

Integrated technologies for the decommissioning of LWR primary systems: cutting, chemical decontamination, and conditioning of spent ion exchange resins

Abstract

This PhD research addresses the technological challenges associated with the decommissioning of Light Water Reactors (LWRs), with emphasis on advanced methods for the dismantling of activated structures, the decontamination of contaminated metallic materials, and the conditioning of complex secondary waste streams. The work integrates experimental, analytical, and engineering approaches to establish a coherent framework capable of bridging the gap between laboratory-scale validation and industrial deployment. Three core technological axes are investigated: Abrasive Water Jet Cutting (AWJC) for the remote segmentation of highly activated thick-walled components; High-Performance Chemical Oxidation-Reduction Decontamination (HP-CORD-UV) for the selective removal of contaminated surface oxides from stainless steels; and the HYPEX® process, coupling resin comminution with geopolymer encapsulation, for the stabilization of spent Ion Exchange Resins (IERS).

Abrasive Water Jet Cutting (AWJC) utilizes high-pressure water mixed with millimeter-sized abrasives to effectively cut through thick metallic components, making it ideally suited for the large and heavy steel structures found in commercial power-generating nuclear reactors. Furthermore, its ability to generate liquid contaminants rather than dry airborne particles aligns with the nuclear-oriented principle of "minimizing the spread of contamination. Experimental campaigns confirmed the capacity of AWJC to segment reactor internals and vessel under controlled containment conditions, minimizing airborne releases and optimizing secondary slurry management. Design studies have additionally demonstrated its applicability in confined spaces with remote control capabilities and where high-precision cuts are required.

In this context, a comprehensive project requires the decontamination of contaminated (but non-activated) components with the objective of enabling their clearance and reducing the volume of primary waste requiring storage and conditioning. The most significant component of interest is the LWR reactor primary circuit, which is heavily contaminated yet practically non-activated. Consequently, stainless steel decontamination has been selected as the focus of study. Chemical processes were prioritized as they ensure remote operability while simultaneously emphasizing the minimization of not only radioactive waste but also chemical effluents. This study demonstrated that HP-CORD-UV achieves high decontamination factors with reduced chemical effluent volumes, thereby enabling the recycling or unconditional clearance of large metallic masses.

Traditionally and in modern operations, the most common approach for removing dissolved ions in nuclear water systems relies on ion-exchange resins. These resins serve routine functions, such as pH control in primary coolant circuits and are also deployed for special operations, including reactor water cleanup or targeted chemical decontamination of specific radionuclides. However, once these resins exhaust their exchange capacity and are not regenerated (as was often the case in the past), they become a radioactive wastes that resist conventional immobilization techniques like cementation in the domain, systematic investigation of resin grinding and geopolymer formulation (an alternative to the cement) established the feasibility of incorporating significant resin loadings while maintaining compressive strength, low radionuclide leachability, and long-term durability under repository-relevant conditions. A preliminary engineering design study of a modular and transportable HYPEX® facility further demonstrated the scalability of this approach, including provisions for remote operation, integrated liquid treatment, and compliance with nuclear safety and waste acceptance standards.

Collectively, these results evidence the complementarity of the investigated technologies: AWJC reduces secondary radioactive waste derived from the cut of activated components, HP-CORD-UV transfers

residual radionuclides from radiologically- contaminated metals into aqueous phases, and the HYPEX® process provides a robust immobilization pathway for the resulting resin-borne contaminants. The integration of these methods within a unified decommissioning workflow offers not only technical feasibility but also significant advances in safety, waste minimization, and cost-efficiency. The thesis thereby contributes a comprehensive, scientifically validated roadmap for the industrial implementation of innovative nuclear decommissioning strategies.