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Security risks in nuclear waste management: Exceptionalism, opaqueness and vulnerability

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ABSTRACT

This paper analyses some potential security risks, concerning terrorism or more mundane forms of crime, such as fraud, in management of nuclear waste using a PEST scan (of political, economic, social and technical issues) and some insights of criminologists on crime prevention. Nuclear waste arises as spent fuel from ongoing energy generation or other nuclear operations, operational contamination or emissions, and decommissioning of obsolescent facilities. In international and EU political contexts, nuclear waste management is a sensitive issue, regulated specifically as part of the nuclear industry as well as in terms of hazardous waste policies. The industry involves state, commercial and mixed public–private bodies. The social and cultural dimensions – risk, uncertainty, and future generations – resonate more deeply here than in any other aspect of waste management. The paper argues that certain tendencies in regulation of the industry, claimed to be justified on security grounds, are decreasing transparency and veracity of reporting, opening up invisible spaces for management frauds, and in doing allowing a culture of impunity in which more serious criminal or terrorist risks could arise. What is needed is analysis of this 'exceptional' industry in terms of the normal cannons of risk assessment – a task that this paper begins.

1. Introduction

This paper examines security risks around the civil 'nuclear fuel cycle' and its relation to waste management; the increasingly important subject of decommissioning of power stations at the end of their lives; and issues around storage, recycling and disposal of the high, medium and low level wastes that result. This is done by means of a PEST analysis (Byars, 1991), scanning the political, economic, socio-cultural and technical contexts of nuclear waste management, and interpreting potential risks primarily from the perspective of what is known or can be surmised about such risks in the broader context of hazardous waste managements.

All such scanning exercises are potentially rather fluid and malleable, so questions properly arise about the perspectives brought to bear, core assumptions, selective (dis-)attention to issues and so. The analysis as performed here is by a small team of criminologists, who specialise in research on the evolution of crime risks in global society and aspects thereof (see for example Vander Beken, 2005), and who have researched such risks in relation to waste management (Dorn et al., 2007; Van Daele et al., 2007). The most specific proposition that the authors bring to this and other work is that *diversity in intelligence and risk analysis* constitutes a public safeguard (Dorn, 2008, see also Dorn and Levi, 2006). More generally, the authors draw upon criminology for the proposition that, since criminality is formed in interaction with controls on it, the specific controls may push risk away from where it may be expected and into other channels: in other words criminality and regulation are *mutually-constitutive*. The authors look for possibilities that crimes and irregularities may arise from lack of or insufficient level of regulation (enabling casual crime within the industry), inappropriate regulation or, in some cases, over-regulation (causing 'displacement' of criminal efforts to less protected areas). In relation the nuclear waste industry, they offer hypotheses below about such possibilities.

There is a sense in which the above proposition may be pushing on an already opening door. Clearly, in recent years a series of unexpected events in the fields of terrorism, weather events and financial markets put into question experts' and regulators' approaches to risk assessment. Put at its simplest, the questioning has two dimensions, which may be summarised as 'subjective' and 'objective'. Regarding subjective aspects, the public may frame its concerns in ways not always totally amenable to the forms of

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evidence that regulators and industry experts collect, estimate or construct (an analogy here is genetically modified food crops, where European public opinion seems reluctant to accept what European scientists have to say about risks). Regarding objective aspects, it is clear from historical and contemporary examples drawn from many fields – most recently the credit crunch of 2007 onwards – that highly-expert regulators and private sector risk-modellers sometimes exhibit 'herd behaviour' and may fail to anticipate 'Black Swan' events. Such dangers are greatest when the dialogue and model-building are highly complex and are comprehended only by a highly-expert group.

A quick introductory example: public concerns about nuclear waste in Europa are mainly on the longer-terms issue of storage and its possible effects on the enforcement (European Commission, 2008, reporting Eurobarometer survey). Even if, as the European Commission claims, such public opinion is largely based upon 'misconceptions that become strong beliefs among citizens' (European Commission, 2008), nevertheless it exists. Thus it appears that, as far as safety is concerned, the strategic focus of the anti-nuclear movement, pointing to the very long-term dangers for 'future generations' and the environment (No2nuclearpower, no date) either quite well reflects or shapes the agenda for European public concern. Furthermore, the specialist focus upon (and protective actions taken in relation to) transportation may be shielding us from realisation of less well shielded risks (see below). Prudent regulators and policy makers take note of such meta-risks (risks about risk assessment: see *inter alia* Brown and Michael, 2002; Scales, 2007). Outsiders can support that process and it is in these terms that we justify this discussion.

2. Political context and players

2.1. International policy

International treaties cover nuclear waste management in two main ways. First, concerning hazardous wastes in general, through the Basel Convention (United Nations, 1989), covering not only radioactive materials but also explosives, compressed gases, flammable solids, and corrosives. Second, concerning nuclear power, the fuel cycle and related waste issues specifically, the Non-Proliferation Treaty (International Atomic Energy Agency, 1970) and other international agreements are relevant and, within the EU context, both the Euratom Treaty and the EC Treaty may be applicable, depending on the precise issues.

In relation to management of hazardous wastes generally; the Basel Convention states that illegal traffic occurs if the transboundary movement of hazardous wastes is taking place under the following conditions: without notification pursuant to the provisions of the Convention to all States concerned; without the consent of a State concerned; through consent obtained by falsification, mispresentation or fraud; when movement does not conform in a material way with the documents; or when movement results in deliberate disposal of hazardous wastes in contravention of the Convention and of general principles of international law. Common methods of illegal traffic include making false declarations or manifests, the concealment, mixture or double layering of the materials in a shipment and the mislabelling of individual containers. […] (Secretariat of the Basel Convention, no date-a). Because hazardous wastes pose such a potential threat to human health and the environment, one of the guiding principles of the Basel Convention is that, in order to minimise the threat, hazardous wastes should be dealt with as close to where they are produced as possible (Secretariat of the Basel Convention, no date-b).

In relation to civil nuclear power and non-proliferation of technologies and materials that might be used for weapons purposes, the Treaty on the Non-Proliferation of Nuclear Weapons (NPT) is a well known and topical landmark. Its objectives are to prevent the spread of nuclear weapons and weapons technology, to foster the peaceful uses of nuclear energy, and to further the goal of achieving general and complete disarmament. The Treaty establishes a safeguards system under the responsibility of the International Atomic Energy Authority (IAEA), which also plays a central role under the NPT in areas of technology transfer for peaceful purposes. The IAEA's mission is underpinned by three main pillars: safety and security, science and technology and safeguards and verification. On safety and security issues the IAEA helps countries to upgrade nuclear safety and security, and to prepare for and respond to emergencies. Work is keyed to international conventions, standards and expert guidance. In the safety area, the IAEA covers nuclear installations, radioactive sources, radioactive materials in transport, and radioactive waste. A core element is setting and promoting the application of international safety standards for the management and regulation of activities involving nuclear and radioactive materials. In the security area, they cover nuclear and radioactive materials, as well as nuclear installations. The focus is on helping states to prevent, detect, and respond to terrorist or other malicious acts – such as illegal possession, use, transfer, and trafficking – and to protect nuclear installations and transport against sabotage. The Nuclear Safety Review of the IAEA presents an interesting overview of worldwide trends and issues in nuclear, radiation, transport and radioactive waste safety and emergency preparedness, highlighting developments (IAEA, 2006).

2.2. Regional/EC policy

As for the European Community's general waste strategy, the aim is seen as reconciling a continuation of economic growth and prosperity, whilst at the same time actually reducing the impact upon the environment of wastes of all kinds. In this vision, whilst economic growth increases, resource-use would increase only marginally and, due to more efficient use of resources, the environmental impacts thereof would actually decline. This would be the intention in relation to waste in general and in relation to hazardous waste. European Commission initiatives in the field of decommissioning nuclear installations are based on chapter 3 (article 37 et al) of the Euratom Treaty and on a number of Resolutions and Directives of the Council (EU, 1985, 1992, 1994, 1996).

2.3. National policies

From a theoretical point of view, there could be common benefits from concentration in just a few countries of the highly expensive, potentially hazardous and technically very demanding aspects of nuclear power for electricity generation and other civil applications – which could service other countries in all aspects of the fuel cycle, including waste (International Atomic Energy Agency, 2004, 6). On the other hand, many countries would prefer not to have their energy security – and nuclear technology – in the hands of another country, especially one that might in any way and at any time in the future be ambivalent, non-cooperative or hostile.

3. Economic context and players

3.1. Nuclear waste management as exceptional business

Although nuclear waste looms large in policy terms, such wastes are not very large in volume terms, when compared with other forms of waste, hazardous and non-hazardous.[2] Much of the world's nuclear waste arises from the generation of electricity where, by volume, fossil fuels of course generate the greatest amount of waste (European Environment Agency, 2001). Enhancing the nuclear energy development is sometimes seen as one of the main solutions in this area (Qiang, 2002). Yet, other alternatives such as hydropower and wind power may come close in this perspective.

Nuclear wastes are of course volumetrically tiny compared with fossil fuels. In business terms, however, nuclear wastes are 'big' and are becoming more so. This is due to three main factors. (i) All aspects of management are highly expensive, one driver of costs being the length of time over which secure storage would be necessary, another being the measures necessary to contain any long-term migration of radioactivity into the immediately surrounding environments or more widely – issues that are sharply contested, with anti-nuclear power groups suggesting that it would be impossible to guarantee that migration could not happen (No2nuclearpower, no date). The costs arise because radioactive wastes from ongoing electricity generations and other uses of nuclear materials are highly dangerous over many hundreds or even thousands of years, the appropriate means of disposal being a matter of controversy (as mentioned above). Reprocessing only marginally reduces radioactivity, even though it may recover some re-usable elements. Even 'temporary' storage (which may last many decades) is not without difficulties, dangers, needs for monitoring and security and attendant financial costs. Commentators differ on whether short-term storage is welcomed by the industry on the grounds of at least having somewhere to put waste (maybe not in the producing country) or worries the industry on the grounds that disposal matters are not 'settled' and controversy remains.[3] The waste outputs from existing and operational nuclear facilities are financially significant, on both a European and global basis. Additional wastes are being generated as nuclear facilities come to the end of their economic/safe lives, and have to be decommissioned, entire facilities then becoming waste.

One of the most interesting areas of debate over the management of nuclear waste in relation to crime and terrorist risks is the issue of transport of the waste. All forms of waste, from the most highly radioactive reactor contents to the low level waste, have to be transported from their places of origin to their places of rest (temporary of other). Transportation might be seen to be more open to terrorist attack (to create local contamination) or criminal misappropriation (for purposes of sale on the illicit market or possibly as an object for blackmail), in comparison with static locations that are seen as being more secure. Our concern is not whether this assessment is correct but in what follows from it: some precautions. Not only are arrangements made for physical security during transportation, also the national intelligence services carry out surveillance of and infiltration into any proto-terrorist or anti-nuclear groups that might, potentially, be tempted to embarrass the industry and government by causing, for example, a derailment of a railway wagon carrying flasks. Assuming competence on behalf of the agencies responsible (at least most of the time), it seems reasonable to assume that such precautionary measures reduce the risks that might otherwise attend transportation. By contrast, static guarding and access control is a relatively routine matter, and common experience suggests that, in such circumstances, boredom, selective attention, slackness and 'making things look right' may creep in. The result may be that, whilst security in transportation stages of nuclear waste management may be held to a high standard, security in static storage may decrease to the extent that simple thefts can arise (example given below). This is an example of the interaction of the 'exceptional' characters of security around nuclear waste management and the 'mundane' characters of everyday operations in the industry, making it unwise to take conventional wisdoms for granted. We need to look at the specifics of such situations against the background of what is known generally of crime and insecurity.

3.2. Owners, investors, costs of entry, profitability/solvency

The nuclear waste management business has a foot in several industrial sectors: energy generation, in particular nuclear generation of electricity; science and health (diagnostic and treatment); the food industry (irradiation); infrastructure (construction, oil/gas exploration); and the military (transport, for example submarines, and of course nuclear armaments, waste from the latter not being dealt within this report).

The industry is a relatively restricted club, both in terms of the countries involved and in terms of numbers of main contractors – although because of the complexity of processes involved, there are a much larger numbers of subcontractors (discussed later). One reason for this being a restricted club is that the cost of entry is high, and getting higher (Turkenburg, 2004).

All European countries with a civil nuclear industry are members of the Euratom, the European Atomic Energy Community (as previously discussed). This was established in 1958 to "create conditions necessary for the establishment and growth of nuclear industries." According to United States Congressional briefing, the US "promoted its establishment to benefit sales of U.S. nuclear power reactors and related equipment, fuels and technology in Europe" (Carl et al., 1996).

As for reprocessing, within the EU the main players are France and the UK. About 20,000 people in the UK are said to be employed in production, reprocessing and waste handling in the UK. The UK processes spent nuclear fuel from countries including Japan, Germany, Switzerland, Spain, Sweden, Italy, Netherlands and Canada. For 2005, the UK Atomic Energy Agency reported a turnover of £378.2m, of which a considerable amount (£291.8m) used to represent grant in aid income received from the DTI. The balance included funding from EURATOM and EPSRC for JET and UK fusion projects, charges for the services of UKAEA Constabulary on non-UKAEA sites and income received from property tenants (UK Atomic Energy Agency, 2006/2007).

Spent fuels either may be held onsite for many years, close to the reactor, or may after an initial cooling period be (partially) reprocessed to separate different grades and types of waste. Reprocessing is expensive and is partial in effectiveness (Schaper et al., 2001). The question may arise as to why, if reprocessing is expensive, increases the volume of the waste, and does not make a fundamental difference to the radioactivity of overall waste, then why is it done at all? The answer is both economic and political. In terms of the economics, reprocessing is a profitable business for enterprises selling this service. Politically, since there are relatively few reprocessing centres in the world, sending waste for repossessing may shift it out of the country of origin, which may help with public opinion there. In part, the customer is paying for relocation of the waste. Even though there may be some return shipments after processing, typically not all the volume or radioactivity that is shipped to another country for reprocessing is returned to the country of origin. A critical perspective on this was

[2] As a reference point, the average French citizen generates about 10 tonnes of all kinds of waste per year, of which radioactive wastes account for about 1 kg. This is 1% of toxic waste, which itself is 1% of *all* wastes. 90% of this kilogram is short live radioactive waste and is disposed of on an industrial basis; the 10% remaining are long life waste (European Commission, 1999).

[3] The authors are grateful to a number of experts on hazardous waste consulted for the wider work from which this paper arises.

presented by Greenpeace stating that reprocessing is a very uneconomic technology: "Countries send nuclear spent fuel for reprocessing to delay having to deal with the nuclear waste themselves – in effect they are dumping their nuclear waste problem onto France, UK and Russia. Most of the nuclear wastes arising from reprocessing will stay in France, UK and Russia forever." (Greenpeace UK, 2001).

Irrespective of the location of nuclear facilities and or reprocessing and disposal sites, the economics of waste are impressive.

Decommissioning and cleanup of the global civil nuclear legacy represent a massive management, technological and environmental challenge for the UK and international community over the next century. The Nuclear Decommissioning Authority (NDA) is responsible for a work programme lasting for decades worth billions of pounds and the development of a long-term, diverse, robust and competitive supply chain. The scale of investment required by the UK alone is £50 billion, opening up opportunities for both existing companies and committed new entrants. This is dwarfed by the global market, estimated to be worth £300 billion over the next 30 years, providing major opportunities for the UK. For example, over 400 civil nuclear reactors in operation worldwide will need to be decommissioned over the next several decades (Greenpeace UK, 2001).

In summary, there is a global market for nuclear decommissioning (Bambrough and Buckley, 2005).

3.3. Industrial processes and their management

Models of the inputs and outputs of a nuclear waste management organisation are characterised by a high level of complexity (Mortensen and Pinci, 1997). For present purposes, important questions arise around transport, financing of waste processing and disposal, the keeping of administrative records and management thereof.

3.3.1. Transport

Nuclear waste is seldom stored or reprocessed at the location where it was produced. This imposes special security risks related to the transport of such materials. While the starting and end point of the nuclear waste are fixed sites that can be secured in various ways, transport happens in a much more flexible environment. About 20 million transports of radioactive material (which may be either a single package or a number of packages sent from one location to another at the same time) take place around the world each year (World Nuclear Association, 2008). Though many efforts have been put into the safety and security of such transport it stays a significant point of attention. The costs of transport of nuclear waste are considerable and the sector under pressure.

The depressed market for uranium production, the restructuring in the nuclear industry worldwide, and reduced economic margins following electricity market deregulation and liberalisation have placed additional strong pressures on the nuclear transport industry. It must become more cost-efficient, flexible and even more responsive to the needs of utilities and others (Bjurström, 2000, 2).

3.3.2. Who pays?

Who pays for nuclear waste storage/disposal/recycling? Although the details vary across different countries, there are four main 'end-payers': future generations, which will have at least some financial costs in monitoring, maintaining and/or remedying problems; today's general taxpayer, who picks up some of the bill (partly through cost-sharing and special funding at a European level); electricity consumers, domestic and/or industrial, who in some countries face a levy based on electricity consumption; and, in some countries, those producing or consuming nuclear electric power specifically. How costs should be allocated is not something to which just one answer has been given (UK Nirex and others, 1999, 162).

If we deem costs to be allocated fairly when the charges for individual waste streams, and hence the charges to individual waste producers, exactly match the proportional contributions which those waste streams have made to overall costs, then a levy on all electricity generation is the least likely mechanism to deliver this objective. [...] Fairness is not just a matter, furthermore, of fairness between waste producers. Another important aspect is that of intergenerational equity. [...] The issue here is whether, since the present generation cannot canvass the views of future generations, the present generation has the right to take a decision to adopt such policies, thereby acting, in effect, as proxy for future generations. (UK Nirex and others, 1999, 162).

Considering all the ways in which EU member states are applying funds to disposal of ongoing wastes and to decommissioning, it could be impossible to reconcile all aspects with the competition provisions of the EC Treaty. The European Commission applies competition provisions to the nuclear sector as to other types of energy generation (Areva case ECJ), however there is some commentary on whether or not current nuclear ownership structures and financial support, and the use of State Aid, may be easily reconciled with competition policy. As far as policy is concerned on the management and financing of decommissioning, the EU partially deflects competition issues by using the Euratom Treaty. (UK Nirex and others, 1999, 162).

For all the good intentions on competition and proper use of funds (Nuclear Engineering International, 2004), the situation leaves open issues about transparency, etc, as previously discussed. There may be potential fraud issues.

3.3.3. Record keeping

Safeguards are based on a structure of *material balance areas*, in which the radioactive inventory must be accounted for. This is backed up by various forms of surveillance and monitoring and by inspections (Schaper et al., 2001). In some countries, record keeping may be complicated by a reluctance to refer to some highly radioactive waste products as such. According to the House of Lords the IK inventory of radioactive wastes would be much more valuable as a tool for development of an integrated strategy if it included all the materials which may be declared to be wastes. The situation in which materials such as plutonium, depleted uranium, and spent fuel for which there are no definite plans for reprocessing are excluded, can lead to gaps and inconsistencies in national planning for waste storage and disposal (House of Lords, Select Committee on Science and Technology, 1999, paragraph 4.5).

3.3.4. Risks arising in relation to processes and management

One potential risk concerns government employees – as well as other industry-employed experts – 'improving' data, in order to be able to make a coherent and public policy case regarding management of nuclear waste. The State of Nevada in 2008 submitted to the US regulator some legal arguments against the siting of a high-level radioactive waste disposal facility at Yucca Mountain. Nevada's objection included observations on the lack of concrete standards for protecting Yucca Mountain from terrorist acts and for keeping track of and accounting for sensitive nuclear materials that may be shipped to Yucca Mountain. It was argued that these standards are critical because vast quantities of highly dangerous radioactive materials will be stored above ground at Yucca Mountain, where they will be exposed to potential acts by terrorists. Also, it was stated that if some of these same materials (high-enriched uranium and plutonium) are stolen from the Yucca Mountain site, they could be used to manufacture nuclear bombs for use against United States targets (Nuclear Regulatory Commission, 2008, 20).

The reference to management arrangements for keeping track of material underlines points made above. Also, it is clear the arguments are not only scientific – in terms of the margin of safety if such a depository is properly managed – they are also procedural and political. The procedural complexity arises as a result of the many levels of debate and consultation (federal departments and regulators, state level legislatures, local communities, scientific advisors, environmental and health activists spanning all these levels). The political complexity has been added to by post-2001 concerns over terrorism: the more that government alerts states, agencies and citizens to a terrorist threat, the more difficulty it may experience in persuading them of the virtues of large dumps of radioactive material. Similar observations could be made regarding European and other countries.

In Pakistan, for example, the overall security situation is unstable with large number of terrorist groups operating within the country, with an armed insurrection ongoing in Balochistan and with the government loss of control of several provinces to Taliban. This generally unstable security situation is considered not well conducive to stable long-term expansion of nuclear power capacity and both economic and security trade-offs are play when considering large scale nuclear capacity expansion in Pakistan's situation. (Braun, 2008, 278).

In Chechnya, several incidents with terrorism potential that involved nuclear waste material and its repositories have been reported. Already during the Chechen military campaign between December 1994 and August 1996, about half of some 900 m^3 of radioactive waste, went missing from a repository near Grozny. Many suspected that Russian soldiers have stolen the radioactive material and sold it on the black market. Others, however, argue that the waste could also have been removed by the Chechen militants, who demonstrated their readiness to use such material in furthering their goals by burying a radioactive container in Moscow's Izmailovsky Park in 1995. Although the radioactivity level of the found containers was not very high, the incident nevertheless caused great concern about the possibility of more serious radiological terrorist attacks in the future. Special radiation search teams were set up in Moscow and some other large Russian cities to detect, secure, and dispose of dangerous radiation sources (Zaitseva and Hand, 2003, 838).

Other potential risks include circumvention of import/export regulations (Greenpeace International, 2005). Such risks are in addition to those implied in the use of private contractors, in relation to which there have been historical problems. The US General Accounting Office argues that the DOE [the US Department of Energy] almost entirely relies on contractors to carry out its production, research, and cleanup missions. They call the department's history of inadequate management and oversight and of failure to hold its contractors accountable for results as a high-risk area vulnerable to fraud, waste, abuse, and mismanagement (United States General Accounting Office, 2004, 10).

Because fraud risks of a general nature arise – multiple opportunities in relation to procurement and sub-contracting, work done incompletely and falsely reported, managerial and auditing misrepresentations – the need to audit is well appreciated. It is argued that a thorough risk evaluation to determine the likelihood of material error, including fraud, occurring might help to determine the level of audit evidence needed to support the audit opinion, concentrate efforts towards high-risk areas and improve the cost-effectiveness of audit testing (International Atomic Energy Agency General Conference, 2001, 43).

These methods of steering audits towards areas thought to be higher risk are well-known across all areas of auditing. At first glance, they appear sensible and there are indications that they may make cost effective use of limited resources. However, their effectiveness relies upon an assumption that high risks do not arise in ways unknown to one – something of a 'hostage to fortune'. In summary, audits are especially vital when accounting for hazardous products and services, they may have additional rigour when there is high political sensitivity, however the record suggests that both errors and misdemeanours occur in this area as in others. This potentially opens the door to fraud and crime.

4. Social/cultural context and players

Societal risks and risk perception are particularly important in nuclear waste disposal issues (Voganov and Yim, 2000). Appropriate information provision is therefore indispensable.

4.1. Attitudes to risk: energy security versus waste disposal fears

There are at least two universal expectations from innovative reactors. The first demand is the guarantee of no significant release of radioactivity in the environment under any circumstances. The second expectation concerns almost unanimously the radioactive wastes: less waste, less long-lived wastes, and no waste at all if possible. However the most significant expectations are expressed in the following wishes of common people: "I expect power when I flip my switch" and "Do not increase my electricity bill" (Barré, 2004, 83).

According to Turkenburg (2004, 46–50) nuclear waste management and disposal is probably the issue where the gap between nuclear supporters and opponents is widest. Debates on the pros and cons of using nuclear energy show that the public resistance and (perceived) disadvantages are related mainly to the following issues: 1. Public acceptance of nuclear fuel cycles; 2. Safety risks of nuclear power plants and other components of the nuclear fuel cycle; 3. Lifetime and management of nuclear waste, especially high-level waste; 4. Proliferation of fissile materials and nuclear weapons; 5. Accumulation of radionuclides in the biosphere up to unacceptable high levels; 6. Scarcity of nuclear resources; 7. Cost of nuclear energy; 8. Industrial development (local capacities, customers interest, spin offs, employment); 9. Lock-in effects (impact on development of non-nuclear options).

Indeed, mainstream political, industry and expert opinion is in favour of disposal in deep geological formations, on the basis that the risks there over many centuries would be lower than the risks to indefinite storage on the surface (CoRWM, 2006). Since the scientific evidence is not definitive – a major difficulty being how to foresee possible seepages or vents and their implications over thousands of years – the points of view arrived at have a strong cultural component. For example, sealing a problem underground may feel more comfortable than having to tend for it on the surface, because although the authorities can more easily manage a surface facility, the long-term continuation of the authorities and hence of their care cannot be guaranteed, opening up the possibility of malign environmental or human interventions. A UK House of Lords committee attempted to weigh up the issues. It stated that surface storage of conditioned, packaged wastes in modern facilities for several decades is feasible and safe. Beyond periods of this length it will be necessary to refurbish stores extensively and perhaps replace them. Repackaging of wastes may also become necessary. Further surface storage for several centuries raises much greater problems, the likelihood of societal breakdown being the major one. Indeed, worldwide, there are many examples of civilisations which have appeared and disappeared within a century. According to the Committee even a lesser change in society could have serious consequences if it led to stores falling into disrepair, and wastes and packages degrading to such a degree that it would be risky to retrieve packages and very difficult to convert wastes to a stable form again. Furthermore, the Committee argues that over several centuries there could be climatic changes (particularly sea level rises) which would make it necessary to move wastes to new stores in other locations. This would entail risks, particularly to workers. Another concern of the Committee is that over centuries the foundations and reinforcement in stores could weaken, making them more vulnerable to earthquake damage. Again this would necessitate building new stores and moving wastes to them (House of Lords, Select Committee on Science and Technology, 1999, paragraphs 4.32–4.34).

Deep storage may *feel* safer in these terms. Also, at least some experts believe that some deep geological conditions offer disposal options which would be highly stable and very low risk (CoRWM, 2006). However, public surveys seem to suggest that a majority of the general population in some European countries may not trust experts and governments on the nuclear issue. As Turkenburg puts it on the basis of general population survey results, '*The size and persistence of the resistance [to nuclear power] leads to the question whether it will ever be possible to obtain public acceptance of nuclear power again*', partly because the public does not entirely '*trust nuclear experts*' (Turkenburg, 2004, 47). Experts generally work with a concept of risk in which their calculations of very low probabilities should be regarded literally (10^{-8} chance of death for individuals, for example). However, the public, may not 'buy' that message, because absence of evidence of problems does not mean that there will be no problems (Shrader-Frechette, 1993) and because the possibility of severe accidents with many victims cannot be excluded in principle after all (Turkenburg, 2004). Moreover, application of decision analysis models has concluded that the policy for storing waste in underground repositories is misguided since the assumptions underlying this policy are inappropriate (Keeney and von Winterfeldt, 1994).

It is further argued that social acceptability has to be put on equal footing to technical concerns in such discussions. This implies that a viable program and satisfactory solutions can only be created through a long-term process of building public trust and deeply engaging potentially affected communities in the planning process (Flynn et al., 1992, 1995; Easterling and Kunreuther, 1995). The substantially increased public fear of technological hazards, "stigmatizing" certain places and products (like nuclear power plants), makes it hard for expert opinions to be influential in the decision making process (Gregory et al., 1996).

A similar argument may be developed concerning the transport of nuclear waste. From a technical point of view, the transport link of the nuclear fuel cycle is a very safe and robust link. Experience shows, however, that the perception of transport of radioactive materials by the general public, and the response to this by political decision-makers, authorities and carriers, may cause concerns and has led to far reaching demands (Bjurström, 2000; Binney et al., 1996; Riddel, 2009).

4.2. Information for public debate: transparency versus security

A US action group, which works to limit the production and storage of high-level radioactive waste and to oppose license renewals for nuclear plants until there is a permanent safe and operating solution to the storage of high-level radioactive waste, opines that the integrity of "force-on-force" tests that are designed to ensure a power plant can defend against a minimum attack scenario, in terms of the number of attackers, their tactics, and their training, has been undermined by a conflict of interest. The group states that Wackenhut Corp. holds contracts to guard 31 of the 64 commercial nuclear sites in the US and will be hired to conduct the force-on-force exercises at all the nuclear plants in the country. In that way, they state, "*Wackenhut will be testing itself at half the sites*." (Alliance for Nuclear Responsibility, 1–2).

More broadly, the same source believes that the public plays a critical role in providing oversight of the NRC and its enforcement of security regulations. Though the events of September 11 have stimulated a call for stronger standards, such as forcing inclusion of a truck bomb attack scenario and the creation of uniform training and qualification standards for mock adversaries, the NRC announced in August 2004, that it would no longer release any information about security at nuclear plants for fear that publicly identifying major weaknesses could help terrorists (Alliance for Nuclear Responsibility, 1–2).

Thus, security concerns may undermine security, in the sense that checks and balances – previously provided to some extent by outside scrutiny – can be discarded by a regulator's decision to scale back transparency, citing fears of terrorism and suggesting that public knowledge of regulatory failures might 'help terrorism'. One could argue that such secrecy provides spaces of impunity in which managerial mistakes and technical failures can be covered up, and a culture of 'adjusting' the record can become normalised, decreasing control and increasing a range of risk running from terrorism to fraud. Corporate sensitivities in nuclear waste management can give cover to mundane employee frauds.

The events happened in 2002 in Los Alamos National Laboratories illustrate this. Two employees who had successfully been exposing credit card and purchase order fraud as well as security problems were fired by the Director of Safeguards and Security. It was stated that all signs indicate that leaders at Los Alamos were motivated in the firing by a desire to silence these and other individuals who are uncovering widespread corruption (Project on Government Oversight, 2002).

A government inquiry corroborated a number of the concerns expressed by the terminated security officials related to weak internal controls and other property management issues (U.S. Department of Energy, 2003, 4). Of course, frauds and cover-ups are not unknown in broader contexts. However, the heightened sensitivities in this industry may exacerbate the initial risks of frauds and possibly also increase some persons' motivations to take actions against any whistleblowers. The brutal assault on one of the auditors who reported a disturbing pattern of financial irregularities in the Los Alamos Lab procurement division, in apparent reference to his upcoming congressional testimony on this fraud, shows that such actions are not unlikely to happen (Project on Government Oversight, 2005).

4.3. Risks in the corporate culture of management

Any appraisal of risks must be controversial, partly because of entrenched political, economic and value positions to be found in the public arena, and partly because of the difficulty of defining 'low probability' of crimes and other adverse events. How low does 'low probability' have to be, to be regarded as zero probability for all practical purposes? Is it therefore a so-called hard risk (Blockley and Godrey, 2007)? Or should 'low' probability be enough? In a spirited exchange of views in the US, a panel of advisers expressed concern about terrorist action against pooled nuclear waste, leading to radioactive fires (National Research Council, Committee on the Safety and Security of Commercial Spent Nuclear Fuel Storage, 2006), whilst the regulator referred to such scenarios as 'improbable' (Skane and Petty, 2005).

Some might say that, given the potential seriousness of adverse events, only zero probability should be acceptable. A counter-argument to that could be that such a requirement could lead to falsification of the odds and of the vulnerabilities in the human and technical systems (and unexpected interactions between the two) that generate those odds.

5. Technical context and players

5.1. Nuclear waste management is technology

In discussions of waste, the distinction is conventionally made between hazardous waste and non-hazardous waste – with the proviso that in many cases the two are mixed. The aims of waste management are to minimise the amounts of waste generated, to minimise the proportion that is hazardous, to minimise the level of hazard that remains, if possible to the level where what previously was hazardous can be re-classified as non-hazardous. It can then be disposed of by relatively inexpensive means (Weissenbach, 2001) such as landfill.

As for the extent and manner of treating hazardous waste in general before disposal, this varies – from chemical treatment of the constituents in order to deal with separately, to landfill without treatment (sometimes after a delay in time). Nuclear waste is a category of hazardous waste. Those who produce it, wish to do with it what all producers of hazardous waste wish to do: they want to transform it into less- or non-hazardous forms, to secure it from accident to interference and/or to transfer it to locations which are regarded as remote in a social sense as well as a geographical sense. Where any remaining radioactivity is at a very low level, and where sites safely can be returned to public or normal commercial use, then that may be done – particularly because of the demonstrative/symbolic value of photographs of green-filled sites and happy people. That said, nuclear wastes, and particular high-level wastes with high longevity, pose particular problems and consequently offer a big market for those operators capable of mastering the technologies and economies of scale, taking into account that some of longer-term costs of waste management may be capped, by government underwriting them (Department for Business, Enterprise & Regulatory Reform, 2008, 153, para 372) and also taking into account an expected fine-tuning of future tax obligations (Department for Business, Enterprise & Regulatory Reform, 2008, 154, para 373).

5.2. Technical options in waste storage/recycling/disposal

The situation in relation to current practices regarding management of reactor fuels varies in the EU member states. The most simple option, which also minimising the volumes of such waste, is not to reprocess it (at least not for the present) but to keep it onsite, in pools or in casks. According to Schaper et al. (2001) the necessary technical steps to be followed, if reprocessing is not chosen as waste management strategy, are either a) to keep the spent fuel in extended pond storage at the reactor or in external storage ponds (preferred option e.g. in Sweden), or b) to package the spent fuel into dry storage casks and store these either onsite or off-site in central storage facilities. After an extended cooling time of at least 20 years the spent fuel is ready to be disposed directly into a final repository in deep geological formations, if such a facility is available at that time. Prior to final disposal repackaging of the fuel into specially designed casks is foreseen in most of the currently followed waste management plans. Compared to the reprocessing route, the necessary technical steps are less complex, lead to smaller waste volumes and a much smaller number of different waste forms to be stored and finally disposed (Schaper et al., 2001).

The situation in relation to reprocessing varies amongst European countries as well (Schaper et al., 2001, 48–49). As for the future, the main characteristics of the innovative fuel cycle concepts are to introduce additional waste management options, such as partitioning and transmutation, in order to reduce the mass and radioactivity of wastes going for final disposal. They are trying to close the fuel cycle not only for plutonium but also for the minor actinides. Compared with the results of the conventional fuel cycle options, on the whole, the innovative fuel cycles have much more benefits in terms of natural uranium use and reduction in spent fuel (Chang, 2004, 102).

Unfortunately, nuclear fuel recycling processes, designed to reduce (a) long-term radioactivity of waste and/or (b) potential availability of materials for proliferation, may themselves have some adverse environmental effects, such as emission of radionuclides into the biosphere (Turkenburg, 2004, 47).

5.3. Risks based on the technical nature of nuclear products/waste

Historically, EU research on nuclear questions and safeguards has dealt mainly with technical and safety questions (Schaper et al., 2001, 15). Following 2001, proliferation has moved up the research agenda. That is a highly controversial area which seems as much driven by power politics as technical risk assessment. This point is underlined by the run-up to the invasion of Iraq and by the efforts of the United States and some other countries to prevent Iran from mastering the fuel cycle – whilst assisting some other countries such as India. These high-level political risks are especially difficult to integrate into a more general assessment of security risks.

6. Conclusion

Nuclear waste management is regulated as part of the nuclear industry (Non-Proliferation Treaty, Euratom), as well as in terms of hazardous waste (Basel, EC Treaty). The industry involves state, commercial and mixed public–private bodies, mostly in electricity generation but also other civil applications. There are major international and national nuclear industry players. Waste management processes include capturing, grading and separating the various levels of radioactive waste; storing it (sometimes for decades); transporting it locally, nationally or internationally; processing it; recycling some elements; and/or (semi-) permanently depositing the remainder, under secure conditions in the case of remaining high-level radioactivity.

The social and cultural dimensions of nuclear waste management – risk, uncertainty, future generations – resonate deeply. Waste management attracts public disquiet, government support, industry lobbying, scientific debate and, increasingly since 2001, scrutiny for possible security risks. During the same period, climate change has become a mainstream political as well as scientific issue and – to the dismay of anti-nuclear campaigners and the delight of the nuclear industry – the global risk of climate change is being counter-posed against those of nuclear waste (Beck, 2008). Running across this is a strongly politicised set of international allegations and denials about proliferation, which has a strong waste management aspect insofar as certain products of the nuclear cycle can be weaponised.

In this fervid atmosphere, some of the more mundane crime and fraud risks run by the waste management industry may be overlooked by analysts, commentators, regulators and governments. Yet, the authors maintain, it is more likely through this relatively lightly guarded ‘back door’ of the industry that the larger security risks may be facilitated (see for example the examples above secrecy, reduction of oversight, increased opportunities for management mis-reporting, etc). There is merit in peeling away the claims of exceptionalism made equally by the industry’s advocates and detractors, and examining its processes and oversight for risk factors in the same way one would do for an 'ordinary' industry or sector. One then finds not only the 'ordinary' crime and frauds risks – notably around procurement, management or staff misappropriation, bribery and corruption, and improper record keeping – one finds also security meta-risks, which may be increasing. These meta-risks arise from a mix of an exceptional security regime and a shielding of management from full transparency (this being justified partly on the basis of security). Extraordinary risks, yes, and an extraordinary industry and regulatory regime. All the more reason to apply to it some basic fundamentals of crime risk assessment, a start towards this having been attempted in this paper.

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