INVESTIGATING RADIATION EFFECTS IN MATERIALS USING STATE-OF-THE-ART PARTICLE ACCELERATORS

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We describe in detail a methodology for comprehensively characterizing radiation effects in nuclear and other materials using large-scale particle accelerator facilities [1]. Key to this approach are swift heavy ions with a penetration depth of ~100 µm, which is high enough to produce sufficient quantities of irradiated material for characterization using bulk techniques [2]. Irradiation experiments are performed at the UNILAC accelerator at the GSI Helmholtz Center using Au ions of 2 GeV kinetic energy (Figure 1). The irradiated samples are complementarily characterized by means of advanced (accelerator-based) scattering techniques at the Advanced Photon Source (APS) and Spallation Neutron Source (SNS). High resolution diffraction, absorption, and total scattering experiments reveal ion-beam induced structural and chemical modifications, such as defect formation (*e.g.*, CeO_2), disordering (*e.g.*, $Ho_2Ti_{2-x}Zr_xO_7$), crystalline-to-crystalline phase transformations (*e.g.*, Gd_2O_3) and amorphization (*e.g.*, Dy_2TiO_5). Diffraction techniques give information on phase behaviour and disordering/amorphization of the average crystal structure (long-range), while pair distribution function (PDF) analysis from total scattering data provides detailed real-space information on the local defect structure. X-rays provide excellent sensitivity to high-*Z* elements, while neutrons scatter strongly from low-*Z* elements. The combination of short and long length scale characterization techniques with high sensitivity to both cations and anions is particularly important for characterizing radiation effects in oxide materials for nuclear application (*e.g.*, UO_2). Based on several examples, we demonstrate that accelerator-based characterization techniques yield fundamental insight into radiation effects in materials that are much more complex than previously thought [3-6].

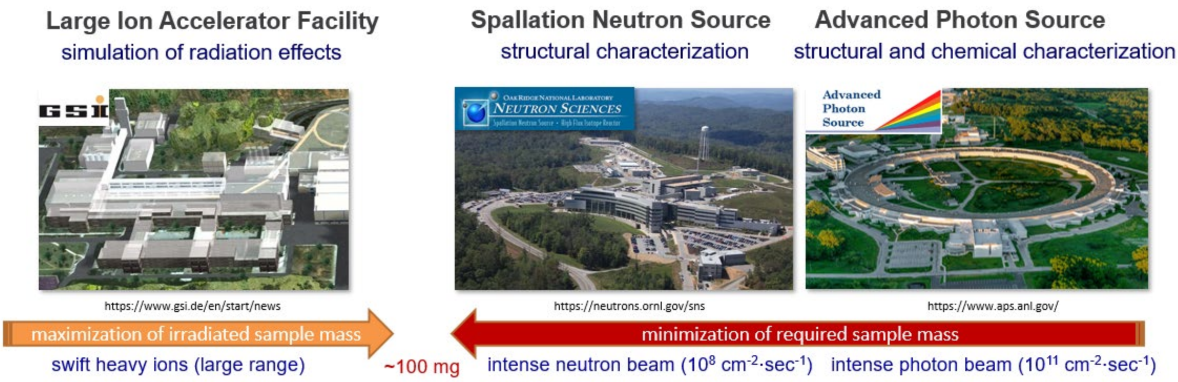

FIG. 1. Swift heavy ions with large penetration depths are required to produce sufficiently large quantities of homogeneously irradiated materials (~100 mg) that can be analysed by spallation neutron and synchrotron X-ray probes.

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