6th RaDIATE Collaboration Meeting

Report of Contributions

Contribution ID: **1** Type: **Oral presentation**

Post irradiation Examination of a spent Antiproton Production Target

Thursday, 12 December 2019 09:00 (25 minutes)

The current contribution will detail a Post Irradiation Examination (PIE) on a spent antiproton production target (AD-target), which has been irradiated for around 10 years in the AD machine. The iridium core is estimated to have been irradiated up to 5 DPAs. The cutting procedure has well as all the measurements executed on the samples will be discussed as well as the path forward to other studies as well as the complementarity with HiRadMat experiments.

Primary author: Dr CALVIANI, Marco (CERN)

Presenter: Dr CALVIANI, Marco (CERN)

Session Classification: 8th Oral Session

Contribution ID: **2** Type: **Oral presentation**

Status of Post Irradiation Examinations of the RaDIATE CERN2 capsule

Tuesday, 10 December 2019 09:50 (25 minutes)

The contribution will provide a status report of the Post Irradiation Examination of the RaDIATE-sponsored CERN2 capsule. The PIE will focus on the Mo-coated samples (MoGR and CfC), including microscopy analysis as well as coating adhesion. Perspectives on the schedule as well as on the other samples will be provided.

Primary author: Dr CALVIANI, Marco (CERN)

Presenter: Mr SOLIERI, Nicola (CERN)

Session Classification: 4th Oral session

Contribution ID: **3** Type: **Oral presentation**

Experimental investigation of radiation damage effects in beryllium: updates on recent results obtained on proton, neutron and He-ions irradiated samples

Tuesday, 10 December 2019 12:45 (25 minutes)

Beryllium is an essential material for target components material in the currently running (NuMI) and near-future multi-megawatt accelerator particle sources (LBNF), reflectors and moderators in material testing nuclear reactors, plasma facing material (JET, ITER) and potential neutron multiplier (DEMO) for fusion reactor designs, and it is under extensive investigation by fission, fusion reactors and proton accelerator facilities communities.
The presentation gives an overview of the recent results obtained in the Materials Research Facility of the UKAEA on beryllium samples:
• exposed to high energy protons in the NuMI beamline at 50°C (maximum dose 0.5 dpa, 2000 appm of helium transmutant);
• after helium implantation at 50°C and 200°C (0.1 dpa, 2000 appm of helium);
• after neutron irradiation at different DEMO relevant conditions during HIDOBE-2 campaign in the HFR and investigated within the collaboration with Karlsruhe Institute of Technology (Germany).
• after thermal-shock experiments in the HiRadMat facility.
The main part of the paper will be devoted to the micromechanical tests results obtained using nanoindentation hardness measurements and microcantilevers fracture tests. The local properties data will be analyzed in combination with observed microstructural changes. The presentation will also give an overview of the future plans.

Primary author: Dr KUKSENKO, Slava (United Kingdom Atomic Energy Authority)

Presenter: Dr KUKSENKO, Slava (United Kingdom Atomic Energy Authority)

Session Classification: 5th oral session

Contribution ID: **4** Type: **Oral presentation**

Analyses and HiRadMat Experiments for CERN Beam Intercepting Devices

During the last two years, a wide range of analyses were performed on different beam intercepting devices at CERN, including numerical simulations, proton-beam impacts at HiRadMat and different post-irradiation examinations. The contribution will focus on new observations related to three recent experiments, one associated to LHC collimator materials and other two more related to targetry applications for secondary beam production.

One of the analyses was focused on the effect of grazing impacts of high-intensity proton beams on metallic coatings applied on different carbon-based materials, tested at HiRadMat (HRMT-35). Apart from the inspections of the damage generated by beam impact, by means of techniques such us X-Ray tomography, FIB, electrical characterisations and adhesion tests, an ad-hoc numerical model was developed, allowing to perform simulations showing good agreement with the experimental results.

In order to obtain the most robust design for the future Antiproton Decelerator target at CERN, several options and combination of refractory metals have been tested under high-energy proton beams at HiRadMat (HRMT-42 and HRMT-48 experiments). According to simulations, extreme dynamic stresses and temperatures were produced in the targets, leading to potential failure of the core material. Extensive post irradiation examination was performed on these targets, including high-resolution neutron tomography, microscopy analyses and other destructive techniques.

In parallel with HRMT-48, in the framework of the future design for the n_TOF target, two prototypes, based on pure lead as core material, were tested at HiRadMat (HRMT-46). Approximately 2500 pulses were impacted on the targets to try to estimate the fatigue behaviour of the core materials under the two different configurations. One of the targets was disassembled and neutron tomography was performed on the lead blocks, which, in addition, were subsequently inspected by other techniques.

A description of the experiments, numerical simulations and post-irradiation observations obtained during 2019 will be presented, together with their impact on the design and operation of such devices.

Primary authors: Dr PERILLO MARCONE, Antonio (CERN); Dr TORREGROSA, Claudio (CERN); Ms BAHAMONDE, Cristina (CERN); Mr LAMAS, Inigo (CERN); Dr MAESTRE, Jorge (CERN); Dr CALVIANI, Marco (CERN); Mr ESPOSITO, Raffaele (CERN)

Presenter: Dr PERILLO MARCONE, Antonio (CERN)

Contribution ID: **5** Type: **Oral presentation**

Calculations of damage energy spectra of nuclear reaction products and plan for displacement damage cross section measurements using 120 GeV protons at FNAL

Wednesday, 11 December 2019 12:20 (25 minutes)

The displacement per atom (dpa) value is widely used for the index of radiation damage in materials under high energy proton irradiation. It is possible to calculate dpa values using the screened Coulomb scattering theory for incident proton-nucleus collisions and the nuclear reaction model for nuclear reaction product-nucleus collisions in the high-energy region (>10 MeV). For defect production, it is the number of recoils weighted by the damage energy produced in each recoil that is most important. This quantity is determined by "weighed"the recoil spectra by the damage energy produced in each recoil. However, the damage energy spectra have not been investigated yet for the proton energy range from several MeV to hundred GeV, where recoil is regarded as nuclear reaction product. The contribution of each nuclear reaction product to the total dpa cross section has not been studied yet, although many kinds of nuclear reaction products are produced by nuclear reactions with increasing incident proton energy. In this work, we calculated damage energy spectra and dpa cross sections of all nuclear reaction products under high energy proton irradiation on tungsten with the energy range from 10 MeV to 120 GeV using the Particle and Heavy Ion Transport code System (PHITS).

The damage energy spectrum of target nucleus includes the nuclear elastic scattering component in the low-energy part and the nuclear inelastic scattering component in the high-energy part. The average damage energy of tungsten was 63.7 keV for 100 MeV proton, 76.9 keV for 400 MeV, 38.3 keV for 1 GeV and 28.7 keV for 10 GeV, respectively. The damage energy spectrum of others include inelastic component only. For example, the average damage energy of lutetium produced by inelastic scattering was 628 keV for 100 MeV proton, 895 keV for 400 MeV, 872 keV for 1 GeV, 637 keV for 10 GeV, and 587 keV for 120 GeV, respectively. Note that the damage energy to the lattice atom is always smaller than the kinetic energy of nuclear reaction products because electric energy lost is subtracted in the displacement model. The damage energy of nuclear reaction product increased with proton energy up to around 1 GeV, but it decreased slightly with incident proton energy above 1 GeV. On the other hands, the number of nuclear reaction products increased with proton energy. In consideration of the relationship between the damage energy and the number of nuclear reaction products, the total dpa cross section of tungsten increased with the proton energy range from 400 MeV to 1 GeV and be almost constant over 1 GeV. The experimental data of total dpa cross sections indicated same trend with calculated results for the proton energy below 2 GeV.

In this presentation, we will also introduce our experimental plan for measurement of dpa cross sections with 120 GeV protons at Fermi National Accelerator Laboratory (FNAL).

Primary author: IWAMOTO, Yosuke (Japan Atomic Energy Agency)

Co-authors: IWAMOTO, Hiroki (J-PARC/JAEA); YONEHARA, Katsuya (Fermi National Accelerator Laboratory); YOSHIDA, Makoto (KEK); Mr HURH, Patrick (Fermi National Accelerator Laboratory); MEIGO, Shin-ichiro (J-PARC/JAEA); HASHIMOTO, Shintaro (Japan Atomic Energy Agency); SPINA, Tiziana (Fermi National Accelerator Laboratory)

Presenter: IWAMOTO, Yosuke (Japan Atomic Energy Agency)

Session Classification: 7th Oral session

Contribution ID: **6** Type: **Oral presentation**

In situ tensile testing and electron backscatter diffraction characterization of irradiated 316L from Spallation Neutron Source Targets 8 and 9

Tuesday, 10 December 2019 10:15 (25 minutes)

Tensile testing of material from the Spallation Neutron Source (SNS) Target 2 showed abnormally large ductility for a specimen irradiated to approximately 5.4 displacements per atom (dpa). Subsequent electron backscatter diffraction (EBSD) characterization of these tested Target 2 specimens showed deformation-wave behavior from transformation-induced plasticity was responsible for the large ductility values observed. To study the deformation behavior of the target material after irradiation, relatively small "micro"tensile specimens were fabricated from material removed from SNS Targets 8 and 9, which were irradiated to approximately 7 dpa. In situ tensile testing of these specimens and unirradiated reference material was performed in a scanning electron microscope equipped with an EBSD detector system. EBSD maps were captured during different stages of each test to characterize the deformation mechanism(s) occurring during testing. This presentation will review the initial results from these tests and discuss future work for the SNS PIE program.

Primary author: MCCLINTOCK, David (Oak Ridge National Laboratory)

Presenter: MCCLINTOCK, David (Oak Ridge National Laboratory)

Session Classification: 4th Oral session

Contribution ID: **7** Type: **Oral presentation**

The current Status of CSNS solid target

Monday, 9 December 2019 11:50 (25 minutes)

A 100 kW solid target was successfully developed for the CSNS phase one. Tungsten was selected as the CSNS target material and a layer of tantalum with a thickness of only 0.3mm as a protective layer. Eleven target blocks were fixed in parallel in a stainless steel target container with 1.2mm gap between each block. Using a specially designed spreader, the target plug can be easily replaced. During the nearly two years of operation, the parameters of the target cooling water were stable and normal, the temperature rise of the target cooling water inlet and outlet increased as the proton beam power increased. Every year, the target surface was carefully observed by a high definition camera in the hot cell. Last year, no abnormal were found on the target surface, however, the surface of the target showed signs of turning yellow in some regions.

Primary author: Mr WEI, Shaohong (Institute of High Energy Physics, Chinese Academy of Sciences)

Presenter: Mr WEI, Shaohong (Institute of High Energy Physics, Chinese Academy of Sciences)

Session Classification: 1st Oral Session

Contribution ID: **8** Type: **Oral presentation**

Development of ultrasonic meso-scale fatigue testing of irradiated titanium alloys for proton beam window applications

Monday, 9 December 2019 14:25 (25 minutes)

Titanium alloys such as commercially available Ti-6Al-4V are currently used as the beam window material in the T2K (Japan) proton beam target for neutrino production due to their high specific strength and low thermal expansion coefficient. Thermal spikes from the pulsed beam cause high frequency stress waves with magnitudes well below the yield stress, which subject the component to high-cycle-fatigue (HCF) loading. The effect of proton irradiation on the fatigue life in the HCF regime is largely unknown, especially at the high radiation damage doses seen in operation. With the desire to increase the incident beam power to in excess of 1 MW in future experiments, causing damage doses well in excess of 1 dpa per annum, there is a growing need for the beam window manufacturer (STFC, UK), to fully understand the material performance limits under these extreme conditions.

In this collaborative research project, thin foils of titanium alloys have been irradiated to 0.25 and 1 dpa at the Brookhaven Linac Isotope Producer (BLIP) at the Brookhaven National Laboratory (BNL), USA. The alloys included the current Ti-6Al-4V beam window material in addition to several potentially radiation-resistant grades.

Using an evolution of the ultrasonic meso-scale fatigue test developed at the University of Oxford, we will perform high-cycle fatigue testing on these irradiated specimens at the Materials Research Facility (MRF) at the Culham Science Centre, UK. Microstructural investigation yielding crystallographic (EBSD) and chemical (EDX) information will be performed. The effect of irradiation damage on each alloy will be assessed and related to the microstructure. This will allow suitable materials to be specified for future beam window designs.

This presentation will cover the developments in the design and commissioning of an ultrasonic fatigue rig (UFR) at the MRF, UK. The capabilities of the UFR and associated real-time diagnostics will be outlined, along with the proposed ultrasonic test procedures and data analysis routines. An update on the materials research will be given, including microstructural and chemical analysis on the unirradiated specimens.

Primary author: Mr EARP, Phil (University of Manchester / United Kingdom Atomic Energy Authority)

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Presenter: Mr EARP, Phil (University of Manchester / United Kingdom Atomic Energy Authority)

Session Classification: 2nd Oral session

Contribution ID: **9** Type: **Oral presentation**

Blisters study in tungsten irradiated by MeV protons: Fracture morphology and mechanical properties

Tuesday, 10 December 2019 11:55 (25 minutes)

Proton irradiation damage is a common problem in structural materials at accelerators and nuclear fusion reactors. This damage may result in the degradation of the mechanical properties of structural materials and jeopardize the safe operation of nuclear facilities.
Tungsten and tungsten alloys are utilized as building blocks of nuclear facilities, due to their excellent mechanical and thermal properties. Nevertheless, tungsten may also suffer from blister erosion due to proton irradiation. The choice of tungsten as material for the divertor in ITER (future thermal reactor) led to an increase in the number of studies on blister formation and hydrogen retention in tungsten in the last two decades.
Most of the studies focus on low energy protons, up to several keV's and on hydrogen plasma interaction with tungsten. Irradiation by low energy protons is characterized by shallow implantation depths, high sputtering yield and low irradiation temperatures.
In spite of the extensive research carried out on the evolved damage due to irradiation by keV protons\deuterium ions, the mechanism of blisters formation and growth in tungsten remains not well understood. In contrast, under MeV proton irradiation the evolving damage should differ from that from keV protons due to deeper penetration depths, lower sputtering and higher irradiation temperatures. These differences are expected to affect the blister formation and growth processes and their analysis should contribute to improving our understanding.

In this study, we investigated the evolution of irradiation damage in tungsten by high energy protons (MeV's) at several fluxes and temperatures, to obtain a better understanding of the mechanism of blister formation and growth during irradiation. A cooled target cell was designed and built to allow ambient temperature irradiation experiments.
Single and polycrystalline tungsten samples were irradiated with 2.2 MeV protons at Soreq Applied Research Accelerator Facility (SARAF). Hydrogen blisters were obtained for both single crystal and polycrystalline samples. Blisters were formed at doses of the order of 1017 protons/cm2, which are below the reported keV critical threshold for blister formation. Large, well-developed blisters are observed, indicating that for MeV range protons the critical threshold is at least an order of magnitude lower than the lowest value reported previously. The effect of temperature and flux on the critical formation dose for blisters and on their dimensions was studied. It was found that for single crystals, the critical formation dose is one order of magnitude higher than for polycrystalline tungsten at high-temperature irradiation conditions. Upon reducing the irradiation temperature to ambient, the critical dose for the formation of blisters in single crystals was reduced by a factor of three, in contrast to polycrystalline tungsten where there was no significant change with temperature; thus indicating the role of grain boundaries in blister formation. Larger blisters were obtained in single crystals than in polycrystalline tungsten at ambient temperature conditions, identifying the grain boundaries as a preferential additional hydrogen trap. The height to area ratio of the blisters is found to be strongly temperature dependent and only weakly dependent on irradiation flux for both single and polycrystalline samples.
The morphology of the irradiated samples was observed by examining cross-sections of blisters obtained by the use of a focused ion beam (FIB). The thickness of the blister cap was found to be in good agreement with the irradiating protons stopping range, regardless of sample structure, temperature or total dose. Increased curvature of the surfaces was observed with increased temperature for polycrystalline and single crystal blisters and was interpreted as increased ductility of the blister growth process. The ductility is more substantial in single crystal blisters, pointing

to the role of grain boundaries in blisters growth mechanism. The cap of one blister was removed, exposing the inner fracture surface of a blister and supporting the validity of the cross-sectional observations.
The mechanical properties in the vicinity of a blister formed in a single crystal sample were characterized by nano-indentation. The hardness near the irradiated surface was found to increase both in the vicinity of the blister and beyond. This observation suggests that the elevation of the blister cap does not cause significant strain hardening. For the blister cap, the hardness was found to increase with increasing depth from the irradiated surface, correlating with increased irradiation damage. Comparison with neutron irradiation hardening is presented.

Primary author: Mrs GAVISH SEGEV, Inbal (Soreq)

Presenter: Mrs GAVISH SEGEV, Inbal (Soreq)

Session Classification: 5th oral session

Contribution ID: **10** Type: **Oral presentation**

Overview of the ISOLDE Facility and of the EPIC Project

Monday, 9 December 2019 11:00 (25 minutes)

The operation of the on-line isotope separator ISOLDE at CERN allows the production of a wide variety of radionuclides that are delivered in the form of Radioactive Ion Beams (RIBs) to different experimental setups installed in the ISOLDE beam lines. The radionuclides are produced in thick targets bombarded by the pulsed proton beam delivered by the Proton Synchrotron Booster (PSB). During the period 2018-2019, major improvements and consolidations of the CERN injector chain are implemented under the auspices of the LHC Injectors Upgrade (LIU) project. For ISOLDE, the higher available proton current with the new Linac4 as injector and the increase of the PSB energy from 1.4 GeV to 2.0 GeV open new perspectives and improvement objectives identified in a project proposal called EPIC (Exploiting the Potential of Isolde at CERN). For example, the higher available energy results in an increase of the production of short-lived radionuclides at the limit of nuclear existence, in particular the ones produced by fragmentation and spallation reactions. The higher available proton current allows a reduction of the required beam time for experiments previously limited by the low RIB intensity. Alternatively, the experimental capabilities and available beam time can also be significantly enhanced by the operation of new target stations constructed in such a way that RIBs can be delivered in parallel to the low energy and high-energy beam lines. In order to receive the 2 GeV beam from the PSB and construct new target stations, major modifications of the target area must be performed. In particular, the HRS and GPS beam dumps absorbing the remaining beams and secondary particles after the two target stations will have to be replaced by two new systems capable of sustaining the higher beam power and meeting modern radiation protection standards. Parasitic or dedicated irradiations have occasionally been performed in the past to serve mainly the needs of target developments but operational limitations and constraints have been identified and limit a more systematic use of the facility. The replacement of the beam dumps and the construction of new target stations could be a unique opportunity to foresee an infrastructure adapted to material irradiations in parallel to ISOLDE operation. The presentation provides an overview of the EPIC project with an emphasis on the target area upgrades and provides an assessment of the radiation fields in the areas of interest in order to assess the performances of ISOLDE for parasitic irradiations of material or equipment. A description of the strengths of ISOLDE with the presence of a laboratory dedicated to the management of radioactive material, remote handling capabilities as well as the presence of a shielded hot cell to address the radiation protection challenges associated to irradiation experiment is also provided.

Primary author: VOLLAIRE, JOACHIM (CERN)

Co-authors: NEYENS, Gerda (CERN); Dr CALVIANI, Marco (CERN); CATHERALL, Richard (CERN); GILES, Tim (CERN)

Presenter: VOLLAIRE, JOACHIM (CERN)

Session Classification: 1st Oral Session

Contribution ID: **11** Type: **Oral presentation**

Harvesting Experiments on Additive Manufactured Titanium Alloy Beam Stopper with Radiation Assisted Corrosion Impacts

Thursday, 12 December 2019 09:25 (25 minutes)

In preparation for isotope harvesting with a water-filled beam dump at the Facility for Rare Isotope Beams (FRIB), a flowing-water target connected to an isotope harvesting water system has been created and used in preliminary experiments. The target shell was made with a Ti64 alloy through additive manufacturing to reflect the material that is planned for the FRIB beam dump. Experiments with this target have involved low-power irradiations for isotope harvesting with 40,48Ca and 78Kr beams at the National Superconducting Cyclotron Laboratory (NSCL). Recently, a higher-power durability test was performed at the University of Wisconsin-Madison Cyclotron Lab to measure the degradation rate of the target shell material under similar irradiation conditions as those expected at the NSCL and FRIB during isotope harvesting. The flowing-water target was irradiated for several hours with a 5-50 μA proton beam, slowly increasing the beam intensity over time. The 48Ti(p,n)48V reaction, which occurred in the front face of the target shell, was used to measure the degradation rate of the target material. During the irradiation, a small quantity of 48V accumulated in the water and on an anion exchange resin in the water system. This radiotracer indicated a degradation rate of the target wall thickness on the order of 1E-8 μm/J. The implications of this rate on the durability of the target material for isotope harvesting will be discussed.

Primary author: Mrs ABEL, Emily (Michigan State University)

Co-authors: Mr KALMAN, Colton (Michigan State University); Dr SEVERIN, Greg (Michigan State University); Dr ENGLE, Jonathan (University of Wisconsin-Madison); Dr DOMNANICH, Katharina (Michigan State University); Dr BARNHART, Todd (University of Wisconsin-Madison); Mr WALKER, Wes (Michigan State University)

Presenter: Mrs ABEL, Emily (Michigan State University)

Session Classification: 8th Oral Session

Contribution ID: **12** Type: **Oral presentation**

Post-Irradiation Examination of Proton-Irradiated Ti-base Alloys

Thursday, 12 December 2019 11:30 (25 minutes)

Currently titanium alloys are used as beam windows in several accelerator facilities due to favorable beam interaction properties, high tensile strength, and high fatigue strength. The T2K neutrino beam-line currently uses the alpha+beta alloy Ti-6Al-4V as the material for its primary beam window and target beam window. Planned upgrades to the accelerators to 1.3 MW will require pushing the windows closer to their operational limits. Likewise, the Long Baseline Neutrino Facility (LBNF) facility, under design for 1.2 MW primary proton beam power at Fermilab, is planning to use this Ti alloy as the downstream target containment beam window. However, relatively little is known on how this common Ti alloy is affected by high energy proton irradiation. Understanding these radiation damage effects on this Ti-base alloy and others will lead to accurate lifetime prediction, more robust multi-MW targets, and development of new materials to extend target lifetimes.

The presentation will include the latest post-irradiation examination results on a variety of Ti-base alloy samples irradiated in the BLIP facility to three different fluences. Materials include different varieties of Ti-6Al-4V, Ti-3Al-2.5V, Ti-5Al-2.5Sn, and the beta-Ti alloy Ti-15V-3Cr-3Sn-3Al. Tensile test results will be discussed, including data at room temperature and 200℃. Microscopy will also be discussed, including results from SEM/EBSD and TEM. The SEM/EBSD results will be correlated to the extent possible with nanohardness measurements made via atomic force microscopy. Finally, updates will be provided on interactions with other laboratories including shipping irradiated fatigue samples to Fermilab and meso-scale fatigue foils to the Culham Centre for Fusion Energy.

Primary author: Dr SENOR, David (Pacific Northwest National Laboratory)

Co-authors: Dr CASELLA, Andrew (Pacific Northwest National Laboratory); Dr EDWARDS, Dan (Pacific Northwest National Laboratory); Mr PRABHAKARAN, Ramprashad (Pacific Northwest National Laboratory); Dr RIECHERS, Shawn (Pacific Northwest National Laboratory)

Presenter: Dr SENOR, David (Pacific Northwest National Laboratory)

Session Classification: 9th Oral Session

Contribution ID: **13** Type: **Oral presentation**

Proton irradiation effects on the phase stability of (α+β) Ti-6Al-4V irradiated at BLIP using dilatometry and high energy X-ray diffraction techniques at the BNL synchrotrons

Thursday, 12 December 2019 10:15 (25 minutes)

Several super-alloys in the mid-Z range have been explored as targets for pion production to enable high-intensity neutrino sources. These allows have included Inconel-718, super-Invar, the Gum multi-functional alloys and the α+β titanium alloy Ti-6Al-4V.

In this presentation the phase stability of the Ti-6Al-4V following irradiation with 140 MeV protons at the Brookhaven Linac Isotope Producer (BLIP) is described.. Specifically, following two sequential irradiation phases with peak fluences of ~5x10^20 p/cm^2 along with post-irradiation annealing between irradiations, the influence of irradiation on the stability of α and β phases were studied using precision dilatometry. Subsequently, by using high energy X-rays at the BNL synchrotrons (NSLS and NSLS-II) along with Energy Dispersive X-Ray Diffraction (EDXRD) and X-Ray Diffraction (XRD) techniques (where the latter was augmented with a refined Rietveld analysis), the phase evolution of these materials was studied. In-situ stresses during X-ray diffraction were applied with both techniques to assess (a) the role of twinning in accommodating deformation in the hcp a phase of titanium and (b) the effect of strain on α/β phase content. These studies revealed (a) identifiable α to β transformations based on the thermal expansion coefficient evolution with temperature, (b) the influence of proton-irradiation on these transformations, (c) the appearance of the ω phase following proton irradiation, (d) a tension-compression asymmetry based on activation of the twinning mechanism, and (e) the influence of applied strain on α and β phase fraction.

Further studies of Ti6Al4V samples, in both their as-received state and after proton irradiation, are planned as part of an upcoming NSLS-II experiment. This experiment will utilize X-ray tomography to study the impact of variations in the in-situ multi-dimensional stress state as enabled by a specially designed stage. First results from the experiment, including the capabilities/features of the experimental set-up at the NSLS-II XPD beamline for X-ray tomography and XRD on irradiated materials will also be shown.

Primary author: Dr SIMOS, Nikolaos (Brookhaven National Laboratory)

Co-authors: Dr PALMER, Mark (Brookhaven National Laboratory); Prof. KIRK, McDonald (Princeton University); Dr CHARITONIDIS, Nikolaos (CERN)

Presenter: Dr PALMER, Mark (Brookhaven National Laboratory)

Session Classification: 8th Oral Session

Contribution ID: **14** Type: **Oral presentation**

Computer Simulation of Radiation Damage in Materials

Wednesday, 11 December 2019 11:30 (25 minutes)

We present an overview of computer simulation methods used to study radiation damage from the atomic to the continuum scale. Within the framework of multiscale materials modeling, the study of irradiation damage and associated materials property degradation has required modifications tailored to the application. Particle irradiation damage in accelerator targets begins at the nanometer scale and its effects can be seen at the millimeter scale and beyond. Similarly, the effects of picosecond-scale processes manifest themselves after hours and even months of continued operation. The complex phenomena associated with energetic particle impact include charge transfer, heat transfer, atomic displacement, preferential sputtering, local chemical changes, melting, and phase transformations, such as amorphization and precipitation. Modeling of irradiated materials at different scales to provide a fundamental scientific understanding of radiation-induced changes in microstructure and properties will be discussed.

Primary author: Dr DEVANATHAN, Ram (Pacific Northwest National Laboratory)

Presenter: Dr DEVANATHAN, Ram (Pacific Northwest National Laboratory)

Session Classification: 7th Oral session

Contribution ID: **16** Type: **Oral presentation**

The formation of radiolysis products during isotope harvesting with a flowing water target

Thursday, 12 December 2019 09:50 (25 minutes)

The harvesting of rare isotopes at the National Superconducting Cyclotron Laboratory (NSCL) is accomplished by the deposition of heavy ion beams in a water filled beam blocker. With the dissipation of such large amounts of energy, not only a plethora of radionuclides is formed, radiolysis reactions are induced as well. The thereby created various radiolytic products can either react with each other, resulting in mutual annihilation, or escape into the bulk solution. In general, molecular products such as hydrogen peroxide, molecular oxygen and hydrogen exhibit longer life times and could potentially increase to considerable levels in open systems. In order to ensure adequate water conditions for isotope harvesting, knowledge about the behavior of these species is vital. This will become particularly significant when considering the intended utilization of an aqueous beam blocker at the upcoming Facility for Rare Isotope Beams (FRIB).

In several exploratory experiments at the NSCL the formation of H2O2, H2 and O2 was investigated with heavy ion beams of low intensity. To mimic the conditions expected at FRIB, the water filled beam blocker was irradiated with a high intensity proton beam (5–50 µA) for several hours at the Cyclotron Research Laboratory at the University of Wisconsin–Madison. The formation of H2O2, H2 and O2 in the harvesting system's water was calculated based on the applied beam power; however, the measured levels (max. 586 µM H2O2, 5.5% H2, 10 ppm dissolved O2) were considerably lower. Based on these observations, an aqueous phase reaction of hydrogen peroxide and hydrogen is rendered possible. Additionally, elevated water temperatures could be expected, which would influence the primary yields of both species. The current model would support the interaction of all radiolytically formed species, even though the volume of irradiated water (~40 L) was much larger compared to conventional aqueous cyclotron targets.

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Co-authors: Mr KALMAN, Colton (NSCL); Mrs ABEL, Emily (Michigan State University); Prof. SEVERIN, Gregory (NSCL, MSU); Prof. ENGLE, Jonathan (University of Wisconsin - Madison); Mr BARNHART, Todd (UW-Madison, Cyclotron Lab); Mr WALKER, Wesley (NSCL)

Presenter: Dr DOMNANICH, Katharina (NSCL, MSU)

Session Classification: 8th Oral Session

Contribution ID: **17** Type: **Oral presentation**

Irradiation induced failure investigation of NT02 graphite target fin through numerical simulation

Wednesday, 11 December 2019 11:55 (25 minutes)

Some of the NT02 target fin made up of isotropic POCO graphite grade has developed crack and fractured after few years of operation. The highly energetic pulsed proton beam with small beam sigma would create thermal stress wave as well as radiation damage such as displacement damage, void formation, swelling, gas formation among few. A complex interaction of dynamic loading due to beam, material degradation due to irradiation are thought to have caused such failure. Here we present a numerical simulation to capture combined effect of swelling and dynamic effect of thermal stress wave due to beam heating, to explain the failure of target. An empirical formula has been developed to take into account swelling as a function of temperature and proton fluence and has been implemented in commercial finite element code. Extensive X-ray diffraction (XRD) are done on fractured surface to understand lattice parameter change due to irradiation and the parameters of the empirical model are adjusted accordingly. Simulation results show swelling plays a major role in elevating stress state in the material closer to failure strength while the pulsed beam heating introduces fatigue loading that would explain brittle fracture emanating from inside of the material and propagating outward. Such empirical formula can be used as a predictive tool to estimate the service life of future multi-megawatt neutrino targets and targets in other accelerator environments.

Primary author: Dr BIDHAR, Sujit (Fermi National Accelerator Lab)

Co-author: Mr HURH, Patrick (Fermi National Accelerator Laboratory)

Presenter: Dr BIDHAR, Sujit (Fermi National Accelerator Lab)

Session Classification: 7th Oral session

Contribution ID: **18** Type: **Oral presentation**

Fatigue Performance of Proton Irradiated Ti6Al4V Alloy

Tuesday, 10 December 2019 09:25 (25 minutes)

Titanium alloy Ti6Al4V currently used in beam windows in accelerator facilities are subjected to thermal stresses and high cycle fatigue loading due to intense pulsed proton beam. There materials interacting with beam will also undergo various radiation damage which will affect their endurance limit. Till now there is no fatigue data available for high energy proton irradiated titanium alloy. In this study we carried out fatigue test on proton irradiated Ti6Al4V using a custom-made fatigue tester. The samples are irradiated with 180 MeV proton beam at Brookhaven National Lab to receive upto 0.25 DPA. Two different grades of Titanium alloy, Grade 5 and Grade 23, with different levels beta-phases are fatigue tested and compared with unirradiated samples.

Primary author: Dr BIDHAR, Sujit (Fermi National Accelerator Lab)

Co-author: Mr HURH, Patrick (Fermi National Accelerator Laboratory)

Presenter: Dr BIDHAR, Sujit (Fermi National Accelerator Lab)

Session Classification: 4th Oral session

Contribution ID: **19** Type: **Oral presentation**

AN EXPLORATORY PRODUCTION OF TITANIUM-BASED OXIDE DISPERSION-STRENGTHENED ALLOY MATERIAL

Wednesday, 11 December 2019 10:15 (25 minutes)

An &alpha+&beta dual-phase titanium alloy Ti-6Al-4V (ASTM Grade 5 or its Extra Low Interstitial grade 23) is widely utilized as the beam window material for high-intensity particle accelerators, because of its low density and high specific strength. However, it is known that proton beam irradiation with only 0.1 dpa-NRT rapidly initiates radiation-induced hardening and loss of ductility. High-intensity beam penetration (order of 10^14 protons-per-pulse) through the beam window in the area of a few tens of mm^2 area causes a few hundred MPa compressive stress, and initiates propagation of shock waves in a few microsecond cycle. Resultant high cycle fatigue can lead to failure of the radiation-embrittled beam window in a very short time scale. There are indications that single-HCP phase &alpha-Ti alloys, such as Grade-6 Ti-5Al-2.5Sn, provide preferable ductility compared to the &alpha+&beta dual phase Ti-6Al-4V. Recent work by some of the authors indicates that this is due to radiation induced &omega-embrittlement that occurs only in the &beta phase [1]. If improved radiation tolerance of the single &alpha-phase alloy is realized, it can be adopted as the beam window material in future accelerators with upgraded power, which should bear damage levels of one to a few dpa-NRT within one year operation. It may also be attractive for certain components in fusion reactors.
In order to improve the tolerance against radiation embrittlement of titanium alloys, we firstly try an oxide dispersion-strengthen (ODS) approach on titanium, which developed in other alloy systems for fusion material science based on Fe, V, Cu etc. To start with, we utilize single &alpha-phase pure titanium as the simplest case. By following the method developed on pure vanadium by one of the authors[2], pure titanium powder with addition of ~2 wt-% yttrium is processed with mechanical alloying (MA). It aims to convert solute oxygen and nitrogen impurities, which are originally contained in the base powder (and will become harmful sources to decrease ductility), to form a large number of nano-scale precipitates, working as sink sites of radiation-induced defects. The MA process dissolves all added Y into the base Ti matrices. Subsequent thermo-mechanical treatments cause reactions between solute Y and O/N impurities, resulting in oxide (Y2O3) and nitride (YN) dispersed in the base Ti matrices as nano-scale precipitates. In this presentation, our exploratory productions of the ODS-titanium alloy, aiming to optimize the MA processing and thermomechanical treatments (such as sintering), will be reported.

[1] "New Aspect of Radiation Damage Behavior on Titanium Alloys under High-Intensity Proton Beam Exposure", T.Ishida, E.Wakai, A.Casella, D.Edwards, D.Senor et al, ICFRM-19, San Diego,U.S.A., Oct.29, 2019.

[2] "Microstructure Control to Improve the Resistance to Radiation Embrittlement in Vanadium", H.Kurishita et al., J. Nucl. Mater. 343 (2005) 318-324.

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Presenter: ISHIDA, Taku (J-PARC)

Session Classification: 6th Oral Session

Contribution ID: **20** Type: **Oral presentation**

Measurement of displacement cross section in J-PARC for proton kinematic energy range from 0.4 GeV to 30 GeV

Tuesday, 10 December 2019 09:00 (25 minutes)

For damage estimation of structural materials in the accelerator facility, displacement per atom (DPA) is widely employed as an index of the damage calculated based on the displacement cross section obtained with the calculation model. Although the DPA is employed as the standard index of material damage, the experimental data of displacement cross section are scarce for a proton in the energy region above 20 MeV. Among the calculation models, the difference about 8 times exists for tungsten so that experimental data of the displacement cross section is crucial. To obtain the displacement cross section, which can be obtained by the change of resistivity of the sample under irradiated with proton with cryogenic temperature, we have started the experiment in J-PARC to measure the displacement cross section between 0.4 and 3 GeV. As a preliminary result, the displacement cross-section of copper was successfully obtained for 3-GeV proton. The present results showed that the widely utilized Norgertt-Robinson-Torrens (NRT) model overestimates the cross section about 3 times, as suggested by the previous experiment in the lower energy region. It is also found that the calculation with a recently proposed athermal recombination-corrected (arc) model by Nordlund et al. shows remarkably good agreement with the present data.

Primary author: Dr MEIGO, Shin-ichiro (J-PARC/JAEA)

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Presenter: Dr MEIGO, Shin-ichiro (J-PARC/JAEA)

Session Classification: 4th Oral session

Contribution ID: **21** Type: **Oral presentation**

Microstructural Characterisation of Four Grades of Fine Grain Graphite over Multiple Length-scales

Monday, 9 December 2019 14:50 (25 minutes)

Abstract

`High power particle production targets are key for current and future generation accelerator dr`

`In collaboration with U.S. Fermi National Accelerator Laboratory under international RaDIATE p`

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[2]. Kelly B, Burchell T. Structure-related property changes in polycrystalline graphite under neutron irradiation. Carbon. 1994;32(3):499–505.

[3]. Brocklehurst J, Kelly B. The dimensional changes of highly-oriented pyrolytic graphite irradiated with fast neutrons at 430 C and 600 C. Carbon. 1993;31(1):179–183.

[4]. Krishna R, Jones AN, McDermott L, Marsden BJ. Neutron irradiation damage of nuclear graphite studied by high-resolution transmission electron microscopy and Raman spectroscopy. Journal of Nuclear Materials. 2015; 467:557 –565.

[5] Liu D, Gludovatz B, S Barnard H, Kuball M, Robert O R. Damage tolerance of nuclear graphite at elevated temperatures. Nature Communications. 2017 6;8.

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Session Classification: 2nd Oral session

Contribution ID: **22** Type: **Oral presentation**

PRESENT STATUS OF DEVELOPMENT FOR TUNGSTEN ALLOY, TFGR W-1.1%TiC, AS ADVANCED TARGET MATERIAL

Wednesday, 11 December 2019 09:25 (25 minutes)

J-PARC (Japan Proton Accelerator Research Complex) consists of a series of world-class proton accelerators and the experimental facilities that make use of the high-intensity proton beams. Recently, higher intense proton beams are requested due to requirement of further physics research. However, the upgrade of the intensity is dominated by the target technologies.
Tungsten (W) is a principal candidate as proton-accelerator target material because of its high density (19.3 g/cm3) and extremely high melting point (3420°C). Actually, a W target is considered to be used in the upcoming projects such as COMET Phase 2 and MLF 2nd Target Station at J-PARC, Mu2e at Fermilab, SNS 2nd Target Station at ORNL, and neutron target at ESS. However, W is known to exhibit significant embrittlement by recrystallization (recrystallization embrittlement) and by irradiation (irradiation embrittlement). Extensive efforts have been made to develop embrittlement tolerant W materials and TFGR (Toughened, Fine Grained, Recrystallized) W-1.1%TiC has been considered as a realized solution to the embrittlement problems. TFGR W-1.1%TiC exhibits grain boundary reinforced nanostructures containing a high density of effective sinks for irradiation-induced point defects, a DBTT (Ductile-to-Brittle Transition Temperature) down to around RT and enhanced resistances against surface damages by thermal shock/fatigue in the recrystallized state. We initiated to fabricate TFGR W-1.1%TiC and/or more improved W materials with sufficient dimensions for the target applications and investigate their feasibility as the target materials in 2016. While applying for budget acquisition to embody and integrate the W alloy fabrication processes, we are in the stage of producing TFGR W-1.1%TiC samples successfully with the size of about 20 mm in diameter and about 3 mm in thickness. Gradually, the performance of the TFGR-W1.1%TiC has been upgraded. The presentation will address our methodology to surmount the shortcomings of the conventional W materials and focus on prospective outcomes from the applications of the TFGR W alloys to proton-accelerator targets.
This program has been supported by KEK-MTC collaboration since 2016, the Joint Usage/Research Center PRIUS, Ehime University, Japan, and JSPS KAKENHI Grant Number19H01913.

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Presenter: Mr MAKIMURA, Shunsuke (KEK, J-PARC)

Session Classification: 6th Oral Session

Contribution ID: **24** Type: **Oral presentation**

Characterization of radiation damage effects in high-energy neutrino target graphite using low-energy ion irradiation

Tuesday, 10 December 2019 12:20 (25 minutes)

Neutrino targets are constantly irradiated by high-energy protons to produce secondary particles that decay into neutrinos. Over time, radiation damage effects the macroscopic physical and structural properties of target materials and result in shortened operation lifetimes. The resulting decrease in the material's thermal shock resistance combined with greater embrittlement results in an increased chance of component failure. The DUNE experiment at LBNF calls for a 2+MW, 60-120 GeV pulsed proton beam which is expected to push targets and other beamline components to new levels of damage; therefore, it is vital to predict what macroscopic effects may result. However, directly studying material properties of targets exposed to high-energy proton accelerators is frequently unrealistic. This is due to both the high residual dose rate of samples and the high user costs associated with these facilities. Additionally, high-energy proton irradiations have the disadvantage of a very slow number of displacements per atom (DPA) accumulation rate, for instance samples irradiated at the Brookhaven Linac Isotope Producer (BLIP) accumulated just 0.11 DPA during a 55 day irradiation. This results in an extremely long time to reach the total accumulation levels expected for the DUNE experiment. A plan for determining equivalent low-energy ion irradiation conditions that will induce the same level of damage observed in previously failed targets and expected in future higher intensity targets has been initiated at FNAL. The specific advantages of ion irradiation over high-energy protons include high DPA/s resulting in short irradiation sessions, low operating costs, and no risk of sample activation. After graphite samples have been irradiated by low-energy ions, the post-irradiation-examination (PIE) results will then be compared to previous results obtained by members of the RaDIATE collaboration. This includes PIE work done on a failed NT-02 graphite target fin and on samples from high-energy irradiations performed at BLIP. The incident ions will be helium (He++) which has been chosen due to its combination of high damage rate and significant penetration depth as compared to protons/electrons and high-Z ions respectively. Irradiation by He++ ions at 5MeV is predicted to reach 1 DPA near the surface in only ≈30hrs allowing for much more rapid irradiation cycles resulting in more possible iterations of the experiment. PIE work on the irradiated graphite will focus on: DPA, swelling and lattice spacing changes, changes in mechanical stress, strain and embrittlement, and thermal properties. The proposed irradiation will be performed at the Michigan Ion Beam Laboratory (MIBL) at the University of Michigan utilizing the 1.7MV "Maize"Tandem particle accelerator and costing roughly $100/hr. For future experiments helium ion implantation can also be performed at the same facility using a dedicated low-energy implanter allowing for simultaneous damage inducement and implantation.

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Presenter: Mr BURLEIGH, Abraham (Illinois Institute of Technology, Fermi National Accelerator Laboratory)

Session Classification: 5th oral session

Contribution ID: **25** Type: **Oral presentation**

BLIP 2020 Quality Assurance Trial Irradiation

Monday, 9 December 2019 16:10 (25 minutes)

The RaDIATE collaboration recently completed a two-phase material irradiation experiment at the Brookhaven Linac Isotope Producer facility at Brookhaven National Laboratory. Various materials of different grades were encapsulated in stainless steel capsules and bombarded with 181 MeV protons for a period of up to eight weeks. However, upon completion of the irradiation campaign, three out of nine capsules were observed to have been breached at the weld line, thus compromising the enclosed material specimens and irradiation parameters. Potential contributing factors to the capsule failures have been identified and are currently under investigation. Computational Fluid Dynamics (CFD) simulations are under way to examine flow characteristics around the capsules to determine whether the capsules overheated due to inadequate cooling. Thermo-mechanical Finite Element Analysis (FEA) of the capsules to explore whether beam offsets could have increased the heat deposition and stresses near the weld line is also in progress. Furthermore, improved weld designs and welding procedures are being developed to ensure a more robust capsule design. This talk will cover the ongoing efforts to better design and perform future long-term irradiation campaigns at BLIP, as well as plans to execute a quality assurance trial irradiation at the facility next year.

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Presenter: Dr AMMIGAN, Kavin (Fermilab)

Session Classification: 3rd Oral Session

Contribution ID: **26** Type: **Oral presentation**

Lifetime Assessment of Beam Intercepting Devices and Moderators at the ESS Target Station during Initial Operations Phase

Monday, 9 December 2019 11:25 (25 minutes)

The ESS Target Station is designed to convert the 2 GeV protons to a high flux of low energy neutrons for scientific research, at 5 MW beam power. It will start receiving proton beam from the linac for neutron production in 2022. Upon commissioning "beam-on-target,"the linac will deliver protons at 571 MeV, which is lower than the nominal value 2 GeV. During the initial operations phase after the beam commissioning, the proton energy and beam power will be ramped up continuously towards 1.3 GeV and 3 MW, with sequential commissioning of super conducting cryomodules during long shut down periods. During neutron production, the spallation target, proton beam window, multi-wire beam profile monitor and moderators are exposed to intense flux of primary and secondary particles, suffering from radiation induced structural degradation. The service lifetimes of these components are limited mainly by the displacement damage, helium production rate, and solid transmutations, where the extent of the radiation damage depends on the kinetic energy and particle density of the impinging protons. To secure availability and reliability of the neutron production during this ramp-up phase, the proton energy dependent radiation damage rates in the core target components have to be assessed and the dose-limited lifetime be defined for the timely maintenance of the affected systems. In this talk, we present the lifetime criteria of core functional components in ESS target environments, during the proton energy ramp-up phase. Finally, we propose a set of proton beam parameters that have to be monitored, to plan the maintenance and replacement of the devices affected by radiation damage.

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Presenter: Dr LEE, Yong Joong (ESS)

Session Classification: 1st Oral Session

Contribution ID: **27** Type: **Oral presentation**

Radiation induced effects in ISOL targets

Monday, 9 December 2019 12:15 (25 minutes)

The Isotope Separation On Line (ISOL) method is adopted in several accelerator facilities around the world in order to produce a number of isotopes of interest for a variety of branches of science. At the core of ISOL facilities is a target and ion source assembly which has to withstand extreme temperature conditions and constant particle irradiation, which are both playing a role in the material performance, evolution and degradation of the central components of an ISOL facility infrastructure.

At TRIUMF, the ISAC facility currently delivers a 500 MeV, 50 kW proton beam to ISOL targets in order to trigger nuclear reactions with the target material and produce radioisotopes. Moreover, the new ARIEL facility will provide a 35 MeV, 100 kW electron beam onto a Bremstrahlung converter to subsequently induce photofission in uranium carbide. Both facilities include areas of high temperature and radiation field conditions on a variety of materials.
This contribution will present some of the phenomena taking place at the core of our facilities, with major focus on the ongoing efforts to understand the transport properties of our target materials and their evolution over 3 weeks of operation, and the electron-to-gamma converter material investigation studies which led to the selection of tantalum-aluminum as the metal pairing to be used as converter material.

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Co-author: Dr GOTTBERG, Alexander (TRIUMF)

Presenter: Mr EGORITI, Luca (TRIUMF)

Session Classification: 1st Oral Session

Contribution ID: **28** Type: **Poster**

Thermal transport in ISOL target materials

Tuesday, 10 December 2019 17:00 (2 hours)

The ISOL method (Isotope Separation On-Line) is used worldwide to advance research in multiple fields, including medicine, astrophysics, materials science, and fundamental particle physics by producing radioactive isotopes. The nuclides of interest are created by directly irradiating a target material with accelerated particles. During operation, the target material must sustain temperatures around 2000℃ while withstanding continuous thermal loads from interactions with the incident beam. The thermal limits of the target material restrict operation and target lifetime. Thermal properties are therefore of significant interest in target materials development.

In this work, the thermal challenges facing ISOL target materials are discussed. The mechanisms of heat transport through target materials are studied and an off-line method is developed for studying target material thermal transport properties. The optimization of target material microstructures to enhance thermal transport is briefly discussed.

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Presenter: Ms AU, Mia (TRIUMF)

Session Classification: Poster session

Contribution ID: **29** Type: **Poster**

Procedure for the SEM analysis of irradiated target material.

Tuesday, 10 December 2019 17:00 (2 hours)

For the production of radioactive ion beams with the ISOL method, a target material is irradiated with a high energy driver beam that induces nuclear reactions and produces isotopes. This process consequently leads to the deterioration of the target material.
The characterization of post irradiated target materials provides information about the level of sintering the target material suffers during irradiation. Systematically observing the same type of material submitted to different irradiation conditions will allow the development of materials with greater endurance.
In contrast with other laboratories were the scanning electron microscope (SEM) is in their shielded nuclear radiation containment chambers, in TRIUMF, the SEM is in a separated room. At TRIUMF we observe different target materials previous irradiation with the in house SEM, therefore to use the same SEM to analyze pos irradiated target material it is crucial to guaranty the safety of not only the personnel during the analysis of the irradiated target materials but also the safety of the already established SEM users. That is why a procedure for the analysis of target materials is being developed.
The procedure for the analysis of the material includes the retrieval of the irradiated target material, its transportation from the shielded nuclear radiation containment chambers to the SEM room, and it also comprehends the installation of the sample in the SEM. Additionally, the procedure covers the disposing of the sample and the safety measurements in case of contamination.
Implementing this procedure as part of the target quality control will provide the baseline data for the synthesis of tailored target materials with enhanced isotope diffusion.

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Session Classification: Poster session

Contribution ID: **30** Type: **Poster**

High voltage breakdown studies under the influence of radiation fields

Tuesday, 10 December 2019 17:00 (2 hours)

The ARIEL facility at TRIUMF will add two new state-of-the-art target stations to produce radioactive ion beams using the Isotope Separation On-Line (ISOL) method. In the ISOL method, a driver beam impinges a target material creating radionuclides that are ionized and extracted with a high electric field. The driver beam and target interaction cause radiation fields of around 10^9 Gy/h that in turn affect the breakdown strength of the gas used for cooling the target station. To guarantee reliable operation, it is mandatory to assess the effect of such radiation levels on the gas breakdown strength. For this, a spark gap has been employed and a clear decrease is observed at low radiation levels. More experiments are envisioned to map the breakdown strength at levels similar to the ones expected online.

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Presenter: Mr MALDONADO MILLAN, Fernando Alejandro (UVIC/TRIUMF)

Session Classification: Poster session

Contribution ID: **31** Type: **Poster**

Macroscopic and microscopic post-irradiation characterization and analysis capabilities at BNL

Tuesday, 10 December 2019 17:00 (2 hours)

The array of post-radiation capabilities at BNL that link campaigns at its irradiation facilities (200 MeV Linac/BLIP and Tandem van de Graaff) with characterization of the effects in both the microstructure and the macrostructure will be presented. Emphasis will be given to the recently achieved
Brookhaven, due to decades-long continuous operation of medical isotope production augmented with proton and spallation-based fast neutron irradiation studies of particle accelerator and nuclear materials, has maintained the handling and characterization capabilities of highly radioactive materials. Specifically, capabilities within the BNL hot cell laboratory, essential for nuclear material studies, include photon spectra and isotopic analysis using high-sensitivity detectors, radioactivity measurements and high precision weight loss or gain assessment.
Macroscopic post-irradiation characterization within the hot cell laboratory is supported by the following capabilities:
• Mechanical post-irradiation behavior consisting of tension-compression, 3-point and 4-point bending analysis.
• Evaluation of thermal expansion including thermal annealing of irradiated samples
• Thermal conductivity based on 4-point electrical resistivity measurements
• Magnetic Whole probe
• Ultrasonic measurements of irradiation-induced degradation of material modulus

Microscopic Analyses: For microscopic, post-irradiation characterization of heavily irradiated materials relied over the years on the high energy X-rays of its synchrotrons, NSLS (now decommissioned) and now NSLS-II (world's brightest light source). High energy X-rays at the BNL synchrotrons, and in particular the XPD (and future HEX that is currently under construction) beamlines at NSLS II, offer a path in establishing this important connection between micro-scale effects and physical properties of novel materials exposed to high radiation fluxes. Multiple X-ray techniques –XRD, EDXRD, SAXRD, XAS, X-ray Tomography (XPD, HEX), X-ray Imaging (HEX beamline currently under construction) have been commissioned and utilized extensively to-date to micro-characterize proton and fast neutron irradiated materials for several accelerator and reactor initiatives. Such capabilities include in-situ complex state of stress and various environments:
• Multi-directional complex stress (pure bending, tension, compression, twisting)
• Stress intensity/fracture toughness facilitated by high energy X-ray micro-beams recently achieved at NSLS II XPD beam
• Creep (experimental set-up is under preparation/commissioning at NSLS-II
• High-temperature effects, irradiation annealing with simultaneous characterization
• Corrosive environments
• X-ray tomography of irradiated materials (upcoming commissioning experiment)

Characterization of the microstructure under extreme temperatures (currently on unirradiated materials) is provided by Center of Functional Nanomaterials (CFN) for electron microscopy (TEM, SEM, EDS), thermal analysis (DSC, TGA). In coordination with CFN, plans are being evaluated to enhance the hot cell laboratory (Target Processing Laboratory) with electron microscopy which will, in combination with the micro-characterization techniques at NSLS-II based on high-energy X-rays provide a complete PIE.

Characterization of select, relevant irradiated materials of interest to the particle accelerator and reactor materials communities will be presented.

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Presenter: Dr KIM, Dohyun (Brookhaven National Laboratory)

Session Classification: Poster session

Contribution ID: **32** Type: **Oral presentation**

Material irradiation and investigation capabilities at ISAC-TRIUMF

Thursday, 12 December 2019 12:20 (25 minutes)

ISAC-TRIUMF operates targets under proton irradiation in the high-power regime of 50 kW to produce radioactive isotope beams using the ISOL method. During irradiation, high-energy protons passing through the ISOL target are available for studies of radiation damage in materials. Additionally, the existing hot-cell capabilities for the routine maintenance of target components allow immediate in-situ material characterization of highly activated samples as well as preparation of microscopic samples with dose rates that allow hands on material investigation. Future direct proton irradiations aim to qualify materials for use in components for accelerator, fusion and fission applications as well as to investigate the radiation resistance of novel promising materials. Notably, nanostructured materials have undergone increasing interest in the nuclear industry due to an increased number of structural boundaries (grain boundaries, layers, precipitates) resulting in an enhanced radiation resistance by point-defect recombination. Although such materials have had traditionally the drawbacks of reduced ductility and poor microstructural stability, recent stabilization and grain structuring techniques might have unlocked their use as high performing materials under radiation fields.
The ongoing development of irradiation capabilities at ISAC-TRIUMF will be presented with the achievable proton and neutron fluxes, DPA rates and helium production.

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Co-author: Dr GOTTBERG, Alexander (TRIUMF)

Presenter: Mr BOIX PAMIES, Ferran (TRIUMF)

Session Classification: 9th Oral Session

Contribution ID: **33** Type: **Oral presentation**

Post-Irradiation Examination of Proton-Irradiated Beryllium

Thursday, 12 December 2019 11:55 (25 minutes)

Beryllium is currently of interest for use in beam-intercepting devices. As such, samples of multiple beryllium grades (PF-60, S-65F, S-200F, S-200FH, and ultra-high purity) were irradiated in the RaDIATE BLIP irradiation and subsequently shipped to PNNL for post irradiation examination. To date, dimensional measurements of irradiated samples and tensile tests of irradiated and unirradiated samples have been completed on two grades (PF-60 and S-65F). The tensile tests were completed at two different temperatures (room temperature and 300℃) and were used to determine ultimate tensile strength, uniform elongation, total elongation, and yield strength. Currently, preparations are being made for TEM examinations of these samples. Additionally, options for correlating EBSD to AFM thermal scans are being explored.

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Presenter: Dr CASELLA, Andy (PNNL)

Session Classification: 9th Oral Session

Contribution ID: **34** Type: **Oral presentation**

Exploration of High-Entropy Alloys for Irradiation Applications

Wednesday, 11 December 2019 09:50 (25 minutes)

High-entropy alloys (HEAs) have become the focus of research in many fields often exhibiting unique thermal, mechanical, chemical, and electrical properties. In addition to this, several HEAs have been shown, in both modeling and experiments, to exhibit enhanced resistance to radiation damage. While several theories have been proposed to explain this behavior, often owing to the chemical complexity and diffusion properties of HEAs, such theories require substantial experimental study over a range of HEA composition to develop a fundamental understanding. To accelerate the development of HEAs for irradiation applications, among others, researchers at the University of Wisconsin-Madison are employing high-throughput (HTP) techniques for synthesizing, testing, and characterizing arrays of different HEA compositions. These HTP techniques are then coupled with both traditional and in situ irradiation experiments and characterization methods, which add depth to the HEA development process and further the ability to link atomic-scale features with macroscopic properties.

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Presenter: MOOREHEAD, Michael (University of Wisconsin-Madison)

Session Classification: 6th Oral Session

Contribution ID: **35** Type: **Poster**

Rotating proton beam onto TRIUMF ISAC targets

Tuesday, 10 December 2019 17:00 (2 hours)

Two AC magnets were installed to scan the 500 MeV proton beam in a circular pattern on the TRIUMF ISAC target.
Rotating a proton beam of reduced width on the ISAC targets contributed to a more homogeneous temperature distribution across the target and enabled the operation at a higher average temperature. Narrower beam rotation resulted in higher local power density, which enhanced the diffusions of isotopes; and an average power distributed over a larger surface area, resulted in less steep temperature gradients and enhanced the effusion of isotopes. Having the power deposition closer to the target walls, improved the heat dissipation and allowed for higher beam currents.
Online tests have shown that we can increase the longevity of the target and the radioactive ion beams (RIB) yields while maintaining the same maximum temperature.

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Presenter: LAXDAL, Aurelia (TRIUMF)

Session Classification: Poster session

Contribution ID: **36** Type: **Poster**

Recirculating electron beam photo-converter for rare isotope production

Tuesday, 10 December 2019 17:00 (2 hours)

The TRIUMF 30-75 MeV electron linac has the potential to provide cw beams of up to 0.5 MW to the ARIEL photo-fission facility for rare isotope science. Due to the cooling requirements, the use of a thick Bremsstrahlung target for electron to photon conversion is a difficult technical challenge in this intensity regime. Here, we present a different concept in which electrons are injected into a small storage ring where they make multiple passes through a thin internal photo-conversion target, exploiting an optimized energy range for production of gamma rays used for photonuclear reactions inside of a secondary target. The remaining energy is then deposited in a central core absorber, which can be independently cooled. We discuss design requirements and propose a set of design parameters for the Fixed Field Alternating Gradient (FFAG) ring. Using particle simulation models, we estimate various beam properties, and electron loss control.

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Presenter: LAXDAL, Aurelia (TRIUMF)

Session Classification: Poster session

Contribution ID: **38** Type: **Oral presentation**

Developing ultra-strong and ultra-tough metallic materials with gradient nano-grained structures.

Wednesday, 11 December 2019 09:00 (25 minutes)

Controlling microstructural features in crystalline materials is one of the keys to achieving materials that combine mutually exclusive properties, such as strength and toughness. In this presentation, I will show the efforts made in my group to understand the generation of gradient nano-grained (GNG) structures in metallic materials under several manufacturing methods, including the impact of particles at high-velocities, and surface mechanical treatments. Specifically, I will show what are the main ingredients needed to achieve GNG in the high-velocity impact of particles, obtained directly from atomistic simulations. These results are compared with experimental works carried out in using laser impact techniques of Silver (Ag) microcubes. Our results suggest that the GNG transformation happens if three factors are present during the impact, i) large shock-wave stress, ii) at least eight slip systems are available to accommodate plastic deformation and iii) the kinetic energy is large enough to produce severe plastic deformation. Possible application of GNG materials under radiation environment will be also discussed in the presentation.

Primary author: Prof. PONGA, Mauricio (The University of British Columbia)

Presenter: Prof. PONGA, Mauricio (The University of British Columbia)

Session Classification: 6th Oral Session

Contribution ID: **39** Type: **Oral presentation**

TRIUMF Irradiation Capabilities

Monday, 9 December 2019 15:45 (25 minutes)

TRIUMF had been operating high intensity proton beams at >100 μA and 480-500 MeV over 40 years for producing pion, muon, neutron, radioactive ion beams and medical isotopes. During this time many radiation damage effects have been observed and measured. The highest fluences are on the meson production targets at about 1023 protons/cm2per year. TRIUMF has several locations for proton irradiation studies and these will be described along with a few examples of radiation damage measurements.

Primary author: Dr BLACKMORE, Ewart (TRIUMF)

Presenter: Dr BLACKMORE, Ewart (TRIUMF)

Session Classification: 3rd Oral Session

Contribution ID: **40** Type: **not specified**

Welcome to TRIUMF

Monday, 9 December 2019 09:00 (10 minutes)

Presenter: Dr GOTTBERG, Alexander (TRIUMF)

Session Classification: Opening Plenary

Contribution ID: **41** Type: **not specified**

Associate Director's Welcome

Monday, 9 December 2019 09:10 (5 minutes)

Presenter: Dr KESTER, Oliver (TRIUMF)

Session Classification: Opening Plenary

Contribution ID: **42** Type: **not specified**

Meeting objectives and overview

Presenter: Mr HURH, Patrick (Fermi National Accelerator Laboratory)

Contribution ID: **43** Type: **Oral presentation**

Overview of RaDIATE Activities and Meeting Objectives

Monday, 9 December 2019 09:15 (30 minutes)

Presenter: Mr HURH, Patrick (Fermi National Accelerator Laboratory)

Session Classification: Opening Plenary

Contribution ID: **44** Type: **not specified**

How to make a Radioactive Ion Beam - An Alchemist's Dream

Monday, 9 December 2019 09:45 (45 minutes)

The family of Radioactive Ion Beam (RIB) facilities is growing and gaining capabilities with new projects in preparation at RISP (Korea), INFN-LNL (SPES), GSI (FAIR) and expanding facilities at ISAC (ARIEL), NSCL (FRIB), ISOLDE (HIE-ISOLDE and EPIC), RIKEN (RIBF), ANL (Caribu) and others. The programs are based on the ISOL or fragmentation production techniques with added capabilities of gas-stopping and reacceleration for the fragment approach and the fragmentation of reaccelerated RIBs produced using the ISOL technique. Physics programs are\ broad with increasing interest in the development of theranostic ions for medical applications. This talk will give an overview of the global progress in developments critical ingredient for making a radioactive ion beam.

Presenter: Dr GOTTBERG, Alexander (TRIUMF)

Session Classification: Opening Plenary

Contribution ID: **45** Type: **not specified**

Ideal Accelerator Target Irradiation Facility

Monday, 9 December 2019 16:35 (25 minutes)

Presenter: Mr HURH, Patrick (Fermi National Accelerator Laboratory)

Session Classification: 3rd Oral Session

Contribution ID: **46** Type: **not specified**

Status of Ion Beam Irradiation at HIT Facility

Tuesday, 10 December 2019 11:30 (25 minutes)

An optical transmission radiation (OTR) foil as beam monitor, which is Ti-15V-3Cr-3Al-3Sn alloy with 0.05 mm in thickness, used in the J-PARC neutrino facility was examined for the irradiation damage analysis in the Pacific Northwest National Laboratory under the RaDIATE collaboration. The foil was irradiated by 30 GeV proton beam with 1.4x10^20 POT. The foil microstructures of β-phase Ti-15-3-3-3 alloy had very high densities of nano size clusters of omega phase and α" phases before the irradiation, and these phases were relatively stable after the irradiation. It was also found to be very low density of defect clusters formed by irradiation about 0.06 dpa. The result can suggest that Ti-15-3-3-3 alloy may have a high resistance for radiation damage. The correlations of radiation hardening measurement method from cm-scale to nano-scale can be given by tensile tests, Vickers hardness, and nano-indentation tests. From the data of tensile test and Vickers hardness test, it can be evaluated to be σy⍰3 Hv, and from Vickers hardness test and nano-hardness test, it can be evaluated to be Hv⍰60×Hm. Low energy ion irradiations such as HIT (High Fluence Irradiation Facility of The University of Tokyo) ion experiments are very useful in the evaluation of high DPA irradiation hardening behavior. The main objectives of this study in the HIT ion beam experiments are (1) to support for the evaluation and analysis of radiation damage induced by high energy proton irradiations, (2) to obtain the estimation of irradiation hardening behaviors in high DPA and DPA dependency of the materials, and (3) to evaluate the materials selection for higher radiation damage resistance. In the tandetron accelerator of HIT facility in the University of Tokyo, Fe^2+ ions with an energy of 2.8 MeV were irradiated to specimens under a displacement damage rate of about 8.4x10^-4 dpa/sec to 1 dpa, 5 dpa, and 10 dpa. The specimens of Ti-15-3-3-3 (metastable β-alloy, solution treatment, not aged (ST)), Ti-15-3-3-3 (metastable β-alloy, solution treatment and aged (STA)), Ti-6V-4Al with α+β phases annealed (A), Ti-64 with α+β phases heat-treated with STA (WQ+Aging), and TFGR (Toughened Fine-Grained Recrystallized) tungsten were used for the experiments. After the irradiation, the nano hardness was examined by Shimazu- DUH-211S type nano indentation testing. As preliminary results, nano-hardness data of Ti-64 A, Ti-15-3-3-3 ST, and Ti-15-3-3-3 STA irradiated to 10 dpa at RT were obtained. The radiation hardening of these Ti-15-3-3-3 alloys were smaller than Ti-64 alloy. Especially, Ti-15-3-3-3 ST was hardly increased by the irradiation. DPA nano-hardness dependence from 1 to 10 dpa will be measured, and the correlation between the BLIP data and the HIT data is under examining. Further experiments and these data analysis of HIT experiments will be performed in 2020.

Presenter: Dr WAKAI, Eiichi

Session Classification: 5th oral session

Contribution ID: **47** Type: **not specified**

A review of mechanical testing methods across multiple scales

Monday, 9 December 2019 14:00 (25 minutes)

Presenter: Dr EFTINK, Benjamin (LANL)

Session Classification: 2nd Oral session

Contribution ID: **48** Type: **Poster**

High Emissivity Micro-machining for Increased Emissivity of Tantalum ISOL Target Containers

Tuesday, 10 December 2019 17:00 (2 hours)

TRIUMF's Advanced Rare IsotopE Laboratory (ARIEL) requires a new design of an ISOL target container that approaches an emissivity (ε) of 1, as is achieved at ISAC via cooling fins [1]. ARIEL's new target geometry precludes the use of cooling fins as a viable option for heat dissipation, leading to exploration of other high-emissivity options. Small-scale (μm) surface modification is considered as a way to increase the emissivity [2,3,4]. Simulations were constructed using COMSOL Multiphysics to mimic basic reflectance measurement results from literature; the same model was then used to simulate tantalum micro-geometry surface structures and report the average reflectance. Geometries were found that increased the emissivity by greater than $\Delta\varepsilon = 0.5$ in a select wavelength band. Test pieces have been designed and will be used to validate the results of the simulations as well as explore the survival of the structure at $\approx$ 2500 K.

Primary author: Ms DONALDSON, Cassidy (TRIUMF)

Co-authors: Mr CARBO, Alexander (TRIUMF); Dr GOTTBERG, Alexander (TRIUMF); Dr BABCOCK, Carla (TRIUMF); Mr MALDONADO MILLAN, Fernando Alejandro (UVIC/TRIUMF); Mr BROWNELL, Mathew (TRIUMF); DAY GOODACRE, Tom (TRIUMF)

Presenter: Ms DONALDSON, Cassidy (TRIUMF)

Session Classification: Poster session

Contribution ID: **49** Type: **Poster**

LightHouse Isotopes: Challenges in the target environment of a 3 MW electron accelerator

Tuesday, 10 December 2019 17:00 (2 hours)

The broad applicability of the gamma-decay of Tc-99m for diagnostic imaging makes it the most widely used medical isotope with forty million patients each year. Due to its short half-life of 6 h, it is produced directly in the hospitals utilizing the decay of Mo-99 to Tc-99m with a half-life of 66 hours. The world-wide demand of Mo-99 is currently provided by neutron-bombardment of highly purified U-235 in a few aging reactors. The bombardment of Mo-100 with high-energy electrons can also produce the desired Mo-99 in a much cleaner way that does not require a fission reactor and enriched U-235. In order to reach Mo-99 concentrations that are sufficient, however, the electron beam intensity has to be very high (40 mA at 75 MeV in the LightHouse Isotopes concept). Here we will discuss some of the challenges that result from the associated high heat load (3 MW energy input) and damage rates (~ 1 dpa/day) for the design and operation of a molybdenum target and its environment. In particular, we focus on the assessment and testing of the degradation of target material and its support structures upon irradiation. The aim is to produce a target chamber that can withstand this hostile environment for prolonged time to reliably supply the world with 'clean'Mo-99.

Primary author: Dr JOBST, Johannes (Demcon Advanced Mechatronics)

Co-authors: Dr BLEEKER, Arno (ASML); Dr OP 'T HOOG, Koen (Demcon Advanced Mechatronics); Dr GUPTA, Kriti (Demcon Advanced Mechatronics); Dr WESSELINK, Rien (Demcon Advanced Mechatronics); Dr PERINETTI, Umberto (Demcon Advanced Mechatronics)

Presenter: Dr JOBST, Johannes (Demcon Advanced Mechatronics)

Session Classification: Poster session

Contribution ID: **50** Type: **Poster**

ARIEL Quick Disconnect Service Tray: Design for High Radiation

Tuesday, 10 December 2019 17:00 (2 hours)

The primary function of the TRIUMF's new Advanced Rare IsotopE Laboratory (ARIEL) is to produce and deliver radioactive ion beams to experiments though two separate target stations. The ARIEL Electron Target East (AETE) station will be used to enable the impinging of an electron driver beam for the production of exotic isotopes and to facilitate their extraction, ionization and acceleration into a radioactive ion beam. The AETE module requires several services to complete this, including power, air, gas, water, sensors and vacuum. However, due to shielding requirements, it is not possible to deliver these services directly to the target module; instead a feedthrough was developed to transport them from the top of the module to a quick-disconnect ground service tray below. This project focuses on the design of the ground service tray & components from the bottom of the feedthrough to the target module.
Theoretical radiation mapping shows an expected does of 1x105Gy/hr and with a 30-year lifecycle gives a design limit of 1.2x1010Gy. This high dose of radiation limits material and component selection and requires that any maintenance be done in a hot-cell. Vacuum Coupling Radiation (VCR) fittings were chosen for between the connection plate and feedthrough as only metal sealing components can be used. Aluminum was chosen for the support structure and busbars for both weight and activation. Any insulators must be either Macor or Aluminium Nitride and transportation of water, air, and gas along the service chase is done through flexible stainless-steel braided hose.
Hot-cell operations prove to be challenging due to the complexity and accessibility of the service tray, and decommissioning of the assembly means that every piece must be accessible and able to fit into a standard 55Gallon drum. Several custom tools have been developed including, pincer extensions (to engage Swagelok fittings) and a pivoting wrench (to meet torque requirements). A lifting mechanism to engage/disengage the service tray is still under development. In the next stage of development, a test stand will be used in a hot-cell to validate tooling and identify new challenges.

Primary author: Mr BROWNELL, Mathew (TRIUMF)

Presenter: Mr BROWNELL, Mathew (TRIUMF)

Session Classification: Poster session

Contribution ID: **51** Type: **Poster**

Reliability Indexing Methods and their Application in Medical Isotope Targetry

Tuesday, 10 December 2019 17:00 (2 hours)

Reliability indexing methods provide a means to combine explicit operational data with structural analysis techniques to better assess the ability of a design to undergo specific loading cases. Load variability can be assessed to add additional limits on the stresses components are able to handle, allowing for a more comprehensive estimate of operational life to be made. In design cases, this methodology can be combined with Kriging methods (Gaussian process regression) to minimize the number of Finite Element simulations required to converge on a given feature of a part.

Primary author: Mr MOSKVEN, Louis (TRIUMF)

Presenter: Mr MOSKVEN, Louis (TRIUMF)

Session Classification: Poster session

Contribution ID: **52** Type: **not specified**

poster 1

Contribution ID: **53** Type: **not specified**

The ARIEL Proton Target West Irradiation Station

Tuesday, 10 December 2019 17:00 (2 hours)

The TRIUMF ARIEL Proton Target West irradiation station will employ a 100 μA, 500 MeV proton beam to irradiate ISOL targets for the production of Radioactive Ion Beams. The APTW will combine the technical developments undertaken for the ARIEL Electron Target East irradiation station, with the developments and operational knowledge built up over the last 20 years of proton target irradiations at the TRIUMF ISAC facility. The design considerations and the current status of the APTW will be presented.

Presenter: DAY GOODACRE, Tom (TRIUMF)

Session Classification: Poster session

Contribution ID: **54** Type: **not specified**

Radiation resistance studies on vacuum seals

Tuesday, 10 December 2019 17:00 (2 hours)

In the pursuit of increased research capacity, TRIUMF is constructing the Advanced Rare Isotope Laboratory (ARIEL), intended to multiply TRIUMF's scientific output by a factor of 2-3. The ARIEL facility will provide two target stations, one driven by a proton beam and the other by an electron beam. The target stations use a modular design which requires actuated, radiation hard, high performance, reliable, and reusable vacuum seals, to interface the beam pipe between modules. TRIUMF has developed a novel solution to this unique challenge, which has been dubbed the Pillow Seal. The Pillow Seal's purpose is to remotely, and reliably, connect vacuum space between removable modules. In addition, the expected dose rates may be as high as 10 MGy/hr within the target stations of ARIEL facility, requiring sealing solutions that do not consist of elastomers or rubbers. Due to the modular design of the target stations, limited space is available for sealing solutions, producing a challenge for the required clamping forces needed for metal seals. An investigation into the radiation hardness of Spring Energized PEEK seals is being conducted to evaluate them as a potential sealing solution.

Presenter: Mr MCEWEN, Sam (TRIUMF)

Session Classification: Poster session

Contribution ID: **55** Type: **not specified**

ISAC Target Ion Source Assembly & Manufacturing

Tuesday, 10 December 2019 17:00 (2 hours)

Presentation of the various ISAC target ion sources used for the production of Radioactive Ion Beams at TRIUMF along with assembly methods, a quick overview of the SIS (Surface Ion Source) , FEBIAD (Forced Electron Beam Induced Discharge), & IG-LIS (Ion Guide Laser Ion Source) target ion sources, historical data and quality checks & parameters.

Presenter: Mr SCHMIDT, Aaron (TRIUMF)

Session Classification: Poster session

Contribution ID: **56** Type: **not specified**

ISAC Target Material Production

Tuesday, 10 December 2019 17:00 (2 hours)

Radioactive Ion Beam demand often centers around specificity and yield. This has made it necessary for TRIUMF to develop methods for the production of an array of Targets using materials that can best tailor the particular beam and yield demand.
An overview of various ISAC target materials, their current processing methods and quality assurance methodology, as well as some historical data, will be presented.

Presenter: Mr ORTIZ ROSALES, Darwin (TRIUMF)

Session Classification: Poster session

Contribution ID: **57** Type: **not specified**

Incorporation of np-SiC into polyacrylonitrile (PAN) using electrospinning

Tuesday, 10 December 2019 17:00 (2 hours)

Since the first discovery of a radioactive elements, expending the chart of nuclide has been essential for the fundamental of nuclear physic research and for many other disciplines including medicine. One common method to produce radioactive ion beams is using the Isotope Separation On-line technique in which target materials are irradiated with proton driver beams. The common materials for isotope production targets are refractory materials which combine short diffusion paths and high temperature resistively needed to promote the release efficiencies. However, the inevitable sintering process has a negative impact on short-lived isotopes due to grain growth and removal of pores, thus reducing the release efficiencies. Fabrication of nanofibrous target materials is a promising way to improve the RIB intensities for such high demand short-lived radioisotopes. Nano-SiC fibres have been successfully developed and are able to be operated at high temperature with the preservation of the nanostructures.

Presenter: Mr WONG, John (TRIUMF)

Session Classification: Poster session

Contribution ID: **58** Type: **not specified**

The ARIEL Symbiotic Target Module (ASTM)

Tuesday, 10 December 2019 17:00 (2 hours)

TRIUMF is currently expanding its capacity for science by developing the Advanced Rare IsotopE Laboratory (ARIEL), an Isotope Separation On-Line (ISOL) facility utilizing 500 MeV proton and up to 50 MeV electron driver beams. The ARIEL Proton Target West (APTW) has been optimized for nuclear spallation reactions –with up to 20% of the proton driver beam being deposited in the ISOL target. Instead of immediately directing the beam to a copper dump, the remaining beam will be used to produce medical isotopes, in particular 225Ac. Thorium targets –comprised of discs weighing up to 1.5 kg total –will be hermetically sealed and irradiated immediately upstream of the APTW beam dump. This irradiation station will be housed within the ARIEL Symbiotic Target Module (ASTM), adhering to the modular design paradigm used in ARIEL. The target will then be rapidly transported via pneumatic transfer system to a hot cell for post processing and packaging. This design effort resulted in the definition of ASTM, including equipment for remote actuation, supply of cooling water to the target, and other infrastructure essential to of the medical isotope production.

Presenter: Mr SMITH, Joshua (TRIUMF)

Session Classification: Poster session

Contribution ID: **59** Type: **not specified**

Cyanate ester insulation for the ARIEL target modules high voltage feedthrough

Tuesday, 10 December 2019 17:00 (2 hours)

Fibre-reinforced cyanate ester resin-based composites have been studied and used for applications in high radiation environments such as electrical insulation for magnet coils. Here we explore the composite's planned use in a unique, large-scale high voltage insulation application; the high voltage feedthrough (HVFT) for the ARIEL target modules. To be discussed are physical properties and characteristics of the composite relevant to the HVFT, in addition to associated technical challenges and risks.

Presenter: SHKURATOFF, Alexander (TRIUMF)

Session Classification: Poster session

Contribution ID: **60** Type: **Oral presentation**

Status of Ion Beam Irradiation at HIT Facility

An optical transmission radiation (OTR) foil as beam monitor, which is Ti-15V-3Cr-3Al-3Sn alloy with 0.05 mm in thickness, used in the J-PARC neutrino facility was examined for the irradiation damage analysis in the Pacific Northwest National Laboratory under the RaDIATE collaboration. The foil was irradiated by 30 GeV proton beam with 1.4x10^20 POT. The foil microstructures of β-phase Ti-15-3-3-3 alloy had very high densities of nano size clusters of omega phase and α”phases before the irradiation, and these phases were relatively stable after the irradiation. It was also found to be very low density of defect clusters formed by irradiation about 0.06 dpa. The result can suggest that Ti-15-3-3-3 alloy may have a high resistance for radiation damage.
The correlations of radiation hardening measurement method from cm-scale to nano-scale can be given by tensile tests, Vickers hardness, and nano-indentation tests. From the data of tensile test and Vickers hardness test, it can be evaluated to be σy⊠3 Hv, and from Vickers hardness test and nano-hardness test, it can be evaluated to be Hv⊠60×Hm. Low energy ion irradiations such as HIT (High Fluence Irradiation Facility of The University of Tokyo) ion experiments are very useful in the evaluation of high DPA irradiation hardening behavior. The main objectives of this study in the HIT ion beam experiments are (1) to support for the evaluation and analysis of radiation damage induced by high energy proton irradiations, (2) to obtain the estimation of irradiation hardening behaviors in high DPA and DPA dependency of the materials, and (3) to evaluate the materials selection for higher radiation damage resistance.
In the tandetron accelerator of HIT facility in the University of Tokyo, Fe^2+ ions with an energy of 2.8 MeV were irradiated to specimens under a displacement damage rate of about 8.4x10^-4 dpa/sec to 1 dpa, 5 dpa, and 10 dpa. The specimens of Ti-15-3-3-3 (metastable β-alloy, solution treatment, not aged (ST)), Ti-15-3-3-3 (metastable β-alloy, solution treatment and aged (STA)), Ti-6V-4Al with α+β phases annealed (A), Ti-64 with α+β phases heat-treated with STA (WQ+Aging), and TFGR (Toughened Fine-Grained Recrystallized) tungsten were used for the experiments. After the irradiation, the nano hardness was examined by Shimazu- DUH-211S type nano indentation testing.
As preliminary results, nano-hardness data of Ti-64 A, Ti-15-3-3-3 ST, and Ti-15-3-3-3 STA irradiated to 10 dpa at RT were obtained. The radiation hardening of these Ti-15-3-3-3 alloys were smaller than Ti-64 alloy. Especially, Ti-15-3-3-3 ST was hardly increased by the irradiation. DPA nano-hardness dependence from 1 to 10 dpa will be measured, and the correlation between the BLIP data and the HIT data is under examining. Further experiments and these data analysis of HIT experiments will be performed in 2020.

Primary author: Dr WAKAI, Eiichi (J-PARC, Japan Atomic Energy Agency)

Co-authors: Prof. ABE, Hiroaki (University of Tokyo); Dr KANO, Sho (University of Tokyo); Mr MAKIMURA, Shunsuke (KEK, J-PARC); ISHIDA, Taku (J-PARC)

Presenter: ISHIDA, Taku (J-PARC)

Contribution ID: **61** Type: **Poster**

NEW ASPECT OF RADIATION DAMAGE BEHAVIOR ON TITANIUM ALLOYS UNDER HIGH-INTENSITY PROTON BEAM EXPOSURE

Titanium alloys are widely utilized as structural materials for aerospace/submarine applications etc., because of their high strength-to-weight ratio, good fatigue property, and good corrosion/erosion resistance, even at elevated temperatures. It also satisfies low-activation requirement as nuclear power materials. If the radiation-damage tolerance is improved, titanium alloys have potential as a structural material for fusion reactor needs, especially for high-temperature components, where iron-based materials have difficulties. Under the aegis of the RaDIATE collaboration, Radiation Damage In Accelerator Target Environments, a high-intensity proton beam exposure with 181 MeV energy was conducted at Brookhaven Linac Isotope Producer facility on various material specimens for accelerator target and beam window applications. They include titanium alloys as future target and beam window materials in US and Japan high-intensity proton accelerator facilities (LBNF and J-PARC) aiming at next generation long-baseline neutrino oscillation experiments. The radiation damage level of two titanium capsules reached 0.25 and 0.96 dpa-NRT, respectively, at an irradiation temperature around 120 degree C. Compared to low-energy neutron irradiation, high-energy proton irradiation gives a higher order of hydrogen and helium nucleation, thus can be referred to as high-irradiation regime for the fusion condition.

Tensile tests of the low-dose capsule specimens showed increased hardness and a large decrease in ductility for the dual-phase Ti-6Al-4V Grade-5 and Gr23 extra low interstitial alloys, with the Gr9 Ti-3Al-2.5V still exhibiting uniform elongation of a few % after irradiation. TEM analyses on Ti-6Al-4V indicates clear evidence of a high-density of dislocation loops (<2 nm) in each alpha-phase grain. The beta phase did not contain any visible defects such as loops or black dots, but the diffraction patterns indicated omega phase in an advanced formation stage. The radiation-induced omega-phase production in the beta phase could lead to greater loss of ductility in Ti-6Al-4V alloys in comparison with Ti-3Al-2.5V with less beta-phase. We will continue systematically studying existing titanium alloys in the high dose capsule, including metastable beta phase alloy and other radiation-tolerant candidate grades.

Primary author: ISHIDA, Taku (J-PARC)

Co-authors: Dr CASELLA, Andy (PNNL); Dr SENOR, David (Pacific Northwest National Laboratory); Dr WAKAI, Eiichi (J-PARC, Japan Atomic Energy Agency); Dr AMMIGAN, Kavin (Fermilab); Mr HURH, Patrick (Fermi National Accelerator Laboratory); Mr MAKIMURA, Shunsuke (KEK, J-PARC)

Presenter: ISHIDA, Taku (J-PARC)