

THE HUMAN ELEMENTS OF A NUCLEAR INCIDENT

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HISTORY OF SELLAFIELD

The Sellafield Nuclear Licensed site is situated on the West Coast of Cumbria, just outside the village of Seascale and is currently operated by Sellafield Ltd. It covers approximately four square kilometres and contains more than 200 nuclear facilities and provides work for over 10,000 people.

From 1971 until 2005 the site was owned and run by British Nuclear Fuels Ltd or BNFL. Since the 1st of April 2005 the site was managed and operated by British Nuclear Group which then changed its name to Sellafield Ltd. This was all during the set up and introduction of the government body the Nuclear Decommissioning Authority or NDA.

REPROCESSING ON THE SELLAFIELD SITE

2 types of used nuclear fuel are reprocessed at the Sellafield site; firstly Magnox Fuel which is reprocessed in the older plants within the separation area. Secondly, oxide fuels and advanced gas cooled reactor fuel, which are reprocessed at the Thermal Oxide Reprocessing Plant or THORP. Active operations began in THORP in 1994 after 9 years of building, inactive and active commissioning.

THORP OPERATIONS

Nuclear fuel is cooled in storage ponds for numerous years before being fed to the Feed Pond area of the plant where the fuel is monitored for its enrichment content. This fuel is then sent to the Shear Cave where the fuel is sheared into small sections allowing the Uranium, Plutonium and waste fisson products to be leached out by using hot nitric acid. The resulting product liquor is clarified in one of two centrifuges before being fed to the Chemical Plants for processing into separate streams of uranium, plutonium and nuclear waste. The recycled uranium and plutonium is then sent to the Sellafield MOX plant, SMP to be turned into new nuclear fuel. The waste products are sent to the High Level Waste Plants for concentration and eventual conversion into glass in the vitrification process.

THE FEED CLARIFICATION CELL EVENT

THORP spent 11 years running with only one or two major problems that effected operations. Shearing operations reached through put rates of up to 900 tonnes of fuel in one year. However one problem had not been detected and was built into the plant during commissioning and lay dormant until 2005.

On the 20th of April 2005 a camera inspection was carried out into the Feed Clarification Cell within the Head End Chemical facility. When the camera was inserted a large quantity of liquid was found to be in the cell covering a large area.

This liquid was sampled at the earliest opportunity and was confirmed to be the product liquor from the THORP dissolvers. In total 83 m^3 of product liquor had leaked from a fractured pipe on one of the two Head End Accountancy Tanks, Fig.1. This liquor equated to 160 kg of Plutonium and 22 tonnes of Uranium.

Evidence from later camera inspections showed that the fracture of the pipe had occurred due to a swaying or swinging movement of the Accountancy Tank during routine operations. These movements were induced by changes in the design during the commissioning stages of the plant and by operational changes over the life cycle of the plant.

The worst aspect of the event was perhaps not that the pipe fractured, but that the leak had gone unnoticed by operators and management from as early as the 28th of August 2004 even though the cell had sump instrumentation and a discrepancy had been identified by the accountancy and safeguards department.

However the leak was contained in the secondary containment sump and there was no release of radioactive material to the environment, but was still rated as a level 3 incident on the INES scale.

It is this human element of the event that are discussed in this paper.

ROOT CAUSE

The root cause of the leak was found to be the failure of the product liquor feed nozzle into accountancy tank “B”. This failure was caused by fatigue of the pipe work during plant operations. Certain operations caused the tank to move and oscillate on its four suspending tie rods.

During the design of the vessel and its subsequent commissioning some concerns were raised by design engineers about a horizontal movement seen during simulated operations. This horizontal movement was seen when the tank was nearly empty and the tank agitation was on. This movement was caused by the changing momentum of the fluid within the tank as the fluid is sucked one way and then pushed another.

At the same time these concerns were being raised the accountancy techniques for Thorp had not been finalised. The accountancy within the Head End Chemical area could have been done by two methods, one by volume and one by weight. Accountancy using the volume in the tank would have meant the tank would have to be rested on its supporting framework to remove horizontal movement of the liquor and the tank. To prevent horizontal

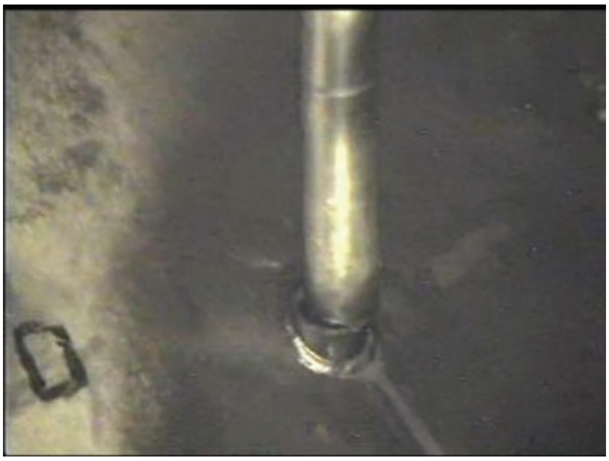

Figure 1. The fractured pipe on the accountancy tank

movement shear blocks would be welded to the frame. However accountancy was finally decided to be done by weight, therefore the shear blocks were never fitted meaning horizontal movement was not restricted.

The stress on the pipe work which resulted in the failure of the nozzle was caused by operational changes made through the life of the plant.

In 1997 it was suggested that crystallisation of uranium within the accountancy tanks could cause blockages in the process pipe work and effect the accuracy of the accountancy. Therefore a change was made to extend the agitation time during emptying operations. This meant that the tank was agitating whilst emptying into the zone that concerned the engineers some 10 years before.

It was this changed coupled with the decision not to fit the shear blocks that caused the pipe to eventually fail. Running the agitation system with the tank almost empty caused the tank to swing horizontally due to the change of direction of the fluid inside. This motion then stressed the fixed process pipe work, eventually resulting in the failure of the pipe.

HUMAN INTERACTION

With any industry human interaction determines success or failure, either very quickly in the case of direct errors for example pressing the wrong button on a keyboard. Or latently where the failure or weakness is stored waiting through time to align with other failures to cause one major one, as was the case in Thorp.

The event was made more likely to occur due to the human interactions within four key areas. These areas were Accountancy, level detection within the sump, management of alarms and sampling arrangements.

ACCOUNTANCY

Any nuclear site has to account for its material to comply with the non-proliferation treaty set out by the International Atomic Energy Authority. It is this accountancy that gave first initial warnings that something was wrong within Thorp. A shipper receiver difference or SRD is given for every campaign run through the plant. Experience of running the plant showed that SRD in accountancy could be explained by the statistical errors in the plant instrumentation, errors in documentation or incorrect information. However on four occasions the SRD was highlighting another larger issue.

There were 4 significant campaigns all of which had an accountancy "stock take" done on them, to ensure the material put into the plant could be accounted for.

- At the end of January 2005 a campaign finished with a SRD of 3.5%
- At the end of February 2005 a short campaign finished with a SRD of 3.9%
- At the end of March 2005 a campaign finished with a SRD of 10.03%
- When the leak was discovered in April 2005, the SRD for the campaign was running at 10.03%

Although when written as clearly as this it is easy to see there is an issue of material not being accounted for during the early months of 2005. However the accountancy process often took 6 weeks to fully complete due to sample result turnaround times. Also the calculations that had to be carried out when these sample results had been reported. It was often 6–8 weeks before the SRD could be calculated, by which time the plant was processing the next campaign.

During the investigation the culture of the Thorp workforce was one that the plant was "new" and failures such as this could not occur. This "culture" meant that the SRD was not investigated on the first occasion but simply put down as instrument error. Although subsequent SRD's were investigate it was never put down to a leak until April 2005.

LEVEL DETECTION

The nuclear industry use concrete enclosed cells to protect the workforce from the radioactive properties of the material they deal with. The vessels and process pipe work within the cell are classed as the primary containment. The secondary containment is the cell itself; therefore the cell floor and walls are clad in stainless steel to give it the same properties as the primary containment.

This secondary containment is designed to have a gradient which moves material towards a sump which has instrumentation in to give a level indication. The level indication within the feed clarification cell sump is based on reading the back pressure of air passed down a dip leg into the sump. The back pressure is provided by the air being pushed out of the dip tube overcoming the static head of the liquor within the sump.

The level detection system in the feed clarification cell sump failed to give a correct reading due to a simple piece of equipment. A rota meter, which regulated the air flow down the dip leg showed signs of dirt ingress causing the float to stick at the point which showed a healthy flow, however it was later found that the actual flow through the rota meter was greatly reduced and near to zero giving the incorrect reading. This was not identified until the leak was found.

Once the instrumentation fault was identified and rectified the level within the sump immediately read 1.8 m, which equated to the 83 m^3 volume.

The fault with the level instrument was not picked up due to insufficient maintenance and testing techniques. This was down to the maintenance and testing procedures and supporting documentation not being correct in scope, for example they only maintained part of the loop during maintenance activities. These checks did not include health checks on the flow systems.

The fact that this documentation could be repeatedly done with no questions asked as to its effectiveness, shows again that the culture within the plant lacked underlying training on the instrumentation systems. Also it appeared that both the engineering and operations staff did not possess a questioning attitude which could be symptomatic to "blind compliance".

MANAGEMENT OF ALARMS

Thorp was designed to be run in part by a distributed control system, which generated priority 1, 2 and 3 alarms for instances where information was outside a defined set of values.

It was common prior to the event for the operators of the Head End Chemical desk to have to manage vast numbers of alarms during normal operations often in excess of the HSE guidelines.

There was an alarm tolerant culture within the operations workforce, which allowed the plant to be run using the alarms as plant indicators instead of notification of a fault or abnormal condition. The problem was exacerbated by the fact that an alarm, if generated was not resolved quickly it would move to a second page on the control system screens and therefore not be in the operators field of view leading to it going unchecked.

In the months leading up to the event the sump was in alarm; however the sump was in low alarm. This meant that the priority of the rectifying operations dropped. When operations tried to top the sump up in response to the low level alarm they were unsuccessful, which is not surprising as the sump instrumentation was faulty and the sump was already filling with product liquor from the fractured pipe.

SAMPLING ARRANGEMENTS

As a routine task the secondary containment sumps across the Thorp plant are sampled to detect any leaks by showing that radioactive material had entered the sump.

The first failure of this routine task was that since the plant started operation, operators had struggled to obtain samples from the feed clarification cell sump. This was due to an overly complex sampling system different to any other type of sampling system within the area. Also there was no process of prompting or recording when a sample had failed to obtain a volume for analysis. Additionally with no process for highlighting failed samples meant investigations and rectification steps could not be taken.

Secondly, results that proved positive for material such as uranium were not acted upon by the operations staff. The feed clarification cell sump did at one stage give a positive result for activity. However this was not acted upon, and with the results not being trended or reviewed, meant this indicator went unnoticed.

It was this lack of awareness on the importance of routine sampling and ensuring the results are maintained and reviewed that compounded the event even further.

OTHER INDICATIONS

Other indications of a fault with the Thorp plant and the feed clarification cell were also discovered during the investigation into the event. The most prominent of these was the report of banging noises heard coming from the feed clarification cell. The noises were quickly and easily dismissed as normal pipe work creaking; however it was more than likely that the noises were from the fractured pipe hitting the vessel during agitation. This was another opportunity that was sadly missed by the plant operations team; again the "new" plant culture meant that the mindset was that nothing could break.

The temperature within the feed clarification cell had started to rise since the start of 2005. This was due to the leakage rate of the liquor becoming greater and not cooling prior to reaching the sump and its instrumentation. Although this was another warning sign, very much like the positive sample results the operations management did not have the processes in place to pick these underlying trends up and therefore act upon them. This was however exacerbated by the alarm rates at the control system.

Further more, the filters casings that house the HEPA filters that clean the cell air prior to discharge up the Thorp stack had undergone a lot of corrosion. It was unclear at the time why the mild steel casings were corroding, but in hindsight the acidic nature of the leaked liquor was the probable cause of this corrosion. Yet one more indication, the plant was giving clues as to the developing problem in more than one way.

THE CULTURE

The culture of the personnel within the Thorp plant was one that the plant was "new" as it was one of the newest buildings on the site. However the plant was constructed during the 1980's and commissioned in the early 1990's. So at the time of the event the plant was 20 years old.

The thought was that an issue of this scale and magnitude could not affect the flagship of the Sellafield site.

Prior to the discovery of the leak in April 2005 there was another event that could have indicated that the plant was starting to show the effects of 20 years of operation. In February 2005, 3 personnel were contaminated after removing a thermocouple from an in cell thermo-well pocket. Although the contamination of the personnel is the worst possible scenario in this instance the event was made worse as the 3 personnel walked through the plant not realising their gross contamination levels. They checked their clothing on 3 separate monitors, not believing the first so trying the next and so on, until a background radiation monitor showed high levels of radiation. Only then did they believe they were contaminated. The failure of this thermo-well pocket and the subsequent actions of the personnel could have been an initial indication to the possibility that failures of this "new" plant could occur and that attitudes needed to be changed.

There was an attitude of production was key and nuclear safety was not focused on in day to day operations. This was clearly identified when the plant remained in production over a weekend with a known accountancy problem. It was this culture of production first that allowed areas such as sump management and sample trending to go unchecked. With often confusion over the responsibilities of who was to do what when it came to sampling, trending and analysis of results.

The scale of the event and the shortfall in the operations of the plant sent shockwaves around the globe. Newspapers across the world led with headlines about the leak and conjectured on the future of reprocessing operations not only at Sellafield but across the globe. The leak was discussed in the houses of parliament, and operations personnel likened to Homer Simpson.

IMPACT

Often a forgotten aspect of such events is the impact on the workforce who still have to carryout their day to day jobs in the midst of intense media speculation. This was felt more by the Head End Chemical Shift Team Managers than any other party. In the weeks after the event the management chain above them was removed and not immediately replaced. This effectively left the Shift Managers wanting for clear direction and leadership during the recovery operations which were closely scrutinised by the site, the nuclear industry and the world as a whole.

The stress of the months following the event and the recovery operations did begin to tell firstly on the Shift Managers. Discussions with the team found that many of them had become depressed and alcohol had become a larger factor in one particular person's life. The management chain above them had been removed, an internal board of inquiry was ongoing with them as the focus, a management review was being carried out to understand if people were in the correct jobs and the nuclear installations inspectorate where conducting interviews under caution which eventually resulted in Sellafield Ltd being fined £500 k.

The investigation and due process being followed at the time was understood as necessary by the operations personnel. However what was unexpected was the ridicule and harassment of some of the operations personnel. One shift manager was shouted at in the street and then subsequently ignored by people who he had known for many years. The "banter" between work colleagues compounded the situation further as there appeared to be no escape from the issue, during either the home life or work life.

Often in major situations such as this, the well being of the people involved is forgotten. The personnel involved in this event had to work under immense amounts of pressure whilst being concerned for their jobs and their way of life. It is also often misplaced that the operations personnel did not come to work to make this happen. They did what they thought was the right thing to be doing, by getting the production run through the plant. It was the culture that caused the event not malicious acts of a few people.

THE CULTURAL SHIFT

Culture within the Thorp plant rightly had to change and nuclear safety had to become the overriding priority.

The first major change seen during the years after the event was the introduction to the workforce of Human Performance and most of all the building of a "questioning attitude" in the staff operating the plant. This included the introduction of 7 human performance tools, phonetic alphabet, pre-job brief, post job review, peer review, independent verification, 3 way communications and the use of STAR, which stands for Stop, Think, Act, Review.

More importantly the human performance issues had to be embedded for the future and not glossed over to facilitate the re-start of the plant. Leadership was instrumental during this process, so that the leaders could be seen to be using and also prompting people when not using it. It was this buy in by the plant leaders that allowed for human performance to become a day to day part of the plant operations, where challenge is willingly accepted. Another factor was professionals such as the plant chemical engineers using these tools and techniques in addition to the plant management. The human performance strategy was fully supported by the introduction of human performance coaches. Key influential plant operations personnel were trained in how to coach people in the use of the human performance tools. This was backed up by a human performance team, whose purpose was to be a visible presence on plant prompting the use of human performance in every day tasks.

A second change across the whole Sellafield site was the introduction of operational focus meetings. The intent of these meetings was to get the correct quorum of people in one room and discuss the safety of the plant first and any factors that affected the plant. To focus the discussion a nuclear safety dashboard was introduced, which was adopted from the nuclear reactor 4 C's dashboard. The dashboard like any car was indications of Red, Amber or Green on the 4 areas of nuclear safety. These were criticality, containment, control and cooling for the reactor stations and criticality, containment, control and discharge for the Thorp plant.

The shift manager for the plant is responsible for the dashboard for their area and uses it to flag issues that may effect or have affected nuclear safety by raising an Amber or Red condition. These issues are then discussed at the operational focus meetings prior to any other discussion. The introduction of the operational focus and the dashboards now focuses the plant operations team onto the nuclear safety issues and drives the direction of resource onto those key tasks first. It is important to note that factors effecting production are not reflected on the nuclear safety dashboards.

Over the years the plant was operated with production in mind, the plant personnel lost knowledge of some of the plant fundamentals. The most important of these was why sumps were maintained, so training was undertaken across the Thorp workforce to broaden knowledge and understanding. This re-training ended with the operations teams working to set action levels rather than to alarms. Therefore actions were taken prior to the sump reaching either a high or low alarm. The training also enabled plant operators to recognise the signs of faulty instrumentation.

The most important change was to start recording and analysing plant indications. This was done by raising Event Report Forms, which detailed an event or occurrence that was out of the ordinary. If this monitoring was applied to the Thorp plant, event reports would have been raised for positive results seen in the samples taken from the feed clarification cell, high SRD values at the end of campaigns and noises heard from the vicinity of the accountancy tank. Although the raising of a form would not have prevented the event, having all the information in one place which is trended may have prompted investigation earlier. This operational experience feedback or OEF has full support both managerially and financially by Sellafield Ltd. OEF teams for each operational area coordinate the raising and trending of events and also report back the progress of actions to the plant management.

The importance of this operation experience feedback cannot now be stressed enough; however it can only be successful if the events are raised correctly and the trending is done. Otherwise it falters and becomes another process that people see that they have to do. Although it should not be limited to the operational experience of the plant, it should endeavour to cover learning from all other industries.

The Thorp plant was restarted some 3 years after the discovery of the event after all the re-training had taken place. However the physical and emotional scars are still very raw to some of the personnel who were closely involved. Nuclear Safety is now the number one overriding priority of the plant personnel, with people not afraid to challenge the norm and to ask the perhaps "stupid" question. The plant operations teams particularly within Head End Chemical have matured, but are determined never to let this happen again. A new wave of accountability within the Thorp operations management has meant focus remains on the safety of the plant. With support for closing operations down if nuclear safety is threatened. Although operation re-started tentatively and with trepidation the plant is now classed as fully operational, although it will not be shearing the throughput rates it saw in its early years.

CONCLUSIONS

There is no doubt that this event was significant for the nuclear industry as a whole. The ripples felt across the world were varied and have led to complex re-negotiations to win back customer and regulator confidence.

The root causes of this event have been seen in other large events around the world out with the nuclear industry. Therefore it is important that as professional engineers learning of such events is spread across all industries at every opportunity.

Two key aspects come out of this event, firstly the defence in depth principle must be maintained. Erosion of this principle breaks down the barriers that lead to significant events. Poor design or operational decisions remove defence layers which moves operations closer to the boundary of the safe operating envelope. Secondly, as personnel working in high hazard industries serious questions must be asked of ourselves. Are other administration tasks taking over time that used to be dedicated to plant monitoring? What are the plant indications telling you? What are the underlying trends? And overall, whats the worst that could happen?

The purpose of this paper is to share the experiences and faults which occurred during one of the major nuclear events in the UK. The paper itself cannot ask the correct questions, however it should prompt people working on plants to ask themselves some searching questions. Are their systems and processes robust enough to ensure a similar event does not occur in their area?

In the event in Thorp all the evidence was there, the problem was no-one was looking.

So ask yourself, what is your plant telling you?

REFERENCES

There are no references within this paper, due to a unique and differing quality.

The paper is written by a Shift Team Manager that lived through the feed clarification event, the subsequent re-training and the plant re-start. Who is now confident enough to write about the event to ensure the events that happened to him do not happen in other industries.