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**HIGH LEVEL RADIOACTIVE
LIQUID WASTE AT SELLAFIELD:**

**Risks, Alternative Options and
Lessons for Policy**

Report on an IRSS Study

by

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Preface

This report summarizes a study conducted at the Institute for Resource and Security Studies (IRSS), Cambridge, Massachusetts. Gordon Thompson prepared the report and performed most of the research for the study. Other contributions to this project are described in the Acknowledgements section, below.

The most difficult part of this study was obtaining information. In the UK there is a strongly established tradition of secrecy about nuclear industry matters. The present and preceding UK governments have promised greater openness, but implementation of this policy is proceeding very slowly and much of the information needed for an independent investigation of the UK nuclear industry is unavailable.

The UK tradition of secrecy contrasts markedly with the openness which prevails in the USA. This difference is not obvious to a citizen reading a newspaper. At that level of scrutiny, the two societies seem rather similar. However, to a technically informed analyst who seeks to make an independent judgement about the safety or economic viability of a nuclear facility, the two societies present very different faces. In the USA, access to information is not perfect, but an independent analyst can usually obtain the information that she needs. The same analyst, working in the UK, will spend much of her time trying to infer a true picture from fragments of information that are often mutually contradictory.

A repeated theme in this report is the need for open, comprehensive assessments of issues facing the UK nuclear industry. Such an assessment will have three major features. First, it will be open, in the sense that information will be available to all interested parties, official bodies will be required to account for their findings, and technically informed people will have opportunities to contribute opinion and analysis. Second, it will be comprehensive, in the sense that it will account for all factors relevant to society's interests. Third, it will not be confined to just one proposed action, but will also consider a range of alternative options. An assessment with these features can improve the quality of decision-making, and can help to ensure that decisions enjoy lasting public support.

In this report, IRSS provides an independent assessment of risks and alternatives for a particular practice at the Sellafield site -- storage of high level radioactive waste (HLW) as a liquid. No comparable assessment has been published by any other entity. Official statements have been made about risks and alternatives for liquid HLW storage, but some of those statements lack credibility. A detailed, comprehensive assessment of risks and alternatives would require a considerably larger budget and much better access to information than IRSS had available for its present study. Nonetheless, this interim assessment is unique and provides important lessons for policy making.

About the Institute for Resource and Security Studies

The Institute for Resource and Security Studies (IRSS) is an independent, non-profit, Massachusetts-based corporation. It was founded in 1984 to conduct technical and policy analysis and public education, with the objective of promoting peace and international security, efficient use of natural resources, and protection of the environment. IRSS projects always reflect a concern for practical solutions to resource, environment and security problems, and can range from detailed technical studies to preparing educational materials accessible to the public.

About the Author

This report was prepared by Gordon Thompson, who is the executive director of IRSS. Thompson studied and practised engineering in Australia, was based in the UK for the period 1969-1978, and received a DPhil in applied mathematics from Oxford University (Balliol College) in 1973. He participated in the Windscale Public Inquiry (1977) as a member of the Political Ecology Research Group, and submitted evidence to the Sizewell Public Inquiry (1984) on behalf of the Town and Country Planning Association. Dr Thompson has extensive experience in assessing nuclear facility risks and alternatives, and has also worked on a range of other subjects related to energy, the environment and international security.

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IRSS acknowledges assistance from several organizations in the UK and Ireland. Personnel of the UK Nuclear Installations Inspectorate provided documents and answered questions through correspondence. The UK Atomic Energy Authority and the Environment Agency provided documents, and the Uranium Institute and Cumbria County Council made their libraries available. British Nuclear Fuels provided documents and hosted a visit to the Sellafield site. The Radiological Protection Institute of Ireland hosted a seminar where IRSS's research was discussed.

Gordon Thompson prepared this report, conducted most of the research, and is the IRSS point of contact for questions about the report. Paula Gutlove of IRSS contributed to the research and report preparation.

A final acknowledgement is due to Peter Taylor, who has drawn attention to the risks of high level radioactive waste storage and performed related research, first during the 1977 Windscale Public Inquiry and subsequently on other occasions.

Abstract

This report provides an independent assessment by IRSS of risks and alternatives for a long-standing practice at the Sellafield site -- storage of high level radioactive waste (HLW) as a liquid. The report also addresses some related issues, including the economics of nuclear fuel reprocessing at Sellafield, the UK approach to assessing nuclear activities and alternative options, and the effectiveness of the UK Nuclear Installations Inspectorate.

Spent fuel from nuclear reactors is brought to the Sellafield site from across the UK and from other countries. When the fuel is reprocessed, most of its radioactive content appears as liquid HLW. This hot, acidic liquid is placed in stainless steel tanks which must be cooled and carefully managed for as long as liquid HLW remains within them. An accident or malicious act could cause radioactive material to be released from the tanks, either as a liquid release that would enter the Irish Sea or as an airborne plume.

The Sellafield HLW tanks represent one of the world's most dangerous concentrations of long-lived radioactive material. This danger has not received proper attention from the responsible authorities, because of systemic weaknesses in nuclear safety regulation in the UK. The danger could have been avoided decades ago if the plant had been designed differently. The danger persists now because plutonium separation is a continuing activity at Sellafield. Yet, plutonium separation is widely recognized as a threat to international security and a source of environmental pollution. IRSS also shows that further plutonium separation is uneconomic.

In recent years, a new facility at Sellafield has begun to convert stored liquid HLW to glass blocks, a safer storage mode. A suspension of reprocessing would allow the backlog of liquid HLW to be converted to glass by 2007. Moreover, a suspension of reprocessing would eliminate a potential, proven by experience at reprocessing plants, for a destructive chemical explosion at Sellafield.

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1. Introduction

"Although current practice is to store all the high-active waste as liquid in underground tanks, this can only be regarded as an interim measure, and ultimate disposal methods are required. These are defined as those which fix the fission-product activity in a non-leakable, non-leachable form so that general dispersal can never occur. Storage of liquors in tanks does not meet this criterion since conceivably at some distant date part or all of the tank's contents could be released to the environment because of vessel deterioration or catastrophe. Rapid dispersal leading to gross contamination over a wide area could then follow."

K. Saddington, UKAEA, 1958 ¹

Forty years ago, scientists recognized that storage of high level radioactive waste (HLW) as a liquid is a dangerous practice which should only be used as an "interim measure". Yet, storage of liquid HLW was subsequently expanded at Sellafield, continues today, and on present trends will continue for another 20 years or longer. As a result, the Sellafield site houses one of the world's largest concentrations of easily mobilized, long-lived radioactive material.

In this report the Institute for Resource and Security Studies (IRSS) provides an independent assessment of: (i) risks associated with liquid HLW storage at Sellafield; and (ii) alternative options. No comparable assessment is available from the UK Nuclear Installations Inspectorate (NII), from British Nuclear Fuels (BNFL), or from any other entity. The absence of such an assessment highlights a general problem in the UK -- the lack of open, comprehensive reviews of issues facing the nuclear industry. Partly as a result of that lack, decisions have not always been well informed, and public trust in the nuclear industry and its regulatory bodies is low.²

Nuclear industry issues are interconnected, as is evident in this report. Although IRSS's investigation has focussed on the storage of liquid HLW, we have necessarily addressed some related issues. For example, IRSS has examined the economics of nuclear fuel reprocessing at Sellafield, options for managing separated plutonium, and the effectiveness of the NII.

In the UK, there is a longstanding habit of secrecy about nuclear matters, which has complicated IRSS's investigation. For an independent analyst, obtaining information about the UK nuclear industry is a difficult and frustrating enterprise. Typically, knowledge must be inferred from fragments of information which may be mutually

¹ Saddington, 1958, page 294. Saddington was head of research and development laboratories for UKAEA Industrial Group at the Windscale Works, Sellafield. Note that the liquid high level waste tanks at Sellafield are above ground, not underground as stated by Saddington.

² A UK survey suggests that "fewer than 10-15 percent of people trust either the government or industry to tell the truth about environmental risks" (POST, 1997, page 80).

contradictory. However, when knowledge is eventually constituted, it can support important findings. Interestingly, one of IRSS's findings is that secrecy has limited NII's and BNFL's understanding of the risks posed by Sellafield facilities.

A precondition for sound decision making about nuclear risks and alternatives is the conduct of a comprehensive, open assessment of these issues. For the liquid HLW tanks, IRSS's report comes closer to satisfying that precondition than any other available literature. However, in conducting this study IRSS did not command the level of resources or the access to information that would be needed for a detailed, comprehensive assessment of risks and alternatives. Such an exercise would require a much larger budget and considerably better access to information than IRSS had available for this study.³ Nevertheless, this report is unique. It provides an interim guide for decision making and an illustration of the type of assessment that is needed.

The remainder of this report has seven sections which are supported by nine appendices. Section 2 introduces the Sellafield site and its hazards, including storage of HLW. Processes for assessing risks and alternatives are reviewed in Section 3, and the risks of liquid HLW storage are examined in Section 4. Alternatives to liquid HLW storage are examined in Section 5, and an integrated view of risks and alternatives is presented in Section 6. Conclusions and recommendations are set forth in Sections 7 and 8, respectively. All of the citations in this report, and in the appendices, are to documents listed in the bibliography provided as Appendix A.

Detailed information is placed in the appendices, so that this main text can be comparatively brief and accessible to the general reader. In the appendices, consistent with our call for openness, IRSS has sought to make all major assumptions explicit and to cite supporting literature wherever relevant. If readers have further questions about the report's assumptions, sources and methodology, these can be directed to IRSS.

2. The Sellafield Site: High Level Waste and Other Hazards

2.1 An Introduction to the Site

The Sellafield site (previously known as the Windscale site) was established for a military purpose -- to provide plutonium for UK nuclear weapons. Activities at the site are now predominantly commercial. Plutonium was first produced at the site in two air-cooled reactors (the Windscale "piles"). Subsequently, the four Calder Hall reactors were built at the site to produce both plutonium and electricity.

Plutonium is produced inside the uranium fuel assemblies of a reactor, and is therefore not readily accessible. Before the plutonium can be used, the fuel assemblies must be removed from the reactor and reprocessed. In a reprocessing plant, fuel from a reactor is dissolved in nitric acid and then separated into its components by chemical processes. The major components are plutonium, radioactive waste, and unburned uranium.

³ IRSS's total budget for all work related to this report was approximately £30,000.

Reprocessing is now the major activity at Sellafield. Initially, reprocessing was conducted in building B204, which is now closed. Currently, fuel from Magnox reactors is reprocessed in building B205 and oxide fuel (fuel from advanced gas-cooled reactors [AGRs] and light water reactors [LWRs]) is reprocessed in the THORP facility. Spent Magnox fuel and oxide fuel is brought to Sellafield from across the UK and from other countries, stored for a period of months or years in water-filled ponds, and then reprocessed.⁴

A reprocessing plant generates a stream of high level radioactive waste (HLW) in liquid form. This stream contains most of the radioactivity that was present in the spent fuel. At Sellafield, the streams of liquid HLW from the B205 and THORP plants are sent to building B215, where the liquid HLW is stored in tanks. Building B215 is a major focus of attention in this report. The remaining radioactive waste from reprocessing is either released to the Irish Sea, released to the atmosphere, or discharged as a stream of intermediate level waste (ILW) or low level waste (LLW). After a period of storage and processing, the ILW and LLW streams are packaged in solid form. Packaged LLW is taken to a surface-located repository at Drigg. Packaged ILW is stored, pending the development of a repository for ILW.

Most of the plutonium that has been separated at Sellafield remains in storage at the site. In previous decades, nuclear industry managers thought that plutonium would be used in breeder reactors, but this market has collapsed. An alternative, highly controversial option is to incorporate plutonium into mixed oxide (MOX) fuel for use in light water reactors. A MOX fuel fabrication plant with a capacity to make 8 tonnes of MOX fuel per year is in operation at Sellafield, and a plant with a capacity of 120 tonnes MOX fuel per year will soon be ready to operate.

A variety of projects are under way at Sellafield to decommission old facilities and process radioactive wastes that were improperly stored. These projects generate packages of ILW and LLW.

2.2 Categories of Environmental and Other Impacts

This report examines the management of liquid HLW at Sellafield. In performing this examination, we identify and characterize some of the major impacts of current arrangements and selected alternatives. A systematic examination of this kind will improve the quality of decisions, because decision-makers will have a better understanding of the choices available to them and the implications of those choices. For each alternative, decision-makers need the best possible information about the alternative's costs, benefits, known impacts, and potential impacts. But, what types of impact are relevant?

⁴ Under current contractual arrangements, some UK-origin oxide fuel may be stored at Sellafield without reprocessing.

Here, IRSS defines "impacts" as effects on humans, their society, and the biosphere, both now and in the future. Impacts can be physical (e.g., exposure to radiation) or non-physical (e.g., reduction of people's trust in government). In this report, "risks" are defined as impacts that people dislike and seek to avoid, while recognizing that complete avoidance may not always be possible. Table 1 shows six major categories of impact from Sellafield operations, grouped into two classes -- impacts from routine and non-routine events. The designation "non-routine" means that events are not planned or readily predictable, although their occurrence may not be a surprise.

In the class of impacts from non-routine events, the first category in Table 1 encompasses impacts from large releases of radioactivity, which could arise either "accidentally" (initiated by natural events, equipment failures, etc.) or through malice (acts of sabotage, terrorism or war). Large radioactive releases could occur at the Sellafield site or during transport of radioactive material to or from the site. The second category encompasses impacts attributable to diversion of plutonium, either at Sellafield or during transport associated with Sellafield. These impacts will vary, depending on the nature and purpose of the diversion. The third category encompasses the impacts of nuclear weapons proliferation, where such proliferation is promoted by Sellafield's operations. Underlying this category is a concern that commerce in plutonium, and the accumulation of stocks of separated plutonium, will encourage States to acquire nuclear weapons.⁵

<p>Impacts From Routine Events</p> <ul style="list-style-type: none">• Impacts from planned releases of radioactivity• Future impacts from repositories for HLW, ILW and LLW• General impacts associated with an industrial site <p>Impacts From Non-Routine Events</p> <ul style="list-style-type: none">• Impacts from large releases of radioactivity due to accident or malice• Impacts from diversion of plutonium• Impacts from greater proliferation of nuclear weapons <p>TABLE 1: CATEGORIES OF IMPACT FROM SELLAFIELD OPERATIONS</p>

Any environmental impact statement (EIS) that is worthy of the title will address physical impacts of routine events. Many EISs also address non-physical impacts (e.g., social and economic impacts) of routine events. However, EIS practice varies in its

⁵ The Royal Society (Mason et al, 1998) has expressed concern about the potential for diversion and nuclear weapons proliferation associated with the UK's stock of separated plutonium.

treatment of impacts from non-routine events. In the USA, prevailing practice for nuclear facility EISs includes an examination of potential accidents, but the scope of this examination varies. Table 1's second and third categories of impact from non-routine events are rarely addressed in EISs. Nevertheless, these impacts are highly relevant to decisions about a site such as Sellafield.

2.3 High Level Waste at the Site

When spent nuclear fuel arrives at Sellafield, it contains large amounts of radioactive fission products, activation products and transuranic isotopes. After the fuel is dissolved and reprocessed, most of its radioactive content appears in the liquid HLW stream. Also present in this stream is a small fraction of the plutonium and unburned uranium that were in the fuel. About 5 cubic metres of liquid HLW are produced for each tonne of spent fuel that is reprocessed in THORP or B205.

Liquid HLW is transferred from each reprocessing plant to building B215 via stainless steel pipes. A group of these pipes is supported and shielded within an elevated pipebridge, which has the form of a square-section concrete tube supported at intervals on concrete columns. One pipebridge connects THORP to building B215, while another pipebridge connects building B205 to B215.

Building B215 is a comparatively small structure (in comparison to the reprocessing plants) which is located roughly in the centre of the Sellafield site. This structure houses 21 liquid HLW tanks, three operable evaporators, six shut-down evaporators, and related equipment. The first part of B215 was built in 1955, and the facility was then developed in stages, reaching its present form by 1990.⁶ Appendix C provides some details.

After liquid HLW is received in building B215, it is concentrated in one of the three operable evaporators and then sent to one of the HLW tanks. Liquid HLW can be transferred from one tank to another, as required. After a period of storage, liquid HLW is removed from B215 and transferred to the adjacent Waste Vitrification Plant (WVP). In the WVP, liquid HLW is converted to a calcine which is fed into a melting pot with crushed glass. The molten glass-waste mixture is poured into stainless steel containers, where it solidifies. These containers are sealed and placed in a storage vault. WVP first operated in 1991 and has two production lines. A third line is being built.

Table 2 illustrates the radioactive content of the liquid HLW tanks, and compares this radioactivity with the amount released during the 1986 Chernobyl accident and in fallout from nuclear weapons testing. One radioactive isotope -- caesium-137 (Cs-137)-- is chosen for this illustration. Cs-137 has a half-life of 30 years, is relatively volatile (hence released comparatively easily in an accident), adheres strongly to surfaces, and is a strong source of gamma radiation. Most of the offsite radiation exposure from the Chernobyl accident is attributable to Cs-137. (NOTE: 1 TBq = 10^{12} Bq, and 1 Bq = one disintegration per second.)

⁶ For further details, see HSE, 1995a.

Thirteen of the 21 liquid HLW tanks at Sellafield (tanks 9-21) are of newer design and construction. Each of these tanks has a nominal capacity of 150 cubic metres. NII requires that one quarter of the capacity be spare. Thus, no more than 1,440 cubic metres of HLW can be stored in tanks 9-21. The older tanks (tanks 1-8) have a nominal capacity of 70 cubic metres each. In recent years there have been failures of cooling coils in tanks 9-21, causing concern that some of these tanks might have to be taken out of service.

	Activity (TBq)	Mass (kg)
In liquid HLW tanks at Sellafield (end of 1997)	7,070,000	2,120
In Chernobyl reactor core	0,230,000	0,069
Released from Chernobyl reactor	0,089,000	0,027
N. Hemisphere fallout from nuclear weapons testing	0,740,000	0,220

TABLE 2: Cs-137 QUANTITIES, SELLAFIELD AND ELSEWHERE ⁷

2.4 Scenarios for Liquid High Level Waste

Appendix B develops three scenarios for reprocessing at Sellafield, and estimates the flows and stocks of liquid HLW for each scenario. These scenarios are described in this report as "operational alternatives" for HLW management.

The Base Case scenario features continued reprocessing at THORP until 2012 and at B205 until 2013. In the THORP Shutdown scenario, oxide fuel reprocessing ceases but Magnox fuel reprocessing continues in B205. The oxide fuel that would have been reprocessed at THORP is placed in long-term storage and ultimately sent to a final repository. In the THORP and B205 Shutdown scenario, all reprocessing ceases and the UK's remaining Magnox reactors are shut down. B205 is not shut down instantly, but operates for 1-2 years to reprocess residual Magnox fuel that has been wet-stored. Magnox fuel that has been dry-stored remains in that mode. After each Magnox reactor is shut down, its final load of fuel is stored for some years in the reactor, and then placed in

⁷ Assuming an end-1997 liquid HLW inventory of 1,345 cubic metres (see Appendix B). Activities are taken from Appendix D. Masses are calculated at 0.3 g/TBq.

long-term dry storage. Ultimately, all of the stored Magnox fuel is sent to a final repository.

Shutting down B205 requires shutting down the Magnox reactors because the UK has adopted a Magnox fuel cycle which requires reprocessing. Most Magnox spent fuel is wet-stored, but the fuel deteriorates if left in water for long periods and must therefore be reprocessed. An alternative Magnox fuel cycle, which does not require reprocessing, could have been developed in the past. Now, the Magnox reactors are nearing the end of their useful life, and investment in developing a new fuel cycle could not be justified.

Table 3 shows IRSS estimates of production and stocks of liquid HLW for the three scenarios. These scenarios take effect from the beginning of 1998, so that they can be anchored as closely as possible in historical data. As time passes, the scenarios can be compared with the actual sequence of events.

	Base Case	THORP Shut-down	THORP & B205 Shutdown
Liquid HLW produced after 1997	2,536 m ³	0,591 m ³	0,064 m ³
Peak inventory of liquid HLW after 1997	1,657 m ³	1,268 m ³	1,268 m ³
Year of peak inventory	2005	1998	1998
Year when liquid HLW inventory is eliminated	2020	2009	2007

TABLE 3: LIQUID HLW STOCKS AT SELLAFIELD FOR THREE SCENARIOS ⁸

Future inventories of liquid HLW will depend on the rate of production of liquid HLW and the rate at which liquid HLW is vitrified. Experience at WVP shows a rate of vitrification which is consistently below the design level, and the estimates in Table 3 assume that this situation continues. If higher production of vitrified waste containers is achieved at WVP in the future, then future inventories of liquid HLW will be lower than shown in Table 3. Conversely, lower container production at WVP would lead to

⁸ Appendix B provides a detailed description of these scenarios.

increased inventories of liquid HLW, placing a strain on the storage capacity at building B215.

For the Base Case, Table 3 shows that the inventory of liquid HLW will reach a peak in 2005 and then decline. However, the inventory will remain above 1,440 cubic metres -- the maximum capacity of tanks 9-21 -- for each of the years 1999 through 2011. Thus, a substantial fraction of the inventory must be stored in tanks 1-8. If some of tanks 9-21 are taken out of service, and/or container production at WVP is low, then the storage capacity at building B215 will be fully utilized, and reprocessing must cease.

For the THORP Shutdown scenario, Table 3 shows that the liquid HLW inventory will immediately begin to decline in 1998, but it will not be eliminated until 2009. This finding contradicts a claim by NII that a shut-down of THORP would allow the HLW tanks to be emptied within three and a half years.⁹ For the THORP and B205 Shutdown scenario, the liquid HLW inventory will be eliminated in 2007.

Other differences between the scenarios are worth noting. Notably, the Base Case involves the separation, after 1997, of 98 tonnes of plutonium. By contrast, the THORP Shutdown scenario involves the separation of 29 tonnes of plutonium after 1997, while the THORP and B205 Shutdown scenario involves the separation of only 3 tonnes of plutonium. Also, the Base Case involves the production at WVP of an additional 9,700 containers of vitrified waste. There is insufficient storage capacity at WVP to hold all these containers, and about 3,300 containers would have to be exported from the site or new storage capacity would have to be constructed. For the other two scenarios, the existing container storage capacity at WVP would be adequate.

3. Processes for Assessing Risks and Alternatives

3.1 The Current UK Approach

This report is predicated on the concept that decision-making about nuclear facilities should be preceded by a systematic examination of a contemplated course of action and a set of alternatives. For each alternative, the costs, benefits, known impacts, and potential impacts should be assessed. Risks are important impacts of a nuclear facility, and should receive special attention. The entire process should proceed openly, with opportunities for public involvement. Such an approach is now used routinely in the United States when a new nuclear project is contemplated, and it has also been used in the USA to examine the merits of continued operation of existing nuclear facilities.

In the UK, a different approach is taken. First, only one project concept is proposed, and alternatives are not identified. Second, project proponents do not undertake a comprehensive examination of the project's costs, benefits and impacts. Some of those issues are examined, but usually within a narrow paradigm determined by the proponent's perceived interests. Third, risks typically receive a cursory examination. Fourth, project

⁹ HSE, 1995a, page 20.

proponents and government regulators generally work in secret, and publish only limited information about the project. Fifth, opportunities for public involvement are limited, and their design tends to cast citizens in the role of "objectors".

Underlying this approach is an unfortunate assumption that the proponents are wise and have the public interest at heart, while members of the public are ignorant and prone to hysteria. Members of the UK nuclear establishment are usually too discreet to voice this assumption publicly, but it evidently remains dominant. There can be no other explanation for the persistence of a decision-making approach that has proven to be very costly.

The costliness of the traditional UK approach is illustrated by Nirex's abortive attempt to develop a Rock Characterization Facility at Sellafield. After a public inquiry, the UK government refused planning permission for this facility. Nirex had spent about £250 million on studies related to this facility, and spent about £12 million more during the inquiry.¹⁰ Only a fraction of this expenditure has generated knowledge of lasting value.

Nuclear safety regulation in the UK follows the traditional approach. Risks and alternatives are given a cursory examination, and little information is published. Moreover, NII employs a "non-prescriptive" approach to safety regulation, which means that each nuclear safety issue is a subject for negotiation between NII and the licensee. This negotiation takes place secretly, and the supporting documentation is secret. It is also clear to an observer of NII that its staff and the licensees' staff view each other as members of an elite club to which the public is not invited. On occasion, NII takes a position against a licensee, but this occurs within a broader climate of accommodation.

In addition, NII is a small, low-budget organization by comparison with its US equivalent -- the US Nuclear Regulatory Commission (NRC). The NRC has a staff of 3,060 and a budget of £280 million, and oversees 110 licensed reactors (an average of 28 staff and £2.5 million per reactor). NII has a staff of 280 and a budget of £17.5 million, and oversees 35 licensed reactors (an average of 8 staff and £0.5 million per reactor).¹¹ Moreover, NII also oversees the Sellafield and Dounreay sites, while NRC has no equivalent responsibility. (NOTE: Commercial reprocessing does not occur in the USA.) Interestingly, both NII and NRC receive most of their funding from fees levied on licensees.

NII's mode of operation, size and budget have limited its capability to understand the risks posed by nuclear facilities. As is evident from subsequent discussions in this report, NII does not conduct probabilistic risk assessments that meet prevailing international standards, nor does it require its licensees to conduct such assessments. Similarly, NII does not conduct or require systematic assessments of alternatives. Secrecy and a lack of peer review have allowed these deficiencies to persist.

¹⁰ POST, 1997, page 17.

¹¹ Thompson, 1998b, page 115.

3.2 Probabilistic Risk Assessment

In the 1960s, as the commercial nuclear industry took shape, decision-makers sought information about the probability and consequences of potential accidents at nuclear facilities. Engineers recognized that new analytic techniques were needed if these parameters were to be estimated. Important early work on this subject was done in the UK by Farmer and others, but leadership later passed to the United States.

Beginning with the NRC's Reactor Safety Study of 1975, practitioners in the USA and elsewhere have developed an engineering discipline known as probabilistic risk assessment (PRA). Nuclear facility PRAs are performed at three levels. At Level 1, a PRA will estimate the probability of a specified type of accident (e.g., severe core damage at a reactor). At Level 2, which builds upon Level 1 findings, a PRA will estimate the nature of potential radioactive releases from the facility. In turn, the Level 2 findings can be used in a Level 3 exercise, which will estimate the offsite consequences (health effects, economic effects, etc.) of radioactive releases. For all three levels, a PRA can be performed for "internal" accident-initiating events (equipment failure, operator error, etc.) and for "external" accident-initiating events (earthquakes, floods, etc.).

Most potential accidents at a nuclear facility will involve a chain of events that might, individually, cause limited concern. Mathematical techniques have been developed whereby PRA analysts can examine each link in a potential chain, estimate its probability, and combine these estimates into an overall estimate for the probability of the resulting accident. These techniques are very helpful, but the analyst must also exercise common sense, be aware of historical experience, and consider the potential for subtle interactions among a facility's systems. Historical experience shows that accidents involving complex technologies can proceed in complex and surprising ways.¹²

Thus, application of PRA techniques requires more than the simplistic use of mathematical techniques. It also requires the consideration of a variety of complicating factors, which may not all be susceptible to mathematical analysis. These factors, which can interact, include: (i) gross errors by plant personnel (errors beyond historical experience); (ii) gross defects in equipment and/or structures (defects that have been undetected and exceed historical experience); (iii) earthquakes; (iv) fires or explosions; (v) acts of malice; (vi) unanticipated accident sequences; and (vii) dependencies among events.

Because of these factors and statistical effects, the findings of a PRA, even one performed to prevailing international standards, contain substantial uncertainty.¹³ A PRA which yields very low accident probabilities is unlikely to be credible. In illustration, analysts examining the credibility of PRA findings for nuclear reactors have stated that a core

¹² Perrow, 1984.

¹³ Hirsch et al, 1989.

damage probability below 1 per 100,000 reactor-years is "very suspicious" and a probability below 1 per 1 million reactor-years is "clearly incredible".¹⁴

Experience shows that the development of PRA techniques, and the application of those techniques in a particular PRA, demand a high level of openness and thorough peer review. By contrast, a climate of secrecy will have a stultifying effect on PRA practice. BNFL claims to have conducted PRA investigations for facilities at Sellafield, but this work remains secret and thus cannot have received thorough peer review. There is reason to doubt that BNFL's probabilistic studies are systematic or comprehensive. BNFL officials concede that, if Sellafield were overseen by the NRC, a PRA would have been prepared and published for the site's major facilities.

Most of the nuclear PRA experience worldwide is with reactors. Every commercial reactor in the USA has now been subjected to a PRA or similar analysis. Five representative reactors were studied in great detail, in a PRA exercise run by the NRC.¹⁵ Large military reactors at the Hanford and Savannah River sites have also been subjected to PRAs. Worldwide, no PRA has been published for a reprocessing plant or a facility such as building B215. Some probabilistic investigations have been conducted for military reprocessing plants in the USA, but these investigations have been of limited scope.

3.3 Environmental Impact Assessment

Section 2.2 identifies categories of impact from Sellafield operations, and points out that some of these impacts are currently addressed in environmental impact statements. Any competent EIS must address the physical impacts of routine events, and many EISs also address non-physical impacts (e.g., social and economic impacts) of routine events. In regard to impacts from non-routine events, some EISs involve an examination of potential accidents, but the scope of this examination varies. Impacts from non-routine events such as the diversion of plutonium are rarely addressed in EISs, although these impacts are highly relevant to decisions about a site such as Sellafield.

Thus, the environmental impact statement is partially developed as a tool for examining the impacts from a proposed nuclear project and its alternatives. In the future, the scope of EISs may grow, at which point they may be given a different title. Ultimately, the full range of impacts from nuclear projects may be assessed. However, the EIS is already well developed as a tool for identifying and characterizing a range of alternatives. As an illustration, consider an EIS recently prepared by the US Department of Energy, examining options for the storage and disposition of plutonium and highly-enriched uranium that is surplus to US military requirements.¹⁶ This document, and an accompanying body of published literature, provide copious information about the selected options.

¹⁴ Fragola and Shooman, 1991.

¹⁵ NRC, 1990.

¹⁶ DOE, 1996a.

US government agencies have been publishing EISs for nuclear projects since the 1970s. Where applied to military nuclear projects, EISs have expanded in scope over the last decade, consistent with a trend toward greater openness in the USA regarding military nuclear matters. In the UK, there is no equivalent to the US practice of preparing EISs for nuclear projects. Instead, the proponents of a project put forward a single project concept, and provide a limited amount of information about the project's costs, benefits and impacts. More information may emerge if there is a planning inquiry, but objectors must fight for each item of information. The proponent may have made large expenditures on the project before a planning inquiry occurs, thus creating pressure for a decision that favours the proponent's concept.

3.4 Science, Democracy and Safety

Nuclear safety is an engineering field, but it employs scientific principles and occasionally requires scientific research. It is therefore important to note that science is a competitive and somewhat chaotic enterprise. Nevertheless, in the aggregate and in the longer term, science converges on an ever-more accurate understanding of nature. This is possible because science is guided by three powerful forces: (i) open exchange of ideas and information; (ii) peer review; and (iii) empirical findings.

These three forces, which have proven to be essential ingredients of good science, must be consistently applied in the nuclear safety field if that field is to have any credibility. Moreover, in the nuclear safety field there is little opportunity for full-scale or otherwise representative experiments, so that openness and peer review become especially important.¹⁷

Even if openness and peer review are available in ample supply, nuclear safety experts should nevertheless be conservative in their findings and recommendations. Empirical support for their findings will always be limited. Moreover, their findings must take account of phenomena such as human error and human malice, which are difficult to predict. Also, the nuclear safety expert has responsibilities which differ from those of a laboratory scientist competing to make a new discovery. In a democracy, major decisions about nuclear energy matters should be made by democratic processes, and the expert's role is to provide relevant technical information in a balanced, accessible form.

Regrettably, nuclear engineering activities have often been pursued in secret and without public accountability. Experience shows that secrecy has been costly in at least four major respects. First, it has bred public mistrust of government. Second, it has led to wasteful expenditures. Third, it has prevented the nuclear industry from acquiring an accurate understanding of the hazard potential of nuclear facilities. Fourth, it has allowed high-risk nuclear activities to continue.

¹⁷ There are cases where technical progress has been made under conditions of secrecy. For example, nuclear weapons and ballistic missiles were developed in secret. Yet, many full-scale experiments, with many failures, were needed to develop these technologies. Comparable experiments have not been conducted in the nuclear safety field.

Appendix E provides some historical evidence to illustrate the costs of secrecy and the benefits of openness. One illustration of the cost of secrecy is provided by the 1986 Chernobyl reactor accident. From the 1960s onward, a few Soviet scientists knew that the Chernobyl type of reactor (the RBMK reactor) has a built-in tendency to explode and burn. However, this information was suppressed, with the result that engineers and managers in the Soviet nuclear industry were unaware of the reactor's hazard potential. Ironically, the 1986 accident occurred during a safety test. The operators did not, despite allegations to the contrary, violate established safety rules. The accident was caused by a combination of secrecy and bad design. Moreover, suppression of knowledge about the RBMK reactor's hazard potential contributed to a lack of preparation for post-accident response.

At various points in this report, practices in the UK and the USA are compared. In each instance, the USA exhibits greater openness and readiness to undertake systematic assessments of risks and alternatives. This comparison does not imply that the USA is a superior society, but simply reflects a difference in how the two societies address nuclear issues. More importantly, the US government's openness and readiness to examine risks and alternatives have improved steadily over recent decades, and this improvement was achieved through considerable effort by citizens and public-interest scientists.¹⁸ The UK could make a similar transition.

3.5 Decision-making and the Acceptability of Risk

The merits of a nuclear activity depend on its costs, benefits and impacts. However, these merits are perceived differently by different parties, so a process is needed for making decisions about which nuclear activities to pursue. Risks are important impacts of nuclear activities, so the decision-making process requires some framework for determining if risks are acceptable.

Major decisions about nuclear activities should be made by democratic processes, informed by the best available technical information. As mentioned above, UK citizens are not given good information about nuclear matters, and their role in decision-making is limited. Central government is the dominant decision-maker in the UK.

Detailed decisions about nuclear safety must be made under the aegis of a regulatory body. NII has that role in the UK. In order to provide a conceptual framework for its regulatory decisions, NII has articulated a set of safety assessment principles (SAPs). These principles are summarized and critiqued in Appendix D.

Some of the SAPs articulated by NII are admirable. For example, principle P61 calls for inherently safe design of nuclear facilities. This is a policy which the chemical industry has sought to pursue since the Flixborough chemical plant accident of 1974.

¹⁸ Ford, 1982; Primack and von Hippel, 1974; von Hippel, 1991.

Unfortunately, the liquid HLW tanks at Sellafield are not inherently safe, nor are most nuclear facilities in the UK.

Other SAPs accept that accidental releases of radioactivity may occur, but stipulate a maximum probability for a given release. This concept reflects an assumption that a large release is acceptable if it has a low probability, and vice versa. That assumption was formalized by Farmer in 1967 as a "limit line" for the acceptability of reactor accidents. However, Farmer failed to recognize that a reasonable citizen could find a large release unacceptable, whatever its probability. This is especially true when the potential release is composed of long-lived isotopes such as Cs-137. The biosphere is already contaminated with Cs-137 from nuclear weapons fallout and the Chernobyl accident, and would be further contaminated by another release.

Principle P44 is NII's contemporary expression of Farmer's "limit line" concept. It represents a substantial retrograde step. Notably, P44 stipulates that a release of more than 200 TBq (60 grams) of Cs-137 is acceptable if the estimated probability of that release is less than 1 per 100,000 years. A release of 2,000 TBq or 200,000 TBq is equally acceptable to NII. A release of the entire inventory of liquid HLW at Sellafield, containing (see Table 2) over 7,000,000 TBq (2,100 kilograms) of Cs-137 is also acceptable to NII, provided the release's estimated probability is less than 1 per 100,000 years. Many citizens will find this provision distasteful. Moreover, an informed citizen will realize that NII has no means to credibly determine if the probability limit in P44 is met, because PRA practice in the UK does not meet prevailing standards.

In discussing the acceptability of a potential release of radioactivity, NII takes it for granted that the risk of the release is offset by some benefit. Yet, many of the people who bear the risk do not receive any benefit. For example, the citizens of Ireland bear the risk of a release from Sellafield, but Ireland does not use nuclear power. Future citizens of Europe would be irradiated by Cs-137 released from Sellafield today, but would receive no benefit from Sellafield's current operations. Moreover, many analysts argue that Sellafield's operations represent a net cost to UK citizens, both financially and in terms of reduced international security.

Overall, NII's safety assessment principles are inadequate for their purpose. To compound this problem, the principles have no legal force and are frequently violated by UK nuclear facilities. Instead of firmly relying on its SAPs, the NII employs a "non-prescriptive" approach to nuclear regulation, and makes licensing decisions based on its "judgement". Yet, because there is no systematic, open assessment of risks and alternatives, NII's judgement lacks a rational basis.

4. Risks of Storing High Level Waste as a Liquid

4.1 NII Assertions

NII has published a report on the safety of the liquid HLW tanks at Sellafield.¹⁹ In that report, NII makes a variety of assertions about the nature and probability of potential accidents which involve the HLW tanks. Those assertions are summarized and reviewed in Appendix C. None of the assertions is supported by any published technical analysis.

One accident scenario mentioned in NII's report is a loss of cooling to a HLW tank. This scenario was a subject of discussion during the 1977 Windscale Inquiry. The scenario arises because liquid HLW is intensely radioactive and therefore self-heating. Thus, a loss of cooling means that the liquid will rise in temperature and then boil. If the loss of cooling continues, and water is not added, the tank will eventually dry out. Then, the solid residue will be self-calcined (converted to oxide) and will rise in temperature, eventually melting through the bottom of the stainless steel tank. During the boiling period and thereafter, radioactive material will be released to the atmosphere via the tank ventilation system or other pathways. Analysis presented at the Windscale Inquiry by BNFL showed that a tank filled with HLW from five year-cooled LWR fuel would, if tank cooling were interrupted, begin boiling after about half a day and boil dry three days later.

NII asserts that the probability of a 24-hour cooling loss is less than 1 per 1 million years, while the probability of a prolonged cooling loss, leading to tank dryout, is less than 1 per 10 million years. Such a low probability is not credible (see Section 3.2). NII does not provide any estimate of the consequences of a prolonged cooling loss, but states that these consequences are known to be "very severe".

Drawing upon analysis by BNFL, NII asserts that a large commercial or military aircraft could, if it crashes on building B215, penetrate the concrete cell around a HLW tank and the tank itself. The probability of this event is said to be 1 per 100 million years. This very low probability derives from an assumption that aircraft crash is a random event. No information about the potential consequences is provided. Interestingly, BNFL presented analysis to the Windscale Inquiry, stating that a crashing aircraft would not penetrate a HLW tank cell.

According to NII, an earthquake with a peak acceleration of 0.25g could temporarily disable the cooling system for the HLW tanks but would not directly damage the newer tanks (numbers 9-21).²⁰ NII says that the older tanks (numbers 1-8) might leak after such an earthquake but their cells would not leak. NII asserts that the exceedance probability

¹⁹ HSE, 1995a.

²⁰ The cited acceleration of 0.25g (where g is the acceleration due to gravity) refers to the peak, high-frequency, horizontal ground motion caused by the earthquake.

of a 0.25g earthquake is 1 per 10,000 years. NII does not discuss the tanks' vulnerability to more severe earthquakes.

NII's report provides a cursory discussion of the potential for fire or explosion to damage the HLW tanks. According to this discussion, NII cannot identify any mechanism by which fire or explosion could damage a tank. In effect, NII asserts that damage by fire or explosion is deterministically precluded, which is a strong claim in the field of nuclear safety analysis.²¹

4.2 A Systematic PRA Approach

NII's assertions about the safety of the HLW tanks do not derive from a comprehensive PRA. Instead, they derive from piecemeal analyses that leave many issues unaddressed. These analyses are generally supplied by BNFL, and are secret. Experience shows that such an approach does not yield a credible picture of the risk posed by a facility. A systematic, open PRA approach is required. Section 3.2 describes the features, strengths and limitations of the PRA approach.

Application of PRA to the HLW tanks should occur within the context of a broader PRA for the Sellafield site. Facilities at the site are interlinked and interdependent in various ways, and piecemeal analyses will not capture these connections. For example, a severe earthquake or an explosion might affect multiple facilities at the site. As another example, process disturbances at B205 or THORP could cause organic material to be forwarded to building B215 through a HLW pipeline, creating the potential for an explosion in B215.

A PRA should be performed for all major facilities at the Sellafield site. This study should be done to Level 3, for both internal and external accident initiators (see Section 3.2). No comprehensive PRA has ever been published for a group of facilities of this kind, so the development of some new PRA techniques may be required. The PRA should first be published in a draft version which is opened for public comment and subjected to intensive peer review. Reasonable criticisms should be reflected in the final version, which should be published with all its supporting documentation. This exercise should be administered by a body other than NII or BNFL, because their credibility is compromised.

For the present study, IRSS did not command either the resources or access to information that would be needed to conduct a comprehensive PRA for the Sellafield site or building B215. Instead, we conducted focussed, limited analyses of risk issues that are relevant to building B215. Our findings are primarily qualitative.

²¹ A potential accident is said to be deterministically precluded if it is against the laws of nature. If, however, an accident is physically possible but is normally prevented by engineered systems and operational procedures, then it is a subject for probabilistic analysis.

4.3 Seismic Risk

A subset of PRA practice addresses seismic risk -- the potential for an earthquake to cause a release of radioactive material from a nuclear facility. In the United States, seismic PRA techniques are well-developed, and have been applied to every commercial reactor. These techniques are not used in the UK, where a cruder, more limited approach is taken to seismic risk. Appendix F contrasts seismic PRA with the UK approach.

In the UK, the responsible authorities assume, in effect, that severe earthquakes are impossible. As a reflection of this assumption, the seismic vulnerability of nuclear facilities is not assessed for any earthquake more severe than 0.35g. (NOTE: NII has not disclosed any findings about the vulnerability of the HLW tanks to an earthquake more severe than 0.25g.) By contrast, a seismic PRA will develop "fragility curves" for a facility, showing the probability of damage as a function of earthquake-induced acceleration. Fragility curves provide insight about a facility's vulnerability to larger, lower-probability earthquakes. By failing to develop fragility curves, NII and other bodies in the UK have denied this insight to themselves and the UK public.

Historical data for the UK do not show earthquakes of the magnitude experienced elsewhere in the world. However, historical data provide limited direct guidance when one is considering earthquakes with an exceedance probability of 1 per 100,000 years or lower. Yet, such low-probability earthquakes will be significant in assessing the risk profile of the HLW tanks. Thus, a systematic process is needed for estimating the probabilities of earthquakes at a nuclear site (the "seismic hazard curves" for that site). In the USA, seismic hazard curves are developed by combining the judgements of experts through an open process. No comparable process exists in the UK.

NII has made statements about seismic risk that are contradicted by available evidence. Notably, NII has claimed that analyses equivalent to a seismic PRA are conducted in the UK. However, other information reveals that a cruder and more limited approach to seismic risk is taken, as described above. These contradictions illustrate the corrosive effects of secrecy and a lack of peer review.

A comprehensive PRA for Sellafield, as recommended in Section 4.2, would encompass a seismic PRA analysis for building B215. The findings of such an analysis cannot be readily predicted. However, IRSS anticipates that the estimated median probability of an earthquake-induced release from the HLW tanks could be as high as 1 per 100,000 years.

4.4 Fire and Explosion

NII asserts that fire and explosion do not pose a threat to the HLW tanks. No technical evidence is provided to support this assertion, and the entire issue is dismissed in a few paragraphs of NII's report. Yet, reprocessing plants around the world have suffered large and small explosions, and there is reason to fear an explosion in building B215. Appendix G reviews this issue.

In one explosion, at Kyshtym (USSR) in 1957, a liquid HLW tank dried out through neglect and then exploded with an energy release of 5-100 tonnes of TNT equivalent. The resulting plume of radioactivity travelled downwind, causing extensive contamination. About 10,000 people were permanently evacuated from contaminated land, over an area of about 1,000 square km.

The Kyshtym event was the most severe explosion at a reprocessing plant to date, but it was not unique. In 1975, a uranyl nitrate conversion facility at the Savannah River reprocessing plant (USA) suffered an explosion. The energy release during this explosion was about 0.7 tonnes of TNT equivalent. In 1993 a process vessel at the Tomsk-7 reprocessing plant (Russia) exploded. The vessel was destroyed, a wall of the surrounding building was blown out, and the building's roof collapsed. Offsite contamination was limited because the vessel contained little radioactivity. A variety of less severe events have occurred, including one in 1973 at building B204, Sellafield.

Reprocessing plants have a propensity to suffer explosions because they employ highly reactive chemicals. Organic chemicals such as tributylphosphate come into contact with concentrated nitric acid and nitrate solutions. Components of spent fuel, such as fission products, uranium, and zirconium from fuel cladding, may be present in dissolved or particulate form. This combination of chemicals, together with radioactivity and its associated heat, holds the potential for violent explosion. A particular combination of conditions (reactants, temperature, pressure, configuration of vessel, etc.) is required to produce an explosion, but experience and analysis show that explosive conditions can occur in practical situations.

Building B205 and THORP are designed and operated so that, under normal conditions, organic chemicals are not forwarded to building B215 via the HLW pipelines. However, there is no physical barrier to the passage of organic chemicals. Instead, their presence in building B215 is normally prevented by engineered systems and operational procedures. Similarly, if organic chemicals enter building B215, there is no physical barrier preventing them from entering the evaporators and HLW tanks.

Thus, an explosion could occur in building B215, in the evaporators or the HLW tanks. The energy release could be about 1 tonne of TNT equivalent. Such an explosion could be sufficiently powerful to initiate a large release of radioactivity from the HLW tanks. An estimate of the probability and nature of such a release could be made using PRA

techniques, and would be part of a comprehensive PRA for the site. No such estimate has been published by NII or BNFL, and it is likely that neither body has made a thorough study of this matter.

NII does not explain why it dismisses the fire and explosion threat to the HLW tanks. Given the NII's culture of secrecy, the Inspectorate's reasoning must be inferred from fragmentary information. By inference, it appears that the primary basis for NII's position is an assumption that organic chemicals will not enter building B215. This assumption is not credible, and reflects the lack of a PRA culture in the UK.

4.5 Other Risk Issues

In Section 3.2, we identify complicating factors which must be considered in a probabilistic risk analysis. These factors include gross errors by personnel, gross defects in equipment, and unanticipated accident sequences. Such factors, together with statistical effects, lead to uncertainty in PRA findings. Another complicating factor is the potential for acts of malice (war, terrorism and sabotage). The relevance of malicious acts to the HLW tanks is reviewed in Appendix H.

War, terrorism and sabotage are common events in history. During the 20th century, energy facilities in general, and nuclear facilities in particular, have been targets of war, terrorism and sabotage. The Sellafield site and building B215 are highly vulnerable to such events. For example, a release from the HLW tanks could be initiated by a commando-type action. No-one can reliably estimate the probability that a malicious act will cause a release from a HLW tank, but this probability may be much higher than 1 per 10 million years, which is the probability asserted by NII for a prolonged loss of cooling to a HLW tank.

IRSS recommends a systematic assessment of the vulnerability of the Sellafield site to malicious acts. Such an assessment might have been made secretly. However, the responsible authorities in the UK have failed to systematically assess risks and alternatives at Sellafield, so they may not have performed a thorough vulnerability assessment. By contrast with PRA work, which should be conducted in a completely open manner, some aspects of a vulnerability assessment should remain secret.

4.6 Consequences of Radioactive Releases

A comprehensive, Level 3 PRA should be performed for the Sellafield site. The "Level 3" designation means that the PRA would estimate the offsite consequences of radioactive releases. An indication of the potential consequences is provided by a computer modelling exercise, using the COSYMA model, which hypothesized a release from the HLW tanks.²²

²² Taylor, 1994.

In Appendix D, we have performed some simple calculations to illustrate the consequences of a release from the HLW tanks. Such a release could take the form of liquid draining to the Irish Sea, or an atmospheric plume travelling downwind. To illustrate the impact of the latter, we assume that the inventory of Cs-137 in a typical HLW tank (470,000 TBq or 140 kilograms of Cs-137) is uniformly deposited over the Irish land mass. Over the first 30 years, occupants of this land mass would receive an annual radiation dose about 15-20 times the natural background dose. This exposure could lead to an increase in the present incidence of cancer fatalities by about 40-50 percent (males) or 50-70 percent (females), each death representing a lifespan reduction of about 16-18 years.²³ The event would undoubtedly lead to substantial social, economic and political consequences, but these are difficult to estimate.

4.7 Summary of Risk Assessment

A quantitative assessment of the risks posed by the HLW tanks must await the completion of a comprehensive PRA. However, IRSS's interim assessment allows some qualitative findings.

Reactor accidents provide a benchmark for discussing the risks posed by the HLW tanks. A large body of PRA work has been done for reactors, and many reactor PRAs show core damage frequencies of the order of 1 per 10,000 reactor-years.²⁴ Worldwide, 437 reactors are now operating, and 8,600 reactor-years of operation were accrued through 1997.²⁵ Thus, PRA findings are consistent with experience, which includes the Three Mile Island and Chernobyl accidents. Note that a core damage event could be associated with a small radioactive release to the environment (as at Three Mile Island) or a large release (as at Chernobyl).

It appears that three major influences will determine the probability of a release from the HLW tanks. These influences are: (i) earthquake; (ii) fire and explosion; and (iii) acts of malice. Of these influences, the third is not amenable to PRA analysis, and is not considered in PRAs. The first two influences, when they are eventually subjected to PRA analysis, will yield a release probability that can be compared with the findings of reactor PRAs. At present, the overall probability of a HLW tank release is rather uncertain, but it undoubtedly exceeds the level asserted by NII (1 per 10 million years or less).

The long-term consequences of a HLW tank release could be much more severe than the consequences of a reactor accident. This is evident from Table 2, which shows the Cs-137 inventories in the HLW tanks (7 million TBq) and the Chernobyl reactor core

²³ In the USA, about 21 percent (males) or 18 percent (females) of the population die of cancer. See Appendix D, Table D-5.

²⁴ See Appendix F, Figure F-1. The range of PRA-derived core damage frequencies in this figure is from 0.7 to 4.4 per 10,000 reactor-years.

²⁵ IAEA Press Release PR 98/3, 8 May 1998.

(230,000 TBq). Overall, it is fair to say that the Sellafield HLW tanks represent one the world's most dangerous concentrations of long-lived radioactive material.

5. Alternatives to Liquid High Level Waste Storage

5.1 A Systematic Approach to Alternatives Assessment

Section 3.3 describes how environmental impact statements have become well developed as tools for identifying and characterizing a range of alternatives to a proposed or existing nuclear project. EIS methodology is long overdue for application to UK nuclear projects. During the 1977 Windscale Inquiry, Gordon Thompson and his colleagues in the Political Ecology Research Group called for this methodology to be applied to the Sellafield site.²⁶ The UK nuclear establishment has chosen to continue its traditional approach (see Section 3.1).

The limited scope of IRSS's present study has precluded the preparation of a comprehensive EIS for building B215. Instead, IRSS has identified a selected set of alternative options for HLW management and has partially characterized these alternatives. The alternative options are categorized here as "engineering alternatives" or "operational alternatives". The category of engineering alternatives encompasses the development and construction of new equipment for processing and storing HLW. All the engineering alternatives involve continued reprocessing at Sellafield.²⁷ By contrast, the category of operational alternatives encompasses a reduced scale of reprocessing or a suspension of reprocessing, at either or both of the THORP and B205 plants. Combinations of engineering alternatives and operational alternatives are possible.

When a set of alternatives has been identified, their costs, benefits and impacts should be assessed. For nuclear projects, where risks are important, impact assessment should include an assessment of risks using PRA methodology. Here, IRSS has partially characterized a selected set of alternatives, with special attention to risks and costs.

5.2 Engineering Alternatives

One can identify a variety of engineering alternatives for HLW management. Appendix C reviews some of these options. Three selected alternatives are shown in Table 4. These alternatives have been available for many years, and were identified in 1979 as options for the then-proposed reprocessing plant at Gorleben, Germany.²⁸ The second alternative in the table -- storage of HLW as calcine (oxide powder) -- is a variant of a HLW storage method that has been used for decades in Idaho, USA.

The third alternative in Table 4 -- limiting liquid HLW to a buffer volume -- became a requirement for German reprocessing plants after 1979. This option was also a design

²⁶ Stott and Taylor, 1980.

²⁷ Some engineering alternatives could involve changes in the operation of the WVP.

²⁸ Thompson et al, 1979.

feature of a 1970s Exxon proposal to build a reprocessing plant in the United States. Indeed, NII prefers this option for Sellafield, but is willing to wait for two decades while Sellafield's existing backlog of liquid HLW is cleared. From the safety perspective, this option is attractive because all but a small fraction (the buffer volume) of HLW is stored in vitrified waste containers. With appropriate design, a vault containing vitrified waste containers can confine HLW in a wide range of circumstances, including severe earthquakes and terrorist attacks.²⁹

Each of the alternatives in Table 4 could have been implemented at Sellafield decades ago. Now, alternatives I and II would require substantial new investment, and would involve a long implementation period. On current trends, alternative III will take effect in about 2020 (see Appendix B), by which point reprocessing at Sellafield will probably have ceased. Implementation of alternative III could be accelerated by expanding vitrification capacity at the WVP, but substantial new investment would be required. Thus, none of these alternatives can be implemented rapidly or cheaply.

I. SAFER STORAGE OF LIQUID HLW

Liquid HLW would be held in spatially segregated tanks with independent services. Tank containment would be vented through robust filters.

II. STORE HLW AS CALCINE

HLW would be calcined and stored in canisters in underground vaults with natural cooling.

III. LIMIT LIQUID HLW TO A BUFFER VOLUME

Liquid HLW would be vitrified soon after its production. Storage of liquid HLW would be limited to a small buffer volume.

**TABLE 4: SOME ENGINEERING ALTERNATIVES FOR
HLW MANAGEMENT AT SELLAFIELD³⁰**

²⁹ IRSS has not assessed the safety of vitrified HLW storage at Sellafield.

³⁰ See Appendix C, Figure C-4, for a more detailed table.

5.3 Operational Alternatives

Three operational alternatives have been described in Section 2.4, in the form of three scenarios for Magnox and oxide fuel reprocessing. From Table 3 it will be seen that the THORP Shutdown and THORP & B205 Shutdown scenarios allow Sellafield's liquid HLW inventory to be eliminated by 2009 and 2007, respectively. Thus, these two scenarios provide a comparatively rapid way of converting the liquid HLW inventory to vitrified HLW in containers. As mentioned above, a vault containing vitrified HLW containers can provide much better confinement of HLW than is provided by the HLW tanks.

Although the THORP Shutdown and THORP & B205 Shutdown scenarios are similar in terms of their timeline for elimination of the liquid HLW inventory, there are two important differences between these scenarios. First, the THORP Shutdown scenario involves the separation of 29 tonnes of plutonium after 1997, while the THORP & B205 Shutdown scenario involves the separation of only 3 tonnes of plutonium. Second, in the THORP & B205 Shutdown scenario, all reprocessing ceases. After process backlogs are cleared, there will no longer be a potential for organic material to be forwarded to building B215. The explosion hazard at building B215 will then be greatly reduced.

The economic implications of IRSS's three reprocessing scenarios are explored in Appendix I. Our economic analysis focusses on the differential costs of the three scenarios, rather than the absolute costs. Several simplifying assumptions are made, the most notable being that we ignore BNFL's contractual arrangements for reprocessing. Instead, the overall costs and benefits of the scenarios are estimated, without regard to contractual influences on the distribution of these costs and benefits. This approach is analytically convenient, but also serves an important policy purpose. If a scenario yields an overall public benefit, this fact should be widely known. That knowledge can stimulate contract renegotiations which allow the benefit to be realized and equitably distributed.

Appendix I shows that the suspension of THORP reprocessing would yield a net overall public benefit of £1.9 billion. The assumptions underlying this estimate tend to favor reprocessing, so the finding of a net overall benefit is robust. The magnitude of the estimate suggests that there are good prospects for contract renegotiations. BNFL's gain or loss will depend on the outcome of those renegotiations.

A suspension of Magnox reprocessing, according to the scenario set forth in Section 2.4, would require long-term dry storage of about 6,000 tonnes of spent Magnox fuel. Ultimately, this fuel would be sent to a final repository. The technical arrangements, and hence the costs, for long-term storage and disposal of Magnox fuel are not well characterized. However, Appendix I shows that a suspension of Magnox reprocessing would yield a net public benefit if the costs of storing and disposing of 6,000 tonnes of

Magnox fuel do not exceed about £2.4 billion (£400,000 per tonne of fuel). This amount seems adequate for the purpose.

5.4 Summary of Alternatives Assessment

The operational alternatives described in Section 5.3 offer good prospects for eliminating Sellafield's liquid HLW inventory comparatively quickly and economically. Indeed, a suspension of oxide and Magnox fuel reprocessing would yield a substantial net economic benefit to the general public (electricity customers and taxpayers). The engineering alternatives described in Section 5.2 would be comparatively slow and costly to implement.

The comparative disadvantage of these particular engineering alternatives does not mean that engineering initiatives will not be needed at Sellafield. On the contrary, a suspension of reprocessing will need to be accompanied by a variety of engineering initiatives. In particular, the safe, economical storage of unprocessed fuel will pose engineering challenges.

6. An Integrated View of Risks and Alternatives

6.1 Sellafield in a Global Context

Reprocessing and MOX fuel fabrication activities at Sellafield create a variety of environmental, economic and international security impacts. The geographic scale of these impacts ranges from the local to the global. A release from the HLW tanks would have physical impacts (e.g., radioactive contamination of the environment) and non-physical impacts (e.g., reduced trust in government). These impacts would be felt most strongly in the UK and surrounding countries, but would also be felt globally. However, the international security impacts of Sellafield's activities are predominantly global, and the site should be viewed in that context.

As of March 1997, about 54 tonnes of separated plutonium were held at Sellafield.³¹ Current plans for reprocessing imply the separation at Sellafield, after 1997, of about 100 additional tonnes of plutonium. These amounts of plutonium should be viewed in the context of a global problem -- controlling military and civilian fissile material. At the end of 1994 the world stock of fissile material comprised about 1,160 tonnes of plutonium (910 tonnes civilian, 250 tonnes military) and 1,770 tonnes of highly enriched uranium (20 tonnes civilian, 1,750 tonnes military). However, most of the civilian plutonium (755 tonnes) was locked up in spent reactor fuel.³² Thus, reprocessing at Sellafield will significantly increase the amount of plutonium that is separated and therefore available for use in nuclear weapons.

³¹ See Appendix I, page I-8.

³² Albright et al, 1997, pp 397-398.

International security would be enhanced by a reduction in military stocks of plutonium. The United States government has recognized this need, and has a two-track program for disposition of surplus US military plutonium. The surplus plutonium will be placed in an underground repository or incorporated into MOX fuel. Russia is moving in the same direction but its program is less developed.

Given the importance of reducing military stocks of plutonium, further accumulation of plutonium at Sellafield is imprudent from an international security perspective. IRSS's study also shows that continued reprocessing at Sellafield creates an ongoing potential for a large release of radioactivity from the HLW tanks. Moreover, our study shows that continued reprocessing is uneconomic. Taken together, these considerations argue strongly for a suspension of reprocessing.

6.2 Selected Alternatives and their Implications

IRSS's study shows that operational alternatives provide the fastest and cheapest available means of eliminating the risks posed by storage of liquid HLW at Sellafield. Specifically, a suspension of reprocessing at THORP and B205 would allow the liquid HLW inventory to be eliminated by 2007, with a net economic benefit to affected citizens and taxpayers. A suspension of reprocessing is also indicated on international security grounds (see Section 6.1). However, the implications of a suspension of reprocessing deserve consideration, and two implications stand out. One is the effect on electricity production. The other is the effect on BNFL.

A suspension of THORP reprocessing would have no significant effect on the generation of electricity, other than making this activity slightly cheaper. Closure of the Magnox reactors, a corollary of suspending reprocessing at B205, would reduce the amount of electricity generated by nuclear power in the UK. However, these reactors would soon close anyway (see Appendix B). Their early closure would have little effect on greenhouse gas emissions from UK electricity generation, whose trends are more heavily affected by the introduction of gas-fired combined cycle plants.³³

BNFL would lose revenue if reprocessing were suspended. However, BNFL has broad capabilities in waste management, decommissioning and site cleanup. These capabilities could be employed, for example, to manage the spent fuel that would have been reprocessed at Sellafield. BNFL's longer-term profitability might be enhanced if the company abandoned reprocessing and sought other business.

³³ See Appendix I, Table I-10.

7. Conclusions

- C1. Sellafield's stock of liquid HLW represents one of the world's most dangerous concentrations of long-lived radioactive material.
- C2. The danger posed by the liquid HLW tanks has not received proper attention from the responsible authorities, because of systemic weaknesses in nuclear safety regulation in the UK.
- C3. The danger posed by the liquid HLW tanks could have been avoided decades ago if the plant had been designed differently, and persists now only because plutonium separation continues at Sellafield.
- C4. Plutonium separation is uneconomic, a threat to international security and a source of environmental pollution.
- C5. A suspension of reprocessing at Sellafield would allow the site inventory of liquid HLW to be converted comparatively quickly to vitrified waste containers, a safer storage mode. Moreover, a suspension of reprocessing would eliminate a potential, proven by experience at reprocessing plants, for a destructive chemical explosion at Sellafield.
- C6. A suspension of reprocessing would yield a net economic benefit to citizens and taxpayers of affected countries. Realization and equitable distribution of this benefit would require the renegotiation of reprocessing contracts.

8. Recommendations

IRSS makes four major recommendations:

- R1. Reprocessing at Sellafield should be suspended. As a corollary, the UK's Magnox reactors should be closed. The oxide and Magnox spent fuel that would have been reprocessed at Sellafield should be safely stored, pending development of a final repository.
- R2. The UK approach to nuclear decision-making and safety regulation should be comprehensively reformed, to introduce openness, accountability, public involvement, and the systematic assessment of risks, benefits, costs and alternatives.
- R3. Sellafield's current operations should be comprehensively assessed, and its future operations regulated, under the new approach recommended in R2.
- R4. During the renegotiation of current reprocessing contracts and subsequently, BNFL should seek business that employs its capabilities in waste management, decommissioning and site cleanup.
