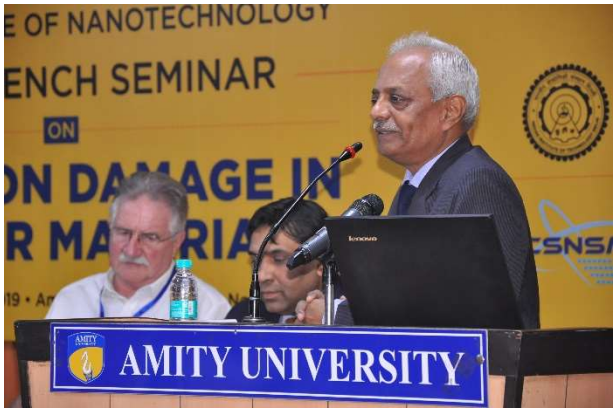
REPORT ON INDO-FRENCH SEMINAR ON "RADIATION DAMAGE IN NUCLEAR MATERIALS"- RADIUM 2019

The Indo French seminar on Radiation Damage in Nuclear Materials – RADIUM 2019 started on 18th Feb 2019 at 9:30 am with the inaugural session in F3 seminar hall of AUUP. Dr. Ranu Nayak and Dr. Richa Krishna invited the dignitaries on the dias. The dignitaries on the dias were Prof. (Dr.) Balvinder Shukla, Vice Chancellor, AUUP, chief guest Dr. Purnima Rupal, Director, IFCPAR/CEFIPRA, Coordinators of the Indo French Seminar, Dr. A. Debelle, Prof. Santanu Ghosh, Prof. D.K. Avasthi and the keynote speaker, Dr. Marcel Toulemonde.

The program started by lighting the lamp and Saraswati Vandana. This was followed by opening remarks by Prof. D.K. Avasthi and Dr. A. Debelle.

Lighting of lamp at RADIUM 2019

Thereafter Vice Chancellor AUUP, Prof. Dr. Balvinder Shukla and Dr. W. Selvamuthy addressed the audience. They emphasized on the need of nuclear energy for the future and mentioned the importance of the topic of the seminar.



Prof. Dr. Balvinder Shukla, Vice Chancellor, AUUP, and Dr. W. Selvamurthy, Director ASTIF addressing the audience

The chief guest of the inaugural session Dr. Purnima Rupal, Director, IFCPAR/CEFIPRA briefed about the various funding opportunities available at CEFIPRA.

Chief Guest Dr. Purnima Rupal talking about CEFIPRA activities

The dignitaries on the dias thereafter formally released the abstract booklet of RADIUM 2019.

Dignitaries releasing the abstract booklet

The keynote address on "Material transformation by Interaction between nuclear, electronic and potential energy deposition" was given by Dr. M. Toulemonde. He talked about the interaction between nuclear, electronic and potential energy deposition induced by an individual ion which were illustrated by five different experiments. Defects created by nuclear energy loss are annealed by electronic energy loss in Fe irradiated by ions in the GeV energy regime, showing a competitive interaction, He was felicitated by the Indian Co-coordinator Prof. Santanu Ghosh from Indian Institute of Technology, Delhi

Keynote address by Dr. M. Toulemonde

The inaugural session was concluded by Vote of Thanks from Prof. Santanu Ghosh. This was followed by tea

Vote of thanks by Prof. S. Ghosh, IIT Delhi

After tea, the first technical session commenced under the session chair, Prof. Ajay Gupta, Director ACSM, AUUP. Prof. Gupta invited Prof. D.K. Avasthi to give an overview of Radiation Damage in Nuclear Materials.

Prof. Avasthi mentioned the role of energetic ions from accelerator in experimental simulation of radiation damage to the structural material in nuclear reactor. Such studies are of a great relevance to the structure materials of Tokamak plasma reactor and electronic ICs used in space satellite. The ion accelerator facilities at IUAC Delhi have ion and energies corresponding to the energies of fission fragment (typically 100 MeV of ions with mass of 100 amu) and low energies representing alpha recoils (typically ranging from tens of keV to hundreds of keV).

Prof. D.K. Avasthi giving an overview of the RADIUM 2019

Normally the operating temperature of nuclear reactor is ~ 1000K. A facility of irradiation at 1000K is implemented at IUAC accelerator beam line of materials science, funded by a BRNS project and research activities focused on the dependence of radiation damage on grain size ranging from nano to micron size.

Participants at RADIUM 2019

The next speaker of the session was Dr. Aurelie Gentils who talked about "Nuclear materials and ion irradiation studies using the JANNuS-Orsay *in situ* dual ion beam TEM". It is a key tool to investigate different phenomenon such as phase transition far from the equilibrium, solid-state nucleation/growth, defects recombination, and ageing of materials used in nuclear or space industries. Based on a 200 kV Tecnai G^2 20 Twin FEI microscope coupled with two ion accelerators, it offers a large choice of ions and energies (range from 10 keV to 6 MeV) and a complete set of complementary analytical equipment (EDX, STEM and GIF) associated with different specimen holders (from LN_2 temperature up to 1000°C). Launched in 2009 as an open facility, known as JANNuS-Orsay, it allows each year 6 to 8 worldwide teams to process *in situ* ion irradiation/implantation TEM experiments.

Dr. A. Gentils being felicitated by Prof. Ajay Gupta

The last speaker of the session was Dr. Francois Willaime who presented “Primary damage in ferritic steels revisited by atomistic simulations”. The amount, nature and spatial distribution of primary displacement damage introduced by energetic particle interactions in crystalline material are essential ingredients for evaluating radiation damage effects. A new complementary displacement production estimate that extends the NRT-dpa by providing more physically realistic descriptions of primary defect creation in materials.

Dr. F. Willaime giving invited talk at RADIUM 2019

In recent times, the unique properties of neutrons have been very widely exploited in the study of condensed matter and they have proven useful in many scientific disciplines. Neutron scattering methods are now firmly established as invaluable complements to x-ray scattering techniques in fields of physics, chemistry, biology, materials science, engineering and many others. An extremely wide range of experimental neutron techniques and instrumentation presently available has facilitated solution of scientific and technological problems of ever-increasing complexity and has relevance in studies of nuclear structural materials.

Dr. V. Siruguri being felicitated by Prof. D.K. Avasthi and Prof. Sunita Rattan

The next talk was given by Dr. Pierre Desgardin on "The study of vacancy type defects formation in tungsten crystal from helium accumulation". At high energies the mean penetration depths are high and defects induced by collision lead to the formation of damages in the substrates. At low ion energies the formation of the characteristic damage features such as blistering, fuzz formation and even flaking takes place.

Dr. P. Desgardin presenting his work

The last talk was given by Dr. Mukesh Ranjan from Institute of Plasma Research, Ahmedabad. He talked about "Investigation of yield behaviour and surface patterns after the bombardment of low energy ion on surfaces". Graphite is used as a plasma facing component (First wall, Divertor) in tokamaks, also used in space applications as electrode materials in plasma torches. In all such applications graphite interacts with plasmas of very low density (10^6 cm^{-3}) to very high density plasma (10^{18} cm^{-3}). The energies of interacting ions varies from 10s of eV to keVs. Properties of graphite degrades (thermal conductivity, thermal expansion coefficient) during erosion and re-deposition of

various impurities from the reactor wall. Various studies are performed for the plasma wall interaction with graphite for both physical and chemical sputtering. All these results only present macroscopic topographies observed under various bombarding conditions and considering a pure system i.e. excluding the effects of impurities. Such structures formed on the graphite surface retain the large amount of tritium, which is undesirable. Since graphite erosion investigation is an important issue, we aim to investigate the role of impurities on the sputtering yield of graphite and its effect on the observed surface topography. Ar ions were used to bombard Highly-*Oriented Pyrolytic Graphite (*HOPG) surface. Fluence and ion energies chosen were relevant to fusion research. Systematically various impurities like Cu, Al and Fe were introduced during ion bombardment and their effect on the sputtering yield and surface topography was reported. Also observed results were explained in the view of Bradly-Harper theory.

Dr. Mukesh Ranjan at RADIUM 2019

This was followed by Poster session. Around 18 posters were presented from different institutes.

Poster session at RADIUM 2019

The second day, 19th feb 2019 commenced under the session chair Dr. V. Siruguri. First talk was given by Dr. M. Toulemonde where he presented the work of Dr. C. Dufour. He basically talked about "Ion track formation by swift heavy ion which has a role in radiation damage in materials". The passage of swift heavy ion in material which results in a transient temperature spike described by thermal spike model. The development of thermal spike model to explain the ion track formation was discussed in details for the explanation of experimental results.

Dr. M. Toulemonde presenting the work of C. Dufour

The next talk was given by Prof. Santanu Ghosh, IIT delhi. He spoke about “Radiation tolerance of Yttria stabilized Zirconia in electronic excitation regime".

Dr. Siruguri felicitating Prof. Santanu Ghosh

Poly-crystalline YSZ pellets were irradiated with 80 MeV Ag^{6+}ions to investigate its radiation tolerance.These ions were chosen to simulate fission fragments. To simulate a nuclear reactor environment, the irradiations were carried out at typical nuclear reactor temperature along-with room temperature over the fluence range 10^{13} – 10^{14} ions/cm^2. Poly-crystalline YSZ was found to be stable against fission fragments with a high temperature environment exhibiting radiation tolerance.

The last talk of the fourth technical session was given by Dr. Isabelle Monnet on “Investigations of structural and chemical order in III-N semiconductors irradiated by swift heavy ions”. The nitride semiconductors, (Al,Ga,In)N, display remarkable optoelectronic properties and can provide valuable application dedicated to space exploration. When used in the outer space, these materials are exposed to high energy particles which can strongly damage these electronic Hence, high energetic ions bombardments are employed to achieve such radiation and to get finally, a better understanding space radiation effects on these kinds of materials.

Dr. I. Monnet at RADIUM 2019

The fifth technical session commenced under the session chair Prof. H.S. Sharma from AINST, AUUP. The first technical talk was given by Dr. B K Panigrahi on "Development of radiation resistance materials using low energy ion beams and materials modeling". Radiation damage to the structural materials due to intense neutron bombardment is one of the major issues in the development of fast rectors.

Prof. Sharma felicitating Dr. Panigrahi

At Indira Gandhi Centre for Atomic Research (IGCAR), a focused program on ion beam simulation of neutron damage of materials towards the development of radiation resistant steels such as D9, D9I and ODS alloys is being pursued. Apart from UHV irradiation facility, a dual beam facility for simultaneous irradiation has been setup for studying synergetic effects. Using these facilities, detailed studies on the temperature and dose dependence of void swelling and the effect of minor alloying elements like Ti, P.

The next talk was by Dr. Aurélien Debelle on "Swift-heavy-ion-beam induced expitaxial crystallization (SHIBIEC) and Synergetic effects between Nuclear (Sn) and Electronic (Se) Energy Losses (SNEEL) phenomena. He talked about the effect of electronic energy deposition (S_e) on defects created by nuclear collisions (S_n) with two approaches: (i) swift heavy ion (SHI) irradiation subsequent to low-energy irradiation and (ii) simultaneous electronic and nuclear energy deposition. We used essentially RBS/C to monitor the disorder level, and we also performed some TEM analyses, along with MD calculations.

Prof. A. Debelle at RADIUM 2019

The 6th technical session commenced under Dr. S.K. Srivastava, IIT Kharagpur as the session chair. First talk was given by Dr. Vinita Grover Gupta where she spoke about "Radiation response in ceramics". The results on correlation of structure and morphology with radiation response on fluorites, disordered fluorites, pyrochlores and their composites were discussed

Dr. Srivastava felicitating Dr. Vinita

The next talk was by Dr. S. Amirthapandian on "Low energy ion irradiation effects in ThO_2, UO_2 and ZrO_2". The ion beam induced effects in these materials (like lattice expansion, bubble formation and phase transformation were discussed in the light of basic ion solid interaction and defect migration.

Dr. S. Pandian presenting his work at INDO FRENCH seminar

The session ended with the talk by Dr. Mukul Gupta from UGC DAE CSR, Indore. He talked about "Thin film growth using ionized physical vapor deposition & study using synchrotron and neutron-based techniques". He presented detailed magnetic depth profile studies of magnetic films using neutron reflectivity technique.

Dr. Mukul Gupta at RADIUM 2019

This was followed by conferring Honorary Professorship to Dr. Aurélien Debelle, Dr. A. Gentils and Dr. Anny Michel. Prof. Dr. Balvinder Shukla felicitated the recipients

Prof. Dr. Balvinder Shukla presenting Honorary Professorship to Dr. Debelle, Dr. Gentils and Dr. Anny Michel

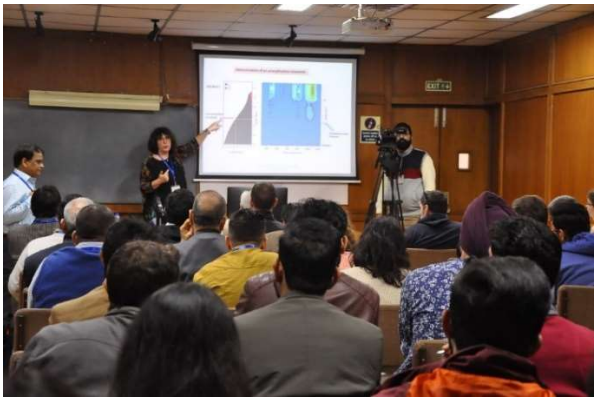
A rigorous panel discussion was followed just after. The discussion commenced with the comments from Dr. W. Selvamurthy, Director ASTIF. The participants of RADIUM 2019 took active part in the discussion. The panelist on the dias were Dr. A. Debelle, Dr. Gentils, Dr. I. Monnet, Dr. Panigrahi, Dr. Selvamurthy and Prof. D.K. Avasthi. The main points discussed in the panel discussion were utilization of complementary facilities by India and France. The outcome of the seminar should be in the form of joint research project and PhD. The JANNuS-Orsay *in situ* dual ion beam TEM **is** unique in the world and its wide utilization can lead to the deep understanding of materials science. Dr. F. Willaime made good suggestions about molecular dynamics simulations**.**

The panelist on the dias and participants at the panel discussion

The final day of RADIUM 2019 started on 20th feb 2019 at Inter University Accelerator Centre with the address of Prof. A.C. Pandey, Director IUAC.

Prof. A.C. Pandey, Director IUAC addressing the audience on 3rd day of RADIUM 2019

The first technical session started under the session chair Dr. Panigrahi. The first speaker was Dr. Moncoffre who spoke about "Structural modifications of boron carbide irradiated by heavy ions". Due to its high capacity to absorb neutrons, boron carbide is a ceramic widely used in the control rods of nuclear reactors to control the power and the safety of nuclear plants. Understanding ageing phenomena of this material submitted to extreme conditions of irradiation and temperature remains a challenge to take up. In that context, ion irradiation was used to simulate the created damage in B_4C at the laboratory scale.



Dr. Moncoffre presenting her work at RADIUM 2019

The next talk was given by Dr. Pawan Kulriya on "Swift heavy ion irradiation induced structural transformation on the pyrochlore". The pyrochlores show immerse applications as nuclear waste forms, and inert fuel matrix for incorporating radionuclides. The *in-situ* X-ray diffraction (XRD) along with micro-Raman spectroscopy analysis on zirconate pyrochlore irradiated at both temperatures were found relatively resistant to irradiation, whereas titanate pyrochlore readily amorphized. The effect of irradiation temperature was prominent only at low-level irradiation and didn't affect the stability of the zirconate under more severe irradiation.

Dr. Panigrahi felicitating Dr. Kulriya

The next session was chaired by Dr. Ambuj Tripathi, IUAC, New Delhi. The first talk of the session was given by Prof. Anny Michel

Dr. Michel at RADIUM 2019

She spoke on "The effect of ion irradiation on sputter-deposited thin films and its importance to stress build-up and relaxation". She spoke about kinetic effects contributing to stress generation and relaxation, low mobility materials, namely Mo and $Mo_{1-x}Si_x$ alloys deposition onto Si substrates. The next speaker was Prof. S. V. S. Nageswara Rao who spoke about "Ion induced phase transitions and structural modifications in hafnium oxide" A detailed study on the swift heavy ion irradiation induced grain fragmentation, grain growth and phase transitions in HfO_2 thin-films was presented. The results are expected to provide useful information for future integrated circuit technology.

Dr. Ambuj Tripathi felicitating Prof. Rao

In a very friendly gesture, the French delegates gathered and appreciated the organizing committee of RADIUM 2019.

French delegates appreciating the organizing team of RADIUM 2019

After lunch, French delegates held an informal session with the students in order to inculcate interest on the topic of nuclear materials. The students also went for the facility visit at IUAC.

The next session commenced under the chairmanship of Prof. G.K. Mehta, former director of IUAC. The speaker was Dr. Prashant Sharma, Institute of Plasma research. He spoke about "Energetic Ion Irradiation to Emulate Damage by Neutron Irradiation in Fusion Reactor". In a tokamak based fusion reactor the D-T fusion reactions produce energetic neutrons (14.1 MeV) and alpha particles (3.5 MeV), which results in radiation damage in the materials surrounding the hot plasma core. This can cause changes in the structural and functional properties, which is an important issue for structural materials like tungsten and its alloys that have been proposed to be used in such reactors. In particular, the 'divertor' is a region where the magnetic field is specially contoured to re-direct the hot 'plasma-flame' to specially designed and actively cooled tiles. These are subjected to a harsh environment of high heat flux, energetic neutrons and charged particles bombardment. As there is no high-energy and high-flux neutron source available (other than the reactor itself), qualification of the material by 'offline' tests is impossible. Hence the ion beam irradiation is being used world-wide to imitate the neutron damage in tungsten. The radiation damage in terms of crystallographic defects generated (Frankel pairs, defect clusters, dislocations and dislocation loops) in material by energetic ions are different from those generated by neutron irradiation in fusion environment due to change in defect kinetics by heat, so it is important to understand the limitations.

The concluding session started with the concluding remarks from Dr. M. Toulemonde, Dr. Panigrahi and finally Prof. Avasthi. They emphasized on the submission of bilateral projects on nuclear materials

and mentioned that RADIUM 2019 would lead to many collaborative ventures between India and France.
Finally, the vote of thanks was given by Dr. Richa Krishna.
This concluded RADIUM 2019