AREVA Experience in Cementation Technologies to Immobilize Radioactive Waste – 14457

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ABSTRACT

Cementation is the most widespread process used to immobilize low and intermediate level radioactive waste (most liquid, slurry, sludge and solid wastes). Depending on the waste particle size, the cementation may be homogeneous (waste immobilized by loading in a binding agent matrix for a safe and long term storage) or heterogeneous (grouting of bulky waste in a container, immobilization of a primary container in a secondary container).

For over 30 years, AREVA has been developing and enhancing the cementation immobilization process, delivering turnkey systems in each of the three technologies to be described while an improved batch mixing technology is under testing. Skills and knowledge consist in designing, constructing, testing, and commissioning cementation facilities for nuclear power plants, nuclear research centers, and nuclear fuel cycle facilities as well as for D&D activities. AREVA is also the industrial operator of five radioactive waste cementation facilities in France.

Pre-treatment and cement formulations has also been developed for several projects based on an in-depth knowledge of cement chemistry and following a scientific methodology which includes testing in pilot facilities in the “Hall de Recherche de Beaumont” (HRB), France, and laboratory analysis. AREVA’s HRB testing platform is used extensively to fine tune the cementation process for each specific waste stream characteristics, and to guarantee the delivery of a fully tested and qualified process. The methodology is indeed qualified by ANDRA (French National Agency for Radioactive Waste Management), which ensures compliance with stringent final product acceptance criteria for each type of waste.

INTRODUCTION

Cementation is the most widespread process used to immobilize low and intermediate level radioactive waste (most liquid, slurry, sludge and solid wastes). Depending on the waste particle size, the cementation may be homogeneous (waste immobilized by loading in a binding agent matrix for a safe and long term storage) or heterogeneous (grouting of bulky waste in a container, immobilization of a primary container in a secondary container). Concrete can also be used for the immobilization of waste contaminated with transuranic elements.

HOMOGENEOUS VERSUS HETEROGENEOUS CEMENTATION

Cement-based materials consist of a mixture of anhydrous cement, water and aggregates of various sizes – cements nature and additives being adapted to the type of waste to immobilize. Several categories may be distinguished depending on whether aggregates are present or not, their size and the water / cement ratio:

- Paste: consist of only cement and water
- Grouts: paste or fine mortars mixed with a low sand content
- Mortars: mixture of cement, water and aggregates (sand)

In a homogeneous process, waste, cement and water (& additives) are mixed together to produce grouts. As a result, the mixing equipment becomes contaminated – which is the reason why this technology has to be implemented in an active cell. Waste to be immobilized by homogeneous cementation consists of sludge, evaporator concentrates, ashes from incineration, used ion-exchange resins- all types of radioactive waste generated by nuclear reactors, research laboratories and fuel cycle facilities.

Three types of mixer technology exist for homogeneous cementation: batch mixer, in-drum mixer and continuous flow mixer.

In a heterogeneous process, the mixing equipment (producing the concrete, usually mortars) is not contaminated and is installed in an inactive enclosure cell. Waste (metallic, technological, etc.) is then encapsulated in drums with the concrete. Heterogeneous cementation can be achieved through a batch mixer or a continuous flow mixer.

CEMENTATION TECHNOLOGY

For over 30 years, AREVA has been developing and enhancing the cementation immobilization process, delivering turnkey systems in each of the three technologies (batch mixer, in-drum mixer and continuous flow mixer) while a fourth technology is under testing.

Skills and knowledge consist in designing, constructing, testing, and commissioning cementation facilities for nuclear power plants, nuclear research centers, and nuclear fuel cycle facilities as well as for D&D activities.

AREVA is also the industrial operator of five radioactive waste cementation facilities in France.

Batch Mixer Technology

The batch mixing cement solidification system accommodates all types of radioactive waste generated by nuclear installations:

- Evaporation concentrates from power plants,
- Liquid effluents from chemical processes,
- Spent ion exchange resins from purification systems,
- Sludges and ashes.

The principle of Advanced Batch Mixer (illustrated in Fig. 1) is the mixing of the waste with the grout powder in a separate device before pouring (by gravity through a chute) into drum (200 L) or other package (up to 3 m^3 containers).

The mixer is mainly characterized by the particular shape of its stirrers, which is located at the tank bottom. The high efficiency blade located at the bottom of the mixer achieves good grout homogeneity (Fig. 2) with a very short mixing time (less than five minutes).

Since the mixer has been completely emptied, rinsing can be accomplished with just a few liters of water. The rinsing water can be reused for the next batch if the water quantity addresses the mortar recipe; otherwise water is collected in a dedicated drum. The discharge gate/chute is rinsed automatically after emptying each batch, and before closing the gate, by means of two nozzles which spray water. The very small volume of effluent generated in this case is collected in the container being filled or due to be filled with concrete. Most of the time no secondary effluent is generated.

The batch mixing technology has been improved through recent development and a pilot is nowadays under testing.

Fig. 1: 350-L advanced Batch Mixer for LLW

Fig. 2: Perfectly homogeneous concrete paste obtained with the Batch Mixer

The batch mixing system minimizes operating costs by using standard, commercially-available hydraulic binders and reagents. The Cement Solidification System comes with a remote control and mimic diagram. Most operations are automated, lowering the need for operating personnel and minimizing radiation exposure.

The batch mixing technology had been applied to cement waste from:

- NPP (Saint Laurent des eaux in France;),
- Nuclear research laboratory (CEA Marcoule, CEA Valduc, both located in France; Chalk River, Canada; Lung-Tan in Taiwan)
- Reprocessing plant (several active cell of the La Hague plant owned and operated by AREVA)
- Waste management plant (ONDRAF, Belgium; Zwilag, Switzerland; ENRESA, El Cabril, Spain).

In-Drum Mixer Technology

The in-drum mixing approach is used for the homogeneous cementation of evaporator concentrates, spent resins, and sludge type materials. This technology cannot be used for heterogeneous cementation.

Cementitious materials are mixed with water and the waste in a drum. Once hydration takes place, the concrete begins to cure. The drum is then capped with extra inactive grout if necessary and fit with a lid before disposal.

This technology (called “Lost Paddle Technology”) is usually carried out with a sacrificial paddle which remains in the drum with the concrete-waste mixture (Fig. 3).

Fig. 3: In-drum test facility (left) and inside of a 1100 L drum after curing (right)

The in-drum mixing technology had been applied to NPP Vandellos, Spain and is currently foreseen for cementation of sludge and used Ion Exchange Resins (IER) at La Hague plant in France (plant under construction).

Continuous Flow Mixer Technology

The continuous flow cementation technology can easily be used for the heterogeneous cementation (grouting of solid waste), as well as for homogeneous cementation (for the conditioning of evaporator concentrate, spent IER, sludge). Liquid waste is indeed continuously fed to the mixer (Fig. 4) where cement is added. After a brief residence time in the mixing zone (2-3 L), the mixture is poured in drums or other packages for final disposal. Production rate is approximately 800 L/h.

Fig. 4: Continuous flow Mixing equipment

The low volume of the mixing chamber and the provisions for remote disassembly of the mixing chamber facilitate intervention in case of unexpected incidents (such as loss of power supply), for which there is high risk of curing inside the mixing part. The lower part of the mixer can be indeed remotely separated and dropped in a container for disposal as waste (fits into a 200 L drum, for example for later grouting).

The continuous flow cementation technology had been mainly applied to cement waste from NPP: (NPP Bohunice, Slovakia; NPP Trillo, Spain; NPP Ignalina, Lithuania; NPP Kola, Russia; NPP Taishan, China (under construction)), as well as for the Hahn Meitner Institut in Germany.

KNOW-HOW AND SERVICES RELATED TO CEMENTATION

AREVA has also developed pre-treatment and cement formulations for several projects based on an in-depth knowledge of cement chemistry and following a scientific methodology which includes testing in pilot facilities in the “Hall de Recherche de Beaumont” (HRB), France, and laboratory analysis. Moreover cooperation with institutes and R&D centers for the research of alternatives to Portland cement allows to propose the best cementitious compound regarding waste to be conditioned and to optimize volume to be stored.

AREVA’s HRB testing platform (Fig. 5) is used extensively to fine tune the cementation process for each specific waste stream characteristics, and to guarantee the delivery of a fully tested and qualified process. The methodology is indeed qualified by ANDRA (French National Agency for Radioactive Waste Management), which ensures compliance with stringent final product acceptance criteria for each type of waste.

The process development and qualification includes the waste pre-treatment steps, needed to condition the waste in a physical and chemical form compatible with the cementation operation, and accommodate the variety of waste streams which can be encountered (pH levels, organic content, etc.).

Our typical approach starts with preliminary characterization based on laboratory analyses, and continues through semi-scale feasibility, sensitivity and suitability testing. This culminates in definition of the concrete formulation and production process followed by construction of the full-scale facility. A process control plan is established to define the characterization needs, and consists in the foundation of the cementation validation plan prepared for any cementation project.

Fig. 5: AREVA's demonstration platform is used to test and qualify cementation and pre-treatment formulations in compliance with final waste package acceptance criteria

The physical and chemical properties of specimens of grouted products and their performances (mechanical resistance, leach resistance, etc.) are all measured in the HRB laboratory where entire grout characterization programs can be completed.

The HRB has also built up know-how and database in radioactive products simulation and cementation formulations. HRB test activities are executed in compliance with ISO 9001 standards.

KNOWLEDGE OF BOTH DESIGN AND PLANT OPERATION

In order to meet the specific requirements of each project, AREVA integrates cementation solutions in various configurations of equipment layout, either for fixed units installed in new or existing facilities, or for modular skid-mounted waste treatment units, which can be more easily pre-assembled and tested off-site prior to installation, and even re-located from site to site using mobile units. The compactness, the leak tightness for both gases and liquids, the flexibility with regards to the radioactive waste to be processed, and to the shapes of the packages to be filled make the different cementation solutions compatible with several different arrangements.

The knowledge and capability accumulated through the years has benefited tremendously from the experience and lessons learned from not only the development, engineering, and turn-key delivery of various sizes and configuration of cementation systems, but also from years of operations of waste treatment facilities including cementation units.

The nuclear facilities implementing waste immobilization by cementation, for which AREVA has had operational responsibilities, are:

- The Liquid Effluents Treatment Facility of Fontenay Aux Roses, in France, operated for the CEA (French Atomic Energy Agency) until 1995,
- The Liquid Effluents Treatment Facility of Cadarache, in France, operated for the CEA (French Atomic Energy Agency) for many years and still on-going,
- The sodium treatment facility of Creys Malville, for EDF (Electricité De France), since 2008, for the neutralization and cementation of 5,556 MT of sodium retrieved from the Superphenix Fast Breeder Reactor cooling system,
- The TWIN cementation unit of the TRIADE facility, in Bollene, France, owned by AREVA,
- The ACR and MDSB facilities of the La Hague spent fuel reprocessing plant, in France, for the immobilization of spent ion exchange resins, and residues (ashes) from solvent pyrolysis.

CONCLUSIONS

AREVA benefits from 30-years feedback on all steps of a cementation project: R&D, simulation, formulation, mock-up, analysis, design, and last but not least operation of facilities and these for each of the three, almost four, technologies of cementation (batch mixing, in-drum mixing and continuous flow mixing). Moreover cementation formulation deals with both the Portland cement and its alternatives (in-development) since the R&D is nowadays mainly dedicated to the curing of alternative cementitious compound.

These knowledge and know-how are a guarantee for each new cementation project to have the most adapted technology and installation of cementation to be implemented regarding the waste to be immobilized and the installation layout, as well as the waste performance criteria and the acceptance criteria for storage to be addressed.