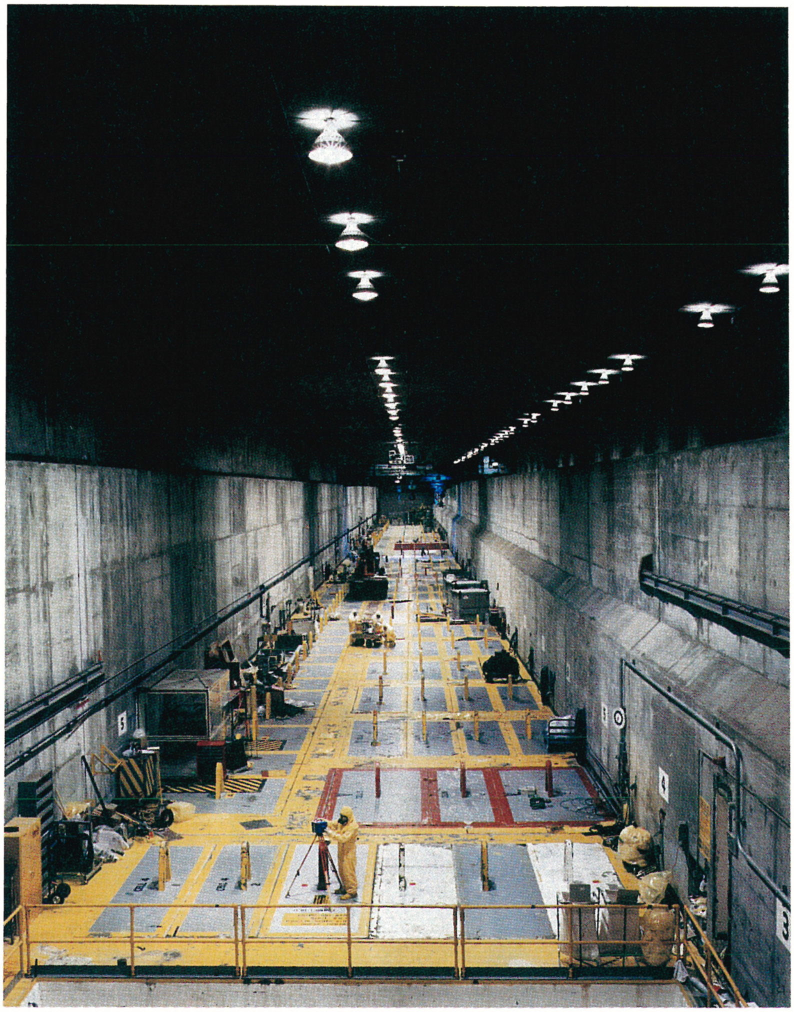
RADIOACTIVE WASTE

What can be done with radioactive waste? This extremely difficult question has not really been answered anywhere in the world; yet it must be answered. Like death and taxes, radioactive waste is with us—it cannot be wished away. This special, five-article issue of PHYSICS TODAY reviews the technical problems and risks, outlines the reasons why the basic question posed above has not been answered and suggests some possible new approaches that could enable us to make progress.



NO LONGER NEEDED, the B Plant at DOE's Hanford site in Washington State is being prepared for closure. Systems are being shut down and radioactive and hazardous materials are being removed. (Photo courtesy of Fluor Daniel Hanford.)

The radioactive waste problem was briefly recognized in the early development stages of nuclear power, but was assumed to be easily solvable. During the nuclear arms race of the cold war, other priorities overrode concerns about environmental issues. We now have a legacy from that era: large amounts of radioactive material in less-than-optimal storage. From many years of operating the world's largest nuclear energy program, we also have accumulated large amounts of spent nuclear fuel in storage facilities that are safe but rapidly reaching capacity. In addition to the high-level waste, the US is faced with disposing of TRU waste and a large amount of low-level waste.

In the first article (page 24), I outline the origins and types of radioactive waste, and provide current estimates of how much of it has accumulated in the US and where it is located. High-level waste, which has most of the radioactivity, consists of both used-up nuclear fuel from commercial reactors and a large amount of waste held by the Department of Energy (DOE) as a legacy of many years spent producing nuclear weapons. The largest amount of radioactivity, as I note, is in the spent fuel from commercial reactors, although the volume of high-level waste at the former weapons production sites is quite large. The other main types of waste are transuranic waste (TRU), again coming from nuclear weapons programs, and low-level waste, the major producers of which are utilities, industry and the Federal government. Almost all of the waste is currently being stored at the sites where it was generated, in facilities that were not built for long-term storage.

In the second article (page 32), Kevin Crowley describes the technical challenges faced by the countries wishing to resolve the radioactive waste problem. As he notes, these challenges are "daunting." Moving forward toward solutions could save substantial taxpayer dollars and also reduce risks, both to the workers who must deal with the waste and to the people who live near the storage sites. Crowley reviews the current programs for transferring high-level waste from commercial reactors to an underground repository being developed at Yucca Mountain in Nevada by the Department of Energy, and the treatment being proposed for the weapons-production wastes at other DOE sites. The major problems concern wastes stored in tanks. Those wastes are difficult and costly to characterize—as much as $1 million per sample from each tank. "Cleanup of US defense sites is a massive undertaking that will involve the remediation of hundreds of tanks and thousands of buildings, including dozens of reactors and reprocessing facilities." Crowley briefly discusses some alternatives to the geological repository, noting that they too pose significant technical problems.

The third article (page 41), by William Kastenberg and Luca Gratton, addresses the hazards and risks involved in dealing with nuclear waste. They suggest that the appropriate framework for assessing future hazards is standard risk analysis, and ask three questions: What can go wrong? How likely is it to go wrong? What are the consequences? But there is another class of concerns related to risks from events that have already occurred, such as waste that has leaked from tanks. Again, noting

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that the waste tanks present perhaps the most difficult waste management problems, Kastenberg and Gratton examine the hazards posed by those tanks. They also discuss the hazards presented at the Waste Isolation Pilot Plant (the proposed location for TRU waste) and at Yucca Mountain. They note that the 10 000-year performance criterion for Yucca Mountain is being reviewed because it does not address the largest estimated risks, which occur on a time scale of several hundred thousand to a million years. They conclude that there are many issues still to be addressed with regard to repository performance assessments for TRU and high-level waste, but the highest risks are associated with the high-level waste tanks at the DOE weapons complexes.

In the fourth article (page 48), Warner North describes the US nuclear waste programs as being "far behind schedule and mired in public controversy." Focusing on Yucca Mountain, he describes the problems that have been faced in analyzing repository performance, but concludes that the most formidable problems are political. He recommends that social scientists get more involved in helping to solve these problems and advises that, to move forward, the stakeholders—including local residents and public officials—must be involved in the discussions to a greater extent than they have been.

Finally, beginning on page 56, Charles McCombie reviews the worldwide perspective: Although the US waste management program is one of the most complex in the world, the task of implementing environmentally sound management is also a major challenge in many other countries. He makes a point—often unappreciated in the US—that in spite of much effort, no country has yet found a "demonstrably acceptable" site for either simple storage or final disposal of spent fuel; further, all waste-generating countries have plans that will not come to fruition for a decade or more. A major reason for this lack of emphasis in other countries is that they do not have enough spent fuel to make a repository economic. Unlike the US, they do not have a large backlog of high-level waste, which leads McCombie to conclude that interim storage must be an integral part of a sound waste management strategy. Like other authors in this special issue, McCombie makes the point that "the sociological and political problems raised by disposal projects have been massively underestimated." The key issues that he believes will bear on progress in any country are the influence of national policy, commitments to geological disposal, technical issues, organizational issues, sociological issues and economic issues. As in the US, the main obstacle internationally remains finding an appropriate site, even for interim storage. In what is perhaps an apt summary for all five articles, McCombie notes that within the international waste management community today, there is a general consensus that technical answers are available to many of the problems. There is also a general recognition that technical answers by themselves are inadequate for answering political questions.

These articles do not present solutions to the waste management problems. There are many technical issues, with which many readers of PHYSICS TODAY have helped, and many more could get involved. Political problems will require more involvement from the general public, as well as recognition by the scientific community that what is really needed is a true interchange through dialog—not just experts telling the public what should be done.

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Further Reading in Physics Today

▷ "Addressing Public Concerns in Science," by John F. Ahearne, September 1988, pp. 36–42.
▷ "Hanford Seeks Short- and Long-Term Solutions to Its Legacy of Nuclear Waste," by Barbara Goss Levi, March 1992, pp. 17–21.
▷ "Nuclear Contamination from Weapons Complexes in the Former Soviet Union and the United States," by Don Bradley, Clyde Frank and Yevgeny Mikerin, April 1996, pp. 40–45.
▷ "A Physical Heritage of the Cold War: Excess Weapons Plutonium," by Wolfgang Panofsky, April 1997, pp. 61–62.

Glossary of Terms Regarding Nuclear Waste

Types of material

actinides: Any of the series of elements that begins with atomic number 88 (actinium). Uranium and plutonium are actinides.

high-level waste (HLW): The highly radioactive waste that results from the reprocessing of spent fuel from nuclear reactors and from some processes in the production of nuclear weapons. In general, it requires permanent isolation; HLW contains highly radioactive, short-lived fission products, hazardous chemicals and toxic heavy metals. HLW includes liquid waste produced directly in reprocessing and any solid waste derived from the liquid. See also *spent nuclear fuel.*

intermediate-level waste (ILW): A category of radioactive waste used in several countries, but without a consistent definition. For example, it may or may not include transuranic waste.

low-level waste (LLW): A catchall term for any radioactive waste that is not spent fuel, high-level waste or transuranic waste.

mixed waste: Waste that contains both chemically hazardous and radioactive materials.

spent nuclear fuel (SNF): Fuel elements and targets that have been irradiated in a nuclear reactor. The Nuclear Regulatory Commission (NRC) includes spent nuclear fuel in its definition of high-level waste, but the Department of Energy does not. DOE does recognize, however, that NRC has a different definition and may require permanent isolation of spent nuclear fuel.

transuranic waste (TRU): Waste containing alpha-emitting transuranic elements having halflives of more than 20 years, in concentrations of more than 100 nanocuries per gram of waste. DOE allows its managers to include as TRU material containing other radioactive isotopes such as uranium-233 and strontium-90.

Units of measurement

curie (Ci): The amount of radiation emitted from one gram of radium-226. One curie of radioactive material undergoes 37 billion decays per second.

metric tons of heavy metal (MTHM): The mass of plutonium and uranium isotopes present in spent fuel from nuclear reactors.

rad: A unit of absorbed dose, equal to the amount of radiation that deposits 0.01 J kg^{-1} in any absorbing material.

rem: A unit of equivalent dose of ionizing radiation that has the same effect on biological tissue as one roentgen of high-energy x rays or one rad of any ionizing radiation. The name comes from "roentgen-equivalent for mammals."

roentgen (R): The amount of ionizing radiation that produces 2.58×10^{-4} coulombs of electrons per kilogram of air at standard temperature and pressure.