

Enhancing HLW Vitrification Performances Through Continuous Process Improvement

Régis Didierlaurent *, Norma Maria Pereira Machado *, Victor Piovesan *, Eric Leveel *, Céline Roussel **, Emilien Sauvage ***, Caroline Michel ***, Patrice Brun ***, Elise Regnier ***,
Eléonore Welcomme ***

* Orano Recyclage, Prisme, 125 avenue de Paris, 92320 Châtillon, France

** Orano Projets, 23 Pl. de Wicklow, 78180 Montigny-le-Bretonneux, France

*** CEA, ISEC, DES, DPME, Univ. Montpellier, Marcoule, France

HLW generated during irradiation in reactors and separated during reprocessing has been industrially vitrified by Orano for over 40 years, providing durable and standardized containment of radionuclides for optimized storage pending disposal, reducing final waste volume, and enabling waste conditioning operation at industrially relevant throughputs.

The industrial vitrification of HLW began at the Marcoule Vitrification Facility (AVM), where Orano and the CEA (French Alternative Energies and Atomic Energy Commission) gained extensive operational experience. Building on this successful foundation, the vitrification process was deployed at industrial scale in the late 1980s at Orano's La Hague commercial reprocessing plant through the R7 and T7 vitrification facilities, which were designed to operate in line with the UP2-800 and UP3 reprocessing plants.

Both R7 and T7 facilities are equipped with three vitrification lines, providing significant processing capacity and operational flexibility. The vitrification process operated at the La Hague plant is a two-step configuration combining a calciner and a glass melter operating inline. The gas generated by the calcination and vitrification processes are treated by an off-gas treatment system (OGTS). Separating the calcination and vitrification functions enables simpler and more compact equipment (including the melter) and smaller vitrification cells. This architecture is fully adapted for HLW management and enables remote maintenance and in-cell modifications using moderately sized tools (overhead cranes, remotely operated manipulators, remotely controlled tools). In addition, the volume of secondary waste generated by maintenance operations is also minimized.

Since the start of industrial operations, continuous efforts have been undertaken to optimize process performance and technological systems, as well as to adapt glass matrix formulations in accordance with feed streams characteristics while keeping on standardizing the ultimate vitrified waste form. The long-standing partnership between CEA and Orano has driven numerous improvement programs, resulting in significant advances in vitrification performance at the La Hague plant.

The Induction Heated Metallic Melter (IHMM) was first developed over 40 years ago and has been successfully operated ever since, benefiting from continuous improvements driven by operational feedback and dedicated R&D programs. These process and technological advances have increased the incorporation rate of noble metals into the glass, enhanced melting throughput, and extended melter service life. From commissioning through the end of 2025, the R7 and T7 facilities produced more than 26 000 vitrified canisters, corresponding to approximately 11 billion Ci of radioactivity processed and vitrified using the IHMM.

A structured optimization program was also implemented to increase the calciner throughput, combining thermal upgrades, equipment reinforcement, and extensive qualification testing. The improvements, such as enhanced heating systems, surface treatments, tube thickening, rabble bar reinforcement, and optimized bearings substantially increased both thermal efficiency and mechanical reliability. As a result, the calciner throughput increased from its initial design value of 60 L/h to 90 L/h and subsequently to 108 L/h following a minor OGTS upgrade.

Orano's continuous improvement strategy has driven the development and deployment of the Cold Crucible Induction Melter (CCIM) technology. The CCIM entered commercial operation at the La Hague plant in April 2010, marking a major breakthrough. The system was installed in a highly radioactive cell with no human access, while preserving existing infrastructure and maintaining full compatibility with upstream and downstream equipment. The CCIM was initially used to vitrify effluents from the UP2-400 facility decommissioning operations, as well as legacy liquid waste from reprocessed U-Mo-Sn-Al spent fuel produced in the mid-1960s. Since 2020, the technology has been used for the vitrification of fission products solutions generated by ongoing spent fuel reprocessing operations at the La Hague plant. Several optimizations have been implemented on the CCIM since its industrial commissioning. Key technological upgrades have included improvements to the temperature measurement system, bubblers, and the mechanical stirrer. Most of these enhancements have focused on increasing glass throughput while reducing downtime associated with maintenance operations.

The R7 and T7 vitrification facilities at the La Hague plant have demonstrated outstanding industrial performance in terms of total glass production, noble metals incorporation, plant availability, safety, and remote in-cell maintainability. This industrial success is the result of Orano's long-standing continuous improvement program, encompassing process optimization, technology development, operations, maintenance, and operator training.

Through decades of industrial experience, Orano, with the support of CEA, has developed unique expertise in the design, construction, commissioning, operation, and maintenance of HLW vitrification facilities. This expertise has enabled the deployment of highly reliable and safe technologies, consistently delivering high-quality waste forms while meeting the performance objectives of modern reprocessing plants. Building on this experience, Orano and CEA have developed the DEM&MELT In-Can Melter (ICM) technology, a robust, simple, and versatile in-situ vitrification process designed for high- and intermediate-level waste. DEM&MELT is capable of treating both liquid and solid waste streams while generating minimal secondary waste. The technology has been specifically engineered to minimize capital and operating costs without compromising process performance. A full-scale pilot facility, commissioned in 2020, successfully demonstrated the simplicity, robustness, and operational flexibility of the technology. DEM&MELT enables high waste loading while producing durable vitrified waste forms and minimizing radionuclide volatility during thermal treatment, making it an attractive solution for a wide range of radioactive waste management applications.