Experience with Stabilization of SGHWR Sludge in a Commercial Plant in the United Kingdom - 9044

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ABSTRACT

In July 2000, following a competitive tender, Nuvia Limited was contracted to design, build and commission a waste treatment plant to stabilise the active sludge stored in the External Active Sludge Tanks (EAST) at Winfrith, UK. The sludge was generated during the operational lifetime of the Steam Generating Heavy Water Reactor (SGHWR), which was in the early stages of decommissioning. This was in support of UKAEA's mission, which is to carry out environmental restoration of its nuclear sites and to put them to alternative uses wherever possible. Latterly, a new body, the Nuclear Decommissioning Authority (NDA), has become responsible for managing the UK decommissioning legacy and since 2004 UKAEA has been contracted to the NDA to deliver decommissioning work at Winfrith and other UK sites.

The purpose of this commercial plant is to stabilise the radioactive sludge by encapsulation into a cement matrix within a purpose-designed 500 litre steel drum. The drum design incorporates a lost paddle mixer used to maintain homogeneity of the sludge as well as mixing it with the stabilising powders.

The sludge in the EAST tanks is prepared for recovery by a process of homogenisation using in-tank stirrers. The means of reaching a narrow ratio of suspended solids within an aqueous medium will be described together with some of the problems encountered and the practical solutions devised. The material is transferred to the purpose-built Winfrith EAST Treatment Plant (WETP), where it is held in stainless steel tanks in a process area prior to being metered into a 500 litre stainless steel drum in the cell line for stabilization with powders.

The cell line consists of five cells separated by shield doors designed to maintain strict contamination control. The line has a wet cell where the drums are filled with the sludge and powder, a cell with stations for curing and grouting the drums, a cell for lidding, bolting and QA inspection, a maintenance and gamma monitoring cell and a buffer store to hold the completed drums. After completion, drums are moved in a shielded overpack to the Treated Radwaste Store located on a different part of the Winfrith site.

More than 300m^3 of active sludge, held in four adjacent concrete tanks, has now been stabilised into 978 drums that have been placed into the dedicated store. The process of recovery and homogenization of the residual sludge in the bottom of each tank to the required specification will be described together with the means of recovery and disposal options for a quantity of unexpected materials found at the bottom of each unit. The means of dealing with the final quantities of sludge and water from the last two concrete tanks by recovering it into a tall steel filtration vessel located within one concrete tank will also be described.

The final aspects of the paper will briefly describe the approach to be adopted for the final decontamination and demolition of both the EAST facility and WETP plant. The WETP plant is now in the latter stages of commercial operation leading to a second programme of stabilisation of a quantity of thorium metal for UKAEA ahead of its final decommissioning and demolition.

INTRODUCTION

The External Active Storage Tanks (EAST) is a set of four concrete storage tanks located in the south-west corner of the UKAEA Winfrith site (Figure 1). It was constructed at the same time as the Steam Generating Heavy Water Reactor (SGHWR) to accept the radioactive effluent and ion exchange resin that arose from the operation of various sections of the reactor plant. Various campaigns of reactor circuit cleaning were involved throughout the operating period from the 1960's to 1990, aimed principally at the removal of iron and other metallic contaminants. Although of relatively low specific activity, the principal isotopes present being Co^{60} and Cs137, the sludge is unacceptable for disposal at the Low Level Waste Repository (LLWR) site due mainly to its high C^{14} content and is therefore treated as Low Level Waste unacceptable for LLWR. The concrete tanks are each 7m x 7m x 4.3m high and are fitted with four submersible stirrers mounted from the roof structure to provide a means of suspending and homogenising the sludge.

Figure 1: Exterior view of the WETP facility with the EAST Tanks Building in the background

Most of the details about the processes concerned with recovery and treatment of the sludge in the four tanks has already been reported, (Reference 1). One of the key features is the requirement for the sludge to be homogenised by stirring within the tanks and sampling to demonstrate that it contains the required solid to liquid ratio necessary for stabilisation in the 500 litre drums. The means by which this ratio is adjusted to the required level has also been described before but in essence allows for the removal after stirring of calculated quantities of supernatant water after a short period of settlement followed by transfer to a holding tank at the WETP plant.

The emptying of the four tanks has almost been completed with two completely empty and the remainder currently concentrating upon recovery of a quantity of sludge residues found at the bottom. The discovery and means of recovery for disposal of these materials will be discussed later. The four electric stirrers are cooled by supernate in the tank and it is imperative that they do not become exposed during operation. Due to their constructional dimensions and similar issues associated with the dip pipe suction cage used to prevent materials >2mm entering the sludge recovery route, the sludge in each tank could only recovered initially down to around the 400-500mm from the tank base. For these reasons a means of homogenization and recovery of what is termed the 'heel' from each tank has been devised, (Reference 1).

The latter stages of the sludge stabilisation concern the transfer of the final residues and debris from Tanks 1 and 4 into Tank 2 and the introduction of a tall steel filtration vessel into Tank 1 to be used to hold and then homogenise the 'final heel' sludge from Tanks 2 & 3. The reasons for this are based upon the large floor area of the tanks and the need to be able to homogenise and concentrate the sludge from the two final tanks to meet the delivery specification ahead of the stabilisation.

This paper will set out the means by which the tanks have been emptied and also the plans that are in place to allow the receipt and encapsulation tanks in WETP to be emptied of sludge residues ahead of the proposed decommissioning and demolition of the plant. This latter process will also be described together with some details about the demolition of the EAST tanks which may be of interest to others working in a similar environment.

OVERVIEW OF STABILISATION PROCESS

As noted above, the process of homogenization of the SGHWR sludge, its recovery to the WETP plant and stabilisation into 500 litre drums for intermediate storage on the Winfrith Site has already been described in an earlier paper, (Reference 1). Briefly, the sludge is homogenised and prepared to meet the stabilisation criteria of solid to liquid ratio after which it is pumped across from the EAST facility to the WETP plant. Here it is held and kept stirred within a larger vessel from which smaller quantities are passed to an encapsulation vessel used to supply ~350 litre batches of sludge to the individual drums. A mixture of Ordinary Portland Cement (OPC) and Blast Furnace Slag (BFS) is then added to the drum which has a 'lost paddle' to provide for full mixing of the contents for a specified period. After standing for 24 hours the drums are then cap-grouted with a mixture of OPC and Pulverised Fly Ash (PFA) to complete the sealing of the contents. After a further 24 hours to allow for final solidification and curing, the drums are lidded and swabbed to ensure the external surfaces are clean and ready for transfer to the on-site Treated Radwaste Store, (TRS). A pair of drums is recovered into a transfer stillage and then moved using a large fork-lift truck to the store where an automated crane is used to load the drums into vertical storage tubes, where the materials will remain for a period of years ahead of other disposal options being considered.

The WETP plant was constructed by Nuvia for the purpose of stabilising the sludge and once all materials have been treated will then be used to stabilise a small quantity of Thorium metal into similar 500 litre drums for location in TRS. Full details about the design of this plant and how it operates are given in Reference 1 and will not be repeated here. Suffice to note that after initial work-up the plant has operated extremely well, producing from 4-6 drums per working day over most of the time. Unless further stabilisation work is identified for treatment in this plant, the final stage of the project will be to decommission both the EAST tanks and the WETP facilities and then carry out demolition.

TANK EMPTYING PROGRESS

The tank emptying process comprised three main phases commencing with removal of bulk sludge from each tank down to around 400-500mm from tank base. The electric stirrers, which were introduced through four roof openings into each tank, were then removed and recovery of what is termed the 'bulk heel' (the materials from 400-500mm to the base) undertaken using a small submersible pump. Once the sludge reached a level of around 25mm from the base of the tank, it ceased to flow to a single retrieval point so a high pressure water jet was then used to move the sludge toward the submersible pump for removal. Although this process was successful, this method introduced significant additional quantities of water into the tank and dose uptake by operatives during this activity was higher than planned.

During the latter stages of retrieval of sludge from each tank, it was discovered that each contained a quantity of material>2mm together with some bolts, lengths of wire and other extraneous items that must have fallen into the tank over the many years of operations, (Figure 2).

Figure 2: Examples of Mixed Debris Items Recovered from EAST Tanks

The origin of the material >2mm is unknown but may have come about during the pouring of the tank roof during construction or later work on the tanks when an additional 200mm of concrete shielding was applied to the original roof. Various methods were used to recover the extraneous items from the tank but the >2mm materials were more problematic. In order to assist with recovery of these materials and to help to concentrate the residues of sludge and water into one tank, a powerful vacuum pumping system was purchased and used to transfer these materials from Tanks 1 and 4 into Tank 2.

The vacuum system operates by drawing air and sludge plus any other contents from the 4.3m deep tank base up to the roof level and then discharging it via a holding tank in the machine into Tank 2. This had the effect of emptying both Tanks 1 and 4 to produce a greater quantity of sludge, water and material >2mm in Tank 2, allowing Tanks 1 & 4 to then be rinsed and further emptied to complete this stage of the decommissioning. The rinsing was undertaken using a commercial crop irrigation head introduced in turn through each of the tank roof ports. The head provides a powerful water jet that can be articulated by the water flow such that it covers almost a 360° arc to rinse all surfaces within about 5m of its nozzle. This process was extremely successful and images from the two tanks after rinsing showed that each had been efficiently cleared of sludge and debris. This process was also confirmed by monitoring of the tank internals where low levels of residual activity down to a few tens of microsieverts/hour were recorded.

During subsequent operations at Tanks 2 & 3, it became clear that removal of the material >2mm from the contents of both tanks was a priority. The stabilisation process does not provide a route for treatment of any sludge particles >2mm in diameter so it is imperative to recover these materials for separate disposal. To achieve this objective, the opportunity was taken to first transfer all the sludge and debris from Tank 2 into Tank 3 with the vacuum system as was carried out at Tanks 1 & 4 earlier. This then allowed the gravelly debris to be gradually removed during the return of all Tank 3 materials back into Tank 2 through a separate 2mm filter located within the roof port. This ensured that the resulting sludge contained only solids <2mm in size in compliance with the terms of the Letter of Conformity required for the resulting drums. Since this tank had been emptied earlier, it allowed the operation to take place within an acceptably low dose-rate background. After rinsing the debris in the filter within Tank 2 to wash off any remaining sludge, these materials were recovered using the vacuum system and placed into 200 litre drums for disposal. At the time of writing, these operations are still in progress but it is anticipated that they will lead to recovery of the 'final heel' sludge into the filtration vessel in Tank 1 as set out below.

INTRODUCTION OF THE SLUDGE FILTRATION VESSEL

One of the difficulties met with retrieval of the sludge residues arose from the large floor area of each tank, being approximately $54m^2$. Every centimeter of depth thus comprised 500 litres of liquid/sludge and due to the specific activity of the sludge it was important to recover as much as possible for stabilisation rather than to leave it as tank internal contamination. Fortunately during the final stages of sludge recovery, particularly with Tanks 1 & 4, use of the powerful vacuum system followed by rinsing led to each being cleared of sludge and debris to a high standard. The concentration of these residues finally into Tank 2 also increased the volume of materials within this one tank, making the task of homogenisation, removal of excess supernate and transfer of sludge to WETP that much easier.

It was recognised that for recovery of the final vestiges of sludge from Tanks 2 & 3 it would be helpful if the materials could be recovered into a tall, slim steel vessel located within one of the empty tanks. This would overcome the problem of the large floor area of each concrete tank and assist with concentration of the residual sludge and supernate into a much smaller receptacle with shielding provided by the concrete tank.

The sludge filtration vessel (SFV) was designed to hold about $6m^3$ of sludge and supernate within which it could be homogenised, excess supernate removed after sampling to determine the initial solid to liquid ratio and the remaining sludge sent to WETP for stabilisation. This recognised the difficulty in recovery of the sludge tailings from each tank and the need to remove the gravely debris ahead of its stabilisation. The steel tank is 1.5m in diameter and 4.7m tall with three base mounted support legs. It is provided with an electric stirrer at the lower end and a small filter unit at the top end to assist with removal of any materials >2mm in diameter from the sludge. However, following earlier experience, the filter unit will only now act as a secondary device, removing any residual materials>2mm across that may have escaped earlier attention in Tanks 2.

Figure 3: Stitch Drilling an Opening at Tank 1 Roof Position for Sludge Filtration Vessel

In order for the SFV to be introduced into Tank 1, one of the roof openings had to be enlarged to accept the tank diameter. A concrete cutting specialist was contracted to undertake this task, largely by diamond stitch-drilling, the removed materials being supported and then recovered at the roof level for later disposal, (Figure 3). This allowed an external crane to be used to lift the tank into the building through one of the many roof ports and directly into the required Tank 1 position. All necessary services were applied to the tank for it to operate as required.

RECOVERY & DISPOSAL OF MATERIAL GREATER THAN 2MM

The presence of material >2mm in diameter within the sludge was totally unexpected and has led to some delays in completing the sludge stabilisation programme. The materials appear (Figure 4) to comprise gravel and concrete with some of the sections several inches across. After rinsing with water within the filter unit at the top of the main tanks the activity of the debris was reduced to generally lie within a LLW disposal range. At present the precise disposal route for these materials is being developed but its recovery into 200 litre waste drums is now underway, allowing the operational plan to use the SFV within Tank 1 to proceed as planned. In a later version of this paper this subject will be updated taking into account the progress made.

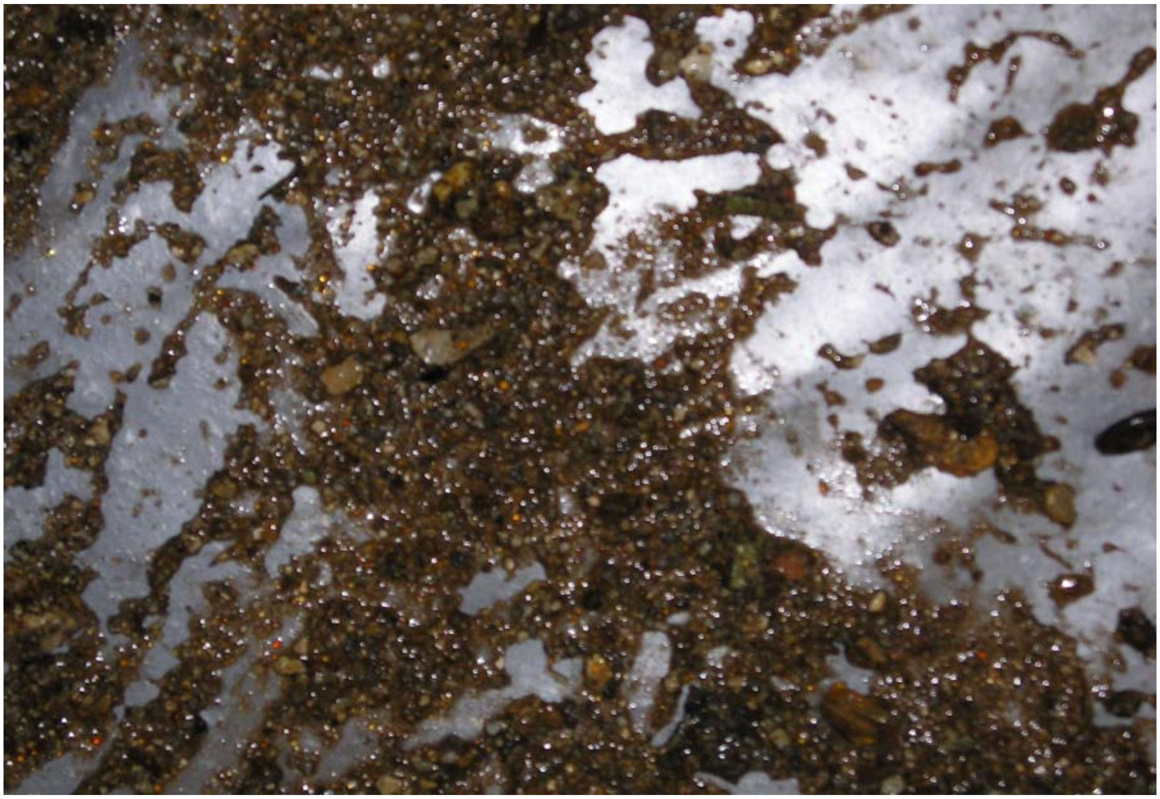

Figure 4: Some of the greater than 2mm material at base of Tank 3

PROGRESS WITH STABILISATION OF SLUDGE IN WETP

Over the past year the bulk of the SGHWR sludge has been homogenised and the bulk contents of all four tanks transferred to WETP for stabilisation. Later the recovery of the 'bulk heel' commenced from each tank culminating in the consolidation of the residual 'final heel' into Tank 2. This provided the opportunity for Tanks 1 & 4 to be emptied, flushed with water and completely cleared using a powerful vacuum system. The WETP plant has continued to receive and stabilise the sludge and to date 978 drums have been produced, virtually without incident. On the basis of current estimates, less than another 100 drums will be produced from the materials in Tanks 2 & 3 to complete this task. Some problems have been experienced during periods of extreme wet weather, causing some dampness in the batches of OPC delivered from the external silo. However, the plant performance has remained good and some of the plant slowdown has been caused as noted earlier by the discovery of significant quantities of debris at the base of each tank.

Once the plant has completed the stabilisation of the main sludge inventory it will enter a pipework/tank flushing regime to recover any residues left in the system. A specific procedure for undertaking this non-standard routine has been prepared and it is possible that as a result a small number of non-specification drums may result owing to the difficulty of meeting the solid/liquid ratio required in the main stabilisation programme. The issues surrounding this possible outcome are currently being investigated. This will avoid having to deal with small amounts of residual sludge at the end of the next project which concerns the stabilisation of a batch of Thorium metal bars within the 500 litre drums.

EAST TANKS & WETP DECOMMISSIONING PLAN

A comprehensive decommissioning plan has been prepared to cover both the EAST and WETP facilities based upon previous experience with projects of this nature, (Reference 2). The project falls into two reasonably distinct phases since at the end of the sludge recovery process the EAST tanks will be available for post operative clean-out (POCO) and decommissioning well ahead of the WETP plant. This is because the latter plant will, after flushing to recover residual sludge, be reprogrammed to undertake a small programme of stabilisation of a quantity of Thorium metal for UKAEA using similar 500 litre drums. Later, the second phase concerning the POCO and decommissioning of the WETP facility will be undertaken. Here the plant was designed and constructed with ultimate decommissioning in mind so that the process is anticipated to be achieved more readily than will be the case for the EAST facilities constructed mainly in the 1960's.

The EAST tanks are enclosed within a portal framed building constructed in the mid 1990s to provide weatherproofing for the facilities. They comprise a concrete structure with 0.6m thick walls standing 4.9m high and occupying a floor area roughly 16.4m x 18.0m. The four tanks have internal dimensions of 7.3m x 7.3m x 4.27m high and all surfaces except the roof structure are coated with an epoxy/phenolic paint to minimise contamination from the sludge. Recent sampling of concrete from the outer shield walls and roof has revealed that the whole structure is contaminated with tritium (H^3) whilst the roof structure also contains measurable levels of fission products Cs^{137} and Co^{60}. This is probably due to the absence of any paint on the roof inner surface, a notable omission during its construction. These contaminants put the materials into a LLW category unless significant decontamination can be undertaken. The general absence of significant penetration of fission product contamination into the external walls, and by implication the interior walls too, suggests that this may yet be possible. The ultimate fate of only tritium-contaminated sections of concrete has yet to be agreed with UKAEA and the Environment Agency.

The decommissioning plan provides for the cutting of openings into the walls of each tank by diamond sawing to provide man and machine access from ground level. The interior of each tank will be monitored and then cleared of residual items and debris such that man entries become possible. The interior will be decontaminated manually and the walls and floor coated with a tie-down layer to permit subsequent concrete cutting. The concrete roof will be supported and then cut away by diamond sawing for disposal followed by large sections of the shield walls. Gas-powered fork-lift trucks with ~10Te capacity will be used to handle the concrete sections, moving them out of the building for temporary storage ahead of further decontamination and size reduction. The plan is to clear most of the tank structure to create space within the building and then to bring the sections back for scabbling in a horizontal plane using mechanical equipment. The building will be provided with a new ventilation system ahead of all these operations to minimise the risk of escape of contaminants to the environment.

Work on decommissioning of the WETP facilities will follow later but in parallel with parts of the programme for the EAST tanks. Here the levels of internal contamination from sludge are known to be low and being of modern construction much more thought has been given to its ultimate decommissioning and demolition. As a result the vast bulk of materials from the process cell are expected to be disposed of as exempt waste with a significant amount of recyclable material from the steel structures.

OPERATIONAL EXPERIENCE & LESSONS LEARNT

In an earlier paper (Reference 1), the original problems associated with setting to work the WETP plant and creating 500 litre drums of stabilised sludge have been described. Several important lessons were learnt during this period and over the past year a different range of problems have emerged to be solved associated with the production phase and dealing with the unexpected.

The original plans for recovery of the ‘bulk heel’ and ‘final heel’ of sludge from the EAST tanks were amended to reflect the difficulties associated with the rather viscous nature of the sludge exposed at the base of each tank. In the last 400-500mm depth of tank the electric stirrers could not operate effectively and were thus withdrawn. However, for the last tank with bulk sludge present they were actually used down to about 310mm from the base without failure occurring, recognizing that they were to be withdrawn and disposed of at the end of this process. There was thus an urgent need to create conditions for re-suspending this viscous sludge and operatives worked from the tank roof to move jetting nozzles spraying recycled supernate with long poles to good effect about the tank base. However with relatively low liquid levels this process also led to greater than predicted operative dose uptake. If the process was to be repeated on tanks holding well compacted sludges it would be imperative to provide mechanical stirrers that reach right to the base of the tank to avoid this problem. Alternatively, at an early stage a dedicated piece of remotely operated equipment might have been designed to incorporate a mechanical agitation and pumping system to reduce operator doses from this source.

The presence of lots of extraneous items and materials >2mm at the bottom of each tank was entirely unexpected. The mixture of these materials along with the sludge greatly complicated the latter stages of recovery of the sludge into the right solid to liquid ratio for subsequent stabilisation. Whilst the recovery of the mainly metallic items (see Figure 2) was relatively simple, the coarser debris was much more difficult. The solution here was to purchase a powerful vacuum pumping system to recover all but the largest sections of concrete from the tank base into a >2mm mesh filter box at the tank roof. However, its separation from the adherent sludge by spraying with water would have been much better undertaken at the tank base position rather than the tank roof since operatives’ radiation exposure levels were greater than predicted. This shows the importance of better knowledge of the tank contents such that solutions can be found ahead of need rather than devised to solve an immediate problem.

CONCLUSIONS

Over the past year the recovery and stabilisation into 500 litre drums of sludge left over from the operation of the SGHWR plant at Winfrith has continued within a new WETP facility constructed by Nuvia Limited and a total of 978 drums have been produced.

Early decommissioning problems were overcome by harnessing the skills of the engineers and work force to develop practical solutions and the plant throughput has been high over the past year. As the tanks reached an empty state two unexpected problems emerged associated with the viscous nature of the sludge at the base and the unexpected discovery of gravelly and other debris at the tank base. Solutions to these problems have now been developed and it is anticipated that up to about 100 more drums will be produced to complete the project.

A comprehensive decommissioning plan for the EAST facilities and WETP plant has been produced and it is anticipated that this will commence during the first quarter of 2009.

ACKNOWLEDGMENTS

This paper is published with the permission of the United Kingdom Atomic Energy Authority and Nuvia Limited. The assistance of many team members in their contributions to the success of this project is gratefully acknowledged.

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