

Articles and Commentaries Submitted to the LLW Forum

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Disclaimer: The articles submitted reflect my personal views and were provided in my individual capacity as a member of the LLW Forum, not on behalf of the Commission.

Article 5 - Iodine-129 in Low-Level Radioactive Waste: Overestimated Risk and the Case for Improved Characterization – A Pennsylvania Study

Iodine-129 (I-129) poses unique challenges for low-level radioactive waste (LLRW) disposal due to its exceptionally long half-life (1.7×10^7 years) and its chemical behavior that enhances mobility in groundwater. Even in small amounts, it can become the primary driver of long-term radiological dose. A study by Pennsylvania (PA), the host state of the Appalachian Compact, conducted several years ago but still relevant, used state-specific waste inventories and hydrologic assumptions and found that I-129 frequently dominates groundwater exposure scenarios, such as hypothetical receptor wells.

A critical issue identified by PA is the routine overestimation of I-129 in waste inventories, often by one or more orders of magnitude. This overestimation stems from the common practice of reporting at the lower limit of detection (LLD) when actual measurements fall below detection thresholds. Because I-129 is frequently produced in trace quantities, LLRW generators often report default LLD-based values, inflating inventory totals and overstating dose projections in performance assessment models. This can lead to unnecessarily conservative conclusions about long-term safety.

I-129 presents challenges for LLRW disposal due to its extremely long half-life, high mobility in groundwater, and the difficulty of measuring it accurately at low concentrations. Other long-lived radionuclides listed in 10 CFR Part 61, such as Technetium-99 (Tc-99), may pose similar issues, especially when conservative reporting practices, based on detection limits rather than actual measurements, inflate projected doses. I-129, in particular, often dominates long-term dose projections, making it a key case study for improving waste characterization and reporting protocols. Improving data quality will require nuclear utilities to reevaluate current inventory assumptions and adopt more precise analytical methods.

The PA study demonstrated how I-129 can disproportionately drive performance assessment outcomes and highlights a broader national need to reduce uncertainty in inventory estimates and regulatory modeling. Addressing these gaps through improved measurement techniques and more data-driven reporting will help ensure that LLRW management decisions remain technically credible and publicly defensible.

Article 6 - Rethinking Low-Level Radioactive Waste Management in the United States

In the United States, low-level radioactive waste (LLRW) is classified into Classes A, B, and C under NRC regulation 10 CFR Part 61, based primarily on radionuclide concentration and long-lived isotope content. This classification drives disposal requirements, including packaging and facility waste acceptance criteria.

While the U.S. system relies heavily on radionuclide concentration and half-life, it is also shaped by the origin of waste and the regulatory authority overseeing it. In contrast, most countries follow the International Atomic Energy Agency (IAEA) framework, which applies a more integrated approach that classifies all radioactive waste based primarily on radiological hazard and disposal pathway, rather than by origin or regulatory jurisdiction.

The U.S. framework has proven effective in protecting health and the environment, but it was developed in the 1980s with commercial light-water reactor waste in mind. It may no longer provide the most efficient approach for advanced reactors, next-generation fuel cycles, and innovative nuclear technologies. These produce new waste streams with isotopic profiles or non-standard mixes of radionuclides that do not fit neatly into the current classification scheme.

This challenge extends beyond waste types to disposal technologies. Modern engineered barriers, advanced treatment, and solidification methods can make some waste streams more stable and suitable for near-surface disposal. Reliance on rigid, table-based classification limits can restrict the system's ability to accommodate new waste forms or performance-based evaluations, highlighting the need for a more flexible, risk-informed approach.

Under the current waste classification system, exceeding Class A limits, even by a narrow margin, can trigger more restrictive disposal requirements regardless of the actual hazard. Similarly, even though NRC staff have concluded that some GTCC waste could be safely managed at a near-surface facility, current NRC rules generally default GTCC to geologic disposal. Beyond classification, the fragmented U.S. regulatory structure presents additional challenges. Waste from commercial nuclear plants, industrial, and medical facilities falls under NRC rules, while similar materials from DOE sites or technologically enhanced naturally occurring radioactive material (TENORM) from the oil and gas industries are governed by a patchwork of DOE orders, EPA guidance, and state regulations. This inconsistency complicates efforts to manage waste in a consistent and risk-informed manner.

In summary, **the U.S. LLRW management system is fundamentally safe**, but in some cases the classification and disposal requirements do not line up well with the actual hazard posed by specific waste forms. As nuclear technologies continue to evolve, updating the system will likely require criteria that better reflect risk and the performance of engineered barriers. If implemented, the proposed *NRC 10 CFR Part 61 Integrated Rulemaking* would be a step in the right direction, as it would alleviate some of the problems and weaknesses in the current system. However, the rulemaking alone does not address the full set of inconsistencies in the U.S. radioactive waste management framework. Some disparities remain among NRC, DOE, EPA, and state regulatory authorities, particularly where similar waste streams are regulated differently.

based on origin rather than risk. Addressing these gaps will require broader regulatory coordination to improve integration among NRC, DOE, EPA, and the states, harmonize standards across waste types, and better align U.S. practice with international best practices.

Ultimately, the question is not whether LLRW is adequately regulated, but whether it is being managed in the most effective, risk-informed, and forward-looking manner possible.

Article 7 - State Oversight: Enhancing Nuclear Safety and Public Perception

States are increasingly involved in supporting nuclear energy to meet growing grid reliability needs. As electricity demand rises and carbon reduction goals become more urgent, nuclear power remains a dependable, carbon-free source of baseload generation. With that support comes responsibility. In addition to federal regulation by the U.S. Nuclear Regulatory Commission (NRC), states should maintain independent oversight that complements federal inspection and regulatory activities.

Federal oversight provides a strong regulatory foundation, while state involvement adds a second layer of protection and transparency. Independent monitoring enhances public protection by focusing on localized environmental surveillance, operational awareness, waste management, and emergency preparedness.

During my tenure with the Pennsylvania Department of Environmental Protection (PA DEP), we monitored nuclear facility operations within the Commonwealth. Our responsibilities included independent oversight of plant operations; environmental surveillance of air, water, and soil; tracking the generation and management of low-level radioactive waste (LLRW); and participating in emergency preparedness drills and exercises. These activities ensured that the state maintained its own technical expertise and did not rely solely on utility or federal regulatory reports.

One of the most important lessons from the Three Mile Island Unit 2 accident was that states must be prepared to gather and evaluate information independently. Relying exclusively on federal interpretation or utility communications can slow decision-making during rapidly evolving events. By maintaining in-house expertise (engineers, health physicists, and emergency planners), the state can directly assess plant conditions, interpret monitoring data, and advise leadership appropriately. This capability strengthens crisis response and improves coordination among plant operators, federal agencies, and local officials.

State participation in emergency preparedness drills is equally critical. Full-scale exercises test communication systems, field monitoring capacity, public notification protocols, and interagency coordination. Maintaining these capabilities ensures that, should an incident occur, the state can respond timely and effectively.

As states continue to support nuclear energy to meet grid demands, independent oversight remains essential. A strong federal-state partnership, where the NRC provides national regulatory authority and states contribute localized oversight, enhances safety, transparency, and public confidence in nuclear energy.

Article 8 - Inside Nuclear Energy: Understanding Light Water Reactors and Low-Level Radioactive Waste Generation Characteristics

Light Water Reactors (LWRs) are the most common nuclear reactors in the United States for producing electricity. Water plays a critical role in their operation. It serves several essential functions: it removes heat from the reactor core (cooling), it slows down neutrons so that nuclear fission can occur efficiently (moderation), and it provides radiation shielding that helps protect workers and equipment (radiation shielding). Another advantage is that ordinary water is abundant, inexpensive, and readily available. There are two main types of LWRs: pressurized water reactors (PWRs) and boiling water reactors (BWRs)

In a PWR, the water in the reactor core is kept under very high pressure. This high pressure prevents the water from boiling, even at high temperatures. Instead of producing steam directly in the reactor vessel, the heated water flows through a heat exchanger called a steam generator. There, it transfers heat to a secondary water loop that does boil and produce steam. The steam from the secondary loop drives the turbine that generates electricity. Because the radioactive water remains in the primary loop and doesn't reach the turbine, PWR designs provide separation between radioactive components in the primary system and the power generation equipment in the secondary side.

In a BWR, the water in the reactor core is allowed to boil directly, producing steam inside the reactor vessel itself. That steam then flows directly to the turbine, eliminating the need for a steam generator. This design simplifies the overall system because there are fewer components. However, since the steam that reaches the turbine originates in the reactor core, turbine equipment must be shielded and managed with radiological controls.

Both designs rely on multiple engineered barriers, including fuel cladding, reactor coolant boundary, and robust containment structures, as part of a "defense-in-depth" safety philosophy. Nuclear reactors in the United States operate under stringent regulatory oversight by the Nuclear Regulatory Commission (NRC) to ensure safety. In the U.S., the majority of operating nuclear reactors are PWRs.

Both BWRs and PWRs generate several common types of low-level radioactive waste (LLRW), including dry active waste such as contaminated clothing, rags, paper, and plastics; spent ion-exchange resins from water purification systems; used filter cartridges and filter media; contaminated tools and small equipment; sludges and concentrates from liquid waste processing; activated corrosion products captured in cleanup systems; and irradiated reactor components, such as control rods, in-core instrumentation, and other internal hardware that become radioactive through neutron exposure.

In BWRs, the direct steam cycle allows trace quantities of radionuclides, primarily activated corrosion products and other activation products to be transported with the reactor steam into the turbine and balance-of-plant systems. This typically results in more widespread radiological contamination of downstream components, which can contribute to higher volumes of contaminated equipment, filter media, resins, and dry active waste compared to PWRs, where the secondary system remains largely non-radioactive due to the use of an isolated steam generator.

In summary, LWRs use ordinary water to cool the reactor and to help sustain the nuclear reaction. PWRs keep water under pressure and use steam generators, while BWRs generate steam directly in the reactor. Both designs have demonstrated long-term operational performance and are subject to comprehensive NRC regulatory oversight and safety requirements. Both reactor types generate LLRW during normal operation, with differences driven mainly by system design and contamination control practices.

Article 9 - Nuclear Power Plant Decommissioning: Key Process Overview and Waste Management

Decommissioning is the process of safely retiring a nuclear power plant after it permanently ceases operations. It involves removing the facility from service and reducing residual radioactivity to levels that allow the site to be released for other uses and the operating license to be terminated under regulatory approval.

Regulatory Oversight - The U.S. Nuclear Regulatory Commission (NRC) oversees the entire decommissioning process. Plant owners are required to complete decommissioning within 60 years of shutdown and must meet strict safety, environmental, and financial requirements throughout.

Decommissioning Methods - There are three primary methods of decommissioning allowed under U.S. regulations.. The DECON method involves the prompt removal and decontamination of radioactive components, allowing for earlier release of the site. SAFSTOR, by contrast, places the facility in a safe, stable condition for several decades to allow radioactivity to decay before dismantling begins. The ENTOMB approach involves permanently encasing radioactive materials onsite and monitoring them until they are safe for license termination; however, this method has not yet been approved or implemented for commercial nuclear power plant decommissioning in the United States.

Phases of Decommissioning - Decommissioning occurs in several key phases. During the transition phase, plant operations cease, fuel is removed, and the Post-Shutdown Decommissioning Activities Report (PSDAR) is submitted to the NRC. This is followed by the period of major decommissioning activities, which includes the dismantling of structures, systems, and components, along with the management of radioactive materials and waste. The final phase is license termination, during which final site surveys are conducted and a License Termination Plan is approved, ultimately allowing the site to be released for other uses.

Decommissioning Funding - Plant operators are required to set aside funds during the operational life of the facility to ensure sufficient resources are available for decommissioning. The NRC establishes minimum funding levels and requires regular financial reporting to ensure adequacy.

Business and Ownership Models - U.S. reactor decommissioning can be carried out by the licensee directly, through a contractor-managed approach, or by transferring the NRC license to a specialized decommissioning company on a temporary or permanent basis. The ultimate

responsibility for permanent disposal of spent nuclear fuel resides with the U.S. Department of Energy (DOE).

Public Involvement - The decommissioning process includes multiple opportunities for public engagement, such as public meetings, comment periods, and citizen advisory panels. Transparency and community involvement are key elements of successful decommissioning projects.

Radioactive Waste Management - Decommissioning generates significant volumes of low-level radioactive waste (LLRW), including contaminated materials such as concrete, piping, and equipment. Effective waste management is a critical component of the process. Several important lessons have emerged from U.S. decommissioning projects:

- *Cost sensitivity:* Waste disposal is one of the biggest costs in decommissioning. Changes in disposal prices or access can strongly affect project budgets.
 - *Early Planning is Critical:* Detailed waste characterization and segmentation strategies developed early in the process help reduce costs and avoid delays.
 - *Disposal Capacity Constraints:* Limited availability of disposal sites, particularly for Class B and C waste, requires careful coordination and long-term planning. Constraints vary by facility based on acceptance criteria, including allowable activity levels (as at WCS, which has limits on activity levels for out-of-compact waste) and waste class limitations (as at EnergySolutions Clive, which is limited to Class A waste). As a result, disposal pathways may require interstate compact access, alternative approved disposal routes, or on-site storage until suitable capacity is available.
 - *Waste Minimization:* Mixing waste streams can unnecessarily increase disposal volumes and costs. Segregation of clean, slightly contaminated, and highly contaminated materials helps minimize the amount of radioactive waste requiring licensed disposal. Techniques such as decontamination, metal recycling, and waste compaction can significantly reduce disposal volumes and costs.
- On-Site Storage Considerations:* Temporary on-site storage in appropriately controlled and protected areas may be required for certain waste streams, including siting considerations such as flood risk and other environmental conditions. Projects have shown the importance of designing interim storage strategies early in the planning process.
- *Mixed Waste Complexity:* Waste containing both radioactive and hazardous chemical components (“mixed waste”) is significantly more difficult and expensive to manage because it must satisfy both radiological and hazardous waste regulations. Early identification and segregation of mixed waste streams are important.
 - *Transportation Logistics:* Transportation of large components (e.g., steam generators and reactor vessel internals) present unique handling, packaging, and disposal challenge, and require coordination with the parties involved including the local communities.
 - *Data Quality, Legacy Records, and Leak Documentation:* Incomplete or non-digitized historical records, including operations data, waste inventories, surveys, maintenance history, and system configurations, as well as discrepancies between design drawings and

as-built conditions, can complicate waste characterization and classification during decommissioning. Past issues, such as tritium leaks at nuclear plants, underscore the importance of maintaining complete records of leaks, corrective actions, monitoring, and remediation. Poor documentation can result in added investigations, conservative assumptions, higher costs, and delays.

Other Considerations

- *Emergency Preparedness:* Even during decommissioning, facilities must maintain emergency preparedness capabilities for waste handling incidents, transportation accidents, contamination events, or severe weather impacts affecting stored waste.
- *Multi-Unit Sites:* At sites with multiple reactors or shared infrastructure, coordination among units is important because decommissioning activities, waste handling systems, staffing, disposal schedules, and security arrangements may compete for limited resources. The presence of an operating plant alongside a unit undergoing decommissioning can also create operational and logistical challenges due to differing priorities and requirements.
- *Stakeholder Engagement:* Open and ongoing communication with host communities and regulators regarding decommissioning activities and waste management practices builds trust and reduces opposition. This includes mechanisms such as citizen advisory panels, public meetings, and transparent reporting systems that provide opportunities for community input and address concerns in a timely manner.

In summary, decommissioning is the process of permanently shutting down a nuclear facility and carrying out the cleanup and removal of radioactive and contaminated materials, equipment, and structures. It minimizes environmental impacts and allows the land to be reused for future economic or community purposes. Managing nuclear waste effectively is an important part of completing these projects safely, on time, and within budget.