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Tritium in Fusion Energy: Ensuring Traceable and Responsible Deployment

Liberty Fusion is a New Mexico–based startup pursuing Plasma-Jet Magneto-Inertial Fusion (PJMIF), a cost-focused path to commercial fusion energy. Our mission is to achieve sub-$50/MWh electricity through scalable plasma gun–driven systems. In parallel with technical milestones (high-fidelity simulations, prototype plasma gun design, and relocation of the Plasma Liner Experiment from Los Alamos), Liberty Fusion is engaging in policy and standards development. Specifically, we are addressing tritium accountability, safety, and proliferation-resistance as early design requirements, ensuring commercial readiness and regulatory acceptance.

Liberty Fusion is developing a framework for tritium accountability that addresses the regulatory and safeguards gaps expected in commercial fusion operations. Current systems rely on batch-based inventory and environmental monitoring, which are insufficient for continuous operations handling 100+ kg of tritium annually. To address this, we are proposing a permissioned blockchain accountability framework. This system ensures immutable, verifiable records of tritium flows across facilities, processing systems, and international transfers. By integrating IoT-enabled real-time monitoring with smart contracts for compliance automation, the approach provides both operational practicality and international safeguards compatibility.

We systematically benchmark against:
• Existing nuclear material safeguards (IAEA INFCIRC/153, NSG export guidelines).
• National regulations for tritium handling, particularly Canada, South Korea, and EU frameworks.
• Fusion-specific initiatives, such as European Fusion Development Agreement reports and U.S. DOE tritium handling protocols.
• Parallel industries, including pharmaceutical cold-chain blockchain trials and uranium accountability frameworks, to derive transferable best practices.

This comparative analysis highlights where fusion-scale tritium operations diverge from current regulatory practices, identifying areas requiring new standards.

1. Inventory Control
   • Gap: Batch-based calorimetry/mass spectrometry have 2–10% uncertainty, inadequate for 100+ kg/yr tritium operations.
   • Proposed C&S Need: Standardized real-time monitoring protocols (e.g., blockchain-linked IoT sensors).
2. Breeder Blanket Oversight
   • Gap: No accepted measurement standards for in-situ tritium breeding.
   • Proposed C&S Need: Protocols for continuous breeding rate measurement and accountability.
3. Retention and Permeation Accounting
   • Gap: Up to 2.2 kg of tritium retained annually in reactor materials, unaccounted.
   • Proposed C&S Need: Codes for estimating, monitoring, and reporting retention.
4. Transfer and Waste Accountability
   • Gap: No chain-of-custody standards for intra-site transfers, waste processing, or decommissioning recovery.
   • Proposed C&S Need: Smart contract–based transfer verification; waste-stream tritium monitoring standards.
5. Cross-Border Transport
   • Gap: Export controls inconsistent; no international verification of end-use compliance.
   • Proposed C&S Need: International blockchain-based ledger for tritium shipment verification, modeled on nuclear export controls.

References:
• NSG Guidelines for Nuclear Transfers (INFCIRC/254/Rev.14/Part 1) –export thresholds for tritium.
• IAEA INFCIRC/153 –general safeguards obligations (note: tritium excluded).
• EPA & CNSC tritium safety regulations –environmental release monitoring.
• Science & Global Security, Vol. 5 (Kalinowski, 1994) –tritium safeguards challenges.

Technical Categories Addressed

Cybersecurity

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