An Environmental Policy Imperative

Addressing Security Concerns at the Back End of the Nuclear Fuel Cycle

Current discussions on reducing security concerns with the nuclear fuel cycle tend to focus on the front end (enrichment) or on reprocessing—but there are also important security issues associated with storage and disposal of spent fuel and radioactive wastes.

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In the early days of nuclear energy and again in recent years, there have been repeated proposals for establishing multinational cooperation approaches that could reduce the security concerns with spreading nuclear technologies. The International Atomic Energy Agency (IAEA) established a high-level group that reported on potential multilateral approaches,[1] but few specific actions have resulted as yet. Initiatives have been proposed by both Russia[2] and the United States[3]—each aimed at promoting nuclear power while limiting security concerns. These initiatives are generating discussion but, as yet, little action; furthermore, they concentrate strongly on enrichment and reprocessing activities. Meanwhile, interest in expanding nuclear power programs and in introducing nuclear power to new countries continues to grow rapidly. Reactor vendors are jostling to position themselves in the expanding market and are even becoming concerned about the possible bottlenecks in the supply of components or of qualified personnel. Assuming that the current economic crisis does not break the momentum, this "rush to nuclear" will continue, with potential users focused on secure energy supplies and vendors focused on business opportunities.

It is, however, an environmental policy imperative that waste disposal issues not be neglected, as they were during the early decades of the development of nuclear power (and, arguably, still are even today in some countries). This general environmental and ethical point is discussed in a companion paper in this publication (see "A Nuclear Renaissance Without Disposal?" this issue, p. 19). There is an associated issue that initiatives to avoid increased security risks may be hindered by the urgency of the new nuclear build programs. Discussions are already more muted on security aspects and, in particular, on the role of multilateral approaches to reducing security concerns. Such discussion as there is tends to focus on the front end (enrichment) or on reprocessing—but there are also security issues associated with storage and disposal of spent fuel and radioactive wastes.

What Are the Security Risks?

The security concerns associated with fuel cycle wastes are essentially those of fissile materials being used for nuclear weapons production by proliferating states or by terrorist organizations and the use of other radioactive materials in acts of terrorism or war. They can broadly be categorized as follows:

- **The diversion of fissile materials separated during civil reprocessing of spent fuel.** This essentially means plutonium, of which several countries have stockpiles amounting from tens of tonnes up to a hundred or more. In practice, of course, these countries are almost all nuclear weapons states (Japan being the exception), the material is closely guarded, and the isotope mix may be less than ideal for weapons use, so that the security risks appear relatively small. The facts that plutonium is stockpiled and inventories are growing do, however, indicate that the owners do not know what to do with it. Although it can be an extremely valuable energy source, means of deploying plutonium—as mixed oxide (MOX) fuel in light-water reactors or in fast reactors—are not yet available or are not widespread or are not economic. The economics and proliferation aspects of the separation and use of plutonium are well studied and beyond the scope of this article. Nevertheless, a decision on whether plutonium is a valuable resource or just an "albatross around the necks" of its owners seems impossible to make in some countries, so that storage continues. If plutonium were to be declared as a waste material "surplus to requirements," then this would present challenges for the safe and secure management and disposal of the waste. There have been many studies on conditioning it as a waste form for geological disposal (glass, ceramic, "disposal MOX"). The disposal options are in a conventional mined repository along with spent fuel and high-level waste or separate, extremely high-isolation disposal in very deep (3–5 kilometer) boreholes. We discuss these aspects of plutonium as a waste in the next section.
- **Clandestine reprocessing of spent fuel to produce weapons materials.** This could, in principle, be done by Nuclear Nonproliferation Treaty signatories in contravention of the treaty, by nonsignatories, or by substate terrorist groups. There is a historical perspective that is not often closely addressed—and may present an intractable difficulty. Countries that are trusted today by the international community as being stable and nonbelligerent may currently store or, in the future, dispose of their spent fuel. They are regarded as trustworthy guardians of a potentially hazardous material. But history tells us that social and political upheaval on a decadal time scale can change all that. Today's trusty guardian may be an unpredictable regime some decades in the future, when spent fuel remains a sensitive material. Providing national and international surveillance and safeguards for spent fuel stores or repositories is straightforward when times are peaceful, but may become impossible in times of societal disruption. Furthermore, at longer times into the future, the inherent radiation barrier built into spent fuel becomes less intense, making handling and treatment procedures less hazardous for those attempting clandestine diversion.
- **Disruption of waste storage facilities in acts of terrorism or war.** Spent fuel is stored in wet or dry storage facilities at reactor sites or centralized surface stores. These stores are generally in robust structures, designed to withstand attempts at attack and disruption. Very little spent fuel is stored underground. Some HLW still exists in unconditioned liquid form; the vitrified material is located in surface stores—again robust. Some long-lived low- and intermediate-level waste (LILW) is stored in impact-resistant, reinforced surface storage buildings, while other LILW is often stored in simple warehouses. Security in terms of controlled access is normally very high in all these cases. However, post-9/11, concerns were raised about the security of spent fuel stores at reactors,[4] and regulatory bodies looked at the vulnerability of some storage facilities (as well as reactors) to impact by large objects such as planes or munitions.[5] There are undoubtedly significant hazards associated with some types of store. Although the probability of disruption might be regarded as very small, maintaining large numbers of spent fuel stores at numerous locations for time periods extending to many decades, as has been suggested in different national programs, clearly does not maximize security.
- **Diversion of radioactive wastes with the intention of dispersion and contamination.** The so-called "dirty bomb" scenario suggests that the explosive (or other) dispersion of radioactive materials in a populated area, in a water supply, or in a transport system would have massive social and economic impacts, even if the actual health hazards might be relatively low. The psychological effect of radioactive contamination means that even small quantities of low-activity wastes could be seized and used to create havoc in a community or region. Greater actual impact could arise from the attack and disruption of spent fuel transport systems or the disruption of high-specific-activity radiation sources from outside the nuclear fuel cycle. Because many nuclear fuel cycle wastes have to be transported outside the normally high-security area where they were generated, this scenario may represent the highest likelihood security risk, even if the potential consequences are not catastrophic.

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Are There Easy Solutions to Any of These Risks?

The most obvious answer to practically all of the risks posed in the previous section is the timely return of fissile materials into the fuel cycle (recycling) and the secure

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deep underground disposal of all highly radioactive materials declared as waste. But this is simply not happening. Uncertainty about the development of future nuclear energy systems, lack of wide-scale use of MOX, and the absence of geological repositories leaves most of the materials in storage—fortunately, generally secure storage. Even when repositories become available, there will be continuing operational security issues that need to be addressed. In this section, we look at some possible security enhancing approaches and at matters that arise from them.

Disposal of Plutonium

Getting excess plutonium deep underground clearly reduces security risks. Means of conditioning plutonium for direct disposal have been studied extensively over the last 20 years. Innovative ceramic waste forms and relatively well-established processes (vitrification, low-specification unburned MOX) have both been proposed and tested. Codisposal of MOX spent fuel with conventional spent fuel has been evaluated in depth, and the thermal implications and criticality issues are well understood and tractable in designing and managing a conventional geological repository. Direct disposal of plutonium waste forms raises a tricky safeguards issue, in that conventional geological repositories allow relative ease of retrieval of waste containers for some hundreds of years. Indeed, some are programmed to remain partly open to permit access for decades or even hundreds of years. Mixing HLW with plutonium to achieve canisters with "spent fuel standard" radiation levels (providing sufficient quantities of HLW are available) or interspersing plutonium containers with HLW or spent fuel containers in disposal tunnels can deter, but not prevent, determined attempts to retrieve the material. In some senses, retrievability is the enemy of safeguards. One (partial) answer to this problem is early, complete repository closure; another (almost complete) answer may be very deep borehole disposal using designs that obliterate the borehole location and access. In the latter model, disposal is as close to "practically irrecoverable" as currently possible to envisage. However, the system technology is largely undeveloped and currently untested. Unfortunately, none of these solutions removes the requirement for permanent and presumably remote safeguards surveillance of the disposal site to ensure that illicit removal by some group (possibly including a national government) is not taking place. Note the word "permanent," which is apparently acceptable to the safeguards community, although the principles espoused by disposal experts assert that continued monitoring or maintenance should not be required.

Disposal of Spent Fuel

As for separated plutonium, spent fuel deep underground is clearly more secure than at the surface. Disposal solutions for spent fuel are, of course, well researched, well advanced, and partially tested in several nuclear power countries. Many of the points made previously about the disposal of plutonium and retrieval, surveillance, and safeguards apply to conventional spent fuel and MOX spent fuel as well. A major difference is that both are somewhat less attractive targets for illicit retrieval. Moreover, it is often observed that a technically well-equipped state would find it easier to "start from scratch" to manufacture plutonium for weapons than to excavate and reprocess spent fuel from a repository, given the hazards and the technical difficulties of dealing with the material. That this is always the case is not, however, so obvious, as it would depend on the exact nature of the fuel that was accessible, its burnup and isotopic composition, the ease of access to the repository, the time elapsed after disposal, the probability of detection, and the determination and attitude toward hazard of the "diverter." We draw attention again to the need for permanent safeguards surveillance. As short-lived fission products decay, spent fuel becomes more tractable, and the inherent safeguards barrier decreases with time. The full implications of committing to providing safeguards over repositories for 500 years have not been analyzed. Perhaps this is simply hubris—future generations will certainly have different decision drivers and, possibly, ad-

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vanced technologies that make our current views and provisions rather irrelevant.

Disposal of HLW

As opposed to the cases of separated plutonium or spent fuel, HLW does not represent a potential energy source, and there are no strategic reasons for delaying its emplacement underground. There is a valid technical justification, however, in that allowing some decades of storage before disposal results in significantly reduced heat emission from the waste and therefore in simplified repository designs with higher emplacement densities. One cost of these engineering advantages is the extended need for secure storage, as discussed later. In practice, extended storage is proving necessary for the more mundane reason that many national disposal programs appear unable for political or economic reasons to implement deep geological repositories for some decades into the future.

More Physically Secure Storage

This is one area where more secure solutions are certainly possible. Sweden already stores its spent fuel underground beneath some tens of meters of granite, pending packaging for disposal. Canada has suggested the same approach as an option within its staged waste management strategy. A trend in past decades has been to build "hardened" surface stores for long-lived and higher activity wastes (e.g., HABOG in the Netherlands and ZWILAG in Switzerland), although the costs of such facilities are significantly higher than conventional surface stores. In those countries that have not made up their minds about geological disposal, in those that are only able to move slowly toward disposal, and even in those with advanced disposal programs, consideration could be given to more resistant, preferably underground, stores (possibly also encapsulation facilities) for HLW and spent fuel. This would require centralization of storage and significant investments and would have to be evaluated against potential improvements in security through other options.

Centralized Storage

If waste and spent fuel storage facilities are judged to present significant security risks, then minimizing the number of such facilities and maximizing their engineered and institutional protective measures would obviously improve the situation. In some cases (e.g., in Germany), the opposite strategy has been implemented: asserting that transport risks are dominant, the government there has encouraged long-term interim storage at the power plants rather than at the existing centralized storage facilities at Ahaus and Gorleben. Keeping spent fuel at the site of an operating reactor may not lead to much increased risk, because these sites are normally kept very secure—but bigger problems will arise when the operations cease.

Reduced Transport Requirements

Despite the proven safety record of nuclear transports, radioactive materials in transit are exposed to risks of theft and misuse. All wastes must be transported at least once. To minimize transport requirements, it would be most efficient to locate centralized stores and waste encapsulation/conditioning facilities at the site of a repository. Unfortunately, this is not easily achievable. Locating a site for treatment or storage is a lesser technical or societal problem than locating a geological repository, and also it is not straightforward to connect the timings of each activity in a waste management program effectively. Consequently, multiple waste transports are an almost inevitable feature in any national or multinational waste management program. Comprehensive measures to ensure their security and to respond effectively to any disruption have accordingly already been implemented in most programs.

How Can Multinational Solutions Help?

All the security problems identified previously are relevant for any country in, or entering into, the nuclear power arena, and all of the possible solutions should be considered at the national level. At the present time, for example, countries considering, reconsidering, or implementing the development of new nuclear power programs include Algeria, Australia, the Baltic States, Chile, the United Arab Emirates, Iran, Italy, Indonesia, Jordan, Malaysia, Nigeria, Peru, Poland, Thailand, Turkey, and Vietnam. With this potential rapid increase, it is sensible to consider also whether additional security benefits can be achieved through multinational cooperative efforts of the countries involved. The security and nonproliferation front-end problems of a rapid expansion and spread of nuclear power have been recognized, and they may be partly addressed by framework projects such as the United States' Global Nuclear Energy Partnership and Russia's Global Nuclear Power Infrastructure, should these develop successfully. We do not address these projects here (see the companion paper) other than to note that neither of them yet presents a complete committed solution to secure management of wastes.

The IAEA[1] has correctly noted that successful global fuel cycle projects would need to provide assurance of fuel supply to user nations. This can be achieved by ensuring diversity of supply to avoid politically biased monopolies or by international control (e.g., through a fuel bank). If the back end is to be served by such broad-scope multinational projects, the same objectives are valid for disposal of wastes, offered as a service. At the moment, however, neither the United States nor Russia is offering to take foreign waste and dispose of it permanently within their own borders. In addition, today no other country is seriously considering the provision of an open disposal service for higher activity wastes. Nevertheless, there are other credible approaches to providing multinational disposal facilities that could increase global security, as well as bring economic and environmental benefits. Chief among these is the concept of shared, regional disposal, such as advocated and explored in depth in the European SAPIERR project[6] What, then, do multinational waste storage and disposal solutions have to offer in terms of improved nuclear security? While we fully recognize the value and need for a number of national repository programs that are progressing today, there are security advantages that can ultimately arise from the availability of multinational solutions:

- **Limited numbers of facilities to be secured.** Gathering waste from disparate storage locations into a limited number of disposal facilities is clearly capable of enhancing security. Current storage conditions are quite variable among nations in terms of the physical protection they offer and the strength of the security they can provide. They are overseen by disconnected organizations with different standards and financial capabilities. A single facility, involving many nations, should, in principle, be easier to control and, for the public, more transparent to monitor.
- **Enhanced engineered and institution security measures.** The "few multinational repositories" model would ensure that the highest possible standards were adopted in all aspects of safety and security for wastes that might otherwise be subject to differing control regimes. They would, indeed, encourage the harmonization of standards, an issue that is currently high on the European agenda, with 15 nuclear power states, each with different regulatory approaches. It might be expected that common, centralized storage facilities and repositories would be built to the highest security specifications. Indeed, this is likely to be a stipulation of the countries and communities that host them.

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- **Enhanced levels of international oversight.** A few international disposal facilities for spent fuel would present a simpler safeguards surveillance task and would be likely to attract more interest and attention in ensuring that safeguards were maintained into the far future. Safeguards activities could be carried out stringently but more economically than for numerous separate facilities. International oversight is guaranteed, not only by the normal IAEA mechanisms, but also by the insight required by the nations that would be sharing a disposal facility.
- **Improved financing arrangements.** The general economic advantages of shared disposal that result from economies of scale are widely recognized. Sharing should make finding the funds for long-term disposal projects easier. It should also result in closer financial control and oversight. There is less chance that funds to provide security for waste facilities could be diverted to more pressing needs in times of national stress in any single country.

An Idealized Safe and Secure Back End

The nuclear renaissance is in danger of focusing attention only on the upside of delivering clean, economic nuclear electricity. There is a potential risk that—once again—the waste issues will be forgotten or sidelined until a more convenient moment. This is no longer acceptable, either for a national program or globally.

Looking maybe 30 years to the future, with perhaps double the nuclear generating capacity worldwide in double the current nuclear power countries, it would be a less secure world if the wastes were still being managed as they are today. While it is not possible realistically to quantify the risks outlined in this article, they would undoubtedly be greater and probably scale nonlinearly with the growth of nuclear power facilities. In fact, it is widely recognized that a major safety or security incident at any single nuclear facility would likely have a strong impact on nuclear power globally. To minimize this risk, national waste management organizations, international agencies, and the technology provider countries can act concertedly today.

A vision of waste management in 20 years' time might include the following features, designed not only to stiffen and embed global security, but also for obvious reasons of efficiency and economics:

- A few major national nuclear programs operate state-of-the-art geological repositories that serve as valuable models for further multinational facilities.
- The number of waste storage and disposal facilities worldwide is far lower than the number of nations enjoying the benefits of carbon-free nuclear electricity production.
- A range of provider countries offer all or part of the range of fuel cycle services sought by nuclear power states. Users can choose to buy or lease and return their fuel, to have it reprocessed, to have all/any of their recycled or waste materials stored temporarily, or to have their wastes disposed of. Service providers are competitive but sufficiently networked to ensure continuity of availability of each service offered.
- A very small number of truly international geological repositories operate in politically stable countries, offering the highest standards of disposal services to all comers on a commercial basis. These facilities offer disposal for all classes of higher activity wastes to ensure that no country had to manage isolated waste streams alone.
- A few regional storage and disposal facilities, restricted to neighboring countries, work together on a nonprofit basis and with a strong focus on regional security and assistance for politically connected countries and regions. Candidate regions could include the European Union, Southeast Asia, South America, and the Gulf States.
- Safety and security standards for all multinational facilities are defined and agreed upon internationally and policed by the IAEA. An international safeguards and security organization is charged with monitoring all storage and disposal facilities.

All this is possible if the nuclear community pulls together. It would be tragic if it were to take a catastrophic breach of security in one country to give the required substance to the current round of concepts for expanding nuclear power without significantly increasing global proliferation and security risks.

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