Vitrification Assistance Program: International Cooperation on Vitrification Technology (Part II) - 10157

D.Marsden*, B.McGowan*, B.Garth*, N.Skillen*, S.Scott*, HN.Guerif**, E.Guillois**, T.Flament**, S.Sartelet**, A.Prod'homme***, F.Pereira-Mendes****, J.Lauzel****, JF.Hollebecque*****

* Sellafield Ltd, Seascale, UK
** AREVA NC, France
*** AREVA FEDERAL SERVICES LLC, USA
**** SGN (AREVA Group), France
***** CEA, Marcoule, France

ABSTRACT

With ten vitrification lines in operation (3 on Waste Vitrification Plant - WVP at Sellafield, 1 on Atelier de Vitrification Marcoule - AVM at Marcoule and 6 on Ateliers de Vitrification Hague - AVH at La Hague) for decades, Sellafield Ltd and AREVA have benefited from the largest experience worldwide in vitrifying highly active liquors in the frame of commercial operations.

Based on the two-step process design, implemented through a calciner and an induction heated hot melter and initially deployed at Marcoule in 1978 (AVM), vitrification core equipments have benefited over the years from many improvements deployed independently by both companies according to their respective technical constraints.

In April 2005, Sellafield Ltd and AREVA signed the Vitrification Assistance Program (commonly referred as VAP); a cooperative work over 4 years that enabled Sellafield Ltd to benefit from the successful experience gained in La Hague and Marcoule vitrification facilities in order to accelerate its own improvement program.

The VAP project ended successfully in March 2009. This paper, as a sequel of a previous one presented in Waste Management Symposium in 2008 [1], highlights the benefits and lessons learned brought to WVP operations as a result of the joint effort of the VAP team. For this purpose, the following points will be developed in this paper:

- Summary of the preparative work prior to VAP equipment implementation on WVP
- Details of the enhancement recorded on VAP equipped vitrification lines including current operation achievements
- Future challenges to be dealt with on WVP

INTRODUCTION

This section emphasizes induction heating technology used for vitrifying high active liquors coming from the nuclear fuel commercial recycling activities as well as the capabilities of this technology for adapting through continuous improvement programs. A brief introduction to the content of the Vitrification Assistance Program is also given.

HLW Vitrification and Induction-heating Technology

Vitrification of high-level liquid waste (HLW) is the internationally recognized standard to minimize the potential impact to the environment resulting from waste disposal, as well as the volume of conditioned waste.

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 (also referred as melting pot); the joule heating being simply delivered using external electric inductors.

Learning from early industrial-scale vitrification prototype unit (PIVER), the basic principles leading to the choice and design of the French industrial two-step vitrification process with heat induction metallic melter [2] are diagrammed in Figure 1:

- The separation of the processing functions (calcination/melting), to benefit from simpler and more compact equipment, allowing maintenance to be performed with moderate sized overhead cranes, master-slave manipulators and remote controlled tools.
- The minimization of solid waste generated during operation.
- The implementation of in-line stream recycling from the off gas treatment system (Dust Scrubber) to the melter to enhance overall decontamination factor for volatile species.

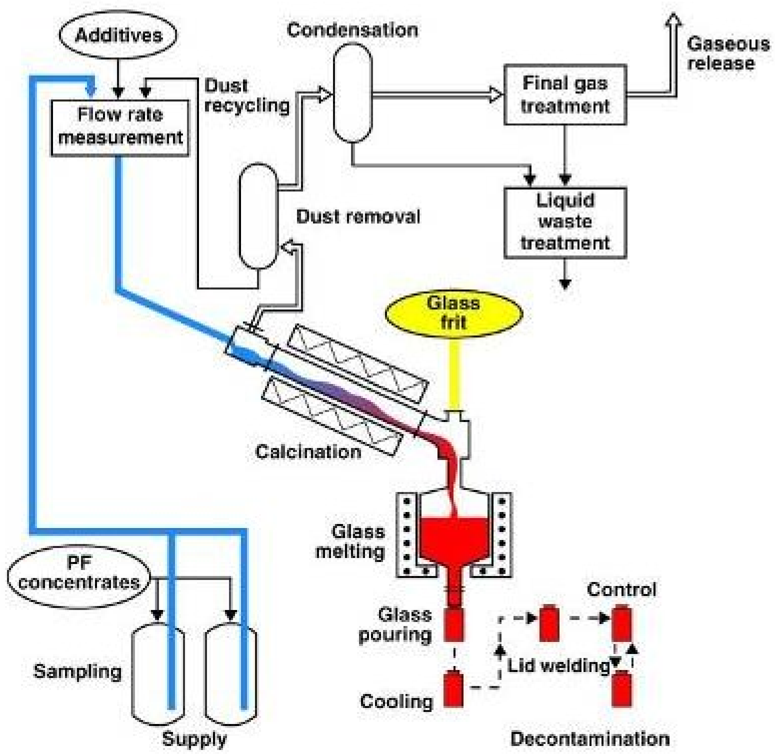

Fig. 1: The two-step vitrification design

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 Gas

Cooled Reactor 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 (see Table 1). 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.

Table 1: AVM Records of Operation

Number of canisters produced since start-up in 1978	3 159
Total activity immobilized since start-up (10^6 TBq)	16.9

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/hr. 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.

This early design already included bubbler technology provided through a single bubbler within the melters.

Continuous Improvement Programs

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

- In the mid-1990s, the implementation of an automatic heating control system operated at 4 kHz in France, alongside melter design improvements, extended the lifetime of this key equipment. Bubbler technology was generalized and optimized to provide enhanced thermal mixing (multiple bubblers within the melter). Finally, the implementation of mechanical stirring permitted an increase to the noble metal content in the glass. More recently, calciner throughput has been increased to 90 l/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 [4]

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 single year, the best yearly plant production records being 519 canisters for T7, 512 canisters for R7 and 482 canisters for WVP. As a result more than 18600 canisters have been produced since operation start-up, corresponding to an overall 300×10^6 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 activities) provided adequate supporting programs (studies and experiments) are anticipated.

Vitrification Assistance Program

In addition to the developments already identified and implemented by BNFL, the signing of the VAP contract in 2005 provided an opportunity to benefit from other improvements already deployed by AREVA to enhance productivity on BNFL 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) to Sellafield
- The training of Sellafield Ltd employees, at the AREVA 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 (referred as Help-line)

This program has been implemented over 4 years.

TECHNOLOGY AND KNOWLEDGE TRANSFERS

This section relates to the delivery of AREVA technology and to supporting activities dedicated to efficiently embed operational experience and lessons learned within Sellafield Ltd teams.

Equipment and Knowledge Files

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

In order to achieve quick delivery goals, engineering interface studies (referred as Interface Study I) have been finalized within 3 months from the kick-off of the project through joint effort of both teams and intensive technical exchanges. Some procurement activities were also initiated in parallel to accelerate the schedule.

The two major challenges met in this phase of the project (validate interfaces and managing schedule to align on WVP outage program) were a consequence of the need for implementing modified equipment in active hot cells in a plant under commercial production constraints.

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.

Fig.2: Inspection process in France

The first delivery of each type of equipment occurred from October 2005 to January 2006 slightly ahead of schedule. Remaining pieces of equipment were delivered throughout the period of the contract to meet Sellafield Ltd implementation program.

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

- Enhanced melter design with optimized multiple bubblers technology
- Reinforced calciner tubes
- Improved Lower End Fitting (referred as LEF) targeting an extended lifetime
- Optimized Recycle Constant Volume Feeder (referred as RCVF) preventing blockage to occur

Knowledge files gathered the knowledge gained from R&D, engineering and operation fields over more than 15 years to provide a full picture of the enhancement made. The technical exchanges between the companies generated by the review of the documents have been very stimulating and fruitful for the project.

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

Training Program

Another key part of the VAP was to implement an extensive training program first in France for a limited number of Sellafield Ltd peoples then in the UK as part of a cascade process to train most of WVP operators.

The core training at La Hague was delivered over a full year to 4 groups of 3 people, each group spending 12 weeks in France. An additional group came to be specifically trained on welder technology. High level course, in English, on the most up-to-date operational practices deployed in the La Hague vitrification facilities were put together from scratch for this purpose. This was facilitated in part by the experience gained from similar training activities already successfully managed by AREVA with the Japanese and thanks to the involvement of experienced Shift Team Leaders from R7 and T7 that were dedicated to the VAP project.

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

Fig. 3: Training at La Hague

Once the first group of trainees returned from La Hague to Sellafield, work was started jointly 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 organization of training sessions for WVP operating teams. For practical reasons, WVP1&2 personnel were prioritized, but some WVP3 operators were also encouraged to attend the sessions.

The training covered the full core vitrification process (Melter, Calciner, Dust Scrubber, Primary Off-Gas System) providing background information on the new equipment, basic theory about the process, normal operation and trending, malfunctions and how to react.

Practical exercises were specifically designed, using real data from the monitoring system in use on WVP, to allow the trainees to review historical operational situations encountered on WVP.

As part of the training process, additional classes and refreshing sessions were organized when needed over the period of the VAP to complete WVP personnel training. New material was added to include the automatic control system implemented on WVP1 (see below). Specific presentations were also delivered to people from Sellafield Ltd technical department and NNL (Nuclear National Laboratory) personnel extending the initial scope of the program.

Initial work was spread over more than 8 months in 2006 and demanded a huge investment by Sellafield Ltd in its workforce. Additional sessions and refreshers were organized as needed in 2007, 2008 and 2009, and were supported by the On-site-support personnel.

Additional Technology: Thyristor Induction Control System (TICS)

When the project started in 2005, melter heating on line 1 was still manually controlled whereas Sellafield Ltd had already converted lines 2 and 3 to automatic control using 50 Hz technology as part of its continuous improvement program.

To align line 1 heating control with automatic principle already deployed on the other lines of WVP while keeping in mind the spirit of the VAP, Sellafield Ltd decided to implement the 4 kHz based automatic control system used at La Hague for heating melters.

As a result of this modification, Sellafield Ltd benefited fully from the lessons learned and the experience gained by AREVA in terms of melter heating at La Hague.

The equipment called TICS was provided by AREVA and SGN. Again adaptation to WVP required works to be done for interfacing with Sellafield Ltd Digital Control System. To facilitate integration and start-up, this part of the project has been followed by dedicated experts from AREVA and SGN involved in each steps from the specification to the start-up of the equipment along side Sellafield Ltd project personnel. They also provide specific additional training to various WVP organizations (Operator, Maintenance, etc…).

BENEFITS AND LESSONS LEARNED FROM OPERATION

This part relates to progress made on WVP since the beginning of the VAP contract. It relies partly on work performed by the VAP team on different parts of the process at Sellafield prior to the implementation of the VAP equipment then focuses on later benefits obtained with the enhanced equipment deployed and the teams fully trained and adequately supported. This work has greatly benefited from the On-site-support team provided through the VAP contract (one to five AREVA, SGN and CEA people seconded within WVP and their Sellafield Ltd counter parts) and Help-line studies performed as needed

Enhanced Working Practices

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

- From mid-2005: Calciner Operation
- From mid-2006: Dust Scrubber Operation (including recycle circuitry)
- From early 2007: Primary Off Gas System Setting

The implementation of enhanced working practices has produced the following 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 / two breakage on WVP 3 during the same period over which more than 1300 canisters were produced)
- Improved control of the Dust Scrubber has led to a reduction in RCVF blockages.
    - 4 blockages on WVP 1 and 2, with 175 canisters produced in 2005/06;
    - Since implementing tighter controls in mid-2006 up to the end of the contract in March 2009, only two blockages have occurred on WVP 1 and 2 while producing more than 375 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 …);

This work has benefited from the issuance of a resource document describing best operational practices for the optimal performance of the equipment supplied. This document written as an operational interface studies (referred as Interface Study II) gathered the appropriate operational windows for the important parameters from process and equipment point of view. It has been used to provide operational guidance to the operators and WVP Control Rules have been modified to be consistent.

The methodology employed for this study focused 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.

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

Equipment Implementation [5]

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 Through-wall-crossing section change, as well as the implementation of a multiple sparging system for the bubbler technology provided with the enhanced melter.

Due to operational constraints on WVP, 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 program. The start-up of the newly equipped line 1 took place in May 2007.

For the start-up of WVP line 1, fully equipped with VAP equipment (but the TICS), Sellafield Ltd placed additional personnel on shift to monitor the process consistently with the training and 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 shift team leaders who were involved in their training. 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. The benefit from this specific role has led Sellafield Ltd to make it permanent albeit some adaptation.

The first campaign following VAP equipment implementation was known to be a short one (8 weeks) allowing only to get a first idea of how the equipment would behave. This was due to the need for a planned outage required on some line 1 system. Sellafield Ltd took benefit from this outage to implement the TICS. At that time the flexibility provided by the contract was also used to utilize Help-line service to support some of the activities of Sellafield Ltd project related with the outage.

Restart of line 1 by the end of 2007 has been unfortunately stopped unexpectedly after 6 weeks by a major failure of the melter power supply unit. Sellafield Ltd teams demonstrated their ability to manage strong technical issue providing adequate response to this failure. VAP project had to adapt consequently to unexpected operational constraint and took the opportunity to prepare the retrofit of line 2 and planned some fine tuning on the TICS from the early trends monitored during these 6 weeks.

By the end of 2008, WVP1 was ready to start again. Few weeks following start-up were necessary to implement the fine tuning of software parameters and PID required by the TICS so that the system was able to deliver its full efficiency. The line demonstrated then very good production records up to then end of the contract and continued without major problem up to its next planned outage period in June 2009.

In parallel WVP2 retrofit has been implemented and start-up occurred in April 2009. Again the line demonstrated very good behavior and is still running at the time of writing.

Feedback from Operation on Lines 1 & 2

Early account for preliminary feed back has been provided in the first paper of this series [1].

By November 2009, line 1 produced more than 230 canisters with VAP equipment deployed and line 2 more than 150 canisters, both lines totalizing together more than 20 months of operation with the enhanced equipment.

Records of operation are very good and consistent with the project expectation and early benefit already discussed. This view is actually shared by Health and Safety Executive who stated in its most recent Quaterly Report [6]:

"Sellafield Ltd is investing in improvements to the throughput and reliability of the vitrification process via its links with COGEMA: the recent success of Lines 1 and 2 underlines the importance of this work."

As part of these benefits one can mention:

- Calciner control has been sufficiently satisfactory to ensure that the rabble bar remained straight after more than 5500 hrs of operation of the calciner of WVP1. Current Rabble Bar operated on WVP2 has been used for more than 6000 hrs without problem and it is planned to continue to use it up to the next planned outage. Along side with calciner tube reinforcement, the good results obtained with the Rabble Bar allows to clear this piece of equipment from the list of possible cause necessitating anticipated preventive outage to be performed every 2000-2500hrs.
- The extended lifetime provided by the enhanced design of the LEF graphite seal has been recognized by Sellafield Ltd early in the project and its use has been generalized over the 3 lines of WVP as soon as mid 2006. Results from last campaigns confirmed this view. Line 1 graphite seal has actually been operated for more than 8500hrs extending by a factor 4 the average lifetime experienced with the former design and achieving results beyond the project expectations (i.e. 4000 hrs). This result is also confirmed by a good behavior of the seal on line 2 that is totalizing more than 6000hrs in operation at the time of writing. Like for the Rabble Bar, graphite seal extended lifetime suppressed the need for performing intermediate outage every 2000-2500hrs.
- 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-bubblers melter design enabled a significant reduction in soaking time due to improved thermal homogeneity in the glass. When producing magnox glass, heating optimization 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 bubbler melter design (i.e. a gain of about 12% in productivity).
- Melter on WVP1 has produced 140 canisters consistently with project expectations. Preventive exchange has been performed at the time of the planned outage in summer 2009 and no sign of failure was monitored at that time. Currently melter operated on line 2 has already produced more than 150 canisters and planned outage schedule is being discussed to take benefit from additional lifetime. Deformation monitoring based on operational parameter trends is currently indicating very good behavior for this equipment. This is an important result as it is the first time for this enhanced design to be operated with a 50Hz heating control system.

These observations are consistent with the past experience of AREVA and with the expectations of the VAP project. As explained earlier these successes must be viewed as the result from the deployment of a complete program rather than just equipment as well as the outcome of a joint team collaborative work. In addition to enhanced technology, it included knowledge transfer through significant training and support through secondment within WVP organization to ensure adequate embedding within teams and make sure operating practices will align to provide maximum benefits.

FUTUR CHALLENGE AND PURSUING COLLABORATION

This part deals with continuation of work between both companies since April 2009 and future challenges to be faced in both Sellafield and La Hague vitrification facilities in the years to come.

Calciner Feeding Throughput

WVP is currently operated with a calciner feed throughput around 40 L/hr of High Active Liquor (referred as HAL) thanks to highly concentrated feed stream. Taken into account recycling from Dust Scrubber and sugar addition, it corresponds to a total flowrate of 60 L/hr. Since HAL evaporating capacity of Sellafield Ltd is shortening, it has been anticipated a decrease of the concentration of HAL to be processed by WVP for the next years. By keeping constant the feed rate of the calciner, these dilute feeds would lead to reduce the waste oxide production rate.

AREVA has already upgraded the feeding throughput of La Hague vitrification facilities R7/T7 from initial 60 L/hr to first 76 L/hr, now to 90 L/hr [3] and soon to 110 L/hr. Sellafield Ltd has thus asked to AREVA to perform a study in order to identify all the potential limitations to an increase of feed throughput in its vitrification facility and to propose a program of adaptations, upgrades and tests to be realised on WVP.

Such study called “Dilute Feed Study” has begun in May 2009 and should finish in December 2009. In order to have a good identification of the possible required upgrades, the following topics have been analysed:

- Definition of WVP future needs: In order to be able to propose the best fitted upgrade program, it is necessary to have an accurate estimation of the future flow to be vitrified in Sellafield. Such study is currently performed by Sellafield Ltd using a new model specifically developed for this purpose.
- Check of the core equipment capacity: SGN is currently determining the maximal feed throughput that can be processed by each of the main equipment of the core process that will be impacted by a throughput increase. The calciner has been looked at first then the off gas treatment system (incl. the dust scrubber, the condenser, the NOx recombination column and the pressure regulation system). In order to perform such checking, SGN has used different models developed in order to provide operating support to the vitrification facilities of AREVA [7]. These models have been adapted and bench marked as necessary to comply with possible differences between the two facilities.
- Check of the capacity of the ancillary systems: It is necessary to assess that all ancillary systems will not be limiting the throughput increase targeted, in particular the feeding system (incl. pumps, constant volume feeders, piping line) and the feed tank preparation (i.e. feed batch preparation time). This study is primarily performed by Sellafield Ltd and supported by AREVA.

Future streams and other challenges

Evolution of feed streams to be vitrified in the future is faced on both sites. Actually, as part of their mission both Sellafield Ltd and AREVA will have to deal with legacy waste containing high content in species known to be difficult to vitrify (e.g. U, Mo, etc.) and also to consider the possibility to vitrify streams from future decommissioning activities.

To answer these challenges, AREVA is deploying the new CCIM technology on one of its line in R7 facility [8]. Sellafield Ltd on its side initiates a program to study and find solutions adapted to its own needs.

Another challenge faced by the plants is to minimize the volume of high level waste generated by maintenance activities (e.g. melter dismantling). Years ago, AREVA has been challenged on this specific subject and implemented as a response efficient tools and procedures to drastically limit the generation of these wastes [9].

Facing the same challenge for clearing its breakdown cell, Sellafield Ltd is engaging discussions with AREVA in order to investigate any potential for future cooperation on this subject.

Pursuing Operational On Site Support

In order to pursue cooperation on vitrification subject, VAP contract has been extended beyond April 2009 to provide further On-site-support and Help-line capabilities as well as the necessary back office support.

As a result, one AREVA personnel is still seconded within WVP organization to support operation and provide insight on any operational issue.

As part of its current assignment, he is following and optimizing the heating of melter on line 2 with the 50Hz control system in order to provide the best possible response of the equipment. In the future, an oversight of the retrofit of a VAP melter on line 3 may be provided. This retrofit is currently planned in 2010.

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 programs.

VAP, as a complete package to support vitrification technology and knowledge transfer from AREVA 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.

Both companies are preparing future challenges. The bridge built during VAP is believed to provide many opportunities to benefit from synergies from the improvement programs being deployed on both sides of the English Chanel.

REFERENCES

[1] Ch.Penrice, B.McGowan, B.Garth, J.Reed, S.Sartelet, HN.Guerif, JF.Hollebecque, T.Flament, A. Prod'homme – "Vitrification Assistance program: International Co-Operation On Vitrification Technology", WM'08 Conference

[2] R.Do Quang, E.Pluche, Ch.Ladirat, A.Prod'homme – "Review of the French vitrification program", WM'04 Conference

[3] V.Petitjean, R.De Vera, JF.Hollebecque, E.Tronche, F.Pereira-Mendes, T.Flament, A.Prod'homme – "La Hague continuous improvement program: Enhancement of the vitrification throughput", WM'06 Conference

[4] K.Bradshaw, N.Gribble, D.Hughes, A.Riley – "UK full scale non active vitrification development and implementation of research finding onto the waste vitrification plant", WM'07 Conference

[5] C.Haughin – "Specialist Equipment will boost VIT production rate", FOCUS (Sellafield Limited publication), Issue 25, Sept.2006

[6] Health and Safety Executive, Quaterly Report, April – June 2009, http://www.hse.gov.uk/nuclear/llc/2009/wcssg2.htm#a2p5

[7] E.Chauvin, Ph.Mahut, E.Tronche, Ph.Gruber, F.Pereira-Mendes, N.Huon, J.Lauzel – "La Hague continuous improvement program to go beyond the current high level of equipment availability of the vitrification facility: Operation support with specific numerical tools", WM'10 Conference

[8] Sandrine Naline, Frédéric Gouyaud, Christophe Girold, Benoit Carpentier, Vincent Robineau – "Vitrification 2010: A Challenging French Vitrification Project to Retrofit a Cold Crucible Inductive Melter at La Hague Plant", WM'10 Conference

[9] R.Do Quang, E.Pluche, J.F.Hollebecque, C.Ladirat, A.Prod'homme – "COGEMA Experience in Operating and Dismantling HLW Melter", WM'04 Conference