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Storage of Liquid High-Level Radioactive Waste at Sellafield

An Examination of Safety Documentation

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EXECUTIVE SUMMARY

Liquid high-level radioactive waste arises from the reprocessing of spent nuclear fuel at Sellafield. The waste is held in tanks known as Highly Active Storage Tanks (HASTs). The radioactive inventory of a HAST is extremely large and decays away very slowly. The decay process produces heat and so the tanks require continuous cooling to prevent evaporation and ultimately, in the case of those tanks with the larger radioactive inventories, boiling and possible release to the atmosphere. The risk of an accidental release of radioactivity to the atmosphere has been a matter of concern in Ireland for some time.

Following a request from the Irish authorities, British Nuclear Fuels plc (BNFL) agreed that two representatives of the Radiological Protection Institute of Ireland could visit the plant to examine the latest safety analysis, entitled the Continued Operation Safety Report (COSR), and supporting documentation relating to the operation of the HASTs.

The principal objectives of the examination were to:

- determine whether the COSR includes all significant hazards,
- evaluate the COSR's conclusions on the probability of occurrence of a number of accident scenarios,
- determine whether confidence can be placed in the reliability database used in the COSR and assess the significance of any shortcomings,
- assess the need for further improvements in safety.

Based on this examination the report concludes that the present risks of a severe accident associated with the HASTs are low, but that they could be reduced further by attention to the points listed below. The report also emphasises the inherent risks associated with the storage of high-level radioactive waste in liquid form. The process, which is in progress, of converting the material to a safer solid form should be expedited. Among the specific findings were:

- The risk of damage from a severe earthquake has not been fully analysed. All other major accident scenarios appear to have been considered.
- While the probability of an accident involving a significant release of radioactivity is low, certain safety weaknesses were identified. These include:
  - the need for improved data on the reliability of components whose performance impinges on safety.
  - although there are a number of alternative water supplies for cooling the tanks, they are not fully independent of each other.

- there is currently no instrumentation for detecting possible hydrogen build-up in the HASTs.

- the lack of a programme for random checking of plant personnel for alcohol/drug abuse.

- the consequences of a very severe accident, if one did occur, have not been adequately assessed. Such an assessment would assist emergency planning.

BNFL is asked to give early attention to these matters.

1. INTRODUCTION

Liquid high level radioactive waste arises from the reprocessing of spent nuclear fuel at Sellafield. The waste is held in tanks known as Highly Active Storage Tanks (HASTs). Because of the large amount of heat produced by radioactive decay, the tanks require continuous cooling to prevent evaporation and ultimately, in the case of those tanks with the larger radioactive inventories, boiling of their contents.

The potential therefore exists for a release of radioactivity to the environment either as a result of failure of a tank itself, failure of cooling resulting in boiling of contents or an explosion. An explosion could in principle occur as a result of a chemical reaction in a tank or, if a sufficient mass of fissile were to be introduced into a tank in error, from a criticality accident.

The risk associated with the storage of liquid high level waste at Sellafield has been identified as representing a serious threat for Ireland. Because of this, the opportunity had been sought for some time for scrutiny by Irish experts of detailed documentation incorporating assessments of the risks associated with such storage, but this had been refused by British Nuclear Fuels plc (BNFL) on the grounds of commercial confidentiality.

Following sustained Irish Government pressure, in 1998 BNFL modified this stance and agreed to give Radiological Protection Institute of Ireland (RPII) personnel access to documentation which makes up what is known as the Continued Operation Safety Report (COSR), subject to the condition that the documentation was examined at Sellafield and not removed or copied. In 1999 a preliminary visit was made to Sellafield to assess the feasibility of carrying out a useful examination of the COSR. The outcome of the visit was positive and arrangements were made for detailed scrutiny of the COSR in early 2000.

This scrutiny involved a visit over a two-week period (14-25 February 2000) by two RPII representatives in the persons of the authors of this report.

The principal objectives of the examination carried out were to:

- determine whether the COSR includes all significant hazards
- evaluate the COSR's conclusions on the probability of occurrence of a number of accident scenarios
- determine whether confidence can be placed in the reliability database used in the COSR and assess the significance of any shortcomings
- assess the need for further improvements in safety.

2. LIQUID HIGH LEVEL WASTE AT SELLAFIELD

2.1 Production and Storage of High Level Waste (HLW)

The wastes produced by the reprocessing of nuclear fuel in the Magnox and THORP reprocessing plants at Sellafield may be conveniently categorized as High, Intermediate or Low Level Waste depending on their radiotoxicity and heat generating characteristics. Only HLW in liquid form is stored in the HASTs; the ILW and LLW are stored elsewhere on the Sellafield site. This HLW liquid is the result of the dissolution of the spent fuel in nitric acid and the separation, by solvent extraction, of plutonium and uranium. The liquid is discharged to an evaporator where it is highly concentrated - one tonne of spent Magnox fuel gives rise to seven cubic metres of dilute liquid which, by evaporation, is reduced to about 45 litres- and stored in the HASTs. This liquid contains almost 37 gigabecquerels per millilitre of fission products of which some 10% is caesium-137. The radioactive decay of these fission products generates significant heat, several kilowatts (kW) per cubic metre.

The HASTs are designed to hold in safe storage the highly active liquid radioactive waste prior to incorporation in glass (vitrification) and long-term storage or disposal. The process of production and storage of this waste is shown in Figure 1. The first eight HASTs were commissioned in 1955 and sequentially brought into active use between 1955 and 1970. Although the waste was known to contain long lived radiotoxic and chemotoxic substances there was, except for some limited vitrification trials at Harwell in the 1960s, no plan at that early stage for its final treatment and disposal. In order, therefore, to accommodate the increasing volume of waste a further 13 HASTs (nos. 9-21) were built during the 1970s and 1980s all of which are similar in design. There has been an evolution in the design from the beginning such that the later HASTs are more sophisticated. All of the HASTs are located in building B215.

A policy of keeping one tank empty for every three in use has always been maintained. This is to ensure that should there be a serious problem, such as a leak, there would be spare capacity into which the contents of the leaking HASTs could be transferred. In 1990 a vitrification plant started to convert the waste from liquid into solid glass. This is a much safer form of waste for long term storage. In-storage cooling of vitrified waste is assured through natural circulation of air, rather than forced flow of liquid coolant using complex engineered systems, as is required for the liquid waste.

2.2 Description of HASTs

Each of HASTs 1-8 has a working volume of 70 m^3. They are horizontal cylinders with dished ends. The overall length is 10.67 m and the diameter is 3.05 m. HASTs 1-4 have a cooling capacity of 180 kW provided by only one cooling coil. However, the maximum heat content is typically less than 40 kW. HASTs 5-8 each has two additional cooling coils, nevertheless their heat load is also less than 40 kW. HASTs 9-21 are vertical cylinders measuring 6 m x 6 m. Each has a working volume of 145 m^3 (the actual volume is 160 m^3) and is fitted with seven cooling coils, five horizontal and two vertical. The cooling capacity of each tank is about 2000 kW, while the actual loading is typically only 460 kW. All HASTs are fitted with agitation systems to prevent sedimentation and/or plating out of substances on surfaces.

The HASTs are housed in thick reinforced concrete cells. The walls and roofs of the cells range in thickness from 0.9 m – 2.5 m. The first 8 HASTs are housed two per cell and the remainder singly. Each cell is internally clad with stainless steel to a height of a few metres so that any leak from a tank would be contained. The contents of a tank or the spillage in a cell can be transferred to the designated standby tank using normal vacuum lift methods or by steam ejectors. Cooling water to the coils is provided by one of two pumped supplies from one of two cooling towers or alternatively directly from either of two pressurized ring mains. Should all of these fail then there is an emergency cooling water ring main. There are also other sources of cooling water and means of distribution to the HASTs.

The ventilation systems in the old and the newer HASTs provide a negative pressure in the HASTs so that any air leak will be into rather than out of the HASTs. They also ensure that any gases – most importantly hydrogen, produced by radiolysis or other processes – or aerosols will be exhausted to atmosphere through appropriate decontamination and filter systems. The vessel ventilation clean-up systems fitted to the newer HASTs are more sophisticated and, for example, include an electrostatic precipitator. There has been no evidence of the generation of significant levels of hydrogen. If the exhaust fans fail it is claimed that the slight pressure differential which exists between tank and atmosphere will promote sufficient natural ventilation to prevent a build up of hydrogen. This issue is discussed in further detail under **4.2 Chemical Reactions**.

2.3 Contents of HASTs

When first removed from a reactor spent nuclear fuel is stored at the reactor site to allow the iodine-131 which has a half life of 8 days to decay. This not only reduces the hazard during the transport and reprocessing of the spent fuel but also means that the HASTs into which the liquid waste is discharged after the extraction of the plutonium and uranium contain only long lived radioisotopes. The isotopic inventory of a freshly filled HAST, (Table 1), differs from that of a reactor in that there are no short-lived radioisotopes. Note that in Table 1 the activity is expressed in becquerels per millilitre: to calculate the total activity of any particular isotope in a typically filled large tank the given specific activity should be multiplied by 10^8 (the volume in the tank is assumed to be 100 cubic metres).

The total volume of liquid waste stored in the HASTs reached a peak value of $1500m^3$ in 1990. Over the remainder of the period 1985 to 1995 it remained practically constant at slightly less than this value. By the end of 1999 the total volume had decreased to a slightly lower value than at the end of 1995. The activity of some of the more important isotopes (from the safety point of view) is given in Table 2. Together caesium-134, caesium-137 and strontium-90 account for the largest quantity of radiologically harmful substances in the HASTs. The table also compares the inventory of waste with the isotopic releases from the No. 4 reactor at Chernobyl.

It is clear that a huge potential for damage to the public and to the environment is present. The damage potential of the waste in the older HASTs is considerably less than in the others. This is because of the difference in the age and volume of the waste and because the heat generated by the contents of each tank is such that boiling is not possible.

Details of the heat loadings are given in Table 3 for the status of the HASTs in 1996. Also it should be noted that for each of the 21 HASTs the heat generated is less than 15% of the heat removal capacity of each tank - there is a large safety margin. The initial rate of heat generated falls off by about 50% in 3 years: it then takes a further 10 years approximately to decay by another 50% i.e. to 25% of its original rate. The heat generation is important in assessing hazards since it determines the time to reach vaporization of the contents (the most important mechanism for release to the environment) following a failure of cooling. The last HASTs to be built, numbers 20 and 21, were put into operation in 1990, the same year in which the Waste Vitrification Plant came into operation.

3. CONTINUED OPERATION SAFETY REPORT (COSR)

Prior to the production in 1999 of the Continued Operation Safety Report (COSR), the safety documentation relating to the HASTs comprised what was referred to as the Fully Developed Safety Case (FDSC). By 1997-98 BNFL had formed the view that the FDSC, while including probabilistic risk assessments (PRAs) for the wide range of fault scenarios that it was believed could occur, did not:

- consider the plant engineering in sufficient detail
- provide a fully visible demonstration of the ability of the plant to continue to function in the manner the safety case assumes.

In order therefore to further improve the demonstration of safety, a series of meetings of BNFL/Nuclear Installations Inspectorate (NII) working groups were set up. A number of important improvements in the way BNFL presents its safety cases were identified; in particular was the development of a methodology for integrating "engineering substantiation", i.e. evidence for the continued safety of components, structures and systems, into BNFL's safety assessments. In addition to developing new assessment methodologies, the working groups, taking account of the need to streamline the safety case, proposed the development of a Continued Operation Safety Report (COSR). This was intended to bring together the conclusions of detailed reviews, assessments, engineering substantiation and analysis work. It was this new style of safety report which BNFL agreed the RPII could examine, together with supporting documentation. It should be noted that, as indicated above, the recent NII report on the HASTs [HSE, 2000(a)] was based on the FDSC and supporting information provided by BNFL. The COSR was not complete when NII was preparing HSE, 2000(a).

The COSR expands on the FDSC to include engineering substantiation and provides an auditable trail of subsidiary documents.

It comprises the following sections:

- Introduction
- Description of plant, process and operating philosophy
- Review of operational safety experience
- Safety assessment summary
- Engineering substantiation
- Demonstration of compliance with NII Safety Assessment principles [HSE, 1992] including the requirement that radiation exposures must be kept as low as reasonably practicable
- Conclusions
- Auditable trail

For security reasons provisions against acts of war and/or terrorist attack are not included in the COSR.

The COSR includes both traditional deterministic safety assessments and PRA. The PRA involves consideration of possible outcomes of different unlikely initiating events, e.g. complete loss of electrical supply, and subsequently the significance of the failure of different mechanical and electrical safety devices which have been installed to prevent further development of the accident scenario. The COSR aims to show that the NII's licence requirements are met and that the overall risk is at least "tolerable" as defined in the NII's Safety Assessment Principles.

These principles stipulate, inter alia:-

- that the annual frequency of occurrence of an event must be evaluated if that event could lead to doses to members of the public in excess of 0.1 mSv.
- a basic safety limit of one in a hundred per year for events leading to doses to the public of between 10 and 100 mSv.
- a basic safety objective, defined as the point beyond which the NII need not seek further improvements, of one in ten thousand per year for events leading to doses to the public of between 10 and 100 mSv.
- a basic safety limit of one in ten thousand per year for events leading to doses to the public in excess of 1 Sv.
- a basic safety objective of one in a million per year for events leading to doses to the public in excess of 1 Sv.
- that if the postulated frequency of occurrence is clearly very low in comparison to the above criteria, then there is no requirement to calculate it numerically.
- that all radiation exposures must be kept as low as reasonably practicable.

The basic safety limit is defined as the maximum frequency at which the corresponding event is just "tolerable". The basic safety objective is defined as the point beyond which the NII need not seek further safety improvements. There is still an obligation, however, to improve safety beyond the basic safety objective if it is reasonably practicable to do so.

Although there are no formally agreed international standards on tolerability of risks, the NII principles, as outlined above, and explained in more detail in HSE 1992, generally reflect internationally accepted principles.

The COSR does not consider the radiological consequences of very low probability high consequence accidents because, once the basic safety objective is achieved, no further safety improvements are required by the NII. However, we believe that a more complete analysis of the consequences of such accidents should be undertaken, in order to assist judgement on the need to adjust or enhance accident management and emergency response procedures.

The next section considers the treatment, in the COSR, of a number of specific issues relevant to safety, and in the case of each issue evaluates whether the above principles are satisfactorily complied with.

4. SPECIFIC SAFETY ISSUES

4.1 Loss of Cooling

We decided to concentrate on loss of cooling to the whole of the building housing the HASTs (building B215). This decision was based on the assumption, which we accepted, that in the case of loss of cooling to a single HAST and subsequent boiling of its contents, the ventilation extract and cleanup system would prevent significant discharges to the environment. However BNFL accept that, if there were to be complete failure of cooling in all the HASTs, the system including electrostatic precipitators, and scrubbers, could be overwhelmed.

It was noted that, due to the physical proximity of parts of the different ring mains which supply cooling water to the HASTs, the cooling circuits for the HASTs cannot be described as completely independent. Even though there is a high level of redundancy in the cooling system, this lack of independence represents a safety concern.

There are four designated cooling pumps at each of the two cooling towers whereas only one pump and tower are required to ensure cooling. Water supplies include two reservoirs, one of which is normally used to top up the cooling towers. Water can also be drawn from the Calder River. There are a number of options for connecting these water supplies to the HAST cooling coils. Moreover if all the pumps should fail, water can be extracted from any of these sources using fire hoses and portable pumps. Even if all the water supply pipes were frozen, water could be pumped from the Calder River using fire hoses. This issue is discussed further under **4.6 External Events**.

It has been calculated that the HAST with the highest anticipated heat loading would start to boil in about 14 hours following loss of cooling and that significant evaporation would commence after about 12.5 hours, i.e. when the contents were within a few degrees of boiling. It is pessimistically assumed, in the COSR, that once boiling commenced it would continue until 24 hours after the time cooling was lost. In order to estimate the significance of loss of cooling to all HASTs it has also been assumed that the 10 filled HASTs in the group 9–21 would start boiling after 10 hours following loss of cooling; in the case of HASTs 1-8, the radioactivity has decayed to levels at which the heat produced is insufficient to cause boiling. The calculated dose to the most exposed member of the public following boiling caused by a sustained loss of cooling for 24 hours is less than 31 mSv. The annual probability of failure to reintroduce cooling within 10 hours has been calculated as less than four in a million, which is below the value of one in ten thousand at which further improvements in safety are required. Nevertheless it was noted that increasing the level of automation in water supply switch-over procedures and improving the physical protection of essential equipment, such as cooling pumps, would reduce the probability of failure still further.

We confirm that the calculations indicate that the NII safety principles, as summarised in section 3, are met.

4.2 Chemical Reactions

4.2.1 Hydrogen Burning/Explosions

There is a radiation induced mechanism known as radiolysis that generates hydrogen in water or aqueous solutions such as the radioactive liquor contained in the HAST.

However, the presence of hydrogen was never detected by the instrument initially fitted in the HAST ventilation system. The accepted lower limit of flammability for hydrogen in air is 4%. The maximum operating concentration in air is taken by BNFL to be 1%. The hydrogen detector was capable of measuring below this level. Because hydrogen was not detected in the ventilation system over many years of operation, the detector was removed. Rightly, however, concern about the generation of hydrogen in the tanks has not been dismissed. The possibility of detecting hydrogen within a tank, directly above the liquor, is now being investigated.

We believe that, given the serious hazard that the presence of hydrogen would pose in an emergency situation, one (or preferably two) hydrogen detectors in the ventilation system would aid operators in their diagnosis of the emergency and in deciding on corrective measures.

4.2.2 Red Oil Reactions

Under certain specific conditions in a mixture of nitrates and organic solvents a runaway chemical reaction, often referred to as "Red Oil" reaction, may occur. It was the cause of an accident at the nuclear fuel reprocessing facility at Tomsk, in Russia, in 1993. The possibility of solvent carry over from the Magnox or THORP reprocessing plants to the HASTs, although very low because of operating procedures and also the process of evaporation of the liquid prior to storage in the HAST, cannot be ruled out. The loss of cooling to the HAST and an increase in temperature of a HAST's contents, which contains nitrates, can also not be ruled out. Thus three of the acknowledged prerequisites of a "Red Oil" reaction may be present in a HAST, albeit with a very low probability.

The final condition necessary for the reaction is pressure. Since the HASTs are permanently vented to atmosphere and mechanisms for pressurisation are difficult to conceive, the overall probability of the reaction is judged to be well below the risk standard set by the regulator.

Nevertheless, given the potentially very serious consequences of an explosion as a result of a "Red Oil" reaction, we believe that the COSR should at least include an unquantified fault tree to indicate more clearly the number of steps required for such an occurrence and hence its low probability.

It was also noted that BNFL are continuing to investigate "Red Oil" reactions.

4.3 Condition of Underground Cooling Water Pipes

The cooling water supply pipes to and from the HASTs run underground for a distance of some 200 metres. We were concerned about their condition since they have been in use for some 40 years. We noted that, should a water supply pipe fail or freeze, there were several alternative methods of supplying cooling water to the HASTs.

4.4 Breakthrough of Highly Active Liquor into Cooling System

Bearing in mind the thickness of the HAST walls, we accepted that the more likely route for liquor to escape is via a leakage into the cooling coils. These are made of the same material as the HASTs but have much thinner walls to increase heat transfer. We therefore examined the safety analysis involving the leakage of highly active liquor into the cooling system via a defective coil, leading to a release of radioactivity to the atmosphere. This could occur in the very unlikely event of a reversal of the usual positive pressure differential between cooling water and HAST contents. We were satisfied with the analysis which concluded that the doses to the most exposed members of the public were a fraction of a mSv. We checked the fault tree calculations and agreed with the estimate of the annual probability of this accident being less than 2 in 10,000.

4.5 Criticality

The possibility of a criticality accident, that is an accident where there is sufficient mass of a fissile material to initiate a nuclear chain reaction, is a matter of concern in any process involving the production, handling or storage of fissile material.

In essence two scenarios are considered:

- the concentration of fissile material in the bulk liquid in the HASTs
- local concentration of fissile material in either solids, colloids or in free phase solvents.

We noted that the highest concentration of fissile material in feed liquor from THORP is not greater than 4.10^{-3} grams $litre^{-1}$, while the concentration in liquor arising from the reprocessing of Magnox fuel is much lower. This is well below the concentration of 6.8 grams $litre^{-1}$ in water at which criticality is deemed impossible regardless of the geometry involved. No credible scenarios have been identified where the concentration in the bulk liquid could reach this limit.

Also the levels of fissile material in solids separated in THORP, which might be transferred to B215, are well below the criticality limit.

With regard to the production of solids within the HASTs themselves we noted that, even if all the liquid fraction was evaporated, the mass of plutonium in the remaining solid material would be less than the critical mass for the geometry in question.

Likewise it is demonstrated in the COSR that the production of colloids would not result in the concentration of a critical mass of plutonium.

The presence of free phase solvents, as a result of their inadvertent transfer from THORP, and higher than normal concentrations of fissile material, could also lead, in principle, to the accumulation of a critical mass. We would accept the conclusion in the COSR, that the probability of this occurring is very low, i.e. less than one in a million per year. However the inclusion of quantified event trees to demonstrate this, as well as to illustrate the other potential criticality scenarios referred to above, would be helpful in clarifying the overall situation.

4.6 External Events

4.6.1 Earthquakes
Earthquakes present three potential hazards:

- Damage to the cells resulting in loss of shielding and consequently elevated external dose rates.

- Damage to a tank or transfer pipe, resulting in spillage of highly active liquor, which could ultimately boil, leading to on and off site consequences.

- Damage to the cooling and ventilation systems also leading to on and off site consequences.

A full PRA has not been carried out in relation to earthquakes. The assumed annual probabilities for earthquakes with a peak horizontal ground acceleration of 0.125g and 0.25g are one in a thousand and one in ten thousand, respectively. While it is not possible to relate these accelerations in any simple way to the more commonly used Richter Scale, the higher figure may be taken as corresponding to a severe earthquake.

The cells in which HASTs 1-16 are located and the HASTs themselves, were not designed to take account of potential earthquake damage. Later cells were designed with some consideration of this hazard in mind while HASTS 20 and 21 were explicitly designed to withstand a 0.25g earthquake.

A retrospective study, which is included in the COSR, has concluded that all the HASTs, the cells in which they are located and most ancillary equipment would withstand 0.125g and that all HASTs, cells and critical in-cell systems would probably withstand 0.25g without any loss of containment.

It may reasonably be concluded that a 0.25g earthquake would not result in elevated external doses as a result of shielding damage.

Some of the associated structures, in particular the cooling towers, are not designed to withstand earthquakes. It is believed, in particular, that one of the cooling towers would not withstand a 0.125g earthquake and that the other would become unserviceable if subject to a 0.25g earthquake. The unavailability of these towers, while reducing the level of defence in depth, is most unlikely to lead to an accident with significant off site consequences. Back up equipment to provide essential services, in particular electricity, cooling water and compressed air would probably still be available. It is estimated in the COSR that the frequency of HASTs boiling for a sufficient time to result in individual doses in excess of 1 Sv, as a result of loss of cooling following earthquake damage, would be less than one in ten thousand per year. The NII deems this to be a tolerable risk. Much higher public doses could in principle arise if the building B215, in which the HASTs are sited, was so badly damaged that workers could not enter it to restore cooling. The ability of the building to withstand earthquakes is still being assessed within the framework of the COSR.

Recommendations in the COSR include:

- Carrying out a full PRA review.
- Improving the compressed air supply to purge the HASTs as existing compressed air supplies for this purpose would probably be unserviceable following an earthquake.
- Erecting a simple earthquake proof store in which to locate vital equipment.
- Upgrading or replacing the cooling towers.
- Upgrading the fabric of building B215 to reduce the impact of earthquakes.

It was noted that operating procedures involving the transfer of liquid HLW would be suspended if earthquakes in excess of 0.05g are detected or suspected.

We concluded that the safety studies are incomplete for structures outside of the cells. Consequently, while recognising that intensive work by BNFL is ongoing, we cannot confirm that NII risk standards are fully complied with.

4.6.2 Aircraft Crash
Two scenarios are considered in the COSR:

- A collision with cooling plant causing loss of cooling ultimately leading to boiling.
- Immediate aerial release following a crash into one of the cells containing HLW.

Either scenario could result in public doses to the critical population in excess of 1 Sv from dispersed activity. However it is stated in the COSR, that only a heavy commercial or military aircraft could inflict sufficient damage to result in either of these scenarios and that the annual probability of such an event is less than one in a million, which is below the NII value at which further safety measures are required. On the basis of the information provided in the COSR we would accept this conclusion. It should also be pointed out that this analysis takes no account of restrictions which exist on low flying over or within a specified radius of the Sellafield site.

4.6.3 Loss of Cooling to a HAST due to a Crane Collision
Although no heavy objects are routinely moved within building B215, cranes operate close to this building. We therefore examined the possibility of a crane collision, which we considered to be akin to a “heavy load drop accident”.

All crane operations must be carried out by trained personnel, in accordance with explicit operating instructions and in line with the appropriate British Standard BS 7121 (Safe Use of Cranes). Contractors make written application to use cranes and supply a written Risk Assessment and Safety Statement. The slewing angle and boom radius are restricted by mechanical means in the form of welded stops to prevent operation over critical buildings and equipment.

If, due to failure of these precautions, crane collision damage did occur, the dose to the most exposed member of the population, as a result of airborne contamination, is estimated as 0.8 mSv from damage involving two HASTs, or 3.8 mSv if the ventilation clean-up systems also fail. A crane collision causing damage to the ventilation systems of more than two HASTs is not considered to be a credible event.

Increased activity in the cooling system could also ultimately be discharged to the sea. The critical group dose in this case could exceed 0.56 mSv. However it is estimated, in the COSR, that the annual frequency of occurrence of such an incident is less than one in a million.

4.6.4 Gas Cloud Explosion
We enquired as to what the probability of a gas cloud explosion over the plant might be. This could arise from the release of liquid petroleum gas or liquid natural gas from a ship in the vicinity. We were supplied with data on the passage of such ships off the Cumbrian coast which showed that this hazard is well within the risk standard laid down by the regulator.

4.7 Reliability Database
The failure rate for each system, whose function impinges on safety, is calculated by combining what are believed to be representative failure rates for the components and structures, e.g. pumps, pipes, seals, valves, etc., which make up that system. The assembly of information on failure rates for such components is referred to as the reliability database.

We found that the reliability database relies to a significant degree on data from sources which are some 20 years old or more. Data are also collected on site but are not supplemented to any significant degree from modern national and international external databases. This means that the data used are based on small equipment and component inventories and may not therefore be of high accuracy. No effective quality assurance system appeared to be in use.

We were informed that it is intended to examine the feasibility of using large external databases and also to carry out a peer review of the management of the database. Meanwhile resources need to be dedicated to correcting inaccuracies in the database.

It was not possible to quantify how existing shortcomings in the database may have affected PRA calculations. This uncertainty is a matter for concern.

4.8 Human Factors

The COSR details normal and emergency operating procedures and training programmes for operators. We examined a sample of the training records of operators and team leaders (foremen). Because operation is so important to safety in building B215 we felt that the training programme should be subject to a QA programme and to audit on a regular basis. We were concerned to learn that, unlike many other similar organisations which rely on alert, well trained, operators, the COSR did not make reference to a system for random checking for drug and/or alcohol abuse. Senior staff confirmed that, while if a worker is suspected of being under the influence of alcohol or drugs he/she will be sent to the medical centre for examination, there is no system of random checking in place.

4.9 Document Management

The COSR makes reference to a number of safety manuals, licences and environmental regulations. It was not possible, within the time available, to examine these documents in detail but only to consider whether they covered all the major safety management issues and whether they were referenced in such a way to ensure that personnel, for whom they have relevance, are directed towards them. No omissions were noted and all the relevant documents are clearly referenced.

4.10 Third Party Assessment of COSR

Recently, BNFL has initiated a practice of having assessments of their safety cases carried out by external consultants, or by BNFL staff who have had no involvement in the production or implementation of the safety cases. This additional tier of appraisal of the safety cases is a positive development.

5. CONCLUSIONS AND RECOMMENDATIONS

While it was possible to carry out only a sampling of the substantial documentation which makes up the COSR, it is believed that the sampling included the major safety related issues.

As a result of the examination, which was carried out, the following conclusions were reached regarding the COSR and the safety of the storage of highly active liquid waste at Sellafield:

The COSR

- Apart from the seismic safety case the COSR appears to include all the major accident scenarios. For security reasons provisions against acts of war and/or terrorist attack are not included.

- A more complete analysis should be undertaken of the radiological consequences, in terms of released activity and doses to critical groups, of very low probability high consequence accidents. This would assist judgement on the need to adjust or enhance accident management and emergency response procedures.

- The reliability database needs updating and expansion to incorporate data from relevant external databases. It also needs to be subject to an effective QA system. It was not possible to quantify how existing shortcomings in the database may have affected PRA calculations.

- Fault trees are used in the HAST safety analyses in some instances but not always. Generally they are omitted when the safety case can be made by deterministic methods. We feel that unquantified fault trees would often be helpful in these cases if only to ensure that the overall fault logic is correct. Also there are instances where unquantified fault trees are used but we think they should be quantified in order to demonstrate compliance with risk standards.

- The set of safety manuals, licences and environmental regulations appeared to be complete and to be listed in such a way that staff for whom they have relevance are directed towards them.

- The COSR should include a glossary of terms. The absence of such a glossary makes understanding difficult for readers unfamiliar with the acronyms, abbreviations and terminology. More importantly, however, a glossary would help authors to use familiar terms in a consistent way. Frequently such words as *hazard, accident* and *fault* are used synonymously in some places, while in others a subtle difference between them is implied; another similar example was, *safety feature, safety measure* and *safety mechanism.*

- The recent introduction of assessment of the COSR, by parties not responsible for its production and implementation, represents an improvement in ensuring safety.

- It was noted that, since BNFL took over ownership of the plant in 1971 there have been no recorded releases of radioactivity from the HASTs to the environment and no fires in Building B215.

Overall Safety

- Except for the concrete cells and the HASTs themselves, the ability of plant systems and their associated structures and components to withstand a 0.25g earthquake, that is an earthquake with a return frequency greater than one in 10,000 years, is not yet fully proven.

- Apart from earthquake damage, we are satisfied that the NII's standards of safety, which generally reflect internationally accepted practice, are being met.

- The fact that, although there is a high level of redundancy in the HAST cooling water supply and distribution system, the HASTs do not have fully independent cooling water supply circuits represents a safety concern.

- The hydrogen detector in the HAST ventilation system was removed over 10 years ago; we understand because it never recorded the presence of hydrogen. We believe that, given the serious hazard that the presence of hydrogen would pose in an emergency situation, one (or preferably two) hydrogen detectors in the ventilation system would aid operators in their diagnosis of the emergency and in deciding on corrective measures.

- Because safety relies so heavily on the good performance of the operators, the principles of QA should be applied to their training (both initial and refresher).

- Contrary to the situation that obtains at many nuclear sites, there is no random checking for drug and/or alcohol abuse among the work force. Since HAST safety is so dependent on competent and alert operators a system of random checking should be introduced as soon as possible.

- While noting the NII's severe general criticism, in its February 2000 report on its Team Inspection at Sellafield, of the management of safety at the site [HSE, 2000(b)] it did not appear to us that this criticism is applicable to the staff with responsibility for the HASTs whom we encountered. We formed the view, based on our detailed discussions with them, that they were competent and well motivated. This view is not inconsistent with the NII's report [HSE, 2000(a)] on Storage of Liquid High Level Waste, in which the only reference to the quality of the staff associated with the HASTs is a favourable one.

While the present risks associated with the HASTs are relatively low, we believe that they could be reduced further by attention to the matters set out above. We recommend that BNFL be pressed to address these points as a matter of urgency.

The safety of the storage of high-level radioactive waste in liquid form in the HASTs depends on the continual vigilance of human operators and on the reliable functioning of powered safety systems. When converted into solid form by vitrification the waste can be safely stored without such dependence. It is therefore important that risks associated with the storage of waste in liquid form be minimised as soon as possible by increasing the rate of vitrification or decreasing the output of the Magnox or Thorp reprocessing plants, or by a combination of both.

REFERENCES

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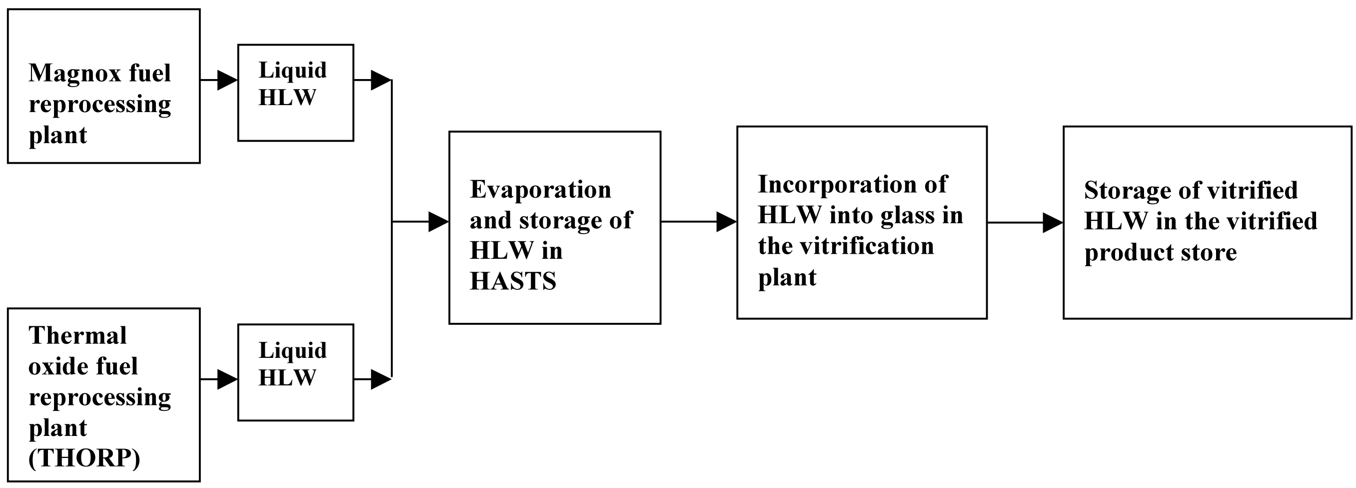

Figure 1
Liquid High Level Waste (HLW) Production and Management at Sellafield

Table 1

Typical Isotopic Inventory of a New HAST

Isotope	Activities (Bq/ml)
Zr-95	1.40. 10^7
Nb-95	5.80. 10^6
Ru-106	1.33. 10^8
Sb-125	1.64. 10^7
Cs-134	1.04. 10^8
Cs-137	5.26. 10^9
Ce-144	9.65. 10^7
Eu-154	4.41. 10^7
Eu-155	3.39. 10^7
Sr-90	3.60. 10^9
Am-241	2.72. 10^7
Cm-242	4.57. 10^5
Cm-243+244	1.92. 10^6

Table 2

Comparison of Isotopic Inventory (in gigabecquerels)

Isotope	Released from Chernobyl	In HASTs 1-8	In HASTs 9-21
Cs-134	1.85.10^7	1.94.10^4	2.7. 10^8
Cs-137	1.0. 10^7	4.7. 10^8	6.25.10^9
Sr-90	7.4. 10^6	3.7. 10^8	4.4. 10^9

Table 3

Heat Loading of Highly Active Storage Tanks (1996)

HAST	Heat Content (kW)	Designed Heat Removal Capacity (kW)
1	20	180
2	14	180
3	Spare	180
4	28	180
5	40	500
6	30	500
7	Spare	500
8	Spare	500
9	105	1700
10	Spare	1700
11	144	1700
12	262	2500
13	329	2500
14	Spare	2500
15	340	2500
16	261	2500
17	Spare	2500
18	323	2500
19	215	2500
20	Spare	2500
21	350	2500