted history of geologic tranquillity over the past 50 to 100 million years. And there is no reason to believe that these particular sites are extraordinary. On the contrary, thousands of cores from other midplate locations since examined as part of the Ocean Drilling Program indicate that the sediments that were studied originally are typical of the abyssal clays that cover nearly 20 percent of the earth. So one thing is clear: although other factors may militate against subseabed disposal, it will not be constrained by a lack of space.

Reviving an Old Idea

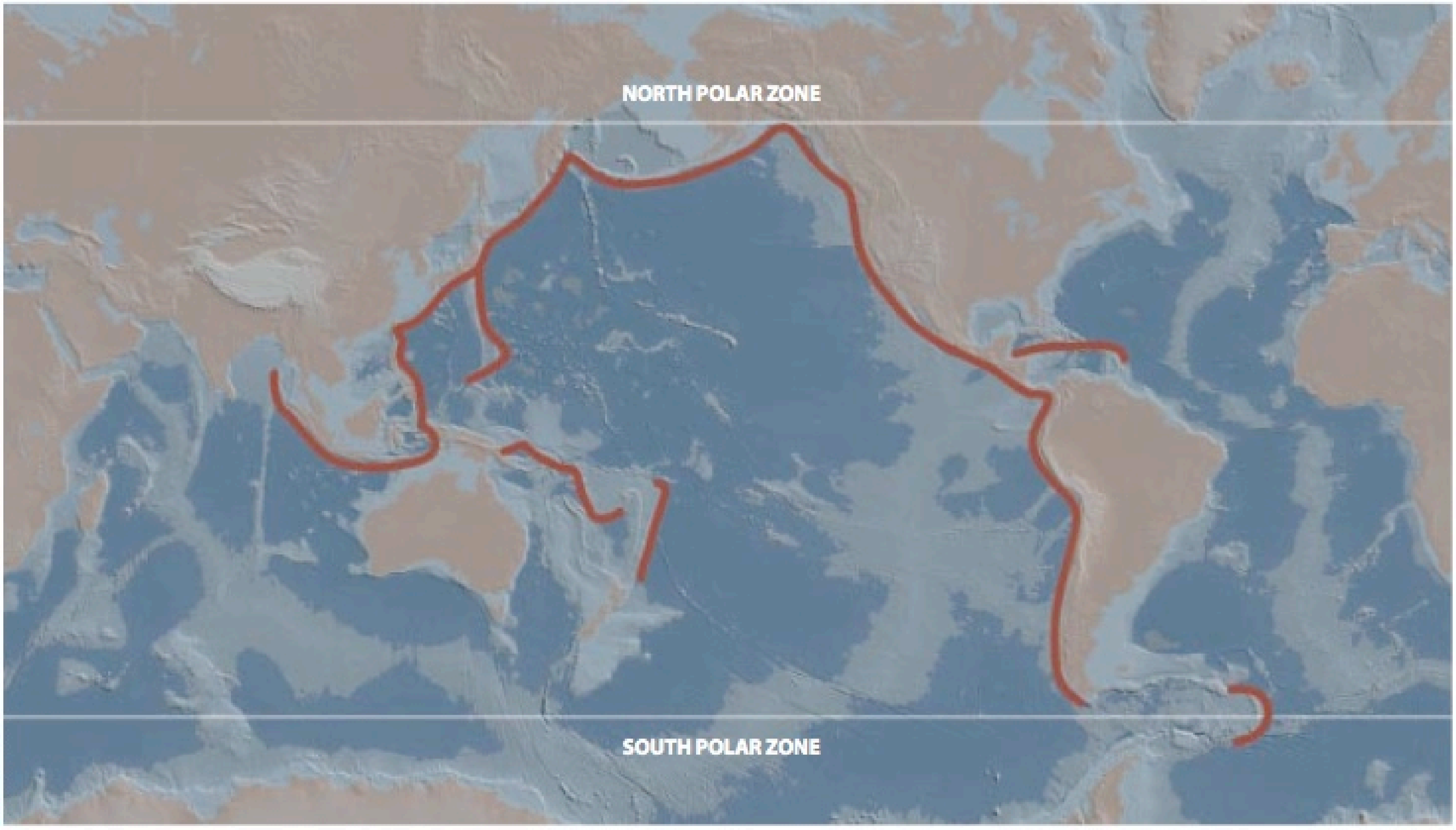
The Seabed Working Group concluded that although a substantial body of information supports the technical feasibility of the concept, further research "should be conducted before any attempt is made to use seabed disposal for high-level waste and spent fuel." Unfortunately, the additional investigations were never carried out because the U.S.—the principal financial backer of this research—cut off all funding in 1986 so that the nation could concentrate its efforts on land-based disposal. A year later the federal government elected to focus exclusively on developing a repository at Yucca Mountain—a shortsighted decision, especially in view of current doubts as to whether the facility will ever open. And even if the Yucca Mountain repository does become operational, it will not be able to handle all the high-level wastes from military and commercial sources that will have accumulated by the time of its inauguration, let alone the 2,000 or more tons of waste each year the nuclear industry will continue to churn out.

At some point, policymakers are going to have to face this reality and start exploring alternative sites and approaches. This view was precisely the conclusion expressed in a 1990 report from the National Academy of Sciences, which said that alternatives to mined geologic repositories, including subseabed disposal, should be pursued—a recommendation that remains absolutely valid today.

Fortunately, most of the experiments needed to assess more fully both the reliability and safety of subseabed disposal have been designed, and in many cases prototype equipment has already been built. One important experiment that remains to be done would be to test whether plutonium and other radioactive elements move through ocean-floor clays at the same rates measured in the laboratory. And more work is required

DANIEL HULSHIZER AP Photo

DEEP-SEA DRILL SHIP, such as the one used by scientists of the Ocean Drilling Program, could bore holes under the seabed, insert nuclear waste containers and seal them with mud.



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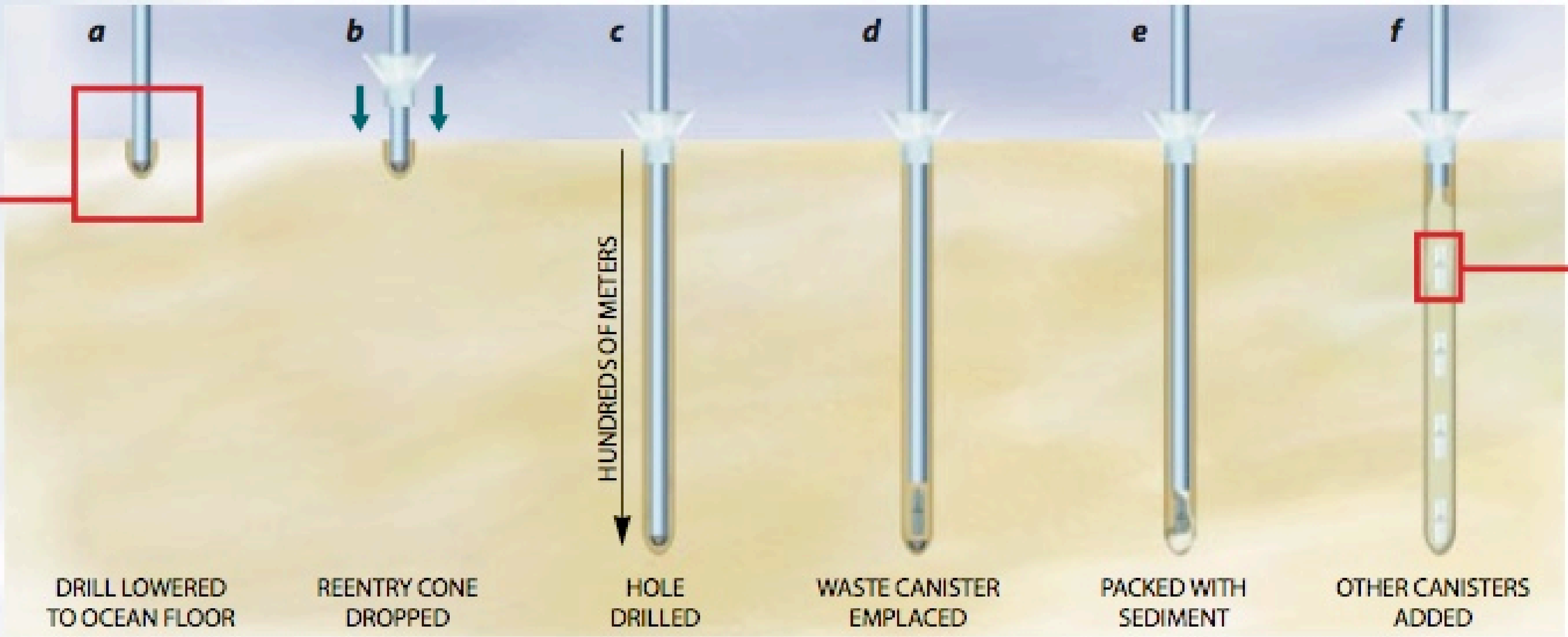
SEAFLOOR PROVINCES are not all suited for the disposal of nuclear wastes. In searching for candidate areas, scientists would probably eliminate places where the ocean floor is shallower than about four kilometers (*light blue*), because these areas coincide with plate-tectonic spreading centers and are often blanketed by inappropriate types of sediments. They would also rule out other regions of tectonic activity, such as plate collision (*red*) or vulcanism. Polar zones (latitudes higher than 60 degrees) would be discounted because marine sediments there commonly contain coarse rock fragments carried in by icebergs. Even after these and other broad areas (such as around continental rises, where the sediments are thick enough to house valuable quantities of oil or gas) are exempted, vast stretches of seafloor still offer ample possibilities for burying nuclear wastes (*dark blue*).



to learn how the heat given off by fuel rods (caused by the rapid decay of various products of nuclear fission) would affect surrounding clays.

Research is also needed to determine the potential for disturbing the ecology of the ocean floor and the waters above. At present, the evidence suggests that mobile, multicellular life-forms inhabit only the top meter or so of the abyssal clays. Below a meter, there appear to be no organisms capable of transporting radioactive substances upward to the seafloor. Still, scientists would want to know exactly what the consequences would be if radioactive substances diffused to the seafloor on their own. Researchers would want to ascertain, for instance, exactly how quickly relatively soluble carriers of radioactivity (such as certain forms of cesium and technetium) would be diluted to background levels. And they would want to be able to predict the fate of comparatively insoluble elements, such as plutonium.

So far no evidence has been found of currents strong enough to overcome gravity and bring claybound plutonium particles to the ocean surface. Most likely the material would remain on the seabed, unless it were carried up by creatures that feed on the sea bottom. That prospect, and all other ways that radioactive materials might rise from deep-sea sediment layers to surface waters, warrant further investigation. The transportation of nuclear waste on the high seas also requires careful study. In particular, procedures would need to be developed for recovering lost cargo should a ship carrying radioactive materials sink or accidentally drop its load.

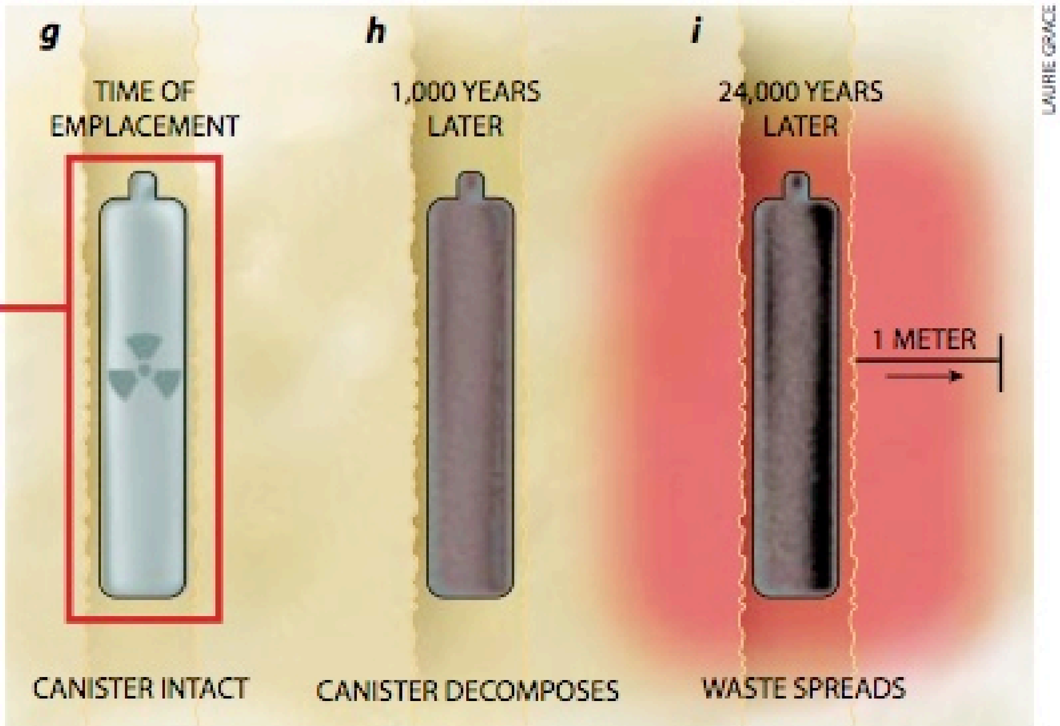
Engineers would probably seek to design the waste containers so that they could be readily retrieved from the bottom of the ocean in case of such a mishap or, in fact, even after their purposeful burial. Although subseabed disposal is intended to provide a permanent solution to the nuclear waste crisis, it may be necessary to recover material such as plutonium at some point in the future. That task would require the same type of drilling apparatus used for emplacement. With the location of the waste containers recorded at the time of interment, crews could readily guide the recovery equipment to the right spot (within a fraction of a meter) by relying on various navigation aids. At present, no nonnuclear nation has the deep-sea technology to accomplish this feat. In any event, performing such an operation in a clandestine way would be nearly impossible. Hence, the risk that a military or terrorist force could hijack the disposed wastes from under the seabed would be negligible.

All Eggs in One Basket

The overall cost of a concerted program to evaluate subseabed disposal might reach $250 million—admittedly a large sum for an oceanographic research endeavor. But it is a relatively modest price to pay considering the immense benefits that could result. (As a point of comparison, about $2 billion has already been spent on site evaluation at Yucca Mountain, and another billion or two will probably be needed to complete further studies and secure regulatory approval. No actual construction, save for exploratory tunneling, has yet begun.) Yet no nation seems eager to invest in any research at all on subseabed disposal, despite the fact that it has never been seriously challenged on technical or scientific grounds. For example, a 1994 report by the National Academy of Sciences that reviewed disposal options for excess weapons plutonium called subseabed disposal "the leading alternative to mined geologic repositories" and judged implementation to be "potentially quick and moderate to low cost." But the academy panel stopped short of recommending the approach because of the anticipated difficulties in gaining public acceptance and possible conflicts with international law.

Convincing people of the virtues of subseabed burial is, admittedly, a tough sell. But so is the Yucca Mountain project, which is strongly opposed by state officials and residents of Nevada. Subseabed disposal may turn out to be easier to defend among the citizenry than land-based nuclear waste repositories, which are invariably subject to the "not in my backyard" syndrome.

In any case, subseabed disposal is certain to evoke significant opposition in the future should the idea ever go from being a remote possibility to a serious contender. Oddly, the concept has recently come under direct fire, even though no research has been done in more than a decade. A bill introduced last year in the House of Representatives contains a provision that would prohibit the subseabed disposal of spent nuclear fuel or high-level radioactive waste as well as prevent federal funding for any activity relating to subseabed dis-



SEAFLOOR DISPOSAL would require a series of operations. After lowering a long, segmented drill pipe several kilometers to the ocean floor (*a*), technicians on the ship would put a "reentry cone" around the pipe and drop the device to the bottom (*b*). (The cone could guide another drill pipe to the hole later, should the need arise.) Turning and advancing the pipe (to which a bit is attached) would drill it into the ocean floor (*c*). By releasing the bit, the drillers could then lower a waste canister within the pipe using an internal cable (*d*). After packing that part of the hole with mud pumped down through the pipe (*e*), they would emplace other canisters above it (*f*). The topmost canister would reside at least some tens of meters below the seafloor (*g*). In about 1,000 years the metal sheathing would corrode, leaving the nuclear waste exposed to the muds (*h*). In 24,000 years (the radioactive half-life of plutonium 239), plutonium and other transuranic elements would migrate outward less than a meter (*i*).

posal—apparently including research. The intent of part of this bill is reasonable: subseabed disposal should be illegal until outstanding safety and environmental issues can be resolved. But it makes absolutely no sense to ban research on a technically promising concept for the disposal of weapons plutonium and high-level nuclear wastes.

Subseabed disposal faces serious international hurdles as well. In 1996, at a meeting sponsored by the International Maritime Organization, contracting parties to the so-called London Dumping Convention voted to classify the disposal of nuclear material below the seabed as "ocean dumping" and therefore prohibited by international law. This resolution still awaits ratification by the signatory nations, and the outcome may not be known for several years. But regardless of how that vote goes, we submit that "ocean dumping" is a wholly inappropriate label. It makes as much sense as calling the burial of nuclear wastes in Yucca Mountain "roadside littering."

Yet even assuming that the nations involved uphold the ban, the bylaws of the London convention would allow for subseabed disposal to be reviewed in 25 years, an interval that would provide sufficient time to complete a comprehensive appraisal of this disposal method. The 25-year moratorium could be wisely spent addressing the remaining scientific and engineering questions as well as gaining a firmer grasp of the economics of this approach, which remains one of the biggest uncertainties at present. In our most optimistic view, the legal infrastructure already established through the London convention could eventually support a program of subseabed disposal on an international basis.

A parallel effort should be devoted to public education and discussion. Right now there seems to be a strong aversion among some environmental advocates to any action at all to address the nuclear waste problem—and a solution that involves the oceans seems particularly unpalatable. But it makes no sense to dismiss the possibility of disposal in stable suboceanic formations—which exceed the land area available for mined repositories by several orders of magnitude—simply because some people object to the concept in general. It would be much more prudent to base a policy for the disposal of nuclear waste, whose environmental consequences might extend for hundreds of thousands of years, on sound scientific principles.

Barring a miraculous technical breakthrough that would allow radioactive elements to be easily transformed into stable ones or would provide the safe and economic dispatch of nuclear wastes to the sun, society must ultimately find somewhere on the planet to dispose of the by-products of the decades-long nuclear experiment. Americans in particular cannot responsibly pin all hopes on a single, undersized facility in a Nevada mountainside. They owe it to future generations to broaden their outlook and explore other possibilities, including those that involve the thick, muddy strata under the sea. SA

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Further Reading

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