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Determination of Radiation Damage Limits to High-Temperature Superconductors in Reactor-Relevant Conditions to Inform Compact Fusion Reactor Design

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The recent commercialization of high temperature superconductors (HTS) has opened up a new parameter space for the design of tokamak fusion pilot plants. The lack of significant critical current degradation at high magnetic fields of HTS allows tokamaks to be designed with much higher on-axis fields. The ARC reactor design study showed that the use of HTS to design a compact, high-field pilot plant enabled a 3.3 m major radius device to achieve a fusion power of 525 MW. A key finding of the ARC study was that the largest constraint to shrinking the size of a compact, high field reactor was radiation damage limits to the HTS coils. With this constraint in mind, it is critical to determine the absolute lifetime of modern HTS technology in a fast neutron environment as well as develop strategies to mitigate this damage. While previous HTS irradiation work using fission reactors has been performed, reactor studies are costly, require long cooldown times of samples due to activation, and make it difficult to emulate HTS operating conditions such as cryogenic temperature during the irradiation. In order to complement reactor irradiation studies of HTS, an experiment is in progress to develop similarity between neutron and charged particle irradiation damage to HTS. A recent body of work indicates that under certain conditions, charged particle irradiation can be used to emulate neutron damage. The use of accelerator-based, charged particle irradiation to emulate neutron damage of HTS tapes will allow for short turn-around time and experimental flexibility, enabling a large and varied set of HTS damage experiments to be performed to determine HTS lifetimes. HTS samples have been irradiated in the MIT research fission reactor and are currently cooling down. After the samples are safe to handle, critical current measurements and microstructure analysis will be performed and compared with other HTS samples which have undergone accelerator irradiation. Once a correlation between neutron and charged particle damage to HTS has been developed, further accelerator-based irradiation experiments will be performed to determine the HTS lifetime at reactor-relevant temperatures and strains. Results of the above testing and implications for future compact, high-field tokamak design will be presented.

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