Nuclear Waste Management Worldwide

Numerous countries around the world are tackling the task of managing nuclear waste. By considering their approaches, we gain a broader perspective on the US program.

Charles McCombie

The proper management of radioactive wastes involves a broad array of activities. Residues must be minimized and conditioned; waste packages must be safely handled, transported and kept in interim storage prior to their safe disposal. Further major challenges arise in cleaning up sites that have been contaminated in the course of mining uranium, producing reactor fuel and fabricating nuclear weapons. Accomplishing these tasks requires not only the development and deployment of technological processes but also the solution of obstinate socioeconomic and organizational problems: Necessary resources must be made available and—most important—acceptable sites must be found for waste management facilities.

Most countries are not faced with tackling the full spectrum of these tasks. The US program for nuclear waste management is one of the most complex in the world because all of the waste-producing activities mentioned above have been carried out at numerous sites for decades. It is also one of the largest programs since 109 of the 436 nuclear commercial power plants in the world are in the US. The task of implementing an environmentally sound waste management program is, nevertheless, also a major challenge in numerous other countries. For example, some states of the former Soviet Union now face immense problems in cleaning up sites contaminated by poor practices in the past. In some smaller countries, such as Sweden, Switzerland, Finland and Belgium, nuclear power production is a very important element of the national energy strategy, and proper waste management is thus a key political and social issue. Although these small countries must also face the entire range of problems involved in managing reactor wastes, the necessary funding must be provided out of revenues generated by much smaller electricity production programs.

While it is true that the US has a large and complex range of waste management tasks, it also has a huge reservoir of technical expertise in private companies and national laboratories as well as large financial resources. Levies on electricity production yield around $600 million per year for financing civilian waste management, and the Department of Energy allocates $5–6 billion per year for financing its environmental management activities. Typical budgets in other countries are ten times lower. In this situation, one could expect the US to play a leading role in developing and implementing processes and facilities designed to ensure safe and environmentally sound management of radioactive wastes. The extent to which the US is currently fulfilling this role can be judged in the light of the international comparisons provided in this article.

Since nuclear waste management is a broad subject, we must narrow our focus to selected topics. What are the biggest problems? What are the most urgent tasks? What generates the greatest public or political concern? Undoubtedly, the biggest task facing some countries, including the US, is environmental remediation within a weapons complex or at sites used for fuel production activities; nevertheless, this problem is not currently a particularly controversial issue because the broad goals of cleanup programs are indisputable and much of the technical work is performed at private or government sites without intensive public scrutiny. Similarly, the management of radioactive wastes arising from activities other than nuclear power or weapons production is of less public concern, although many countries (including those with no nuclear power, such as Australia and Norway) are extremely aware that their research, medical and industrial facilities can continue to operate properly only if treatment and disposal of radioactive waste are feasible. The waste issue with highest public profile in all nuclear nations, as in the US, is that of management of wastes from nuclear power plants—and in particular of the spent nuclear fuel and the high-level waste (HLW) arising from reprocessing of spent fuel. (See the glossary on page 23.) Figure 1 shows that spent fuel accumulations are concentrated in relatively few countries and that the volumes of low-level waste (LLW) and intermediate-level waste (ILW) greatly exceed those of spent fuel or HLW.

Much effort has been devoted—as yet without success—to finding demonstrably acceptable sites for centralized storage or for final disposal of conditioned spent reactor fuel. Because of the worldwide, controversial nature of plans for disposal of spent fuel and HLW resulting from reprocessing of such fuel, this article focuses to a large extent on that aspect of radioactive waste management.

Geologic disposal

For long-lived wastes from the nuclear fuel cycle, the most promising form of confinement was recognized as early as 1957[1] to be in deep geological formations. Despite the view held today by many opponents, geologic disposal was certainly not chosen as a cheap and dirty option to get the radioactive waste "out of sight and out of mind." Rather, the concept of geologic disposal is a logical consequence of the decay of radioactivity with time, which continuously reduces the toxicity of these wastes. Finite hazardous lifetimes (and low volumes) of wastes led to the idea of protecting the biosphere by isolating wastes long enough for them to decay. That led in turn to the search for environments that showed sufficient stability

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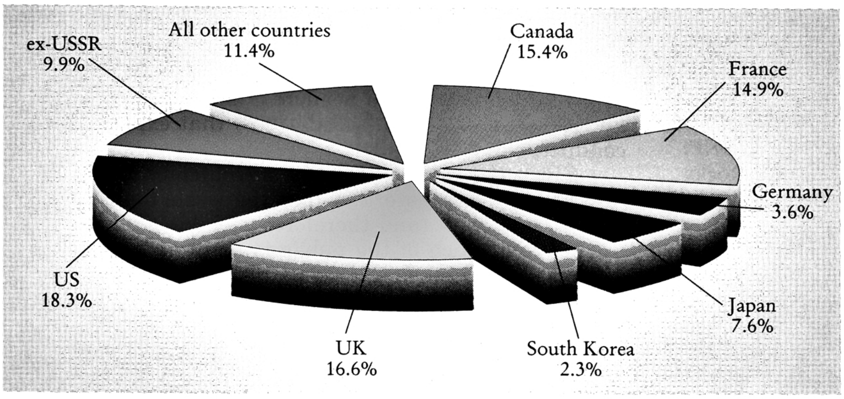

b

	SNF/HLW (m^3)	ILW (m^3)	LLW (m^3)
US* (to 2030)	3.5×10^5	3.1×10^5 **	4.5×10^6
UK (all time)	2.3×10^3	2.9×10^5	1.9×10^6
Germany (to 2010)	6.6×10^3 †	—	2.3×10^5 ††
Switzerland (to 2053)	4.9×10^2	6.5×10^3	1.0×10^5

*No mill tailings or restoration waste included.
**Transuranic (TRU) waste.
†Heat-generating waste only (no spent fuel volumes included).
††Nonheat-generating waste.

FIGURE 1. NUCLEAR WASTE WORLDWIDE. **a:** Lifetime spent fuel accumulations of reactors operating or under construction in 1995, based on International Atomic Energy Agency estimates. The total amount is estimated to reach 447 000 metric tons of heavy metal. **b:** Relative volumes of spent nuclear fuel and high-, intermediate- and low-level waste in four countries.

for the time periods of relevance for long-lived wastes—namely hundreds of thousands of years.

Few environments have yielded evidence of their evolution and their stability over such long timescales. Old, deep geological formations are the most obvious candidates that can be accessed with today's technology. Concepts for geological disposal under the continental Earth's crust or in sub-seabed formations have been developed over many years; the table on page 58 shows the diversity of solutions being considered throughout the world. However, no deep-disposal facility has been implemented. Even the most ambitious plans for emplacing spent fuel or HLW in a deep repository (namely those of Sweden and the US) do not aim to start until 10–15 years from now. Many countries envisage disposal only around the middle of the next century.

Why is that the case? One objective, technical reason is that most countries do not have enough HLW awaiting disposal—in particular because interim storage to allow cooling of the wastes over some decades is foreseen in almost all disposal strategies. (See figure 2.) In other words, contrary to what many activists would have us believe, in most countries there is definitely not a huge backlog of HLW urgently awaiting disposal. Interim storage must be an integral part of a sound waste management strategy.

There are other reasons, however, why in all nuclear nations the progress toward disposal has been slower than many insiders have expected:

▷ The development and acceptance of disposal technology—even within the technical and scientific community—has proven less straightforward than was assumed.

▷ The technical issues associated with site selection and, more particularly, site characterization are more complex than was anticipated.

▷ The sociological and political problems raised by disposal projects have been massively underestimated.

Of course, no solution to the broad third issue can be expected before the technical issues are properly solved. Accordingly, for decades the waste management community has been working on developing technical solutions. A 1991 report[2] documented the international consensus that the safety of these solutions can indeed be demonstrated with sufficient confidence.

In the last few years, an extensive international effort has been devoted to documenting the current technical and ethical consensus on radioactive waste disposal. Expert groups meeting at the International Atomic Energy Agency (IAEA) in Vienna developed a concise document

IAEA Safety Fundamentals: The Principles of Radioactive Waste Management[3]

1: Protection of human health
Radioactive waste shall be managed in such a way as to secure an acceptable level of protection for human health.

2: Protection of the environment
Radioactive waste shall be managed in such a way as to provide an acceptable level of protection of the environment.

3: Protection beyond national borders
Radioactive waste shall be managed in such a way as to assure that possible effects on human health and the environment beyond national borders will be taken into account.

4: Protection of future generations
Radioactive waste shall be managed in such a way that predicted impacts on the health of future generations will not be greater than relevant levels of impact that are acceptable today.

5: Burdens on future generations
Radioactive waste shall be managed in such a way that will not impose undue burdens on future generations.

6: National legal framework
Radioactive waste shall be managed within an appropriate national legal framework including clear allocation of responsibilities and provision for independent regulatory functions.

7: Control of radioactive waste generation
Radioactive waste shall be kept to the minimum practicable.

8: Radioactive waste generation and management interdependencies
Interdependencies among all steps in radioactive waste generation and management shall be appropriately taken into account.

9: Safety of facilities
The safety of facilities for radioactive waste management shall be appropriately assured during their lifetime.

Overview of low-level waste (LLW) disposal facilities and high-level waste/spent nuclear fuel (HLW/SNF) plans

Country	LLW: Facilities	HLW/SNF: Host Rocks
Argentina	(S)	C
Australia	(S)	—
Belgium	(S)	A
Brazil	(S)	—
Bulgaria	S	—
Canada	(S)	C
China	(S)	—
Czech Republic	S, M	—
Finland	M	C
France	S	C, A
Germany	M	St
Hungary	S	—
India	S	—
Italy	(S)	C, A
Japan	S	C, A, T
South Korea	(S/M)	—
The Netherlands	(M)	St
Norway	S, (M)	—
Poland	S	—
Slovak Republic	(S)	—
South Africa	S	—
Spain	S	C, A, St
Sweden	M	C
Switzerland	(M)	C, A
ex-USSR	S	C, St
UK	S, (M)	—
US	S	St, T

S = facilities at or near surface
M = mined repository or old mine
( ) = in planning stage

C = crystalline (granite, gneiss)
A = argillaceous (clays)
St = salt
T = tuff
— = no active HLW program

recording the "Safety Fundamentals"[3] for waste management. The essence of the principles elucidated in this important publication is captured by the International Convention on the Safety of Radioactive Waste, which is currently being prepared for signature by member states of the IAEA (see the box on page 57). The Radioactive Waste Management Committee of the OECD's Nuclear Energy Agency (NEA) in Paris has also prepared a "Collective Opinion" recording the international consensus on the ethical justification for implementing geologic disposal.[4]

Continuing public debate

These extensively debated and carefully worded statements, however, have had extremely little impact on public debate. For many years now in the US, and increasingly in other countries, scientific consensus has been overshadowed by intensive media attention focused on technical or sociopolitical conflicts arising in waste management programs. That is partly because of the media's tendency to give equal space to opposing views irrespective of the numbers supporting either side. It is, unfortunately, also due in part to the academic debates (for example, on the issue of model "validation") that experts love to conduct.

Given the real controversy surrounding disposal and also the frequent assertion that the waste disposal problem is "unsolved" (and therefore insoluble), it is not surprising that much of the public is unaware of the actual progress made to date. The table at left shows that surface or near-surface disposal of LLW is already an ongoing industrial activity in a number of countries. Recent facilities (for example in France, Spain and Japan) include much more sophisticated engineered safety barriers than the older shallow land burial sites in, for instance, the UK, France, the USSR and the US. Underground emplacement of reactor wastes in existing mines (for example in Germany and the Czech Republic) has given way to disposal in specially mined caverns, as have been put in use in Sweden and Finland. (See figure 3.) The remaining challenge is the deep geologic disposal of spent fuel or HLW. As mentioned above, this challenge remains largely because, in many countries, there is not enough waste ready for disposal. In fact, the US is an exception because earlier disposal of spent fuel (ten years after removal from the reactor) is envisaged and thus relatively large inventories are available today; their conditioning and emplacement in a disposal facility could begin, were such a facility available. The US also has large quantities of nonheat-generating, long-lived wastes from military applications, and the Waste Isolation Pilot Plant facility, which is intended for their disposal, may well be the world's first custom-built deep geological repository.

Key issues

It is instructive to identify the key issues that affect the rate of progress in any national waste management program and to comment on the similarities and differences between the US and other countries in various areas.

Influence of national policy. In practice, social, political and economic pressures determine very directly the scope of waste management work and also the required level of public safety. Progress toward geologic disposal, for instance, has been achieved often by countries where strong political or legal requirements were established. In the late 1970s, Sweden's further use of nuclear power was made conditional on showing that safe disposal was feasible, resulting in the KBS-3 series of reports in 1983.[5,6] Because of the Swedish utilities' commitment to nuclear power and their need to provide disposal routes to justify its continued use, this small country has assumed a leading role in concept development, implementation of an underground LLW repository and advanced planning for encapsulation and deep-disposal facilities for spent fuel. (See figure 4.) Similar legal pressures have led Switzerland to make early progress in planning its disposal strategy.[7]

Various countries have extensive requirements for remedial actions at sites contaminated by uranium fuel cycle activities (mining, milling and so on) or by weapons production. Examples are the major weapons states (the US, France, the UK, China and the former Soviet Union) and uranium ore producers such as Australia, Canada and the former East Germany. The efforts invested, however, often reflect not the huge scope of the problem but rather the restricted levels of funding available. In this area of environmental remediation, the US is certainly playing a leading role with its large investments in the DOE environmental management program. Nevertheless, the re-

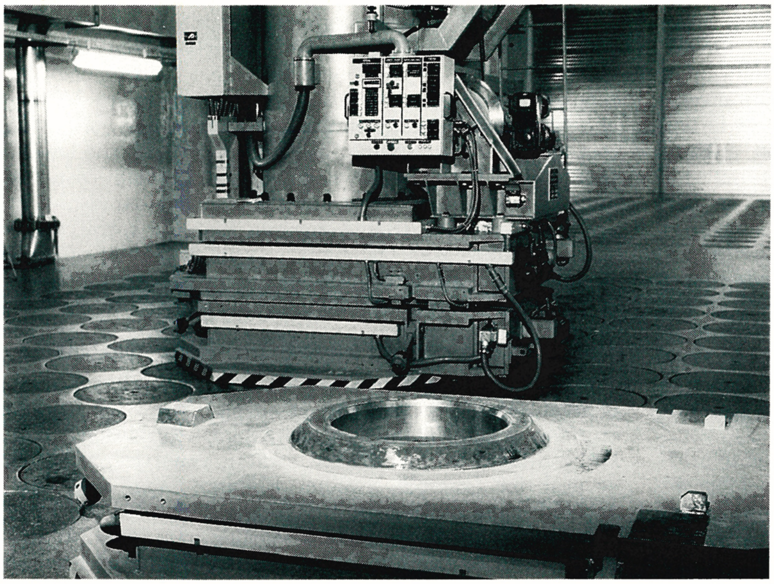

FIGURE 2. HIGH-LEVEL WASTE INTERIM STORAGE FACILITY at Mol, Belgium. At such facilities, canisters of waste or spent fuel are stored in individual bins (the bins' circular tops, flush with the floor, are visible in the photo), which are cooled by forced or natural convection. Contrary to popular belief, outside of the US there is not a large backlog of HLW awaiting disposal because most HLW disposal strategies include some decades of interim storage during which the heat produced by the HLW will drop significantly due to radioactive decay. (Photo courtesy of ONDRAF, Belgium.)

cent trend in this program toward more realistic goals defined by justifiably achievable levels of cleanup will be viewed with relief by various countries that do not wish to see overly ambitious programs setting international precedents.

Commitments to geologic disposal. Despite geologic disposal having been identified 40 years ago by the National Academy of Sciences as the preferred option for radioactive wastes, the feasibility of safe repositories has been repeatedly questioned by a vocal minority in the US and other countries. In recent years, in fact, support has grown for indefinite monitored storage of wastes at the surface. It is a tempting option for many players in the game: Political problems of siting disposal facilities are pushed into the future; large expenditures by waste producers for constructing and operating repositories are postponed; there are no immediate safety concerns since monitored storage is a proven technology; believers in technological breakthrough can wait for the "perfect" solution; researchers have more time and money to do research; and nuclear opponents can continue to point out that the problem is still unsolved.

The prime counterarguments to indefinite storage are predominantly of an ethical nature. The generations profiting from nuclear power production should provide for disposal of the wastes. Continuing surface storage postpones—but does not solve—the task of waste disposal. To the worldwide nuclear community, a much more ethical choice is to dispose of the wastes in such a way that future generations need take no further protective actions. The favored—and, currently, only—disposal method that is judged feasible is the use of deep repositories. Opposing ethical arguments have been made, particularly in Sweden, that it is preferable to leave future generations a maximum choice of options rather than a sealed repository; that is, no irreversible steps toward disposal should be taken yet. If we follow that philosophy, as an ethical minimum we should provide future generations with a suitable technology and sufficient set-aside funding for implementing the concepts developed.

Internationally, the overwhelming technical consensus is still that geologic disposal is the preferred option for long-lived wastes. As an isolated example, The Netherlands has, at present, politically ruled out permanent disposal as a national strategy. In certain countries, however, such as France, the UK, Sweden, Switzerland and Canada, there is increasing pressure to include the option of retrievability in the geologic disposal concept. A question being examined in such countries is to what extent the objective of retrievability over very long times is in conflict with the objective of ensuring repository safety without requiring active care and maintenance.

Technical issues. The most important technical tasks concern the development and deployment of suitable science and technology for implementing safe disposal facilities. Experience worldwide has shown that the most controversial technical tasks, however, are the formulation of appropriate safety requirements together with criteria for demonstrating compliance with these requirements, and the preparation of a comprehensive and transparent case study that demonstrates repository safety. This last issue is crucial. It must be made clear to all interested parties exactly how the engineered and geologic barriers work in concert in a robust manner to provide safety. The quantitative and qualitative arguments that support our understanding of long-term behavior of a repository must be explained. The tendency—also in the US—to distinguish regulatory compliancy issues from real safety arguments should be resisted!

In technical areas, the intensive collaboration between national programs has led to a wide consensus on approaches to most issues. One exception concerns the setting of regulatory criteria for licensing repositories. Almost all non-US countries settled early on safety criteria based on assessing future doses or risks to individuals near a repository. The US Nuclear Regulatory Commission set additional highly specific technical requirements for components of the safety barrier system. The US also chose to differ from many other nations by fixing a hard, rather arbitrary time limit of 10 000 years for assessing future repository behavior. (See the article by William Kastenberg and Luca Gratton on page 41.) Typical results of repository safety assessments (see figure 5) make it clear that there can be no good scientific reason for truncating analyses at 10 000 years. Recurring debate on the US criteria led in 1994 to Congress supporting a National Academy of Sciences study of the technical basis for safety criteria for the proposed repository at Yucca Mountain. The NAS proposals[8] are more in line with international thinking, but they go further than the present international consensus on risk-based regulation and have led to yet more controversy.

The open US system of licensing, with its highly adversarial approach and intensive dependence on legal debate, is viewed with some apprehension by the nuclear community in many other countries. The formalism of the US procedures is nevertheless being increasingly adopted by countries such as Germany, the UK and Canada, which all have recently initiated major public hearings on waste disposal issues.

Organizational issues. In the US, as in some other countries such as Germany, Canada, Japan and Russia, responsibility for disposal of spent fuel or long-lived wastes lies directly with a government department. In several countries, responsibility is also governmental but is embodied in a separate, wholly owned organization, such as Andra in France and ENRESA in Spain. In a number of countries, national waste management programs are run by a dedicated organization financed by the producers of radioactive wastes (who may include the government); examples include SKB in Sweden, Nagra in Switzerland, Nirex in the UK and Posiva in Finland. This model has grown in importance; in an increasing number of countries, waste producers, primarily nuclear utilities that are faced with growing costs, are demanding more influence on disposal projects. This tendency is marked in Canada, Germany and also the US.

Sociological issues. Enormous socioeconomic problems are associated with achieving acceptance for the disposal concept and, specifically, for repository implementation—and even for scientific investigation at a specific site. The traditional industry approach of "decide, announce, defend" floundered because of a deep-seated lack of trust, based to a large extent on the failure to allow affected parties enough participation in the siting process. Combined with the dogmatic opposition of nuclear opponents who have a direct interest in hindering solutions to waste disposal, the early lack of sensitivity of the nuclear industry to the interests of communal and regional groups has led in many countries to the delaying or abandoning of repository projects.

The fact that apparently technological decisions are strongly influenced by perceived as well as actual risks is becoming increasingly recognized due to pioneering work by social scientists such as Paul Slovic (see, for example, reference 9). Somewhat belatedly, awareness has now grown that continuing dialog is important, that an incremental process allowing trust to be built up is more promising, that local groups have a right to compensation for providing services to larger communities and, finally, that the natural time constants involved in achieving social consensus are longer than has been hoped for.

Economic issues. Safe management of radioactive wastes now and in the future is clearly dependent upon the availability of sufficient funding. A deep geologic repository for spent fuel or HLW will cost many billions of dollars to build and operate anywhere in the world—US cost estimates are among the highest, Finnish the lowest. International studies have shown that although costs are high, the ratio of income generated from nuclear electricity to waste volumes arising ensures that the costs can be covered. Moreover, the typical specific costs of disposal (less than 1 cent per kilowatt-hour) do not radically affect the economic case for or against nuclear power.

Preparatory steps toward implementation

The key stumbling block on the path to implementation of facilities is the problem of siting. Even for interim storage—a long-established technology—opposition to centralized facilities has arisen in many countries, although several (for example, Sweden, Finland, Japan and Switzerland) have (unlike the US) finally succeeded in having sites accepted. As mentioned earlier, siting of LLW disposal facilities has also proven feasible—in part because of the more modest geological–hydrogeological requirements and in part because of economic incentives offered to host communities. The US, in fact, was the first country to offer, through amendments to its nuclear waste legislation in 1987, direct payments for hosting interim or final storage facilities. Other countries relied more on indirect benefits through taxation or employment opportunities. The US example, however, has been taken up—with more success—by countries such as France, Switzerland, Japan and Taiwan.

Although scientific and technological advance has not been the rate-determining step on the way toward implementation of disposal facilities, huge efforts and expenditures have been necessary to develop appropriate concepts and technology. In the HLW area, many countries collaborate in active R&D programs on the development and testing of waste matrices, containers and backfill (see figure 6) and also on the characterization of the geologic conditions around a potential deep repository site. For example, many of the rock laboratories around the world (for instance, Äspö in Sweden, the Underground Research Laboratory in Canada, Grimsel in Switzerland and Mol in Belgium) are currently engaged in international projects. In the technical area, Japan, Sweden and Switzerland have collaborated on glass leaching; Finland and Sweden on copper container designs; Sweden, the US, Switzerland and Spain on bentonites (clays); and so on.

Contributions from the US are many and varied, with US pure research groups being at the forefront in many areas. Examples include the development of alternative HLW forms, the development of assay methods for measuring actinide contents in

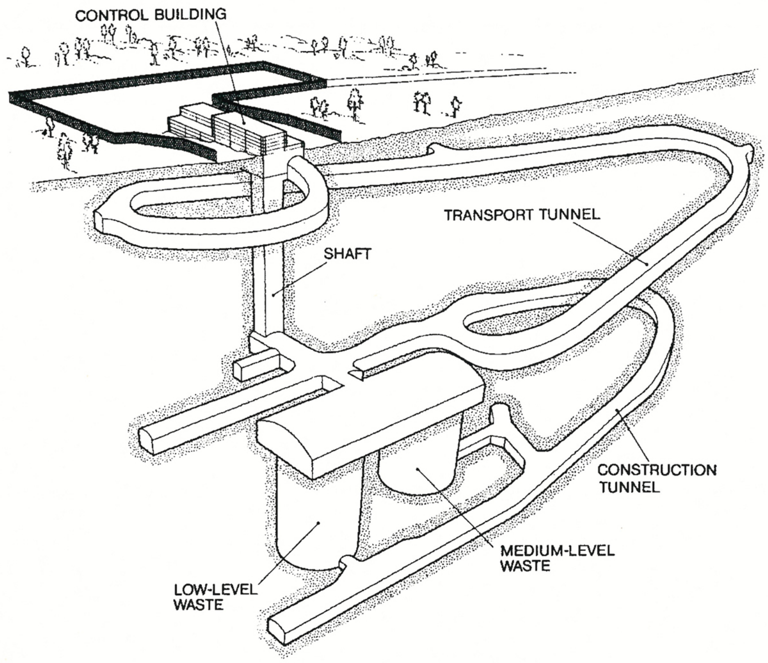

FIGURE 3. REACTOR WASTE REPOSITORY for low-level and intermediate-level waste at Olkiluoto, Finland, the site of two Swedish-built boiling-water reactors. Olkiluoto is also one of the sites being considered for spent fuel disposal. (Finland also has two Russian-built power plants at Loviisa; until recently their spent fuel was returned to the supplier—Russia.) (Image courtesy of Posiva, Finland.)

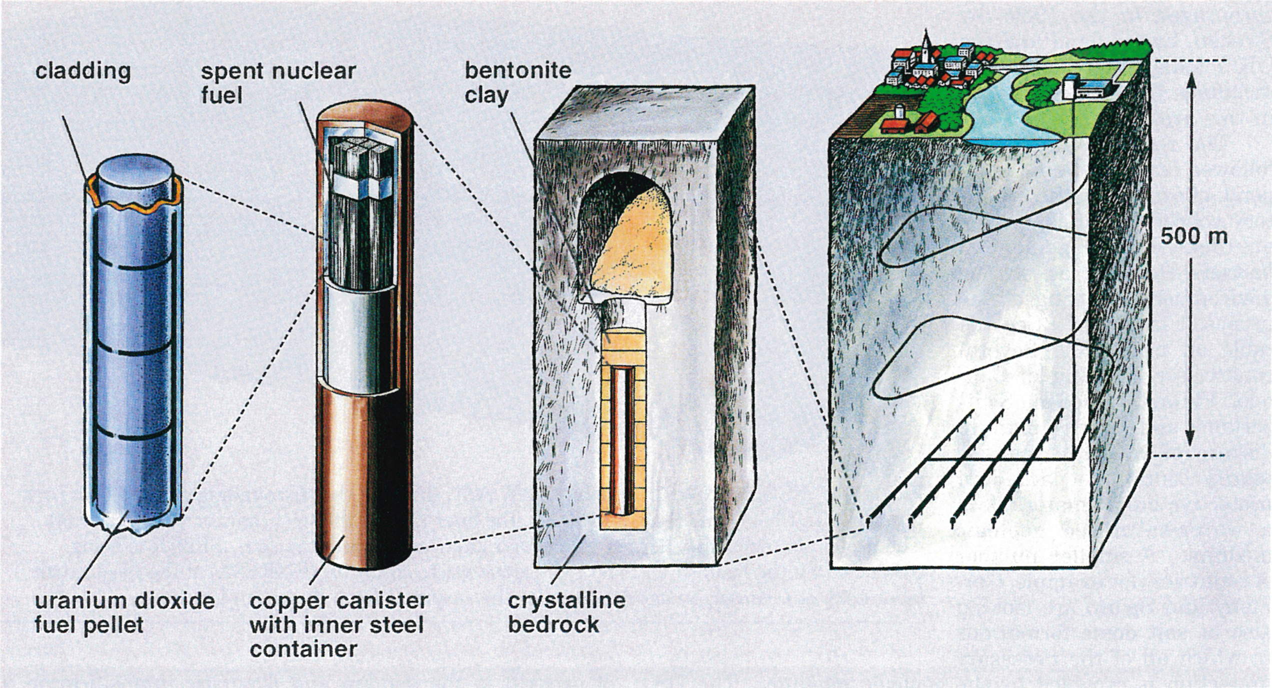

FIGURE 4. DEEP REPOSITORY FOR SPENT FUEL designed in accordance with Sweden's KBS-3 plan. The first (demonstration) phase of the repository should start operation in 2008, with canisters being filled at a rate of one per day, each weighing about 25 tons, including about 2 tons of fuel. The waste first undergoes interim storage for a few decades at a facility that went into operation in 1985. (Image courtesy of Per-Eric Ahlström, SKB, Sweden.)

wastes, and isotopic dating methods for rocks and groundwaters. For a long time, however, other countries with fewer resources but more-focused programs, led the field in integrating all of the interdisciplinary work required and in focusing or prioritizing further R&D work. These were often countries that, early on, had recognized the importance of performance assessment as a vehicle for guiding research in the laboratory or in the field. This recognition often arose out of a formal requirement to carry out total system assessments. In recent years the US has increasingly recognized the value of this approach, which is now an established part of DOE strategy.

With its more diversified, bottom-up approach, the US was also slower to appreciate the value of learning by holistic studies of so-called natural analogs. These are natural systems (such as ore bodies, clay beds and alkaline springs) or archaeological artifacts (Roman glasses, ancient metallic objects and so on) that exhibit some of the key features that repository analysts need to understand. By studying how these systems have evolved over geological timescales, one can gain insight into future repository evolution. Natural analog projects were strongly

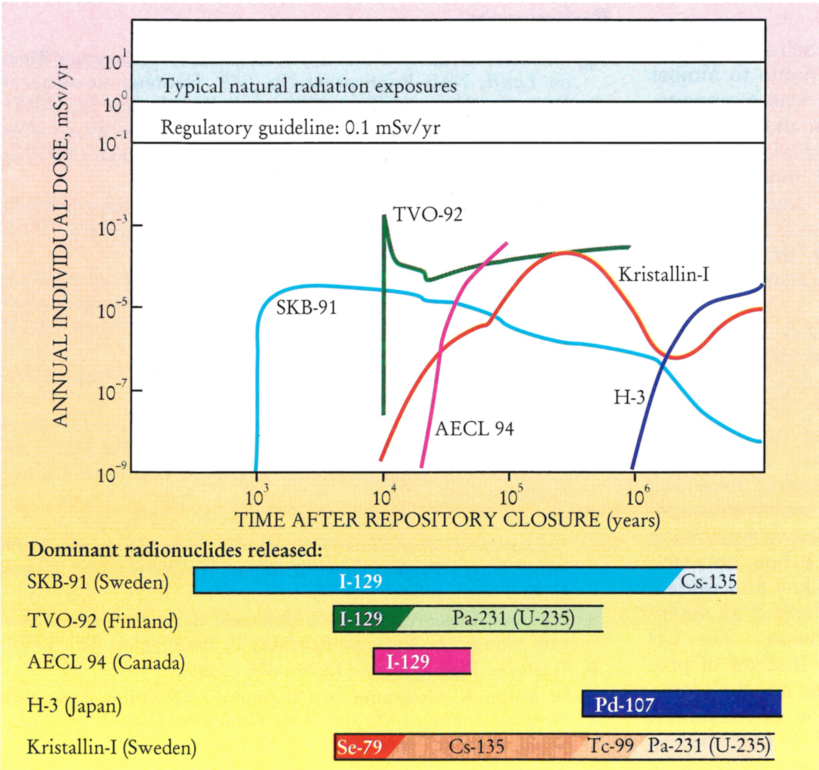

FIGURE 5. DOSE CALCULATIONS from some recent total system performance assessments for repositories of spent fuel or HLW. Releases from a properly designed repository can occur only after tens of thousands of years. The conversion to dose estimates assumes a reference population group at the outflow point in the biosphere, with living and eating habits similar to those of present populations.

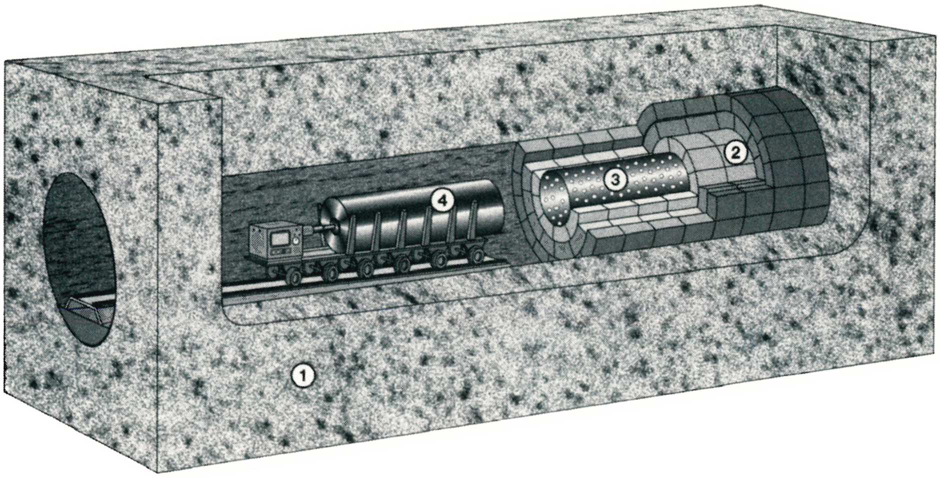

FIGURE 6. **FEBEX,** A FULL-SCALE HEATER TEST, showing the surrounding granitic host rock (1), backfill of bentonite (clay) blocks (2), the liner (3) and the steel canister with heater (4). The heater simulates the thermal effects of a radioactive waste canister. FEBEX is being conducted by the Spanish national radioactive waste company (ENRESA) at the Nagra rock laboratory at Grimsel, Switzerland, under the auspices of the European Union.

encouraged in the 1980s by Sweden, Switzerland and the UK[10]; today, many countries, including the US, are active in this area.

The research lines to be followed in waste disposal depend, of course, on the repository concept—that is, on the engineered and geological barriers—as well as on the environmental setting of the proposed facilities. (See the table on page 58.) Several countries (for example, Canada, Finland, Sweden, Switzerland and Spain) plan to dispose of waste in high-integrity containers packed in protective buffer materials in a water-saturated geologic medium. A smaller number of countries (for example, Germany and Spain) are looking also at salt dome formations in which all of the necessary protection is provided by the geologic medium. The US is rather unusual in planning to locate one project, the Waste Isolation Pilot Plant, in bedded salt and the other, Yucca Mountain, in unsaturated tuff. (Bedded salt formations occur within layered sedimentary rocks. Tuff is a sedimentary rock formed from consolidated volcanic ash.) Moreover, the US also has considered disposal of spent fuel at high temperatures; other countries prefer to minimize the thermal perturbation on the host rock. These differences in emphases are reflected to some extent in the scientific development work, but many of the experimental and modeling approaches are similar enough to allow intensive collaboration between nations.

The future of waste management

The waste management community has reached a general consensus that technical answers are available to almost all of the problems involved in radioactive waste management. There is also a general recognition that technical answers alone are inadequate for political questions. More public involvement is needed, and more trust in technical and scientific bodies must be engendered in public and political circles. The problems will not be solved by throwing unlimited money at them. Some processes take time; even nine women cannot produce a baby in one month!

There is, however, no technical urgency to move to disposal immediately. No major risks are caused by delays. Unnecessary delays, nevertheless, should be minimized to maintain momentum and inhibit cost inflation. There is a potential alliance of political opportunists, nuclear opponents, committed researchers and understandably cautious scientists who are resisting even the gradual, step-wise progress aimed at by waste management programs. The program in the US draws worldwide attention because of its size and diversity; it has, however, earned a reputation for being expensive, slow and unnecessarily complex. Smaller nations often looked at developments in the US with some apprehension. The US program has tended to seek new options instead of proceeding with available technology; examples are the transmutation programs, plutonium vitrification development and the design of a new, one-of-a-kind tunnel boring machine at Yucca Mountain. A further perceived example of overkill is the sudden and dramatic intensification a few years ago of all formal quality assurance procedures.

The view from outside is that significant advances have been made in coordinating the huge US program, but that more scope for improvement exists. The international waste management community is involved in an uncommonly intensive way in technical collaboration. This cooperation includes sharing information, jointly supporting research projects and exchanging technology. One day it may even extend to optimizing repositories, in an engineering, economic and environmental manner, by means of implementing common facilities, using the combined expertise of various countries.

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