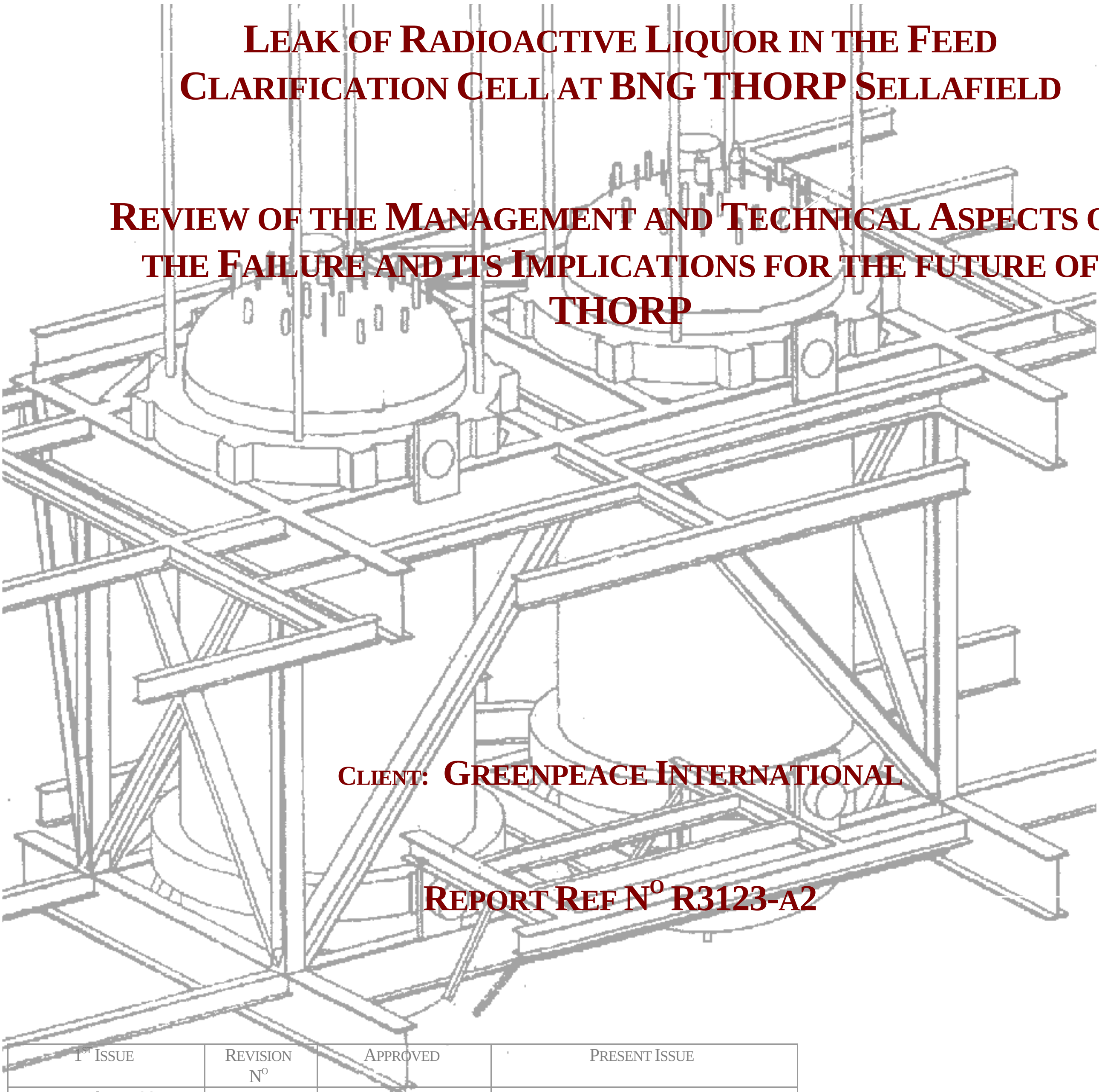
INTERIM REVIEW

LEAK OF RADIOACTIVE LIQUOR IN THE FEED CLARIFICATION CELL AT BNG THORP SELLAFIELD

REVIEW OF THE MANAGEMENT AND TECHNICAL ASPECTS OF THE FAILURE AND ITS IMPLICATIONS FOR THE FUTURE OF THORP



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LEAK OF RADIOACTIVE LIQUOR IN THE FEED CLARIFICATION CELL AT BNG THORP

SUMMARY

This Review examines the failure of pipework in the feed clarification cell of the thermal oxide reprocessing plant (THORP) at Sellafield that resulted in closure of the plant in April 2005. Operation of THORP is contracted to the British Nuclear Group (BNG) and owned by the government agency the Nuclear Decommissioning Authority (NDA).

Following discrepancies in the inventory and nuclear material balance controls at the front end of the THORP chemical separation process, on 20 April 2005 a remotely operated camera revealed a significant quantity of highly radioactive liquor in the sump of Cell 220. In total and over several months previously, approximately 84m^3 of liquor, in the form of a nitric acid solution of fuel and fission products, had accumulated in the sump, leaking from a feed pipe connection to Tank B, one of two accountancy vessels located in the cell. Each of the accountancy tanks receives two separate gravity-fed lines connecting the liquor output of the centrifuges that are also housed in Cell 220.

The entire reprocessing plant was shut down and has remained so since April 2005. The loss of NDA revenue from closure of THORP is reckoned at about £575M per year, although with the continuing and indefinite period of closure the NDA is vulnerable to actions and claims from customers, particularly where overseas customers might be racking up costs in preparing storage facilities for the returned plutonium and vitrified high level waste by-products of reprocessing.

For the last year the NDA has procrastinated and vacillated over this failure and its remediation. First, the NDA allowed BNG in its role as sub-contractor to nominate a number of what can only be considered to be ill-conceived schemes for bringing THORP back on line, resulting in little progress being achieved by mid to late 2005. Now, early in 2006, the NDA has published its second summary report that promotes a repair scheme utilising one of the existing accountancy tanks, abandoning the other tank at the sacrifice of availability of one of the two upstream centrifuges. This NDA preferred option might best be described as an expedient rather than properly engineered and thought through solution, not only will it render the spent fuel throughput of THORP to less than 60% of its design capacity but it is very doubtful that it will satisfy both nuclear safety case and fissile materials safeguards prerequisites.

If THORP is to be repaired and brought back into production then there can be, surely, no compromise over nuclear safety or nuclear proliferation issues. The proper route to an assured solution is to fully decontaminate Cell 220 for man access so that proper and comprehensive replacement and repairs within the cell can be reliably undertaken. If, on the other hand, decontamination is not practicable Cell 220 should be prepared for eventual decommissioning, whilst a new, replacement feed clarification cell is constructed and commissioned. These two fully-engineered solutions will require between one to three years to fully implement.

PART I of this Review examines the causes of the failure, PART II considers the options for repair and restarting THORP, PART III assesses the NDA's preferred repair option, and PART IV examines briefly the financial implications and loss of income to the NDA. At this time the findings of this Review are provisional and incomplete mainly due to the lack of detailed information in the public domain, although the NDA has promised to provide further information under the provisions of the *Freedom of Information Act 2000.*

PART I CAUSES OF FAILURE

From the publicly available information, mainly from the British Nuclear Group's (BNG) own board of inquiry investigation and the NDA's assessment (dating from May and June 2005 respectively), it is possible to extract a number of disturbing findings, namely that:

- The failure commenced with a small and manageable leak from a 40mm diameter (~1.5 inch) pipe stub connection to the head of one of the accountancy tanks.
- If properly operated, the then established management processes established for and detection systems within the cell should have detected the leak at an early stage so that corrective action could have been taken at minimal cost and manageable disruption to the plant output.
- Instead, a series of management bungles, outright errors of judgement and equipment malfunctions permitted the fault to develop to complete failure with the result that THORP overall is completely shut down with the feed clarification cell heavily contaminated.

In terms of nuclear safety, three revelations give rise to considerable concern, including that:

- Some of the operational managers of the plant do not understand (and/or practice) the fundamentals of nuclear safety and that these individuals require retraining in this safety critical area.
- The safety case risk and hazard analysis for Cell 220 operations is defective in that there was no effective detection and assessment of the build-up of leaking fissile material.
- Senior management of THORP chose, even in the face of compelling evidence that the leak situation was serious, to prioritise continuing head-end, accountancy and reprocessing operations rather than to stand down operations in Cell 220 so that an urgently called for cctv inspection could proceed.

In terms of safeguarding and accounting for fissile material within the THORP processes:

- The eventual detection of the leak showed that the BNG Safeguards Department was ineffective in communicating to management.
- That management itself considered fissile material safeguards and audit not to be a priority in relation to continuing production come what may.
- That the paperwork and eventual registering of the safeguards audit has been frequently completed only well after (sometimes months) a particular batch has been chemically processed through the entire THORP system.

Overall, it was a simple failure that should never have happened: At the design stage of the THORP plant, no checks were made for this particular and obvious weakness of the design; when it was known that something was amiss in the accountancy of the fissile material throughputs, no investigation into this was initiated; alarms and indicators of a leak were ignored; and when it became obvious that the transfer pipework was leaking into the cell, senior management prioritise production over nuclear safety.

PART II PRELIMINARY RECOVERY PLANS

In advising the NDA on the recovery options for the future restart of THORP, assuming that the decision to permanently shut down the plant is not taken, BNG identified a number of options:

- BNG proposed four options for repairing and/or modifying the plant so that THORP operations may recommence in the future.
- However, as of June/July 2005, none of the options were sufficiently developed for a final choice to be made.
- At that time and depending on the option selected, the repairs and modifications would involve further delays of at least 6 months before the final option for THORP to recommence chemical separation operation could be considered.
- At that time BNG's (July 2005) preferred option was that of adapting Tank A as a pump-through reservoir only (thereby abandoning weighing and sampling accountancy at this stage) – this option provided NDA a target for a restart of full chemical separation of March 2006.

The whole approach to so-called 'optioneering' which was to lead to a sound choice of the final engineered solution seems to have been poorly overseen by the NDA. This was because it assumed and overly relied upon the cooperation of the Nuclear Installations Inspectorate (NII) to assess the nuclear safety case of each option under consideration whereas the NII was reluctant, or so it seems, to become involved in any pre nuclear safety case submission. This, together with insufficient detailed information being available on each of the BNG options, further delayed the NDA go-ahead decision until the second assessment report of February 2006 was available.

PART III NDA's PREFERRED OPTION

In late February 2006 the NDA made public a second summary report outlining its preferred option that it considered viable to provide for a restart of reprocessing operation at THORP. Underlying this second NDA report is a series of technical analyses and papers which are not, as yet, publicly available.

NDA's preferred option is to use the existing second and apparently sound pipe feed to the undamaged accountancy vessel, Tank A, retaining this set up for accountancy by volume measurement rather than by weighing. Essentially, this option extends the function of Tank A beyond BNG's earlier recommended *'reservoir'* option. Under the NDA's scheme, Tank B would be abandoned and left in situ isolated in the seismic restraint frame in Cell 220, with the frame receiving structural augmentation to render it capable of receiving the load of a fully charged Tank A, should it be required to sit down on the frame at any time during batching operations.

Tanks A and B are virtually identical and same-handed and each tank, working in tandem, has been subject to about the same service life. Thus the loading and fatigue regime pipe feeds and nozzles are expected to be the same for each tank: In other words, the loads and circumstances applied to Tank B and which resulted in the failure, equally applied to Tank A, its connections and nozzles. Yet because of access difficulties, even for robotic equipment, close non destructive examination (NDE) of the tanks, pipes and connections has not possible to date, so the actual condition of either Tank B or Tank A has not be practicably verified. In effect, this means that much of the NDA's reasoning of Tank A's fitness for purpose must be based upon unsubstantiated reasoning and assumption.

Accordingly, the NDA's preferred option includes a number of serious doubts and uncertainties:

- The suitability of the inlet nozzle (N5A) chosen to remain in service has not been non-destructively examined (NDE) in situ, so its condition is entirely the postulate of theoretical analysis. In the words, the actual condition and remaining fatigue life of nozzle N5A has not been proven.
- Other sampling and inspection pipes (about 20 in total) feed to and from Tank A and, of these, only two feeds have been subject to analytical assessment, these being the sampling line N29A and the cooling water outlet N34A. Some further analytical work on all of the nozzles of Tank B has recently been initiated.
- The theoretical remaining fatigue life of these two nozzles (N29A and N34A) is limited, so much so that the NDA concludes that these nozzles should not be used. The in-use failure of nozzle N34A would have significant implications for the nuclear safety case of Cell 220.
- The other nozzle (N4A), feeding from the second centrifuge, which is analogous to the failed nozzle on Tank B, is to be abandoned thereby putting the second centrifuge beyond use, thereby reducing the rate at which liquor batches can be clarified and sent forward to chemical reprocessing in THORP.
- The condition of the seismic constraint frame, which houses both tanks, is so extensively corroded that it cannot be relied upon to receive the weight, either singly or combined, of Tanks A and/or B. The frame will require the fitting of suspension stays or hangers which is a task that may be difficult to achieve remotely, as dictated by the high radiation environment in the cell (in the main, caused by the spillage).
- No account seems to have been given to the requirement of the frame to provide a continuing seismic constraint role.

Overall, the NDA's preferred option is, perhaps, at its best an expediently led compromise and at its worst an engineering bodge.[‡] At the present state of knowledge, as reflected by the latest NDA summary report, further exploratory work has to be completed before the Tank A option can be practicably progressed, this further work includes:

- Detailed and possibly destructive examination of the key nozzles of Tank B, relating these findings to the non-destructive examination of Tank A.
- Although it has been determined that two hangers are required to augment the frame in its role to support Tank A, the scheme for remotely installing the hangers has yet to be developed and proven

The root cause of the nozzle N5B failure was fatigue resulting from oscillation of the tank with respect to the fixity of the input feed pipework. The cause of the tank oscillation is believed to have been agitation of the liquor within the tank, although further trials are required to substantiate changes in the agitation regime for proposed reuse of Tank A:

- Since both tanks are inoperable it is not possible to determine by trial the levels of oscillatory movement generated in the tanks, pipes and adjoining structure during the liquor agitation process but understanding this is essential for the analysis and prediction of the remnant fatigue life of the N4A, N5A and other nozzles which may be brought into service under the NDA's preferred option – trials accurately simulating the oscillatory-fatigue environment, for both the past and the proposed modes of operation, have to be undertaken before any meaningful analysis of the Tank A service life and reliability can be assigned.

If the investigation and trials of the existing Tank A nozzles concludes that there is insufficient remnant life in one or more

[‡] *Bodge* – informal engineering parlance to repair badly or clumsily.

nozzles, and if these nozzles are to be used unmodified, then the nuclear safety case will have to demonstrate a satisfactory fall back system, for example leak-before-break. Similarly, if the restraint frame modifications cannot be implemented then the function of the frame will have to be redefined in terms of the nuclear safety case. Both of these changes, together with others (such as the withdrawal of cooling of Tank A because of the doubtfulness of nozzle N34A) and amendments to the process and its management, bear on the nuclear safety case:

- The NDA's preferred option introduces a number of departures from the existing nuclear safety case for Cell 220 and expanding the scope and detail of the existing safety case will have to be agreed with the NII.

These programmes of further work, necessary to justify practicable implementation of the NDA's preferred option will take, perhaps, in excess of 6 months to complete. Add to this the review and justification procedures for actual implementation of the remedial programme then further delays of 12 months or more are likely, all of which assumes that the NII will accept the nuclear safety of what is, after all, little more than an engineering bodge. In addition, further time may be required to agree with EURATOM the new safeguards regime, particularly relating to the proposal to complete the accountancy by volume rather than weight measure.

All in all, the entire operation of THORP which has now been out of service for 12 months, is likely to remain idle for at least another 12 months until the feed liquor clarification and accountancy processes of Cell 220 can be brought back into operation.

PART IV: At this time all of the overseas light water reactor spent fuel has been imported into the THORP storage ponds and the single UK pressurised water reactor (PWR) at Sizewell is presently committed to storing its spent fuel on site until closure in or about 2027. However, the seven advanced gas-cooled reactors (AGR) operated by British Energy continue to dispatch spent AGR fuel to Sellafield so, with chemical reprocessing at a standstill, the amount of AGR fuel held at Sellafield in increasing and, it is believed, that a number of the AGR power stations have limited pond storage on site so fuel transports to Sellafield cannot be held back if these power stations are to continue generation:

- Should THORP be unable to reprocess AGR fuel over the next 12 months or so, it may be that the growing accumulation of AGR spent fuel at Sellafield requires reassessment of the nuclear safety case of the spent fuel storage pond – this could have significant implications for the continuing operation and generation by a number of the AGR stations should the delays to THORP recommencing reprocessing operations extend to the 2 years or more identified in this Review.

The projected income from THORP, including irradiated fuel storage and reprocessing, for the 2005/6 financial year was forecast by the NDA to be £575M which is about a quarter of the NDA total income (including direct granting from central government). The loss of THORP production for another 12 months or more has the following influences and implications:

- Although there seems to be provision in the fuel reprocessing contracts for the NDA to directly recover from its customers, over some unspecified time period, the costs of repairing THORP, obviously, the plant has to be restarted for this covenant to be enacted.
- If THORP is left permanently closed down as a result of the feed clarification cell failure then the NDA has either to return the unreprocessed fuel to its customers or arrange for the fuel to be reprocessed elsewhere, with both of these options bearing very serious financial consequences.
- Permanent closure of THORP also has serious implications for the continuing operation of the Sellafield MOX Plant (SMP) because it is dependent upon THORP for its plutonium feedstock – at this time drawing down from the UK plutonium stockpile as feedstock substitute, so as to enact 'virtual' reprocessing, is not permitted.
- The THORP plant also provides the contingency role of being able to handle and reprocess the Magnox spent fuel arising from the remaining Magnox power stations, particularly from Oldbury and Wylfa power stations that may continue generation until 2009/10.

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REVIEW OF THE MANAGEMENT AND TECHNICAL ASPECTS OF THE FAILURE AND ITS IMPLICATIONS FOR THE FUTURE OF THORP, SELLAFIELD

PART I FAILURE OF THE ACCOUNTANCY TANK IN THE FEED CLARIFICATION CELL

Following discrepancies the inventory and nuclear material balance controls at the front end of the irradiated fuel thermal oxide reprocessing plant (THORP) at Sellafield, on 20 April 2005 a remotely operated camera revealed a significant quantity of highly radioactive liquor in the sump of Cell 220. In total and over several months previously, approximately 84m^3 of liquor, in the form of a nitric acid solution of fuel and fission products, had accumulated in the sump leaking from a feed pipe to one of two accountancy vessels located in the cell.

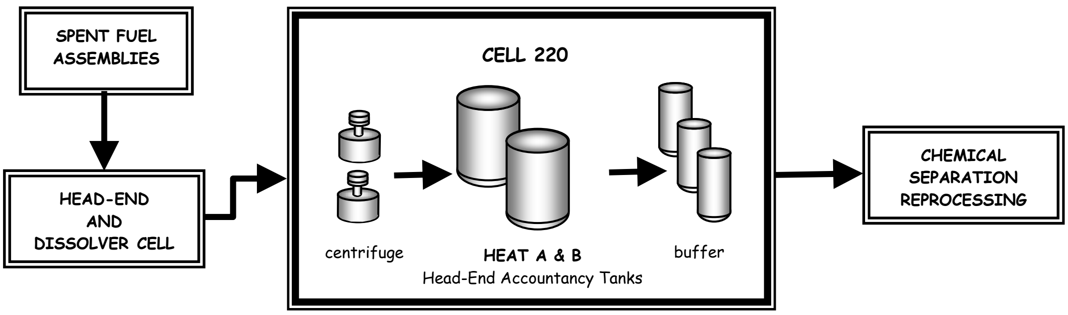
The entire reprocessing plant was shut down and has remained so since. There is today, still a year after the shut down, a great deal of uncertainty if, how and when the accountancy vessel is to be repaired, replaced and/or modified.

Cell 220 and the Accountancy Vessels

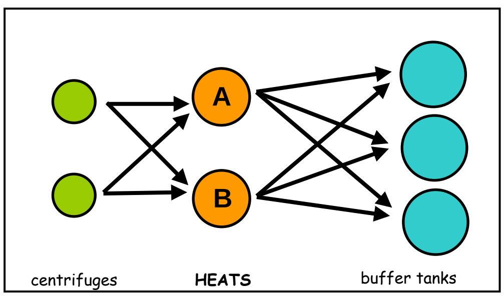
Cell 220 is at the front end of the chemical separation (reprocessing) plant being where feed clarification and accountancy of batches of dissolved fuel. The remotely operated cell is approximately 60m length, 20m width and 20m height, constructed in reinforced concrete and stainless steel lined to form the secondary containment enclosure.

The cell receives liquor from the head-end process where the irradiated fuel pellets are extracted from the cladding of the fuel rod and then dissolved in nitric acid. The liquor is then ‘clarified’ by high speed centrifuge which removes insoluble fines down to 1 micron diameter, with the clarified liquor being transferred to one of two ‘*accountancy*’ tanks. In the accountancy process the liquor is agitated and thoroughly mixed for homogenous sample extraction and weighing of the overall contents of the tank.[1]

The front-end processes prior to chemical separation include staged and batched processes feeding to and from Cell 220 comprise:

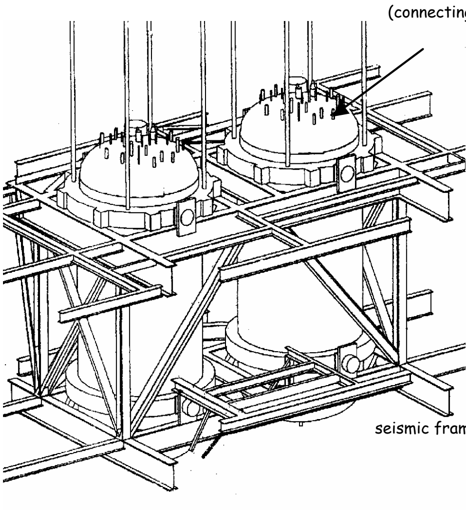


The transfer pipework within Cell 220 is arranged so that the individual process components can be used in a variety of combinations, shown schematically:



Each accountancy tank has a batch volume of about 23m[3] receiving nitric acid (HNO_3 – 2.9M) liquor typically comprised 250g/l uranium by gravity fill via a feed distributor from the centrifuge. The liquor content is agitated within the tank, the weight and level recorded and samples are taken for assaying. Once that these measurements have been completed the accountancy tank contents are transferred to three buffer tanks that are also housed in Cell 220.

Both accountancy tanks, each approximately 2.5m diameter by 4.5m length, are cradled in a seismic protection frame, although each tank is suspended free of this frame on four relatively slender stainless steel tie rods that pass through the ceiling of the cell to a weighing device. The normal operational state of the tanks is in the suspended mode with the tanks being lowered onto the frame for a short period whilst the weighing system is calibrated, usually twice yearly.



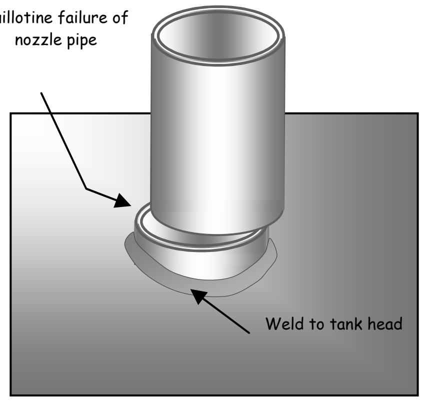
CELL 220 ACCOUNTANCY A & B TANKS

Once Cell 220 had been commissioned and operational, man entry into the cell confines is not practical because of the high radiation environment and, indeed, the design of Cell 220 does not incorporate a facility for ease of man-access.[2]

Accountancy Tank B – Nozzle Failure

Following the detection of the leak, an internal BNG Board of Inquiry[3] reported in May 2005 states that remote cctv inspection of Cell 220 revealed a significant quantity of dissolver liquor in the base of the cell and that a feed pipe to one of the accountancy tanks (Tank B – nozzle N5) had failed by fatigue fracture at a location close to the head of the vessel.

The failure of the feed nozzle is in the form of a complete guillotine break of the 40mm diameter feed pipe just above the pipe to tank welded joint, with the disconnected pipe remaining slightly misaligned above the stub of the pipe. Because of this alignment, the gravity flow of the clarified feed liquor continued to run into the tank, with some of the flow splashing out and running down the tank side, spilling onto sections of the supporting steel frame.



The salient contributory factors of failure have been identified as:-

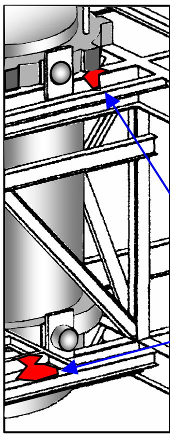
- With the tank operating when suspended from the four tie rod hangers, the vibration of the tank induced by the internally mounted agitator (pulse jet) and during emptying by the reverse flow diverters produced both oscillatory and swaying motions of the tank that was, over time, sufficient to produce fatigue failure in the feed pipe.
- Although the tank system had been originally designed to be restrained within the seismic frame, for the pre-commissioning safety case the assumption was that the tanks would be uncoupled from the frame and, in accordance with this, the tank-frame restraint blocks were never fitted. Moreover, this modified design never seems to have been reviewed and reassessed in terms of induced vibration and the associated cyclic stressing of the pipework connections.[4]

The failure of the feed pipe most probably commenced with a small leak in or about July 2004, thereafter progressively worsening until mid January 2005 when a step increase in the leak rate is now known to have occurred. Even so, no definitive investigative action was taken until April 2005 when the remote cctv inspection discovered seriousness of the leak and finally identified its source to a feed pipe to the accountancy tank. During this interim period there occurred a number of management and systems failures and omissions, including:

- Discrepancies in the heavy metal accountancy were first detected in a processing batch operation that ran from September 2004 through to late January 2005, being referred by the Safeguards Department to another, apparently, more senior BNG management[5] group, with the 3% shortfall discrepancy being confirmed by an independent check, with this increasing to 3.9% and finally 9% upon further checking.
- The results of the Cell 220 sump sampling were misunderstood with both sumps incorrectly assumed to be free of radioactive substances and, as a result of this bungling, no action was taken.

In fact over the previous period and as a matter of routine, from June 2003 through to April 2005, 10 liquor sample recovery operations from the sump serving the accountancy tank area of Cell 220 were undertaken but nothing was recorded because now, it transpires, the sample recovery system may have been at fault (ie there was no liquor in the laboratory catch pot so the laboratory analysis incorrectly assumed the sump to be empty and recorded a zero result).[6] Eventually, in mid-April 2005, it was realised that high uranium readings from second sump in Cell 220 indicated that about 19 tonnes of uranium (equivalent to approximately 84m^3 of dissolver liquor) had been leaked into the Cell 220 sump.[7] About the same time of the Safeguards discrepancy, two samples were successfully extracted and analysed from the sump, both of which yielded the presence of significant concentrations of uranium compared to the design objective of Cell 220 and its sumps to be uranium free at all times of normal operation.

Associated Damage to Support Frame



Over the period of the leak, perhaps for about 9 months, the carbon steel frame sustained significant corrosion, with the spilling nitric acid etching into and completely eroding through the higher and lower south sections of the frame, including the 600mm wide web of the main I-beam at the lower level.

The damage to the steel frame appears to be extensive[8] and repairs, even if possible by remote means operating within the cell, would require opening up the cell access hole which is presently only 300mm diameter to receive new sections of the 600mm web I-beam.

Investigative and Regulatory Actions Undertaken

BNG established its own Board of Inquiry,[9] reporting on 26 May 2005 following which it set out its Recovery Plan[10] for the resumption of operations of the THORP process overall. Independently, the Nuclear Installations Inspectorate served two Improvement Notices[11] relating to management and record keeping issues. The Nuclear Decommissioning Authority (NDA - effectively owners of THORP) established a review team[12] to consider the options available for the eventual recommissioning of THORP, including the preparation of the engineering and safety cases leading to the restart of the plant.

PART I – SUMMARY

It is quite remarkable that such a key element of the chemical separation process had not been designed to incorporate measures of redundancy and diversity to provide for continuing operation of THORP in the event of such a localised (and relatively trivial) engineering failure. This is because the two identical accountancy tanks and their respective feeds shared a common location (Cell 220) and the same mounting (the restraint frame):

- Lacking diversity means that the presently undamaged Tank A is prone to the same failure cause(s) as Tank B and thus cannot operate unless it can be proven that the cause of the feed nozzle failure was unique to Tank B – nothing in the BNG Board of Inquiry findings has shown this to be so;[13] and
- with no redundancy, whereby a second isolated and duplicate of Cell 220 is available, there is no opportunity to divert this head-end process around the failed area thus enabling the THORP production process to continue.

These fundamental oversights have resulted in the complete closedown of the entire THORP reprocessing operations.

Similarly, it is astonishing that the loss of such a large quantity (~84m^3) of intensely radioactive feed liquor was not detected earlier, particularly when a number of separate management departments, including the nuclear materials safeguards personnel, were all involved in monitoring and reporting upon this early stage of the chemical separation process. Moreover, there existed a 'new plant' culture in that because the processes and equipment within the cell had been designed not to leak then these processes '*could not possibly leak'*, which is a disturbing complacency particularly if transferred to other areas of management[14,15] of THORP and its associated processes.

Most disturbing is that the operational managers were not made aware of mounting concerns from the accountancy and safeguards departments on inventory anomalies as these arose,[16] indeed to the extent that their understanding of nuclear safety may have been doubtful;[17] managers remained ignorant of longstanding difficulties with instrumentation in Cell 220 and thus were not in a position to cross link this with the inventory losses; and even when the seriousness of the leak had been irrefutably established by compelling evidence (by 16 April 2005), senior management then chose to prioritise continuing production in THORP rather than to stand down this part of the plant for cctv inspection.

PART II RECOVERY PLAN OPTIONS

Until the feed nozzle connection to Accountancy Tank B is either repaired or the whole process diverted around it, the entire chemical separation activity of THORP must remain at a standstill.

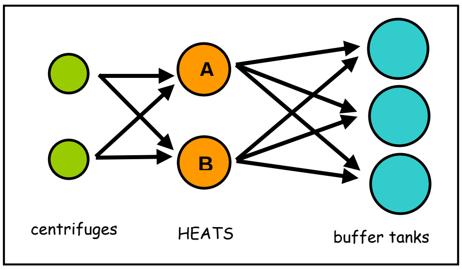
In brief, the NDA review of the failure a Recovery Plan comprising the following options:

i) Tank B Repaired - Returned to Full Operation

Repair Tank B remotely and restore the system but with design and process management revisions.

ii) Man Access - Full Repair Tank B & Framework

Prior to man access, decontaminate Cell 220 for manned repairs to Tank B and the steelwork frame, including modifications to the pipework.



Remote working within the cell (i) would require enlarging the access portal into the cell, presently limited to a 300mm diameter access hole and then, robotically, implementing repairs and modifications to the nozzle connections and steel frame.

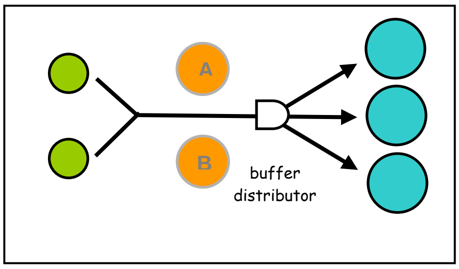
For the man access and repair option (ii) the area, equipment within and lining of Cell 220 are radiologically contaminated and would require thorough decontamination prior to man entry and, even then, it may not be practicable to reduce the radiation exposure rates to acceptable levels for the work programme involved. Given that the plant area could be effectively decontaminated down to an acceptable level, then man access could provide the most thorough and extensive repair, restoring the plant and processes to the original deign intent, if not with modifications.

Proving each of these options would entail challenging development programmes in the robotics and radiological control areas. The man access option provides, on the basis that the radiation exposure to workers engaged in the decontamination and repair options could be minimised to acceptable levels, the best assurance that the repair would be effective and THORP could be returned to full operation. Once radiologically safe entry to the cell had been achieved, the repairs and modifications could be undertaken in a matter of a few weeks to a month or so, but the preparation and decontamination period would likely take many months, if not more than a year once that the overall plan had been approved.

Regulatory approval for the man access -*v*- remote repair schemes would involve balances and cross checks between the levels of individual and collective dose, including for post operation management of the radioactive wastes generated during the decontamination processes,[18] and the achievability and effectiveness of the equivalent robotic repair, particularly with respect to ongoing nuclear safety.

iii) By-Pass Both Accountancy Tanks A & B

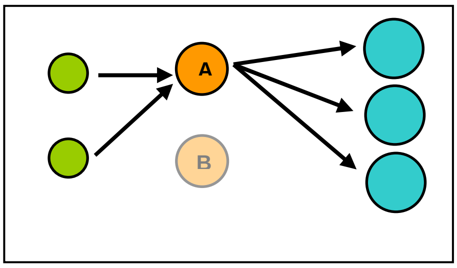
In this option, both accountancy tanks (A and the damaged B) are by-passed with the centrifuged or clarified liquor being fed to any one of the three downstream buffer tanks, with the bypass piping either feeding by gravity or being pumped to the existing buffer tank distributor.



To bypass the remaining accountancy tank (iii) requires remote installation of new pipework directly from the centrifuge, either gravity fed or pumped to the buffer tanks, with the former option possibly resulting in a 20 to 30% reduction of batch throughout because of the height limitations for gravity feeding in the cell.[19] Removal of the accountancy tank process stage requires modification of the head-end process overall to introduce a new weighing stage[20] and plutonium valency conditioning.[1]

iv) Accountancy via Tank A Only

The damaged accountancy tank B is abandoned and the process continues operating only via the present Tank A, albeit with the amended procedure that the tank would only be lifted and suspended when weighing is required, although this option seemingly ignores the potential fatigue to the analogous nozzle N5A.

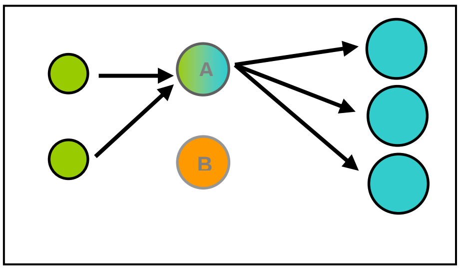


The use of just one accountancy tank would reduce THORP operational throughputs from in excess of 5 tonnes per day to 3 tonnes per day.

Even if the present continuous suspension mode for accountancy weighing is abandoned, further use of Tank A must be conditional on the fit-for-purpose condition of its nozzle and pipe connections. Before this option can proceed, these connections will have to robotically inspected and subject to non-destructive examination. This is because Tank A has been in service and subject to the same conditions that failed the N5 connection to Tank B with at least the Tank A N5 connection being subject to the same number of sway and oscillatory fatigue cycles as its failed counterpart.[21]

v) Tank A as Intermediate Stage Only

Tank A is utilised as a pump-through reservoir with accountancy being undertaken in the buffer tanks which enables the 5 tonne daily throughput to be maintained.



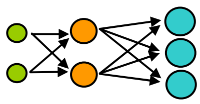
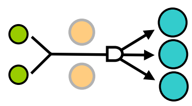
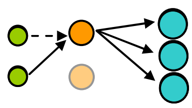
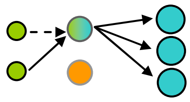
This is BNG's preferred option.

Tank A remains in use as a collecting and pump through reservoir, with accountancy being completed in the buffer tanks, thereby maintaining the 5 tonne daily throughput for THORP.

For Options iii), iv) and v) the acid-eroded steelwork of the seismic frame will have to be carefully cut away and either removed from or safely stored within the cell, and the appropriate repairs to the frame steelwork will have to be completed to the extent required by the particular option. Similarly, other abandoned equipment and vessels (ie Tank B) will have to be secured and/or dismantled and safely stored within or removed from Cell 220.

The options for the recovery of THORP may be summarised as:

TABLE 1 BNG OPTIONS FOR THORP RECOVERY

OPTION		THORP CAPACITY	IMPLEMENTATION TIME[a]	ISSUES
	i/ii) Complete Repair	100%	i) robotic ~ 1 year ii) man access >1 year[b] + Safety Case Resubmission	Full robotic repair may not be possible for i) and Radwaste & Dose elements likely to be significant for ii). Lack of assurance of outcome of robotic repair may not meet approval of safety regulator.
	iii) Bypass Accountancy	70-80% gravity 100% pumped	6 to 9 months + Safety Case Resubmission	Requires securing redundant vessels and frame. Accountancy weighing lost – Safeguards issue.
	iv) Tank A Accountancy	<60%	6 to 9 months + Safety Case Resubmission	Nozzle & pipe connections to Tank A require in depth assessment and NDE. Nozzle AN5 condition determines if 2nd centrifuge is available. Seismic Frame & Tank B require securing.
	v) Tank A Reservoir	100%	8 months[c] + Safety Case Resubmission	Accountancy weighing lost – Safeguards issue. Nozzle & pipe connections to Tank A require in depth assessment and NDE. Nozzle AN5 condition determines if 2nd centrifuge is available. Seismic Frame & Tank B require securing.

Notes:

a) Implementation time taken from date at which the decision to proceed with the option is taken and excludes preparation time until that date.
b) NDA assessment of time involved.
c) BNG's restart target for its preferred option is March 2006 but apparently based upon no delays in the NDA go-ahead decision in or about June 2005.

PART II SUMMARY

Sourcing information about the failure of the feed nozzle failure has been difficult.

Although, overall, the BNG Board of Inquiry[3] identifies the point of failure and the most probable failure mode to be fatigue, it lacks sufficient detail[22] necessary to formulate a range of possible engineering solutions. The principal source of reliable information, albeit in very limited form, is the Engineering Directorate of the NDA via its review of mid-June 2005, although nothing has been made publicly available by the NDA since then.

As of mid-June 2005 the situation was:

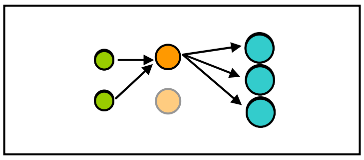
TABLE 2 MANAGEMENT DECISION SITUATION JUNE 2005

Cause of Failure: The technical reasons for the failure of the nozzle to Accountancy Tank B are insufficiently analysed and documented to conclude that movement-induced fatigue was the sole cause.	i) Although movement-induced fatigue was likely to have been a dominant factor, further justification is required to identify other possible contributory causes (corrosion, weldment flows, etc) that could have accelerated failure.
	ii) Once this has been established, other vessel pipe connections where such deleterious factors might persist should be examined and the design analysed to determine if, like in the case of the Accountancy Tanks, fatigue stress was not taken into account – this should apply on plant-wide basis.
Management To and Following Failure: BNG's own Board of Inquiry has identified a series of management failings leading up to and following the nozzle failure, particularly that senior managers prioritised continued head-end and reprocessing operations over standing down Cell 220 for cctv investigation once that the seriousness of the fault had been established by *'compelling evidence'*.	Unlike previous incidents at BNG Sellafield, such as the MOX data falsification, the responsibility and blame has been placed (allegedly) with operatives and junior tiers of management. In this case, however, a senior level of management has been identified to be at fault yet no corrective action seems to have been implemented, either by BNG or the NDA.
Recovery Options: Each the recovery options presented is insufficiently detailed to enable a single option to be selected and developed – there seems to have been a lack incentive to determine the actual condition and reliability (and service life) of the Tank A connections and a blind eye seems to have been turned of the severely damaged restraint frame in BNG's board of inquiry investigations.	iv) Further work is required to assess the remaining life of the in situ equipment (tanks, nozzles, frame) as appropriate to each option, and each option should be referred to both nuclear safety and environmental audits before a final recovery plan is settled.
Nuclear Safety Issues: Two significant safety issues have been identified during the course of the BNG Board of Inquiry, these being the apparent lack of understanding of nuclear safety fundamentals, and that the Head End Safety Case[23] is deficient in its assessment of the detection of the build-up of fissile material in Cell 220.	v) Both safety issues should be addressed and resolved before any recovery plan is put into place and THORP prepared for resumption of chemical separation.

PART III NDA'S PREFERRED OPTION – MARCH 2006

In March 2006 the NDA issued a redacted version of a further summary in which it identified its preferred option to enable THORP to return to sustained operation.[24]

The preferred option is that of iv) Tank A accountancy only identified in the previous table, essentially comprising operation of the feed clarification in the existing Cell 220 with Tank B isolated but with Tank A operating without cooling and at restricted levels of agitation. This preferred option requires assessment of the performance of Tank A in terms of



- potential for future nozzle failure
- adequacy of the seismic restraint frame enclosing Tank A
- evaluation of the options

Future Nozzle Failure: In justifying its preference for returning Tank A to service, albeit restricted, the NDA acknowledges that the duplicate nozzle (N5B) that failed on Tank B had exceeded its fatigue lifetime by a factor of x10 using an accepted fatigue characteristic for the nozzle material and its geometry. However, the assessment of the N5B failure seems to be incomplete with the scope of future operations dependent upon the findings of this analysis.

From application of the same fatigue analysis for Tank A, the NDA has concluded that the analogous nozzle (N4A) had also significantly exceeded its maximum fatigue lifetime although another (second) inlet feed nozzle of Tank A the NDA goes on to conclude that *"Depending on the potential future duty, Nozzle N5A has significant residual life left"* – these reasons, in terms of fatigue life, taken for this judgement are quantified in the following table:

TABLE 3 ANALYSIS OF REMNANT FATIGUE LIFE OF SELECTED NOZZLES

NOZZLE	DESCRIPTION	F2 FATIGUE	D FATIGUE
N4A	Feed inlet to Tank A (analogous to failed Tank B N5B pipe)[25]	20.05	5.67
N5A	Feed inlet to Tank A	0.48	0.14
N29A	Sample line	~4.0	~1.1
N34A	Cooling water outlet from jacket	~4.0	~1.1

Notes:
a) **F2** and **D** are fatigue characteristics derived from slightly different assumptions.

The choice of the N5B nozzle and, by inference, the disuse of N4B means that one of the two centrifuges located in Cell 220 can no longer be deployed upstream of Tank A. In other words, the batching capacity of the centrifuged liquor is halved by the non-availability of the feed line leading to N4A. Before nozzle N4A could be returned to use a remote non-destructive examination (NDE) would have to be undertaken at the nozzle-tank intersection.

Adequacy of Seismic Restraint Frame: Three of the principal members of the structural frame have been severed (see APPENDIX I) with other damage to the vessel trimmers and a further structural member of the frame.

The NDA's overall assessment is that *". . . the support frame local to Tank B renders the frame inadequate for future use at all"* so, unless modifications are undertaken to strengthen the frame in the locality of Tank B, the Tank B tank must remain suspended in a safe and stable state irrespective of whether it is ever returned to use.

For future operation of Tank A, the NDA concludes that if the fully charged Tank A was lowered on to the frame then the frame members and joint welds would be overstressed unless, that is, two additional structural support hangers were installed to reinforce the restraint frame. However, the provision of additional hangers to supplement the strength of the corroded seismic frame is technically challenging and presently under consideration as an active contingency by NDA.

Evaluation of the Options: In its final choice of its preferred option the NDA deploys functional and multi criteria decision analysis (MCDA), discussing these at some length but in doing so providing virtually no quantitative information of how the final decision for continuing use of Tank A was reached.

The outcome of the choice evaluation is:

- Isolation of Tank B with Tank A utilised for accountancy
- Tank B to be isolated and suspended not to load on seismic frame
- Feed to Tank A to be via nozzle N5A
- Accountancy by volume measurement, in tank density measurement and sampling - all in Tank A
- Tank A to be operated suspended on rods.
- Tank A cooling system not required as a safety function
- Tank A operated in batch mode as per current practice
- Tank A will continue to be agitated prior to sampling at high levels of tank
- Tank A emptying to follow current practice using one of the two RFDs
- Seismic Frame to be Augmented with 2 hangers

Interestingly, the so-called high level options of i) man entry into Cell 220 for repairs and ii) building a new cell complete were rejected on excessive radiation dose and cost and complexity respectively.

PART IV NDA'S PREFERRED OPTION - SAFETY, PRODUCTION & FINANCIAL IMPLICATIONS

At present, according to the Nuclear Decommissioning Authority (NDA),[26] THORP plays a strategic role in that the plant i) generates an income source via the execution of committed reprocessing contracts for overseas light water reactor fuel; ii) reprocessing of British Energy AGR[27] irradiated fuel; and iii) THORP provides an alternate contingency route from reprocessing other spent fuel arisings, such as UK generated Magnox fuel. In fact, approximately 50% of the NDA's present annual budget of £2.2B derives for various commercial activities and of this more than a half is generated by the storage and reprocessing of irradiated fuel – for the year 2005, this storage/reprocessing income element was forecast to be £575M.[28]

As of December 2005, the NDA had not reached a conclusion on which of the options outlined in PART II could be practicably developed so, even if BNG's preferred repair Option v) (Tank A as Intermediate Stage Only) was to proceed from, say, January 2006, then on BNG's own time scale reckoning THORP could not be expected to restart fuel reprocessing operations until at least September 2006. If repair Option v) was completed, although considered very unlikely from both technical and safeguards aspects, THORP production would have been halted for around 18 months, thus representing a considerable loss of real income to the NDA.[29] According to the NDA, when and if THORP is restarted this lost income and the cost of whichever repair option is implemented may be recovered from its customers over time.

Now if the NDA's adopts as its own preferred option iv) (Tank A acting singly) the nine-month v) option time scale will most likely extend whilst a number of uncertainties are resolved, these being:

- NII's acceptance of a revised nuclear safety case for the Cell 220, particularly:
  - proving the remnant life of nozzle AN5
  - withdrawal of cooling from Tank A because of uncertainties with nozzle N34A
- Leaving Tank B in situ and suspended on its hangers.
- Augmenting the seismic frame for the sit-down of a fully charged Tank A.
- Discounting the need for the seismic constraint role of the frame.
- Possible nuclear safety issues arising from the accumulating stockpiling of AGR fuel at Sellafield.

and there will also be issues relating to accountancy and auditing of the liquor batches, which is to be by volume rather than weighing, passing though the modified Cell 220 process, that will need to be agreed with Euratom.

However, the NDA's analysis of minimising its losses omits to account for the interaction with and dependence of the Sellafield MOX Plant (SMP) upon continuing operation of THORP.[30] If THORP does not re-open then the plutonium yield of spent fuel awaiting reprocessing could not be delivered back to customers as MOX, so there not only is a loss of SMP MOX sales[31] but the unreprocessed fuel would have to be either returned to the customers or transferred elsewhere for reprocessing, all at cost to the NDA. A possible solution would be for the NDA to deem the stockpile of irradiated fuel to have been reprocessed, that is *virtual* reprocessing,[32] with SMP drawing its feedstock from the UK safeguarded plutonium stockpile, although this proposed arrangement is not currently permitted and there are likely to arise safeguards issues.

As noted earlier, the sources of information relating to the investigation and progress of the recovery plan remain firmly rooted within BNG and the NDA. Both of these organisations, as well as the Nuclear Installations Inspectorate which is currently undertaking its own investigation into nuclear safety, have been approached for further information but, to date and other than two summary reports,[12,24] nothing has been forthcoming. Other than the public issue of these summary reports, the underlying references and technical information lies inaccessible within a maze of bureaucracy, there is nothing certain in the public domain on how long THORP is to remain inactive awaiting remedial actions, if there are any nuclear safety issues associated with the spent fuel storage ponds accumulating consignments of fuel which cannot, at this time, be reprocessed, and how much all of this is costing.

In Conclusion: As a direct result of the discovery of a simple pipe failure in the feed clarification cell, THORP was shut down and has remained so since April 2005. The loss of NDA revenue from closure of THORP is reckoned at about £575M per year, although with the continuing and indefinite period of closure the NDA is vulnerable to actions and claims from customers, particularly where overseas customers might be racking up costs in preparing storage facilities for the returned plutonium and vitrified high level waste by-products of reprocessing.

For the last year the NDA has procrastinated and vacillated over this failure and its remediation. First, the NDA allowed BNG in its role as sub-contractor to nominate a number of what can only be considered to be ill-conceived schemes for bringing THORP back on line, resulting in little progress being achieved by mid to late 2005. Now, early in 2006, the NDA has published its second summary report that promotes a repair scheme utilising one of the existing accountancy tanks, abandoning the other tank and at the sacrifice of availability of one of the two upstream centrifuges. This NDA preferred option might best be described as an expedient rather than properly engineered and thought through solution, not only will this render the spent fuel throughput of THORP to less than 60% of its design capacity but it is very doubtful that it will satisfy both nuclear safety case and fissile materials safeguards prerequisites.

If THORP is to be repaired and brought back into production then there can be, surely, no compromise over nuclear safety or nuclear proliferation issues. The proper route to an assured solution is to fully decontaminate Cell 220 for man access so that proper and comprehensive replacement and repairs within the cell can be reliably undertaken. If, on the other hand, decontamination is not practicable Cell 220 should be prepared for eventual decommissioning, whilst a new, replacement feed clarification cell is constructed and commissioned. These two fully-engineered solutions will require between one to three years to fully implement.

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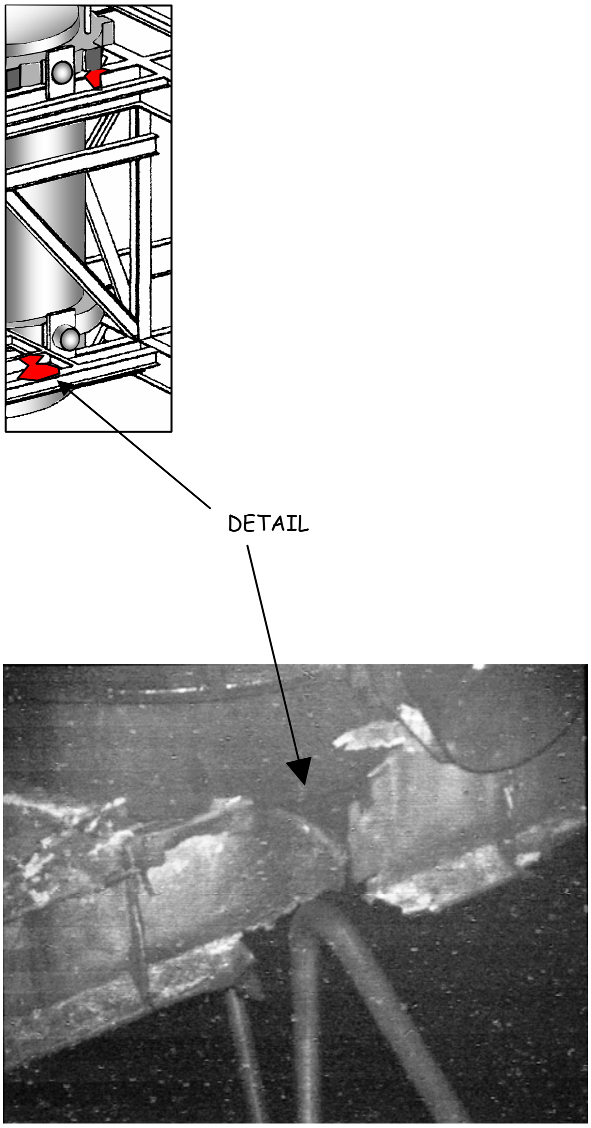
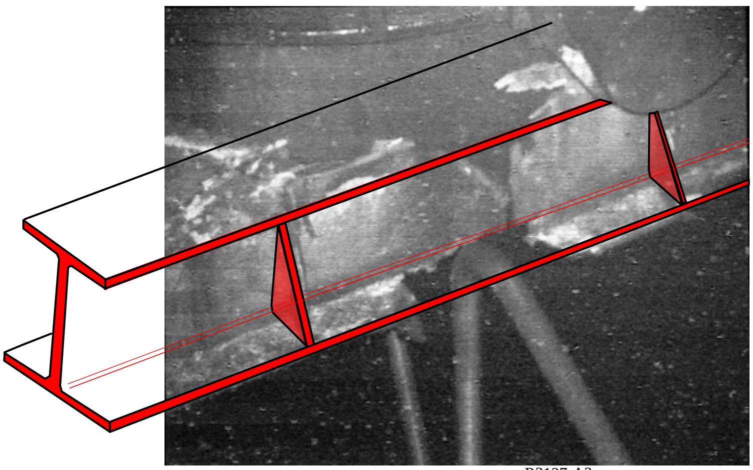
APPENDIX I – FRAME DAMAGE





REFERENCES AND NOTES

1 It is understood that the plutonium conditioning for the subsequent chemical separation process takes place in the accountancy tank, with the plutonium valency being switched from Pu *VI* to Pu *IV*, although details are sparse and this may be achieved elsewhere in Cell 220 or downstream of chemical separation.

2 It is believed that the largest access portal is about 300mm diameter.

3 Board of Inquiry Report, *Fractured Pipe with Loss of Primary Containment in the THORP Feed Clarification Cell*, 26 May 2005, BNG but released publicly in redacted form on 29 June 2005.

4 In fact some of the seismic frame steelwork was also modified at that time to intentionally permit the tank freedom of movement, even so no reassessment of vibration induced fatigue was undertaken.

5 The identification of this second BNG group has been redacted in the BNG Board of Inquiry Report.

6 In fact, it is now known that the sample bottle was actually collecting liquor from the sump but, because of a mis-match of timing in transferring the sample to the laboratory catch pot, the sample was running back to a second sump in Cell 220

7 Even though routine sampling of this second sump showed high uranium concentrations (9g/l and 61g/l in November 2004 and February 2005 respectively) no further action was taken to investigate the reason for this or, indeed, deduce a link between the absence of samples from the other sump in Cell 220.

8 The steel frame sections (I-beams) are only protected with paint and thus very susceptible to corrosion by the strong nitric acid content of the spilled clarified liquor. The extent of corrosion is given by some poor quality photographs in the NDA Review (12) which shows sections of both higher and lower level beams completely eroded through – Appendix 1.

9 Board of Inquiry Report, *Fractured Pipe with Loss of Primary Containment in the THORP Feed Clarification Cell*, 26 May 2005, BNG BN05040181 SE 9924 SIR 35/05.

10 TCC Integrated Recovery Programme, BNG 15 June 2005

11 Nuclear Installations Inspectorate, 17 June 2005

12 *Review of THORP Feed Clarification Cell Nozzle Failure Mechanism and Proposed Options to Enable the potential Return of THORP to Sustained Operation*, C14 Preliminary Review, NDA Engineering Directorate, Region 3, 13 June 2005

13 In fact, the BNG Board of Inquiry concludes that the design of the accountancy tank connections (including the failed nozzle) did not give consideration to fatigue stress during operation.

14 Such a transfer could apply, particularly with the nuclear materials Safeguards Department which has material accountancy responsibilities across the entire THORP process – in fact, over the period of the leak from Tank B, the Safeguards Department put unaccountable losses or SRDs (Shipper Receiver Difference) of 3% and 9% down to calculation errors – about 19 tonnes of uranium had been lost over three reprocessing campaigns.

15 Amongst other omissions and shortfalls, over the months and in the run up to the eventual discovery of the nozzle failure, alarms in the Cell 220 sump level pneumercator were not acted upon., the automatic prompts for sump sampling every three months seems to have been ignored since December 2000

16 It is reported that often the Safeguards Division could not provide the accountancy data, including the SRDs, until weeks or months after a particular fuel separation campaign had been completed – this has very serious safeguards implications.

17 Recommendation 9.6.1 of the BNG Board of Inquiry requires that *"managers with operational responsibilities should be interviewed to check their understanding of the nuclear safety fundamentals and key safety case requirements of the plant and process for which they are authorised. Any shortfall from the expected level of understanding should be promptly corrected by remedial training and re-examination"*.

18 The decontamination task would be complex, possibly using etching acids to scour out the existing pipework and vessels, and clean out the surfaces of the cell and sump liners than filling all the pipework and vessels with water to block emissions, install temporary shielding, all of which would generate significant volumes of fission product bearing radioactive wastes.

19 With a gravity line, once the liquor had been transferred from the centrifuge there should be no back-up of liquor in the feed pipe, which necessitates the buffer tanks being entered at a lower level.

20 Removal of the accountancy weighing stage may have nuclear materials safeguards implications.

21 Neither the BNG Board of Enquiry Report nor the NDA Review irrefutably identifies the swaying and oscillatory motions of Tank B to have been the sole cause of the nozzle failure.

22 For example and quite remarkably, the BNG report does not make reference to the condition of the steel framework being completely eroded through in places, even though this will present major problems for any recovery scheme.

23 Safety Case BNG HAZAN C6

24 *Review of THORP Feed Clarification Cell Nozzle Failure Mechanism and Proposed Options to Enable the potential Return of THORP to Sustained Operation*, C14 Preliminary Review, NDA Engineering Directorate, Region 3, undated (31 January 2006) – supplement to previous NDA CT14 report.

25 The nozzle nomenclature is somewhat confusing with the failed Tank B nozzle identified as N5B to which the Tank A N4A is the analogous nozzle and similarly N4B is analogous to N5A.

26 The NDA is a non-departmental public body, set up in April 2005 under the Energy Act 2004 to take strategic responsibility for the UK's nuclear legacy. The NDA's objective is to ensure that the 20 civil public sector nuclear sites under its ownership are decommissioned and cleaned up safely, securely, cost effectively although, that said, the NDA is not at all prohibited from continuing to operate plants such as THORP for as long as it considers to be viable (either economically or in terms of fuel management considerations). Income from the operation of such plants as THORP are received and managed by the NDA.

27 AGR – Advanced Gas-Cooled Reactor such as at Heysham, Torness and elsewhere proving a total of about 8,400MW_e installed capacity

28 See NDA Press Release of 16 November 2005- http://www.nda.gov.uk/News--News_(1250).aspx?pg=1250

[29] The NDA claims (see 28) that the actual losses are mitigated by a number of factors including i) that customers will continue to make certain staged payments, ii) that the THORP 7 week production break for maintenance will be absorbed in the outage, ii) staff are redeployed, and iii) there is insurance cover, which, all in all, the NDA reckons the 2005/6 year income will only be reduced by 5% although, even if this is accepted, this cost offsetting cannot be extended ad infinitum.

[30] Of course, for continuing operation with new orders THORP is equally dependent upon the SMP because MOX is regarded by many overseas nuclear power utilities as the only feasible route for dealing with returned fuel reprocessed plutonium.

[31] In which case the SMP would, as a result of the loss of MOX orders because of the customer's fuel remaining unreprocessed, develop empty production windows, thus threatening the somewhat precarious financial performance of SMP.

[32] Review of the Sellafield MOX Plant and the MOX Fuel Business, NDA - Arthur D Little, 26 July 2005