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The BRIDGE

LINKING ENGINEERING AND SOCIETY

International Perspectives on the Reprocessing, Storage, and Disposal of Spent Nuclear Fuel
Charles McCombie

The Current Status, Safety, and Transportation of Spent Nuclear Fuel
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Will the United States Need a Second Geologic Repository?
Per F. Peterson

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Editorial

Lawrence T. Papay is sector vice president for integrated solutions for Science Applications International Corporation and an NAE member.

The Science and Politics of Radioactive Waste Disposal

About 20 years ago, I took on overall responsibility for the nuclear program at Southern California Edison. As part of that responsibility, I became Edison's representative on the Steering Committee of the Utility Nuclear Waste Management Group of the Edison Electric Institute (EEI), which was responsible for overseeing the scientific and technical program being conducted by the U.S. Department of Energy (DOE) to determine the best method for the permanent disposal of spent fuel from nuclear power reactors. (Spent nuclear fuel is one of three types of waste constituents defined by the U.S. Nuclear Regulatory Commission [USNRC] as high-level waste—the other two are reprocessed nuclear fuel waste and other highly radioactive materials that require permanent isolation.)

High-level nuclear wastes have been part of the "nuclear scene" since the start of the Manhattan Project. In terms of the civilian nuclear program, radioactive wastes have been with us since the 1950s when reactors first generated power for civilian use. In 1957, a report by the National Academy of Sciences, *The Disposal of Radioactive Waste on Land*, recommended the geologic disposal of radioactive wastes. As a result, the Atomic Energy Commission (AEC) began to investigate the concept of mined geologic repositories.

The search for potential repositories continued through the 1960s and 1970s. In 1982, Congress passed the Nuclear Waste Policy Act (NWPA), which formally legislated a process for determining suitable repositories. In 1985, DOE, the successor to the AEC, issued environmental assessments of five potential sites; in 1986, DOE recommended three sites for characterization. During this time, I served on the EEI committee.

In 1987, NWPA was amended to direct DOE to characterize only the Yucca Mountain site in Nevada. The characterization was completed in 2001, and DOE Secretary Abraham subsequently recommended Yucca Mountain to the president, who agreed with the finding. In accordance with the amended NWPA, the governor of Nevada had the opportunity to agree with the president's action or veto the approval. He chose to veto the approval, but Congress overrode the veto. At that point, DOE charged its Yucca Mountain contractor, Bechtel SAIC Corporation, LLC, to proceed with the license application, which DOE intends to submit to USNRC at the end of 2004. If the schedule and funding levels hold, the first emplacement of wastes will occur at Yucca Mountain in 2010.

For me, the story of spent nuclear fuel has come full circle, as I am currently a member of the Board of Managers of Bechtel SAIC Corporation. As this chronology demonstrates, the potential disposition of radioactive wastes has followed a tortuous path that has included not only a great deal of science and technology, but also a great deal of political heat, both pro and con, and a good deal of acrimony.

Where do we stand today on the subject of high-level radioactive waste disposal? In February 2003, NAE held a National Meeting Symposium in honor of the retirement of Foreign Secretary Harold Forsen, who chose "Technology and Policy for Disposition of Spent Nuclear Fuel" as the topic. A variety of papers were presented covering everything from the current status of the Yucca Mountain Project to developments in the international arena to alternatives to direct disposal, including advanced nuclear fuel cycles, particularly the so-called "Generation IV" concepts and the Advanced Fuel Cycle Initiative, both major DOE strategies. A good deal of the focus, however, was on the status of the Yucca Mountain Project, existing interim storage at utility sites, and the process by which spent fuel will be removed and transported to the disposal site.

Several participants touched on security issues, but the potential impact of terrorism on the current possessors of spent fuel and the vulnerabilities of transportation systems and the repository design were not fully explored. However, I think everyone was of the opinion that placing spent fuel in the Yucca Mountain repository would greatly lessen the potential for acts of terrorism. This issue deserves more thought and discussion. The papers by Charles McCombie, John Garrick, and Russell Dyer and Margaret Chu in this issue are based on symposium presentations. A fourth paper by Per Peterson rounds out the issue.

In his survey paper, "International Perspectives: Reprocessing, Storage, and Disposal," Charles McCombie notes that by and large the technical issues related to these technologies have either been solved or are solvable. Deep geologic disposal is the preferred approach for disposal, although the costs may be very high. The chief obstacle, however, has been the lack of public acceptance. If the Yucca Mountain Project stays on schedule, it may be the first operational deep geologic disposal site for spent fuel. Yucca Mountain would then become a reference facility for other national programs.

The focus of John Garrick's paper, "Spent Nuclear Fuel: Current Status, Safety, and Transportation," is on the safety aspects of handling spent fuel and transporting it from interim, on-site storage sites to the repository site. He concludes with two recommendations: (1) the "record of experience with the shipping of spent nuclear fuel should be made available in a factual, understandable, and comprehensive form;" and (2) "realistic risk studies should be done of specific alternate routes and means of transporting spent nuclear fuel to the repository site." He believes that these steps are necessary to increase public acceptance of the measures necessary for the safe storage and disposal of spent nuclear fuel.

Russ Dyer, Assistant Deputy Director, Office of Repository Development, Office of Civilian Radioactive Waste Management, U.S. Department of Energy, presented "Yucca Mountain: Licensing, Design, and Construction," which covered many of the technical programs under way at Yucca Mountain. Russ pointed out that the focus of the national program has shifted from policy and science to the licensing requirements of the USNRC (e.g., site characterization, construction authorization, construction, etc.). The authors believe that ultimately the license application should be amended.

In the companion paper, Per F. Peterson of the Department of Nuclear Engineering at the University of California, Berkeley argues that the strategy for designing and sizing geologic repositories should be dictated by (1) the number of commercial nuclear reactors in operation in the future (which may increase as well as decrease); and (2) the future reprocessing of spent fuel to extract usable isotopes of plutonium, if and when the economics dictate. At that point, long-term monitoring will become very important, and the number and size of repositories should be reassessed.

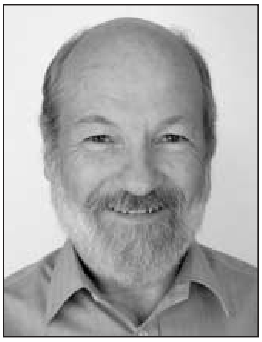
In the saga of spent nuclear fuel in this country, 2002 was a momentous year. But, if "past is prologue," we must all realize that a great deal remains to be done. Many issues will have to be resolved, including an extended regulatory process and appropriate levels of funding for (1) the design and construction of the repository; (2) transportation studies and, probably, the construction of new rail facilities; and perhaps (3) increased interim storage at newly emerging "merchant" nuclear power plants.

The next seven to ten years will be challenging and interesting to say the least. One thing is certain. A resurgence of nuclear power requires that the spent fuel question be resolved satisfactorily, not only in a regulatory sense, but also in the minds of the public.

The chief obstacle to geologic disposal is the lack of public acceptance.

International Perspectives on the Reprocessing, Storage, and Disposal of Spent Nuclear Fuel

Charles McCombie



Charles McCombie is an international consultant and executive director of ARIUS: Association for Regional and International Underground Storage, Baden/Switzerland. A longer version of this paper was presented at the NAE National Meeting Symposium on Technology and Policy for Disposition of Spent Nuclear Fuel in February 2003.

The technical maturity and development potential of technologies for the storage, reprocessing, and disposal of spent nuclear fuels differ greatly, as do the political and social issues they raise. The material flows and waste products are summarized in Figure 1, normalized to one tonne of reactor fuel in a light-water reactor, closed-fuel cycle. All of the operations listed in Figure 1 produce radioactive wastes in solid, liquid, or gaseous forms. Although the greatest environmental challenges may be associated with wastes at the front end of this chain—namely, the millions of tonnes of mining and milling tailings that remain on or near the land surface of uranium-producing sites—most of the time, effort, resources, and public attention have been focused on the management of the low-volume, but highly hazardous wastes from the back end of the fuel cycle—spent nuclear fuel (SNF), if this is regarded as waste, or the vitrified high-level waste (HLW) and the accompanying long-lived transuranic wastes that remain after reprocessing.

The most controversial issue today is disposal of these waste streams. Deep geologic repositories are currently the only recognized feasible method of safe permanent disposal. This will be the main focus of this paper, but let us look at the three technologies in turn.

Storage

Storage of nuclear wastes, a long-established technology, is widely practiced today and will continue to be necessary for many decades to come. During storage, the key goal is to ensure the safety and security of stored HLW and SNF. Early on, SNF was stored primarily in water pools in well protected nuclear facilities (wet storage). Increasingly, however, SNF and HLW are being stored in strong, sealed, shielded containers (dry storage) or in vaults. Both wet and dry storage can provide safety and security. Dry storage is better suited for very long periods of time, although some wastes (e.g., SNF from U.K. magnox reactors [with magnesium alloy cladding]) must be kept under water for safety reasons. Although no new technical developments are necessary to ensure the safety of stored nuclear wastes, work continues on monitoring fuel creep, hydrogen migration, and so on. The recent increase in terrorist acts has also led to a reexamination of some security concerns, such as vulnerability to missile attack.

Some important policy issues must still be addressed, especially the duration of storage and the location of storage sites. When reactors or reprocessing plants were built, it was believed that the SNF or HLW would be removed (after limited storage to allow for cooling) and shipped to a disposal facility. The huge delays in implementing disposal facilities have meant that storage periods have been drastically extended. In some countries, geologic repositories are still so far off that no date can be predicted; in a few countries, not even the feasibility of geologic disposal has been accepted, thus making storage "indefinite." Additional storage can be located at reactor sites, provided that licenses can be amended, or at new centralized storage facilities, provided that these can be sited. But, communities that currently host stores of SNF or HLW, or that are being proposed as hosts, understandably do not wish to become de facto final repositories. As the delays in disposal continue and requirements for storage are increased, this controversy grows.

The situation in the United States concerning storage and disposal illustrates how policy issues can directly affect technical programs. Reactor operators who do not have sufficient on-site storage for SNF have initiated litigation against the U.S. Department of Energy (DOE), which failed to meet the 1998 target date for DOE acceptance of such fuel. This problem has also led to proposals for storage facilities run as private enterprises. To run disposal operations as efficiently as

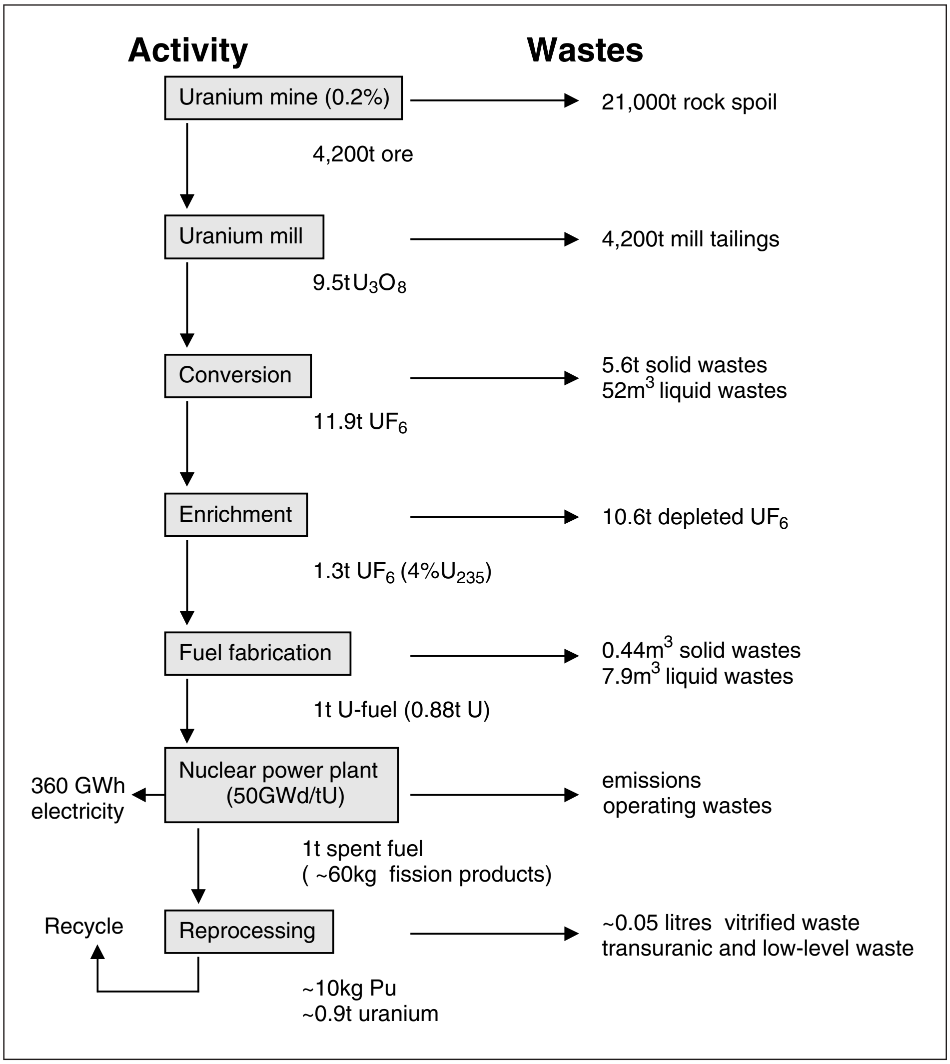


FIGURE 1 Typical material flows (t = tonnes) in the nuclear fuel cycle.

possible, it would be advantageous to have a large storage capacity close to the repository so that waste emplacement could be decoupled from DOE acceptance and could be planned to minimize thermal-loading problems. A recently published study by the National Research Council on repository staging suggests that storage facilities should be located adjacent to the Yucca Mountain repository (NRC, 2003). However, because of the political sensitivities associated with implementing a large storage area before a repository is available, this may not be a feasible policy option.

Reprocessing

Civil reprocessing technology was developed to obtain unused uranium and plutonium for use in fast reactors. The technical challenges associated with this process have been solved, and large-scale reprocessing plants are in operation in France, United Kingdom (U.K.), Russia, and the United States; in other countries (e.g., Belgium and Italy), they have been operated as research facilities. France, the U.K., and Russia offer commercial reprocessing services that are being used or have been used by a number of countries (e.g., Japan, Germany, Switzerland, Italy, Spain, and Sweden); Japan is currently building its own commercial reprocessing plant.

Technical improvements are still possible, such as increases in separation efficiencies and reductions in emissions of radioactive substances during operation. There are bigger technical challenges, however. One is to develop an advanced reprocessing and fuel fabrication cycle that avoids having segregated plutonium at any stage. This could greatly reduce the risk of proliferation associated with reprocessing. Another technical challenge might be to develop a "second-generation" waste form to succeed the borosilicate glasses in which fission products are included. A great deal of work has been done on the development of ceramics and synthetic minerals. The question is whether the improved performance with these materials is necessary to increase the already high levels of safety predicted for repositories.

In practice, the main technical challenge associated with reprocessing may be the mundane challenge of reducing costs. The costs of reprocessing are so high today that they cannot be recouped either by the value of the recovered materials or by the savings on storage and disposal costs. Commercial repositories will break even only if the price of the uranium feed increases far beyond the current typical uranium prices of $20 to $40/kg. Subsidies for utilities willing to use mixed plutonium-uranium oxide (MOX) fuel would make MOX fuel more attractive commercially and could help reduce excess weapons-grade plutonium.

The policy decisions that led to the development of commercial reprocessing were based on conserving uranium resources by providing a supply of plutonium for fast reactors. This argument has been severely weakened over time by the slow growth of nuclear power, which has kept the price of uranium low. Moreover, because the deployment of breeder reactors has been postponed, the demand for, and therefore the value of, plutonium has been reduced. In fact, the excess plutonium already produced from reprocessing has become a liability (it is expensive to store and degrades in storage) and has created a potential risk of proliferation. The nuclear industry is using some plutonium in MOX fuels, although the costs are high and the uranium savings are only around 20 percent. Options being seriously considered include (1) reactors designed to burn excess plutonium; and (2) disposing of plutonium as a waste.

The main technical challenge associated with reprocessing may be reducing costs.

In summary, the key policy issues associated with reprocessing are the now weak resource-conservation arguments, increasing concerns about nuclear proliferation, and the economic costs associated with the low price of fresh uranium. Countries that currently follow a reprocessing strategy do so for one or more of the following reasons:

- They believe that uranium resources may yet become scarce or that access to uranium will become difficult for countries with no indigenous resources; plutonium would then become a valuable fuel.
- They wish to move spent fuel off reactor sites, but neither storage nor disposal facilities are available.
- Reprocessing reduces the volume of high-quality waste products (vitrified HLW) that can be stored and disposed of at lower cost.

- They have invested large sums in reprocessing technology; these must in any case be amortized so that only marginal costs are relevant.

Geologic Disposal

Geologic disposal is the least tested technology of the three nuclear technologies discussed in this paper. In fact, although the concept of disposal in deep geological formations was long ago recognized as the most promising form of confinement for long-lived wastes from the nuclear fuel cycle (NRC, 1957), to date, no deep geologic repository for SNF or HLW is in operation. Every waste disposal program in the world has experienced delays—often significant delays. If the Yucca Mountain project passes its current hurdles, the United States may be the lead nation, followed closely by Finland and Sweden. By around 2020, there could be three operating repositories. Other countries (such as Japan and Switzerland) will have no need to implement deep disposal of SNF/HLW until 2030, or even 2050. In some countries (e.g., U.K., Canada, Spain, Netherlands), decisions on geological disposal are still wide open, and implementation may be a hundred years off. In fact, after catastrophic failures of their repository development programs, U.K. and Canada have officially declared that geologic disposal is no longer established policy and must be considered along with other waste-management options.

> *To date, no deep geologic repository is in operation for spent nuclear fuel or high-level waste.*

Technical Challenges

Implementing a deep repository involves designing or selecting engineered and natural safety barriers, undertaking major underground construction, building and operating equipment and facilities for transporting, encapsulating, and emplacing SNF or HLW, running emplacement operations, and backfilling and sealing the facility after many decades. Most waste-management organizations agree that a staged or stepwise program is the best approach to this major long-lasting project.

Despite the scale and complexity of the engineering and science involved, however, the only really controversial technical issue is the credibility of predictions of repository system behavior for tens or hundreds of thousands of years into the future, and the debate on this issue has been intensifying. On one hand, opponents of nuclear power fear that accepting geologic disposal as a safe end-point might encourage the use of nuclear technology. On the other hand, proponents of geologic disposal often overstate the certainty of their arguments, failing to make it clear that absolute certainty and zero risk are unattainable.

In my opinion, no strictly technical issues prevent implementation of geologic repositories, although the task is by no means trivial. In fact, this opinion is held by the majority of the scientific and technical community. Even many technical experts who are still concerned about uncertainties would be prepared to initiate the disposal process, if it could be reversible for the coming decades. The common impression that a great technical controversy exists is largely attributable to the media's tendency to give equal coverage to both sides of every argument, regardless of where the weight of opinion lies.

Most of the controversial issues associated with geologic disposal are, therefore, questions of policy rather than questions of technology. Are there credible alternatives to geologic disposal? When should disposal projects be implemented? Where, if anywhere, can repositories be equitably sited? Can they satisfy technical safety criteria and also win sufficient support from the public? Can the disposal strategy be reversed if unforeseen problems arise? These are the key questions repeatedly being posed about geologic disposal.

Although recent documentation by various organizations has confirmed the confidence of the scientific community in geological disposal, a significant fraction of the public does not share this confidence. The lack of public support is often related directly to the controversial issue of siting nuclear facilities, which has a troubled history that has led to continual changes in the selection processes. Early on, some sites were chosen purely by experts and officials behind closed doors. The selection of the Gorleben site in Germany in the 1970s is a prime example. In the 1980s, international bodies, primarily the International Atomic Energy Association (IAEA), mapped out a top-down, technical procedure intended to narrow a range of choices through objective criteria to a single site that would be recognized by all stakeholders as the most appropriate. However, experience in various countries (e.g., France, U.K., and Switzerland) showed that this "decide, announce, and defend" (DAD) strategy could lead to controversy, delays, or failures.

Since then, more importance has been put on societal criteria, particularly the degree of acceptance in potential host communities, although the capability of a site to provide long-term isolation remains a condition sine qua non. This approach has been successful, particularly in the Scandinavian countries. In Finland, the implementer, the local community, the parliament, and the government have agreed on a geological repository site. In Sweden, local communities at two potential sites have agreed to investigations that could lead to implementation. Japan has requested that interested municipalities volunteer (more than 3,000 have been contacted).

Must every country have its own geological repository? In fact, the nuclear fuel cycle is already international, and there are no ethical, technical, or other reasons to compel countries to implement national solutions. Mining, enrichment, fuel fabrication, and reactor construction are all carried out by relatively few nations for the dozens of countries that use nuclear power. In a similar way, other toxic wastes are imported and exported when better environmental results can be achieved. International agreements (e.g., the IAEA Radioactive Waste and Spent Nuclear Fuel Convention) recognize the legitimacy of these transfers, as long as the waste-producing country is responsible for the safe and secure management of the waste. Nevertheless, some individual countries have legislated against importing waste. This is a national prerogative that must be respected, even though it is based more on considerations of public opinion and political feasibility than on ethical considerations.

A final policy-related issue in waste disposal concerns the security implications of moving wastes and spent fuel from distributed surface-storage facilities to centralized underground repositories. It seems clear that more safeguards against misuse and better physical protection against terrorists can be offered at repositories. Counterarguments are the risks involved in transporting wastes to repositories and the potential attraction of centralized sites for terrorist groups. This debate is, however, of little immediate relevance because there is no way of accelerating repository programs enough to have a major impact on security in the next 10 years or more.

Conclusions

The technologies for storing, reprocessing, and disposing of HLW and SNF have all been developed to the implementation stage. The challenges are in all cases more societal than technical.

Storage technologies are well tried and present no technical problems. As reactor storage facilities fill up, the siting of centralized storage facilities presents a serious societal challenge.

Reprocessing technology has been developed and implemented in various countries; improvements could be made, but there is little incentive to pursue them, primarily for economic reasons. The recurring debate about the hazards of proliferation associated with reprocessing may result in the development of new technologies that avoid segregating plutonium.

There are no ethical, technical, or other reasons compelling countries to implement national solutions.

The technology for geologic disposal is developed and could be implemented today, although significant optimization of designs is possible. The chief obstacle has been the lack of public acceptance. Some countries, however, are moving ahead in a way that promises the operation of repositories in the next 10 to 20 years; these facilities could then act as reference facilities.

With the implementation of the project at Yucca Mountain, the United States could become the first country to implement deep geologic disposal of spent fuel, thus following upon the long-delayed success of the Waste Isolation Pilot Plant (WIPP) Project in New Mexico. But not all of the lessons that can be drawn from the U.S. programs are positive. First, the enormous costs involved are horrific examples for smaller nations. Second, the laudable transparency of progress has been somewhat tarnished by political bargaining and legal wrangling.

The National Academies have had a long-lasting, important influence on waste-management strategies. This is illustrated by reports produced at regular intervals, from the landmark report of 1957 (NRC, 1957) through various other strategic reports (e.g., NRC, 1990, 1995, 1996, 2001) to the staging report released on the day of this symposium (NRC, 2003). In addition, numerous technical reports have been produced by scientists and technologists working within the framework of the extensive committee system of the National Research Council. These reports continue to provide unbiased input on issues vital to the safe management of all radioactive wastes.

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Strong evidence shows that spent nuclear fuel can be stored and transported safely.

The Current Status, Safety, and Transportation of Spent Nuclear Fuel

B. John Garrick

B. John Garrick is an independent consultant based in Laguna Beach, California. This paper was presented at the NAE National Meeting Symposium on Technology and Policy for Disposition of Spent Nuclear Fuel in Irvine, California, on February 6, 2003.

Spent nuclear fuel, nuclear fuel that has been in an operating nuclear reactor, is listed by the U.S. Nuclear Regulatory Commission (USNRC) as one of the three constituents of high-level waste—the other two are reprocessed (nuclear fuel) waste and "other highly radioactive material that the USNRC, consistent with existing law, determines by rule requires permanent isolation" (USNRC, 10 CFR Part 63). The current status of spent nuclear fuel is addressed by three acts of Congress: (1) Nuclear Nonproliferation Act of 1978; (2) Nuclear Waste Policy Act of 1982; and (3) Nuclear Waste Policy Amendments Act of 1987.

The Nuclear Nonproliferation Act of 1978 (P.L. 95-242), passed during the Carter administration, had the biggest impact on the disposition of spent nuclear fuel because it deferred indefinitely the commercial reprocessing and recycling of plutonium produced in the U.S. commercial nuclear power program.[1] The Nuclear Waste Policy Act of 1982 (P.L. 97-425) cleared the way for the federal government to select a site for a geologic repository for the disposal of high-level waste and directed utilities to levy a tax of 1 mil per kilowatt-hour on electricity generated by nuclear power to be paid into the

[1] The Reagan administration lifted the ban on the reprocessing of domestic fuel in the early 1980s, but by then the economic situation, increased reserves of uranium ore, and a declining nuclear power industry provided little incentive for industry to resume reprocessing.

Federal Nuclear Waste Fund, which would be used to develop and operate a repository. In return, the federal government agreed to accept ownership of spent fuel when a repository becomes available.

The 1987 Nuclear Waste Policy Amendments Act of 1987 (P.L. 100-203) altered the siting process and mandated that a single site, Yucca Mountain, Nevada, be characterized as a possible location for a geologic repository. The 1987 decision had a major impact on the nuclear fuel cycle, because pools of spent fuel had to be expanded and upgraded to accommodate the new interim storage requirement. The expansion involved installing high-density fuel racks so that more assemblies could be safely stored and required extensive safety analyses and licensing amendments. Today, some modified pools have reached their capacity, and on-site storage capabilities at some nuclear power plants have had to be augmented with dry storage casks.

On July 9, 2002, the U.S. Senate voted to allow the Yucca Mountain repository project to move into the licensing phase. On July 23, 2002, President George W. Bush signed the congressional resolution on Yucca Mountain allowing the U.S. Department of Energy (DOE) to prepare a license application for the repository. DOE has indicated that a license application will be submitted to USNRC by the end of 2004. Operation of the repository is scheduled for 2010.

Characteristics and Properties of Spent Nuclear Fuel

Spent nuclear fuel is produced by many types of reactors—light-water reactors, liquid-metal reactors, gas-cooled reactors, military reactors, test reactors, research reactors, and developmental reactors. Spent fuels involve a plethora of materials, including oxides of fissile materials, alloys of zirconium (zircaloy), stainless steel, aluminum, and for developmental reactors, exotic materials such as molten mixtures of several fluoride compounds. Fuel assemblies for commercial light-water reactors are bundles of zircaloy tubes filled with uranium dioxide (UO_2) pellets that are slightly enriched in uranium 235 (^{235}U), pressurized with helium, and closed with welded zircaloy end plugs (Figure 1). For a pressurized-water reactor, the tubes have outside diameters of approximately 0.4 inch and overall lengths of approximately 14 feet; in a large reactor, some 200 tubes make up an assembly, and approximately 200 assemblies comprise the reactor core. The dimensions and fuel enrichments are different for boiling-water reactors, but the materials and neutronics are similar. Thus, they have essentially the same requirements for management of spent fuel.

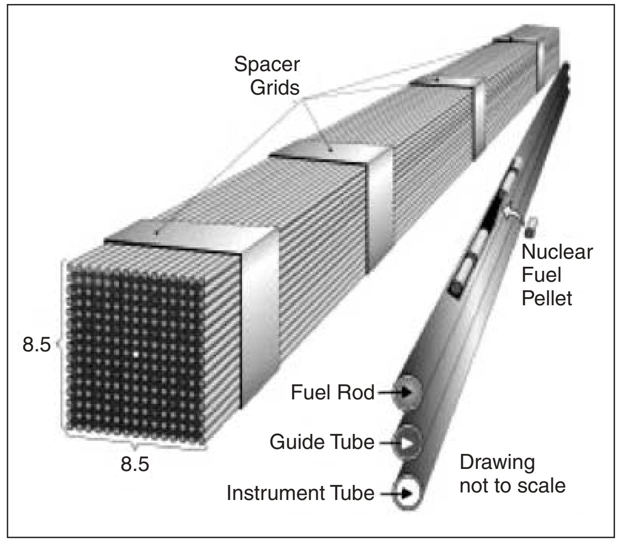

FIGURE 1 Typical fuel assembly for a light-water reactor. Source: DOE, 2003.

The extent to which the fuel is irradiated (burned up) in the reactor determines the amount of radioactive waste created. The units of burn-up are usually taken to be the amount of energy produced per initial unit weight of the fuel (megawatt days per metric tons of heavy metal [Mwd/MTHM]); in nuclear reactors, the heavy metal is essentially uranium. When a nuclear reactor has achieved equilibrium in the production of radioactive species, there are some 51 new actinides and 250 fission product species, all radioactive, that were not there originally. Fortunately, only a few of these are important in spent fuel disposal; most of the other species are in very small quantities, have short half-lives, and have minor biological consequences.

There are three important categories of radioactive species for the design of a geologic repository. The first (^{90}Sr and ^{137}Cs) is not considered a health risk because of the relatively short half-lives of these species; they are, however, the main contributors to the heat released by spent fuel during the first several decades. The heat load is a major issue in repository design. In addition, ^{137}Cs is of concern during preclosure operations because of its shielding requirements.

The second category of radioactive species important for repository design comprises the fission products ^{99}Tc and ^{129}I. These products are very long-lived (half-lives of 2.12×10^5 and 1.7×10^7 years, respectively), and they are present in abundance in the inventory. In addition, they are generally soluble under geologic conditions and thus can migrate relatively quickly under ordinary groundwater conditions. The third category, from the actinide group of radioactive species, includes uranium, plutonium, neptunium, americium, and curium. Figure 2 gives some indication of the toxicity levels of these actinides as a function of time. The DOE Supplemental Science and Performance Analyses indicates that only ^{237}Np poses a long-term risk (more than 100,000 years); the peak dose is ~35 mrem/yr at ~1 million years (DOE, 2001). The annual doses between 10,000 and 100,000 years are dominated by ^{99}Tc, with lesser contributions from ^{237}Np and ^{129}I. Annual doses during the first 10,000 years are dominated by groundwater transport of carbon 14 (^{14}C) and ^{99}Tc from waste packages that have undergone early failure. In case of an igneous disruption, the major contributors to the dose would be the actinides of americium and isotopes of plutonium.

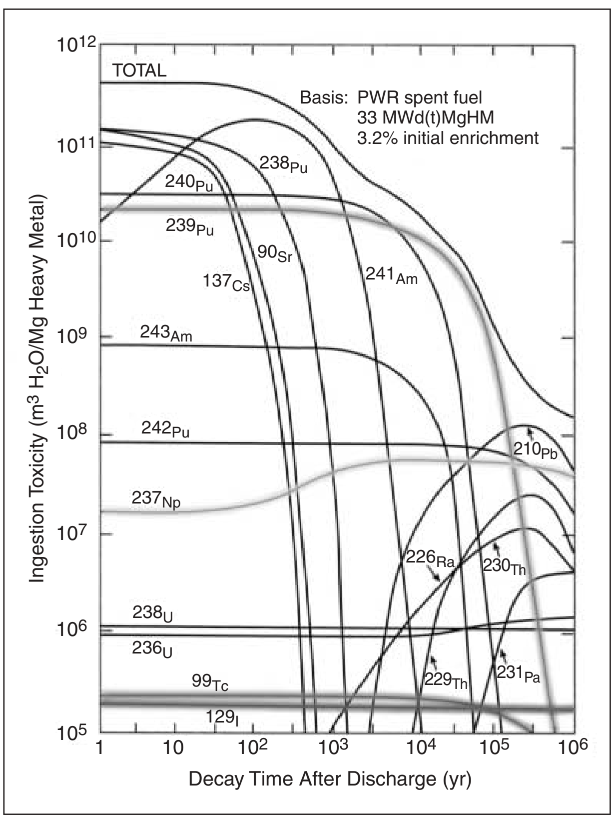

FIGURE 2 Toxicity from ingestion as a function of decay time for a number of nuclides in spent fuel from light-water reactors. Source: NRC, 1996.

Current Disposition of Spent Nuclear Fuel

The total estimated amount of spent nuclear fuel in the United States is ~50,000 MTHM. Some 47,000 MTHM is commercial spent fuel; ~2,500 MTHM is owned by the government and managed by DOE. If and when the Yucca Mountain geologic repository goes into operation, DOE will take ownership of all spent nuclear fuel. Table 1 is an estimate of the current disposition of all spent nuclear fuel in the United States based on projections from 2001 data (Holt, 2002).

Commercial Fuel

The combination of the continued operation of 103 U.S. nuclear power plants since 1972 (~20 percent of the nation's electric energy supply) and no reprocessing of spent fuel has resulted in an estimated total of approximately 47,000 MTHM. About 46,000 MTHM, or 98 percent of it, is stored at 72 commercial nuclear power plant sites in 33 states. Approximately 43,000 MTHM is stored in fuel pools, and 3,000 MTHM is in dry storage. Thus, more than 90 percent of commercial spent fuel is still in pools at nuclear plant sites. To date, 16 sites also have dry storage facilities, which were allowed under a general license issued to all operating nuclear power plants in the early 1990s. Fuel must be stored in casks that have been preapproved through a USNRC rule-making process. Another nine dry spent-fuel storage facilities were approved under site-specific licenses, a more complicated process that usually involves site-specific hearings. Two of the site-specific sites are owned and operated by DOE, at the Fort St. Vrain site in Colorado and at Idaho National Engineering and Environmental Laboratory (INEEL). Additional dry, site-specific storage facilities are in the planning stage or are going through the licensing process.

Beyond the nuclear plant sites, a small amount of spent nuclear fuel (less than 1,000 MTHM) is stored at other locations, including the General Electric Morris Operation in Illinois, the West Valley Demonstration Project in New York, and INEEL. Storage at the Morris and Idaho sites accounts for almost 95 percent of the approximately 1,000 MTHM.

Fuel Managed by DOE

DOE currently manages approximately 2,500 MTHM from the N-Reactor; experimental power reactors; material-production reactors; naval reactors; and test, research, and educational reacors. DOE also manages some 280 MTHM of commercial fuel submitted for examination and development purposes (DOE, 2002a). The majority of the fuel, about 2,100 MTHM, is from the N-Reactor and is stored in the K-East and K-West

TABLE 1 The Disposition of Spent Nuclear Fuel in the United States (estimated through 2002)

Fuel Type	Quantity (MTHM)	Location and Type of Storage	Comments
Commercial	43,100	Nuclear plant site (pool)	Stored at 72 plant sites in 33 states
Commercial	3,000	Nuclear plant site (dry)	Stored at 16 plant sites
Commercial	700	General Electric Morris Operation (pool)	May be shipped back to generator
Commercial	30	West Valley (WV) Demonstration Project (dry)	May be shipped back to generator
Commercial	170	Idaho National Engineering and Environmental Lab (INEEL) (pool)	May be double counted with DOE stored commercial fuel
N-reactor	2,100	Hanford (pool)	Combination power and material production reactor
Electric power	283	Savannah River Site (SRS), WV, and various national laboratories (pool)	Commercial fuel shipped to DOE for examination and development
Experimental power	58	SRS, INEEL (pool)	Fuel from developmental reactors
Material production	28	SRS (pool)	Fuel from weapons-production reactors
Test, research, and education	26	SRS, INEEL (pool)	Includes some fuel from foreign reactors
TOTAL	~ 49,500	~ 95 percent commercial spent nuclear fuel	

Source: Holt, 2002.

basins at Hanford, Washington. The spent fuel from the other reactor types represents a little more than 100 MTHM. DOE also manages about 1,000 MTHM of unirradiated fuel, the disposition of which has not been determined, but one possibility is that it will be treated as waste. Thus, the total amount of spent and unirradiated nuclear fuel managed by DOE is approximately 3,500 MTHM (NRC, 2003). A considerable amount of DOE-managed fuel (about 85 MTHM) will require some level of treatment to meet the requirements of the proposed Yucca Mountain geologic repository.

Interim storage for all of DOE's spent nuclear fuel is to be provided at three national laboratories—Hanford in Washington, INEEL, and the Savannah River Site in South Carolina. New storage facilities will be necessary at all three sites. Waste from naval fuel is shipped to INEEL for storage at the Idaho Nuclear Technology and Engineering Center. Fuel from test, research, and educational reactors is stored at the Savannah River Site and INEEL. Table 2 is an estimate of the amount of commercial and DOE waste forms for disposal in the Yucca Mountain repository (DOE, 2002b).

Worker and Public Safety in Shipping

Experiential Evidence

The worldwide experience of storing, handling, and shipping spent nuclear fuel and high-level wastes is based on more than 50 years of operating nuclear reactors. Thirty thousand to 50,000 canisters have been shipped by all surface modes of transport (i.e., road, rail, and sea) involving an estimated 100,000 MTMH (Pope et al., 2000). U.S. experience is based on an inventory of approximately 50,000 MTHM. In the United States, between 1964 and 1997, 829 MTHM were shipped by road and 1,445 MTHM by rail; a total of 3,025 shipments. Although there were many more shipments by road, the tonnage of rail shipments exceeded the tonnage of shipments by road by a factor of about 2 (USNRC, 2002). Included in the rail shipments are naval spent fuel, which has been shipped for more than 40 years by rail in shielded shipping containers from naval shipyards, and prototypes, which are shipped to the Expended Core Facility at the Naval Reactors Facility in Idaho, where the fuel is removed from the containers and placed into water pools. U.S. experience includes both commercial and DOE-managed fuels. The data indicate that from 1979 to 1995 the commercial nuclear industry completed about 1,300 shipments of spent fuel—1,045 by highway and 261 by rail.

The U.S. Department of Transportation reports that four highway shipments and four rail shipments were involved in accidents between 1971 and 1995, only one of which resulted in detectable damage to the cask. Although the driver was killed in the accident, radiation surveys at the scene indicated that the structural integrity of the cask was not compromised, and there was no release of radioactive contents Weiner and Tenn, 1999). No injuries, deaths, or nonroutine exposures to radioactive material have resulted from transportation accidents.

Scientific Investigations

Numerous analytic studies and field tests have been done on the safety of transporting spent nuclear fuel by manufacturers of shipping containers as part of the licensing process, as well as by national laboratories, private contractors and consultants, DOE, and USNRC. USNRC studies include an environmental study on transport by air and other modes of transport, a study in 1980 on transporting radionuclides through urban areas, a study in 1987 on the response of shipping containers to severe highway and railway accidents, and in 2000 a reexamination of risk estimates for spent fuel shipments (USNRC, 1977, 1980, 1987, 2000a). As these analytical studies increasingly relied on risk assessments, the estimated safety levels increased.

Field tests have also been performed, and more are planned, to subject shipping casks to severe accidents. Sandia conducted crash tests sponsored by DOE in the mid-1970s: (1) a flatbed truck loaded with a full-scale cask crashed into a 700-ton concrete wall at 80 miles an hour; (2) a cask was broadsided by a 120-ton locomotive traveling 80 miles per hour; and (3) a transportation container was dropped 2,000 feet onto soil as hard as concrete (the container was traveling 235 miles per hour at impact) (Jefferson and Yoshimura, 1977).

Other tests were conducted by the Central Electricity

TABLE 2 Spent Nuclear Fuel and Vitrified High-Level Waste Targeted for Yucca Mountain (repository capacity = 70,000 MTHM)

Properties of Spent Nuclear Fuel	Commercial Pressurized-Water Reactors	Commercial Boiling-Water Reactors	Naval Reactors	N-Reactor and Production Reactors	Vitrified High-Level Waste
Metric tons of heavy metal	40,950	22,050	65	2,100	4,667
Fuel type or waste form	Uranium dioxide	Uranium dioxide	Uranium-based Zr alloy clad	Uranium metal fuel with Al or Zr alloy clad	Borosilicate glass
Fuel cladding	Zr alloy	Zr alloy	Zr alloy	Al or Zr alloy clad	Reprocessed defense and commercial fuel
Average burn-up (Mwd/MTHM)	41,200	33,600	—	—	—
Initial U-235 enrichment	3.75 percent	3.03 percent	93 to 97 percent	—	N/A
Fuel rod array in assembly	17 x 17	8 x 8	—	—	—
Typical size	14 feet	14.75 feet	—	—	Glass in a canister 10 feet long, 2 feet in diameter
Weight of assembly	1,450 lbs	700 lbs	—	—	4,400 lbs per canister

Source: DOE, 2002b.

Generating Board of Great Britain. Known as Operation Smash Hit, these tests included a live television demonstration of the integrity of a fuel cask. The test involved ramming an unmanned locomotive at 100 miles an hour into a cask used for shipping spent fuel from the United Kingdom Magnox nuclear power stations.

In no test, either in the United States or the United Kingdom, was a cask damaged to the point that radioactive material was released. The test results indicated that at the time of the tests analytical and scale-modeling techniques could predict vehicular and cask damage in extremely severe accidents with reasonable accuracy. They also indicated that spent fuel casks are capable of surviving very severe accidents.

In no test was a cask damaged to the point that radioactive material was released.

Currently, USNRC is engaged in a program (referred to as the Package Performance Study [PPS]) to confirm the safety of full-scale casks licensed for rail and truck shipment (USNRC, 2000b). The program involves extensive public participation in the design of the tests. PPS will reexamine the level of protection provided by USNRC-certified transportation package designs under severe accident conditions. The program has two major objectives: (1) to demonstrate to the public through full-scale testing the safety of the spent fuel casks to be used to ship fuel to the proposed Yucca Mountain repository; and (2) to validate the methods used to assess the risk of transportation accidents involving shipments of spent nuclear fuel. The program is in the study and planning phase and is expected to continue through 2005.

The evidence showing the safety of the management and transport of spent nuclear fuel is impressive. This reflects both strict standards for shipping casks (e.g., impact, fire, and water-immersion tests), but also the relatively benign forms of the spent fuel. Unlike most hazardous materials, spent nuclear fuel is not a gas, liquid, or powder. In addition, neither mechanical or thermal energy is present to serve as a dispersion mechanism in the event the casks are penetrated or engulfed in fire. On the whole, undamaged fuel assemblies are very rugged and represent the first containment barrier for radionuclides.

There are some safety issues to be addressed, however, primarily because of differences between past and future shipments: the greater magnitude and increased complexity of the planned shipping campaign; the larger inventories of fuel assemblies that will be handled at any one time at multiple locations; new handling operations; and finally, subsurface emplacement operations.

The United States has limited experience in transporting spent nuclear fuel on the scale expected to support operations at Yucca Mountain. The proposed shipping campaign for Yucca Mountain is expected to last for 24 years and include shipments from 72 commercial sites and five DOE sites. If the shipments are by rail (something yet to be decided), 450 shipments will be required annually, a total of 10,700 shipments. If the shipments are by truck, the estimated number will be 2,200 annually, a total of 53,000 shipments (DOE, 2002b).

The risk-assessment studies performed to date have several limitations. The most significant limitation is that the studies are mostly generic, rather than operation-specific. Future studies should be performed for specific routes with specific human and mechanical resources. Alternative routes should also be considered to determine the most advantageous route. The public is entitled to have choices based on assessments of the risks, costs, and benefits of different routes and support systems.

Finally, there is the risk of terrorist attacks. USNRC, shipping cask manufacturers, and licensees should analyze the risk of terrorist attacks on spent nuclear fuel as rigorously as they analyze nuclear power plant safety. Specific scenarios should be developed and analyzed to pinpoint the vulnerabilities in the spent nuclear fuel cycle. Studies should include the likelihood and consequences of specific types of terrorist attacks under specific conditions.

Conclusion

There is strong evidence that operations involving spent nuclear fuel can be done safely. The experience base is solid in terms of the types of operations but limited in terms of the magnitude and repository-specific activities expected for future operations. Clearly, more emphasis must be put on repository-specific operations for the public to feel confident of the safety of geologic repository operations. For example, more risk-informed evidence will have to be developed on the safety of specific routes of shipments to the proposed Yucca Mountain repository.

I consider two actions very important. First, the record of experience with the shipping of spent nuclear fuel should be made available in a factual, understandable, and comprehensive form. The absence of a centralized, independent organization to collect, analyze, and disseminate the data has compromised the value of studies done to date. The case for the safety of operations involving spent nuclear fuel has not been well represented in the public domain. A centralized information collection and processing system would help.

Second, realistic risk studies should be done of specific alternate routes and means of transporting spent nuclear fuel to the repository site. Even if it turns out, as expected, that all of the routes can be made safe, the quantification of the risk, including the uncertainties of specific shipping routes, could reassure the public.

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Investigations of the natural processes at Yucca Mountain indicate that public health and the environment can be protected.

Licensing, Design, and Construction of the Yucca Mountain Repository

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The deep geologic disposal program in the United States began more than 20 years ago, in 1982, with the passage of the Nuclear Waste Policy Act (NWPA), which set forth processes for characterizing, recommending, selecting, and licensing sites for permanent geologic disposal of commercial spent nuclear fuel (resulting from electricity generation) and high-level radioactive waste (resulting from atomic energy defense activities). In 1987, NWPA was amended (P.L. 100-203) to limit characterization to one site, Yucca Mountain, Nevada. The mission of the U.S. Department of Energy (DOE) Office of Civilian Radioactive Waste Management (OCRWM) is to "manage and dispose of high-level radioactive waste and spent nuclear fuel in a manner that protects public health, safety, and the environment; enhances national and energy security; and merits public confidence."

The consolidation of spent nuclear fuel and high-level waste from 131 sites in 39 states and safe disposal at Yucca Mountain are vital to U.S. national interests. Disposal in a geologic repository is necessary to maintain energy

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options and national security, to advance the cleanup of weapons-production sites, to continue the operation of nuclear-powered ships and submarines, and to advance international nonproliferation goals.

In 2002, we completed nearly 20 years of site investigations of the natural processes that could affect the isolation of radionuclides from spent nuclear fuel and high-level radioactive waste. These investigations show that a repository at Yucca Mountain can provide the reasonable expectation required by the U.S. Nuclear Regulatory Commission (USNRC) that public health and safety and the environment will be protected. The underlying basis for these investigations and engineering designs has withstood many independent scientific peer reviews and thorough examination by national and international organizations.

In February 2002, the secretary of energy recommended the site to the president, and on July 9, 2002, Congress passed a joint resolution approving Yucca Mountain as a suitable site for repository development. The president signed the bill approving the site on July 23, 2002 (P.L. 107-200) thus completing the site characterization phase. Near-term efforts are now focused on seeking a license from the USNRC to construct a repository and develop a transportation system for shipping waste to the proposed repository.

Receiving Waste in 2010

To meet our objective of receiving waste at Yucca Mountain beginning in 2010, we must (1) seek and secure authorization to construct the repository, (2) begin constructing the repository, (3) receive a license to operate the repository, and (4) develop a system to transport waste from civilian and defense storage sites.

We will need construction authorization from the USNRC no later than 2007, which means we must submit a high-quality, defensible License Application (LA) no later than 2004, because the USNRC will require at least three years to consider the application. Because past funding constraints forced us to defer critical work on the transportation system, we must now accelerate its development. Meeting the 2010 objective will also require far greater resources than have thus far been appropriated. We estimate, for example, that it will cost about $8 billion—more than 80 percent of the budget required to meet the 2010 objective—to construct the repository and develop the transportation system.

Developing the Yucca Mountain License Application

The LA must present a defensible position that the repository can be constructed, operated, and closed without unreasonable risk to the health and safety of the public. The USNRC has issued a site-specific licensing regulation, 10 CFR Part 63, which is risk-informed and performance-based. DOE must demonstrate that the repository will meet the specified performance objectives during operations and that after closure, the health and safety of the public will be protected for 10,000 years.

Developing a Transportation System

Even though specific routes are not expected to be identified until four years before waste transport begins, a number of critical steps are ongoing. By the end of 2003, a national transportation strategic plan will be issued that addresses policies; plans for interactions with states, local, and Native American tribal governments through whose jurisdictions waste could pass; identifies necessary activities; and describes the approach to having an operational transportation system in place by 2010.

Meeting the 2010 objective for receiving waste will require far greater resources than have been appropriated so far.

Initial procurement of the cask fleet and orders for long lead-time transportation cask systems and equipment will be placed as soon as possible, focusing first on transportation cask designs that have not been previously developed by industry and already certified by USNRC. We will also prepare for the acquisition of transportation and logistics services, determine the approach for performing cask maintenance, develop initial site-specific service plans in consultation with nuclear utilities, and develop facility and equipment needs assessments for waste acceptance at DOE defense waste sites.

The U.S. rail system has been used for the last 25 years to ship radioactive waste safely across the country. To link the national rail system and the Yucca

Mountain site would cost an estimated $300 million to $1 billion, depending on the corridor and alignment. The final Environmental Impact Statement (EIS) for Yucca Mountain examined five potential rail corridors in the state of Nevada that could be used as transportation routes to the repository (DOE, 2002). If a decision is made to use rail transportation, then we must analyze the environmental impacts of constructing a rail line within the chosen corridor.

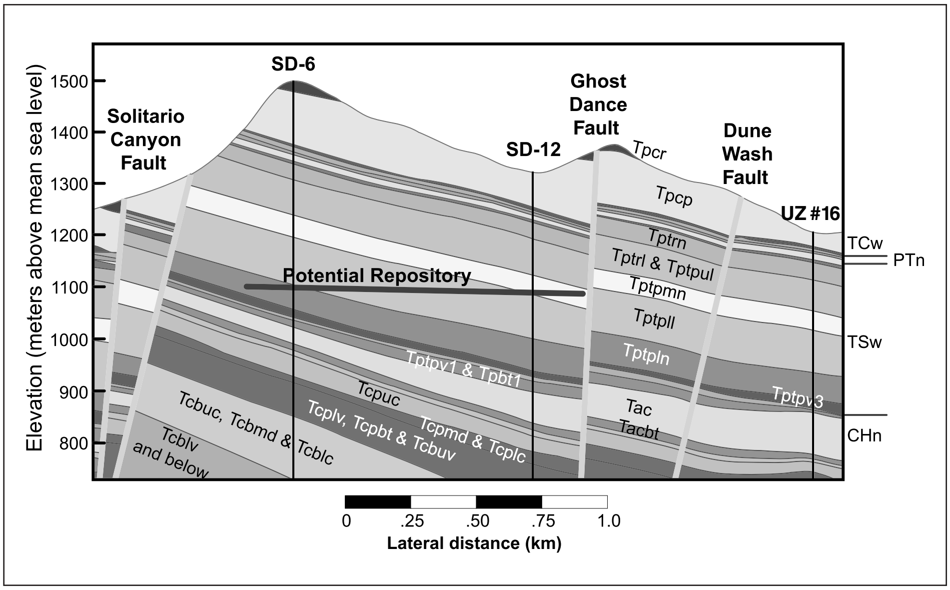

FIGURE 2 Layers of volcanic rock.

Yucca Mountain

Yucca Mountain is located on land controlled by the U.S. government in a remote area of Nye County in the southern part of the state of Nevada, approximately 100 miles northwest of the Las Vegas urban area. Southern Nevada, one of the most arid regions of the country, has annual precipitation of about 7.5 inches, more than 95 percent of which either runs off or is lost to evaporation or transpiration, thereby limiting the amount of water that could seep into the repository. Measurements of the water level in boreholes at Yucca Mountain indicate that the water table is approximately 1,600 to 2,600 feet below the ground surface.

FIGURE 1 Photograph of Yucca Mountain.

Yucca Mountain consists of a series of north-south trending ridges extending approximately 25 miles. The elevation at the crest of the ridges varies from approximately 3,000 to 5,900 feet above sea level. At the proposed repository site, the crest of Yucca Mountain is 4,600 to 4,900 feet above sea level. The mountain slopes gently to the east and is incised by a series of east-to-southeast trending stream channels. The elevation at the base of the eastern slope is approximately 1,100 to 1,500 feet below the ridge crest. To the west of the crest is a steep slope that drops approximately 1,000 feet into Solitario Canyon (Figure 1).

Yucca Mountain consists of layers of volcanic rock (Figure 2), approximately 11.5 to 14 million years old, formed by eruptions of volcanic ash from calderas to the north of the mountain. Most of these volcanic rocks are ash-flow tuffs of two types (welded and nonwelded) that formed when hot volcanic gas and ash erupted violently and flowed quickly over the landscape. As the ash settled, it was subjected to varying degrees of compaction and fusion, depending on temperature and pressure. At higher temperatures, ash was compressed and fused to form a welded tuff—a hard, brick-like rock with low porosity (i.e., very little open pore space in the rock matrix). At lower temperatures, ash was compacted and consolidated between the welded layers. These nonwelded tuffs are less dense, brittle, and have higher porosity (i.e., more open pore space in the rock matrix).

The resulting layers have very different hydrologic behavior.

Exploratory Studies Facility

During the site characterization phase, we conducted many studies from the surface that involved excavating approximately 200 pits and trenches, drilling more than 450 boreholes, and instrumenting more than 25 wells. To get scientists underground where they could see and test the rock near the repository horizon, the exploratory studies facility (ESF), a U-shaped tunnel (approximately 5 miles long and 25 feet in diameter) about 1,000 feet below the crest of Yucca Mountain was excavated. Additional areas were subsequently excavated to enable direct observation of geologic and hydrologic conditions, the engineering properties of the rock, and the response to construction activities. The ESF, along with a smaller cross drift (16.5 feet in diameter and 1.6 miles long), excavated in 1998, have been used extensively to conduct tests in 13 alcoves and niches. The cross drift crosses over the ESF main drift and provides access to the deeper rock units of the proposed repository (Figure 3). Since the start of active testing in the ESF in 1996, more than 20 major experiments have been completed or are in progress. The remainder of this paper summarizes current ambient testing and ongoing and completed thermal tests.

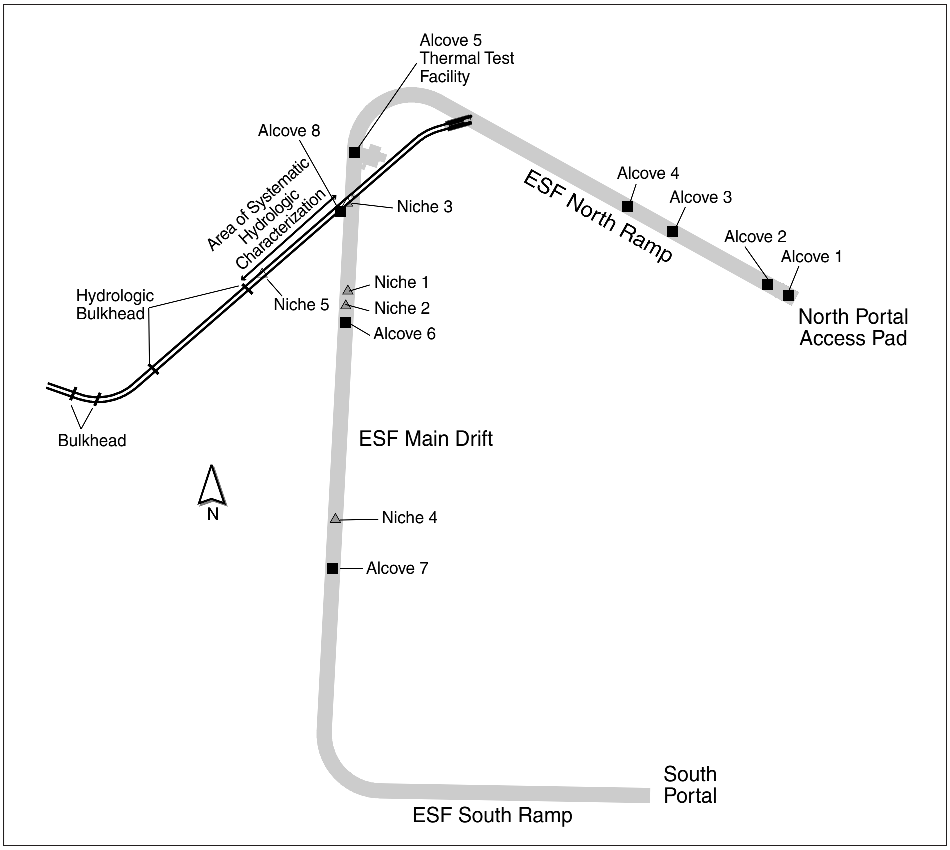

FIGURE 3 Drawing showing deeper rock units of the proposed repository.

Ambient Testing

On the most fundamental level, the climate and the hydrologic properties of the rock units are the important factors affecting performance of the Yucca Mountain unsaturated zone as a natural barrier to radionuclide release. Estimates of parameters for percolation flux[1] at the repository horizon and potential seepage[2] into waste emplacement drifts are derived from these two basic components. These, in turn, are central to development of the unsaturated zone flow and transport process model, which is part of the total system performance assessment model that will be used in the LA.

Alcove 8/Niche 3

Tests in Alcove 8/Niche 3 started in 1999 to help determine how water flows through the repository horizon and investigate flow and transport within a fault zone. Alcove 8, located off the cross drift, overlies Niche 3, which is situated on the ESF main drift. The detailed objectives are to quantify flow and seepage processes at the scale of tens of yards and to evaluate

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[1] Percolation flux, the flow of liquid water to the repository horizon, strongly influences drift seepage and radionuclide transport. Percolation flux is a quantity derived from knowledge of various parameters, including climate and infiltration, chemical analyses (i.e., major/minor ions, total chlorides), environmental isotopes, perched water occurrences, heat flow, and analysis of fracture-fillings.

[2] Seepage is the flow of liquid water into an underground opening. Potential seepage into the repository drifts is an experimentally determined quantity investigated through water-release studies.

matrix diffusion mechanisms in long-term flow and transport tests across a lithophysal-nonlithophysal interface. Water containing tracers is released in Alcove 8 (lithophysal rock), and any resultant seepage is collected in Niche 3 (nonlithophysal rock), located approximately 66 feet below. Results to date include determination of seepage threshold (i.e., the value of applied percolation flux below which no seepage is observed) under high-humidity conditions (behind the hydrologic bulkhead to isolate the test from effects of tunnel ventilation) and measurements of tracer diffusion within a fault zone.

> *Isolated behind multiple hydrologic bulkheads, Alcove 7 has been monitored for about four years.*

Systematic Hydrologic Characterization

Tests in the cross drift systematically characterize the hydrologic properties of the Topopah Spring welded (TSw) lower lithophysal unit. Testing started in 1999 in a section of the cross drift approximately 1,640 feet long. A series (nine planned) of inclined boreholes, 98 feet long, were drilled into the crown of the cross drift, and water was released from packer-isolated sections of the individual boreholes. Additional boreholes were also drilled perpendicular to the drift in the horizontal plane. Water moving through the fracture system of the rock is being collected and analyzed to determine the seepage threshold and matrix-diffusion properties of the TSw lower lithophysal medium. Because of the considerable size of the test bed, this study will also provide data to assess scaling issues concerning hydrologic-property spatial variability within this repository unit.

Tests in the cross drift also help evaluate the effects of ventilation on moisture. Observations designed to quantify the effects of dry-out (from ESF ventilation) and rewetting (in areas isolated behind hydrologic bulkheads) began in 1999. A large section of the cross drift (approximately 2,900 feet) is presently being monitored to see if seepage under ambient conditions can be observed. This portion of the cross drift underlies an area that receives relatively high surface infiltration; if seepage were to occur under ambient conditions, this part of the tunnel system should be the most conducive to development and observation of active seeps. Instrumentation within this isolated section includes heat-dissipation probes, temperature probes, relative-humidity sensors, pressure sensors, chemically treated drip cloths, remote television cameras, and sample-collection bottles attached to rock bolts and other potential points of water accumulation. Accumulations of water within the drift have been observed. However, chemical analyses of collected samples suggest the most probable mechanism of condensation is driven by temperature gradients in heat generated from mining and data collection instruments. To date, no seepage has been observed.

Niche 5

Tests in Niche 5 help determine the hydrologic properties and seepage threshold of the TSw lower lithophysal unit. Similar to tests completed in the other niches devoted to seepage studies (ESF Niches 1, 2, 3, and 4), Niche 5 was excavated in 2000 to investigate potential seepage through controlled releases of water. To obtain more realistic estimates of seepage potential than were investigated in Niches 1 through 4, however, the rates of water release were substantially slower, and the time period of injection was longer.

An additional objective of testing in Niche 5 is to see if the effects of the lateral diversion of flow due to the capillary barrier imposed by the excavation of the drift itself can be observed and quantified (account for mass balance). This is being pursued through the observation of water released from boreholes located above the niche to see if it migrates into a collection slot cut into the side of the niche.

Alcove 7

Tests in Alcove 7 help determine whether seepage can be observed in the vicinity of faults. Alcove 7 was excavated in 1997 to provide access to the southern portion of the Ghost Dance Fault. Tests in this alcove concentrate on moisture monitoring to see if any ambient seepage can be detected in the vicinity of the Ghost Dance Fault. Isolated behind multiple hydrologic bulkheads, this sealed alcove has been monitored for about four years. No ambient seepage has been observed to date despite penetration of the alcove by a throughgoing structural feature that provides a potential flow path from the surface.

Chlorine-36 Validation Study

The objective of the chlorine-36 (Cl-36) validation study is to evaluate whether the Sundance Fault and Drillhole Wash Fault zones are "fast" (50 years or less) flow pathways. Cl-36 is a radioactive isotope produced in the atmosphere and carried underground with percolating water. High concentrations of this isotope were added to meteoric water during a period of global fallout from atmospheric testing of nuclear devices during the 1950s and 1960s. This "bomb-pulse" signal has been used to test for the presence of fast transport paths in the unsaturated zone at Yucca Mountain. Because of the important implications of the occurrence of "bomb-pulse" Cl-36 to the site-scale unsaturated zone flow and transport model, a study is ongoing to confirm the apparent Cl-36 signal detected in earlier studies.

The elevated Cl-36 signature appears to be confined to the immediate vicinity of faults (i.e., where structural features provide continuous flow paths from surface to depth). Fifty boreholes, 13 feet long, have been drilled in areas adjacent to the two faults, and the core obtained is presently being analyzed for Cl-36 concentrations. Corroboration of these results would demonstrate the existence of fast flow paths from the surface to repository depths. Final results of this study are expected during 2003.

Thermal Testing

Key objectives of the thermal tests in the ESF have been to obtain data necessary to understand thermally coupled processes. Because the waste in the repository will result in heating of the geologic system, we need to understand the effects of heat on hydrologic, mechanical, and chemical processes and validate the models of those thermally coupled processes.

Drift Scale Test in Alcove 5

Tests in Alcove 5 help determine how heat affects the interactions of hydrologic, mechanical, and chemical processes (i.e., thermally driven coupled processes) in the middle nonlithophysal unit of the proposed repository horizon. The ongoing drift scale test (DST) site consists of an observation drift, a connecting drift, and a heated drift (HD) that is separated from the other drifts by a thermal bulkhead door. In the thermal testing program, the DST is the largest scale test with an HD approximately 156 feet long and 16 feet in diameter. It is also the longest duration test—eight years—in the thermal testing program at Yucca Mountain. The heating stage of the test started in late 1997; the heaters were turned off in January 2002 after slightly more than four years of heating. The cool-down phase is expected to last four years, after which the test equipment will be removed, and portions of the affected rock mass will be sampled for post-test observations and characterization.

The rock was heated using a large number of resistance heaters that provided a total maximum power of approximately 280 kilowatts. The heaters were distributed in two ways. First, inside the HD, nine steel canisters (to simulate the cylindrical waste packages) contain 30 primary heating elements for a total of 7,500 watts per canister. These canister heaters also contain a duplicate set of heating elements for backup to the primary elements (although not planned to be used, these backup elements could be run concurrently for a total of approximately 135 kilowatts output from the in-drift canister heaters). Second, two resistance heaters are located in each of 25 additional boreholes on both sides of the heated drift (50 total) extending into the rock. These "wing heaters" represent an additional 144 kilowatts of heating power. These produce heat sources that were laterally offset from the heated drift, mimicking heat flow from adjacent drifts in the proposed repository. The strategy was to raise the temperature of the HD wall to about 390°F. Over the duration of the DST, the heated volume of rock was approximately 706,200 cubic feet, with more than 70,600 cubic feet of the rock mass driven above the boiling temperature for water (about 205°F at the elevation of this test).

We need to understand the effects of heat on hydrologic, mechanical, and chemical processes.

To monitor and quantify the coupled thermal, hydrologic, mechanical, and chemical processes that occur, almost 150 boreholes were drilled to house the wing heaters and instrumentation packages. Approximately 4,000 sensors are located throughout the rock mass and within the HD to record temperature, relative humidity, gas pressure, mechanical changes in the rock,

FIGURE 4 Photograph showing the 6-yard long, 4-kilowatt heater used in the single heater test in Alcove 5.

microseismic events, changes in water saturation, moisture movement, and fracture permeability. In addition, instrumentation allows the collection of water, gas, and rock samples for analyses of bulk chemistry and isotopic composition of gas and water in the test and mineral alteration. Just outside the HD bulkhead, an associated niche includes a plate loading test to determine bulk thermomechanical properties at ambient and elevated temperatures.

Beyond the studies of these natural coupled processes, the DST includes a number of tests to evaluate materials processes in the heated environment:

- mechanical measurements on a cast-in-place concrete liner in the last 41 feet of the HD
- sample coupons of metal alloys placed in the HD and within boreholes that will be retrieved at the end of the test and evaluated to characterize corrosion processes
- samples of microbes retrieved at the end of the test to evaluate their survivability

Many of the data on coupled processes are used to either validate, or in a few cases calibrate, the coupled-process models that will be used in the LA (i.e., the coupled thermal-hydrologic, thermal-hydrologic-chemical, thermal-hydrologic-mechanical, and, ultimately, thermal-hydrologic-mechanical-chemical processes) to provide confidence that the models capture these processes appropriately.

The rate of temperature decrease has been rapid initially, as expected, based on the thermohydrologic models. Temperature throughout the test block fell below the boiling temperature for water after approximately one year of cooling. The rate of cooling is decreasing in a manner similar to the modeled behavior, and the system is expected to be nearly back to ambient temperature after four years of cooling.

Modeling of this test provided important insights into the hydrologic, mechanical, and chemical properties and responses of the fractured tuff. The test confirmed, at the field scale, that the dual permeability model of the rock-water system is more appropriate to describe the processes than alternate equivalent continuum models. Results show that water moves away from heat sources as vapor, condenses where it is cooled below boiling, and tends to drain downward through fractures. These model results and test observations suggest that gravity drainage through fractures would prevent water from perching above the heated region.

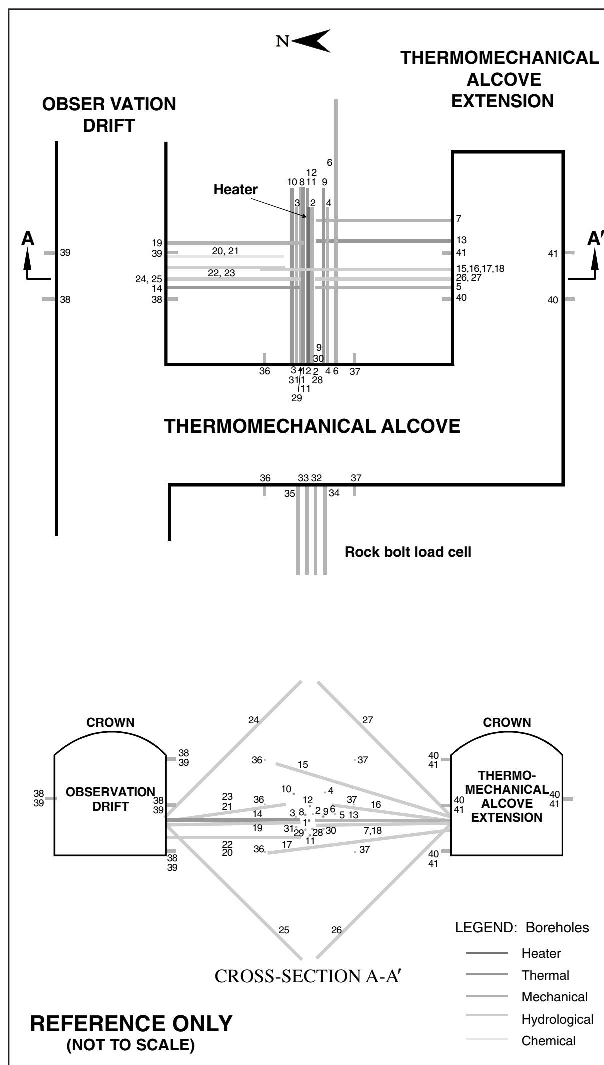

FIGURE 5 Drawing showing the 41 boreholes surrounding the heater hole in Alcove 5.

Evidence of this drainage includes liquid collected in boreholes and changes to saturation distribution around the heat source. Coupled thermal-hydrologic-mechanical models of the DST compare well with observations of the air-permeability changes due to the combined effects of fracture saturation changes and mechanical deformation. Detailed observations of water and gas compositions and of mineral alterations in rock samples taken from the test demonstrate the validity of the coupled (thermal-hydrologic-chemical) modeling that has simulated those changes through the four years of heating.

Single Heater Test in Alcove 5

The single heater test (SHT) was conducted in Alcove 5 to evaluate coupled thermal-mechanical-hydrologic-chemical processes that could occur in a heated rock mass, as well as to improve planning for the larger DST (discussed previously). The SHT consisted of a nine-month heating period followed by a nine-month cooling period, followed by a period of postcooling characterization.

For the SHT, a 900 cubic yard block (approximately 14 yards wide by 11 yards deep by 6 yards high) of the TSw (middle nonlithophysal unit) was exposed on three sides and was heated with a single 6-yard long 4-kilowatt heater (Figure 4). A total of 41 boreholes parallel to, perpendicular to, and surrounding the heater hole were instrumented to monitor the thermal, hydrological, mechanical, and chemical changes (Figure 5). When the test was completed, core was taken from six newly drilled boreholes, and four existing boreholes were overcored to evaluate the thermally altered properties of the rocks.

Modeling of this test provided important insights into the hydrologic properties and responses of the fractured tuff. The test confirmed, at the field scale, that the dual permeability model of the rock-water system is more appropriate to describe the processes than alternate equivalent continuum models.

Condensate drainage was collected in a borehole segment intersected by a fracture drainage pathway. The apparent rapid drainage through fractures indicates that reaction between condensate and fracture-surface mineralogy is limited to relatively short times. The analyzed water compositions indicated that the gas composition plays a role in the water chemistry with carbon dioxide affecting the pH. Overall, the compositions of the collected fluids were consistent with the pore water compositions from this unit. Calcium carbonate, calcium sulfate, and silica minerals were found to have precipitated, and their form suggests that they were deposited by evaporative concentration of fluids.

These observations provided constraints on the possible magnitude and extent of heat-driven geochemical effects on water compositions and fracture mineralogy. In addition, the SHT supplied constraints on thermal properties of the rock-water system, as well as the behavior of thermal-mechanical properties before and after heating. This test was completed in 1998.

Summary

To obtain a license, construct, and operate a repository, we will rely on information gained from more than two decades of scientific investigations at the Yucca Mountain site. The proposed repository would consolidate spent nuclear fuel and high-level waste that is currently stored at 131 sites in 39 states. The repository would be isolated from large population centers, in a desert location, in a closed hydrologic basin, secured 1,000 feet below the surface, surrounded by land controlled by the U.S. government, and protected by multiple natural geologic barriers and robust engineering barriers.

As steward of the U.S. nuclear waste, not just for a few decades after the start of repository operation in 2010, but for hundreds and hundreds of years, we consider the proposed Yucca Mountain repository a key strategic resource for the United States, a critical asset that will pay immeasurable dividends for our citizens.

Reference

DOE (U.S. Department of Energy). 2002. Final Environmental Impact Statement for a Geologic Repository for the Disposal of Spent Nuclear Fuel and High-Level Radioactive Waste at Yucca Mountain, Nye County, Nevada. DOE/EIS-0250F, 4 vols. Washington, D.C.: Office of Civilian Radioactive Waste Management, U.S. Department of Energy.

Between 2007 and 2010, Congress must consider whether the United States needs a second repository for high-level radioactive waste.

Will the United States Need a Second Geologic Repository?

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Per F. Peterson

Nuclear fission energy requires small inputs of natural resources compared to most other fossil and nonfossil energy technologies. When we consider net electricity generation (e.g., net electricity after subtracting consumption by internal plant loads and by uranium enrichment plants), the life-cycle resource inputs for nonfossil power sources are dominated by construction materials, most notably steel and concrete. The construction of existing 1970-vintage U.S. nuclear power plants required 40 metric tons (MT) of steel and 190 cubic meters (m^3) of concrete per average megawatt of electricity (MW(e)) generating capacity.[1] For comparison, a typical wind-energy system operating with 6.5 meters-per-second average wind speed requires construction inputs of 460 MT of steel and 870 m^3 of concrete per average MW(e). Coal uses 98 MT of steel and 160 m^3 of concrete per average MW(e) (Pacca and Horvath, 2002); and natural-gas combined cycle plants use 3.3 MT steel and 27 m^3 concrete (Meier, 2002).

Because of this efficient use of natural resources, compared to other energy technologies, nuclear energy is an important candidate for the long-term, sustainable production of electricity and hydrogen.[2] But any major role for fission will require practical approaches to spent-fuel management with environmental and public health impacts comparable to, or lower than, those of other sustainable energy technologies.

Of the resources required to produce fission energy, repository sites are arguably the only resource that has proven to be scarce. Given this scarcity, the allocation and efficient use of available repository capacity will require well informed technical and policy decisions. The 1982 Nuclear Waste Policy Act (NWPA), as amended in 1987, requires that Congress consider these questions between 2007 and 2010.[3] Advanced fuel cycles (AFCs) cannot eliminate the need for repositories, but do have the potential to greatly increase repository capacity and improve performance (NRC, 1996). AFC optimization and economics will depend strongly on the licensing basis for repository sites and on the extent of AFC R&D performed prior to any large-scale deployment. In this article, I outline the major issues facing the United States in considering the role of AFC technology in nuclear waste management.

Regulatory standards to protect current and future public health, safety, and the environment are adopted through national policy-making processes. The regulatory criteria for Yucca Mountain require, among other things, that the groundwater below the Armagosa Valley near Yucca Mountain be protected for at least 10,000 years; the maximum radiation dose to an individual who drinks two liters of groundwater per day must be less than 4 mrem, in other words, less than 1.3 percent of current U.S. average natural radiation exposures. Like other regulated, engineered systems (e.g., aircraft), repository systems apply redundancy and diversity to meet these regulatory requirements with acceptable uncertainty. Uncertainty in the performance of individual repository barriers and processes are acceptable because redundancy and diversity reduce the uncertainty in total system performance. The isolation provided by deep geologic storage helps bound uncertainties by creating chemical, thermal, and hydrologic conditions that can be predicted with less uncertainty over long time scales than conditions near the surface. Indeed, the fate of geologic repositories may be one of the few important environmental and public health impacts from twentieth and twenty-first century energy production that we can predict with modest uncertainty over millennial time scales.[4]

In 2002, the United States selected Yucca Mountain in southern Nevada as the site for the nation's first high-level waste repository, and Congress directed the U.S. Department of Energy (DOE) to prepare and submit a license application to the U.S. Nuclear Regulatory Commission (USNRC) by the end of 2004. This site-selection recommendation was based on the results of an integrated total-system performance assessment (TSPA-SR) model that included nine different barrier mechanisms. Repeated TSPA calculations, that varied the values of uncertain parameters in the model, generated statistical performance predictions showing that regulatory requirements for groundwater protection could be met by a factor of more than 100 with high confidence (DOE, 2002).

For the upcoming license application, improvements to the TSPA models, particularly in near-field transport and drift seepage, can be expected to reduce the need for conservative assumptions in many of the barrier models. At the same time, questions raised by the USNRC during the license review can be expected to require more conservative and wider uncertainty estimates for some barrier models. Recent "one-off" studies have shown that performance is relatively well distributed across the multiple barriers (Apted et al., 2002; NWTRB, 2002). Thus, to alter the recent TSPA-SR's positive assessment of regulatory compliance, the USNRC would have to identify substantial deficiencies in the uncertainty and conservatism of a substantial fraction of the barrier models. This outcome appears unlikely.

The allocation and efficient use of repository capacity will require well informed technical and policy decisions.

The NWPA limits the capacity of the proposed Yucca Mountain repository to 63,000 MT of initial heavy metal in commercial spent fuel.[5] The 103 U.S. commercial reactors currently operating will produce this quantity of spent fuel by 2014. Recently, the federal government has started to issue 20-year license renewals for U.S. nuclear plants, extending the permitted plant operating life to 60 years. As of May 2003, 16 U.S. plants had received renewals and 14 applications were under review; 22 more applications are expected in the next two years. Because of the low average production cost of nuclear electricity (1.69 cents per kilowatt-hour in 2002), it is anticipated that a substantial fraction of remaining U.S. plants will also seek renewals, thus increasing the total federal spent-fuel management obligation for current reactors to as much as 125,000 MT. Licenses for new plant construction would increase the total further.

Technical Capacity: Commercial Spent Fuel

The capacity of geologic repositories is set primarily by areal heat load limits for decay heat (Figure 1) and by available footprint. At Yucca Mountain, spent fuel and high-level waste will be placed in corrosion-resistant canisters and emplaced horizontally in 5.5-m diameter drift tunnels. The TSPA-SR set a loading limit of 60 MT/acre, based on tunnels spaced 81 m apart and on the nominal characteristics of the first 70,000 MT of defense and commercial wastes planned to be sent to the repository. For spent fuel from pressurized-water reactors (PWRs), comprising 60 percent of commercial spent fuel, the TSPA-SR canister design permits a loading of 87 MT/acre. The boiling-water reactor (BWR) canister design permits 75 MT/acre.

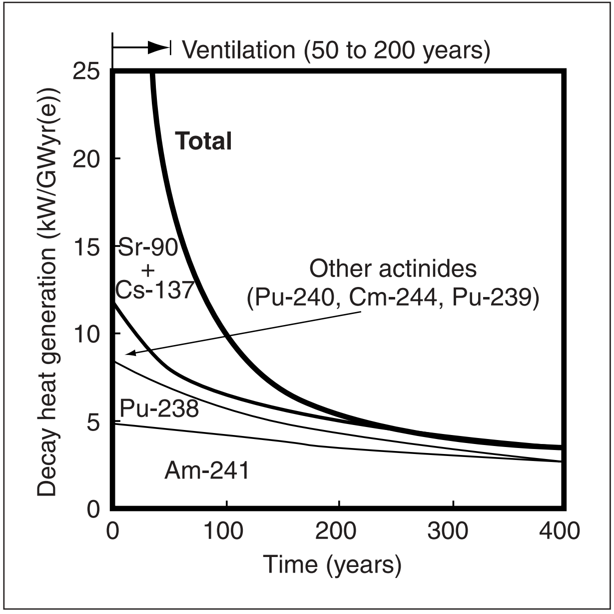

FIGURE 1 The early decay-heat generation from typical commercial spent fuel is dominated by the fission products Sr-90 and Cs-137. Later, actinides, particularly Am-241, play the largest role.

With a relatively modest license amendment to increase the site capacity, an average areal loading of 75 MT/acre for commercial spent fuel is a reasonable assumption. This value has potential conservatisms that might be erased with subsequent, more aggressive license amendments. However, it is unlikely that increases in areal loading could exceed a factor of two or three for commercial spent fuel.

The maximum repository footprint at Yucca Mountain is correspondingly uncertain. An earlier viability assessment (TSPA-VA) concluded that, with a substantial new characterization, the total repository area could potentially be increased to somewhat more than 2,000 acres (8.0 km^2). This suggests a minimum "technical" site capacity of approximately 75 x 2,000 = 150,000 MT of spent fuel, with a maximum site capacity greater by perhaps a factor of two or three. Thus any substantial construction of new U.S. nuclear power infrastructure in the coming decades will almost certainly create a technical requirement (perhaps as soon as 2030 to 2050) either for additional repositories or for the construction of infrastructure for recycling spent fuel.

Technical Capacity: Advanced Fuel Cycles

It is technically possible for AFCs to recycle and transmute almost all of the heavy actinide elements that contribute to decay heat, leaving only fission products and residual actinides for disposal. Only two of the fission-product isotopes—strontium(Sr)-90 and cesium(Cs)-137, both of which have 30-year half-lives—would contribute significantly to the remaining decay heat. Because these isotopes have relatively short half lives, it is technically possible to separate and manage them separately for the 200 to 300 years required for their nearly complete decay. Separation and separate management of Cs-137 and Sr-90 have already been demonstrated at large scale at the Hanford site in Washington state, where both cesium and strontium recovered from high-level waste are currently stored separately in sealed capsules.[6]

Without cesium and strontium, the remaining fission products and residual actinides that require geologic disposal have very small rates of decay-heat generation. Thus, it becomes relatively easy to estimate the capacity of the Yucca Mountain site. If the current canister design for defense high-level waste (capable of holding five 60-cm diameter cylinders of borosilicate waste glass) were used to hold fission products, the fission-product loading could be 500 kg/m of drift tunnel length;[7] this is 7 times greater than the fission-product loading for current 21-assembly PWR canisters. A 1-GW(e) light-water reactor (LWR) (whether a BWR or PWR), which can produce energy for one million typical homes, also produces approximately

1,080 kg of fission products per year. Slightly more than two meters of Yucca Mountain drift could hold a year's fission products from a plant this size.

At 2,000 acres, the Yucca Mountain site could have 100 km of drift tunnels spaced at 81 m. Without decay heat, the spacing could be reduced to 20 m, thus increasing the drift tunnels to 400 km. Using the existing defense-waste canister design, these drift tunnels could then hold 200,000,000 kg of fission products, the energy equivalent of burning one trillion tons of coal. This means that a single Yucca Mountain could replace 170 years of current, total, worldwide coal consumption.[8]

Separation and separate management of cesium and strontium would require management of these materials for one to three centuries, until radioactive decay reduces their heat output sufficiently to permit their disposal. However, there are alternative strategies for managing cesium and strontium decay heat, because it drops greatly over the time scales of surface storage and repository operation.

Because the Yucca Mountain repository is located above the water table, air can be circulated through the tunnels to remove decay heat. In the current design, ventilation will continue for 50 years after the final canister emplacement. As shown in Figure 1, the ventilation extracts most of the heat from cesium and strontium. For every 30 years of operation, the ventilation system regenerates roughly half of the repository's capacity for holding cesium and strontium.

With ventilation, the heavy actinide elements, particularly americium(Am)-241, which has a 460-year half-life, drive Yucca Mountain's postclosure thermal response. To eliminate the need for a second repository, one must therefore cap the total inventory of heat-generating actinides, particularly Am-241, within the thermal capacity of the site.

Relatively large inventories of Am-241 build up in the spent fuel of current LWRs because of successive neutron captures in U-238. Neutron capture in U-238 yields Pu-239, and fission of this Pu-239 provides a substantial fraction of the power output from LWRs (reaching 50 percent shortly before the fuel is discharged). But with the relatively low kinetic energy of neutrons in LWRs, a significant fraction of neutron reactions with Pu-239 are capture reactions that generate Pu-240, and

$$^{240}\text{Pu} + \text{n} \rightarrow {}^{241}\text{Pu} \underset{\beta,\,14\text{yr}}{\rightarrow} {}^{241}\text{Am} \underset{\alpha,\,460\text{yr}}{\rightarrow} {}^{237}\text{Np}$$

Options for reducing the rate of accumulation of heat-generating actinides include adding thorium(Th)-232 into fuel as a substitute for a portion of the U-238. Neutron capture into Th-232 produces U-233, a fissile element like Pu-239 that can generate a portion of the reactor power. Unlike Pu-239, however, neutron capture in U-233 creates relatively light isotopes, thus substantially reducing the buildup of heat-generating actinides.

The need for recycling will only arise if there is substantial construction of new reactors in the United States.

The generation of actinides can be further reduced by increasing reactor operating temperatures and electrical conversion efficiency, as is possible with high-temperature, gas-cooled reactors. At the same time, all of these approaches also increase the volume of fuel materials in which the actinides are contained, which could require substantial changes to the repository system design to take advantage of the reduced heat output and to increase areal loading.

Recycling spent fuel—using chemical reprocessing to separate and recycle some or all of the actinides—greatly reduces volume. Conventional reprocessing and recycling of separated plutonium into LWRs, as is currently done in France and Britain, increases the total inventory of Am-241 that requires management by increasing neutron capture into Pu-240. Therefore, for recycling to help in capping the total inventory of heat-generating actinides, new reactors capable of transmuting these actinides (e.g., fast or epithermal designs) must be developed and deployed.

The need for recycling will only arise if there is substantial construction of new reactors in the United States. Thus, the deployment of recycling infrastructure would occur in an environment with an established, large-scale technical and industrial capacity for nuclear construction.

Economics: The Nuclear Waste Fund

In the United States, national policy requires that "the costs of carrying out activities relating to the disposal of [high-level] waste and spent fuel will be borne by the persons responsible for generating such waste and spent fuel" (NWPA, Section 112). Thus the costs for civilian spent-fuel disposal are internalized by charging a 0.1 cent per kilowatt-hour fee on nuclear electricity consumption.

DOE periodically issues a report assessing whether this fee is adequate to fund the life-cycle cost of spent-fuel disposition. In 2001, when only five reactors had received 20-year license renewals, DOE estimated that the total quantity of commercial spent fuel requiring disposition would be 83,800 MT of heavy metal. Assuming that all of this spent fuel would be emplaced in Yucca Mountain, the total cost of the repository was estimated to be $57.5 billion (2001 dollars). Of that total, 29 percent is assigned to defense-waste disposal, making the cost of commercial waste disposal $490/kg (DOE, 2001).

For an average burn-up[9] of 40 MWd/kg and plant thermal efficiency of 0.32, the current 0.1 cent/kWh fee generates revenues of $310/kg. The Nuclear Waste Fund accrues interest at a real rate exceeding inflation by 2.6 percent (the historical average for government bonds) to 4.2 percent (the rate for 10-year treasury notes) (DOE, 2001). Like plant decommissioning costs, this accumulated interest reduces the present cost of waste management activities that can be delayed to the future. For example, after 30 years of no-cost storage at a reactor, the fund grows to between $670 and $1070/kg of spent fuel. (Most current plants have on-site storage capacity for 30 years; all new plant designs include storage capability for the 60-year licensed life of the plant.)

A lower interest rate would reduce the capital charges for transmutation by more than 50 percent.

The modest $490/kg cost of direct disposal in Yucca Mountain contrasts sharply with current cost estimates for recycling. In a recent study, the OECD Nuclear Energy Agency (NEA) estimated costs of $1,000 to $2,500/kg just for spent-fuel reprocessing and noted that studies in the 1990s of sodium-cooled fast reactors for transmuting separated actinides estimated capital costs some 30 percent higher than for LWRs (NEA/OECD, 2002). Assuming real interest rates of 7 to 10 percent, NEA predicted that closed-cycle nuclear electricity prices are 0.2 to 1.0 cent/kWh higher than for LWR electricity with direct disposal of spent fuel; this is two to ten times the current U.S. Nuclear Waste Fund fee.

But if transmutation is performed primarily to cap the total inventory of heat-generating actinides within the thermal capacity of a single repository site, then transmutation infrastructure can be financed from the fees and interest accumulated in the Nuclear Waste Fund. This is equivalent to financing construction at an effective real interest rate of 3 percent, rather than at a commercial rate of 7 to 10 percent. This lower rate would reduce the capital charges for transmutation by more than 50 percent.[10] The availability of low-interest-rate capital would more than offset the higher capital costs estimated for sodium fast reactors, compared to LWRs.[11]

Future Options

The 1982 NWPA adopted a 70,000 MT limit for commercial spent fuel and defense wastes in an attempt to ensure an equitable distribution of geologic repository sites between the eastern and western United States. Subsequent experience showed that the characterization and siting of a single repository was far more arduous—in cost, time, and acrimony—than the NWPA had envisioned. Since 1982, our understanding has changed in other areas as well. The carbon emissions of nuclear energy's primary competitor, fossil fuel, are now understood to have potentially global environmental effects. Therefore, coal consumption in the western United States affects not only the eastern United States, but also Europe and Asia. In addition, since then the major technical elements for actinide management have been demonstrated at laboratory scale, and engineering designs for AFC demonstration facilities have been developed and remain available for further refinement.

Proponents of once-through fuel cycles commonly cite the costs of reprocessing and transmutation as arguments for direct disposal as the lowest-cost option for the foreseeable future (MIT, 2003; von Hippel, 2001). They present no compelling arguments, however, that the protracted and arduous technical and political process required to select Yucca Mountain could be repeated successfully for a second, third, fourth, and subsequent repositories. Conversely, arguments for reprocessing often do not consider that a large amount of spent fuel can be managed with a single repository before a technical need or economic motivation emerges for recycling a fraction of spent fuel.

Upcoming U.S. policy decisions for civilian spent-fuel management (beyond the current limit of 63,000 MT for Yucca Mountain) cannot be based on large taxpayer subsidies; future policy must be based on a credible Nuclear Waste Fund fee schedule. The Generation IV International Forum currently envisions a deployment goal of 2030 for advanced nuclear energy systems for actinide management (Generation IV International Forum, 2003). With our current understanding of the technical limits of Yucca Mountain's capacity, this timing for the deployment of recycling strikes a balance between two pragmatic realities: (1) finite limits to repository capacity; and (2) the need for R&D to make recycling technology economically attractive.

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Notes

[1] Based on the current U.S. average capacity factor of 90 percent, with data from Bryan and Dudley (1974).

[2] Uranium is abundant, with average concentrations in U.S. soils of 1.8 ppm, or about 2.7 metric tons per square kilometer in the top meter of soil (http://eetd.lbl.gov/IEP/high-radon/gfx/nure.html). Known, economically recoverable, high-quality ores contain 3.3 million MT of uranium and 4 to 6 million MT of thorium, which if used in closed fuel cycles hold energy equal to 1,500 times current total worldwide annual energy consumption (Adams, 2002).

[3] Specifically, NWPA states that "The Secretary [of the DOE] shall report to the President and to Congress on or after January 1, 2007, but not later than January 1, 2010, on the need for a second repository."

[4] At its current statutory capacity limit of 63,000 MT of commercial spent fuel, Yucca Mountain displaces energy equivalent to 5 billion tons of coal, or six years of current U.S. coal consumption. Advanced fuel cycles might expand this capacity by a factor of more than 50. Coal mining mostly occurs at or near the surface, and its combustion products are widely dispersed. Thus, it is difficult even to speculate about environmental and public health consequences in 10,000 years.

[5] Specifically, NPWA states that "The [Nuclear Regulatory] Commission decision approving the first such application shall prohibit the emplacement in the first repository of a quantity of spent fuel containing in excess of 70,000 metric tons of heavy metal or a quantity of solidified high-level

radioactive waste resulting from the reprocessing of such a quantity of spent fuel until such time as a second repository is in operation." Of this quantity, 7,000 metric tons is commonly assumed to be allocated to defense wastes.

6 Cesium-135 is found in very small concentrations in fission products, and has a 2.6 million year half-life.

7 This is the fission-product loading for a glass density of 2,700 kg/m^3, at a fission-product mass fraction of 15 percent.

8 Nuclear fission releases 1 GW-day/kg, or 86 x 106 MJ/kg of fission products. Coal releases around 32 MJ/kg. In 2001, worldwide coal consumption was 3.0 billion MT.

9 Burn-up is the amount of energy released by fission (megawatt-days) in a given initial mass of fuel (kilograms) and is directly proportional to the mass of fission products in the fuel.

10 NEA Case 3a for recycling minor actinides into fast reactors gives total electricity costs from 5 to 25 percent higher than the once-through electricity cost of 3.8 cents/kilowatt-hour. Assuming uniform capital outlays over a four-year period and operation for 60 years, capital charges drop by 52 percent if the interest rate is reduced from 7 percent to 3 percent (NEA/OECD, 2002).

11 In practice, the construction of reprocessing infrastructure could be funded by direct appropriations from the Nuclear Waste Fund. Transmutation services could be procured through long-term contracts with commercial reactor operators, which would permit commercial reactor operators to obtain favorable commercial financing.

NAE News and Notes

NAE Newsmakers

The American Association of Engineering Societies (AAES) presented several awards during a ceremony in the Great Hall of the National Academy of Sciences Building on May 5, 2003. **Stephen D. Bechtel, Jr.**, chairman emeritus and director, Bechtel Group, Inc., was awarded the **Kenneth Andrew Roe Award**, which recognizes leaders in the engineering community who promote cooperation, understanding, and unity among engineering societies in the United States. **Robert Langer**, Kenneth J. Germeshausen Professor of Chemical and Biomedical Engineering, Massachusetts Institute of Technology, was awarded the **John Fritz Medal** for his pathbreaking work on controlled drug-delivery systems and tissue engineering and for his leadership in the field of bioengineering. And, **James W. Poirot**, chairman emeritus, CH2M Hill Companies, received the **Joan Hodges Queneau Palladium Medal** (presented by AAES and National Audubon Society) for his outstanding achievements in environmental conservation. The award underscores the vital importance of mutual understanding between conservationists and engineering professionals.

Donald L. Bitzer, distinguished university research professor, Computer Science Department, North Carolina State University, was awarded an **Emmy** from the National Academy of Television Arts and Sciences. He is a co-inventor of the flat-panel plasma display.

Nick Holonyak, Jr., John Bardeen Chair and Professor of Electrical and Computer Engineering and Physics, University of Illinois at Urbana-Champaign, received the **2003 Institute of Electrical and Electronics Engineers (IEEE) Medal of Honor**. Dr. Holonyak was recognized for his pioneering contributions to semiconductors.

M. Eugene Merchant, senior consultant to TechSolve, who was inducted into the **Automation Hall of Fame**, has been named to the Advisory Board of that institution, which selects new honorees to be inducted. The Automation Hall of Fame honors the most significant contributors to industrial progress.

Frank L. Parker, Distinguished Professor of Environmental and Water Resources Engineering, Vanderbilt University, has received the **2003 Wendell D. Weart Lifetime Achievement in Nuclear Waste Management Award**. The award, sponsored by Sandia National Laboratories, recognizes outstanding contributions to solving the problems of nuclear waste.

Staff Awards Luncheon

Wm. A. Wulf and Barbara Neff.

The National Academy of Engineering (NAE) recently held its annual Staff Awards Luncheon at Ortanique restaurant, Washington, D.C. President **Wm. A. Wulf**, who hosted the ceremony, presented retiring Senior Executive Associate Barbara Neff with an award for her 20 years of service to NAE. Ms. Neff was also presented with an award for 25 years of service to the National Academies.

President Wulf then presented Staff Achievement Awards to Senior Program Officer for Media/Public Relations Randy Atkins, Senior Media/Public Relations Assistant Cecile Gonzalez, Program Officer for Frontiers of Engineering and Gilbreth Lectureships Janet Hunziker, Senior Program Assistant Nathan Kahl, Awards Administrator Leila Rao, and Public Information Assistant Kimberly West. All six received certificates of appreciation and $2,000 cash awards.

NAE Hosts 15th CAETS Convocation

Left to Right: Wm. A. Wulf, Sir David Davies, Lady (Jenna) Davies, and Charlotte Anastasion.

The National Academy of Engineering hosted the 15th Convocation of the International Council of Academies of Engineering and Technological Sciences, Inc., (CAETS) in Hollywood, California, on May 18 to 21, 2003. Despite the war in Iraq, heightened domestic security, and the outbreak of SARS, representatives from 18 of the 26 CAETS member countries (see box) attended the conference. Alex Singer, a film director based in Los Angeles who has more than 40 years of experience in motion pictures and television, chaired the organizing committee. The theme of the convocation was "Entertaining Bytes," the convergence of information technology and entertainment.

Participants heard presentations from, and engaged in conversations with, individuals who use information technology in various aspects of the entertainment industry. Patricia A. Hannaway, a senior computer character animator for feature films, described the development of a facial vocabulary and expressions for the 3D computer-generated character Gollum in "The Lord of the Rings: The Two Towers." Joan Collins Carey, co-producer of "The Story of Computer Graphics," introduced a 45-minute version of the 90-minute documentary cut of the film, which shows stories behind the striking graphics and technology most of us take for granted. Ron Garcia and Dante Spinotti discussed technological developments in cinematography. Internationally renowned futurist and business strategist Peter Schwartz, Global Business Network, **W. Daniel Hillis** (NAE), co-founder of Applied Minds, Inc., and George Joblove, Sony Pictures Imageworks, wrapped up the meeting with a discussion of the entertainment industry and technology in the future. The participants also got a firsthand look at some of the technologies being explored at Rhythm & Hues Studios, Stan Winston Digital, Cinesite, and the Robert Zemeckis Center for Digital Arts at USC.

The group celebrated the 25th anniversary of the founding of CAETS with a dinner dance at the Autry Museum of Western Heritage. International visitors also enjoyed a relaxing evening at The Lobster in Santa Monica. Former NAE President, **Robert M. White**, former CAETS Vice President and Secretary Steve Anastasion, and several former presidents from member academies joined in the festivities.

The 16th CAETS Convocation will be hosted by the Australian Academy of Engineering and Technological Sciences in North Queensland in July 2005.

CAETS Members

Founding Members (1978)

Australia
Mexico
Sweden
United Kingdom
United States

Elected Members

Denmark (1987)
Switzerland (1988)
France (1988)
Finland (1989)
Japan (1990)
Belgium (1990)
Norway (1990)
Canada (1991)
The Netherlands (1993)
Hungary (1995)
China (1997)
Ukraine (1998)
Poland (1998)
Argentina (1999)
Czech Republic (1999)
India (1999)
Spain (1999)
Korea (2000)
Croatia (2000)
Slovenia (2000)
Uruguay (2000)

Message from the Foreign Secretary

George Bugliarello

On July 1, I was honored to assume the position of foreign secretary, succeeding **Harold Forsen**, who had a long and dedicated tenure. At this critical juncture in international relations, this time of heightened concerns about the social and economic conditions of many developing countries and the long-term stability of our world, NAE faces some important, complex tasks. Connections with engineers and scientists in other countries can foster international stability, as was shown by the sustained dialogue between scientists and engineers in the United States and the former Soviet Union during the Cold War.

Thus leaders in engineering who have been elected foreign associates of the Academy are important points of contact and interaction between NAE and the rest of the world. As of now, NAE has 162 foreign associates—many fewer than the National Academy of Sciences has. Given the challenges we face, I believe the numbers of foreign associates should be increased substantially, and I appeal to my fellow NAE members to address this need. It is particularly important that we nominate candidates from countries that are underrepresented, or not represented at all, such as Spain (no foreign associates) and India (one foreign associate), just to mention a few.

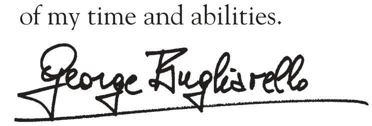
Today, NAE is engaged directly and indirectly (through many National Research Council [NRC] programs), in dialogues with engineers and scientists in several countries, including Russia, Vietnam, and Iran. I believe that dialogue should be expanded to include other countries. The International Council of Academies of Engineering and Technological Sciences (CAETS), of which **Bill Wulf** holds the rotating presidency this year, is another mechanism for developing and broadening that dialogue. The Frontiers of Engineering symposia for younger engineers, which we cosponsor with Germany and Japan, provide another avenue of interaction. These symposia are patterned after our very successful U.S. Frontiers of Engineering program. We are hoping to expand the Frontiers program to include other countries, or even entire regions.

NAE can and should address a host of other needs and challenges through its international programs. Besides reinforcing the international community of scientists and engineers, we can not ignore the endemic problems of poverty, hunger, lack of housing, lack of communications, joblessness, and poor health that affect one-third of the human species. Solving those problems will require the assistance of economically and technologically advanced countries—and the involvement of engineers. Assistance should not take the form of handouts but should be focused on creating indigenous capacities and unifying markets for meeting the common needs of developing countries to stimulate the creation of appropriate technologies (e.g., simplified utilities and transportation systems).

The list of international challenges facing NAE and its sister academies here and abroad does not stop here. Consider the problems of sustainable development, natural disasters, terrorism, the proliferation of weapons of mass destruction, the aging populations of advanced industrial countries, visual pollution caused by space debris, and the prevention of and remedies against natural disasters. All of these problems present enormous engineering challenges and will also require "scientific and technological diplomacy" of the highest order.

International problems range from urgent and immediate problems, such as proliferation, antiterrorism, and hunger, to more long-term problems, like climate change. Addressing these immense challenges will require close interaction with our sister academies, NAS and IOM. These challenges have no disciplinary boundaries and addressing them will require integrated approaches of science, engineering, and health disciplines. I am pleased to report that the foreign secretaries of NAS, NAE, and IOM are working closely with each other and with the presidents of the three academies.

Again, I thank you for the honor you have done me in electing me foreign secretary. I invite your collaboration and suggestions, which I promise to address within the limits of my time and abilities.



Terrorism Scenario Exercise Highlights Communication of Technical Information

Workshop moderator Mike McCurry and NAE Executive Officer Lance Davis.

If an explosion rocked your neighborhood, where would you turn to find out what happened? Would you rely on immediate radio or TV accounts or wait for official word from government spokespeople? How much faith would you put in the media stories? To minimize confusion, the news media and public officials must both provide more accurate technical information about disastrous events, both before and during an emergency. To evaluate how they would respond when a firm grasp of scientific and technological details would be critical, the National Academies hosted a first-of-its-kind workshop on emergency communications on June 20 for news media decision makers, reporters, federal/state/local public information officers, and science and technology experts.

The goals of the workshop were (1) to provide a better understanding of the role each group plays in an emergency; (2) to gauge current preparedness; (3) to provide technical information on potential threats and protective actions; and (4) to establish regional relationships. The National Academies affirmed its willingness to provide balanced, accurate information on engineering, science, and medicine to both government and the media. By opening channels of communication before a catastrophe strikes, the workshop participants will be better equipped to inform the public during a natural disaster, human accident, or terrorist attack.

More than 100 participants engaged in frank discussions about the processes and activities each group must undertake in response to a crisis. The day began with Dan Bartlett, assistant to the President for communications and White House director of communications, and Deborah Potter, executive director of NewsLab, offering their respective government and media perspectives on communicating in a crisis. David Gergen, editor at large for *U.S. News & World Report* and professor of public service and director of the Center for Public Leadership, Kennedy School of Government, Harvard University, then facilitated a hypothetical terrorism scenario involving a "dirty" bomb explosion in Washington, D.C. At certain points in this tabletop exercise, Mr. Gergen stopped and asked key participants what they would be doing under those circumstances. Their answers were followed by discussions, which revealed many potential communication problems. All of the participants came away with a better understanding of the factors affecting the impact of a dirty bomb and the roles of those involved in responding to it.

After the scenario exercise, science and technology experts invited by the National Academies offered practical information about chemical, biological, radiological, and nuclear attacks. Jay Davis, director of ANSER Institute for Homeland Security, described how the situation might evolve as events unfold and facts are collected. **Alice Gast**, NAE member and Robert T. Haslam Professor of Chemical Engineering, vice president for research, and associate provost, Massachusetts Institute of Technology, explained that a chemical attack might be quiet, fast, mobile, and difficult to identify; she described some of the forms chemical weapons might take. Margaret Hamburg, IOM member and vice president for biological programs, Nuclear Threat Initiative, described

Workshop facilitator David Gergen.

the difficulties involved in dealing with biological attacks, which may not be manifest until days or weeks after the actual event. George Whitesides, NAS member and Mallinckrodt Professor of Chemistry, Harvard University, told reporters the key characteristics of the most likely types of attack and the essential protective measures that should be taken. Baruch Fischhoff, IOM member and Howard Heinz University Professor, Department of Social and Decision Sciences and Department of Engineering and Public Policy, Carnegie Mellon University, suggested ways risks could be communicated to the public. These experts were followed by Warren Campbell, of the Maryland Fire and Rescue Institute, who described typical actions of first responders on the scene and how they and reporters could protect themselves near the attack site.

"The discussion brought a host of important issues to the surface. The level of accurate reporting during an emergency situation will undoubtedly improve as a result of key players going through the thought process and analysis demanded by the workshop," according to Mike McCurry, former White House press secretary and workshop moderator. At the end of the day, Frank Sesno, professor of public policy and communication, George Mason University, and former CNN bureau chief, led a discussion. The participants agreed that the lessons differed for each group, from where to deploy news equipment to how to handle traffic jams to how to speed up reports to the public on unfolding events. Discussions also touched on changes in newsroom and other procedures, establishing new contacts, and spreading the word among their colleagues about the day's revelations.

The workshop was convened by the Emergency Preparedness Task Force of the Greater Washington Board of Trade Potomac Conference, the U.S. Department of Homeland Security (DHS), the Radio-Television News Directors' Association (RTNDA), the National Academies, Arrow Mountain LLC, Burson-Marsteller, the Metropolitan Washington Council of Governments, and others, with the support of the Gannett Foundation and the Philip L. Graham Fund.

Randy Atkins, NAE senior program officer for media/public relations, who spearheaded the project for the National Academies, is developing proposals and seeking funding for follow-up activities. Working with DHS and RTNDA, Mr. Atkins hopes to hold 10 workshops modeled after this one in key cities around the country. The goal is to establish relationships among media, public information officers, and experts in each community. For more information, please contact Randy Atkins at <*atkins@nae.edu*>.

Stephanie Cupp, NAE Intern

Stephanie Cupp

Stephanie Cupp is a master's candidate in computer science at George Washington University; she earned a B.S. in computer science from Kennesaw State University. Her research interests have been focused on bringing technology to people, including human-computer interaction and technology presentation. As a graduate research assistant, she is researching and producing a collaborative learning environment for the National Security Agency. The project involves creating an experience for users to learn how to collaborate online to solve "wicked problems." The research involves teaching and learning styles, as well as groupware and other collaborative tools. Stephanie's goal is to continue to explore how science and technology are introduced to children and adults in an effort to interest a broader spectrum of people in engineering.

One of Stephanie's goals for her Christine Mirzayan Internship at the National Academies was to learn more about the role of engineering in government science and technology policy. Although the engineering community has only recently begun to focus on education research to link instructional innovations to learning theory or to evaluate innovations rigorously, significant progress has been made. Education researchers in science, technology, engineering, and mathematics (STEM) have put forward many competing assertions about "best practices" and "promising practices," but the evidence supporting these assertions appears to be incomplete at best, both for recent studies developed specifically for engineering and for earlier, widely cited lists developed for general use. Stephanie's focus has been on assessing the research base that underlies and supports best practices.

Paolo Davidian Moore, NAE Intern

Paolo Davidian Moore

Paolo Davidian Moore is currently working towards an M.A. in instructional systems development at the University of Maryland Baltimore County. His current interest is in reforms in precollege educational systems to increase the visibility of engineering disciplines, which should lead to an increase in the number of students in STEM disciplines. Paolo received a B.S. in electrical and computer engineering from the University of Maryland, College Park, in 1996 and an M.S. in electrical and computer engineering from the University of California, Davis, in 2001. He has conducted research on the attitudes of Baltimore County middle-school students towards mathematics and science; automated, digital hardware testing; computer memory subsystem optimization; and novel computer architectures. Paolo is a member of IEEE and the National Society of Black Engineers.

His work in the Center for the Advancement of Engineering Education (CASEE) has focused on identifying the knowledge, skills, and attitudes necessary for engineering graduates and correlating these attributes with "best practices" in engineering education. Through a rigorous review of the literature, Paolo compared various combinations of desired characteristics to determine the most desirable characteristics for engineering in general and unique characteristics for particular engineering disciplines.

Ericka Reid, NAE Intern

Ericka Reid

Ericka Reid, who hails from High Point, North Carolina, is a doctoral student in educational psychology at Georgia State University (GSU) in Atlanta. She earned a Masters of Education in counseling and development at the University of North Carolina, Greensboro. Her research interests include women in science and engineering and adult education, learning, and instruction; her dissertation topic will focus on African American women in engineering. Ericka looks forward to using her knowledge and energy to encourage and support women pursuing careers in fields where they have been historically underrepresented. As a part of her research assistantship at GSU, she coordinates the Advanced Academy for Future Teachers, a program designed to attract high school students to teaching.

As a Christine Mirzayan Science and Technology Policy Intern at NAE, Ericka worked with Dr. Patricia Mead, senior program officer, Committee on Engineering Education, on reports and documents on IT-based educational materials and the future of the engineering profession. "This internship gave me an opportunity to develop skills that will enhance my professional contributions far beyond program and degree completion," she explained. "The experience gave me a tremendous appreciation for the profession of engineering."

Ericka enjoys writing on personal development, as well as developing and facilitating leadership seminars for the academic community and the general public. And just for fun (when she has time) she enjoys Bikram yoga, kick boxing, salsa, and making jewelry.

In Memoriam

HOWARD C. BARNES, 90, retired deputy chief engineer, American Electric Power Service Company, Inc., died on May 16, 2003. Dr. Barnes was elected to NAE in 1974 for his leadership in projecting electric power transmission to 765 kV and his research on the 1,000 to 1,500 kV range.

L. STANLEY CRANE, 87, retired chairman and CEO, Consolidated Rail Corporation, died on July 15, 2003. Mr. Crane was elected to NAE in 1978 for pioneering the application of modern and creative engineering concepts to railroad equipment and operations.

RALPH E. CROSS, 93, retired chairman, Cross & Trecker Corporation, died on June 26, 2003. Mr. Cross was elected to NAE in 1968 for the development and application of automation principles to machine tools and manufacturing processes.

ROBERT C. DUNCAN, 79, retired vice president, Hicks & Associates, Inc., died on May 17, 2003. Dr. Duncan was elected to NAE in 1981 for his contributions to the Apollo guidance and control system and the SX-70 camera systems.

JOHN W. FAIRCLOUGH, 72, retired chairman, Rothschild Ventures Ltd., died on June 5, 2003. Sir John Fairclough was elected to NAE in 1990 for his contributions to computer technology and his leadership in science and technology policy.

HERMANN A. HAUS, 77, institute professor emeritus, Department of Electrical Engineering and Computer Science, Massachusetts Institute of Technology, died on May 21, 2003. Dr. Haus was elected to NAE in 1976 for his work on electromagnetics and quantum electronics. His contributions to the field include: fundamental analyses of noise in electronic devices; basic theorems concerning the forces exerted by electromagnetic fields on matter; the first measurements of noise in a laser oscillator; the theory of laser mode locking; and the invention of the mode-locked semiconductor laser.

BILLY M. HORTON, 84, professor of mechanical and aerospace engineering, Case Western Reserve University, died on April 28, 2003. Dr. Horton was elected to NAE in 1979 for the invention of fluid amplification and pioneering work in the field of signal processing.

HUMBOLDT W. LEVERENZ, 93, retired staff vice president and chairman, Educational Aid Committee, RCA Corporation, died on May 20, 2003. Mr. Leverenz was elected to NAE in 1970 for his contributions to television phosphors and to the transfer of research results to large-scale manufacturing.

HERBERT L. MISCH, 85, retired vice president, Engineering and Research, Ford Motor Company, died on June 23, 2003. Mr. Misch was elected to NAE in 1976 for his contributions to environmental and vehicle safety policies.

JOSEPH A. PASK, 90, professor emeritus of ceramic science and engineering, Department of Materials Science and Mineral Engineering, University of California, Berkeley, died on June 14, 2003. Dr. Pask was elected to NAE in 1975 for his contributions to the literature and development of the science and technology of nonmetallic materials.

Calendar of Meetings and Events

2003	
September 16–18	AAES Diversity Summit
September 18–20	U.S. Frontiers of Engineering Symposium *Irvine, California*
September 22–23	Assessing Technological Literacy Committee Meeting
September 23	Charles Stark Draper Prize Committee Meeting
September 25	Committee on Engineering Education Meeting
October 8	Governing Board Executive Committee Meeting
October 9	Bernard M. Gordon Prize Committee Meeting
October 10	NAE Finance and Budget Committee Meeting
	NAE Council Meeting and Dinner
October 11	NAE Council Meeting
	NAE Peer Committee Meetings
October 12–13	NAE Annual Meeting
October 14–15	Symposium on Engineering Ethics
October 20	Center for the Advancement of Scholarship on Engineering Education Advisory Committee Meeting
October 21	Women in Engineering Website Advisory Committee Meeting
November 12	NRC Governing Board Executive Committee Meeting
November 12–13	NRC Governing Board Meeting
November 20–22	3rd Japan-American Frontiers of Engineering Symposium *Irvine, California*
December 4	NAE/American Society for Engineering Education Assembly Meeting
December 5–6	Committee on Membership Meeting *Irvine, California*
December 11	Governing Board Executive Committee Meeting
2004	
February 11–12	NAE Council Meeting *Irvine, California*
February 12	NAE National Meeting *Irvine, California*
February 24	NAE Awards Forum/Dinner/Presentation
March 9	NAE Regional Meeting *San Jose, California*
March 18	NAE Regional Meeting *Houston, Texas*

All meetings are held in the National Academies facilities in Washington, D.C., unless otherwise noted. For information about regional meetings, please contact Sonja Atkinson at *satkinso@nae.edu* or (202) 334-3677.

Century of Innovation

This fall NAE will release a book based on the Greatest Engineering Achievements of the 20th Century Project. *A Century of Innovation: Engineering That Transformed Our Lives* will be released at the October 2003 Annual Meeting. The book features 20 chapters with narratives about the achievements, original "how-things-work" illustrations, graphic timelines, and perspectives by NAE members **William A. Anders, Stephen D. Bechtel, Jr., E. Linn Draper, Jr., George M. C. Fisher, Samuel C. Florman, William H. Gates III, Mary L. Good, Wilson Greatbatch, Shirley A. Jackson, Donald L. Johnson, Robert E. Kahn, Kent Kresa, Robert W. Lucky, Gordon E. Moore, Donald E. Petersen, Lee R. Raymond, Donald E. Ross, Ian M. Ross, Roland W. Schmitt,** and **Charles H. Townes**. The volume also includes a thoughtful foreword by **Neil A. Armstrong** and an afterword looking to the future by Sir **Arthur C. Clarke**.

The book will be available (with a members discount) through the *www.nap.edu* website or retail for $45. The volume was underwritten by NAE member **Robert A. Pritzker**, president and CEO of Colson Associates, Inc.

Information Technology (IT)-Based Educational Materials: Workshop Report with Recommendations

In the last half-century, we have witnessed the birth and development of a new era—the information age. Information technology (IT), the primary vehicle of the information age, has transformed the workplace and is critical to the development of new knowledge and the creation of wealth. IT has also dramatically influenced our capacity to educate. So far, however, the application of IT in education has been disorganized and uneven. Pockets of innovation in localized environments are thriving, but the promise of open access, greatly enhanced teaching and learning, and large-scale use has yet to be realized.

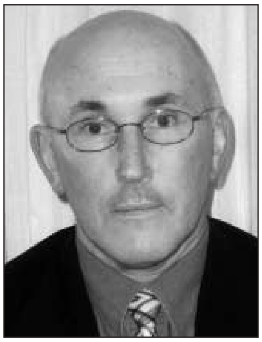
IT-Based Educational Materials: Workshop Report with Recommendations identifies the critical factors in the development and use of IT-based educational materials. The report recommends high-priority steps for transitioning from the current fragmented environment to an IT-transformed future in engineering education. The six recommendations include a call for a national laboratory for evidence-based investigations and other activities to ensure interoperability and effective teaching and learning. The report also stresses the need for open architectures and for engaging researchers from many disciplines, including the social sciences, to address the transformation of faculty cultures and the need to engage the users and developers of IT products in activities driven by learning outcomes.

This initiative is partly funded by the Kavli Institute, Oxnard, California. The report is available in printable document format (PDF) on the National Academies Press website (*www.nap.edu*) and the Kavli Institute website (*www.kavliinstitute.org*). Hard copies are available through the NAE Program Office. Please contact Patricia Mead at (202) 334-3524 or *pmead@nae.edu*.

The National Academies Update

Protecting People from Terrorist Bombing: A National Research Council Success Story

Eugene Sevin (NAE) is an independent consultant.



Richard G. Little is board director of the Board on Infrastructure and the Constructed Environment, National Research Council.

Long before September 11, 2001, made us all painfully aware of the vulnerability of civilian buildings to terrorist attack, the National Research Council (NRC) had been working to ensure that defensive technologies would be widely available. Over the course of six years, two separate NRC committees had considered how blast-mitigation technologies developed by the military could be made available to protect buildings and the people they shelter. *Protecting Buildings from Bomb Damage: Technology Transfer for Blast-Effects Mitigation* was published in 1995, shortly after the attack on the Alfred P. Murrah Building in Oklahoma City that killed 167 people. The principle recommendation of that report was that the federal government begin an aggressive program of research and testing to determine the most cost-effective ways to protect new and existing buildings. Within two years, the Defense Threat Reduction Agency had established the Blast Mitigation for Structures Program and implemented most of the NRC recommendations. To date, this program has invested more than $35 million in analyzing and testing structural methods, materials, and window glazing, developing predictive models for injuries and damage, and producing design guidelines.

The NRC was then asked to develop a technology-transfer strategy for the program. In 2001, *Protecting People and Buildings from Terrorism* was released. The basis of this report was a workshop attended by about 100 major stakeholders, including emergency medical personnel and other first responders. Released shortly after the attacks of September 11, this report recommended a comprehensive technology-transfer program for getting practical information into the hands of planners, architects, and engineers faced with the challenge of keeping people in buildings safe from terrorist attacks. Spurred on by concerns about homeland security in the two years since the attacks, guidance for the civilian design community has been developed and released to the public.

The U.S. Department of Defense (DoD) issued *DoD Minimum Antiterrorism Standards for Buildings* in 2002. This unrestricted document spells out minimum standards for new construction that are applicable to many civilian buildings. The Federal Emergency Management Agency will soon release the first four in a series of manuals on blast effects and blast-resistant construction. The DoD Advanced Materials and Processes Technologies Information Analysis Center (AMPTIAC) has produced a special volume showcasing many of the results of the Blast Mitigation for Structures Program. The Building and Fire Research Laboratory of the National Institute of Standards and Technology (NIST) is developing a life-cycle cost model for security features and, in response to a Congressional mandate, is also establishing a rapid-response team to gather information at sites where buildings have failed, including failures caused by terrorist attacks. The Centers for Disease Control and Prevention have supported the development of a rapid-assessment tool to assist emergency responders in categorizing trauma victims at bomb sites. The Physical Security and Hazard Mitigation Committee of the Federal Facilities Council provides a government-wide resource for networking and outreach to federal agencies. Finally, a special issue of the *ASCE Journal of Performance of Constructed Facilities* will highlight blast-resistant technologies and techniques for the civilian design community.

Many of these activities were recommended in the NRC reports described above. Others are a direct result of outreach activities by the study committees. As the nation comes to grips with the enormous task of homeland defense, a full suite of tools and materials is emerging for designing and constructing safer buildings. As they have in the past, the NRC and the National Academies, as advisors to the nation on critical matters of science and technology, are providing a vital service in a time of need.

Call for Nominations

Nominations for the 2004 National Medal of Technology are open until October 30, 2003. Information about submitting nominations is available online at *www.technology.gov/Medal*.

Publications of Interest

The following reports have been published recently by the National Academy of Engineering or the National Research Council. Unless otherwise noted, all publications are for sale (prepaid) from the National Academy Press (NAP), 500 Fifth Street, N.W., Lockbox 285, Washington, DC 20055. For more information or to place an order, contact NAP online at <*http://www.nap.edu*> or by phone at (800) 624-6242. *(Note: Prices quoted by NAP are subject to change without notice. Online orders receive a 20 percent discount. Please add $4.50 for shipping and handling for the first book and $0.95 for each additional book. Add applicable sales tax or GST if you live in CA, DC, FL, MD, MO, TX, or Canada.)*

Fair Weather: Effective Partnerships in Weather and Climate Services. In 1991, the National Weather Service (NWS) established a "public-private partnership" policy that the NWS would not provide services that the private sector could provide but would continue to collect information and issue severe-weather watches and warnings. NWS and the more than 400 private U.S. meteorology companies have interpreted this policy differently. Private companies have insisted that NWS provide only warnings to the general public; all other weather information, they say, should be provided by the private sector. The situation has been further complicated by a federal rule requiring full and open access to all government data. This study, conducted by the National Research Council and sponsored by NWS, found that the 1991 policy is ambiguous and its guidelines untenable. The report suggests that a new policy be written that spells out processes for making decisions, on an ongoing basis, about whether a particular type of forecast or other weather product should be provided by NWS or the private sector; the focus should be on improving interaction between the private and public providers of weather information. The new policy should include all parts of the National Oceanic and Atmospheric Administration involved in the weather and climate enterprise. NWS should also manage its 135 regional offices in a way that balances respect for creativity with control in areas in which it may compete with the private sector. The report also recommends that NWS set up an independent advisory committee of members of government, industry, and academia to hold periodic discussions of the relationships among providers of weather information and products. Paper, $35.00

Freight Capacity for the 21st Century—Special Report 271. Keeping up with the rapid growth in freight transportation requires that current facilities be used more efficiently and that funding be targeted to projects with the biggest payoffs. A comprehensive national policy to promote better management and investment decisions is crucial to maintaining and improving the nation's freight system. To ensure adequate freight capacity, Congress and federal agencies must coordinate the activities of dozens of separately administered programs that affect the system. This report recommends four principles to guide decisions about using, enlarging, funding, and regulating the freight transportation system: (1) capital improvements, such as new roads—as well as operating practices for public facilities—should aim for the greatest usefulness considering all costs; (2) local, state, or federal governments should be involved only when they can do the job better than any other entity; (3) whenever the primary benefit of a project is lower cost for the facility's users, user fees—not government subsidies—should pay for capital and operating costs; and (4) appropriate choices about financing arrangements should be made at the start of a project. Paper, $23.00. Available from TRB Bookstore at (202) 334-3213 or online at *http://www.national-academies.org/trb/bookstore/*.

Frontiers in Agricultural Research: Food, Health, Environment, and Communities. Globalization, the liberalization of trade, consumer preferences, public concern about food safety and the environment, and changes in the relationship between agriculture and rural communities have changed the context for agricultural research. At the same time, advances in biotechnology and genomics, ecosystem science, and social science have transformed the practices and products of agriculture. Scientific advances have opened new frontiers in agricultural research that have put solutions to global challenges within our reach. The U.S. Department of Agriculture (USDA) is uniquely positioned to carry out research on these exciting new frontiers. The USDA Research, Education, and Economics (REE) mission area is the main engine of publicly funded agricultural research in the United States. Its mission is to create a safe, sustainable, competitive U.S. food and fiber system and strong, healthy communities, families, and youth. In response to a congressional mandate and at the request of USDA, the National Academies convened a committee to review REE research, education, and outreach, identify future opportunities, and recommend future directions. This report is the result of the committee's deliberations. Paper, $39.00.

Government Data Centers: Meeting Increasing Demands. At the request of the U.S. Global Change Research Program, the National Research Council held a workshop to discuss how government environmental data centers should handle the increasing volume and number of data sets and increasing demands from diverse users, which are making it difficult for data centers to maintain the record of environmental change. The workshop objectives were to consider technological solutions that would make it easier for users to find, interpret, and analyze information held in environmental data centers and help data centers collect, store, share, manage, and distribute large volumes of data. This report, based on workshop discussions and committee deliberations, considers how advanced technologies might improve applications of standard translatable formats; allow for greater reliance on online data storage and network access; provide more sophisticated database technologies; expand metadata management and lineage tracking; and allow for greater reliance on nonspecialized, easily available hardware and software. Paper, $18.00.

Government-Industry Partnerships for Development of New Technologies. Based on a comprehensive review of 10 reports on different types of federal government-industry technology partnerships, this summary report puts these cooperative efforts in historical and international perspective. The report synthesizes the best-practice lessons from U.S. public-private partnerships and emphasizes the importance of public-private cooperation and the need for ongoing, objective assessments of such programs. Paper, $33.75.

Information Technology for Counterterrorism: Immediate Actions and Future Possibilities. Information technology (IT) is essential to virtually all of the nation's critical infrastructures making them vulnerable by terrorist attacks on their IT systems. Terrorists could attack an IT system directly or use it to launch or exacerbate another type of attack. IT can also be used as a counterterrorism tool. The report offers two recommendations for protecting the nation's communications and information systems in the short term and several recommendations for protecting them over the longer term. The report notes that planners must take into account how an IT system is used to maximize protection against attacks and maximize its usefulness in responding to attacks. Paper, $32.00.

ISC Security Design Criteria for New Federal Office Buildings and Major Modernization Projects: A Review and Commentary. Physical protection must be integrated into the planning and design process for new federal facilities and for major renovations of existing facilities. The challenge is to design facilities that protect against terrorist explosive threats, without compromising the features that make the facilities desirable workplaces. The Office of the Chief Architect of the Public Buildings Service requested that the National Research Council evaluate the *Interagency Security Committee (ISC) Design Criteria* to determine whether particular provisions might be too prescriptive to allow design professionals "reasonable flexibility" to meet the objectives of security and physical protection. The committee performed a line-by-line evaluation of the criteria and commented at length on certain provisions. One of the concerns expressed by the committee was that the *ISC Security Design Criteria* focuses on vehicle bombs as the primary means of attack and offers little guidance on defending federal buildings and their occupants from other kinds of attack, such as attacks using chemical, biological, or radiological weapons. The committee recommends several steps that should be taken immediately for a more performance-based approach to security-related design and recommends other, less urgent steps. Paper, $18.00.

Minorities in the Chemical Workforce: Diversity Models That Work—A Workshop Report to the Chemical Sciences Roundtable. Even as we rely more and more on science and technology, we are facing a critical shortage of technically skilled workers. This shortage could be ameliorated largely by bringing women and minorities into the technical workforce. In March 2002, a workshop was held to explore how the chemical science community could respond to these workforce issues. The report summarizes the workshop presentations and discussions. Paper, $37.25.

Oil in the Sea III: Inputs, Fates, and Effects. Since the early 1970s, experts have recognized that petroleum pollutants were being discharged into marine waters worldwide from oil spills, vessel operations, and land-based sources. Public attention to oil spills has forced improvements, but a considerable amount of oil is still discharged yearly into sensitive coastal environments. Oil in the Sea provides the best available estimate of oil pollutants discharged into marine waters, including an evaluation of methods for assessing petroleum loads and a discussion about the concerns they raise. Featuring close-up looks at the *Exxon Valdez* spill and other notable events, the report identifies important research questions and makes recommendations for better analysis of—and more effective measures to prevent—pollutant discharges. This update of a problem of international importance will be of interest to energy policy makers, industry officials and managers, engineers and researchers, and advocates for the marine environment. Hardback, $54.95.

Promoting Innovation: 2002 Assessment of the Partnership for Advancing Technology in Housing. The use of new technologies and production processes in housing design, construction, and operation has been considerably hindered by the housing industry, which tends to resist the development and diffusion of innovations. The Partnership for Advancing Technology in Housing (PATH) supports activities to address the problems perceived by the industry. At the request of the U.S. Department of Housing and Urban Development, a National Research Council committee assessed the PATH program's progress toward meeting its objective of expanding the development and use of new technologies in the U.S. housing industry. Each of the 56 PATH activities initiated between 1999 and 2001 was considered, focusing on the activities that seemed most likely to further the program's goals. The report describes a long-term process for program assessment that would facilitate continued improvement. Paper, $18.00.

Science and Technology for Army Homeland Security: Report 1. In light of the U.S. Army's historic role of supporting civil authorities, the September 11, 2001, terrorist attack created substantial new challenges for the Army. The Assistant Secretary of the Army for Research and Technology requested that the National Research Council (NRC) carry out a series of studies on how science and technology (S&T) could help the Army prepare for its role in homeland security (HLS). The NRC Board on Army Science and Technology formed a committee to review relevant literature and activities, determine areas of emphasis for Army S&T to support counterterrorism and antiterrorism activities, and recommend high-payoff technologies to help the Army fulfill its mission. The U.S. Department of Defense Counter-Terrorism Technology Task Force has identified four operational areas categorizing technical proposals for HLS operations: (1) indications and warning; (2) denial and survivability; (3) recovery and consequence management; and (4) attribution and retaliation. The study sponsor asked the committee to use these four areas as the basis for its assessment. The committee concluded that there could be substantial synergy between S&T work by the Army to support its HLS responsibilities and the development of the next-generation Army, the Objective Force. In addition, the Army National Guard will be critical to the success of the Army's HLS efforts. Paper, $38.75.

Securing the Future: Regional and National Programs to Support the Semiconductor Industry. Semiconductors are a major driver of the modern economy and a major source of the gains in productivity that have characterized the U.S. economy since the mid-1990s. Partly because of these benefits, many nations now have national programs to develop and support this industry. As part of its broader analysis of public-private partnerships, a National Research Council committee, led by Gordon Moore of Intel, convened a conference to examine regional and national programs to support the semiconductor industry. The conference brought together experts from several producing countries to discuss the exceptional technical challenges faced by the industry as it seeks to maintain the rapid advances postulated by Moore's Law, to review the scope and design of programs to strengthen national and regional industries, and to explore opportunities for international cooperation. The volume also includes a description of the impact of SEMATECH and an overview of major industry support programs around the world. Finally, this report emphasizes the need for public-private cooperation to ensure the continued progress of the U.S. semiconductor industry. Paper, $66.00.

Tracking and Predicting the Atmospheric Dispersion of Hazardous Material Releases: Implications for Homeland Security. In addition to preparing to deal with accidental atmospheric releases of hazardous materials from industrial sites, energy facilities, and during the transport of hazardous materials, communities are also worried about protecting against the threat of the intentional use of chemical, biological, or nuclear (C/B/N) agents. Predicting and tracking the dispersal of harmful agents has become a critical element in responding to terrorism. Our nation's capacity to respond to atmospheric C/B/N events depends on three interconnected elements: (1) dispersion models that predict the path and spread of a hazardous agent; (2) observations of the hazardous plume itself and of local meteorological conditions, which provide critical input for the models; and (3) interaction among the emergency responders who must use the information provided by the models. This report examines our current capabilities in these three areas and recommends ways to strengthen them. The report is based on a National Academies workshop held in Woods Hole, Massachusetts, on July 22–24, 2002, that brought together atmospheric scientists from academia, government laboratories, and the private sector; emergency management officials and first responders; and experts in national security, risk communication, and other relevant fields. Paper, $27.00.

Use of Lightweight Materials in 21st Century Army Trucks. The ability to place a combat-capable force on the ground anywhere in the world as quickly as possible is critical to military readiness. Trucks and trailers, which are used to transport personnel, equipment, food, water, ammunition, and fuel once forces are on the ground, represent the logistical backbone of military operations. Over time, the Army's truck fleet has aged and become less effective; high fuel consumption takes a financial and logistical toll and limits the Army's agility. To overcome readiness problems, support a more agile military force, and reduce costs over the long term, the Army is looking into using high-strength, lightweight materials in its trucks. The National Research Council was asked to evaluate and recommend research and development (R&D) opportunities for new manufacturing processes and materials that could reduce vehicle weight, improve fuel efficiency, improve corrosion resistance, and lower costs over the lifetime of vehicles without compromising safety. The committee identified opportunities for R&D on lightweight materials for structural components that are achievable over short, medium, and longer time frames. Programs to retrofit or remanufacture older trucks are also discussed in the report, as are ways to track the age and condition of vehicles and to improve the process of soliciting and procuring bids. The study was sponsored by the U.S. Army Tank-Automotive and Armaments Command. Paper, $26.75.

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