

**CALDER HALL COOLING TOWER DEMOLITION: Landmark Milestone for  
Decommissioning at Sellafield - 8497**

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**ABSTRACT**

September 2007 saw a very visible change to the Sellafield site following the culmination of a major decommissioning project; the demolition of the four Calder Hall cooling towers.

A key part of the UK's nuclear industrial heritage, Calder Hall, the world's first commercial nuclear power station, was opened by Her Majesty Queen Elizabeth II in October 1953 and continued to generate electricity until its closure in 2003.

Following the decision to decommission the Calder Hall site, explosive demolition was identified as the safest and most cost effective route for the removal of the towers. The technique, involving the placement of explosive in 60% of the circumference of both shell and legs, is a tried and tested method which had already been used successfully in more than 200 cooling towers in the UK in the last 30 years.

The location and composition of the four 88 metre high towers also created additional challenges. Situated only 40 metres away from the UK's only nuclear Fuel Handling Plant, as well as other sensitive structures on the Sellafield site, the project had to address the impact of a number of key areas, including dust, ground vibration and air over pressure, to ensure that the demolition could be carried out safely and without significant impact on other operational areas on the site. At the same time, the towers had to be prepared for demolition in a way that minimised the amounts of radioactive or hazardous waste materials arising.

This paper follows the four year journey from the initial decision to demolish the towers right through to the demolition itself as well as the clean up of the site post demolition. It will also consider the massive programme of work necessary not only to carry out the physical work safely but also to gain regulatory confidence and stakeholder support to carry out the project successfully.

## INTRODUCTION

Located on the North West coast of England, Sellafield has developed over the years, focusing on a wide range of nuclear goods and services, including reprocessing, defence materials development and power generation, at its Calder Hall power station.

The building of the four reactors started in 1953 and on October 17, 1956 Her Majesty the Queen officially opened Calder Hall, the worlds first commercial nuclear power station. It continued to operate and provide electricity to the national grid until March 2003 when the plant was shutdown and decommissioning work started on various parts of the station, including the four cooling towers.

The four cooling towers are essentially identical, and over the past 30 years, over 200 similar structures have been successfully demolished in the United Kingdom using the proposed technique. This requires that approximately 60% of the circumference of the shell and legs be removed by explosive charges causing the structure to deform, rotate and collapse into the basin directly beneath the tower.

The technique for the demolition of these structures is not unique however the location of these cooling towers on an operational nuclear site within 40 meters of one of the UK's nuclear fuel handling plant created additional challenges. The cooling tower structures have long been a local landmark and their demolition is the most visible demonstration of the site's decommissioning progress.



## TECHNICAL INFORMATION



Calder Hall Cooling Towers

Each of the four cooling towers was approximately 88 meters (m) in height from the pond base and had a hyperbolic reinforced concrete shell. The minimum thickness of shell from the top down to approximately 29 m above the pond base was 114 mm. Below this level the thickness increased linearly to the bottom of the shell where it was 406 mm.

Each tower had 64 raking legs that support the shell which were 7.3 m high and 406 mm in diameter. The internal diameter at the top of each tower was 32 m, and 58 m at the base. The estimated mass of each tower shell including legs was 5,200 tons.

Each tower had a pond structure below the shell. The base and the walls to the pond were reinforced concrete construction and designed as water retaining structures. The pond was octagonal in shape and approximately 68 m between the external faces of opposite flat sides. The walls extended 2.6 m above the base and externally extended above the adjacent ground level.

The Calder Hall cooling water system was a closed system; cooling water was circulated from the cooling towers to the adjacent turbine hall condensers and back again via underground bitumen lined steel pipes.

The progressive deterioration of the Calder Hall cooling towers has been documented throughout their lifetime and regular inspection regime. Various repairs were carried out throughout the 1980s, most notably on the legs and areas of spalled concrete on the shell. For towers of this age, there was some concern that the effects of aging of the towers could become an issue increasing the potential for an inadvertent collapse. This concern was not unwarranted as several towers of similar construction had inadvertently collapsed, resulting in a modification to the UK construction standards. These inspection reports indicated that the towers were in a reasonable condition for structures of their age and type.

## DEMOLITION METHOD

A project team was formed to evaluate potential demolition methods and extensive research was carried out to determine the most appropriate technique, in terms of both nuclear and conventional safety, and also cost effectiveness.

These methods were evaluated against the following high-level safety principle:

*The demolition of the Calder Hall cooling towers must not present an unacceptable nuclear, conventional or environmental safety hazard that could adversely affect the operation of safety significant systems, structures and components or essential services on the Sellafield site or result in significant workforce, public or environmental consequences.*[1]

The evaluation reviewed a number of alternative demolition methods however all the research carried out demonstrated that the best practical method for cooling tower demolition was explosive demolition.

Explosive demolition of hyperbolic reinforced concrete cooling towers has been consistently and successfully demonstrated on sites sensitive to air overpressure and ground vibration, and on cooling towers within close proximity to critical installations such as operational electrical sub-stations, chemical plants and power lines either above or below ground level.

The project team documented their findings and evaluations in a Preliminary Safety Report (PSR) that was presented to the Sellafield Site Nuclear Safety Committee. Due to the tower locations on an active nuclear site, a number of potential hazards/implications were identified that required additional evaluation. These included:

- Debris spread
- Ejected high velocity small fragments
- Ground vibrations
- Air overpressure
- Dust release
- Use of explosives

To address these, the work was broken down into preparation of safety documentation, management of stakeholders, site preparation, removal of the cooling tower internal materials, and shell demolition.

Technical notes addressing ground vibration, debris spread, projectiles, noise, air overpressure, dust, the use of explosives, and an assessment of the radiological status of the towers were prepared. These were based on the standard demolition method for these types of structures referred to as 2/3 leg and shell method. Once these were completed, the results of the hazards and impacts were used to assess the potential affect on the surrounding plants.

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The technical notes evaluated the potential results not only if the demolition went according to plan but also for a worst case or fault scenario. Not all of the fault conditions that were evaluated were credible, but these were still evaluated and documented to address the comments from the Nuclear Safety Committee.

## **SURROUNDING PLANT ASSESSMENTS**

All of the facilities within the 200 m zone of the towers were identified in addition to the utility services, railways, and roads that ran through the project area. The technical note results indicated that most of the potential impacts were restricted to the Calder Hall site, however dust and vibration were identified as having some potential impacts outside the area local to the towers.

The Sellafield Ventilation Technical Support Group was engaged to assess the potential impact of the dust on surrounding plants. The assessment indicated that if the plants reacted by placing their facilities in the same configuration they adopt for emergency exercises, such as closing doors / windows then the risk would be mitigated.

## **CONTRACTOR SELECTION**

As not all of the work could be carried out in house, the project team contracted out two main packages of work to Tier Two suppliers. These were the removal of the internal materials from the towers, and then the actual demolition itself.

Following a lengthy tendering and selection process, Robinson and Birdsell were selected to remove the internals, using a method which maximised waste segregation whilst simultaneously minimising the risk of people working at height.

The contract for demolition of the tower shells was awarded to American firm Controlled Demolition Inc. (CDI), again following a rigorous selection process which took a number of factors into account, including safety, previous performance and value for money. Their proposal was to use the standard cooling tower demolition method with some minor variations to reduce ground vibration.

CDI then subcontracted various elements of the work out further, using a number of local companies for work such as installing the primary and secondary protection and transporting the explosives.

Finally, a firm of independent specialist explosive safety consultants were also engaged to oversee the entire project. Richard Vann Associates provided independent verification of all the project documentation, as well as explosives advice and expertise to the Principal Contractor's team.

## **PRE COMMENCEMENT SAFETY REPORT (PCSR) AND APPROVAL PROCESS**

The approval process for the safety documentation required that the technical notes were prepared with the assistance of specialist contractors in the field of vibration, dust modelling, explosive transportation and explosive placement. Once the technical notes were complete, the notes were verified through the project independent explosive engineer or subject matter expert and engineering departments.

In addition, an Independent Nuclear Safety Assessment review was completed on all of the technical notes and PCSR. The documentation was also assessed and approved by the Calder Hall Management Safety Committee at a special meeting which also included members of safety committees from the surrounding plants.

A summary paper of the findings was prepared and submitted to the Sellafield and Drigg Nuclear Safety Committee. Following their endorsement, the whole safety case was submitted to the Nuclear Installations Inspectorate (NII) for noting and approval. Prior to the NII responding, they ensured that the Environmental Agency was satisfied with the environmental documentation for the project.

The final package of implementation documentation consisted of a Project Implementation Plan, Contractor's Method Statement, Risk Assessments and Work Safety Plan, these were approved either through a document review committee or via the Calder Hall Management Safety Committee as appropriate.

## **STAKEHOLDER MANAGEMENT**

As the cooling tower project developed, a large number of affected people and plants were identified, as well as high levels of interest both on site and in the community. To address this, a separate work stream was identified for stakeholder engagement. A stakeholder engagement plan was developed by outlining any individual, plant, or group that might be affected or interested in the project. The comprehensive list of stakeholders can be categorized into seven main groups, as follows:

1. Potentially affected plants
2. Regulators
3. Sellafield site stakeholders
4. Security
5. Calder Hall workforce
6. External stakeholders
7. Sellafield Ltd employees

Over 110 stakeholders were identified with 30 being classified as key to project success. A comprehensive communications strategy was developed to support stakeholder engagement and ensure that consistent messages about the project were delivered to all stakeholders.

Key stakeholders crucial to the success of the project were the personnel in the surrounding plants. It was known that some of the plants would be affected by the project and may be required to implement physical measures as part of the project precautionary activities or be asked to evacuate their buildings during the demolition to maintain the exclusion zone.

Each of the affected plants conducted their own review process, the result of which was the preparation Safety Case and subsequently a Temporary Operating Instruction detailing precisely what actions they had to take both in the run up to, and during the demolition itself. At one end of the scale, buildings simply had to be evacuated, whereas at the other, plant operations were affected and hold points had to be built into the demolition project implementation plan.

Offsite, a comprehensive programme of public meetings, presentations and open days ensured that stakeholders remained engaged all the way through the projects development and had opportunities to express their questions and concerns. These consultations covered a number of high impact actions, such as a Traffic Management Plan developed in conjunction with Cumbria Constabulary, Cumbria County Council and the Highways Agency, which implemented a complete closure of all major roads in the vicinity during the demolition.

In addition, maintaining security was fundamental to project success. The security for the project involved several organizations and was regulated by the Office of Civil Nuclear Security, through an approved project security plan, submitted 28 days prior to the demolition. Sellafield has its own security force the Civil Nuclear Constabulary (CNC) who was involved with implementing the security arrangements and since the project exclusion zone extended off site, Cumbria Constabulary also had to be involved.

The project security requirements involved controls for bringing explosives onto a nuclear site, safe explosive transportation and maintenance of the exclusion zone. Security off-site involved fencing off the area of the exclusion zone, setting up signs, and establishing roads blocks to minimize the potential for accidents due to the distraction of the demolition.

## **SITE PREPARATION**

Site preparation was complex, and involved the identification of surrounding utilities and removal of redundant plant. The surrounding plants were involved in the review and two potential issues were identified requiring additional protection. These were a process waste line next to one set of towers, and an interceptor sewer line that ran very close to the other set of towers. Additional physical measures were installed on the ground above these two line to protect against damage from debris.

Plants around the structures, including the pump pits for the towers and a water treatment plant, were either demolished or placed in a configuration that eliminated the need to protect the structure during the cooling tower demolition.

## REMOVAL OF INTERNALS

The tower internals consisted of concrete supporting columns and beams, timber framework supporting the plastic pack, and asbestos cement pipes.



Towers showing various layers of internal structure

The towers were re-packed in 1978 and 1994. The total volume of material removed comprised 75 tons (1 mile) of asbestos piping, 6,000 m<sup>3</sup> plastic packing, and 260 tons of tanalised timbers from each tower.



Segregation of internal packing materials prior to disposal

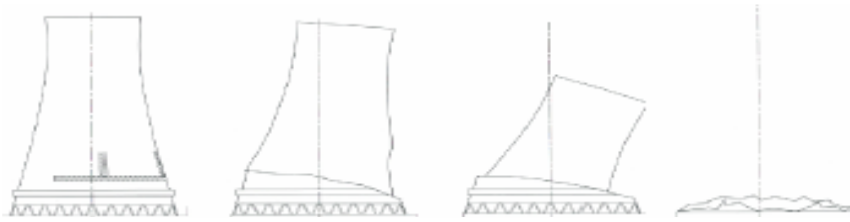
The contracting strategy for the tower demolition required that the internals work be separated from the demolition. Waste management for this part of the project was linked into the overall characterization of the structures and the plastic packing, wood, and asbestos pipe were sampled prior to initiating the work. The plastic packing and wood were free released almost immediately however, adequate samples of the asbestos piping could not be collected, which required a number of samples to be taken as it was removed. The asbestos pipes were then stored until the samples were returned.

## DRILLING AND TEST BLAST

The proposed demolition technique required that approximately 60 percent of the circumference of the shell and legs would be removed by explosive charges. This causes the tower to tilt and collapse landing essentially in its own footprint, as demonstrated

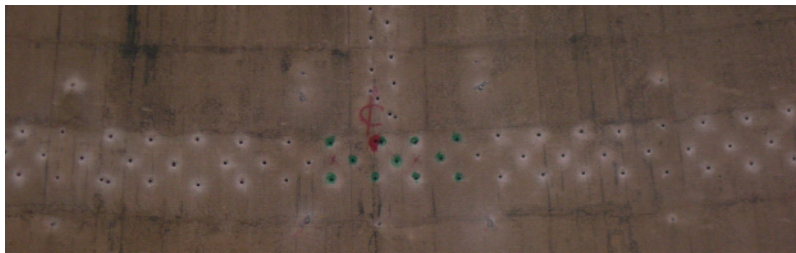


below. This outcome is achieved by the positioning of the charges in the structure, which allow the direction of the gravitational fall to be influenced and controlled as required.



Demolition sequence

Over 5,600 holes were drilled throughout the four towers to enable the explosive charges to be loaded for final demolition. These were placed in a horizontal stitch pattern around the circumference of each shell, and in addition to this, three vertical slots, approximately 10 metres high, were also drilled. This was to ensure that the shell broke up and fell exactly as predicted, within the estimated debris zone. In addition, five holes were also drilled into each of the tower legs, equidistant from top to bottom. The aim of these was break up the concrete in the legs and buckle the supporting rebar sufficiently, thus causing the legs to fail.



Stitch drilling pattern in shell

Following completion of all the preparatory work and submission of the final safety paperwork, the first of the two required Licence Instruments was granted by the Nuclear Installations Inspectorate on Tuesday 7 August, enabling a test blast to be carried out on Saturday 11 August 2007.

This enabled the explosive demolition contractors, Controlled Demolition Inc., to load a small amount of explosive into three of the four shells and a leg from each tower. These were then detonated in pairs, and the findings from the first test blast were fed back into the calculations for the second pair, to ensure that the optimum charge weight could be confirmed.

As well as testing different charge weights the first test blast also indicated that a different charge distribution in the legs would give a more effective outcome. This resulted in the hole pattern being amended so that an additional hole was drilled between the bottom two existing holes. This displaced the rebar more effectively, providing higher certainty and control for the final demolition.



At the same time, the test blast was used as a complete dry run for all the command and control arrangements that would be in place during the actual demolition itself. These included the setting up of a dedicated control suite containing representatives from both the project team and also the off site agencies involved. Although off site measures were not implemented, the full 200 m exclusion zone on site was established, utilising 46 sentries to search the area and maintain line of sight contact throughout.

### **EXPLOSIVE LOADING**

Following the successful test blast the learning was incorporated into the method statement and the project implementation plan, and the final documents, together with the test blast report were submitted to the Nuclear Installations Inspectorate for their final approval and the granting of a Licence Instrument for the final demolition.

Given the number of charges to be loaded, a 10 day loading schedule was prepared, leading to a weekend demolition during Sellafield silent hours. Contractor availability impacted heavily on the programme schedule, so the decision was taken to work on an 'at risk' basis towards the programme date of 29 September 2007, prior to the receipt of the licence instrument.

This decision enabled all the statutory notifications to be submitted with the appropriate period of notice as well as the implementation of a detailed stakeholder communications package that included, amongst other things, over 3,000 letters sent out to all households and businesses within the Sellafield sightline, notices broadcast in the local print media and numerous radio and television interviews by members of the project team.

To protect against projectiles and Air Over Pressure (AOP) during the planned explosive demolition primary blast protection was used for the Calder Hall Cooling Towers - a combination of chain link wire fencing and geotextile fabric. As a potential safeguard in the event of a premature detonation, protection was installed on the shell and legs prior to the placing of the charges, as per standard industry practice. As well as minimising the time when explosives were in place unprotected, this method also minimised the potential for damaging the charged explosives (e.g. pulling them out of their holes, or pulling out a wire connection) when installing the protection. The effectiveness of the primary protection was confirmed by the test blasts.

To further protect against fault conditions, secondary protection was also provided where necessary to minimise the impact of AOP or fragmentation damage to essential facilities that may be susceptible to damage. This was detailed in the Plant Specific Assessments, however the demolition contractor retained ultimate control over the minimum required protection for adjacent facilities/plants. The protection details were then specified in the final detailed method statements and verified by an independent explosives expert.



Primary protection in place on tower legs

To minimise the amount of uncharged explosives on-site at any given time, and to eliminate the requirement for on-site storage, explosives were brought onto site on a day-by-day basis. Only the amount anticipated to be used during each day was transported onto site at the start of each day from a UK Licensed store.

Following receipt of the Final Licence Instrument from the Nuclear Installations Inspectorate on Tuesday 12 September loading commenced on site on Tuesday 18 September under supervision of the UK licensed shot firer. This precipitated a comprehensive programme of road and area closures on site to ensure that the appropriate exclusion zones for persons were effectively implemented for the duration of the off-loading operations.

The recommended size of the exclusion zone during loading operations is dependent on the amount of explosive material present within the tower perimeter and was based on a maximum amount of 50kg TNT on site at any one time. These were determined as at least 70m from the designated off-loading points for people in the open, and 110 m for any glassed area, such as adjacent buildings or vehicles.

It should be noted that the exclusion zones were only required when uncharged explosives were present within or near the towers. Once charged and stemmed within their drilled holes explosives are considered to be secure, with inadvertent detonation only credible via lightning strikes, this eventuality being covered by separate precautionary measures.

## DEMOLITION

From the start of explosive loading, the project was governed by a Project Implementation Plan (PIP), detailing day by day all the steps and hold points which had to be completed for the project to proceed to demolition.

Once loading was complete and the initial connections made, final secondary protection was installed on all affected plants the day prior to the demolition, which took place on Saturday 29 September 2007. As detailed in the Temporary Operating Instruction for each individual plant, this ranged from the taping up of doors to prevent dust ingress to a complete shutdown of the Fuel Handling Plant.

On demolition day itself, a 200 m exclusion zone was established, manned by 61 sentries, and final plant checks were carried out prior to the final explosive connections being made at the command post firing point. The demolition itself occurred in two phases; the north towers were demolished as a pair first, followed approximately four minutes later by the south pair of towers. This delay for visual checks was specifically scheduled into the PIP to ensure that there were no problems with the demolition method statement. Each pair of towers fell in less than 4 seconds, landing almost entirely within the confines of the tower basis as predicted. Debris spread was also confined to the immediate vicinity of the towers, well within the 10 – 20 m range identified by the technical notes underpinning the demolition.



Tower debris prior to clean up work commencing

Following the demolition, post demolition checks were conducted to ascertain whether there were any immediate issues. The only reported damage was cosmetic, consisting of broken glass in some of the facing windows of the reactors closest to the cooling towers. Not unexpected due to the age of the structure and close proximity to the towers, this had been identified as a risk prior to demolition and measures to repair the affected windows were already in place.

## **SITE CLEAN-UP.**

Final clean-up of the two cooling tower sites commenced in November 2007 managed by the demolition contractor CDI and using UK subcontractors Thompson of Prudhoe to complete processing work.

Debris from the towers, consisting of approximately 5,600 tonnes of concrete shell and metal reinforcing bars, will be initially separated on site using excavators to enable the metal rebar to be sent off site for recycling. The concrete will be processed through a crusher and returned to the tower basins to be used as infill. In volume this expected to fill approximately two thirds of the capacity of the basins.

Once this is completed, with the south pair scheduled for completion in March 2008 and the north pair shortly after, the remainder of the voids will be filled with similar waste from other projects across the Sellafield site.



Clearance work underway on site

## **SUMMARY**

The demolition of the four Calder Hall cooling towers was a highly visible symbol of the changes that are occurring on the Sellafield site as it moves forward towards a decommissioning future.

Although in itself the demolition was both straightforward and standard, the various complexities posed by the towers situation at Sellafield introduced an entirely new element to the project, with a number of complex challenges which had to be overcome or resolved before the demolition could take place.

It is a testament to the skill and dedication of the project team and its associated contractors that the project was delivered safely and successfully without a single

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accident, injury or event throughout the entire four years, and with minimal impact on both site operations and the local community.

## **REFERENCES**

- 1 Burnett, A. January 2005. Preliminary Safety Report for demolition of the Calder Hall Cooling Towers. S&DSNSC(05)P01 & RNSC(05)P715.
2. D L Foss, 2006. Demolition of cooling towers from the worlds first commercial reactors: The nuclear factor.