SECURITY CONCERNS AT THE BACK END OF THE NUCLEAR FUEL CYCLE

Charles McCombie[1], Neil Chapman[1] and Tom Isaacs[2]

[1] *Arius Association, Switzerland*
[2] *Stanford University/LLNL, USA*

The security and proliferation concerns associated with the spread of nuclear power in the first decade of this century are almost entirely focussed on enrichment technology at the front-end of the nuclear fuel cycle and on reprocessing. Although these are the highest risk areas, it is also important that the potential security problems associated with waste management (in particular with the storage and disposal of spent fuel and radioactive wastes) are not neglected in the "nuclear renaissance". The international community should continue to strengthen its efforts to highlight the risks and to facilitate solutions that reduce the threats. This crucial issue must not be ignored - either by the countries that are marketing and exporting nuclear power plants or fuel supply services, or by those countries anxious to expand their national nuclear energy programmes. This article examines some of the broader issues surrounding the security aspects of waste management and suggests some solutions.

I. INTRODUCTION

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 of spreading nuclear technologies. The IAEA established a high level group that reported on potential multilateral approaches (Ref. 1), but little specific actions have resulted as yet. Initiatives have been proposed by both Russia (Ref. 2) and the USA (Ref. 3) – each aimed at promoting nuclear power whilst limiting security concerns. These initiatives are generating discussion but, as yet, little action – and they concentrate strongly on enrichment and reprocessing activities. Meanwhile, interest in expanding nuclear power programmes 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. In this "rush to nuclear", potential users are focussed on secure energy supplies and vendors are focussed on business opportunities.

It is, however, an important environmental policy imperative that waste disposal issues are not 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 these proceedings (Ref. 4). There is an associated concern that initiatives to avoid increased security risks may be hindered by the urgency of the new nuclear build programmes. 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.

II. 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 organisations and the use of other radioactive materials in acts of terrorism or war. They can broadly be categorised as follows.

1) 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, up to a hundred or more tonnes. 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 non-ideal for weapons use, so that the security risks appear small. The fact that Pu is stockpiled and inventories growing does, 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 it (as MOX or in fast reactors) are either not yet available or are not widespread or are not economic. The economics and proliferation aspects of the separation and use of Pu are well studied and beyond the scope of this article. Nevertheless, a decision on whether Pu 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 Pu 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 HLW or separate, extremely high-isolation disposal in very deep (3-5 km) boreholes. These aspects of Pu as a waste are discussed in the next section.

2) Clandestine reprocessing of spent fuel to produce weapons materials. This could, in principle, be done by NPT signatories in contravention of the Treaty, by non-signatories or by sub-State 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 non-belligerent 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 tomorrow's unpredictable regime. 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.

3) 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 centralised 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-LL) 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 (Ref. 5) 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 (Ref. 6). There is undoubtedly significant hazard 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 programmes, clearly does not maximise security.

4) 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. Since 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.

III. 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 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.

III.A. Disposal of plutonium: getting excess Pu deep underground clearly reduces security risks. Means of conditioning Pu 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. Co-disposal 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 Pu 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 Pu to achieve canisters with 'spent fuel standard' radiation levels (providing sufficient quantities of HLW are available), or interspersing Pu 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 it is currently possible to envisage – but 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.

III. B Disposal of spent fuel: as for separated Pu, 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 above about the disposal of Pu and retrieval, surveillance and safeguards apply to conventional spent fuel and MOX spent fuel too. 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 Pu 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 burn-up and isotopic composition, the ease of access to the repository, the time elapsed after disposal, the probability of detection and the determination and attitude to 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 analysed. Perhaps this is simply hubris – future generations will certainly have different decision-drivers and, possibly, advanced technologies that make our current views and provisions rather irrelevant.

III.C. Disposal of HLW: as opposed to the case of separated Pu or of 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, 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 below. In practice, extended storage is proving necessary for the more mundane reason that many national disposal programmes appear unable for political or economic reasons to implement deep geological repositories for some decades into the future.

III.D. 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 metres 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. In those countries that have not made up their mind about geological disposal, those that are only able to move slowly towards disposal and, even, in those with advanced disposal programmes, consideration could be given to more resistant, preferably underground, stores (possibly also encapsulation facilities) for HLW and spent fuel. This would require centralisation of storage and significant investments and would have to be evaluated against potential improvements in security through other options.

III.E. Centralised storage: if waste and spent fuel storage facilities are judged to present significant security risks, then minimising the number of such facilities and maximising 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 centralised storage facilities at Ahaus and Gorleben. Keeping spent fuel at the site of an operating reactor may not lead to much increased risk since these sites are normally kept very secure – but bigger problems will arise when the operations cease.

III.F. 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 minimise transport requirements, it would be most efficient to locate centralised 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 programme effectively. Consequently multiple waste transports are an almost inevitable feature in any national or multinational waste management programme. Comprehensive measures to ensure their security and to respond effectively to any disruption have accordingly already been implemented in most programmes.

IV. HOW CAN MULTINATIONAL SOLUTIONS HELP?

All of the security problems identified above 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 programmes include Algeria, Australia, the Baltic States, Chile, the Gulf States, 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 non-proliferation front-end problems of a rapid expansion and spread of nuclear power have been recognised and they may be partly addressed by framework projects such as GNEP and GNPI, should these develop successfully. We do not address these projects here (see the companion paper in these proceedings Ref. 4), other than to note that neither of them yet presents a complete committed solution to secure management of wastes.

The IAEA (Ref. 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 internationally 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. However, at the moment, neither the USA nor Russia is offering to take foreign waste and dispose of it permanently within their own borders. In addition, today, no other countries are yet 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 bringing 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 (Ref. 7). What then do multinational waste storage and disposal solutions have to offer in terms of improved nuclear security? While fully recognizing 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 organisations 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 institutions 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 harmonisation 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, centralised 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.
- **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 recognised. 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.

V. AN IDEALISED SAFE AND SECURE BACK-END

The nuclear renaissance is in danger of focussing attention only on the up-side 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 programme 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 paper, they would undoubtedly be greater and probably scale non-linearly with the growth of nuclear power facilities. In fact, it is widely recognised that a major safety or security incident at any single nuclear facility would likely impact strongly on nuclear power globally. To minimise this risk, national waste management organisations, international agencies and the technology provider countries can act concertedly today.

A vision of waste management in twenty 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:

1. A few major national nuclear programmes operate state-of-the art geological repositories that serve as valuable models for further multinational facilities.
2. 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.
3. 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.
4. 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 in order to ensure that no country had to manage isolated waste-streams alone.
5. A few regional storage and disposal facilities, restricted to neighbouring countries work together on a non-profit basis and with a strong focus on regional security and assistance for politically connected countries and regions. Candidate regions could include the European Union, South East Asia, South America and the Gulf States.
6. Safety and security standards for all multinational facilities are defined and agreed internationally and policed by the IAEA. An international safeguards and security organisation 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.

REFERENCES

1. IAEA, “Multilateral Approaches to the Nuclear Fuel Cycle: Expert Group Report to the Director General of the International Atomic Energy Agency”, IAEA, Vienna (2005)
2. S. V. Ruchkin and V. Y. Loginov, “Securing the Nuclear Fuel Cycle: What Next?”, *IAEA Bulletin* 48/1 (2006)
3. USDOE, *Global Nuclear Energy Strategic Plan*, http://www.gnep.energy.gov
4. C. McCombie and N. Chapman, “A Nuclear Renaissance without Disposal?” Contribution to this Conference, (2008)
5. R. Alvarez, J. Beyea, K. Janberg, J. Kang, E. Lyman, A. MacFarlane, G. Thompson and F. von Hippel F. “Reducing the hazards from stored spent power-reactor fuel in the United States”, *Science & Global Security* 11 pp. 1–51 (2003)
6. USNRC, Nuclear Regulatory Commission Review of ‘‘Reducing the Hazards from Stored Spent Power-Reactor Fuel in the United States”, Science and Global Security, 11:203–211, (2003)
7. SAPIERR Project, www.sapierr.net