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Neutron Irradiation Effects on Magnet Materials

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***Abstract*—Nuclear fusion promises to be a practically inexhaustible energy source and research on its exploitation started in the 1940s, unfortunately, only successful for nuclear weapons so far. Attempts for producing energy for the benefit of humankind set in nearly simultaneously but turned out to be much more challenging. Two different approaches to create a plasma hot and dense enough to produce more energy by fusion reactions than required for its generation were followed since the very beginning: The first being inertial confinement that mimics the mechanism in nuclear weapons. The nuclear fuel is heated and compacted extremely fast resulting in a very dense plasma with a high fusion rate limited to the timescale the plasma needs to expand during the resulting explosion. Recently, a net energy gain, where the fusion energy exceeded the energy deposited in the nuclear fuel (Q>1) was achieved for the first time. The second approach relies on a magnetic confinement of the charged particles and can in principle lead to a continuously burning plasma. However, a net energy gain was not realized so far. In both cases, the progress was continuous but slow, since there was no immediate need for fusion power plants. The first fusion device aiming at a useful energy gain (ITER, Q ≈ 10) has been under construction for many years now and it will take more than another decade until experiments with a burning plasma will start. Europe plans a first demonstration reactor (DEMO) producing electricity for the second half of this century.**

The situation changed with the broad public awareness of the climate change creating an immediate need for alternative energy sources. Fusion was reconsidered but the existing programs were obviously too slow to face the challenge; thus new, privately funded initiatives took the stage. The vast majority of these projects is based on the idea to increase the magnetic field for confinement, which is only possible by using high temperature superconductors. A higher magnetic field enhances the power density of the burning plasma and enables much compacter designs, which in turn promises a significant cost reduction and commercial viability of fusion power plants.

However, the increased power density leads to other challenges, among them the increased neutron (and heat flux) density. A small fraction of the neutrons will reach the superconducting magnets degrading their performance and hence limiting their lifetime.

I will follow the journey of the neutrons from their birth in the plasma to the magnets and discuss the damage production, the resulting defect structure and the influence on the

properties of the insulator, the stabilizer and the superconductor. The change of superconducting properties will be the main focus and demonstrated by results of neutron irradiation experiments on high temperature superconducting tapes performed at the TRIGA reactor in Vienna. The introduced defects have a positive effect on the critical current by improving pinning but the enhanced scattering degrade the transition temperature and the superfluid density because scattering is pair breaking in *d*-wave superconductors. The competition between improved pinning, which dominates at low neutron fluences, and the degrading scattering leads to a peak in the critical current as shown in Fig. 1.[1] While the degradation can be modelled due to its universal behavior, the change in pinning depends on the pristine defect structure of the tape and the energy of the incident particles.

The implication for the lifetime of conventional and compact fusion reactor concepts will be compared. Finally, possible mitigation strategies will be discussed.

***Keywords (Index Terms)*—Nuclear fusion, Radiation damage, Critical currents, Neutron irradiation**

References

[1] Raphael Unterrainer, Davide Gambino, Florian Semper, Alexander Bodenseher, Daniele Torsello, Francesco Laviano, David X. Fischer, Michael Eisterer, *Responsibility of small defects for the low radiation tolerance of coated conductors*, accepted for *Superconductor Science and Technology* **37** (2024)

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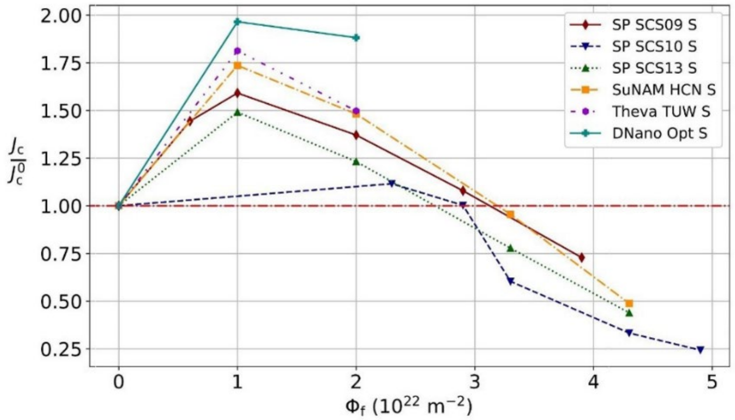

Figure 1. Relative change of the critical current density at 30 K, 15 T after fast neutron radiation (E>0.1 MeV) as a function of fluence.[1]