Review Paper

Summary of Accelerator Application Sessions

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Abstract. A short summary of more interesting topics, presentations and results on Accelerator Application sessions is presented in this paper.

1. Introduction

One of the main areas on the International Toping Meeting on Nuclear Research Applications and Utilization of Accelerators was Accelerator Applications for the material tests, radiation damage investigations and industrial applications of accelerators. This topic included 8 oral sessions, where 33 oral presentations have been presented. Supplementing the oral presentations 3 poster sessions have been organized, where 20 new posters have been presented. Each oral presentation should be made as the poster too and these posters have been presented also on the Poster sessions.

Topics of accelerator application sessions included the following parts:

- Simulation of radiation damage and testing of materials for nuclear systems;
- Research and development of applications for advanced materials;
- Different aspects of industrial accelerator applications;
- Interdisciplinary endeavours.

2. Research and development of accelerator applications for advanced materials

Interesting results for the improvement of oxidation protection of TiAl-alloys and Ni-base super alloys at high temperatures by surface modification using F ion Implantation (Fluorine effect) were reported (Zschau, Germany) on this session.Small angle neutron scattering and radiography methods were adopted for the micro structural investigation of SiC/SiCf composite material and the obtained results shown that the population of pores is increased with increasing temperature from 1400 to 1500°C (Tatlisu, Austria). The neutron radiography gave the size distribution of pores but it will be useful to get image using the higher spatial resolution neutron radiography. It is desired to combine this non-destructive inspection with mechanical performance study and also with the method to reduce the number of pores. Neutron scattering and tomography techniques are the complementary methods, which give comparable results in the microstructure range.

The challenging study to get new optical devices and thermoelectric materials having superior characteristics and interesting method for the getting of quantum-dots/nano-dots pseudo-crystal were presented (Ila, USA).The effects of the Si MeV ion beam fluencies on the thermal and electro

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conductivity were reported. This mechanism should be investigated in more detail to get optimal condition for producing in the future the best materials. The effects of irradiation by protons, oxygen ions and fast electrons have been studied in various zirconium based alloys (Tewari, India). Different defects and phases formed by irradiation have been identified here.

The spectroscopic imaging by using pulsed neutron sources was developed (Kiyanagi, Japan). This method is enough fast and allows to achieve texture data during few hours. The Information on material texture obtained by this method is very useful for the material characterization. However, to obtain quantitative data a simulation calculation code that can include all processes of the neutron scattering in the materials is necessary.

The method for characterization and quantification of active ingredients in commercial solid drugs with using of wide spectrum of methodic was developed (Nsouli, Lebanon). The ability of PIXE and PIGe techniques for rapid and accurate quantification of few active ingredients was confirmed. Interesting program for the increasing the quality of drinking water using accelerator mass spectrometry at the Peletron accelerator facility in Mumbai was presented (Kailas, India) on this session.

3. Different Aspects of Industrial Accelerator Applications

The installation for flue gases treatment of electron accelerators (700 KeV) with the power higher than 1 MW has been constructed in Pomorzany (Chmielewski, Poland). EBFGT process can be applied for high sulfur coal, what was demonstrated at Maritza PP pilot plant. It should be remarked here that the reduction of SO_2 (from 1473 appm to 123 appm) and NO_x (from 166 appm to 17 appm) is higher than 90%.

On this session it was discussed (Basfar, Saudi Arabia) too the experience of Saudi Arabia in using electron beam for flue gas treatment at oil fired boiler. High SO_2 and NO_x removal efficiency can be achieved for Arabian heavy oil fired boilers with EBFGT technology. Cost for this technique compares favourably with that of conventional method. It was shown also on this session (Cleland, USA) the advantages of using carbon composite in place of steel in aero and auto industries. The radiation curing using hard X-rays from high energy electrons or directly electron beams can simplify the manufacture of carbon fibre composite vehicle components.

Also it was suggested (Tsvetkova, Bulgaria) to use of ion beam technique for the modification of amorphous SiC properties for varied applications. Employed focussed Ga ions to make pattern on SiC: H films. It was pointed out (Hamm, USA) about the increasing role of small sized accelerators for industrial applications. Huge investments are being made world over for this purpose. It was shown that using the studying of reaction mechanism of MeV ions with different polymers (Ila, USA) it is possible to tailor their properties for varied applications and in medical field in particular.

A few interesting industrial accelerator applications were suggested in different countries. So Kraiem (Tunisia) pointed out to use two gamma irradiation devices with variable energy up to 10 MeV and electron beam with the power up to 5 kW for applications in the fields of agriculture and sterilization processes, including art, biology and environment.

A big Program was suggested (Kim, Korea), which based on high-intensity, high-duty proton accelerator with the current project costs about $100 M. during last 10 years until 2012 year. Areas of applications of this project include nano-science, biological and medical applications, and materials (e.g., semiconductor, ion-cut technology, ion-beam mixing technology, ion beam implanter, BNCT therapy, rare isotope). For future developments there are plans for a spallation neutron source (0.5 MW, 100 to 200 MeV linac, 1 to 2 GeV synchrotron), therapy and medical facility (slow extraction at 450 MeV for medical applications), and heavy-ion beam programs (similar to the Facility for Rare Isotope Beam FRIG project at MSU of USA with a 4 mA cw, 600 MeV linac). Very interesting proton/carbon therapy facility (MedAustron) was proposed (Leeb, Austria) for the construction it in Vienna. This program is oriented on medical radiation physics, radiation biology and experimental physics including applications: high energy proton computerized tomography, radiation damage in high temperature superconductors, dosimetry and single-hit ion microprobe.

4. Simulation of Radiation Damage and Testing of Materials for Nuclear Systems

On this session in the introduction presentation (Dai, Swetzerland) shown very interesting experimental results for radiation damage formation and strong degradation of the physical mechanical properties (hardening and embrittlement) of materials irradiated on the Neutron Spallation Source (SINQ). Comparing with the neutron irradiation in atomic reactors where the density of fast neutrons is very low these irradiation tests have been performed on SINQ at the high neutron energies up to a few hundred MeV (average neutron energy near 1 MeV) and at high generation rate of helium atoms (near 100 appm/dpa). Such irradiation conditions and obtained data are very important especially for the radiation tests of fusion structural materials. The obtained results here indicated that helium plays an important (even dominant at high helium concentrations) role in embrittlement of ferritic/martensitic steels at temperatures below about 400°C. But it should be remarked also that the measurements of irradiation temperature in spallation targets should be improved due to some problems which can occur with over-focused proton beam. For this reason and interpretation of mechanical test results the additional micro structural investigations have to be performed on these irradiated samples. For the better understanding of obtained results here that can be applied to future fusion reactors the comparison of neutron spectra and following numerical calculations of generation rates for point radiation defects and cascades of atomic collisions on SINQ, fusion reactors (ITER, DEMO) and IFMIF source should be done too.

In the other introduction presentation (Voyevodin, Ukraine) using many experimental results on different types of steels, Zr-alloys. It was confirmed that the charged particle irradiations on accelerators (including using two and three beams) can provide a low-cost method for conducting valuable radiation effects research in absence of, or as a precursor to verification experiments in atomic reactors.

On this session new results were presented for the radiation damage – cascades and sub-cascades formation in various materials such as C, V, Be, Cu, Al, W for fusion reactors and other nuclear applications (Ryazanov, Russia). The results are of high interests for predicting defect cluster formation induced by radiation damage under the irradiation by different neutron spectra. It was shown (Demina, Russia) that the effect of high-energy pulses on tungsten in plasma focus device with the high heat loads ($10^7 - 10^{10}$ W/cm^2) resulted in a melting of the irradiated surface layers, erosion of material surface, formation of different types of surface defects and micro cracks. These results have a strong interest for fusion reactor applications. The effect of plasma impact on the erosion of radiation damaged materials was studied too (Ryazanov, Russia). It was shown that the erosion process in radiation damaged materials is accelerated comparing with plasma interaction on non-irradiated materials.

Radiation damage in transistors was studied (King, USA) using irradiations by various ion beams at different energies and follow these results were compared with that after pulsed neutrons. The obtained results show that the Si ion irradiation can well simulate neutron irradiation for such applications. For the future scientific investigations of radiation damage in materials new proposals have been suggested including using the complex of electrostatic accelerators IPPE (Gulevich, Russia) and ITEP heavy ion accelerators (Kulevoy, Russia).

5. Interdisciplinary Endeavours

Many interesting new produced facilities (Los Alamos, California (USA) and Argentina) based on high neutron technologies have been shown on this session. So a series of high-yield neutron generators using the D-D reaction with an axial geometry has developed (Fuller, California, USA) for neutron radiography and spectroscopy, gamma spectroscopy, explosive detection and fast neutron scattering.

Very interesting ideas and results based on a very powerful technique at small accelerator-based neutron sources and following use of neutron transmission for non-destructive studies of crystalline materials that allows measuring qualification of phases, lattice parameters and preferred orientations have been shown in other presentation (Granada, Argentina).

New Positron Emission Tracking (PET) Facility has been produced in South Africa (Buffler) based on the experience in this area at University of Birmingham (UK). This facility allows to make experimental tests of medical imaging based on positron emission tomography (PET) continues to have wide-ranging clinical impact, particularly in cancer diagnosis and management, cardiology and neurology. Very important that PET can be used as a tool for in-situ characterisation and visualization of particulate flow within aggressive industrial environments, such as tumbling mills, powder mixers and flotation cells.

6. Conclusion

Modern accelerators can be used in different countries for many applications including such fields as medical radiation physics, radiation biology and experimental nuclear physics, agriculture, sterilization processes, art and improving of environment.

The main advantage of accelerators in material science is based on the detail studying of main physical mechanisms of radiation resistance in irradiated materials and separately investigations the influence of different types of charged particle irradiations on physical mechanical property changes of these materials. Selection of different particles and energies allows simulation and reaching of factors that can be realized under fission and fusion neutron irradiations at high doses.

During last 10-15 years in many research centers of international scientific community many interesting results related with the investigations of physical phenomena such as radiation swelling and creep, radiation hardening, helium embrittlement that determine a radiation resistance of fission and fusion structural materials have been obtained under neutron and charged particle irradiations. But the detail comparison of these experimental results (temperature and dose dependencies of these physical phenomena, including effects of accumulation of hydrogen and helium atoms in the matrix) under neutron irradiations in fission atomic reactors, neutron spallation sources and charged particle irradiations does not exist on today. For the development of new future technologies and improving simulation experimental tests of radiation resistance of structural materials on charged particle accelerators for fission and fusion reactors such comparison can be very effective and fruitful especially at high irradiation doses. The IAEA can play here one of key roles in the organization of such International Workshop or International Conference: "Comparable investigations of radiation resistance of fission and fusion structural materials under neutron and charged particle irradiations".