Experimental Simulation of Radiation Damage by High-Fluence and High-Energy Helium Ion Implantation*

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Addressing the challenge posed by elevated levels of transmutation helium in materials for use in advanced nuclear reactors, both fusion and fission, is crucial due to the formation of helium bubbles causing embrittlement and swelling. Our previous study [1] has shown, the effect of transmutational helium reduces the widely accepted "immunity to radiation damage" of oxide dispersion strengthened (ODS) steels only to a shift in the incubation phase of helium bubble growth. Following this study, we designed a novel multi-step high-energy and high-fluence helium ion irradiation experiment [2] targeting ferritic/martensitic steels and their ODS variants, which aimed to achieve a quasi-homogenous displacement damage profile extending up to 65 μm within diverse sample sets for the assessment of engineering relevant properties and material performance.

We have irradiated Eurofer97, ODS Eurofer, SIMP, PM2000, SS 310S, and 800H structural steels using a helium ion beam with gradually decreasing energies ranging from 17 MeV to 1 MeV in 500 keV steps, resulting in a homogeneous irradiated layer with a "box-profile" of cca. 1000 appm helium concentration, which corresponds to a total ion fluence of 5.4×10^{17} at.cm^{-2}. First characterization results are presented including nanoindentation, positron annihilation lifetime spectroscopy (PALS) and small angle neutron scattering (SANS).

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Using a Nuclear Microprobe to Implant Heavy Ions in a Material in a Pattern [*]

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Nuclear microprobe has gained a good reputation in the field of nuclear analysis techniques as well as proton beam lithography. By focusing an ion beam down to micrometer size and scanning a selected area of the sample, it had taken nuclear methods such as PIXE, RBS, ERDA to a new level – it became possible not only to determine the elemental composition of the material, but also their distribution in it. Thanks to the high penetration depth of MeV protons, proton beam lithography has paved the way for the creation of three-dimensional microstructures in photoresist with a high aspect ratio, unattainable with electron beam lithography. However, modifying materials that are more radiation resistant than photoresists requires ions heavier than protons. The nuclear microprobe's ability to use medium-heavy ions such as nitrogen or oxygen allows glass to be modified to create wave channels in it. Another application of a nuclear microprobe is ion implantation with a fluence ranging from one ion to the desired one. However, the latter application is limited by the mass of the ion. This is due to the fact that the rigidity of the magnetic quadrupole lenses in the conventional nuclear microprobe is insufficient to focus heavy ions with MeV energy. Therefore, the implantation of heavy ions are done with the help of masks and broad-beam scanning.

In our work, we will present the possibility of implanting heavy ions, in particular gold, according to the desired pattern, without outsourcing the production of the masks, but using a nuclear microprobe for this purpose. We will describe in detail the experiment, which was carried out at the nuclear microprobe in Řež and included the following steps: i) spin coating of photoresist on the sample; ii) direct proton beam lithography; iii) development of the photoresist; iv) implantation; vi) removing the photoresist. We will show optical and electron microscopy analysis of each step of the process. We will provide an assessment of the applicability of the method, describe the problems associated with each step and summarize the pros and cons of the approach.

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Glass Corrosion Study Using Time-of-Flight Elastic Recoil Detection Analysis

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The generation of radioactive waste material is a significant environmental concern from nuclear power, with spent fuels remaining active for over thousands of years even after disposal. The storage of waste in a vitrified form within glasses is a potential solution to this issue, with radioisotopes immobilised for safe storage and disposal [1]. Stability of these glasses is paramount, especially in a corrosive environment for the duration that the waste material remains active.

To better understand the mechanisms involved along with the long-term durability in geological disposal conditions, the longevity of glasses in aqueous conditions were investigated. This was carried out using several standard borosilicate glasses corroded in multiple pH solutions for varying time periods.

To characterise the corrosion effect on the various glass samples, the technique time-of-flight elastic recoil detection analysis (ToF-ERDA) was used [2]. The ToF-ERDA measurements were undertaken using an incident beam of 16 MeV $^{127}I^{8+}$. The simultaneous measurement of velocity and energy of recoiled atoms allows for an enhanced mass separation. This allows for individual characterisation of elements of interest, in this case Na and B, including the two B isotopes, ^{10}B and ^{11}B. The composition depth profiles from ToF-ERDA were used to compare the different samples, which showed the near surface leaching of both B and Na and allowed the calculation of corrosion rates. From these rates, the diffusion coefficients of B, Na and H_20 could be determined for each pH value.

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Detection of Quality and Geographic Authenticity of Pistachio Nuts by Using X-Ray Fluorescence Spectroscopy and Chemometrics*

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Food quality, safety and traceability represent important milestones in the agri-food sector, having a direct impact on human health. Therefore, in recent years, several analytical approaches were developed to prevent food fraud and counterfeiting [1, 2]. Among them, X-ray Fluorescence Spectroscopy (XRF) has attracted extensive attention by scientists due to the fact that is a simple (requiring minimum sample preparation), fast, accurate, relatively inexpensive and non-destructive analytical tool.

In this study, XRF measurements were performed to assess the quality of "Pistacchio verde di Bronte", a product cultivated in Catania province (Sicily, Italy) recognized by the European Union with the Protected Designation of Origin (PDO) label. The possibility of authenticating the origin of Sicilian Bronte pistachio was evaluated by comparing its elemental profile with that of samples coming from different Sicilian growing areas. Experimental data were extensively studied by using Principal Component Analysis (PCA). The perspectives to apply the implemented procedures in order to disentangle foodstuffs from different geographical areas will be discussed.

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Ternary UMoX Alloys as Alternative Fuels for Research Reactors - Characterization via EDS, RBS and PIXE

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The alloy UMo with a Mo content between 16 - 22 at.% allows U densities in fuel assemblies of research reactors between 8 - 15 g U/cm^3. This jump in density - compared to conventional fuels for research reactors with densities between 1.0 - 4.8 g U/cm^3 - opens the possibility to convert high flux research reactors to the usage of Low-Enriched Uranium (LEU) fuel. However, during in-pile irradiation, a detrimental interface between the fuel and the surrounding Al matrix and cladding develops. Ternary UMoX alloys (X = Pt, Zr, Nb, Ti, W) are candidate materials to suppress or delay interdiffusion. The suitability and precision of Energy Dispersive Spectroscopy (EDS) with keV electrons, Rutherford Backscattering Spectrometry (RBS) with MeV ^{4}He ions, and Particle-Induced X-ray Emission (PIXE) with MeV protons and ^{4}He ions for their analysis were assessed. The study aims to provide a comprehensive understanding of both the alloy properties and characterization methods.

The research involved the analysis of the elemental composition, distribution, and structural properties of ternary UMoX (X = Pt, Zr, Nb, Ti, W) alloys consisting of 4 at.% X, 21 at.% Mo, and 75 at.% U. EDS, RBS, and PIXE were employed for characterization. PIXE measurements were conducted with 4 MeV ^{4}He ions and 2 MeV protons, while RBS was performed with 4 MeV ^{4}He. For EDS, characteristic X-rays were generated using electrons at acceleration voltages between 10 - 20 keV. PIXE data were analyzed using GUPIX software, RBS data using SIMNRA software, and EDS signals using EDAX APEX software.

The samples were produced using arc melting with multiple melting cycles and have been polished manually. The lowest deviation from the nominal average composition for U was achieved with EDS (2 % deviation) and with PIXE using protons (4 % deviation). Mo in this composition generally could not be well measured with PIXE (deviation of 13 % with protons and 27 % with He); the best results were obtained with EDS (8 % deviation). RBS showed a deviation of 20 % for Mo. For heavy elements such as W and Pt, RBS performed well with a deviation below 3 % since those elements were directly visible in the spectrum. However, significant deviations were observed for lighter elements like Nb, Ti and Zr. The deviation of the third alloying constituent (X) was highly individual when examining characteristic X-rays with PIXE. Ti, Zr, and Pt could be well identified, while Nb and W exhibited larger deviations up to 150 %. In all cases, EDS provided reliable results. Thousand times smaller measurement spots in EDS compared to those in PIXE and RBS allowed for the exclusive measurement of pure matrix areas, without accounting for precipitation.

Overall, the best results for ternary UMoX alloys were obtained with EDS and PIXE with protons, particularly as RBS is fundamentally problematic for low concentrations of low- and medium-Z elements in heavier matrices. PIXE measurements with 2 MeV protons provided significantly more accurate results than PIXE measurements with 4 MeV ^{4}He. This is probably due to the larger uncertainty of the excitation cross-sections for ^{4}He ions compared to protons. Due to the small beam spot size, EDS results can show a substantial lateral variation.

Future research aims to simulate the in-pile behavior, such as through heavy ion irradiation, which will provide valuable insights for the use of ternary UMoX alloys as alternative fuels.