WM ’06 Conference, February 26–March 2, 2006, Tuscon AZ

The Development and Delivery of the Waste Encapsulation Plant at UKAEA Harwell

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ABSTRACT

The UKAEA site at Harwell, Oxfordshire currently stores Remote Handled Intermediate Level Wastes (RHILW) generated from its research works dating from the 1950’s and wastes received when Harwell provided the UK National Disposal Service (NDS) for radioactive wastes. Additional RHILW is also being generated from UKAEA’s progressive decommissioning and site remediation activities at Harwell. The reference strategy for the management of RHILW at UKAEA Harwell is to encapsulate the waste within a cementitious grout, thereby rendering it passively safe and in a form suitable for long-term storage and eventual disposal to a national repository. In order to achieve this objective, a purpose built facility, the Waste Encapsulation Plant (WEP) was needed.

The WEP is a key element, and the final part, of the near-term strategy for the management of solid RHILW at Harwell. The successful completion of the WEP will allow UKAEA to significantly reduce the hazards at Harwell, which will lead to significant environmental, safety and cost benefits.

Following a number of feasibility studies and research works to determine the most appropriate encapsulation medium, a competitive two-phase design and build contract was awarded.

This paper describes the development of the project from inception, through the research works, to the novel commercial and technical approaches used to ensure a quality, cost effective solution for these unique and difficult wastes. The final design solution is presented, the benefits in construction, operation, maintenance and decommissioning identified, and the processes used for determined the most appropriate solution explained.

INTRODUCTION

Whilst there is currently no national storage solution for Intermediate Level Waste (ILW) in the UK, the parameters necessary to enable “passive safety” [1] of the wastes, and therefore acceptable for receipt in the Repository, are well defined and enforced by UK Nirex. For RHILW, passive safety effectively means immobilising the waste in an inert medium, and more practically, a cementitious grout.

The Active Waste Retrieval Programme (AWRP) at UKAEA’s site in Harwell lies on the critical path of the programme for decommissioning the whole site. The AWRP is a suite of projects to facilitate the passive safety of all of the RHILW at Harwell. Historical wastes are removed from storage tubes within the ground using a purpose built machine and then transferred to a suite of cells, known as the Head End Cells, that enable the waste to be assayed, tipped, sorted and re-packaged into Nirex approved 500 litre stainless steel drums. They are then transported to a purpose built Vault Store awaiting encapsulation. There are two major projects currently being implemented under the ongoing AWRP. These are: the procurement of a second machine to enhance waste retrieval operations; and the procurement of a facility to condition the re-packaged waste ready for interim storage and final disposal, known as the Harwell Waste Encapsulation Plant (WEP). The final project in the programme is to design and build a Waste Export Facility (WEF) that will interface with the WEP and allow the transportation of the wastes off the Harwell site to the National Repository, when it becomes available.

HISTORY OF THE WASTE ENCAPSULATION PLANT PROJECT

The need for a plant to encapsulate the wastes was always known and planned for. When the Head End Cell facility was built, there were plans to incorporate a cementation cell. Technically, it was decided, that this was the correct approach and it could be achieved with some additional costs (approx £1M in 1990 value). However, due to funding constraints at the time, the decision was made to design and construct a separate facility in future years. Prudently, a provision was made in the design and construction of the Vault Store of a sealed export penetration for future connection of the WEP.

In the late 1990's, work began to assess the feasibility of the WEP and external consultants to determine the viability of various options carried out various studies. After some initial work, the WEP project was identified as a potential Private Finance Initiative (PFI) scheme, whereby the private sector would supply the money to design, build, maintain and decommission the plant. In return they would receive an annual fee throughout the maintenance period to recover their costs, and ultimately make a profit.

In order to achieve the timescales necessary to meet the overall programme the project was effectively split into two parts.

- Technical; and
- Commercial and legal.

The preparation of the technical documentation was primarily the production of an Output Specification. This document described the necessary output for the project in terms of deliverables and was deliberately non-specific so as to promote innovation. The commercial and legal framework for a PFI is the heart of the project, and specialist legal, insurance and PFI experts were employed to develop the necessary paperwork. After approximately one year of concentrated effort, the UK Government decided that PFI in the civil nuclear sector was unacceptable and the project reverted back to a traditional procurement route.

During this time, other works were continuing so the project was de-risked as far as practicable. The main risk to the project was always seen as obtaining planning permission from the local authority, Oxfordshire County Council. In order to mitigate this risk, it was decided that Outline Planning permission together with a voluntary Environmental Statement [1], detailing the environmental impacts of the development, be submitted. This would address the headline issues of the project and agree a non-contentious way forward, ready for the detailed planning application that would accompany the final design. Three dimensional computer modelling was used in the Outline Planning Application so that the public could see the minimal visual impact of the development and be assured that the radioactive discharge from the encapsulation process was insignificant.

The other major risk was the development of an acceptable wasteform, and particularly the development of a suitable encapsulation grout. It was decided that this work be best carried out in two stages:

- Small scale trials (approx 2 litre) carried out by a UKAEA Encapsulation Specialist; and
- Full-scale trials (approx 400 litre) carried out by a Contractor awarded under competitive tender.

The initial trials examined the flow characteristics for both Pulverised Fuel Ash/Ordinary Portland Cement (PFA/OPC) and Blast Furnace Slag/Ordinary Portland Cement (BFS/OPC) /BFS/OPC grouts and developed acceptance envelopes for both mixes in terms of water/solids ratio and the ratio of the pozzalanic material to the OPC. All mixes were tested for flow characteristics over time, compressive strength, bleed water and dimensional stability and the grout acceptance envelopes developed.

The full-scale trials used 400 litre drums to simulate those conditions that would be found in the WEP. From the existing waste database [3], the overall waste characteristics could be summarised and a representative reference sample of wastes determined. This reference waste loading was used for all the trials. The initial trials examined the feasibility of using PFA/OPC or BFS/OPC mixes at both the “thick” and “thin” end of the acceptance envelopes [4]. Whilst both demonstrated acceptable wasteforms when sectioned, see Fig. 1, the BFS/OPC mix showed large volumes of bleed water during curing. Due to the rationalisation of the management of liquid effluent on the Harwell site, liquid effluent within the WEP was considered undesirable and so the BFS/OPC mix was discounted.

Further trials examined the encapsulation of problematic wastes, hydrophobic, hydrophilic and reactive metals in differing proportions and an optimum mix of 3:1 PFA/OPC and 0.42 Water/Solids (W/S) ratio determined. The research complete, the contract was closed. In later months, however, the issue of the reactive metals and the evolution of hydrogen would need much closer examination.

Fig. 1. Sectioned drum showing inactive encapsulated waste

COMMERCIAL APPROACH

In late 2003, the sponsoring UK Government department, the Department of Trade and Industry, instructed UKAEA to stop work on the PFI procurement and instead, consider other contract models to deliver the WEP. Following a UKAEA contract strategy workshop it was agreed that a two-phase approach for the design and construction of the WEP would be the most economically advantageous solution. This approach allowed two competing organisations, or consortia, to enter a four-month period whereby they would develop their scheme design in collaboration with UKAEA. Following this period, during which time the Contractors were continually assessed by the Client, they submitted a final scheme design package and a fixed and target price for phase two of the works, the detailed design, construction and in-active commissioning of the plant. The active commissioning, operation and subsequent decommissioning of the plant would remain UKAEA’s responsibility.

The phase one contract was awarded to Costain Oil, Gas and Process (CoGAP) and RWE Nukem Ltd (RWE) and the final deliverables were clearly set out in the original specification.

They were:

- Options Study and Feasibility Report to confirm Scheme Design;
- Scheme Design including:
    - General Arrangement Drawings (Building and Process);
    - Schematic Drawings (Process);
    - Schedules of Equipment;
- Design Report for the Scheme Design;
- HAZOP Study;
- Preliminary Safety Report;
- Programme for the delivery of Phase 2;
- Fixed and Target Price Cost Schedule for Phase 2; and
- Detailed Technical Specification for Phase 2.

In addition, and following the various development works that had been done in house, various areas of concern were highlighted to the Contractors that should be addressed in the design:

- Drum and Lid Handling;
- Drum Throughput;
- Contamination Control;
- Details of Interlocks and Protection Systems considered to have a radiological consequence;
- Production of an acceptable wasteform (no voidage);
- Hydrogen evolution during grouting; and
- Unproven technology (and the use of mock-ups to prove the plant design).

During the development of the scheme design it was vitally important that UKAEA did not cross-pollinate the ideas between the Contractors thus ensuring that there was sufficient diversity to judge the final scheme designs. It was also vital that commercial information was kept strictly confidential, and limiting the number of project staff with access to the information and educating the staff on the commercial importance of confidentiality to UKAEA, achieved both of these objectives.

Stakeholder acceptance was crucial throughout the process, specifically from the operators of the proposed plant. They were integrated into the discussions, and ultimately the acceptance process, but made aware that any plant enhancements that they wanted would have cost implications for UKAEA and so all changes outside the agreed Specification [5] and Statement of Requirements [6] would need careful justification. This limited the number of changes made by the operators.

As the critical path of a nuclear project will inevitably lie with the Safety Case approval, the Preliminary Safety Report (PSR) was a key deliverable. Whilst the number of risks with such a plant is relatively small the importance of this document was recognised at an early stage. With this in mind, and as the WEP would be a Category A modification to the existing B462.27 Vault

Store Safety Case, both Contractors were invited to present their PSRs to the UKAEA project team, internal stakeholders and Nuclear Installation Inspectorate (NII) and Environment Agency (EA) representatives. Whilst the NII would not comment on the specific elements of the PSRs, it was a valuable exercise that allowed the UKAEA project team to focus the Contractor to general areas of regulatory concern.

The phased approach also allowed UKAEA to further de-risk the project. As the WEP is to be constructed within the B462 complex, it was judged that the more onerous site constraints would lead to additional problems for the Contractor during the construction and hence increased costs. With this in mind, it was agreed that the B462 boundary fencing would be realigned to remove the construction site from the complex, thereby allowing the Contractor to manage his own site, albeit within the general constraints of the Harwell Nuclear Licensed Site. The construction could then be carried out outside the boundary fence and only brought back within the complex upon the completion of in-active commissioning.

Following a pre-defined technical, Safety Case and commercial assessment, RWE were chosen as the preferred Contractor.

THE CHOSEN DESIGN – RWE NUKEM

RWE Nukem's design was chosen as it satisfied the pre-defined criteria that had been set during phase one. The main criteria it satisfied were:-

- Cheapest compliant option;
- Satisfied the UKAEA programme requirements;
- Smallest footprint (less environmental impacts);
- Utilised known technology (using contamination control philosophies used on existing B462.27 plant);
- Less risk inherent in the design (less drum movements);
- Good experience and confidence in the design team (from phase one); and
- Co-location of Client and designer on Harwell site.

The RWE design for the WEP is a compact facility with a shielded cell line constructed in reinforced concrete. Due to expected levels of contamination increasing once the lid is removed, the Grouting Cell is segregated from the rest of the facility by steel walls and floor mounting a double-lidded port system, effectively forming a containment box. The waste drums are moved around the facility on a series of roller conveyors. The waste drums in the Vault Store are free from external contamination and it is essential that the uncontaminated condition of the Store is maintained by ensuring the grouted drums are returned in a clean state.

Fig. 2 and Fig. 3 show the final accepted scheme design for the WEP. Whilst, this was not the original submitted design from RWE, changes and refinements were made in partnership between RWE and UKAEA until the design could be frozen.

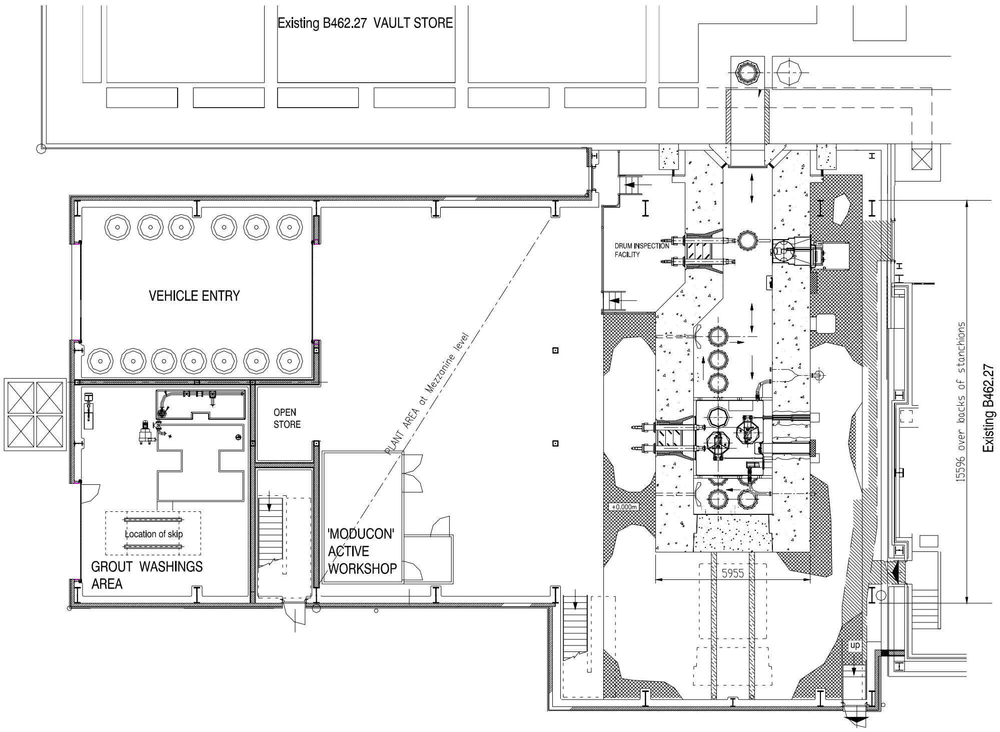

Fig. 2. RWE scheme design – plan layout [7]

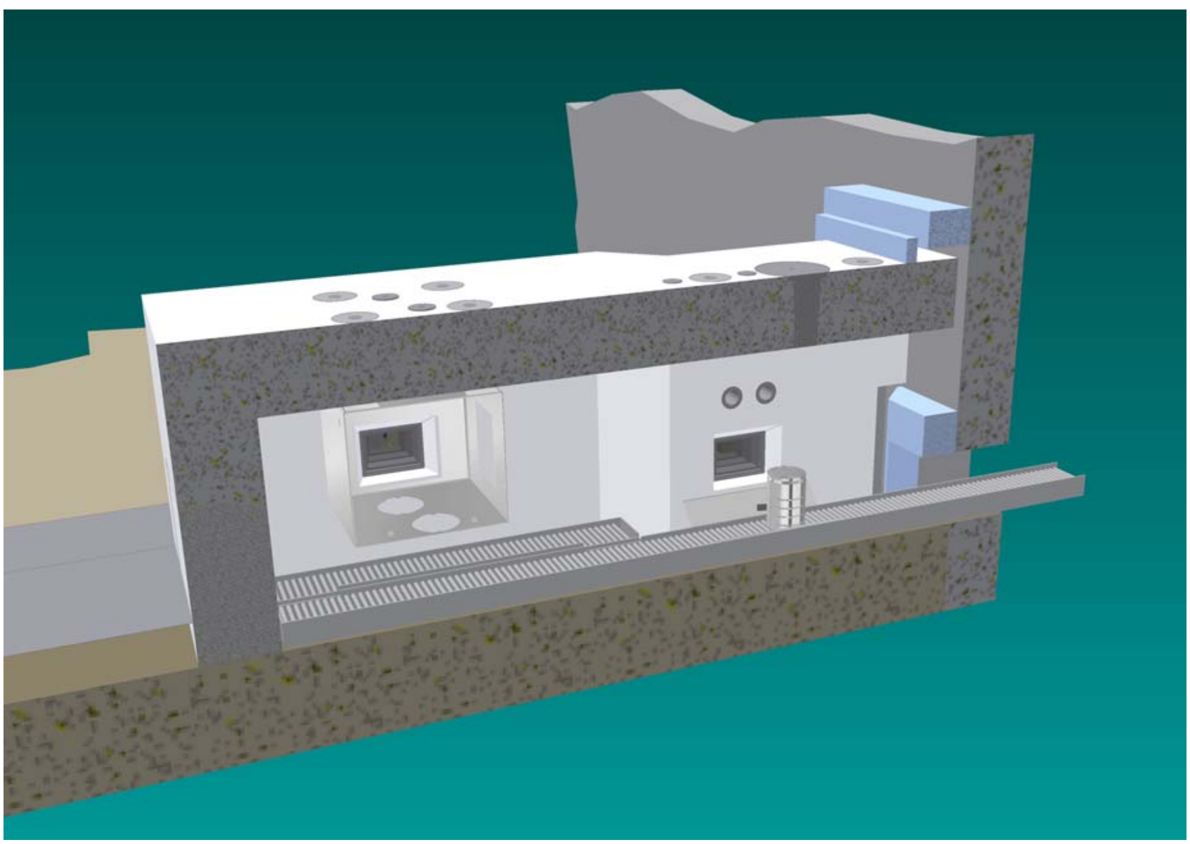

Fig. 3. Section through the WEP [7]

WEP PROCESS

The WEP process is basically a linear progression of activities that is predominately controlled by the curing time for both the matrix and capping grouts.

Throughput models [8] have been used extensively in both phases of the contract and have been useful in giving confidence that the design can meet the throughput requirements stipulated in the contract. Careful consideration has been given to the durations of the various processes, and operator and specialist input has been used to refine the models. Validation of the model by independent consultants was also employed to increase confidence in the applied logic.

A brief summary of the main elements of the WEP process is given below.

The Vault Store crane starts the encapsulation process by delivering a drum of waste through the Vault’s exit plug aperture and onto the conveyor system. The main actions are then:

- The drum stops at the Drum Inspection Facility (DIF) where it is visually examined, monitored, weighed and swabbed. Following the drum checks, the lid is unbolted, although the bolts and the lid remain in place, resting on the drum seal. Containment is maintained throughout this process by the drum’s inner lid.
- The drum moves on to the Grouting Cell where it is raised a short distance to engage with the matrix grout station port. The drum lid is latched to the port door and raised from the drum. The drum’s inner lid is then lifted away and stacked nearby for disposal at a later stage. The grout head is lowered, and the matrix grout added. The drum lid is replaced; the drum is lowered and moved to a position on the conveyor where the grout can cure.
- No less than 16 hours have elapsed after the matrix grout has been added, the drum returns to the Grouting Cell but docks with the capping grout station port. The lid is removed from the drum and the matrix grout examined. If significant bleed water is present it is removed, and the capping grout added. As before, the lid is replaced, the drum is lowered and moved to a position on the conveyor where the grout can cure.
- No less than 16 hours after the capping grout has been added, the drum returns to the DIF.
- At the DIF the lid bolts are tightened and torqued down to 30 Nm. The drum is then weighed, visually examined, monitored and swabbed.
- Finally, the drum is returned through the segregation door to the Vault Store.

Throughout the design process, the Contractor was encouraged to simplify the plant where possible. This was considered a main driver in simplifying the Safety Case and hence the approval process, both internally and by the Regulators.

Safety related interlocks were made mechanical where possible, and where this was not possible, electrically hard-wired interlocks were demanded. No software dependent safety related interlocks were permitted in the design. The control and instrumentation philosophy was therefore kept as simple as possible. Whilst rudimentary drum tracking was needed to identify the locations of specific drums, complex recognition systems were considered unnecessary, due to the linear sequential nature of the operations.

Maintenance was considered throughout the design. The encapsulation plant has an operating period of 5 years whereupon all of the waste will be encapsulated. With such a short operating period, the plant is designed to be remotely maintained with no required man entry in the operating period. This is achieved by over designing elements, such as lifting gear, so they need not be replaced. Items, such as conveyor motors are sited outside the bioshield where practicable, and so can be easily maintained or replaced with minimum plant downtime. Finally, should an unforeseen event occur, all of the drums can be removed to the Vault Store, a man access plug can be removed and safe man-entry made.

In order to minimise the downtime for maintenance and subsequent unavailability of the plant, the following design philosophy was adopted:

- Replacing motor drives with lever operation, where practicable;
- Providing drives using through-wall penetrations where powered drives are essential; and
- Designing instrument mounting features and service connection plugs suitable for Master Slave Manipulators (MSM) operation to ease replacement.

This approach, coupled with selection of equipment suitable for the operational environment, helps to minimise facility downtime and facilitate repair.

GROUTING PROCESS

Encapsulating the waste is the main requirement for the WEP. Pre-blended powders conforming to the UKAEA quality requirements will be delivered from the supplier and stored in the designated area. A single Intermediate Bulk Container (IBC) contains powder to make 500 litres of grout, enough for a matrix and capping pour. Single delivery IBCs were chosen to minimise the potential for a non-compliant mix and batching problems on site. Research works [9], carried out during phase one had also identified the potential for the PFA and OPC powders to segregate during transportation and so complete discharge of the powder content from an IBC was necessary to ensure a quality product.

Grout is prepared in a designated area above the Grout Cell. The powder is dispensed at a controlled rate from the IBC where it is added to chilled water (between $3^{o}C$ and $10^{o}C$) and mixed in a high shear mixer. Following the control systems receiving all of the necessary signals the grout can then be dispensed into the waiting drum.

Grouting is controlled by two independent ultrasonic detectors that measure the top surface of the grout within the drum. They are programmed to mechanically stop the flow of grout once the desired level is reached. Should both of these sensors fail, a mechanical float switch is positioned below the top surface of the drum. Should grout touch the float switch, all of the grout system is shut down, thus preventing the overfilling of a drum. The float switch is tested each time before a grout pour.

Matrix and capping grouts are added to waiting drums from a single IBC, thus halving the testing requirements and ensuring the most efficient use of the grout.

The Grouting Cell forms a containment barrier preventing the spread of contamination from the drums into the cell-line transfer tunnel complex during grout operations. Drum contents are only exposed when the drum is docked with a cell port.

During grouting there is the potential for splashing contaminated liquid grout. Spread of this contamination, both within the cell and outside into the transfer tunnel, is minimised by:

- Using a double-lidded arrangement (combining the port door with the drum outer lid) to separate the cell interior and the drum contents from the drum outer surface;
- Incorporation of a shroud over the grout dispensing head to eliminate splashing into the cell and over the seal itself; and
- Delivering the grout to the drum at a slow rate (a maximum of 10 litres/minute).

Due to the potential for hydrogen generation during the matrix grouting operations all electrical and control instrumentation will be rated for installation in an intrinsically safe environment.

The Grouting Cell is 2900mm × 2585mm × 2585mm high and provides the barrier that prevents the spread of contamination from the drums into the main cell-line transfer tunnel complex during grouting operations. The internal surfaces, that are likely to become contaminated, can be readily cleaned by conventional swabbing using the MSM.
Although the grout cell is a dry cell and no wash down facilities are provided, there will be a general fall across the base to a sump. This is a catch point in the event of leakage from the bleed water removal system. The design and internal layout of the cell reflect the processes to be carried out including installation, operation, maintenance and eventual decontamination.

Waste grout from the encapsulation, testing and flushing processes is pumped to a skip where the solids are settled out and the supernatant removed and neutralised. Following neutralisation the wastewater can be treated as foul waste and sent into the general water treatment system under discharge consent.

VENTILATION

The cells are ventilated through a primary extract and utilise HEPA filtration.

As cement is highly alkaline and a proportion of the wastes include reactive metals, such as aluminium and magnesium, hydrogen gas is produced as part of the grouting process. Hydrogen gas is flammable above concentrations of 4% and hence its evolution and management is a key deliverable of the design and the Safety Case.

Initial trials carried out during phase one identified that whilst hydrogen is evolved in the first 24 hours, its evolution effectively returns to background levels after this time. The design was therefore carried out on this basis.

Following research works into hydrogen evolution [10], it was recognised that the acute rate of hydrogen evolution maybe much higher than anticipated and a chronic evolution of hydrogen was also normal. Further trials have therefore been commissioned to evaluate the consequences of these findings and the design of the WEP ventilation was increased to cope with the worst-case scenario identified from the research.

As the management of hydrogen is such a key issue, it was agreed that an emergency extract system was prudent, and should be included in the design. The emergency hydrogen extract system provides extract from the Grouting Cell and the shielded cell suite in the event of a complete failure of the primary extract system and is independent of all other systems. The system is capable of limiting the hydrogen-in-air concentration to 1% within the shielded cell suite for up to 12 hours when four worst case drums are curing and in the Grouting Cell for up to 12 hours when one drum is curing. The air ejector uses bottled compressed air (CA) as its motive force. The compressed air system will consist of four multi-cylinder pallets (MCP) each holding 15 cylinders containing 11 m^3/cylinder. Further cylinders can be added as necessary in order to maintain the emergency extract indefinitely.

PROJECT MANAGEMENT

The project is being delivered by a dedicated UKAEA project team. This core team is supported as necessary, by UKAEA expertise in the fields of: Safety Case preparation; engineering design; commercial management; operations; maintenance; and decommissioning techniques. This is mirrored by the RWE organisational structure that encourages efficient communications between both parties.

RWE reports progress of the work utilising Earned Value Techniques. Pre-agreed metrics for the measurement of earned value allows unambiguous analysis of progress through the approved contract programme. Early indications of problems are highlighted and a combined approach taken to address issues. An understanding of the overall project objectives for both parties has ensured swift resolution of the issues.

The target price contract [11] incentivises both parties to achieve, or better, the "target" price agreed at the time of contract placement. Delivering the project to the same scope for less money allows the Contractor to receive a significant percentage of the "gain". However, should the project be delivered over budget, the "pain" is also realised by the Contractor who is penalised by the same percentage.

In addition to the normal contract conditions, UKAEA introduced an incentive for the Contractor to deliver the programme early. A bonus/penalty arrangement, calculated from an agreed value for each week the programme is either early or late, will be enforced beyond a neutral zone of ±5 weeks from the agreed contract end date. Liability is capped beyond a 12-week period.

The use of the target price contract [11], with enhancements for improved delivery, has significant benefits in incentivising the Contractor to deliver to time and cost. By allowing the Contractor to realise the "gain" as well as the "pain" there is a real driver to deliver early and increase profits. It is vitally important, however, that the quality arrangements are agreed up front and the target price, using this form of contract, is keenly negotiated from the outset. UKAEA were proactive in this approach and utilised the competition established during phase one, to secure a competitive price. The time taken to negotiate the target price and to clarify all of the technical and commercial issues prior to contract placement has been vital to the success of the phase 2 contract.

CONCLUSIONS

UKAEA has embraced early and continual engagement with the market place to ensure a safe, cost effective project is delivered to the satisfaction of all stakeholders. Close working relationships with the designers, facilitated by co-location, have engendered a seamless development of the design that has promoted design development and innovation in the true spirit of partnering.

The development and design of the WEP has resulted in an inherently safe, simple, low-cost plant that is easy to operate. This has been achieved by:

- Utilising a phased approach to ensure competition;
- Ensuring a proactive approach in pre-contract dialogue with the Contractor to agree deliverables and to negotiate the target price;
- Applying proven sub-system designs to minimise cost and give confidence that the plant will operate as intended;
- Controlling contamination spread to improve operability and eventual decommissioning;
- Using commercially available plant where possible;
- Reducing complexity provided safety is not impaired;
- The use of proven technology where practicable; and
- Ensuring that build standards are appropriate to the facility, and not over-specified.

The result is a compact plant that will achieve UKAEA’s aim of achieving passive safety of the waste by 2015.

ACKNOWLEDGEMENTS

The work in this paper is funded by the UK Department of Trade and Industry through the Nuclear Decommissioning Authority.

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