

INSTITUTE FOR RESOURCE AND SECURITY STUDIES
27 Ellsworth Avenue, Cambridge, Massachusetts 02139, USA
Phone: 617-491-5177 Fax: 617-491-6904
Email: info@irss-usa.org
Web: www.irss-usa.org

**HIGH-LEVEL RADIOACTIVE
LIQUID WASTE AT SELLAFIELD:
An Updated Review**

June 2000

by Gordon Thompson

Abstract

The Institute for Resource and Security Studies (IRSS) published in June 1998 a report titled High Level Radioactive Liquid Waste at Sellafield: Risks, Alternative Options and Lessons for Policy. The present document provides an updated review of these issues, accounting for developments since June 1998. Especially relevant is a February 2000 report by the Nuclear Installations Inspectorate (NII). This NII report and other new information confirm and extend the conclusions and recommendations in IRSS's June 1998 report. They confirm that Sellafield's stock of liquid high level waste represents one of the world's most dangerous concentrations of long-lived radioactive material. Moreover, this danger persists because nuclear fuel reprocessing continues at Sellafield, even though reprocessing is uneconomic and has other disadvantages.

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About the author

This review 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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1. Introduction

At the Sellafield site operated by British Nuclear Fuels (BNFL), steel tanks hold high-level radioactive waste (HLW) as a liquid. The tanks require constant cooling, agitation and supervision. They currently contain about 1,300 cubic metres of liquid, within which there are about 2,100 kilograms of the radioactive isotope cesium-137. For comparison, the 1986 Chernobyl reactor accident released about 27 kilograms of cesium-137 to the atmosphere, and this isotope accounted for most of the offsite radiation exposure from the accident.

An accident, earthquake or act of malice at Sellafield could release the contents of one or more liquid HLW tanks to the environment, as an atmospheric plume or a liquid release to the Irish Sea, with severe consequences for human health over a period of centuries. There is historical precedent for such an event. A liquid HLW tank exploded at the Chelyabinsk site in Russia in 1957, yielding a radioactive plume that rendered 1,000 square km of land uninhabitable.

Storage of HLW at Sellafield as a liquid has been a source of public concern since the 1977 Windscale Inquiry and previously. In a partial response to repeated expressions of concern, the UK Nuclear Installations Inspectorate (NII) has recently required BNFL to perform investigations and plant modifications whose purpose is to characterise and reduce the potential for a release from Sellafield's liquid HLW tanks. This work is ongoing, and at present the potential for a release is poorly characterised. Nevertheless, NII holds that Sellafield's liquid HLW tanks are "acceptably safe". Moreover, NII intends to allow BNFL to increase Sellafield's stock of liquid HLW over the next several years.

In June 1998, the Institute for Resource and Security Studies (IRSS) published a report titled High Level Radioactive Liquid Waste at Sellafield: Risks, Alternative Options and Lessons for Policy.¹ The present document provides a brief, updated review of these issues, taking account of developments that have occurred since June 1998.

Section 2 of this review describes the production and storage of liquid HLW at Sellafield. The hazard posed by storing liquid HLW is summarized in Section 3, and the development of knowledge about this hazard is discussed in Section 4. Liquid HLW is stored in the B215 facility at Sellafield; there are some significant, unresolved safety issues at this facility, which are summarized in Section 5. These safety issues should be viewed in the context of Sellafield's overall safety culture, which is discussed in Section 6. NII's regulation of the liquid HLW hazard is discussed in Section 7.

An issue which is closely related to the storage of liquid HLW is the conditioning of separated plutonium for long-term storage or burial. That issue is addressed in Section 8. Another closely-related issue is the effect of secrecy on evaluations

¹ IRSS, 1998.

of nuclear hazards and alternative options; that issue is discussed in Section 9. Conclusions and recommendations are set forth in Section 10, and a bibliography is provided in Section 11.

2. Production and storage of liquid HLW at Sellafield

Reprocessing of spent nuclear fuel is one of the principal activities at Sellafield. Uranium oxide fuel from UK and foreign reactors is reprocessed in the THORP facility. Magnox fuel from the UK's Magnox reactors is reprocessed in the B205 facility. Reprocessing produces comparatively dilute liquid HLW at THORP and B205, and this liquid is transferred through shielded overhead pipelines to the B215 facility. At the B215 facility, the concentration of the liquid HLW is increased in evaporators, and the concentrated liquid is stored in 21 above-ground steel tanks. The concentrated liquid HLW in the tanks is hot and acidic, and requires constant cooling, agitation and supervision. At present, about 1,300 cubic metres of liquid HLW are stored in the tanks at B215.²

After a period of storage in the tanks at B215, liquid HLW is transferred to an adjacent vitrification plant, where it is incorporated into glass that is cast into steel containers. The containers are stored in a vault where they are cooled by the natural circulation of air. According to NII:³ "This cooling does not depend on the continued availability of installed services such as electricity and water, and is sometimes referred to as passively safe. This may be compared with the situation in B215 where active systems, requiring operator control, are needed to keep the HAL [liquid HLW] in a safe state."

Two vitrification lines are in operation at Sellafield, and a third line is being commissioned. BNFL predicts that vitrification will reduce the stock of liquid HLW to a small "buffer volume" by about 2015. However, BNFL also predicts that the stock will grow by more than 10 percent over the next several years, and will not return to its present level (1,300 cubic metres) until after 2005.⁴ NII has questioned BNFL's predictions, stating (in February 2000):⁵ "From the assessment of the HAL arisings data presented by BNFL and on the basis of the vitrification plant performance to date, NII remains unconvinced that BNFL will achieve the aim to reduce HAL stocks to a buffer volume by around 2015, without the possibility of regulatory intervention by NII to restrict reprocessing operations in THORP."

More recently (May 2000), NII has stated:⁶ "On 18 February we published three reports on BNFL. In relation to the storage of highly active fission products, we concluded that the current storage arrangements are safe but we want to see a clear strategy to reduce liquid volumes, through vitrification, by 2015. We have

² NII, 2000a, page 9.

³ NII, 2000a, page 4.

⁴ NII, 2000a, page 56.

⁵ NII, 2000a, page 54.

⁶ HSE, 2000.

given BNFL until 18 August 2000 to agree this strategy. If agreement is not achieved by this date we will impose volume reduction rates to achieve buffer storage stocks by 2015."

Analysis by IRSS indicates that a suspension of reprocessing in THORP, together with continuing vitrification of HLW at rates typical of recent years, would initiate a progressive reduction in the stock of liquid HLW at Sellafield, and would allow the liquid HLW tanks to be emptied within ten years. This period would be shorter if reprocessing in B205 were also suspended, an action that would imply shutting down the UK's Magnox reactors. However, a stock of spent Magnox fuel would remain in wet storage if reprocessing in B205 were instantaneously suspended. Wet-stored Magnox fuel tends to corrode and release radioactivity into the surrounding water. Thus, on environmental grounds, the suspension of reprocessing in B205 might be deferred for 1-2 years, to allow for the reprocessing of the existing stock of wet-stored Magnox fuel.⁷

The La Hague site in France, operated by COGEMA, provides a comparison with the liquid HLW situation at Sellafield. La Hague is reported to have six vitrification lines and to have already reduced its stock of liquid HLW to a buffer volume.

3. The hazard posed by storage of liquid HLW at Sellafield

The hazard posed by storage of liquid HLW at Sellafield has not been fully characterised. However, enough is known to establish that this hazard has special character and magnitude. The present state of publicly available knowledge about the hazard is accessible through two documents: an NII report published in February 2000; and the IRSS report of June 1998.⁸

One indicator of the hazard potential of the liquid HLW at Sellafield is the quantity of cesium-137 present in the liquid. This fission product is comparatively volatile, and is therefore released to the environment in comparatively large quantities during many types of accidents at nuclear facilities. Cesium-137 has a half-life of 30 years, adheres strongly to surfaces, and emits intense gamma radiation. The 1986 Chernobyl reactor accident released about 27 kilograms of cesium-137 to the atmosphere, and this isotope accounted for most of the offsite radiation exposure from the accident.⁹

The 21 HLW tanks at Sellafield currently contain about 1,300 cubic metres of liquid, within which there are about 2,100 kilograms of cesium-137. An accident, natural event (e.g., earthquake) or act of malice at Sellafield could initiate a sequence of events that releases the contents of one or more liquid HLW tanks to the environment, either as an atmospheric plume or as a liquid release to the Irish Sea. IRSS has described a variety of scenarios and mechanisms that could

⁷ IRSS, 1998, Appendix B.

⁸ NII, 2000a; IRSS, 1998.

⁹ IRSS, 1998, Appendix D.

lead to such an outcome, and has called for a comprehensive assessment of the potential for releases from the liquid HLW tanks.¹⁰

Neither BNFL nor NII has conducted such an assessment. NII has stated:¹¹ "The possibility of a large release (SAP 44) is considered but not demonstrated by the BNFL safety case to be of lower frequency than the SAP [safety assessment principles] criteria. NII has considered BNFL's current safety case arguments in this respect and is pressing BNFL for a more detailed and complete analysis of severe accidents in general, and a more detailed consideration of events leading up to potential large releases in particular."

Thus, the potential for a large release from the liquid HLW tanks has not been systematically and comprehensively assessed. However, IRSS has described scenarios that involve a large release, and these scenarios are uncontested. IRSS has lacked the funding and access to information that would be needed for a fully detailed assessment of the release potential.¹² Given the present state of knowledge, it must be assumed that a significant fraction of the 2,100 kilograms of caesium-137 now in the Sellafield liquid HLW tanks could be released to the environment. It follows that an accident involving the Sellafield liquid HLW tanks could yield offsite radiation exposure which considerably exceeds the exposure that has arisen from the release of 27 kilograms of cesium-137 from Chernobyl. Following a release at Sellafield, the more heavily contaminated areas could exhibit high levels of radiation for several centuries.

There is a historical basis for fearing a release from liquid HLW tanks. A liquid HLW tank exploded at the Chelyabinsk site in Russia in 1957, and the resulting release of radioactive material rendered 1,000 square kilometres of land uninhabitable.¹³

Although the hazard posed by storage of liquid HLW has not been fully characterised, NII has determined that the design and operation of the B215 facility at Sellafield, where liquid HLW is stored, "does not represent what would currently be considered best practice, as it lacks the passive safety features that would be commensurate with the high hazard potential".¹⁴ Despite this determination, and the incomplete characterisation of the hazard, NII intends to allow BNFL to hold an increased stock of liquid HLW over the next five years. NII has stated that it will require the liquid HLW stock to be reduced after that period, falling to a buffer volume by 2015.

¹⁰ IRSS, 1998.

¹¹ NII, 2000a, page 42.

¹² A fully detailed assessment would employ proven techniques of probabilistic risk assessment (PRA), would be conducted openly, and would be subjected to peer review. This assessment would identify a wide range of release scenarios, and would estimate their probabilities and outcomes.

¹³ IRSS, 1998, Appendix G.

¹⁴ NII, 2000a, page 13.

In its February 2000 report, NII claims that it will not hesitate to use its regulatory powers to ensure that BNFL meets the 2015 target date for reducing the liquid HLW stock to a buffer volume. One should note, however, that this target date was not set with a view to minimising the hazard posed by liquid HLW. Instead, the 2015 target can be traced to a 1995 report by NII. In 1995, BNFL predicted that the liquid HLW tanks would be emptied "in the region of 2015".¹⁵ NII chose to accommodate BNFL's plans by accepting 2015 as a target date.

The concept of a buffer volume has been articulated by BNFL and NII to accommodate the possibility that reprocessing will continue at Sellafield after 2015. If reprocessing does continue and a buffer volume of liquid HLW is stored, then the hazard posed by storage of liquid HLW will not be entirely eliminated. However, it is possible that reprocessing will cease. Indeed, present trends suggest that reprocessing at Sellafield will cease before 2015. In that case, liquid HLW could eventually be eliminated, along with the hazard which it poses.

4. Development of knowledge about the liquid HLW hazard

The hazard posed by storing liquid HLW at Sellafield has been partially recognised inside BNFL and its predecessor agencies since the 1950s. Recognition has been partial because BNFL and its predecessors, and NII, have never attempted to fully characterise the hazard. Public understanding of the hazard has developed slowly, handicapped by the culture of secrecy which pervades the nuclear industry in the UK.

A senior scientist at Sellafield wrote in 1958 that liquid storage of HLW "can only be regarded as an interim measure" because of the potential for a release into the environment.¹⁶ Further information about the potential for such a release became publicly available in 1976, in the report of a Royal Commission.¹⁷

During the 1977 Windscale Public Inquiry, members of the Political Ecology Research Group forced the disclosure of some information about the potential for a release from the Sellafield HLW tanks, although the level of secrecy remained high.¹⁸ An analysis of the consequences of a release from the HLW tanks was published in 1994, under the sponsorship of local governments.¹⁹ This analysis aroused public attention which obliged NII to publish in 1995 its first report on the HLW tanks.²⁰

¹⁵ NII, 1995, page 18.

¹⁶ IRSS, 1998, page 1.

¹⁷ Flowers et al, 1976.

¹⁸ Stott and Taylor, 1980.

¹⁹ Taylor, 1994.

²⁰ NII, 1995.

NII's 1995 report was reviewed by Terramares and IRSS in 1996.²¹ IRSS then published in 1998 a detailed analysis of the HLW tank hazard.²² The public attention aroused by IRSS's 1998 report obliged NII to publish in February 2000 its second report on the HLW tanks.²³

NII's second report identifies safety issues that were not addressed in the first report, and describes a variety of ongoing studies and plant modifications that NII has recently required BNFL to perform. It is clear that outside pressure has goaded NII into addressing safety issues that would otherwise have been neglected, and into publishing information that would otherwise have remained secret. Nevertheless, NII and BNFL still do not thoroughly understand the hazard posed by the liquid HLW tanks.

A careful reading of NII's 1995 and 2000 reports is revealing. Both reports employ the same approach. They do not present technical analysis, but describe the findings of technical analysis that remains secret. The reader is expected to simply trust NII. This expectation continues in the second report, even though that report provides information which reveals that the first report contains false assertions about important safety issues. A prominent example is the potential for chemical explosions to occur in the vicinity of the HLW tanks, following the inadvertent forwarding of organic chemicals from B205 or THORP to B215.

This explosion potential was dismissed in NII's 1995 report in two sentences:²⁴ "NII has not identified any other mechanism by which an in-process fire or explosion hazard could occur in the HASTs [liquid HLW tanks]. We have included in our considerations the possibility of reactions with the organic solvent used in the reprocessing plants." Yet, as IRSS's 1998 report shows, violent chemical explosions have occurred at other sites through similar mechanisms, and such an explosion could threaten the integrity of the Sellafield HLW tanks. IRSS concluded:²⁵ "NII asserts that the fire and explosion hazard at Sellafield's building B215 is negligible, but NII's assertion is not credible. Organic material could enter building B215 and cause an explosion that initiates a substantial release of the radioactivity in the liquid HLW tanks. The fire and explosion hazard at building B215 should be systematically assessed, as part of a comprehensive and open PRA [probabilistic risk assessment] study for the Sellafield site."

NII's second report does address the potential for an explosion in B215.²⁶ The report describes ongoing experiments and analyses by BNFL, implying that these will eventually yield estimates of the probabilities and outcomes of potential explosion scenarios in B215. However, all of this work is being

²¹ Thompson and Taylor, 1996.

²² IRSS, 1998.

²³ NII, 2000a.

²⁴ NII, 1995, page 16.

²⁵ IRSS, 1998, page G-13.

²⁶ NII, 2000a, pp 36-40.

conducted in secret, and neither NII nor BNFL show any sign of opening up the work to public scrutiny. Thus, the scientific quality of the work is questionable.

NII's second report reveals that BNFL's safety case for B215 has failed to consider the forwarding of organic chemicals from THORP or B205 to B215. The report states:²⁷ "The prevention of organic chemicals being forwarded to B215 relies on technical and administrative controls, such as the steam stripping of the aqueous process stream to remove organic solvent and maintaining a "heel" of liquor in the transfer vessel. Since failure of these controls would represent a fault in a different plant, in this case either THORP or B205, BNFL has not included them in a probabilistic analysis for B215." This statement is an astonishing admission of inadequate safety analysis by BNFL and lack of oversight by NII, and shows clearly that some of the key assertions in NII's 1995 report had no foundation. Yet, NII expects the public to believe the undocumented assertions in its latest report.

BNFL's investigations of the potential for an explosion in B215 are ongoing. Other investigations relevant to the potential for a release from B215 have not yet begun. NII makes the following recommendation about B215:²⁸ "BNFL should provide a complete analysis of severe accidents and in particular those with a potential for a large release of radioactivity. BNFL should also provide additional analysis and safety case documentation to strengthen the definition of actions required to prevent accident escalation and to implement recovery procedures."

As an indication of the significance of this recommendation, note that THORP operated from August 1998 to April 1999 without steam stripping of organic solvent from the liquid HLW stream sent to B215. NII accepted this omission.²⁹ Yet, to this day BNFL's safety case for B215 does not consider the implications for B215 of process failures in THORP. In other words, BNFL operates the B215 facility without fully understanding the hazard that it poses, and NII accepts this situation.

Even when spurred by high levels of public attention, NII has proceeded at a leisurely pace in developing its understanding of the hazard posed by the B215 facility. Recently (May 2000), NII has disclosed that its 1995 report on the B215 hazard was based on a safety review carried out by BNFL in 1989, while its February 2000 report was based on BNFL's 1994 safety case, supplemented by BNFL responses to some specific questions.³⁰

²⁷ NII, 2000a, page 38.

²⁸ NII, 2000a, page 42.

²⁹ NII, 2000a, page 45.

³⁰ HSE, 2000.

5. Unresolved safety issues at the B215 facility

A careful reading of NII's February 2000 report reveals a variety of unresolved safety issues at the B215 facility. Some of these issues have been discussed in Section 4, but are included in the following list. Detailed citations from NII's report are not provided here, because the issues are discussed at many points in the report.³¹ The unresolved safety issues include:

- (a) safety assessments by BNFL have failed to address important accident phenomena, and have made claims about accident probability that are not based on engineering analyses;
- (b) devices for transferring liquid HLW from a defective tank will work only over a narrow range of temperature;
- (c) nominally separate cooling circuits for the HLW tanks are not truly independent;
- (d) remote inspection techniques must be developed to determine the internal structural integrity of the HLW tanks and evaporators;
- (e) B215 structures are being modified to increase their resistance to earthquakes, but BNFL has not performed a seismic probabilistic safety assessment that meets prevailing standards;
- (f) ventilation, control and instrumentation systems in the B215 facility do not meet prevailing standards;
- (g) BNFL has failed to perform an integrated safety assessment for linked facilities, and therefore does not properly understand the potential for inadvertent forwarding of organic chemicals from B205 or THORP to B215;
- (h) investigations of the potential for violent chemical explosions in B215 are incomplete;
- (i) BNFL has not analysed the development of potential severe accidents in B215 or the opportunities for mitigating such accidents; and
- (j) it is unlikely that BNFL will succeed in emptying the HLW tanks by 2015, in part because of pipeline blockages in the vitrification plant.

It should be recalled that these issues have all been identified by NII, an agency which is complicit in the accumulation of unaddressed safety problems over many years. Therefore, one cannot assume that the above list is complete. Other significant safety issues may exist.

The potential for acts of malice or insanity is not discussed in either of NII's reports about the liquid HLW tanks. Yet, nuclear facilities in several countries have experienced acts of war, terrorism and sabotage. Building B215 is vulnerable to such acts, which could cause a release of liquid HLW.³² Indeed, in March 2000 an act of sabotage occurred at the HLW vitrification plant which is

³¹ IRSS can provide citations upon request, and can explain the significance of each safety issue.

³² IRSS, 1998, Appendix H.

adjacent to B215. Cables were cut, thereby disabling six Master Slave Manipulators (robotic arms). The location was accessible only to authorised employees. It is difficult to conceive a rational explanation for this act.

Of the unresolved safety issues identified above, one issue has particular significance for determining the level of hazard posed by storage of liquid HLW at Sellafield. That issue is the potential for a destructive explosion in B215 due to the inadvertent forwarding of organic chemicals from B205 or THORP. The potential for an explosion in B215 is correlated with the amount of reprocessing in B205 or THORP. More reprocessing will lead to a higher probability of inadvertent forwarding of organic chemicals to B215, and therefore to a higher probability of a destructive explosion, other factors remaining equal. At the same time, more reprocessing will lead to a higher stock of liquid HLW, given a fixed rate of vitrification. Thus, more reprocessing will tend to lead to a higher level of hazard, with increases in both the probability and consequences of a potential release from the liquid HLW tanks.

6. The safety culture at Sellafield

Section 5 summarises safety issues which are specific to the B215 facility. These issues should be considered in the context of Sellafield's overall safety culture, which has been heavily criticised in recent NII reports.

In February 2000, NII published a report on a September 1999 inspection of the Sellafield site.³³ The report's Summary concludes: "There are three key conclusions from this inspection. The first is that there is a lack of a high quality safety management system across the site which is compounded by an overly complex management structure. The second is that there are insufficient resources to implement even the existing safety management system. The third is a lack of an effective independent inspection, auditing and review system within BNFL. Without a vigorous independent inspection, auditing and review system, HSE does not see how BNFL can make acceptable and timely progress in delivering a high quality safety management system across the site."

The MOX Demonstration Facility (MDF) at Sellafield manufactures mixed-oxide (MOX) fuel for reactors. It was revealed in September 1999 that BNFL had falsified quality control data during the production at MDF of a batch of MOX fuel for a Japanese client. In February 2000, NII published a report on its investigation of the data falsification.³⁴ The report's Summary contains the statement: "NII's investigation into possible reasons for the falsification identified that although various individuals were at fault, a systematic failure allowed it to happen. In a plant with the proper safety culture, the events described in this report could not have happened."

³³ NII, 2000b.

³⁴ NII, 2000c.

Since these reports were published, BNFL has replaced personnel and has instituted organizational changes. Over a period of years, these actions might significantly improve Sellafield's safety culture. For the immediate future, it must be assumed that deficiencies in Sellafield's safety culture will persist. Those deficiencies will heighten the significance of the unresolved safety issues that are discussed in Section 5.

7. NII's regulation of the liquid HLW hazard

According to NII, the operations at Sellafield must conform to standards laid down in the UK's Health and Safety at Work etc. Act 1974. One requirement of this Act is that BNFL must reduce the risk arising from Sellafield operations "so far as is reasonably practicable".³⁵

For the liquid HLW hazard, NII has interpreted this requirement by focussing on 2015 as a target date for reducing the stock of liquid HLW to a buffer volume. NII states that it "will not hesitate to use its regulatory powers" if BNFL is not making satisfactory progress towards the 2015 target.³⁶ Use of NII's regulatory powers would imply a reduction in THORP throughput, early closure of some Magnox reactors, or the construction of additional vitrification capacity.³⁷

NII's stated willingness to use its regulatory powers is a positive development. However, one should recall that the 2015 target was established by NII in 1995 so as to accommodate BNFL's planned schedule of operations. Those operations involve continued reprocessing at THORP and B205. Thus, as a general rule, NII assumes that a "reasonably practicable" approach to reducing the hazard posed by liquid HLW must involve continued reprocessing. As a temporary modification of that general rule, NII might require reprocessing to be limited for a period sufficient to ensure that BNFL meets the 2015 target. Nevertheless, NII's general approach to its regulation of the B215 facility is clear. NII values the continuation of reprocessing more highly than the stabilisation and rapid reduction of the hazard posed by storage of liquid HLW.

Yet, reprocessing is a highly controversial activity, for reasons that have been widely debated since the 1970s. For example, reprocessing at Sellafield produces radioactive pollution of the atmosphere and the oceans. Many analysts have concluded that reprocessing is uneconomic, and will remain so for decades to come. Reprocessing increases the world's stock of separated plutonium and therefore, according to many analysts, makes the world less secure.

One could therefore argue that the most "reasonably practicable" approach to reducing the hazard posed by liquid HLW would involve a suspension of reprocessing at Sellafield. THORP reprocessing could be suspended immediately, because oxide fuel can be safely stored for decades. However, the

³⁵ NII, 2000a, page 68.

³⁶ NII, 2000a, page 3.

³⁷ NII, 2000a, page 55.

suspension of B205 reprocessing is a more complex matter. Notably, suspending B205 reprocessing would imply shutting down the UK's Magnox reactors. Also, environmental considerations, as discussed in Section 2, could argue for the suspension of reprocessing in B205 to be deferred for 1-2 years, to allow for the reprocessing of the existing stock of wet-stored Magnox fuel.

NII has taken no action to determine whether a suspension of reprocessing would be a "reasonably practicable" approach to reducing the hazard posed by storage of liquid HLW. Instead, NII simply assumes that reprocessing will continue. NII exhibits a lack of interest in alternative approaches to hazard reduction, which mirrors NII's previous lack of interest, over many years, in properly characterising the hazard posed by storage of liquid HLW.

NII's failure to ensure that the liquid HLW hazard is properly characterised has violated the Inspectorate's own safety assessment principles (SAPs). In their present form, these principles were articulated in 1992.³⁸ There are 5 fundamental principles and 328 additional principles. Two of the fundamental principles are especially relevant to the hazard posed by the B215 facility, as follows:

- **Principle P4:** All reasonably practicable steps shall be taken to prevent accidents.
- **Principle P5:** All reasonably practicable steps shall be taken to minimise the radiological consequences of any accident.

The first task in identifying "reasonably practicable steps" of this kind must be to assess the potential for accidents at the facility in question. SAPs P28 through P41 set forth specific requirements for such an assessment. Yet, as shown in Sections 3 through 5 above, BNFL has never performed a thorough assessment of the potential for large releases from the B215 facility. NII has been complicit in this omission.

When a facility's potential for large releases has been assessed, it becomes possible to develop strategies for accident management. Through such strategies, the facility's operators can intervene to prevent the escalation of accident scenarios or to mitigate their effects. SAPs P331 through P333 set forth specific requirements for accident management strategies. Yet, BNFL has never developed a comprehensive set of accident management strategies for the B215 facility, and NII has been complicit in this omission.

NII concedes (see Section 2) that the storage of HLW at Sellafield as a liquid does not satisfy the requirements of "passive safety", whereas the storage of HLW in vitrified form does meet those requirements. Thus, the storage of HLW as a liquid violates NII safety assessment principles P61, P62 and P64, which refer to the design characteristics of nuclear facilities. NII has allowed this violation to

³⁸ HSE, 1992.

persist, presumably because the Inspectorate has assumed that reprocessing is inevitable.

The legal justification for ongoing storage of liquid HLW at Sellafield must rest upon a determination that continued reprocessing yields benefits which more than offset the hazard posed by the liquid HLW. If it is determined that reprocessing does not yield a net benefit, then the most "reasonably practicable" approach to reducing the hazard posed by the B215 facility will be a suspension of reprocessing.

It is therefore significant that British Energy, BNFL's largest reprocessing customer, is openly seeking to convert its reprocessing contracts with BNFL into spent fuel storage contracts. This initiative is motivated by the adverse economics of reprocessing. Analysis has shown that BNFL's foreign customers have a similar economic incentive to convert their reprocessing contracts into storage contracts.³⁹ Thus, it is becoming increasingly evident that reprocessing in THORP does not yield any net economic benefit. Moreover, BNFL's accounts, although inconsistent and opaque, suggest that continued operation of Magnox reactors and reprocessing of Magnox fuel are uneconomic.⁴⁰

8. Conditioning of separated plutonium

Reprocessing at Sellafield, as at other sites around the world, has yielded many tonnes of separated plutonium that has no economically justifiable use. The present inventory of separated civilian (internationally safeguarded) plutonium at Sellafield consists of approximately 60 tonnes of UK plutonium and 15 tonnes of foreign plutonium.

There is considerable interest in "conditioning" separated plutonium for long-term storage or burial by placing the plutonium in close proximity to highly radioactive material. The radioactive material can provide a radiation barrier that hinders access to the plutonium, thus reducing the probability that the plutonium will be diverted and used in a nuclear weapon. It is common to speak of a "spent fuel standard" for plutonium conditioning, whereby the conditioned plutonium is no more accessible than the plutonium in unprocessed spent fuel.

Two methods for conditioning separated plutonium to the spent fuel standard have undergone detailed examination, primarily in the United States. One method is to incorporate the plutonium into MOX fuel which is then burned in a reactor. The second method is to "immobilise" the plutonium by incorporating it into a solid form which also contains HLW from reprocessing. A third method, which has received less attention, is to co-locate the separated plutonium with pellets of spent uranium oxide fuel, within some type of closed canister.

³⁹ Sadnicki et al, 1999.

⁴⁰ MacKerron, 2000.

On 4 June 2000 the US and Russian governments announced an agreement whereby each of them will condition 34 tonnes of surplus military plutonium to the spent fuel standard. The United States intends to use 25.5 tonnes of plutonium in MOX fuel, and to immobilise 8.5 tonnes with HLW. Russia intends to use 34 tonnes of plutonium in MOX fuel.⁴¹ This agreement addresses an important security issue. However, given the adverse economics of using MOX fuel and the potential for significant political opposition to its use, one can question whether the agreement will be implemented in its present form.

Analysts have suggested that Sellafield's stock of liquid HLW could be used to immobilise separated plutonium at the site.⁴² This could be achieved by placing the plutonium, packaged in a solid form, inside the steel canisters used for vitrified HLW, and then casting vitrified HLW around the plutonium packages. The concept appears technically feasible. The plutonium packages could, for example, consist of thin cylinders (similar to fuel rods) containing uranium-plutonium oxide pellets that are made in the recently completed Sellafield MOX Plant (SMP). Given the poor market prospects for MOX fuel, the SMP may have no other useful function.

However, delays in implementing this concept are likely. Thus, Sellafield's stock of liquid HLW could decline significantly before the plutonium conditioning process becomes operational. Anticipation of that outcome could lead to a call for the vitrification of liquid HLW to be suspended until plutonium conditioning can begin. In that situation, the pursuit of a security objective -- plutonium conditioning -- would conflict with the pursuit of a safety objective -- vitrification of liquid HLW.

In any case, conditioning of separated plutonium with HLW would only be a rationally defensible concept if reprocessing stops at Sellafield. Otherwise, an illogical situation would arise in which the plutonium and fission products in spent fuel are separated at one part of the Sellafield site, while at another part of the site they are recombined inside vitrified HLW canisters.

If reprocessing does stop, then Sellafield's present (June 2000) stock of liquid HLW would suffice for the conditioning of some, but not all, of the site's present stock of separated plutonium. An analysis in IRSS's June 1998 report showed that the end-1997 stock of liquid HLW at Sellafield was just sufficient to condition the site's end-1997 stock of separated civilian plutonium.⁴³ However, more plutonium has been separated at Sellafield since 1997, and our June 1998 analysis used what appears to be an optimistic (low) estimate for the volume of liquid HLW needed to condition each tonne of plutonium. Accounting for these factors, one finds that Sellafield's present stock of liquid HLW might suffice to

⁴¹ White House, 2000.

⁴² Fred Barker and Mike Sadnicki are evaluating this option, among others, as a means for conditioning separated plutonium at Sellafield.

⁴³ IRSS, 1998, pp I-7 to I-9.

condition 43-58 percent of the site's approximately 75-tonne present inventory of separated civilian plutonium.⁴⁴

A key purpose in pursuing the immobilisation of plutonium with HLW at Sellafield would be to establish a precedent for plutonium conditioning elsewhere in the world. The UK could set an example to other nations by conditioning its stock of separated plutonium, and BNFL could potentially gain a market in plutonium conditioning technology and services. However, it is not obvious that there is enough liquid (or calcined) HLW available in the world to condition more than a fraction of the world's separated plutonium. For example, at the La Hague site in France the end-1998 stock of separated plutonium was 50 tonnes, representing a 5-tonne increase above the end-1997 stock.⁴⁵ Yet, as mentioned in Section 2, it is reported that the stock of liquid HLW at La Hague has already been reduced to a buffer volume.

While accepting that plutonium conditioning is a desirable goal, IRSS concludes that the use of liquid HLW is not a promising option for meeting that goal at Sellafield. Instead, IRSS recommends the development of a concept in which the radiation barrier required to meet the spent fuel standard is provided by pellets of spent uranium oxide fuel. There are ample spent uranium oxide pellets worldwide to condition all of the world's separated plutonium, both civil and military. This conditioning technology could provide a significant business opportunity for BNFL. The concept could be executed in a variety of ways. For example, the spent uranium oxide pellets could remain inside intact fuel rods which are placed inside a canister together with rods containing fresh uranium-plutonium oxide pellets, and the canister could be filled with non-radioactive glass.⁴⁶ At first sight, this option appears feasible, but more detailed evaluation is required.⁴⁷

If a version of IRSS's recommended concept proves feasible, then all of Sellafield's present or likely future stock of separated plutonium could be conditioned without any need to delay or interrupt the vitrification of liquid HLW at the site. After the site's present backlog of liquid HLW is vitrified, Sellafield's vitrification plant could be adapted, if needed, for use in plutonium conditioning. For example, the vitrification plant could cast non-radioactive glass

⁴⁴ Our June 1998 analysis estimated that 23 cubic metres of liquid HLW would be needed to condition 1 tonne of plutonium, whereas more recent analyses suggest that 30-40 cubic metres would be needed. Using the latter estimate, one finds that the 1,300 cubic metres of liquid HLW now stored at Sellafield would suffice to condition 33-43 tonnes of plutonium.

⁴⁵ Rivasi, 2000, Table 45.

⁴⁶ The fuel rods used in the UK's AGR reactors will fit inside the canisters now used to contain vitrified HLW at Sellafield.

⁴⁷ In this design option, the heat and radiation load on the glass would be more concentrated than in vitrified HLW. The implications of this effect must be evaluated. If those implications are adverse, one could evaluate the option for matrices other than glass.

into canisters that are loaded with spent fuel rods and rods containing fresh uranium-plutonium oxide pellets.

The Sellafield MOX plant could be adapted to produce plutonium packages that are appropriate for co-location with spent uranium oxide pellets. For example, the SMP could produce rods containing fresh uranium-plutonium oxide pellets. Plutonium packages could be produced in the SMP and stockpiled until arrangements are in place to co-locate these packages with spent uranium oxide pellets.

9. Secrecy and lack of accountability

NII has recently required BNFL to perform new investigations of safety issues at the B215 facility. However, these investigations, like all previous studies of safety issues at Sellafield, are being performed in secret. The groups performing the investigations are not identified and have no direct accountability to the public.

This arrangement violates the culture of science. Any student of a science knows that the scientific culture has some key ingredients. Among these ingredients are openness and personal accountability. Peer review is also important. These ingredients are not luxuries or optional extras, but are essential to the pursuit of a thorough understanding.

The nuclear industry is nominally a science-based industry. Yet, its activities are often shrouded in secrecy, decisions or technical findings are reached anonymously, and peer review is lacking. These characteristics are strongly evident in the approach taken by BNFL and NII to the assessment of hazards and alternative options at Sellafield.

Secrecy and a lack of accountability deprive the public of an effective role in making decisions that relate to the hazard potential of nuclear facilities. Moreover, secrecy and a lack of accountability have an insidious effect inside the nuclear industry. They deprive the industry's managers and regulators of a thorough understanding of the hazard potential of nuclear facilities. They promote complacency, a lack of curiosity, the persistence of unexamined assumptions, and the defense of entrenched positions. IRSS has provided examples from nuclear industry experience that illustrate these effects.⁴⁸ The history of development of knowledge about the hazard posed by the B215 facility, as summarized in Section 4, provides a further illustration of these effects. Sustained public attention has goaded NII to address safety issues that the Inspectorate would, otherwise, have almost certainly ignored.

NII and BNFL have improved their understanding of the hazard posed by the B215 facility. To a limited extent, NII has identified alternative options that pose a lower hazard, and has begun to use its regulatory powers to reduce the

⁴⁸ IRSS, 1998, Appendix E.

hazard. Nevertheless, NII's credibility will remain low until it adopts a scientific approach to the assessment of hazards and alternative options.

10. Conclusions and recommendations

Conclusions and recommendations are set forth in IRSS's report of June 1998.⁴⁹ Developments over the past two years have generally confirmed the merit of these findings. IRSS's updated conclusions and recommendations are as follows:

Conclusions

- C1. Sellafield's stock of liquid HLW represents one of the world's most dangerous concentrations of long-lived radioactive material.
- C2. The hazard posed by the storage of liquid HLW has never been properly characterised, in violation of NII's safety assessment principles.
- C3. The liquid HLW tanks are not passively safe, and therefore violate NII's safety assessment principles.
- C4. The hazard posed by the storage of liquid HLW could have been avoided decades ago if alternative designs had been adopted, and persists now only because reprocessing continues at Sellafield.
- C5. A suspension of reprocessing would be the most "reasonably practicable" approach to reducing the hazard posed by the liquid HLW tanks, and would also yield a net economic benefit to citizens of affected countries. Realization and equitable distribution of this benefit would require the renegotiation of reprocessing contracts.
- C6. Secrecy and a lack of accountability have limited NII's and BNFL's understanding of the hazard posed by the storage of liquid HLW. A policy of secrecy continues, and NII's credibility will remain low until this policy is changed.

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.
- 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 hazards and alternative options.

⁴⁹ IRSS, 1998, pp 28-29.

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.

R5. BNFL should develop and implement an approach to the immobilising of separated plutonium that uses spent uranium oxide fuel pellets to provide a radiation barrier. Plutonium immobilisation should not impede the earliest possible elimination of Sellafield's stock of liquid HLW.

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