

Deployable Modular Electrochemical Decontamination for Nuclear D&D Applications

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Decontamination and decommissioning (D&D) of radiological equipment is frequently constrained by labor-intensive chemical methods that increase operator time-in-containment, drive dose and ergonomic risk, and generate significant secondary waste. These constraints are especially acute for complex geometries such as glovebox interiors, small high-surface-area parts, and long tubing or pipes, where wiping and immersion approaches are slow, inconsistent, and difficult to scale. To address these challenges, Los Alamos National Laboratory developed the Modular Electrochemical Nuclear Decontamination System (MENDS), a scalable, semi-autonomous platform that couples high-strength oxidizing chemistry with closed-loop electrochemical regeneration to deliver rapid decontamination while minimizing liquid waste inventory and reducing hands-on work.

MENDS adapts the cerium redox chemistry used in the Catalyzed Electrochemical Plutonium Oxide Dissolution (CEPOD) process into a closed-loop architecture that continuously regenerates Ce(IV) oxidant from Ce(III) within a flow-through electrolyzer. Continuous oxidant regeneration enables sustained decontamination using a finite electrolyte volume, reducing make-up chemical demand and confining liquid waste to a managed loop. In this approach, oxidizing solution is circulated through an application-specific cleaning interface (e.g., a sealed cleaning head or spray nozzle), returned to the electrochemical cell for re-oxidation, and reused until decontamination endpoints are achieved. This architecture is intended to replace repetitive manual scrubbing with monitored circulation supported by measurable oxidant strength.

Commercial off-the-shelf (COTS) electrolyzers were evaluated but did not meet facility-driven constraints on size, oxidation efficiency, electrical demand, and material compatibility. Consequently, a LANL-designed electrochemical flow cell fabricated via additive manufacturing was developed to maximize active electrode area while controlling hydrodynamics and reducing power draw. Performance testing demonstrated substantial reductions in system mass and footprint relative to comparable commercial units (approximately 6% of the weight) while providing markedly higher electrochemical turnover (approximately a 7× improvement), achieved at substantially lower operating voltage and current. A larger-capacity cell variant has also been fabricated to increase throughput via expanded electrode area, supporting future scaling to higher-flow applications.

A common circulation/oxidation backbone supports multiple modular implementations for different D&D tasks. In the glovebox configuration (GB-Decon), the system uses a closed-loop reservoir and compatible pumps with temperature control to maintain kinetics and stability. An inline UV–Vis flow cell tracks Ce(III)/Ce(IV) conversion in real time, enabling verification of oxidant strength during operation. For glovebox surface decontamination, GB-Decon employs interchangeable cleaning heads manufactured to conform to flats, corners, and obstructed



Size comparison of COTS electrolyzer versus LANL-developed electrochemical flow cell. Two versions of bespoke flow cell are shown with the short cell in front, and the tall cell in back.

geometries. Each head incorporates a compressible gasket that forms a sealed, narrow void against the target surface; negative pressure assists adhesion and draws oxidizing solution uniformly across a defined treatment zone, while quick-connect fittings enable rapid head changes. Preliminary results demonstrate substrate-dependent decontamination to low-level waste (LLW) thresholds on operationally relevant timescales, with 304 stainless steel reaching LLW criteria in approximately 20 minutes and 316 stainless steel in approximately 30 minutes under the tested conditions. By replacing iterative spray-and-wipe cycles with recirculating treatment, GB-Decon is positioned to reduce operator time-in-glovebox, lower dose and ergonomic strain, and improve campaign efficiency.

MENDS also targets long tubing and small-parts decontamination—persistent drivers of D&D cost and complexity. The tube module seals end caps to the tube outer diameter and uses an internal spray to wet interior walls, returning solution for re-oxidation and reuse, thereby enabling decontamination prior to size reduction or disposal. For small, textured, or high-surface-area parts, the enclosed MENDS Recirculator provides an alternative to traditional nitric/hydrofluoric acid soak-and-wipe protocols. In validation tests on Haynes 25 coupons contaminated to high activity levels (up to approximately 10 million dpm/cm², with a release criterion of <100 dpm/cm²), a legacy mixed-acid bath required greater than 12 hours to reach endpoint conditions, whereas the MENDS Recirculator achieved the same endpoint in 19 minutes followed by a brief deionized-water rinse, demonstrating substantial cycle-time reduction without reliance on extended mixed-acid exposure. In addition, the MENDS Recirculator allows for batch decontamination of multiple components in a single pass, all without direct handling or manipulation by operators.

Because MENDS regenerates oxidant electrochemically rather than through continual chemical replenishment, it operates with a fixed solution volume and correspondingly limited secondary liquid waste. Semi-autonomous circulation reduces manual handling of contaminated components and surfaces, while onboard UV–Vis flow monitoring provides a direct measure of oxidant availability and process condition. Across glovebox, tube/pipe, and small-parts demonstrations, MENDS integrates compact, modular hardware with closed-loop chemistry regeneration to enable faster processing, reduced secondary waste, and improved operational safety. Ongoing work focuses on throughput scaling, cleaning-interface optimization, and development of qualification metrics and deployment workflows to transition MENDS into routine production D&D operations.