Recent commercialization of high-temperature superconductors (HTS) enables possibility of high field reactor design

- Crucial advantage of high field is B⁴ dependence of fusion power
- ARC reactor [1] exploits high field to achieve the same fusion power as ITER (500 MW) at 1/7⁷ of the volume
- Although ARC’s magnetic field is higher, structural stress due to JdΦ forces is similar to ITER due to ARC’s smaller magnetic volume

Fission reactor irradiations can be used to test HTS – but are lengthy and expensive

- Fission reactors produce a neutron spectrum similar to that seen by a fusion magnet but experiments are expensive and require long cooldown times due to sample activation
- MIT Reactor Lab has been used to irradiate HTS samples to ~10¹⁵ n/cm² for comparison with critical current degradation due to ion irradiation
- First fission reactor irradiations were performed in pneumatic tube insert in reactor pool, secondary irradiations planned in reactor core where neutron energy spectrum more closely matches spectrum seen by fusion magnet

Nuclear damage to superconductors limits reactor size reduction

- All superconductors experience critical current degradation due to neutron radiation damage
- Lack of shielding space in compact designs makes this a critical issue for small reactors (long pulse or steady state)
- Nb₃Sn radiation response extensively characterized for ITER [2]
- Few REBCO damage studies performed—none in relevant compact reactor conditions (cryogenic temperature, high fluence, strain)

Fusion reactor irradiations can be used to test HTS – but are lengthy and expensive

- Use of ion beams to emulate neutron damage is an established technique for fusion reactor material studies [3]
- Calculations performed with SRIM [4] on HTS sample geometry show approximately uniform damage in superconducting region and no H ion deposition in HTS layer
- Accelerator irradiation/analysis of HTS samples is ~100x faster than fission reactor irradiation, allowing use of ion beams as a screening tool for neutron experiments

Beam target stage controls irradiation temperature and ion profile on HTS sample

- Heated target stage maintained within +/- 5⁰ C of desired temperature with PID controller
- Uniform irradiation important, as total fluence to tape is calculated by average beam current on target
- Beam profile measured with CCD intensity analysis of beam on gold-coated quartz scintillating window and optimized to ensure uniform irradiation as possible
- Gaussian beam peak centered on 4x4 mm HTS sample using four symmetric beam current pickups on target collimator

Proton irradiation degrades critical current

- 77 K, self-field results show clear degradation of critical current with proton fluences on the order of 10¹⁵ p/cm² (degradation corresponds to previously observed neutron results for ~10¹⁵ n/cm² fluence [6])
- Higher irradiation temperature slightly reduces damage with fluence, but more data required to establish clear trend
- Proton irradiation technique has been developed to allow experiments on the order of 1 hour per sample, dramatically reducing experimental turn-around time and allowing a wide range of experimental conditions to be investigated

Future experiments will damage HTS at prototypical reactor conditions

- HTS samples will be mounted on special cryogenically-cooled target stage and irradiated while cold to investigate temperature dependent effects of irradiation defect formation
- 3.5 Tesla HTS magnet designed with field uniformity of >99% at sample location for use in upcoming in-situ accelerator critical current measurements
- Critical current (at cryogenic temp and applied field) will be measured without having to warm and remove sample from accelerator target chamber

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