Report on the outcomes of a Short-Term Scientific Mission[1]

Action number: CA21126

Grantee name: Elchin M. Huseynov

Details of the STSM

Title: Investigation of carbon-based nanocrystalline particles in extreme cosmic environments

Start and end date: 30/01/2025 to 01/03/2025

Description of the work carried out during the STSM

Description of the activities carried out during the STSM. Any deviations from the initial working plan shall also be described in this section.

Throughout the duration of STSM, a comprehensive investigation was conducted to examine the structural stability of nanocrystalline carbon-based particles under ionizing radiation. The main focus of this study was to explore the effects of neutron irradiation on nanocrystalline titanium carbide (TiC) particles, with an emphasis on evaluating their resistance to structural damage and defect formation. The research aimed to provide a deeper understanding of the behavior of carbon-based nanomaterials under extreme environmental conditions, particularly ionizing radiation, which is known to cause significant alterations in the physical and chemical properties of materials.

The initial stage of the work involved the careful preparation of nanocrystalline TiC powders, which have a particle size of approximately 40 nm and a specific surface area (SSA) of 50 m^2/g. These nanoparticles were loaded into high-purity aluminum containers that were specifically designed to be compatible with the TRIGA Mark II reactor channels. The loading process was conducted under highly controlled conditions to ensure that the samples were adequately prepared for the irradiation experiments. Furthermore, before irradiation, each sample underwent a series of preliminary activity tests to confirm that they could be safely handled and that the radioactive materials would not pose any immediate safety risks. These tests ensured that no excessive radiation levels were present at the outset, confirming the safety of the samples prior to their introduction into the reactor. The core of the research involved irradiating the TiC nanoparticle samples using a TRIGA Mark II light-water pool-type reactor, located at the Reactor Center of the Jožef Stefan Institute in Ljubljana (Fig 1). The reactor provided a neutron flux of 5.79×10^{12} n/cm^2s at full power (250 kW). A total of four different neutron doses were applied to the samples, corresponding to neutron fluxes of 1.6×10^{15}, 8×10^{15}, 4×10^{16}, and 2×10^{17} n/cm^2. Each of the four irradiation doses was administered separately to each sample to

[1] This report is submitted by the grantee to the Action MC for approval and for claiming payment of the awarded grant. The Grant Awarding Coordinator coordinates the evaluation of this report on behalf of the Action MC and instructs the GH for payment of the Grant.

evaluate the effects of varying neutron flux levels on the structural integrity and stability of the TiC nanoparticles. The irradiation was conducted over a continuous period of up to seven hours, with the samples remaining under neutron bombardment for the entirety of the experiment.

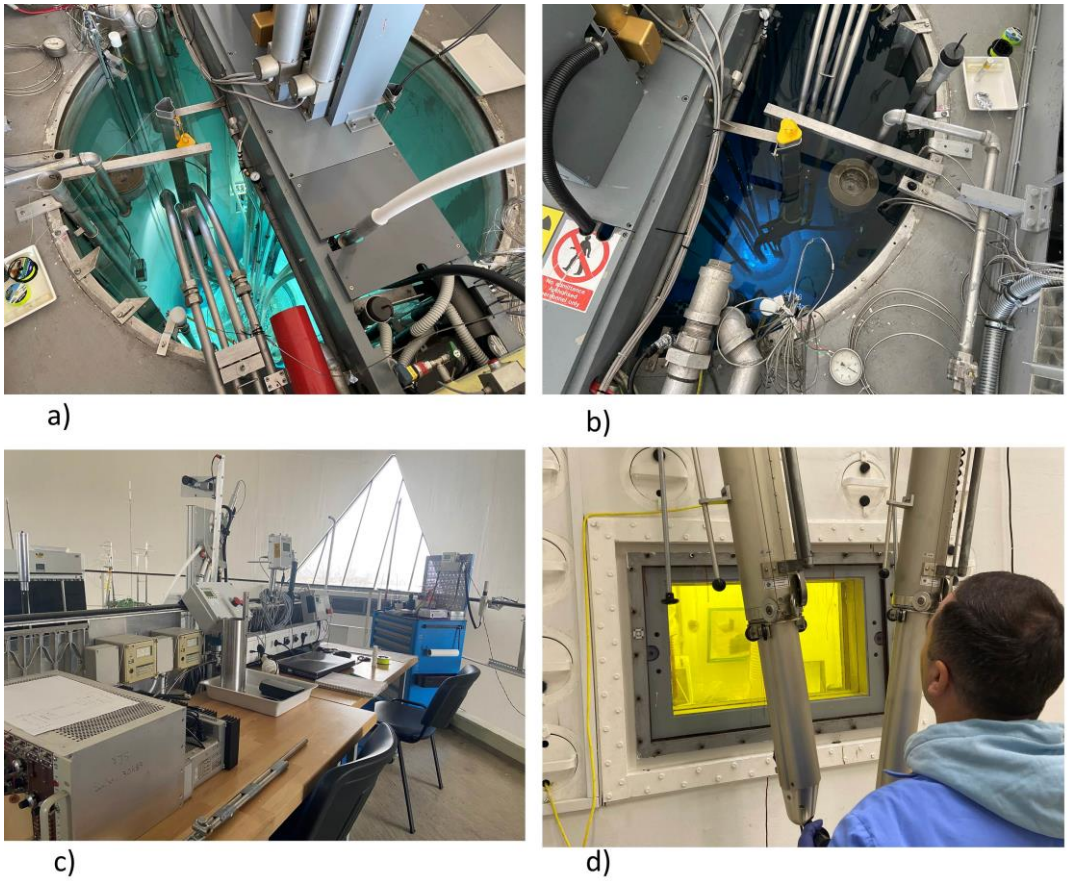


Fig. 1. TRIGA Mark II Light-Water Pool-Type Reactor at the Reactor Center, Jožef Stefan Institute, Ljubljana (a - reactor was shut down, b - reactor operation, c – reactor hall and d – hot cell for irradiated active sample).

As part of the research, the resistance of nanocrystalline TiC nanoparticles to both neutron and gamma radiation was closely assessed. This was done by carefully measuring the total neutron and gamma doses the samples were exposed to during the irradiation process. Accurate dose measurements were crucial to understanding the extent of radiation exposure and to ensuring that the effects observed in the samples could be directly correlated with the neutron flux levels applied. These measurements provided a comprehensive understanding of how the materials responded to radiation over the different doses and irradiation times. Following the irradiation, proper safety protocols were rigorously followed to handle the irradiated samples and manage the radioactive waste generated during the experiment. The samples were stored in designated areas with appropriate radiation shielding and controls, ensuring that all safety regulations regarding radioactive material handling were adhered to. Additionally, any waste generated during the irradiation process, such as contaminated materials or unused samples, was carefully managed and stored according to the prescribed regulations. This included ensuring that all waste was securely contained and properly disposed of or stored in compliance with environmental and safety standards. Post-irradiation, the structural changes and stability of the TiC nanoparticles were thoroughly analyzed using advanced characterization techniques. HRTEM technique was employed to examine the structural integrity of the nanoparticles at the atomic level. It allowed for the identification of any defects, including vacancies, dangling bonds, or other irregularities caused by neutron irradiation. XRD was used to investigate any changes in the crystallographic structure of the TiC nanoparticles following irradiation. This technique provided valuable insights into any alterations in the atomic arrangement and helped identify any phase changes or lattice distortions that occurred due to the exposure to ionizing radiation.

The research conducted during the STSM provided valuable insights into the structural stability of nanocrystalline titanium carbide nanoparticles when subjected to neutron and gamma radiation. The study demonstrated how radiation exposure can induce defects, such as vacancies and dangling bonds, and how these defects can affect the material's overall stability. Although minor adjustments were made to the initial working plan, these deviations did not significantly alter the overall outcome of the research. The findings from this study will contribute to a better understanding of the behavior of carbon-based nanomaterials in ionizing environments, which has important implications for their potential use in various radiation-intensive applications, including electronics, materials science, and nuclear engineering.

Description of the STSM main achievements and planned follow-up activities

Description and assessment of whether the STSM achieved its planned goals and expected outcomes, including specific contribution to Action objective and deliverables, or publications resulting from the STSM. Agreed plans for future follow-up collaborations shall also be described in this section.

The STSM successfully achieved its primary goals, making significant contributions to the objectives outlined in the NanoSpace COST Action, particularly in the areas of research coordination and capacity building. The research focused on the physical properties of nanostructures under harsh cosmic environments, specifically investigating the structural and surface changes of nanoparticles under ionizing radiation. This investigation is highly relevant to the NanoSpace community, as surface modifications induced by ionizing radiation are crucial for understanding the behavior of dust nanoparticles in space environments. The primary objectives were to analyze the effects of radiation on surface morphology, defect formation, agglomeration, and amorphous transformation of TiC nanocrystals. This was accomplished through a combination of advanced characterization techniques, including High-Resolution Transmission Electron Microscopy (HRTEM) and X-ray spectroscopy, which provided valuable insights into the collisional reaction dynamics and the radiation-induced changes in the nanoparticles.

The STSM significantly contributed to the objectives of the NanoSpace COST Action by addressing a critical aspect of nanoparticle behavior in space: how nanoparticles react to ionizing radiation. The results of this research are directly aligned with the goals of Working Group 2 (WG2, T2.1), which focuses on understanding the physical properties of nanomaterials in harsh environments. Additionally, the findings support Working Group 4 (WG4, T4.3), as they will be disseminated through high-impact publications, furthering the Action's mission of scientific dissemination. The STSM provided the applicant with valuable hands-on experience in the field of nanophysics, particularly in understanding the radiation effects on nanocrystalline materials. This experience is crucial for the applicant's professional development and aligns with their long-term goal of building an international career in nanophysics within the European Union. By participating in this research, the applicant enhanced their expertise in radiation-induced effects and nanomaterial characterization, positioning them to contribute to future collaborative research projects in this area.

Following the success of this STSM, there are planned collaborations between the applicant and the hosting institution, the Jožef Stefan Institute, as well as other NanoSpace COST Action members. These collaborations will focus on further experimental investigations into the radiation-induced behavior of nanoparticles, expanding the scope of the current research to include a broader range of nanomaterials and different irradiation environments. The aim is to build on the findings of this STSM and extend the research to explore additional surface modifications and structural changes under different ionizing conditions. The results of the research will be submitted for publication in high-impact journals in the fields of nanotechnology and material science. These publications will not only contribute to advancing the scientific understanding of the behavior of nanomaterials under ionizing radiation but will also acknowledge the NanoSpace COST Action as part of the research's funding and collaboration. The dissemination of these findings will help establish the research group as a leading contributor to the field, while also enhancing the visibility of the NanoSpace COST Action within the international scientific community.

The applicant plans to continue engaging with the NanoSpace community, sharing their findings through presentations at relevant conferences and workshops, as well as through collaborative research projects. This will facilitate the transfer of knowledge and expertise within the network,

contributing to the overall capacity building goals of the NanoSpace COST Action. The applicant is also keen to explore new opportunities for cross-disciplinary research, particularly in the areas of materials science, space technology, and radiation physics.
In conclusion, the STSM was a successful and impactful activity that met its planned goals and objectives. The research made significant contributions to the NanoSpace COST Action by addressing key scientific challenges related to nanoparticles in space environments. The results of the STSM will lead to further publications and collaborations, ensuring the continued development of both the applicant's career and the broader research community's understanding of the behavior of nanomaterials under ionizing radiation.