Regulation of nuclear hazards must be consistent with rules governing other hazardous materials and must balance its risks against those linked to other energy sources.

Although most of the radioactive material generated by nuclear energy decays away over short times ranging from minutes to several decades, a small fraction remains radioactive for far longer time periods. Policymakers, responding to public concern about the potential long-term hazards of these materials, have established unique requirements for managing nuclear materials risks that differ greatly from those for chemical hazards. Although it is difficult to argue against any effort to protect public safety, risk management will be most effective when each risk is evaluated in the context of other risks and balanced against the benefits produced by the regulated activity. Applying extremely stringent standards to one type of risk while other risks are regulated at a lower standard does not improve overall public safety. Similarly, foregoing a socially and economically valuable activity in order to limit relatively small future risk is not a sensible tradeoff. Therefore, developing an effective risk policy for nuclear power and radioactive waste requires looking at how the government regulates all hazardous waste and at the relative health and environmental effects of nuclear power as compared with those of other energy sources.

A key regulatory decision for the future of nuclear power is the safety standard to be applied in the licensing of the radioactive waste depository at Yucca Mountain (YM), Nevada. In 1992, Congress passed the Energy Policy Act, directing the Environmental Protection Agency (EPA) to promulgate site-specific standards for the YM nuclear waste repository project. Furthermore, Congress stipulated that these standards be consistent with the findings and recommendations of the 1995 National Research Council report Technical Bases for Yucca Mountain Standards (commonly called the “TYMS report”).

The standard that the EPA subsequently established was generally consistent with the TYMS report but differed significantly with respect to the compliance period. The EPA ruled that during its first 10,000 years, the YM repository must ensure that no individual in the adjoining Armagosa Valley would be exposed to more than 15 millirems (mrem) of radiation per year from use of the groundwater. The EPA chose the 10,000-year compliance period because that is the period already being applied to the Waste Isolation Pilot Plant repository in New Mexico and is the longest compliance period for any hazardous waste. However, the TYMS report concluded that there is “no scientific basis for limiting the time period of the individual risk standard to 10,000 years or any other value” and recommended that assessment be performed out to the time of peak risk to a maximally exposed individual, which may be several hundred thousand years in the future.

Opponents of the YM project challenged the EPA rules in court. On July 9, 2004, the U.S. Court
of Appeals issued a ruling that denied all challenges, except one. The successful challenge, brought by the State of Nevada, argued that the EPA was not in compliance with the Energy Policy Act, because it had deviated from recommendations of the TYMS report by limiting the regulatory compliance time to 10,000 years. Thirteen months later, EPA issued a revised “twotiered” standard under which maximum exposure beyond 10,000 years will be limited to 350 mrem per year, which is roughly equivalent to the average background exposure for individuals across the globe. No detectable health damage has been associated with this level of exposure.

It should also be noted that in making its recommendation that standards be set for the period beyond 10,000 years, the TYMS report included two important caveats: that the EPA should consider establishing “consistent policies for managing risks from disposal of both long-lived hazardous non-radioactive materials and radioactive materials” and that the ethical principle of intergenerational equity should be considered in the formulation of safety standards.

Here we consider three central questions for the YM standard: What risk does YM pose beyond 10,000 years, how are other long-term risks regulated, and how might such long-term standards affect nearer-term human welfare? We find that the proposed EPA standard for YM does satisfy appropriate long-term safety criteria, and indeed the standard is much more stringent than EPA standards governing other sources of long-term risk. In addition, a risk/benefit analysis of nuclear power indicates that it is a safer choice than the fossil options that now dominate electricity generation.

Nuclear fission extracts large quantities of energy from extremely small masses of fuel. The small quantity of fuel used, as compared to fossil energy alternatives, makes it possible to manage nuclear wastes by isolation as a concentrated, contained solid rather than by release and dilution into the environment as is done with fossil fuels. The vast majority of radioactivity created in nuclear fuels disappears rapidly after reactors shut down, as short-lived radioactive elements (so-called fission products) decay to become stable elements over periods of hours to days. A modest fraction of radioactivity comes from fission products that remain radioactive for decades, and a very small fraction from radioactive isotopes—primarily heavy elements such as plutonium created by neutron capture, as well as some of their radioactive decay products—that persist for tens to hundreds of millennia.

Nuclear reactor safety focuses on providing multiple containment barriers and reliable cooling to allow for the safe radioactive decay of short-lived fission products after reactor shutdown. Interim storage of spent fuel in surface facilities can then permit further substantial reductions in heat generation from the smaller quantities of fission products that take multiple decades to decay. The remaining inventory of very long-lived isotopes could be further reduced—by factors of 40 to 100—by reprocessing spent fuel and recycling it in advanced “burner” reactors. With or without reprocessing, there remains a quantity of residual long-lived radioactive materials that must be stored and isolated from the environment.

A general scientific and technical consensus exists that deep geologic disposal can provide predictable and effective long-term isolation of nuclear wastes. Environments deep underground change extremely slowly with time, particularly when compared to the surface environment, and therefore their past behavior can be studied and extrapolated into the long-term future. The
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largest challenge for safety assessment for deep geologic isolation comes from predicting how the perturbation created by emplacing nuclear waste will change long-term chemical and hydrogeologic conditions—in particular the effect on surrounding rock of the heat generated by the waste over multiple centuries.

In the United States, a protracted and divisive political and technical process resulted in the selection, in 2002, of a national repository site at YM, sitting astride a federally owned area that overlaps the Nevada Test Site, Nellis Air Force Base, and Bureau of Land Management lands in southern Nevada. After a delay to revise its original license application, the U.S. Department of Energy (DOE) has recently announced that it will submit a construction license application for YM to the U.S. Nuclear Regulatory Commission (NRC) in 2008. Under current law, the NRC will have three years to evaluate this application, with a potential one-year extension, to determine whether the DOE repository design meets a safety standard established by the EPA.

Detailed technical review of YM performance will occur during licensing. In the interim, the 1999 Final Environmental Impact Statement (FEIS) provides a preliminary indication of potential long-term performance, assuming the disposal of 63,000 metric tons (MT) of spent fuel and 7,000 MT of defense waste. The peak risk occurs in about 60,000 years, when the waste canisters may become degraded, potentially allowing the radioactive material to be transported down to groundwater and subsequently to the Amargosa Valley. If one considers a worst-case scenario in which future Amargosa Valley residents possess technology for irrigated agriculture but do not employ any basic public health measures to test water quality for natural and human-generated contaminants and do not use the simple mitigative actions that our current public health practice employs, the maximum doses predicted by the FEIS would be of the same order as average natural background radiation, which generates no statistically detectable health effects. For its license application, DOE will implement further changes in repository design and modeling, which may result in somewhat lower long-term dose predictions than those reported in the FEIS.

Other risks

A large number of other important human activities also generate wastes that present persistent or permanent hazards. These include mining wastes; coal ash; deep-well injected hazardous liquid waste; and solid wastes such as lead, mercury, cadmium, zinc, beryllium, and chromium that are managed at Resource Conservation and Recovery Act (RCRA) and Superfund sites.

For these wastes, the longest compliance time required by the EPA is 10,000 years for deep-well injection of liquid hazardous wastes. For all forms of shallow land disposal, compliance times are substantially shorter. For RCRA solid waste management facilities, a typical permit is for 30 years, and the operator bears responsibility over a time horizon of less than a century. RCRA sites cannot reside in a 100-year flood plain unless they are designed to resist washout by a 100-year flood. Although coal and mining wastes pose potential health risks, federal legislation excludes them from the category of hazardous waste.

The short regulatory compliance times for much hazardous waste do not mean that these materials do not pose any potential long-term danger. David Okrent and Leiming Xing at the
University of California Los Angeles have analyzed what would happen over the long term at an approved RCRA site for the disposal of arsenic, chromium, nickel, cadmium, and beryllium. Assuming a loss of societal memory and the absence of monitoring or mitigation, individuals in a farming community at the site 1,000 years in the future would face an estimated 30% lifetime probability of cancer due to this exposure.

Indeed, instead of questioning the adequacy of nuclear waste safety standards, policymakers should be focusing on other risks. The reason that most chemical risks are not subject to long-term regulation is not that policymakers are unaware of the danger. Rather, society has made a deliberate decision to place more weight on the analysis of near-term risks—as well as the benefits derived from these sources of risk—than on very long-term risks. It is also worth noting that some of these risks are not all that long-term. For example, current scientific understanding suggests that the peak risks from 20th- and 21st-century fossil fuel CO2 emissions may occur within several centuries, resulting in major ecosystem alteration, including substantial changes in ocean chemistry and a sea-level rise of up to seven meters.

Benefits

The threat of global warming associated with carbon-based energy sources highlights one of the primary advantages of nuclear power: very low greenhouse gas emissions. The health of the global and U.S. economy depends on energy. The 63,000 MT of commercial spent fuel that would be stored at YM will result from the generation of 2,200 gigawatt-years of electricity, worth $1 trillion, which in turn will support many additional trillions of dollars of economic activity. Although the Nuclear Waste Policy Act currently caps the capacity of YM at 63,000 MT of spent fuel, the actual performance-based capacity of YM is 2.5 to 5 times as large. And if the spent fuel is reprocessed and recycled in burner reactors, the performance-based limit would increase dramatically. YM would have the capacity to store all the waste from the nuclear electricity generation needed to power the country for centuries.

Near-term economic effects also deserve consideration. The government has already spent $8 billion on site selection and characterization for YM. It would cost at least that much to start looking for a new site. Because DOE has defaulted on its legal obligation to begin accepting spent fuel in 1998, storing commercial waste onsite at nuclear power plants now costs taxpayers some $360 million per year. Additional costs for protracted management of military high-level wastes at the Hanford, Savannah River, and Idaho sites will also be borne by taxpayers. Government could certainly find more productive uses for this money.

If nuclear power is not used to generate this baseload electricity, the obvious alternative is coal, which currently generates 54% of U.S. electricity. Indeed, U.S. utilities now have plans to install an additional 62 gigawatts of coal-fired generation. Using coal to produce the same amount of electricity that would be associated with 63,000 MT of spent fuel would require mining and burning 5 billion tons of coal: a full six years of current U.S. coal consumption. This would create 700 million MT of ash and flue-gas desulfurization sludge requiring shallow land disposal, discharge over 650 MT of hazardous mercury, and result in approximately 300 U.S. coal-worker
fatalities. And on top of this, coal burning would produce an enormous quantity of carbon dioxide that would contribute to climate change.

In general, life-cycle assessments like those performed by the European ExternE project show that nuclear energy creates far smaller worker safety, public health, and environmental effects than does any form of fossil fuel use.

**A reasonable standard**

Forced for the first time to create a standard that extends beyond 10,000 years, the EPA has made a sensible choice. The TYMS report recommended that the EPA adopt a risk-based standard for YM falling inside the range of annualized risk that the EPA uses in regulating other materials. The TYMS report tabulated annual risk levels permitted by current EPA regulations for other materials, which range from one death in a population of a million to four deaths in a population of 10,000. For radiation doses, this would correspond to a range from 2 mrem per year to 860 mrem per year. The higher level is the current standard for radon in groundwater and indoor air. The TYMS report recommended that the EPA use values from the lower end of this range as a reasonable starting point in setting its standard for YM. The EPA’s draft revised standard sets the limit at 15 mrem per year for up to 10,000 years and adopts a post–10,000-year standard of 350 mrem per year. For comparison, places such as Denver, Colorado, and Kerala, India, have background levels as high as 1,000 mrem per year, and we know of no cancer clusters in these areas. Thus, a level of 350 mrem per year would clearly meet the standard of avoiding very long-term “irreversible harm or catastrophic consequences,” something that cannot be said for current fossil energy use. If fossil fuels burned today result in global climate change in 50 or 100 years, there will be no way to reverse these effects. If in a few hundred or a few thousand years, future generations decide that the waste buried at YM is too dangerous or that a better way exists to manage it, they can remove it.

The safety standards recommended by the EPA for YM reflect a thoughtful assessment of risk and benefits. Indeed, instead of questioning the adequacy of these standards, policymakers should be focusing on other risks. The United States would be a safer place if this or any very long-term standard were applied uniformly to management of all types of long-lived hazardous waste, for the use of fossil fuels, and for other human activities as well.

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