Aqueous Waste Treatment Plant at Aldermaston

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ABSTRACT

For over half a century the Pangbourne Pipeline formed part of AWE's liquid waste management system. Since 1952 the 11.5 mile pipeline carried pre-treated wastewater from the Aldermaston site for safe dispersal in the River Thames. Such discharges were in strict compliance with the exacting conditions demanded by all regulatory authorities, latterly, those of the Environment Agency.

In March 2005 AWE plc closed the Pangbourne Pipeline and ceased discharges of treated active aqueous waste to the River Thames via this route.

The ability to effectively eliminate active liquid discharges to the environment is thanks to an extensive programme of waste minimization on the Aldermaston site, together with the construction of a new Waste Treatment Plant (WTP). Waste minimization measures have reduced the effluent arisings by over 70% in less than four years.

The new WTP has been built using best available technology (evaporation followed by reverse osmosis) to remove trace levels of radioactivity from wastewater to exceptionally stringent standards.

Active operation has confirmed early pilot scale trials, with the plant meeting throughput and decontamination performance targets, and final discharges being at or below limits of detection. The performance of the plant allows the treated waste to be discharged safely as normal industrial effluent from the AWE site.

Although the project has had a challenging schedule, the project was completed on programme, to budget and with an exemplary safety record (over 280,000 hours in construction with no lost time events) largely due to a pro-active partnering approach between AWE plc and RWE NUKEM and its sub-contractors.

INTRODUCTION

Many of the operations and processes that take place on the AWE site use water. Due to the nature of these operations, this water can become contaminated with a number of substances including trace quantities of uranium and plutonium that makes this water unsuitable for discharging to the environment until these contaminants have been substantially removed.

For the past 50 years, AWE has used a “ferric flocculation” process to treat its radioactive effluent. This process involves changing the pH of the effluent and adding a ferric flocculent which agglomerates with the metallic compounds in the solution and allows it to settle out into a ferric hydroxide sludge. The solids are separated and the remaining clear water is filtered through a sand bed before final discharge. This process was able to remove approximately 95% of the radioactivity.

The treated water was then discharged via an 11.5 mile underground pipeline, known as the Pangbourne Pipeline, to the River Thames. The final discharges were in strict compliance with the exacting conditions demanded by all regulatory authorities, latterly, those of the Environment Agency. This disposal route was successfully used for over 50 years and the contamination levels of the effluent discharged using this route were very low and had been reducing significantly over recent years.

However, in recognition that the treatment plant and pipeline were nearing the end of their operational life, in the year 2000 AWE, along with the Environment Agency, decided that the Pangbourne Pipeline should be closed by 1 April 2005.

Following the decision to close the pipeline, AWE initiated a programme of activities to provide a holistic approach to management of effluent on the site. The main aspects of this were:

- **Waste characterization** to give a clear understanding of the nature and volumes of effluent generated by the donor facilities
- **Waste minimization** to ensure the volumes of active effluent generated are minimized
- **Best Practicable Environmental Options (BPEO) study** to determine the best way to manage the remaining effluent once the Pangbourne Pipeline was no longer available.
- **Implementation of the BPEO** to provide a new Waste Treatment Plant

This paper describes the implementation of this holistic approach and the construction and operation of the new WTP.

CHARACTERISATION

An extensive regime of sampling effluent at source was implemented to determine

- whether all donors were really generating radioactive effluent
- to allow the radioactive effluent to be fully characterized in order to provide an accurate specification and the likely variations of the feed to the planned new Waste Treatment Plant.
- to determine exactly how much effluent was really being generated

Having enabled the production of specification for the feed as an input to the design of the new WTP, it has then been possible to use this to define the Waste Acceptance Criteria for the WTP for any new donors as well as existing donors. This has been extremely useful in the planning of new facilities and processes.

WASTE MINIMIZATION MEASURES

A range of low-level aqueous waste reduction measures has been introduced at the AWE site in recent years to reduce discharges from facilities. This was done in a number of ways, notably:

- The effluent characterization noted above demonstrated that many sources of effluent that were traditionally considered to be active were in fact not actually active, for example effluent from active change room routine hand basins and showers. Modifications to the effluent collection systems at donor facilities were made to enable this effluent like this to be diverted to the normal industrial drain.
- Anecdotal evidence together with the characterization demonstrated that a significant proportion of AWE's effluent was actually rain or ground water ingress into the effluent collection system. Changes were therefore implemented to the collection systems to minimize this ingress including replacement of open tanks and bunds with covered tanks, and decommissioning of the existing below ground effluent drain transfer system and instatement of a new road tanker collection system.
- Decommissioning of redundant collection systems so that they did not collect ground and rainwater which would then have to be treated as RA effluent.
- Use of dry techniques e.g. for decontamination during decommissioning operations, rather than traditional wet techniques.

These measures together have resulted in a significant year on year reduction in the total volume of waste sent to the existing Liquid Effluent Treatment Plant (LETP) that currently discharges via the Pangbourne Pipeline. The ongoing implementation of an Environmental Management System to meet ISO 14001 and waste minimization initiatives are expected to reduce the volume of arisings yet further. Current volumes of low level aqueous waste at AWE Aldermaston site are approximately $1500m^3$ per year (November 2005) from a starting point of over $8000m^3$ in December 2000.

Effluent volumes will be reduced still further over the coming years as decommissioning and waste minimisation work progresses.

BPEO

With the knowledge of its effluent gained from the waste characterization, and the realization of the benefits of the waste minimization measures, AWE undertook a Best Practicable Environmental Options (BPEO) study to determine the best way to manage its remaining active effluent once the Pangbourne Pipeline was no longer available.

The BPEO Study recommended that best available option for treating the remaining effluent would be to filter it using a coarse strainer, evaporate it using Closed Loop Hot Evaporation and then pass the resulting distilled water through Reverse Osmosis Membrane Filtration. The evaporator concentrate that contained the contaminants would then be concentrated up in the evaporator to a suitable level prior to immobilization in a cement matrix in accordance with the Waste Acceptance Criteria for disposal as Low Level Waste (LLW) to the UK national LLW repository at Drigg.

Key criteria in the selection of the preferred treatment process included:

- Decontamination efficiency. The efficiency of this evaporation and reverse osmosis treatment process would be so high, between 99.9% and 99.99% removal efficiency, that the treated water would be acceptable for dispose via the conventional industrial effluent drain to the local public sewer.
- Robustness. The flexibility to cope with fluctuations in feed composition whilst still delivering a high decontamination efficiency and without the need for significant operator intervention to continually tailor the process operating parameters
- Simplicity. A relatively small number of process steps meant an easier plant to control, operate and maintain.
- Operating costs. The simple robust process allowed a relatively high degree of automation and thereby reduced the man power requirements and hence operating costs.

IMPLEMENTATION OF THE WTP PROJECT

The implementation of the new waste treatment process, which was known as the Waste Treatment Plant (WTP) project was undertaken with RWE NUKEM.

The WTP Project involved the design, supply, construction, installation, testing, commissioning and demonstration of the performance of the plant. The project also included all the safety case documentation requirements.

RWE NUKEM’s activities as the main contractor included roles as project manager, main designer and safety case author. There were approximately 30 of the Company’s staff on the project. In addition there have been ten main subcontracts delivering various aspects of the project.

The project has been completed to programme and met its budget targets. The key programme dates in the implementation of the WTP project have been:

- January 2003 – RWE NUKEM contract start with the preparation of the Front End Plant Design and the Pre-Construction Safety Report (PCSR).
- July 2003 – completion of Front End Plant Design and submission of the Pre-Construction Safety Report (PCSR
- August 2003 – start of site construction beginning with groundworks.
- October 2004 - start of setting to work and commissioning

- March 2005 – closure of the Pangbourne Pipeline
- July 2005 – start of active commissioning
- October 2005 - start of 12-month period for 'demonstration of operation' RWE NUKEM is operating the plant for the first 12 months, demonstrating its performance and training the AWE staff.

Fig. 1. WTP during construction

The WTP has cost approximately $35 million and the treatment costs are expected to be of the order of $150-200/m^3 of effluent (see Figure 1).

The safety of a new facility has been justified through a series of Safety Reports for the concept, design, construction, commissioning and operational stages of the project. The approval route for the safety reports has been in accordance with AWE's Corporate Safety Instructions and agreed with the UK's Nuclear Installations Inspectorate (NII).

Safety during plant construction was also paramount. Over 370,000 hours have now been worked on the site from the start of construction without a "recordable accident".

WTP PLANT AND PROCESS DESCRIPTION

The WTP uses evaporation and Reverse Osmosis (RO) filtration to treat effluent arisings. The treatment process is a batch process, treating one or more tanks of received effluent in a campaign and temporarily storing the treated effluent for a short period pending sample analysis results prior to discharge in accordance with the site authorization issued by the Environment Agency under the Radioactive Substances Act 1993.

The performance target for the plant is one of the most stringent for any effluent treatment plant, with Decontamination Factors of many times greater than 1000 being required to meet the normal industrial effluent discharge criteria for gross alpha and beta activity. Tritium is not removed by the treatment process, but tritium levels are very low and well within authorized limits.

WTP Process Plant Construction

Significant consideration has been given to the construction and long-term reliable operation of the WTP process plant and equipment. Materials of construction for different sections of the plant have been selected to give reliable service for a 25-year design life in sometimes arduous conditions including high temperatures, high solids and high chloride concentrations. Nickel alloys are specified as well as plastics and more traditional stainless steels.

The plant has been designed as a number of skid-mounted modules including:

- Several effluent pumping skids
- The two evaporator skids (see Figure 2)
- The RO equipment

Fig. 2. One of the Evaporator Modules Being Installed into the WTP

This skid based approach was chosen to maximize the amount of fabrication and testing that could be carried out at works and thereby minimize the amount of on-site installation, testing and commissioning. The benefits of this approach are:

- better quality control as fabrication could take place in controlled conditions within a factory environment
- an improved implementation programme as fabrication of plant and equipment has been able to take place in parallel with building construction
- and reduced project risk particularly as a significant proportion of the process plant could be tested prior to site installation.

Effluent Receipt

A summary of the WTP effluent treatment process is illustrated in Figure 3.

The process system accepts effluent from Tankers (typically 3-4 m^3 batches) or Approved Containers (45-litre capacity double skinned carboys).

Tankers are parked adjacent to the WTP building and a connection is made from the tanker to the plant. The Tanker Emptying System is located on a dedicated skid within a bunded area adjacent to the tanker parking area inside the building.

Tanker emptying is initiated from the central control room and the contents pumped from the tanker using a centrifugal scavenge pump via coarse cartridge filters and into the designated Receipt Tank.

Approved Containers are off loaded from the delivery truck and stored at the WTP facility. The Approved Container Emptying and Washing Cabinet contains the equipment for handling, emptying and washing approved containers.

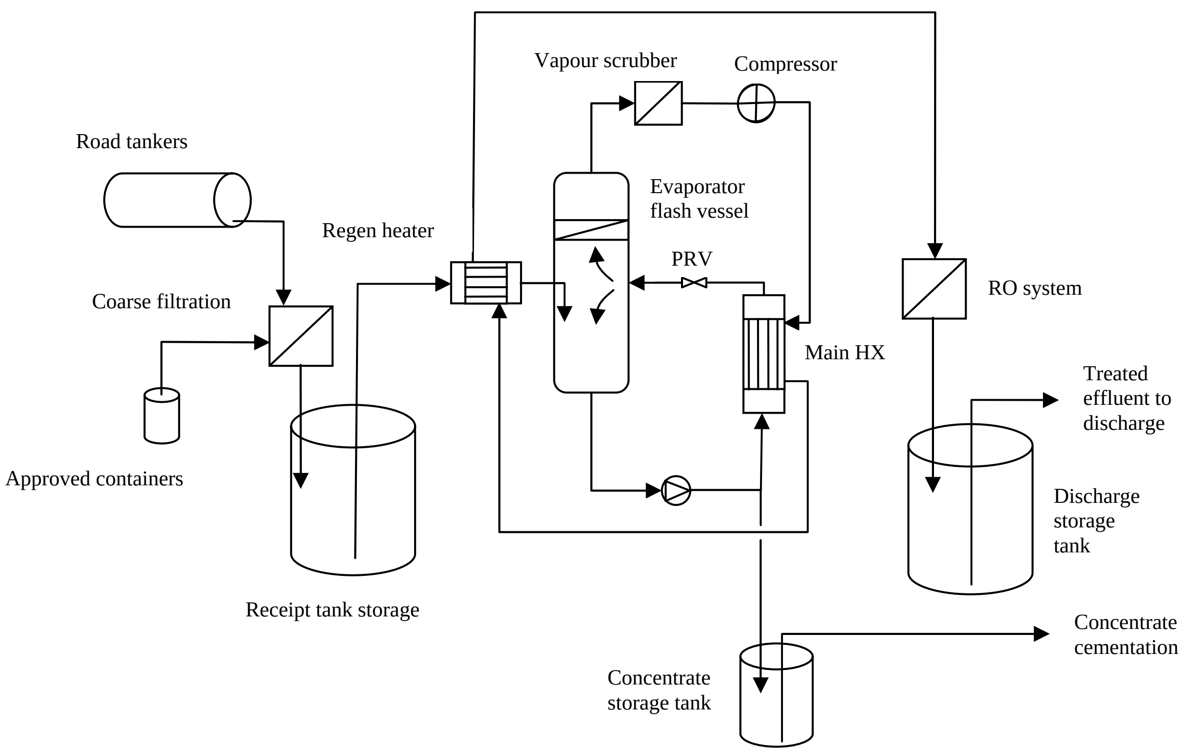

Fig. 3. Overview of the WTP process

Raw Effluent Buffer Storage

Three Receipt Tanks are provided to allow for process segregation, holding and monitoring and the de-coupling of effluent receipt from the downstream processes. Each Receipt Tank is of polypropylene lined GRP construction and has an operating volume of 35 m^3. The tanks are located within a bunded tank room.

Each tank is served by its own self-priming centrifugal pump mounted above each tank. The pump is used to mix the tank contents by re-circulation. Samples can be taken from the recirculation loop for analysis. If required, the tank can be dosed with an anti-foaming agent, acid or alkali via a connection into the recirculation loop of the tanks.

When the contents of the tank are ready for processing, the transfer to the evaporator is via a bleed from the tank recirculation loop.

Evaporation

There are two evaporator systems; each evaporator is capable of treating 50% of the throughput. During the first few years of operation, both evaporators will be required to operate in parallel. In the subsequent 20 years, only one of the two evaporators will be required because of the lower effluent arisings. The arrangement of the evaporators within the plant is illustrated in Figure 4.

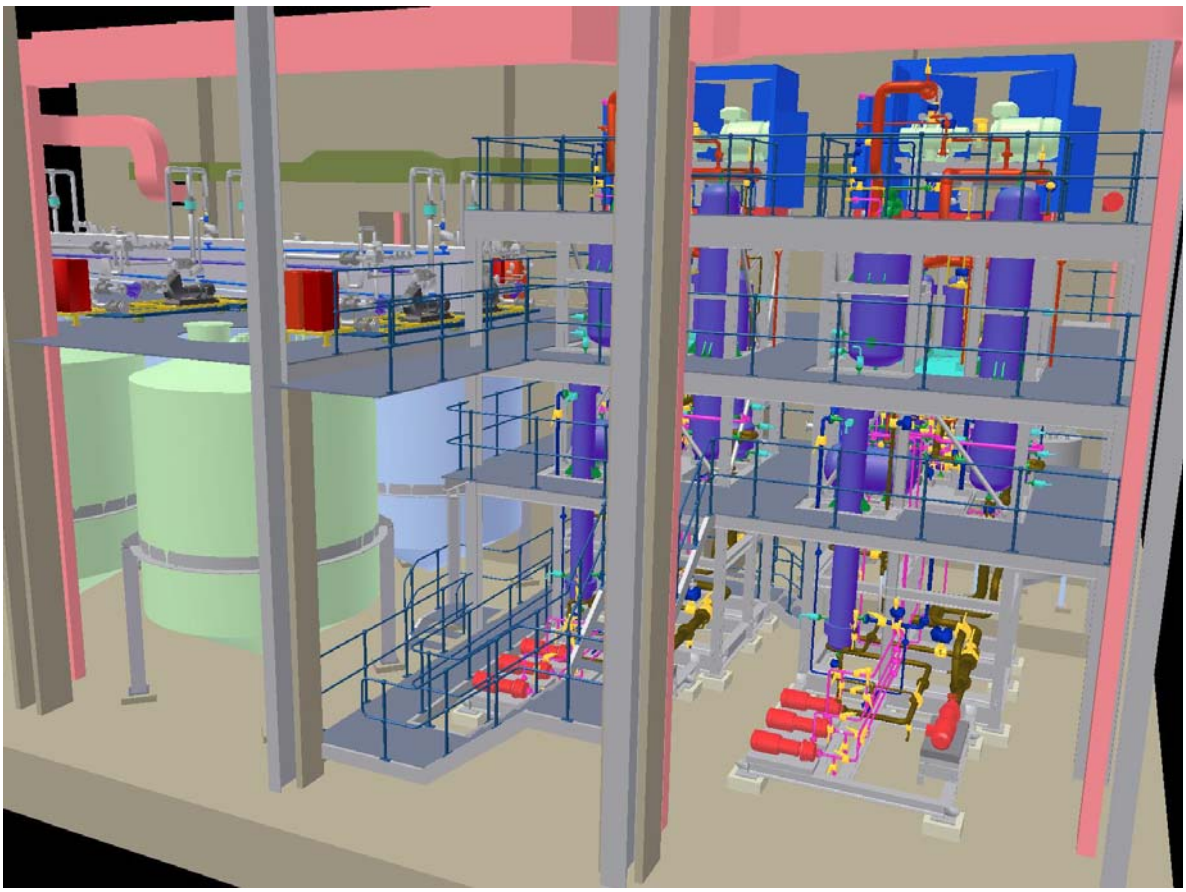

Fig. 4. 3-D model picture of the WTP showing the two evaporator modules

The feed from the Receipt Tank enters the Flash Vessel via a Regenerative Heater that heats the effluent to approximately 95° C before entering the Flash Vessel. The Regenerative Heater is a shell and tube type heat exchanger.

The chosen evaporation technique utilises Mechanical Vapour Recompression (MVR). The vapour from the Flash Vessel is drawn off using a vapour compressor that raises the temperature of the vapour to 114° C and provides the energy for the process to become self-sustaining, without the need for further heating. Variable speed compressors are used and their control is linked to maintaining a constant level of concentrate in the Flash Vessel. The compressed vapour is then injected into the Main Heat Exchanger.

Concentrate is drawn from the Flash Vessel and pumped through the Main Heat Exchanger by a Concentrate Pump. The Main Heat Exchanger is a shell and tube type heat exchanger. In the Main Heat Exchanger, the compressed vapour in the condensate loop heats the concentrate.

A pressure control valve prevents boiling of the concentrate within the Main Heat Exchanger. On release of the pressure after the valve, the concentrate forms a two-phase mixture that separates in the Flash Vessel into a vapour phase and concentrated liquid phase.

The flash vessel is fitted with a disentrainment section and a vapour scrubber to minimise the carryover and hence improve the Decontamination Factor (DF) of the plant. Dis-entrained and scrubbed liquid is returned to the Flash Vessel.

The condensed vapour from the Main Heat Exchanger is collected within the Sump Vessel and then pumped to the RO plant using the Condensate Pumps, via the Regenerative Heater (to pre-heat the new feed to the Flash Vessel) and a Sub-cooler.

Start-up of the evaporator involves a warm-up sequence during which a batch of effluent is recirculated within the evaporator and live steam is injected into the Main Heat Exchanger. Once the evaporator is up to temperature, the MVR takes over as the source of energy input and the steam is shut off.

Evaporator Condensate Polishing

The evaporator condensate is transferred direct to the RO Feed Tank. There are two RO units operating in parallel to treat the condensate from the two evaporators.

In each RO unit, evaporator condensate is pumped by the RO feed pump from the RO Feed Tank into the membrane filter elements. The RO membrane elements effectively separate the pressurized condensate into two streams:

- Permeate that passes through the membrane and is essentially clean water containing a very small proportion of dissolved solids, and
- Retentate that contains the remaining dissolved solids contained in the feed condensate.

The retentate is then returned to the RO feed tank where it mixes with incoming evaporator condensate.

Periodically, the retentate in the RO Feed Tank is transferred back into the designated Receipt Tank for re-treatment via the evaporator.

The permeate is collected in the Permeate Tank. From here the permeate is either processed by further polishing via an Ion Exchange Column or transferred directly to the designated Discharge Tank. The Ion Exchange polishing will normally only be used in the event of the need to re-treat a batch of effluent in a Discharge Tank.

Effluent Discharge Tanks and Wash Water / Discharge Break Tank

The RO permeate is received into one of three Discharge Tanks. Each discharge tank is of polypropylene lined GRP construction and has an operating volume of 35 m^3. These tanks are located within the same bunded tank room as the receipt tanks.

When a tank is full, the contents are recirculated to allow a representative sample to be taken from the recirculation loop.

Once analysis has shown that the tank contents are within the acceptance criteria, the tank is ready for discharge to the Wash Water and Discharge Break Tank. This Break Tank stores a volume of treated effluent for use as wash water within the WTP and provides an atmospheric break at a high point within the building to prevent the accidental emptying of a discharge tank through the establishment of a siphon into the Trade Waste system.

As the treated effluent leaves the building under gravity, the flow and pH are measured and an automatic sampler takes a final representative sample.

If analysis shows the contents of a discharge tank are not acceptable for discharge the contents can be returned to either the evaporator and/or the RO units for reprocessing.

Concentrate System

At the end of each batch campaign, the concentrate from the evaporator is transferred from the Flash Vessel by a Concentrate Transfer Pump on the evaporator skid to one of two Concentrate Tanks.

The Concentrate Tanks are fitted with an impeller agitator to provide continuous mixing of the concentrate. The contents of the Concentrate Tanks can also be recirculated or transferred using a peristaltic pump.

In order to minimise the amount of concentrated material requiring storage, liquor s decanted from the concentrate tanks and returned periodically to the evaporator for further concentration at the end of each campaign. Therefore, the solids concentration of the stored concentrate is gradually increased over a period of several months. When the concentration reaches 20 to 30 wt.% solids, the concentrate is transferred to the second Concentrate Tank to await cementation.

Cementation

Provision is made for the operation of a cementation plant within the WTP facility. The necessary services for operation of the plant are provided within the building infrastructure.

The concentrate is encapsulated into either 205 or 240 litre drums fitted with a "lost-paddle" mixer. The WTP is able to accommodate all the full and empty drums (up to 80) that will be consumed and generated during the annual cementation campaign.

A drum is positioned below the mixing head within a drip tray on a lift table. The drum is then raised to seal the drum against the bottom plate of the mixing head automatically coupling the captive paddle mixer blade within the drum to the mixer drive.

The concentrate is added to the drum, with the quantity being controlled by level within the drum. The paddle is then started and cement powder from the Cement Hopper Discharge unit is added to the waste within the drum. An integral extract unit controls the release of cement dust during its addition to the waste drum.

Once mixed with cement, drums are removed, lidded, monitored and stored overnight to cure. The following day the product is checked before being transferred and loaded into a half height ISO (HHISO) container for transport and disposal as LLW to the UK national LLW repository at Drigg.

Process Control and Operation

Two PC based control stations are installed in a control room that is outside of the radiological designated areas. These control stations provide supervisory and control functions for the process plant and building heating and ventilation system. Each of the control stations has the same access capability to the controlled items.

Process control is designed to be autonomous as far as possible. This enables minimal manning levels to be achieved.

Control is provided by a full featured, industry standard Supervisory Control and Data Acquisition (SCADA) system. The primary interface to the operator is a graphical display (mimic) that shows a representation of the plant or equipment in P&ID form.

Staffing requirements for the building are limited. The day-to-day process of receiving, treating and discharging effluent will only require two to three operating staff in the building, including a health physics surveyor. By minimizing staffing requirements in this manner, overall Life Cycle Costs are significantly reduced.

Once the plant has started processing, it is designed to process effluent without any operator intervention. The control system monitors and controls the batch and then shuts down automatically on competition of the batch. Once initiated, the process will be able to be left processing unmanned overnight to complete a batch of one or more Receipt Tanks. On completion of the batch, the process plant will shutdown automatically, with the evaporator going through a controlled cool down sequence. This can occur with or without the operators present.

The control system can automatically shutdown the plant in a safe manner on detection of abnormal conditions. Safety functions are able to shut down plant items independently of the control system when tripped. All safety related functions are hardwired and operate independently to the software control system.

PLANT PERFORMANCE

Effluent Decontamination

Performance of the treatment process has been demonstrated initially through the use of inactive simulants in pilot scale trials and then through inactive commissioning. Decontamination factors have been determined for the evaporator itself and for the treatment process overall. As the final product is virtually demineralized water, the analytical limits of detection of chemical species limit the determination of the true decontamination performance as chemical species are present at less than their limits of detection.

Overall decontamination factors of the order of 1E4 were expected between the feed and the final treated effluent. The decontamination performance of the evaporator, where there is an equilibrium between the concentrate within the evaporator and the distillate is expected to be greater than 1E5. This was borne out by the inactive simulant tests.

Initial active operation of the plant took place using effluent from the existing liquid effluent treatment plant i.e. after treatment. Effluent was received containing of the order of 5×10^4 Bq/m^3 (1.4 nCi/liter) alpha. After treatment within the WTP, the effluent was discharged at below limits of detection which are of the order of 40 Bq/m^3 (1.1 pCi/liter). This limit of detection did not allow the full decontamination potential of the WTP process to be assessed.

The WTP is now receiving effluent direct from donor facilities so the input contamination levels are have increased and a clearer indication of how the plant is performing is available since decontamination factors can be calculated without hitting the limits of detection. The results from active operation are entirely consistent with the earliest pilot scale trials and the inactive simulant testing on the plant.

The plant is now operating successfully at its design throughput. The aim now is to complete the demonstration needed to justify the unmanned operation of the plant during silent hours. Unmanned operation will allow a significant saving in operating costs.

The high quality of the treated effluent makes it suitable for re-use or recycling. The WTP retains some of the treated effluent for plant washdown purposes in order to reduce the generation of additional waste. Consideration is being given to the use of the treated effluent within other facilities on the AWE site for washdown purposes in order to reduce liquid discharges to the environment.

BENEFITS OF AWE'S APPROACH TO EFFLUENT MANAGEMENT

The principal benefit of AWE's effluent management approach has been to allow AWE to meet its key milestone of closure of the Pangbourne Pipeline and allow disposal of the treated effluent through the AWE industrial effluent system.

The other major benefits to AWE of this holistic approach to effluent management have included:

- A smaller, lower cost treatment plant. The investment in significant waste minimization measures have paid back many times their own value by reducing plant and equipment size.
- Lower operating costs. The smaller plant and equipment reduces energy costs and maintenance costs. The process is relatively simple to control and operate, thereby reducing operator costs. The plan for periods of unmanned operation will allow further cost reductions.
- High availability. As well as being a factor considered in the design of the plant and equipment e.g. by duplication of key equipment, availability is also assured by the simple, robust treatment process that is able to cope with upsets in incoming waste conditions without the need for time consuming tailoring of the process or the need for re-treatment of batches.
- Security of discharge. The efficient treatment process enabling the plant to comfortably meet its current discharge consents and it gives good confidence that it will remain capable of meeting future consents that are expected to become ever more stringent.

The project has been a major success in meeting not only the traditional targets of project cost, programme and quality, but also in enabling AWE to meet high profile targets with its stakeholders including the environmental regulator, the safety regulator and the public.