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Radiation Environment Challenges for a Spherical Tokamak for Energy Production

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The Spherical Tokamak for Energy Production (STEP) programme aims to deliver a UK prototype fusion energy plant by 2040, paving the way for commercially viable fusion power. STEP will harness energy from the fusion of Deuterium and Tritium—a reaction that releases 17.6 MeV, with 14.1 MeV imparted to the resulting neutron. To achieve its mission, STEP must meet two critical requirements: (1) demonstrate a net electrical power output of at least 100 MW, overcoming parasitic power loads, which implies a required fusion power of approximately 1.7 GW (~$6x10^{20}$ neutrons per second); and (2) attain self-sufficiency in tritium fuel production and processing.

The compact radial design of a spherical tokamak, coupled with the intense neutron environment, introduces several engineering challenges. This work outlines key aspects of the radiation environment and the corresponding design strategies adopted to ensure the plant meets its performance targets. Of particular concern is the protection of radiation-sensitive components, including the High-Temperature Superconducting (HTS) toroidal and poloidal field magnets. The limited inboard space typical of spherical tokamaks renders traditional shielding materials, such as those used in ITER, unable to sufficiently attenuate 14.1 MeV neutrons. As a result, the STEP programme is investigating novel, high-attenuation shielding materials to ensure acceptable magnet lifetimes.

Achieving tritium self-sufficiency requires a Tritium Breeding Ratio (TBR) greater than 1, to compensate for decay, system losses, and tritium retention in materials. Given the spatial constraints of the inboard region, full inboard breeding is unlikely to be viable without compromising magnet lifetimes. Consequently, the burden shifts to the outboard blanket, which must deliver high breeding efficiency, introducing further design complexities.

Additionally, high neutron and gamma fluxes, from both the plasma and activated components such as coolant and structural materials, pose radiation hazards to workers and the public. Mitigating these risks demands accurate dose rate assessments, carefully considered plant layouts, and a maintenance philosophy based around remote handling. These considerations necessitate the development of detailed radiation transport models, pushing the capabilities of current simulation tools. This presentation outlines the radiation workflows developed to model, evaluate, and mitigate these challenges, covering key major radiation sources and their interactions within the STEP plant configuration.

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