Radioactive sinkers

Can we devise high-temperature, rock-melting probes, fuelled with the radioactive wastes from reactors, both to dispose of those wastes effectively and to tell us more about the Earth's interior? There are many difficult problems, but the gains in knowledge about the deep regions of the terrestrial mantle could be considerable

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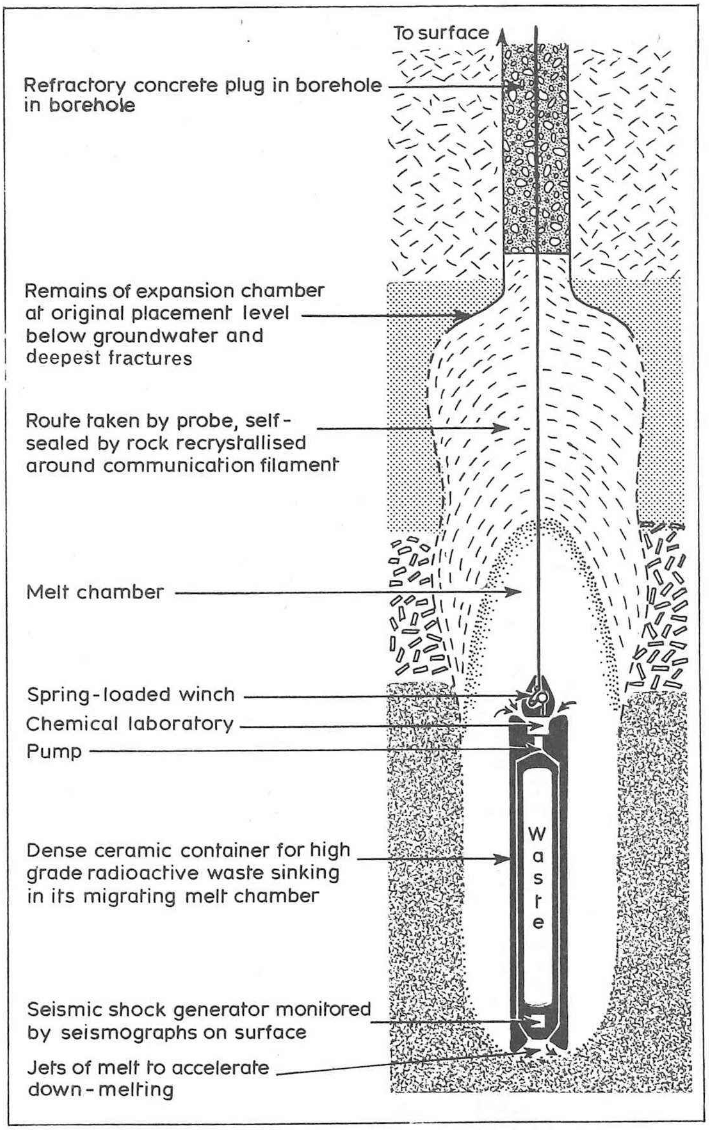
The waste produced by man's future nuclear generated energy will produce such heat and biologically dangerous radiation that, apart from the world's ocean floors (*New Scientist*, vol 73, p 709) there are few areas on the surface of the Earth where it can be disposed of (rather than stored) safely. Actual disposal of such waste into space towards the Sun has been proposed but would be too costly, and involve too many unknowns, to be acceptable. Another suggestion has been to dump or bury the wastes in submarine trenches in the hope that they would disappear into the Earth's mantle along the subduction zones where one of the Earth's lithospheric plates slides under another. However, the plates move at rates of only a few centimetres a year; it would be difficult to guarantee that the wastes would disappear downwards safely without profoundly affecting the column of ocean water above.

The general philosophy behind most suggestions so far has been that the wastes should be stored indefinitely at large sites deeper than 400 m beneath the surface. The Americans have been exploring the possibilities of storing such waste for 20 years in bodies of buried rock salt, as have the Germans for less time. The British and other national groups have started more recently doing the same for hard crystalline rocks such as granite. From confident beginnings the American "salt-vault" publications appear to have become more wary with time and US workers are now looking at other soft rocks as candidates for storage. One of the areas of stable bedded rock salt they were considering as a federal repository for high-grade radioactive waste turned out to be so full of exploratory boreholes dating from early searches for oil that it might have been dangerously permeable.

Impermeable and highly conductive

One of the great advantages of rock salt is that it is potentially so impermeable at comparatively shallow levels that circulating water in the ground is not likely to reach, and be contaminated by, the extensive storage areas required. Tiny pockets of fossil brine do exist in rock salt. They would migrate up the temperature gradients induced by the waste and vent into the storage areas as superheated steam but the expected volumes (no more than 2 to 3 litres annually) could be drawn off by a ventilation system. Apart from its radiation effect (which embrittles salt and turns it deep blue) high-grade radioactive waste is particularly unpleasant because of the enormous quantities of heat it generates for so long. Another advantage of rock salt therefore is its remarkably high thermal conductivity compared to other rocks. Only clean quartzites have comparable conductivities among the most indurated rock types.



A hypothetical model of a radioactive Earth probe

Buried 10 m apart, the waste canisters would accumulate at a rate to fill almost half a square kilometre of storage space each year if all the US electrical energy requirements were met by nuclear power. Each of the stainless steel canisters of concentrated waste currently planned for storage by the Americans would raise the temperature of any immediately surrounding rock. This increase would be 1900°C in a few months if individual canisters were buried one year after removal from the reactor and about 700°C if they were buried after three years. In salt the thermal front would reach an approximate maximum 100 m above and below the permanent ventilated storage level 40 years after emplacement. Thereafter it would retreat as the thermal energy in the waste became spent (*Scientific American*, vol 276, p 21). Packed more closely the thermal energy of a few canisters would be sufficient to melt pockets of any rocks for long periods. Great effort has gone to ensuring that this could not happen because significant volumes of molten rocks (magma) developing in a large permanent repository would not be safe at shallow levels. If, on the other hand, melting of comparatively small volumes of rock at any one time were encouraged it could be used both to dispose of small batches of canisters to great depths, while at the same time exploring the Earth's interior.

The construction of appropriate containers capable of withstanding large pressures, high temperatures and high radiation dosage without developing significant mechanical defects should be possible using refractory alloys or ceramics. Most hard crystalline rocks melt in the range 750 to 1200°C and ceramics capable of withstanding temperatures higher than this already exist. (Modern self-cleaning household ovens could melt granite if oxygen could be excluded safely.) If the new, longer, containers could be built with sufficient overall density they would sink through the comparatively small volumes of melt they would generate around themselves some (designed) time after emplacement in impermeable rocks at depth. The heavy container would then melt its way vertically downward at a rate dependent on the thermal energy output of the enclosed waste. The vertically elongate magma chamber would migrate slowly downwards following the sinking heat source, solidifying at its upper trailing edge. Provision would have to be made in the original deep placement chambers to absorb the expansion which would occur as the rocks were first heated and melted.

The magma chamber would have to remain sufficiently small at all depths to pose no danger to the integrity of the rocks above. A container with an overall density of 13 could sink at least to the Earth's core (about half way to the Earth's centre) if it could yield its thermal energy at appropriate rates for a sufficiently long period.

Sinking laboratories

Such bodies melting their way downwards into the Earth could be turned into laboratories if they could be persuaded to communicate back to the surface. Periodic shocks from the deep Earth probes could be monitored by seismographs at the surface and be used to plot their migration paths. Seismic shocks of known, but variable, energy at known depths far beyond those that could be reached otherwise would tell geophysicists much about the rocks the probes sink through. Seismographs perhaps hundreds of kilometres away could interrogate the rocks between the seismic source and the receivers. The rate and direction of progress of each such probe would relate to the physical properties and any natural movement of the rocks they encounter.

It should not be beyond our ingenuity to arrange to pump small volumes of melt through small enclosed chemical laboratories which would transmit the results back to the surface along an electrically conducting filament fed out behind each probe and incorporated in the solidifying rock above. The outlet(s) from such a pumping system could be used to jet the probe downwards at useful rates —or even to impart lateral components of travel as the directing teams learn the ropes, and if the umbilical filament could be used for two-way communication. Without such pumps the sinkage rates would be so low that scientists would have to be very patient for their results. The guiding capacity might be very useful to counter the effects of any mantle currents if they prove unexpectedly large—quite apart from its exploratory potential (eg for moving sideways through faults and under areas which had been established as unsuitable for starting the probe's downward journeys).

Careful calculations based on experience of rates of fall might one day allow the dropping of weights carrying the waste container downwards. The lightened package could then be allowed to melt its way back up to safe but recoverable levels, temporarily if necessary. The advantage of such returns to comparatively shallow depths would be to bring back actual samples of melts encountered at different levels to be deposited at levels from which they would be mechanically recoverable.

Even the conducting filaments extending into the depths could be exploited for electrical conductivity experiments of the rocks surrounding one, or falling in between several, such filaments.

Original emplacement of each probe would have to be by boreholes to depths below which fractures and groundwater are absent. Geologists believe both to be absent below depths of three kilometres or so in most parts of the planet. Prototypes would first have to prove the safety and benefit of such disposal packages with their incorporated laboratories beneath deserts or other barren lands in safe and tectonically stable regions. Once this stage is passed, it is easy to imagine Earth scientists throughout the world lobbying their governments to invite disposal and the exploration of the depths beneath their own countries. Geologists would leap at the chance of learning all that such probes could tell them about the upper crust below drillable levels—quite apart from the lower crust and mantle. Sites would soon be proposed in every continent and all the oceans. Proponents for routes down salt domes, granite masses, old metamorphic terrains and young mountain chains would compete for priority. Great care would obviously be necessary in probing tectonically active regions involving earthquakes and natural melts but even this might be possible one day.

Innumerable problems would obviously be involved in proofing the scientific packages against the heat, pressure and radiation they would have to sustain; and political doubts would have to be answered satisfactorily. The usual problem of radioactive waste, biological hazard, would decrease with time with this method. However, the geophysical and geochemical information which could be gained should amply repay the cost. This exploratory potential would be an additional benefit of a programme primarily aimed, if not at the actual disposal of dangerous waste, at storing it at depths considerably deeper than those considered so far. ☐

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NOT Acknowledged by

1. M. I. Ozhovan, F. Gibb, P. P. Poluéktov and E. P. Emets (August 2005), "Probing of the Interior Layers of the Earth with Self-Sinking Capsules", Atomic Energy 99 (2): 556-562
2. M. I. Ozhovan and F. Gibb (2008), "Exploring the Earth's Crust and Mantle Using Self-Descending, Radiation-Heated, Probes and Acoustic Emission Monitoring", Nuclear Waste Research: Siting, Technology and Treatment, Edited by: Arnold P. Lattefer, pp. 207-220- "Probing of the Interior Layers of the Earth with Self-Sinking Capsules" (2005) and "Exploring the Earth's Crust and Mantle Using Self-Descending, Radiation-Heated, Probes and Acoustic Emission Monitoring" (2008),

or other recent references to nuclear probes