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Material Inventory and Activation Assessment Under High-Flux DD and DT Neutron Irradiation from an IEC-LCF Fusion Reactor

Inertial Electrostatic Confinement (IEC) fusion systems incorporating Lattice Confinement Fusion (LCF) techniques serve as compact neutron sources, capable of sustained neutron fluxes exceeding 1×10^{11} neutrons per second, and beyond. These reactors produce neutrons primarily through Deuterium-Deuterium (DD, approximately 2.45 MeV) and Deuterium-Tritium (DT, approximately 14.1 MeV) fusion reactions. Such neutron environments necessitate systematic assessments of neutron-induced activation and transmutation in fusion-relevant materials, essential for reactor safety, operation, and long-term management.

This study presents computational analyses aimed at evaluating neutron-induced activation and material inventory in selected fusion-relevant first-wall, breeder-blanket, and shielding materials under intense DD and DT neutron irradiation, characteristic of IEC-LCF fusion reactors. The materials investigated include first-wall candidates such as molybdenum, tungsten, tungsten-based alloys, tungsten carbides, and aluminium alloys (6000 series), breeder-blanket materials including lithium-based ceramics (Li_2TiO_3, Li_4SiO_4), beryllium compounds, lead-lithium eutectics (Pb-17Li), and ceramic insulators such as pure quartz sand and impurity-doped silica. Additionally, neutron shielding materials considered in the analyses include serpentine-containing concretes, borated polyethylene, heavy concrete, lead, and boron carbide.

Neutron transport simulations are performed using the GEANT4 Monte Carlo toolkit, employing multiple nuclear data libraries including TENDL, ENDF/B, JENDL, and JEFF to generate neutron spectra relevant to DD and DT reactions. The simulations are designed to calculate neutron flux distributions, neutron spectra, and secondary particle generation (gamma rays, alpha particles, protons, and tritons). Neutron spectra obtained from GEANT4 simulations using each nuclear data library are subsequently provided as direct input to activation and material inventory analyses.

Activation and material inventory calculations are executed using the FISPACT-II code, integrated with nuclear data libraries TENDL, ENDF/B, JENDL, and JEFF. Detailed isotopic and elemental compositions for each material, including minor impurities, are explicitly defined to accurately predict activation product formation, radioactive decay heat generation, and transmutation pathways during irradiation and subsequent cooling periods. Inventory calculations systematically evaluate short-term, medium-term, and long-term activation behaviours, identifying key isotopes influencing maintenance, remote handling, waste management, shielding effectiveness, and reactor decommissioning strategies.

The assessment focuses on understanding variations in activation responses among selected materials due to differences in neutron spectra (DD versus DT), neutron energy thresholds, and cross-section variations among the nuclear data libraries employed. Particular attention is directed toward evaluating the impact of trace impurities on activation inventories, as even minor impurities can significantly affect material handling and disposal considerations.

Primary author: Dr ANNEWANDTER, Robert (Astral Systems & Bangor University)

Co-authors: BAKR, Mahmoud (University of Bristol); Prof. MIDDLEBURGH, Simon (Bangor University); Dr WALLACE-SMITH, Tom (Astral Systems)

Presenter: Dr ANNEWANDTER, Robert (Astral Systems & Bangor University)