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ACCELERATOR TECHNIQUES AND NUCLEAR DATA NEEDS FOR ION BEAM ANALYSIS OF WALL MATERIALS FOR CONTROLLED FUSION REACTORS

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Integrated science and technology efforts in the field of controlled thermonuclear fusion are directed towards the construction and operation of a rector-class machine for electricity production. In the interdisciplinary world of fusion research, the role of particle accelerators is at least five-fold: (i) provision of nuclear data for ion-material interactions; (ii) ion beam analysis (IBA) of plasma-facing materials and components (PFMC); (iii) ion-induced neutron generation for the material irradiation facility; (iv) ion-induced simulation of neutron radiation effects in surfaces of solids; (v) high current units in the neutral beam injection system for plasma (deuterium and tritium: D and T) heating.

This contribution is concentrated on the role of accelerator techniques in the examination and testing of materials for fusion applications. Quantitative results can only be obtained based on robust nuclear data sets, i.e., stopping powers and reaction cross-sections. Therefore, the work has three equally important strands: (i) determination of nuclear data for selected ion-target combinations; (ii) assessment of fuel inventory and modification of PFMC by erosion and deposition processes; (iii) equipment development to perform cutting-edge research.

Under terrestrial conditions, fusion plasma must be confined by strong magnetic fields and surrounded by walls of a vacuum vessel. Plasma – wall interaction (PWI) processes related to the exposure of PFMC to electromagnetic radiation and particle fluxes modify both plasma and wall materials. Atoms eroded from the wall are ionised, transported along the magnetic field lines and re-deposited together with fuel atoms thus changing the composition and properties of the wall and crucial tools for plasma diagnosis (mirrors, windows). This has an impact on the PFMC lifetime and fuel inventory, i.e., decisive factors for the safety and economy of reactor operation. These are the driving forces for comprehensive analyses and testing of in-vessel components from tokamaks, stellarators, linear PWI simulators and fusion-related material research laboratories. The major materials of interest are beryllium (Be), tungsten (W), molybdenum (Mo). The discrepancies in the existing data base calls for measurements of stopping powers and reaction cross-sections of H and He with these metals.

Over the years, more than fifty different material characterisation techniques have been used in the PFMC research: ion, electron, neutron, optical, magnetic, sound, mechanical, thermal and their combinations. Compositional analyses must cover a broad range of species which are used in a reactor as fuel, gases injected for auxiliary plasma heating or edge cooling, transport markers, wall and diagnostic components and, those for wall conditioning. As a result, the list extends from H, D, T, ^{3}He, ^{4}He, other noble gases (Ne – Xe), isotopes of Li, Be, B, C, N, O, F, via Al, Si to Cr, Fe, Ni and then to W, Re, and even to Au. Such challenge can be met only by accelerator-based ion beam analysis methods (IBA): RBS, NRA, PIXE, ERDA, MEISS, AMS. Taking into account a range of ion beams, spot size,

broad energy spectrum, tens of nuclear reactions and data processing software, the "toolbox" offers a huge number of options.

IBA plays a prominent role in the ex-situ examination of materials retrieved from the vacuum vessel: wall tiles and erosion-deposition probes [1-3], diagnostic components [4] and also dust [5]. The above listed IBA methods are complementary to each other. They are quantitative, sensitive and selective. In many cases allow for depth profiling. The information depth in deuterium retention studies with a ^{3}He beam exceeds 20 µm in low-Z targets. The methods facilitate effective elemental mapping over large surfaces without the need of special sample preparation. Using analysis stations with large-volume chambers, long travel distance (15-25 cm) manipulators and loading ports of 150-250 mm in diameter, no sectioning is required even in the case of big PFC blocks: e.g., 4x16x24 cm and mass of 2 kg. Results from several tokamaks will be shown and explained. Analyses of low-Z isotopes are mostly carried out by means of ^{3}He-based NRA. This situation calls for validation of the existing cross-sections, especially for Li, Be, B, C, N and O isotopes for ^{3}He beams.in the 1-6 MeV energy range.

The other role of accelerators in fusion research is in the ion-induced simulation of neutron damage of materials [6-8]. Ion irradiation modifies the surface structure. It has a major impact on fuel retention in PFC and also on optical performance of crucial diagnostic components like so-called first mirrors, i.e., metal mirrors acting as PFMC in all optical plasma diagnosis systems (spectroscopy and imaging) in ITER; the reactor-class machine under construction. The impact of irradiation with H, He (transmutation simulation) and Mo, Zr, Nb (n-induced damage simulation) on the optically active layer of Mo mirrors will be addressed.

The accelerator-based analysis and modification of materials is not an isolated or a passive strand of fusion research. The results directly contribute to decisions regarding the wall composition and diagnostic planning in ITER. This imposes a quest for improvements and developments of analytical capabilities (nuclear data sets, detectors, chambers etc) to ensure cutting edge research. A brief review of IBA facilities in the fusion research will be presented.

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