Research Project #19

Examination and Correlation of Radiation Damage Effects in Materials Arising from Fission and Fusion Energy Applications (IFN-2 & IFN-1)

The accelerated shift towards carbon neutrality coupled with concerns over energy sovereignty have refocused attention upon nuclear energy technology, particularly conventional fission and future fusion-based forms. Invariably, both energy systems demand materials that can withstand extreme conditions of high temperatures and intense radiation damage for both safe *in operando* performance and as final disposed waste materials. Refractory materials such as those based on uranium, tungsten and zirconium have high melting points with strong radiation tolerances, which makes them suitable for fission and fusion energy applications. Nevertheless, they are still susceptible to material degradation and loss of structural integrity due to variable response from dynamic temperature and radiation doses. These materials are crucial to both fission and fusion energy applications in relation to spent nuclear fuel stability or first wall material candidates in fusion. Understanding and correlating radiation damage effects from both low to high temperatures, and radiation doses, is critical for their safe usage and final disposal. This consequently enables enhanced understanding of critical materials used in both fission and fusion applications, guiding their safe use, deployment and final disposal.

The PhD project is a joint experimental venture between the Institute of Nuclear Waste Management (IFN-2) and Institute of Plasma Physics – Nuclear Fusion (IFN-1) at Forschungszentrum Juelich GmbH. The project will harness the manufacturing and unique radioactive handling facilities of INF-1 and IFN-2 to fabricate high refractory oxide and alloy materials, perform irradiation damage and post-characterization in order to develop enhanced understanding of such materials for fission and fusion applications and disposal. High resolution measurements will involve the use of neutron and synchrotron X-ray scattering techniques, such as diffraction and spectroscopy based, to assess structural changes to materials. Further deployment of scanning and transmission electron microscopy techniques will also be used to assess microstructural changes across variable temperature dose scales. The PhD candidate will explore uranium, tungsten and zirconium oxide and alloy-based material compositions and further seek to explore their behaviour as low and high entropy materials. The overall goal will be to develop a structure-physics based description of radiation damage in fusion and fission-based materials that can be linked across low- to high-dose radiation damage regimes. With support of the supervisors from the participating institutes, the PhD candidate will subsequently develop world leading expertise jointly in nuclear material handling, fabrication, characterization, atomistic simulations and computation analysis.

The Institute of Nuclear Waste Management (IFN-2) focuses on researching materials and processes relevant to the safe management of radioactive waste and its eventual final disposal. The research at IFN-2 is multidisciplinary, although typically the core focus is nuclear related, the institute combines radio-, geo- and materials chemistry disciplines in addition to computation and simulation synergistically. Research at IFN-2 covers the complete post-operative nuclear reactor cycle, from the initial waste generation, such as the discharge of SNF from the reactor core to its eventual disposal in a geological repository, including research examining the long-term safety behaviour. IFN-2 research further supports unresolved issues prior to waste disposal but also supporting general nuclear safety for instance pre-disposal planning, and research on international safeguards for instance supporting the International Atomic Energy Agency (IAEA) among other organisations. Inevitably, many material types encountered in nuclear waste management bear pertinence beyond this field, such as complex oxides, high entropy alloys and materials for hydrogen evolution. As such, the institute pursues research that is not just nuclear relevant but also societally.

The Institute of Plasma Physics – Nuclear Fusion (IFN-1) at Forschungszentrum Jülich has its research goals aligned with the national and European fusion programs. The roadmap of the institute is towards engineering and developmental activities for a fusion reactor in Germany, specifically focusing on Plasma Wall Interaction (PWI) studies for fusion reactors, material and component development, diagnostics development and qualification of first wall materials. The institute has dedicated groups working on PWI studies on linear plasma devices, experimental tokamaks, W-7X stellarator and modelling of the results. Additionally, to qualify materials under reactor relevant conditions, a high temperature materials laboratory with controlled areas for testing and qualification of irradiated materials including study of radiation damage, plasma exposures and high heat flux testing is being developed and modernized.

The specific tasks of the PhD Candidate are:

- To manufacture high purity refractory materials using solid state sintering techniques
- Performing accelerator based ion-irradiations
- Post fabrication and irradiated materials characterization, using state of the art, high resolution X-ray and neutron diffraction, X-ray absorption spectroscopy in addition to electron microscopy techniques.
- Perform radiation damage-based simulations and modelling.
- To effectively collaborate with internal and external partners.
- Dissemination of scientific results in the form of scientific conferences and written publications to medium to high impact journals.

Location of the HITEC Fellow	Forschungszentrum Jülich, Institute of Fusion Energy and Nuclear Waste Management – Nuclear Waste Management (INF-2), Director: Prof. Dr. Dirk Bosbach – Nuclear Waste Management Solid State Chemistry group, Head: Dr. Gabriel L. Murphy https://www.fz-juelich.de/en/ifn/ifn-2
Partners of the HITEC Project	Forschungszentrum Jülich, Institute of Fusion Energy and Nuclear Waste Management – Plasma Physics (IFN-1), Director: Prof. Dr. Christian Linsmeier, Plasma Wall Interactions – Materials, Head: Prof. Dr. Bernhard Unterberg https://www.fz-juelich.de/en/ifn/ifn-1
Specific **requirements**	M.Sc. in Chemistry, Physics, Materials Science or in related disciplines. Prior knowledge and experience in the nuclear field or radiation physics would be advantages but not essential
For **project specific** questions please **contact**	Dr. Gabriel L. Murphy, IFN-2, g.murphy@fz-juelich.de Dr. Rahul Rayaprolu, IFN-1, r.rayaprolu@fz-juelich.de