Contribution ID: **8** Type: **Oral**

The Need for Codes and Standards in Lead-Lithium Eutectic Manufacturing for Breeder Blanket Applications

Lead–lithium (PbLi) eutectic is a cornerstone material for fusion breeding blankets, serving both as a tritium breeder and neutron multiplier. It has emerged as the leading candidate across most liquid blanket concepts: forming the basis of the DCLL, WCLL, and HCLL designs in the EUROfusion DEMO programme; underpinning the WCLL blanket under evaluation in ITER's Test Blanket Module programme; and featuring in self-cooled variants explored in conceptual reactor studies such as ARIES-AT (US), HiPER (EU), and KOYO-F (Japan).

Its performance, however, is extremely sensitive to compositional accuracy and impurity levels. Recent analyses of commercial PbLi ingots by B. Garcinuño et al., 2022 revealed lithium contents varying from 3–18 at% and metallic impurity concentrations exceeding 400 ppm, with oxides and carbonates frequently present. Such deviations shift the melting point away from the eutectic (235 ℃), alter thermophysical properties, and can significantly bias tritium solubility and diffusivity values—parameters central to ensuring reactor-scale tritium self-sufficiency.

At EX-Fusion, we recently completed the first high-purity batch synthesis (EX-LLE-1), achieving reactor-grade PbLi via controlled atmosphere alloying with ICP-AES verification of trace metal impurities. This experience underlined the absence of harmonized standards for PbLi manufacturing, characterization, and acceptance criteria. While codes exist for structural alloys and pressure vessel steels, no equivalent framework governs breeder material production. Current efforts rely on ad-hoc protocols, often non-reproducible across suppliers and laboratories.

We propose that the development of fusion-specific codes and standards for PbLi should cover:

1. Constitutive specifications: lithium content fixed at 15.7 at% ± tolerance, isotopic enrichment targets, and impurity thresholds (metallic and gaseous).
2. Characterization protocols: mandatory use of complementary techniques (ICP-OES/MS, XRD, SEM-EDX, LECO gas analysis) to assess metallic and non metallic impurity content, and assure compositional & structural fidelity.
3. Fabrication QA/QC procedures: environmental controls to prevent Li and Pb oxidation, standardized sampling methods, and traceability of batches to nuclear materials QA standards.

Establishing such standards would reduce experimental discrepancies, provide reliable input data for tritium transport modeling, and ensure that reactor-grade PbLi is safe for irradiation. Together, these are prerequisites for the consistent qualification of breeder blanket technologies across international programs. Without codified manufacturing standards, scaling PbLi supply from laboratory kilograms to industrial tonnes risks bottlenecks in blanket deployment and undermines the licensing basis for fusion pilot plants.

Technical Categories Addressed

Tritium breeder blankets (ex. molten salts, liquid metals)

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Session Classification: Materials and Manufacturing