VITRIFICATION ASSISTANCE PROGRAM: INTERNATIONAL CO-OPERATION ON VITRIFICATION TECHNOLOGY

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ABSTRACT

With 10 vitrification lines in operation (3 on WVP in Sellafield, 1 on AVM in Marcoule and 6 on AVH in La Hague), Sellafield Ltd and Areva NC benefit from the most in-depth experience worldwide in the vitrification of highly active liquors within a framework of commercial operations.

Based on the two-step process design, using a calciner and an induction-heated hot melter, which was initially deployed in Marcoule in 1978, core vitrification equipment has been continuously improved by the independent development programmes of the two companies.

In March 2005, Sellafield Ltd and Areva NC signed the Vitrification Assistance Program (hereafter referred to as VAP); a co-operative project lasting 4 years during which Areva NC is to share some areas of their experience and expertise with Sellafield Ltd.

Now at the halfway point of this project, this paper summarises the work performed by the VAP team to date, highlighting the early benefits and lessons learned.

The following points will be developed:

- Equipment delivery and preparation for implementation on WVP
- Training organization and dissemination to WVP teams
- Lessons learned from the early changes implemented in operations (Calciner, Melter, Dust Scrubber and Primary off gas system), and initial feedback from the first campaign using a VAP equipped line.

INTRODUCTION

HLW Vitrification and Induction-heating Technology

Vitrification of high-level liquid waste is the internationally recognized standard to minimize the impact to the environment resulting from waste disposal, as well as the volume of conditioned waste. Many countries including the USA, France, the United Kingdom, Germany, Belgium, Japan, Russia and India have vitrified high level waste, and several more countries are studying the application of vitrification technology.

Early work on the vitrification of radioactive waste during the late 1950s revealed borosilicate glass to be the most suitable matrix for the containment of waste from spent nuclear fuel [1].

In the 1960s, in both France and the UK, induction-heated vitrification technology was recognized as providing the obvious advantage of keeping the heating system outside the metallic melter (melting pot); the joule heating being simply delivered using external electric inductors.

At this time, each country conducted its own development programme supporting a single stage batch process based on induction heated technology:

- HARVEST (Highly Active Residue Vitrification Experimental Studies) in the UK [2];
- PIVER (Pilote Industriel de Vitrification – see fig.1) in France [1];

Industrial Vitrification Design: The Two-step Process

Learning from the PIVER industrial-scale vitrification prototype unit, the basic principles leading to the choice and design of the French industrial two-step vitrification process with heat induction metallic melter [1] are:

- The separation of the processing functions (calcination/melting), to benefit from simpler and more compact equipment, and to limit the size of the melter, allowing complete in-cell assembly and disassembly with moderate sized overhead cranes, master-slave manipulators and remote controlled tools.
- Limitation of the radionuclide carry-over by the off gas process
- Easy remote maintenance of the processing equipment with optimization of solid waste generated during operation

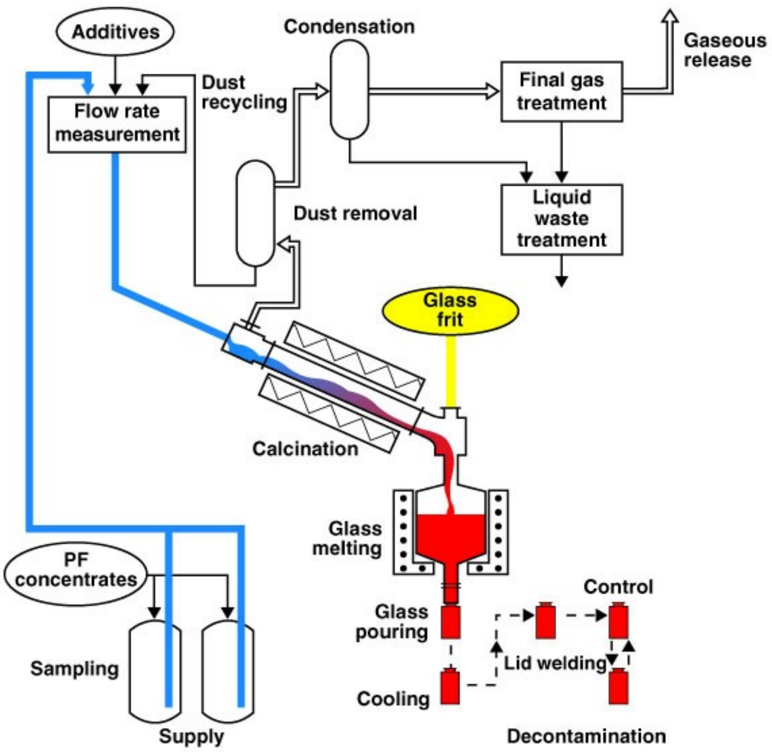

Fig. 1: The two-step vitrification design

Based on these principles, the AVM vitrification facility (Atelier de Vitrification de Marcoule) started active operation in 1978 in Marcoule (south west of France), vitrifying liquors from GCR fuels and research reactor fuels reprocessed in UP1 plant. The AVM facility (equipped with one vitrification line, designed for producing glass at 15kg/hr) is still in operation, delivering excellent production records after almost 30 years of operation. In fact, since UP1 decommissioning began in 1999, AVM has also demonstrated the versatility of the two-step process in managing the vitrification of various types of liquor resulting firstly from reprocessing activities and then from decommissioning activities.

From the industrial experience gained in the AVM, the vitrification process was implemented on a larger scale at La Hague in the late 1980s, in the R7 and T7 facilities, (also known as AVH – Atelier de Vitrification Hague), for operation in line with the UP2 and UP3 reprocessing plants. Both vitrification facilities are equipped with three vitrification lines, each having a maximum glass production capacity of 25 kg/h. With two lines in service and one line on stand-by, each vitrification facility can meet production requirements with sufficient operational flexibility.

In the UK, BNFL also based its vitrification facility (WVP) in Sellafield on this second-generation, two-step vitrification design and as a result WVP Lines 1 and 2 were commissioned in the early 1990s on the Sellafield site.

Continuous Improvement Management

Since operation start-up, both Sellafield Ltd and AREVA NC have developed their own independent improvement programs to optimise the throughput of their vitrification facilities according to their respective needs:

- In the mid-1990s, the implementation of an automatic heating control system in France, alongside melter design improvements, extended the lifetime of this key equipment. The implementation of mechanical stirring permitted an increase to the noble metal content in the glass. More recently, calciner throughput has been increased to 90l/hr on the R7/T7 facilities, (compared with the 60 l/hr from design basis)[3]
- In the UK, in the early 2000s, Sellafield Ltd built, and started to operate, a third vitrification line (WVP3) incorporating the lessons learned from their experience of operation and maintenance of WVP lines 1 and 2. They also deployed a thicker design of melter, allowing for a significant increase in its lifespan, as well as implementing an automatic heating control system on lines 2 and 3, based on a 50Hz induction-heating of the melter

The two-step process has been proven to be efficient technology in the vitrification of high active liquors, as each of the 9 lines mentioned above has successfully produced more than 150 glass canisters in a year, the best yearly production records being 519 canisters for T7, 512 canisters for R7 and 482 canisters for WVP. As a result more than 16700 canisters have been produced since operation start-up, corresponding to an overall xxxx TBq immobilized in glass by the Sellafield and La Hague facilities.

In addition, the process has demonstrated its ability to deal with very different streams (oxide type liquors, magnox type liquors, various blends and some stream from decommissioning) provided adequate supporting activities (studies and experiments) are anticipated.

Vitrification Assistance Program (VAP)

In addition to the developments already identified and implemented by BNFL, the signing of the VAP contract in March 2005, provided an opportunity to benefit from other improvements already deployed by AREVA NC to enhance productivity on its facilities.

This program involves technology and knowledge transfer in vitrification, and includes the provision of the following:

- Delivery of equipment (Melters, Calciner Tubes, Lower End Fittings (connects the rotating calciner tube and the melter), Recycle Constant Volume Feeders (RCVF) and Welding Torches)
- The training of 15 Sellafield Ltd employees, at the AREVA NC vitrification facility in La Hague
- On-site support at WVP in Sellafield, to facilitate the implementation of new equipment and support the operators
- Complementary studies relating to the optimization of the Sellafield Ltd vitrification operations

TECHNOLOGY TRANSFER

This part of VAP relates to the delivery of AREVA NC technology and to its implementation on WVP, as well as to supporting activities (e.g. Interface Study).

In particular, the lessons learned from the improvement programs deployed by AREVA NC over the years have been summarised and documented as ‘Knowledge Files’ thus providing the full background to the improvements, and not just the final product details.

Interface Study I

A key objective was to deploy equipment on WVP as closely resembling that of La Hague as possible, in order to maximise the benefits available from the improvements implemented by AREVA NC. At the same time it was essential to minimise the number of modifications required to the Sellafield Ltd lines due to the difficulty in implementing modifications in an active cell, and to limit the outage time of the lines.

Whilst the initial design of WVP lines 1 and 2 was similar to that implemented at La Hague, the interface study provided essential information relating to differences, such as the one linked to the different layout of the buildings (a clear difference was in the orientation of the melter in relation to the calciner: a difference of 90^o between WVP1&2 and R7/T7 positions). There were also notable differences between WVP1&2 and the new WVP3 (e.g. the orientation of the melter in relation to the calciner on WVP3 is similar to La Hague). This demonstrated the need for specific additional studies to deal with internal differences at WVP.

At this point the schedule was paramount, as the interface studies needed to be completed prior to the manufacture of the equipment. The delivery of the first piece of each equipment type was planned between October 2005 and March 2006. In order to manage this constraint several meetings were held between the AREVA NC and Sellafield Ltd teams in April, May and June 2005 to share views on potential issues, and to facilitate the exchange of information (e.g. drawings).

The main issues identified during this joint exercise were agreed between the parties and summarised in a document identifying the modifications required on the WVP lines to maximise the benefit to be gained from the improved equipment. The document covered process requirements (including utilities and I/E where relevant), mechanical interface, commissioning activities and maintenance, and was delivered 3 months into the contract, providing a key support tool for the Sellafield Ltd design team in preparing the necessary modifications to the WVP lines.

Equipment Manufacture & Delivery [4]

Once the interface requirements were confirmed, the data was incorporated into the equipment design modification studies prior to the manufacture of the equipment.

The manufacturers selected were:

- MECAGEST for the Melter and the Lower End Fitting
- ACPP for the RCVF
- LABOURIER for the Calciner Tube

In order to reduce the manufacturing time as far as possible, to maintain the tight delivery schedule outlined above, early discussions were held with the manufacturers, and long procurement time-frame items (e.g. melter material) were ordered well in advance. In some cases, it was also possible to benefit from the fact that similar orders had been placed earlier by AREVA NC for its own spares, creating the possibility of accelerated manufacturing for VAP without jeopardising the procurement of spares for the vitrification facilities at La Hague. This opportunity was possible due to the close relationship between the people involved in the VAP project and the operational teams at AREVA NC.

On completion of the manufacturing work, the equipment was jigged using Sellafield Ltd jig units sent to France specifically for this purpose. This careful validation process supported the studies performed earlier, and was thus used as the acceptance criteria for the new equipment. As part of this receipt process, representatives from Sellafield Ltd took part in witnessing the jigging activities in France.

The first delivery of each type of equipment occurred as follows:

- October 2005 Melter 1
- October 2005 Lower End Fitting 1
- November 2005 RCVF 1
- January 2006 Calciner Tube 1

The current status of equipment delivery is as follows:

- All 3 Calciner Tubes delivered
- All 3 Lower End Fittings delivered
- All 3 RCVFs delivered
- 4 Melters have been delivered, a further 4 will have been delivered by the end of 2007, and the 2 remaining are under manufacture for delivery in 2008

Fig. 2: 1st Melter delivery in WVP

Knowledge Files Preparation

In parallel with the interface studies and equipment manufacture, a team of vitrification experts was brought together from AREVA NC, La Hague (AVH) and Marcoule (AVM), CEA and SGN in order to document the historical improvements made to the equipment covered by the contract.

The information collected, recorded over a period of 15 years, involved liaison with R&D, engineering and manufacturing teams, providing vast personal experience and testament to the evolution of the vitrification process.

In addition, data was collected relating to the behaviour of the improved equipment in operation at La Hague. This included records of operation, information about identified operational issues, and the way they have been tackled at La Hague.

The data collected was documented for each type of equipment and transmitted to Sellafield Ltd. in order for their VAP team to perform an in depth review, and provide valuable feedback to AREVA NC.

The technical exchanges generated by this review between the companies have been very stimulating and fruitful for the project.

Final documents were delivered within a similar timeframe to the first equipment deliveries.

Implementation on WVP [6]

Initially focused on the French team, the work load began to switch to the UK team as the modifications to WVP line 1 were expected by mid-2006. As explained earlier, the requirements for WVP modifications were kept to a minimum. Nevertheless the work was significant, including a TWX change, as well as the implementation of a multiple sparging system for the melter.

Due to operational constraints, the planned outage for implementation of the necessary modifications was delayed by few months, and was begun in September 2006.

The implementation of the modified equipment on WVP1 went well, from the VAP perspective. Minor issues which have arisen have been satisfactorily resolved, and have had minimal impact on the outage programme. The start-up of the newly equipped line 1 took place in May 2007.

KNOWLEDGE TRANSFER & STAFF DEVELOPMENT

This part of the VAP refers to the transfer of AREVA NC operational knowledge in various formats.

Training at La Hague

As part of the VAP, on-site training at La Hague was organised for a number of Sellafield Ltd employees. The aim was to show how the improved equipment performs during real-time operation, and how it is controlled by the AREVA NC operating teams. In total 15 people from Sellafield Ltd were trained over a one year period. The core training was delivered to 4 groups of 3 people, each group spending 12 weeks at La Hague. A further 3 people focussed on the welding technology.

The challenge, once again, was to manage the tight schedule imposed by the start date of the first training session, planned for September 2005. In fact, in addition to the other activities previously mentioned (e.g. preparation of the Knowledge Files), the task was to put together, from scratch, a high level course, in English, on the most up-to-date operational practices deployed in the La Hague vitrification facilities.

This was facilitated in part by the experience gained from similar training activities already successfully managed by AREVA NC with the Japanese, as well as a buddying system employed in the training of its own staff in new roles. Finally, experienced Shift Team Leaders from R7 and T7 were required to transfer to the VAP project on a full-time basis, without putting the organisation of the AREVA NC operating teams at risk.

On the other hand, the selection process on the Sellafield Ltd side was also crucial to ensure that training and knowledge delivered could be effectively cascaded through the WVP organisation. A variety of profiles were selected (manufacturing support staff, vitrification experts, a shift team leader and operators) in order to benefit from a variety of experience and knowledge within WVP.

Valuable feedback was provided by the Sellafield Ltd trainees allowing for the continuous improvement of the training material whilst the training program was in progress.

Once again, this period was very rich and fruitful in terms of the technical discussion generated, including the opportunities to compare the approach of the two organisations in dealing with similar types of operational issue.

Cascade Training at WVP

Once the first group of trainees returned from La Hague to Sellafield, work was started on the cascade training package for onward delivery to the WVP operating teams.

People from the second group were also involved in this process, including the organisation of training sessions for WVP operating teams. For practical reasons, WVP1&2 personnel were prioritised, but some WVP3 operators were also encouraged to attend the sessions.

The training was divided into four sections, each relating to a different area of the process, as follows:

- Melter
- Calciner
- Dust Scrubber
- Primary Off Gas System

Training in each section covered:

- Background information on the new equipment
- Basic theory relating to the process
- Normal operation and trending
- Malfunctions and how to react

Each section was delivered 4 times in 3-4 days, and was qualified by an evaluation process. Practical exercises were specifically designed, using real data from the powerful monitoring system in use on WVP, to allow the trainees to review historical operational situations encountered on WVP.

A significant number of operators were successfully trained prior to the start up of WVP1 with VAP equipment, including most of them for some teams. Additional sessions have also been designed for the WVP shift team leaders.

This work was spread over more than 8 months in 2006 and demanded a huge investment by Sellafield Ltd in its workforce. It has been very well managed, the training process being implemented without jeopardising operation and production, which continued at the same time.

The AREVA NC shift team leaders who delivered the initial core training at La Hague have actively participated in this phase at Sellafield, supporting the preparation of training materials (manuals) as well as delivering some of the training, thus taking the opportunity to meet the Sellafield Ltd operators.

Fig. 3: English and French personnel from the VAP team

Interface Study II

In addition to the transfer of knowledge through training, the VAP contract also provides for a resource document describing best practice for the optimal performance of the equipment supplied.

The methodology employed for this study focussed on the phenomena involved in possible malfunctions to each type of equipment. The key operating parameters related to these phenomena were documented, and an acceptable range defined according to the experience of AREVA NC.

The final document, produced in May 2006, was the result of 8 months team work, including input from AREVA NC, CEA and SGN, as well as a full review by Sellafield Ltd, and provides a useful tool for process review.

Shift Support for the First Campaign

For the start-up of WVP line 1, fully equipped with VAP equipment, Sellafield Ltd placed additional personnel on shift to monitor the process, consistent with the practices defined within Interface Study II.

The shift support team consisted of a combination of Sellafield Ltd personnel trained at La Hague, and the AREVA NC shift team leaders who were involved in their training. This constituted the last step of the knowledge embedding process offering the Sellafield Ltd operating teams live support in a genuine operating situation.

The integration of the shift support team within the Sellafield Ltd operating teams has been assisted by the relationships already developed during the cascade training.

EARLY BENEFITS & LESSONS LEARNED TO DATE

This part relates to progress made on WVP since the beginning of the VAP contract. It relies partly on the work performed on different parts of the process at Sellafield prior to the implementation of the VAP equipment.

Initial feedback from the first campaign operated with the VAP equipment on WVP1 is also discussed in this section.

Enhanced Working Practices [5]

A review of operational practices, primarily focussing on WVP lines 1 and 2, (the first destined to receive VAP equipment) was scheduled as follows:

- Mid-2005 Calciner Operation
- Mid-2006 Dust Scrubber Operation (including recycle circuitry)
- Early 2007 Primary Off Gas System Setting

The following enhanced working practices have produced positive results:

- A daily meeting with Manufacturing Team has proved central to production, working in real-time rather than historically
- Improved control of the calciner has led to a reduction in rabble bar damage (no breakages on WVP 1 and 2 since mid-2005 / one breakage on WVP 3 during the same period)
- Improved control of the Dust Scrubber has led to a reduction in RCVF blockages. (2005/06 4 blockages on WVP 1 and 2, with 175 canisters produced. Since implementing tighter controls in mid-2006, no blockages have occurred on WVP 1 and 2 while producing 232 canisters)
- Improved control of the Primary Off Gas System (POG) has resulted in better pressure control in the melter and calciner. A procedure for identifying initial POG conditions at start-up has been written (e.g. in-leakage …). Extensive testing of the characteristics of main components of the POG system have also been carried out (e.g. ejector, in-bleed valve …)
- Improvements to ancillary systems have also helped to ensure the process runs smoothly (e.g. increase in sugar to the calciner, water delivery for standby …)

Positive Feedback from the First Campaign

Start-up of the first campaign of WVP1, following VAP equipment implementation, was in May 2007. The campaign lasted for about 8 weeks.

After this relatively short campaign, several points can nevertheless be considered as positive signs from a VAP perspective:

- Calciner control has been sufficiently satisfactory to ensure that the rabble bar remained straight. During the rebuild period following the end of the campaign it was decided to re-use it for the next campaign.

- The wear to the graphite seal on the lower end fitting has been measured at less than 1mm after more than 2000 hours of operation. This is in line with VAP expectations for this equipment. The healthy status of this key element (ensuring connection between the melter and the calciner) enabled it to be re-used for the next campaign. It must be noted, however, that Sellafield Ltd had already introduced this type of graphite seal on WVP3 in mid-2006 having already recognised its benefits, and it is currently used on all 3 lines.
- The work performed on the off gas system settings, together with some defined limits to the water flow rate to be used during stand-by, improved the stability of the pressure control within the calciner, approximately by a factor of 4, compared with previous operations one year ago.
- The implementation of a multi-sparged melter design enabled a significant reduction in soaking time due to improved thermal homogeneity in the glass. When producing magnox glass, heating optimisation of the melter led to a reduction in the down-time due to soaking, by more than 60 minutes per pour compared with the original single sparge melter design.

These observations are consistent with the past experience of AREVA NC, and with the expectations of the VAP project. They can be seen as the first positive results of the work already performed by both Sellafield Ltd and AREVA NC within the framework of the VAP, and need to be developed over the coming months to enable longer campaigns to be operated.

CONCLUSION

The vitrification process and technology implemented at Sellafield and at La Hague, based on the two-step process, have proved to be efficient in treating high active liquor of various types. Ten lines based on this principle have been successfully operated for more than 15 years in France and in the UK. The process has also been demonstrated to be sufficiently versatile to benefit from continuous improvement and development programmes.

VAP, as a complete package to support vitrification technology and knowledge transfer from AREVA NC to Sellafield Ltd, has provided the framework for fruitful technical exchanges and discussions between the two companies.

From equipment delivery to knowledge embedding within the WVP teams, both companies have worked hard together to respect the tight schedule of the contract, despite growing external constraints. This has been closely managed in order to achieve the best results for the VAP without jeopardizing the continuing production operations on both the Sellafield and La Hague sites.

For future campaigns, WVP1 will be equipped with an automatic heating control system similar to the one used at La Hague (i.e. based on 4kHz). This will facilitate the work of the WVP operators and finalise the conversion of WVP melter control systems from manual to automatic, meaning that the melters on all 3 lines will be automatically controlled.

Further implementation of VAP equipment is also planned on the other lines.

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