

## **SIMULANT EVAPORATION TRIALS TO SUPPORT AWE'S NEW RADIOACTIVE AQUEOUS WASTE TREATMENT PLANT**

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### **ABSTRACT**

AWE's future radioactive aqueous wastes are to be treated by evaporation followed by encapsulation of the concentrates in cement for disposal. Pilot-scale trials using simulants were conducted to test the principle of this new operation. The simulants contained soaps and other surface active agents, and several inorganic species including calcium, magnesium, bicarbonate, chloride, sulphate, phosphate, silicate, and also for the third trial uranium, barium and strontium.

It was found that the simulants could be concentrated to at least 20% w/w solids without undue problems due to corrosion or scaling. Foaming was encountered, and this was controlled with an anti-foam comprising a blend of synthetic waxes and non-ionic surfactants in a highly refined mineral oil. A silicone anti-foam was found to be ineffective, and there were indications that it promoted the coagulation of the suspended solids.

The concentrates were solidified with either Ordinary Portland Cement or a 1:3 mixture of Ordinary Portland Cement (OPC) and Blast Furnace Slag (BFS). Set temperatures were about 105 °C with OPC alone and 75 °C with OPC and BFS. Despite the higher temperature with OPC, the matrices showed no signs of excessive shrinkage or cracking and it was concluded that all would meet the criteria for disposal.

The concentration of uranium in the distillate from Trial 3 was below the limit of detection, which indicated that the evaporator in the full-scale plant would achieve high decontamination factors. The main components of the suspended solids formed upon evaporation appeared to be the carbonate, sulphate and phosphate salts of calcium and magnesium. Even though the suspended solids were chemically complex, the evaporator was amenable to acid cleaning.

## INTRODUCTION

AWE (formerly known as the Atomic Weapons Establishment) provides and maintains the warheads for the United Kingdom's nuclear deterrent. At present, radioactive aqueous waste from these activities is treated before being discharged to the river Thames via a dedicated pipeline. AWE made a commitment to stop discharging to the river Thames by 1 April 2005 [1], and in order to meet this commitment AWE has commissioned the installation of a new treatment plant for radioactive aqueous waste [2]. The operation of the new waste treatment plant (WTP) will be based on an evaporator. The concentrates produced by the evaporator will be encapsulated in cement for disposal as solid Low Level Waste. The evaporator is being designed and built by Stork Protech (UK) Ltd. RWE NUKEM is undertaking the overall project to design, supply, install and commission the WTP, with building sub-contracted to Kier Construction. Further details of the overall project are given in reference 2.

The current process for treating aqueous radioactive waste is based on ferric flocculation. An evaporation process will be novel to AWE, so evaporation trials were conducted to test the principle of the WTP. The trials used non-radioactive simulants that were formulated to represent typical future waste streams. This paper presents data from the trials that are considered to be particularly relevant to the operation of the full-scale plant.

## EQUIPMENT, MATERIALS AND METHODS

### Pilot-Scale Evaporator

The evaporation trials were performed using a pilot plant designed and supplied by Stork Protech (UK) Ltd. (Fig. 1). The evaporator was a forced recirculation type with external steam heating. The simulants were circulated around a loop comprising a separator flash vessel, circulation pump, heat exchanger and pressure control valve. The parts in contact with the simulant were constructed in SAF2507 steel. The remaining plant was constructed in 316L stainless steel.

The circulating liquid was heated to about 110 °C in the heat exchanger using steam at about 120 °C. The pressure control valve on the outlet was set to prevent the liquid vapourising in the heat exchanger. The heated liquid entered the flash vessel via a feed distributor, which was at atmospheric pressure to allow vaporisation. Residual liquid collected in the base of the flash vessel for return to the heat exchanger. The batch volume was maintained at about 40 litres by feeding the simulant under gravity into the circuit from the feed tank. The rate of evaporation was about 20 litres simulant per hour. This mode of operation was followed until the concentrate approached 20% solids, when the volume was allowed to fall slowly to about 27 litres. The volumes of simulant evaporated during Trials 1 and 2 were 8.4 m<sup>3</sup> and 11.5 m<sup>3</sup> respectively. The pilot plant was operated for 16 hours per day. The temperature of the concentrate was held above 80 °C between operating periods. During Trial 3, the evaporator was operated continuously and 12 m<sup>3</sup> of simulant were concentrated.

In the first 2 trials, the vapour passed through a demister mesh into a condenser prior to discharge. The pilot plant was modified for the third trial so that the condensed vapour was passed through a Reverse Osmosis membrane filter. This involved the installation of a candle filter to provide disentrainment, a sub-cooler and an improved heat exchanger and a chiller unit

to provide more efficient cooling. In addition, the flash vessel was fitted with a more effective distributor. These modifications were made on the basis of the experience from the previous trials and to model the proposed WTP design.

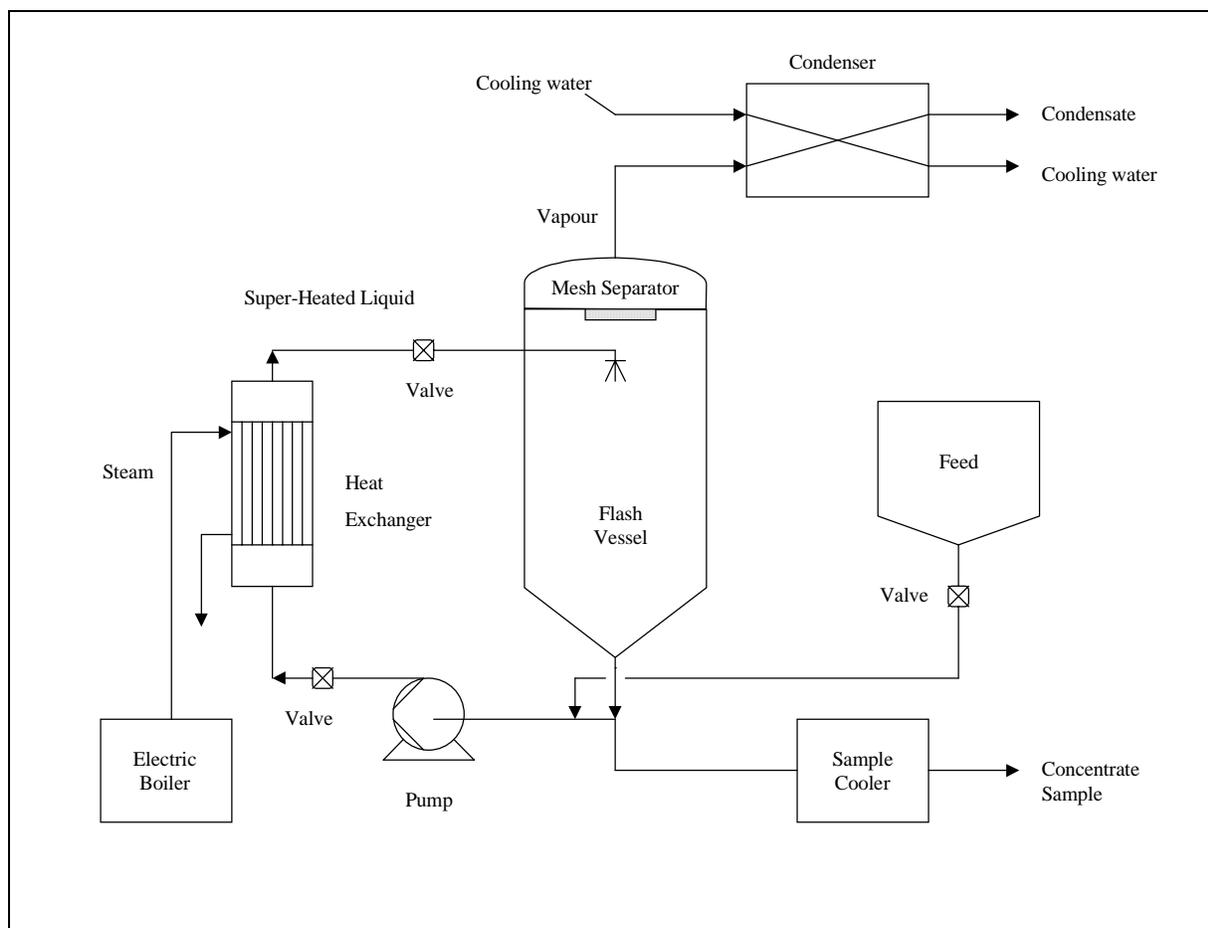


Fig. 1 Schematic of the pilot-scale evaporator

## Formulation of the Non-radioactive Simulants

### Water

A large proportion of the water entering the new treatment plant will be derived from the local supply. Accordingly, the simulants were prepared using 3 sources of water:

- (i) Tap water (from the on-site borehole supply).  
The amount of tap water incorporated into each formulation was chosen so that the tap water supplied all the carbonate in the simulant solution.
- (ii) Demineralised water with silicates (from the on-site supply).  
Demineralised water is produced from the on-site supply of borehole water. Much of the demineralised water supplied to the radioactive facilities still contains the silicates present in the borehole supply. The silicate content of the simulants was supplied by the volumes of tap water and demineralised water used in their preparation.
- (iii) Distilled water or demineralised water further deionised to remove silicates.

This was used to make up the volume.

### Inorganic Components

The following common laboratory chemicals were used in all 3 trials, i.e.:- aluminium sulphate, calcium chloride, ferrous sulphate, magnesium sulphate, potassium sulphate, sodium chloride, sodium metaphosphate, sodium nitrate, sodium sulphate and zinc sulphate. The simulant for Trial 1 also contained disodium hydrogen phosphate and sodium hydrogen carbonate, and the simulant for Trial 3 also contained barium nitrate, strontium chloride and uranyl nitrate.

The formulation of the simulants was based on the likely composition of the future radioactive waste streams. The first trial used a "Standard" simulant that would encompass most of the future waste streams (Table I).

Table I Composition of simulants

	Species/Parameter	Concentration (mg/litre)		
		Trial 1 (Standard)	Trial 2 (High Organics)	Trial 3
Cations	Calcium	65	59	60.5
	Magnesium	16	13	nd
	Sodium	124	65	123
	Potassium	37	16	39.6
	Aluminium	3.6	3.4	3.8
	Iron	7.4	6.0	6.3
	Zinc	3.2	2.8	2.8
	Barium	-	-	0.38
	Strontium	-	-	3.8
	Uranium	-	-	0.57
	Anions	Chloride	149	93
Nitrate		58	42	0.23
Sulphate		142	93	114
Phosphate (estimated from measured phosphorus)		44	28	nd
Bicarbonate / Carbonate		138	110	163
Silicon		8.4	7.9	18.7
Organics		Chemical Oxygen Demand (COD)	84	120
	Total Organic Carbon (TOC)	~20	~30	7.2
Total Solids (Inorganic + Organic Solids)		804	545	650

nd = not determined

The second trial used a "High Organics" simulant to represent those waste streams derived from change rooms. The third trial was based on the "Standard" simulant supplemented with uranyl nitrate (0.84 µg/litre), barium nitrate (0.2 mg/litre) and strontium chloride (5 mg/litre) in order to represent the radioactive components of the AWE aqueous waste.

Calcium, magnesium and bicarbonate were present in significant amounts because the local tap water supply contains typically 330 mg bicarbonate / litre and 70 mg calcium / litre. Metaphosphate, as (NaO<sub>3</sub>P)<sub>n</sub>, was used instead of phosphate, because phosphate caused precipitation. This was considered to be valid because metaphosphate is included in commercial

cleaning formulations as a complexing agent for calcium and other divalent cations. Sodium and potassium salts were included to maintain a charge balance. The pHs of the batches of simulant solutions were 7.3 – 7.7 for Trial 1, 6.9 – 7.1 for Trial 2 and generally between 6.8 – 7.3 for Trial 3 (with a maximum of 8.9).

### **Mixing**

The simulants were prepared in 1 m<sup>3</sup> batches. It was recognised that the various components could give rise to insoluble salts, particularly if mixed at high concentration. Accordingly, the salts were dissolved in 3 separate pre-mix solutions, which were then combined to give the required bulk solution, i.e.:

- Pre-mix A was tap water with an addition of CaCl<sub>2</sub>.2H<sub>2</sub>O.
- Pre-mix B contained metaphosphate (and strontium for Trial 3) dissolved in demineralised water.
- Pre-mix C contained the other salts, except barium nitrate and uranyl nitrate, dissolved in distilled water. Barium nitrate and uranyl nitrate were added as separate solutions to each 1m<sup>3</sup> batch of simulant just before use.

### **Organic Components**

The organic compounds were added after the 3 salts solutions had been combined to make up the volume to 1 m<sup>3</sup>. The choice of organic materials for inclusion in the simulants was based on a survey of their usage in the active facilities. The organic component of the waste were provided by combinations of the following preparations (Table II):

- Hand Soaps
  - Luxury Liquid Soap (produced by Cleenol)
  - Mevon 77 (Cederroth International)
- Shower Gel
  - Hair & Body Gel (Cleenol)
- Sink Cleaner
  - Sprint Cream Cleaner (SC Johnson)
- Cutting fluid extract
  - The aqueous fraction from 5 % w/w emulsion of Solcut E cutting fluid (Houghton Vaughan)
- Lanolin
  - 50 % Hydrous Wool Fat (J M Loveridge)

### **Foaming Agents / Defoamers**

Foaming in Trial 1 was controlled with Drewplus S7270 (a silicone anti-foam supplied by Ashland Drew). In Trials 2 and 3 it was controlled with Anti-foam E6 oil supplied by Basildon Chemicals, which is a blend of synthetic waxes and non-ionic surfactants in a highly refined mineral.

Table II. Contribution of the organics to the chemical oxygen demand (COD) of the simulants

Component	Contribution to COD (mg/l)	
	Trial 1 & 3	Trial 2
Cleenol Luxury Liquid Soap	45.6	-
Cleenol Hair and Body Gel	31.1	-
Lanolin	-	54.3
Mevon 77	-	54.4
Aqueous fraction from 5 % w/w Solcut E cutting fluid	6.2	9.2
Sprint Cream Cleaner	1.4	2.1
Total	84.3	120

### Cementation Methodology

The Ordinary Portland Cement (OPC) was supplied by Lafarge's (formerly Blue Circle's) Westbury works. When calculating the amount of cement required for encapsulation, an allowance was made for the solids content of the concentrates; i.e. that a concentrate with 20% solids would contain 80% free water. The evaporator concentrates from Trials 1 and 2 were mixed with OPC at a ratio of 0.4 : 1 free water : OPC. The concentrates from Trial 3 were solidified with a 1 : 3 mixture of OPC and Blast Furnace Slag (BFS) using a ratio of free water to (OPC + BFS) of 0.34 : 1, which was equivalent to a concentrate to (OPC + BFS) ratio of 0.45 : 1.

The viscosity of a sample of each mix was measured using a Contraves Rheomat 115 Viscometer following procedures established at the United Kingdom Atomic Energy Authority [3]. The cement matrices were cured quasi-adiabatically in Dewar vacuum flasks (capacity ~ 1 litre) covered with a polystyrene cap. The curing temperature was measured using a K-type thermocouple inserted through the cap. The compressive strength of the matrix from Trial 3 was measured using a Toni Technik 200 kN compression testing machine with a rate of increase of load of 2.4 kN per second.

### Analytical Procedures

Inductively Coupled Plasma – Atomic Emission Spectrometry was used to analyse the metals, silicon and phosphorus. The analytical value for phosphorus was then expressed as an equivalent concentration of ortho-phosphate. Concentrations of chloride and nitrate were determined colourimetrically using an on-line UV/VIS spectrometer after developing the colour using standard chemistries in a continuous flow autoanalyser. Sulphate was measured using a continuous flow turbidometric autoanalyser following precipitation as barium sulphate. Carbonate / bicarbonate was estimated from the total alkalinity of a sample, which was determined by titration against a standard nitric acid solution using phenolphthalein and pH 4.5 indicators. Suspended Solids were measured by filtering a known volume of sample through a pre-weighed filter paper that was then dried to constant weight at 110 °C. Total Dissolved Solids were determined by evaporating a known volume of the filtrate to dryness at 105 °C and weighing. COD was measured using Dr Lange test kits according to the manufacturer's instructions. Samples were prepared for TOC analysis by acidification and bubbling with carbon dioxide-free air to remove inorganic carbon. The organic carbon was oxidised with persulphate

and UV light and the TOC was quantified by measurement of the carbon dioxide produced using a non-dispersive infra-red detector in comparison with standards.

## **RESULTS**

### **Production of the Concentrates**

#### **Foaming**

Foaming was encountered at the start of the first evaporation trial, which used the Standard simulant, and a silicone anti-foam (Drewplus S7270) was added to control foaming. However, this product was not very effective. It was found that a concentration of 1000 mg/litre was required to control the foam in the evaporator, even though the recommended use concentration was 5 – 50 mg/litre. This observation was supported by laboratory tests, which showed that the antifoam lost activity when it was boiled in borehole water with a mixture of the organics used in the simulant. The anti-foam was a 10% emulsion of silicone components, so 1000 mg/litre anti-foam would have increased the solids content of the simulant by about 12 %.

The addition of 1000 mg/litre of silicone anti-foam was considered to be unacceptable. Accordingly, tests were undertaken to understand the factors affecting the foaming in order to minimise its occurrence in Trial 2. When the components of the Standard simulant were boiled in laboratory flasks, the hand soap and the shower gel were found to make the greatest contribution to the foaming. A liquid hand soap that is formulated with fatty acids (Mevon 77) produced less foam than the Cleenol hand soap. The laboratory tests also showed that hand washing extracted defoaming compounds from skin. Moreover, silicones are present in some toiletries, e.g. cosmetics, skin-care products and 2 in 1 shampoo [4]. Thus, it was considered likely that future aqueous radioactive waste from hand washing and showering will contain various materials that will tend to lower the foaming effect of the soaps. Consequently, the High Organics simulant for Trial 2 was modified to include lanolin to model the defoaming effects of hand-washing and to use the lower foaming soap, Mevon 77. Lanolin and Mevon 77 were added in amounts that contributed equally to the final COD (Table II). The aqueous extract of Solcut E and Sprint Creme cleaner were kept as minor contributors to the COD.

It was also decided to use a different anti-foam for Trial 2. Anti-foam E6 from Basildon Chemicals, which is a blend of synthetic waxes and non-ionic surfactants in a highly refined mineral oil, was chosen because it retained activity when boiled in the presence of a mixture of organics. The changes made for Trial 2 were effective: only 4.4 mg/litre Anti-foam E6 was required to control foaming. This anti-foam agent was retained for Trial 3. The agent was effective at a mean concentration of 19mg/litre, although it did not completely mitigate foaming.

#### **Behaviour of the Solids During Evaporator Operation**

After the foaming had been brought under control, the evaporator achieved a considerable volume reduction, so producing concentrates with a high solids content (Table III).

Table III. Solids content of concentrates

	Trial 1		Trial 2		Trial 3
Volume Reduction	104 x	190 x	98 x	279 x	~ 440 x
Expected Solids Content (w/w)	10%	20%	~5 %	20%	~ 30%
Measured Solids Content (w/w)	9.1	10.7	5.0	19.4	24.5

However the solids content of the samples of concentrate collected during the evaporation tended to be less than expected from the volume evaporated (Table III). This effect was particularly marked in Trial 1, and it was ascribed to the high concentration of silicone anti-foam required to control the foaming. It was argued that silicones could have absorbed onto the suspended solids, so accentuating the coagulation and settlement in areas of lower flow, e.g. the sample line. The solids collected at the end of Trial 1 had a silky feel, which was consistent with this explanation.

The sample from Trial 3 also had a lower solids content than expected. This might have been a result of the different way that this sample was produced. The final concentration step from nominally 20% solids to nominally 30% solids was done by slowly reducing the volume of liquid in the flash vessel using a reduced rate of evaporation. It is possible that this allowed the suspended solids to settle in areas of lower flow.

### Cementation

The evaporator concentrates were compatible with cementation. When the concentrates from Trials 1 and 2 were solidified with OPC, the viscosities and set times were acceptable (Table IV).

Table IV. Cementation of the concentrates

	Trial 1		Trial 2		Trial 3
Measured Solids Content (w/w)	9.1 %	10.7 %	5.0 %	19.4 %	24.5%
Set-time (hours)	5.1 – 5.2	5.4 – 5.6	4.6 – 5.1	5.6 – 6.0	7.3 – 8.3
Max Temperature (°C)	106	104	104	105	75
Viscosity (Pa s)	0.72	0.57	0.61	0.66	1.1

There was an indication that the higher solids produced a slight retardation of the set. The matrix formed from the 10.7 % concentrate from Trial 1 took slightly longer to achieve peak temperature than the one from the water control (Fig. 2).

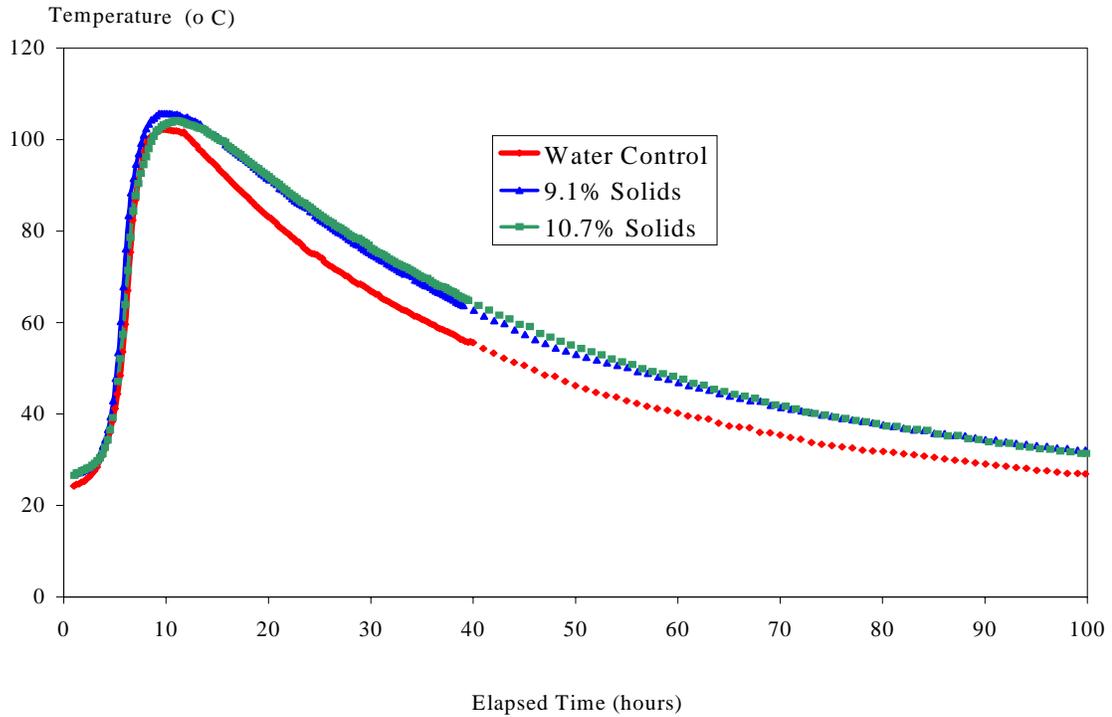


Fig. 2 Temperature during curing of OPC with water or concentrates from Trial 1

Likewise, the peak temperature for the matrix from the 19.4 % solids in Trial 2 occurred later than that for the 5 % solids (Fig. 3) and the water control (Fig. 2). However, the shapes of the temperature/time curves were similar and these differences were not considered to be significant.

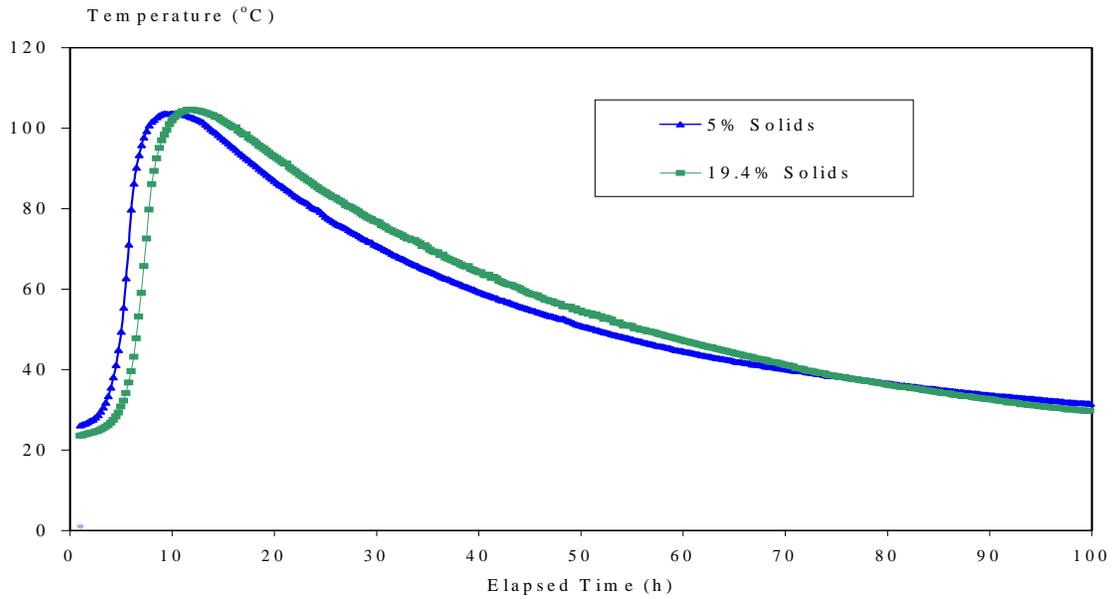


Fig. 3 Temperature during curing of OPC and concentrates from Trial 2

The maximum temperatures recorded during the set (Table IV) were somewhat high due to the relatively high content of OPC. Despite this the matrices showed no signs of excessive shrinkage or cracking, even with the higher content of organics in the simulant for Trial 2. It was decided to solidify the concentrates from the third trial using a mixture of OPC and BFS in order to reduce the maximum temperature (Fig. 4). This reduced the maximum temperature by about 30 °C, whilst only slightly delaying the set time (Table IV and Fig. 4 compared to Figs. 2 and 3).

Additional tests were performed on the cementation of the concentrate from Trial 3 to provide the necessary level of confidence in the cement formulation. The compressive strength of the matrix was found to be  $62.4 \pm 1.5 \text{ N/mm}^2$ , which exceeds the minimum of  $0.4 \text{ N/mm}^2$  for disposal to the UK's national repository for solid radioactive waste at Drigg, Cumbria [5].

Thus, it was concluded from these trials that the concentrates would form a solid matrix that would meet the criteria for disposal.

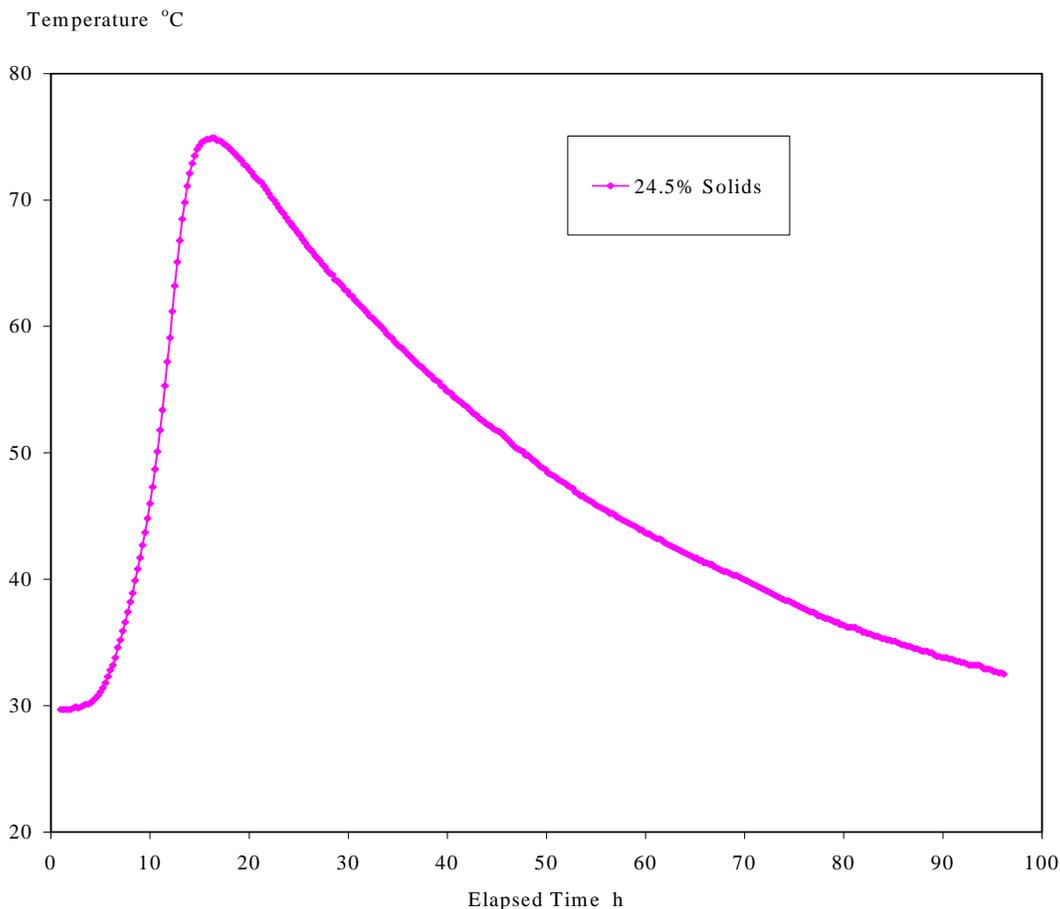


Fig. 4 Temperature during curing of OPC / BFS and concentrate from Trial 3

## Experience of Evaporator Operation

The trials also highlighted various aspects of operation that would need to be taken into account during the design of the full-scale plant. Foaming and the behaviour of the solids have been discussed in the previous sections. Other aspects are presented below.

### Decontamination Factors

The configuration of the pilot plant for Trials 1 and 2 was not designed to maximise the purification of the distillate. The system was modified before Trial 3 in order to gauge the Decontamination Factors (DF) that would be achieved in the full-scale plant. However, this was constrained by the sensitivity of the analytical methods employed: the concentrations of the various species in the distillates tended to be lower than the analytical limit of detection (LoD). For example, the concentration of uranium in the distillate was below LoD of 0.3 µg/litre. This was equivalent to a DF (defined as feed concentration / distillate concentration)  $> 1.9 \times 10^3$ . The concentration of uranium in the concentrate at the end of the trial was 3890 µg/litres. This was equivalent to a Purification Factor (defined as concentrate concentration / distillate concentration)  $> 4.6 \times 10^4$ , which indicates that DFs  $> 10^4$  will be achievable.

### Composition of the Concentrates

The chemical form of the components of the radioactive waste stream are expected to change during evaporation. For example, bicarbonate will disproportionate to carbon dioxide and carbonate, and the carbonate will precipitate with calcium and other cations. Information on the nature of these changes was gained by measuring the concentrations of the various species during the evaporation. The amounts of the soluble species in the evaporator concentrates from Trial 1 were measured by filtering a sample prior to acidification and analysis (Table V). A separate sample was then used to measure the total amounts of soluble and insoluble species. This was done by acidifying the sample to dissolve the precipitate prior to filtration and analysis. This was expected to measure the total amounts quantitatively, but it was reported that not all of the suspended solids dissolved in acid. The measured amounts were compared to the amounts expected from the concentrations of the species in the simulant and the recorded volume reduction (Table V).

Table V. Physical State of the Chemical Species after Evaporation  
(from Trial 1, nominally 20% solids)

Species	Measured Amounts in Concentrates (g/litre)		Expected Total Amount in Concentrate (g/litre)	Soluble Material as Proportion of Expected Total Amount (%)
	Soluble	Soluble + Insoluble		
Cations				
Calcium	1.7	1.6	16.1	10.5
Magnesium	0.05	0.165	3.97	1.3
Sodium	32.0	26.0	30.8	104
Potassium	8.3	7.0	9.18	90.5
Aluminium	0.0006	0.025	0.89	0.07
Iron	0.0003	0.050	1.84	0.02

Zinc	0.0003	0.028	0.79	0.04
Anions				
Chloride	37.0	38.0	37.0	100
Sulphate	26.0	26.0	35.2	73.8
Phosphate	0.218	0.459	10.9	2.0
Bicarbonate / Carbonate	0.552	1.14	34.2	1.6
Silicates as Si	0.013	0.10	2.08	0.62

Sodium, potassium and chloride were present as soluble species (as would be anticipated). In fact, the measured value for soluble sodium was greater than the value for soluble plus insoluble material. This was ascribed to analytical errors. The measured concentrations of these ions were close to those expected. By contrast the measured concentrations of soluble magnesium, aluminium, iron, zinc, phosphate, carbonate and silicate were much less than expected, which indicated that these species were present in insoluble forms. Moreover, the values for the "Soluble + Insoluble" forms were much less those expected. Possible explanations for this are:

- (i) The precipitates did not dissolve completely in the acids used.
- (ii) The precipitates were retained in the evaporator when sampling (see Table III).
- (iii) The disproportionation of bicarbonate upon heating could have produced more carbon dioxide than carbonate [6].

The measured concentrations of calcium and sulphate indicated that they would be partially soluble in the concentrated radioactive waste. About 10% of the calcium added and about 74 % of the sulphate added remained as soluble material.

The analysis suggested that the precipitated solids in the evaporator would be chemically complex, but the main species would be the carbonate, sulphate and phosphate salts of calcium and magnesium. The chemical nature of the insoluble species would be expected to influence the scaling in the evaporator and so determine the cleaning regime. A scale of calcium or magnesium carbonate would be expected to be more amenable to acid cleaning than one of calcium sulphate, so it was of interest that sulphate was found to be partially soluble.

### Scaling

After cleaning the evaporator at the end of Trial 1, it was seen that a slight amount of white powdery material had adhered to some parts of the evaporator. The white material was seen in the outlet pipe from the heat exchanger, and in the heat exchanger end plates, where it accumulated at the join between the baffles and the endplate. A sample of the white material was taken for analysis (Table VI).

Table VI Composition of the scale from Trial 1

Analyte	Concentration (g/kg)
Aluminium	7.1
Calcium	110
Iron	8.1
Potassium	2
Magnesium	44

Sodium	6.4
Zinc	20
Silica as Si	4.9
Phosphate	15
Carbonate	156
Chloride	0.13
Sulphate	97

Assuming that this material was representative of the bulk of the scale formed during evaporation, it was concluded that the main components of the scale would be calcium and magnesium carbonates and calcium sulphate.

The adhesion of the material to the evaporator was weak, and it was easily rubbed off. The sites of adhesion tended to be where the liquid flow was low or where the surface finish was not smooth. It was considered that the more vigorous cleaning-in-place in the full-scale plant should remove this material.

### **Cleaning**

Acid cleaning was found to be effective. The evaporator was cleaned successfully at the end of Trial 2 with several rinses with a mixture of nitric and phosphoric acids. The strongest acid applied was 7.3% w/w nitric + 1.8 % w/w phosphoric. During Trial 3 further laboratory cleaning tests were performed. These showed that a wash of 0.2% nitric acid was effective and this cleaning method was applied in Trial 3. Several washes and rinses removed the solids held up in the evaporator.

### **Corrosion**

The evaporated solutions contained a high concentration of chloride (Table V), so corrosion was a major issue for the evaporation trials. When the evaporator was inspected at the end of Trial 2, the flash vessel and heat exchanger tubes (which had been constructed in SAF2507 steel) did not show any signs of corrosion, despite the high concentration of chloride in the concentrates. The inner surface of the flash vessel was smooth and there was no mark to denote the liquid level. The dividing plates inside the base plate and the inner surfaces of the heat exchanger tubes were also smooth and clean. Likewise, there was no rusting of any of the visible metal surfaces, including the welds.

### **CONCLUSION**

The pilot scale trials confirmed the principles underpinning the design of the new treatment plant, i.e.:

- (i) It was possible to concentrate the simulants without undue problems due to foaming, corrosion or scaling.
- (ii) It was possible to achieve a high solids content in the evaporator.
- (iii) The concentrates were compatible with cementation.
- (iv) The inability to detect uranium in the distillate from Trial 3 indicated that the evaporator in the full-scale plant would achieve high decontamination factors.

The trials supported the choice of evaporation for the treatment of AWE's aqueous radioactive waste. Thus, they will assist AWE in fulfilling the commitment to the regulators to cease discharges to the river Thames.

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## REFERENCES

- 1 A. Crane and V. Freestone. "Future Treatment and Disposal of Aqueous Actinide Contaminated Waste at AWE Aldermaston", In: Proceedings of Waste Management 03, Tucson, USA, February 23 - 27, 2003, WM Symposia Inc. (2003).
- 2 D. Keene, P. Gilmour, J. Fowler and M. Harrison. "Aqueous Waste Treatment Plant at Aldermaston", In: Proceedings of Waste Management 03, Tucson, USA, February 29 - March 4, 2004, WM Symposia Inc. (2004).
- 3 M. J. Dalton. "Rheological Measurements on Cement Grouts", United Kingdom Atomic Energy Authority report (Ref: AEEW-R 2094, June 1986).
- 4 E. Connock. "Advances in the Use of Silicones in Cosmetics", *Chimica Oggi* Jan/Feb 38-40 (1998).
- 5 J. P. Storer. "Conditions for Acceptance by BNFL of Radioactive Waste for Disposal at Drigg (CFA)", Issue 2/01, 23 October 2002.
- 6 C. D. Barnes, T. B. Calloway, Jr. and R. E. Eibling. "Thermodynamic modelling of the AWE Radioactive Aqueous Waste Treatment Plant Evaporator", Westinghouse Savannah River Company report (Ref: WSRC-TR-2002-00567).

## FOOTNOTES

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