Accelerator Applications Summary

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International Topical Meeting on Nuclear Research Applications and Utilization of Accelerators, Vienna, 4-8 May, 2009

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Vienna, 4-8 May, 2009

Accelerator Applications:

- 7 sessions:
- 23 presentations
- 3 poster sessions:
- 54 posters

04.05.09 Accelerator Applications:
AP/INT-01: Y. Dai: The Status of Studies on Structural Materials under High Energy Proton and Neutron Mixed Spectrum (PSI)

- **Present Status:**

  In the last decade, a significant progress on the studies of materials for spallation source applications was achieved through irradiation experiments performed at SINQ and LANSCE targets and related PIE. Microstructure and mechanical properties of different structural materials, especially for ferritic/martensitic steels, have been investigated. The results indicated that helium plays an important (even dominant at high helium concentrations) role in embrittlement encountered at temperatures below about 400° C.
- **Problems, Lessons, Experience, and Recommendations:**

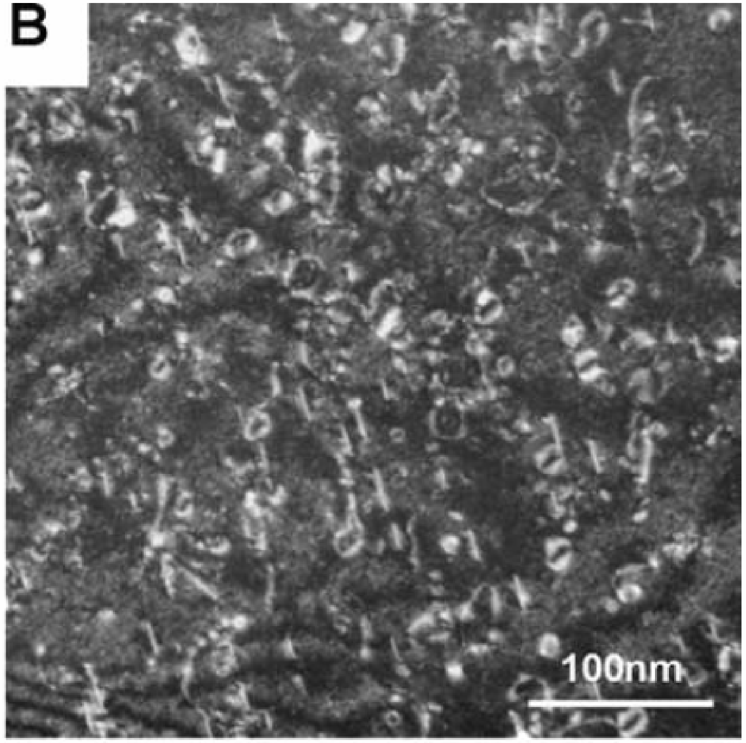
  For irradiation experiments in spallation targets, the irradiation temperature cannot be well controlled due to large variation and beam trips of proton beam. In some cases, high temperature excursions can take place as consequence of over-focused proton beam, which should be avoided as much as possible. In order to understand or interpret results of mechanical tests, microstructural investigations have to be performed.
- **Perspectives:**

  The STIP irradiation experiments will be continued to meet special needs from spallation materials community, and fusion materials community as well. The PIE of irradiated specimens, particularly those from the MEGAPIE target, will provide an abundant database for R&D of high power spallation targets.

Introduction

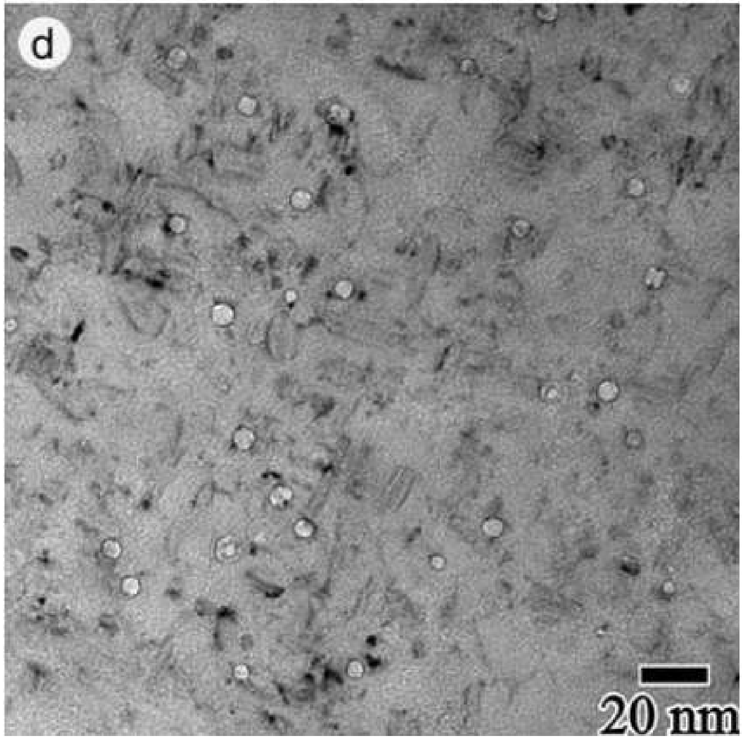
Radiation damage induced microstructural changes in materials

$AlMg_3$ irradiated to 3.6 dpa at ~60°C at SINQ target



Hamaguchi & Dai, JNM 329-333 (2004) 958.

SS 316 (CW) irradiated to 12.2 dpa at 343°C at Tihange 1 (PWR)

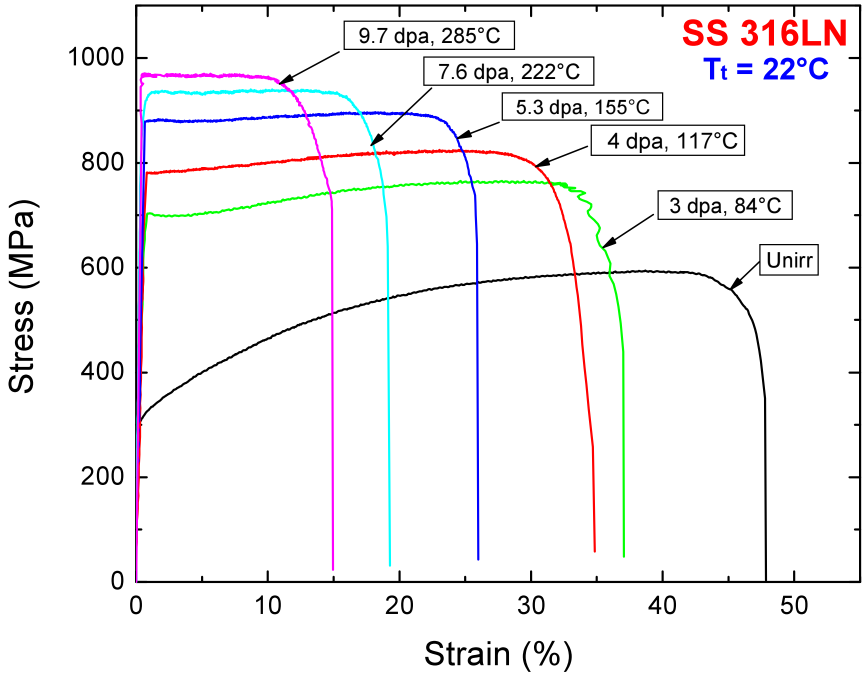


Edwards et al. JNM 317 (2003) 32.

Introduction

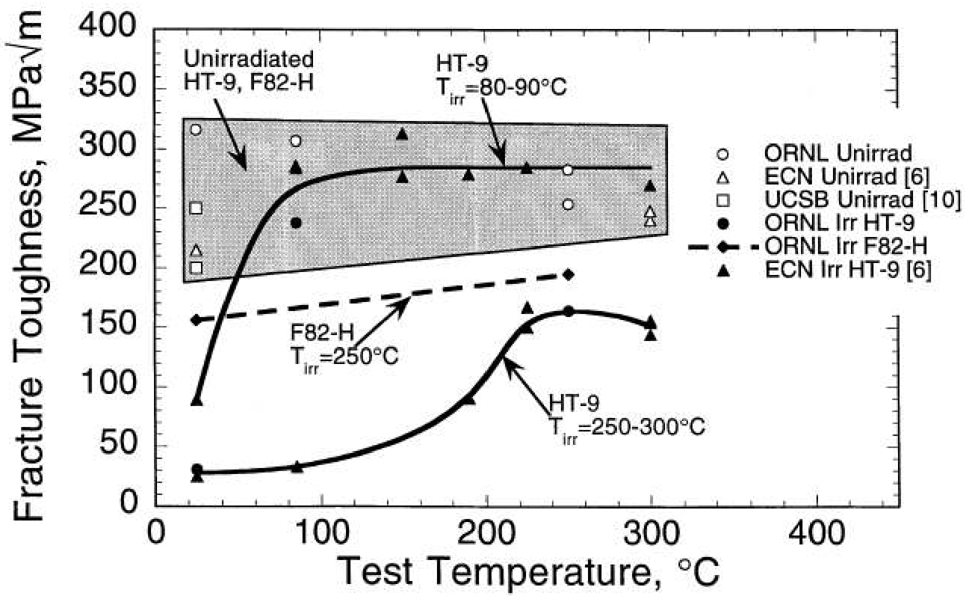
Radiation induced hardening and embrittlement effects in materials

Austenitic stainless steel EC 316 LN irradiated at SINQ target

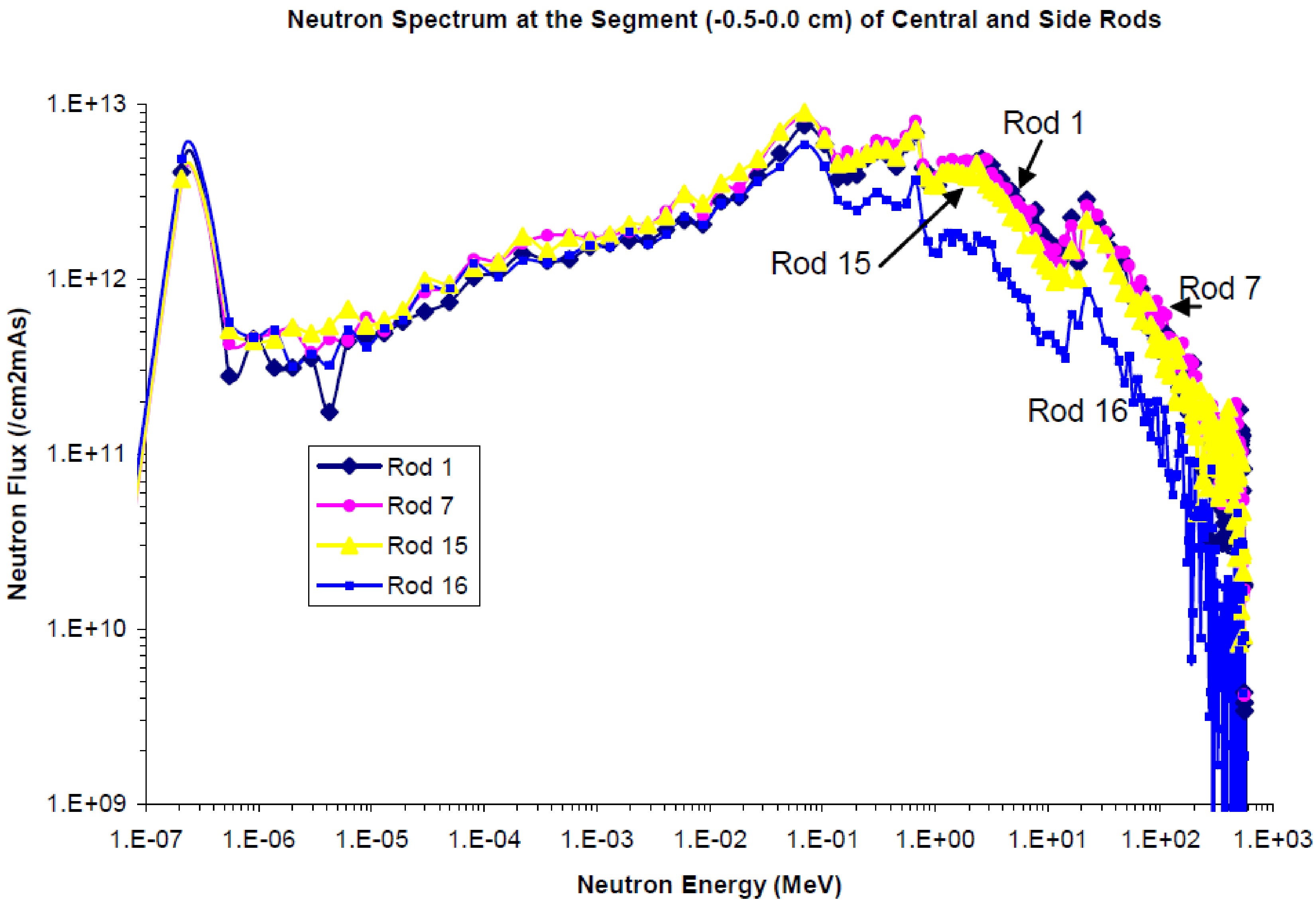


Dai et al. JNM 377 (2008) 109.

Martensitic steels F82H and HT-9 irradiated to 15-2.5 dpa at HFIR (ORNL)

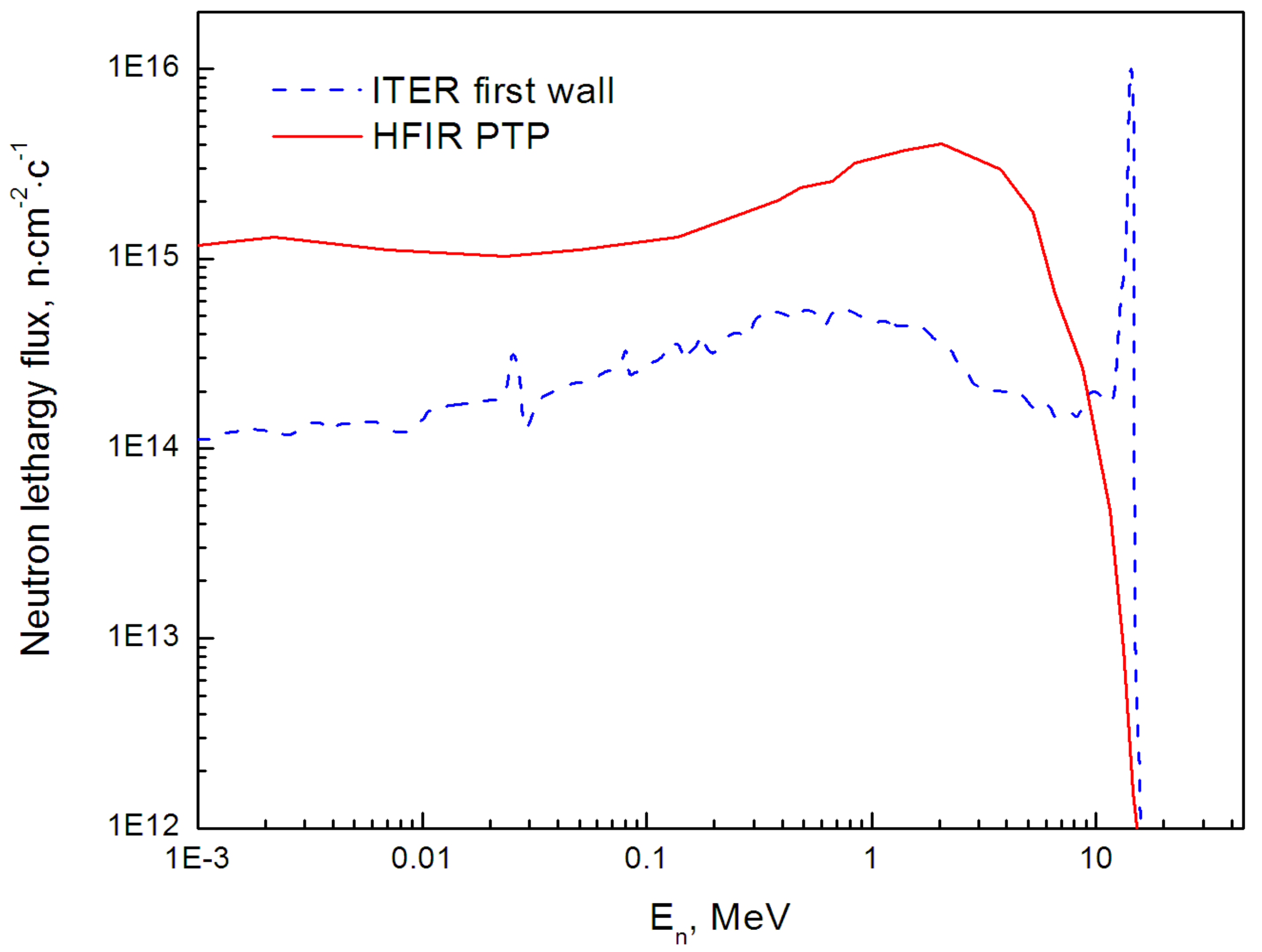


Rowcliffe et al. JNM 258-263 (1998) 1275.

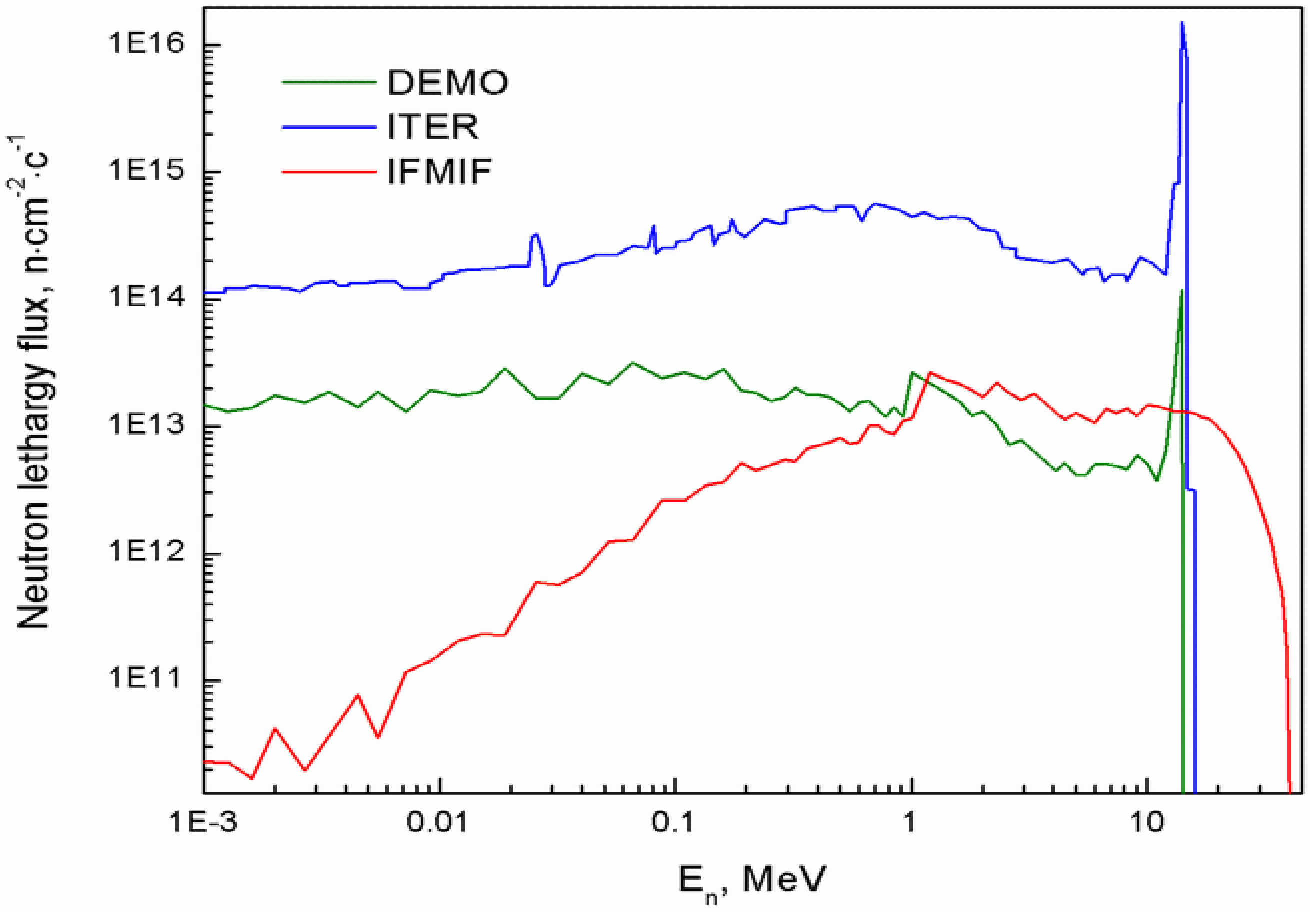


Neutron Spectrum at the Segment (-0.5-0.0 cm) of Central and Side Rods
Neutron Flux (/cm2mAs)
Neutron Energy (MeV)
1.E+13
1.E+12
1.E+11
1.E+10
1.E+09
1.E-07
1.E-06
1.E-05
1.E-04
1.E-03
1.E-02
1.E-01
1.E+00
1.E+01
1.E+02
1.E+03
Rod 1
Rod 7
Rod 15
Rod 16

Neutron Energy Fluxes for different Fast Neutron Facilities (HRIR, ITER)



Neutron Energy Fluxes for different Fast Neutron Facilities



AP/INT-02: **V.Voyevodin. "Modern Status of Accelerators in R&D of Structural Materials for Nuclear Reactors"**

Modern status of using accelerators demand by such main tasks:

- **Understanding of radiation damage mechanism of nuclear materials; achievement of better knowledge of the nature of point defects and interaction between them;**
- **Set up the correlation between radiation-induced defects, structure phase evolution and material degradation mechanism;**
- **Investigation of stability of systems which have nanoscale features. It is especially important for development and prediction of radiation behavior at high irradiation doses of nano-precipitates in ODS steels, which are the most pronounce materials for of next generation.**
- **Development of technology forestimating and predicting radiation damage up to doses, needed for reactors of future generations.**
- **Model predictions must be validated with advanced experimental techniques which are able to determine materials properties in a multiscale approach.**

Advantage of ion and electron simulation

Why accelerators are needed?

- **Higher damage rate (10^{-4}–10^{-2} /accelerator/ vs 10^{-6}–10^{-10} dpa/s /reactor/)**
- **Good control of experimental parameters (temperature, flux and environment), possibility of parameters separation**
- **Ideally suited for optimizing minor alloying composition**
- **Only one possible choice in the absence of high flux neutron irradiation facility. Many nuclear facilities are shut down now (FFTF, RAPSODIE, DFR, PFR, Superfenix, EBR-II, BR-10, BN-350 etc.)**
- **Irradiated specimens are not radioactive, unlike reactor specimens which are highly radioactive and may have to be handled only in hot cells**

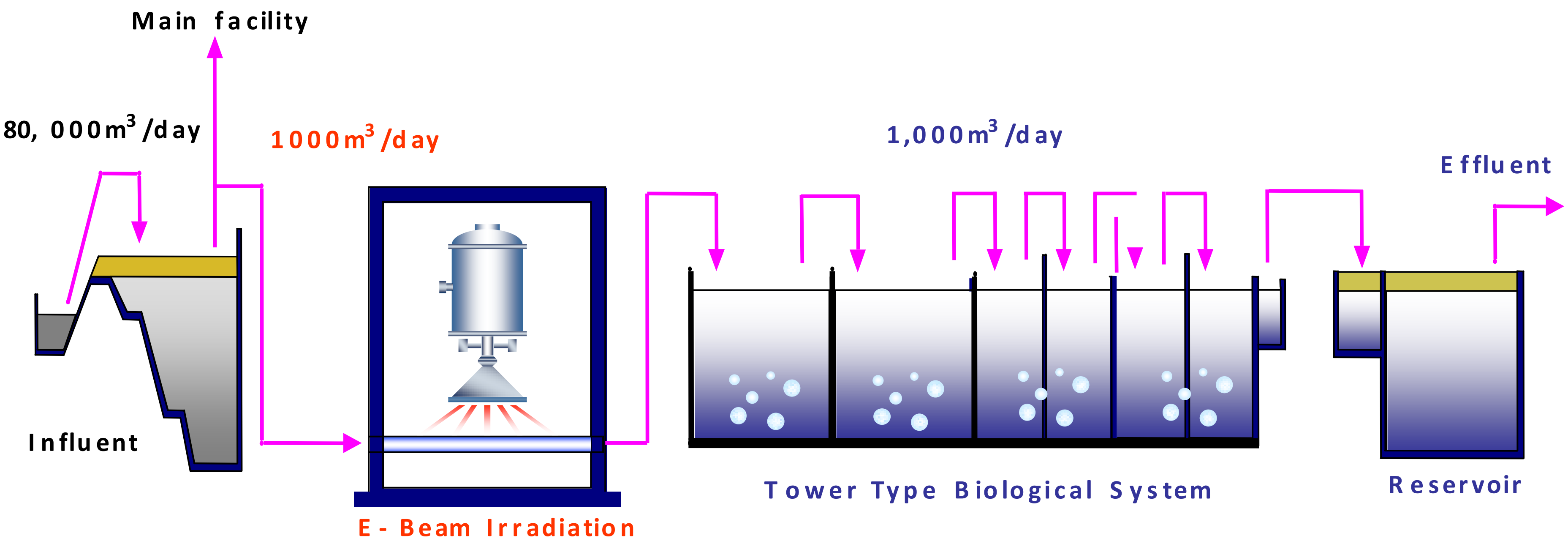
Envinronmental applications:

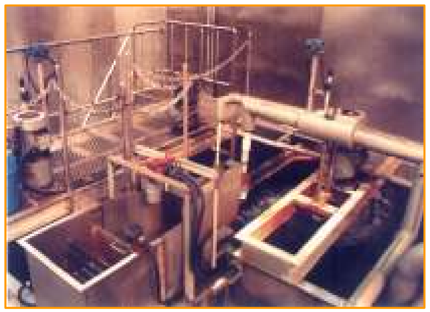
AP/INT-03: Chmielewski, A. G.

“**Electron Beam Processing – What are the Limits**”

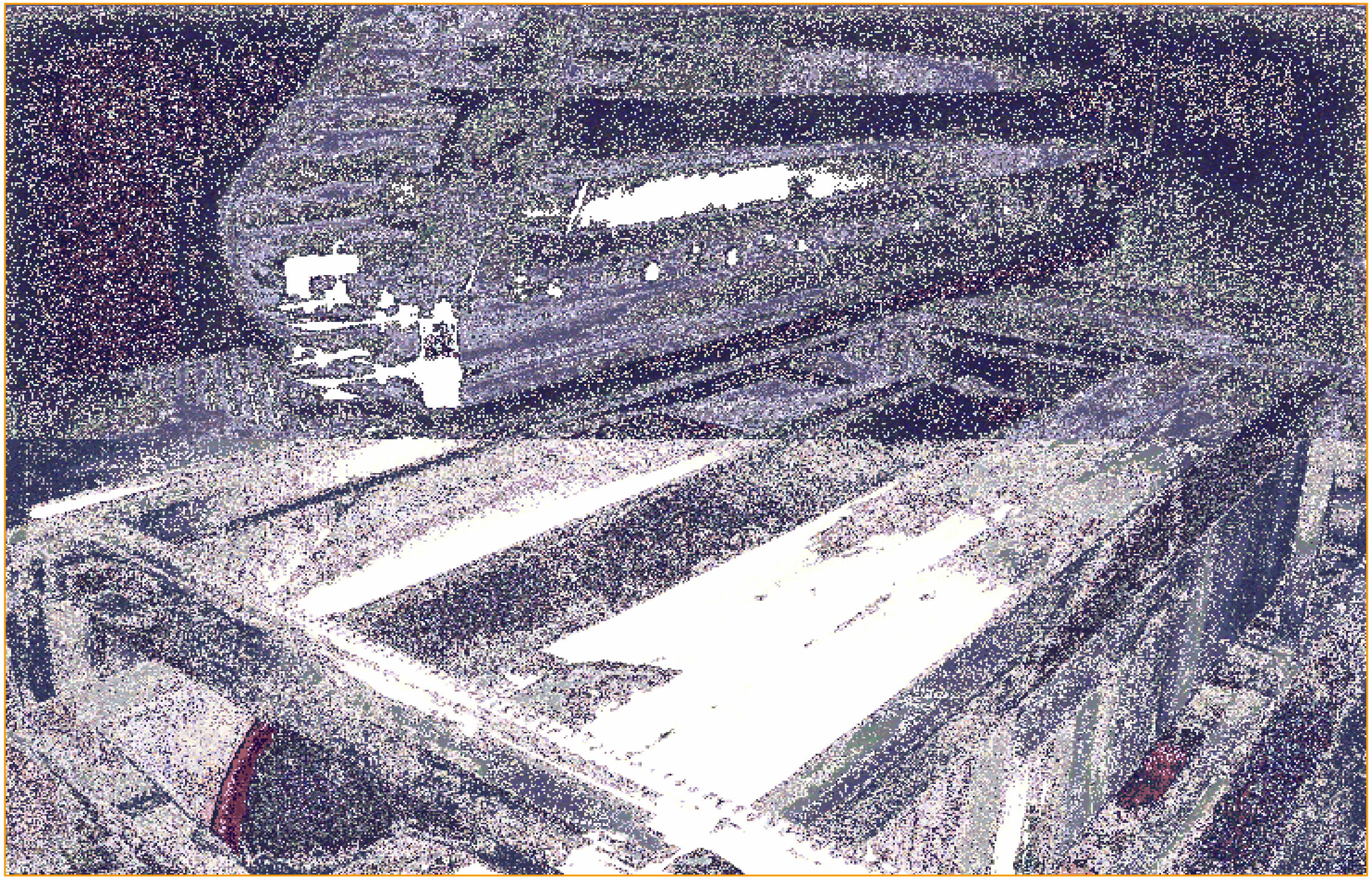
Institute of Nuclear Chemistry and Technology, Warsaw (Poland)

【 Schematic Diagram of Pilot Plant 】





Wastwater eb treatment



- Up to 2000 electron accelerators are used for radiation processing. The radiation sources are installed in service centers or are incorporated as a unit in the technological line. The biggest application of the process concerns sterilization and polymer cross-linking.

- However the biggest challenge regarding electron accelerators are environmental applications, where accelerators are inserted in fluid treatment line.

- First, all these are continuously operated installations with the required operational time 8500 hours per year. Second, because of huge flow rates high power accelerators are needed.

- The installation for flue gases treatment has been constructed in Pomorzany, Poland. Power of electron accelerators (700keV) used is higher than 1 MW.

- EBFGT process can be applied for high sulfur coal, what was demonstrated at Maritza PP pilot plant, The reduction of SO2 and NOx is higher than 90%.

  SO2 1473ppm ➔ 123 ppm

  NOx 166ppm ➔ 17 ppm

- Wastewater treatment industrial plant has been constructed in ROK to treat 100 000m3 per day, organic contaminants were destroyed with high efficiency and E Coli content reduced by orders. Accelerator (700 keV) with power 400 kW has been applied in this case.

05.05.09 Research and Applications for Advanced Materials

1) Prof Y.Kiyanagi from Hokkaido University showed results of spectroscopic imaging using an accelerator based pulsed neutron source for obtaining not only the different contrast imaging but also the information of the texture depending on the position. This method is enough fast and allow to achieve texture data during few hours, but problem-how is cost and which additional information will be achieved with using this method.

2) Dr.B.Nsouli (Director of Lebanese Atomic Enrgy Commission) presented characterization and quantification of active ingredients in commercial solid drugs with using of wide spectrum of methodics.

Ability of PIXE and PIGe techniques for rapid and accurate quantification of few active ingredients is confirmed. It was shown the aspect of sample preparation and the role of excipient. Now the procedure of certification of developed methodics is going.

3) Prof A. Gulevich (Deputy Director of IPPE, Russian Federation) presented information about the modern using of complex of electrostatic accelerators IPPE for solving the whole raw of tasks which are important for creating a new technological platform for nuclear power in Russia. His proposals was establishment of a collective-use center on the base of IPPE tandem electrostatic accelerator of multiply charged ions for investigations in the area of nuclear power and nanotechnologies.

4) Prof S.Kailas (BARC,India) presented programme of AMS (accelerator mass spectrometry) at the Peletron accelerator Facility in Mumbai. The main task-increasing the quality of drinking water and determine of 36Cl in a water samples. In order to separate 36Cl from the interfering 36S, a multi anode gas and silicon detector setup has been developed and employed for the AMs measurements.

It is proposed to extend this programme with measurements for 129I

- AP/AM01 ***A.Ryazanov (Russia)***

  "***Influence of radiation damage obtained under fast charged particle irradiation on plasma-facing erosion of fusion structural materials"***

  The study on effect of radiation damage is very important for estimating life of the PFM. The method used in this study is very useful at present since we do not have high intensity neutron source simulating the fusion neutron source. The results obtained give useful information concerning to erosion and radiation damage. It is desired that the similarity and the difference between this method and the neutron irradiation will become clear. It is recommended to adopt the method combined with plasma exposure for future study using not only ion but also neutron irradiation to lead the decision of allowed maximum dpa for PFM.

- AP/AM02 ***H.E.Zschau (Germany)***

  "***Application of accelerators in high temperature materials research"***

  Improvement of performance of the materials used at high temperature is important to get higher efficiency of the energy generation and also to elongate the life of the materials. An optimal irradiation condition of F to the Ni based alloy was obtained to form layer having oxidation resistance, and the mechanism was also discussed. Although the useful result on optimal condition was already proposed, to get more precise condition it is better to study in more detail for cost saving of industrial production.

- AP/AM03 ***H.Tatlisu (Austria) "Non-destructive inspection of SiCf/SiC composite structure"***

  SiC/SiC composite material is famous for good mechanical properties and also radiation resistance. Evaluation of pore size and distribution is required to assess the effect of the pores on performance of this material. Small angle neutron scattering and radiography method were adopted and got the result that the large pores were not affected by heat treatment. The neutron radiography gave the distribution of the 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.

- AP/AM04 ***D.Ila (USA)***

  "MeV ion beam assisted formation of pseudo-crystals".

  This is challenging study to get new optical devices and thermoelectric materials having superior characteristics. The method to make quantum-dots/nano-dots pseudo-crystal was presented and the effects of the fluence on the thermal conductivity and on the electro conductivity were reported. The mechanism should be investigated in more detail to get optimal condition for producing the best materials.

- AP/AM05 ***R.Tewari (India)***

  "Microstructural investigation of zirconium alloys subjected to electron, light and heavy ion irradiation".

  Omega-phase of Zr-20Nb by irradiation of electrons was studied experimentally and theoretically in detail, and the mechanism was explained. Irradiated Zircaloy-2 was also studied. Furthermore, effect of the oxygen irradiation on Zr-1Nb was studied, and it was indicated that ZrO phase appeared. The phase transition mechanism by irradiation is important to predict the damage of the irradiated samples. Further experimental and theoretical studies are helpful to understand the mechanism generally.

06.05.98. Different Aspects of Industrial Accelerator Applications

- **AP/IA-03 A.A. Basfar (Saudi Arabia)** Discussed the experience of Saudi Arabia in using electron beam flu gas treatment at oil fired boiler. Achieved high removal efficiencies for the polluting SO2 and NO2. Cost for this technique compares favourably with that of conventional method.

- **AP/IA-04 M.R.Cleland (USA)** Discussed the advantages of using carbon composite in place of steel in aero and auto industries. He highlighted that radiation curing using hard X-rays from high energy electrons or directly electron beams can simplify the manufacture of carbon fiber composite vehicle components.

- **AP/IA-05 T.Tsvetkova (Bulgaria)** Discussed the use of ion beam technique to modify the properties of amorphous SiC for varied applications. Employed focussed Ga ions to make pattern on SiC:H films.

- **AP/IA-12 R.W.Hamm (USA)** Pointed out the increasing role of small sized accelerators for industrial applications. Huge investments are being made world over for this purpose.

- **AP/IA-13 D.Ila (USA)** Studied the reaction mechanism of MeV ions with different polymers. With this understanding it is possible to tailor their properties for varied applications and in medical field in particular.

- Summary – Recommendations

  Accelerators primarily developed for basic research in nuclear and particle physics are increasingly being employed for various applications in the field of medicine, industry and material researches. Both electron and ion accelerators are used for various applications. Electron accelerators for flue gas treatment and curing of carbon composites. Ion accelerators for material modifications – amorphous SiC and biomaterials

- 1. Optimise/standardise the accelerator types-specifications for different applications
- 2. The procedure and results for each application
- 3. Intercomaparison of results to standardise the procedure
- 4.Training of interested personnel in established centres
- 6. Engage research students in these programmes involving accelerator applications

07.05.09.
Simulation of Radiation Damage and Testing of Materials for Nuclear Systems :

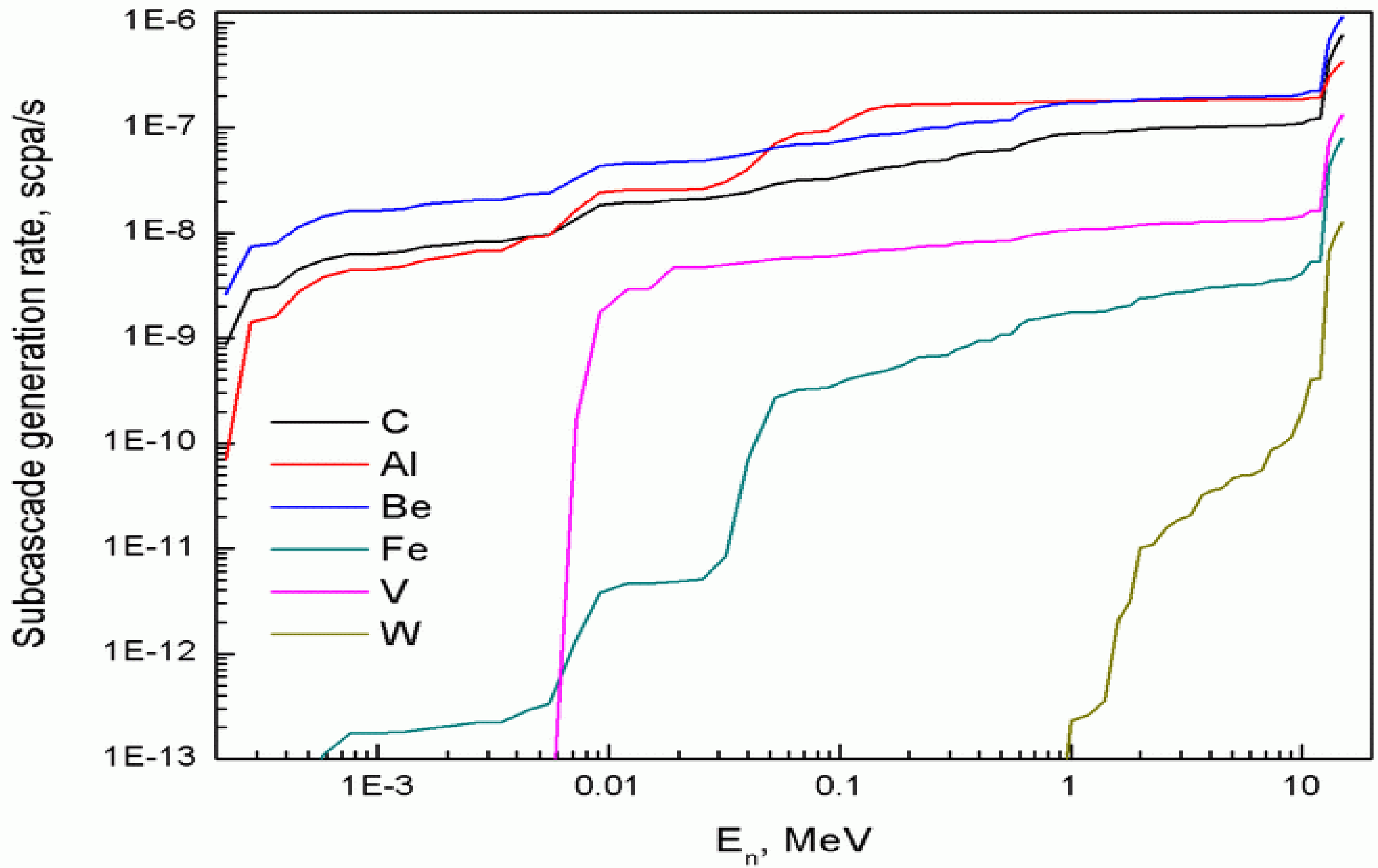
AP/DM-02: "Modeling of cascade and sub-cascade formation in materials irradiated by fast charged particles on accelerators and by fast neutron using fission and fusion" by A.I. Ryazanov et al. (Kurchatov Institute, Russian Federation)

- **In this work, theoretical models and computer tools were developed for investigating of radiation damage – cascades and sub-cascades formation, in various materials such as C, V, Be, Cu, Al, W, for fusion and other nuclear applications. The results are of high interests for predicting defect cluster formation induced by radiation damage.**

AP/DM-03 : "Application of a plasma accelerator of the dense plasma focus type in simulation of radiation damage and testing of materials for nuclear systems" by E.V. Demina et al. (Baikov Institute, Russian Federation)

- **The results of this work show that the damage of tungsten under high-energy pulses in DPF (plasma focus device) with high heat loads (10^7 – 10^{10} W/cm^2) resulted in melting of the irradiated surface layers, erosion of materials (mass loss by evaporation and thinning of samples), formation of different types of surface defects and microcracks, which is of great interests for fusion reactor applications.**

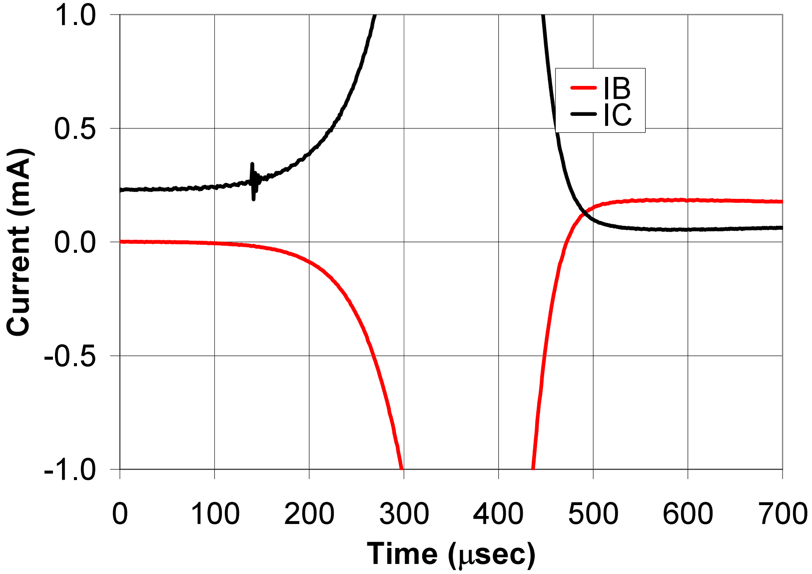
Sub-cascade Generation Rate in different Materials under Neutron Irradiation in ITER

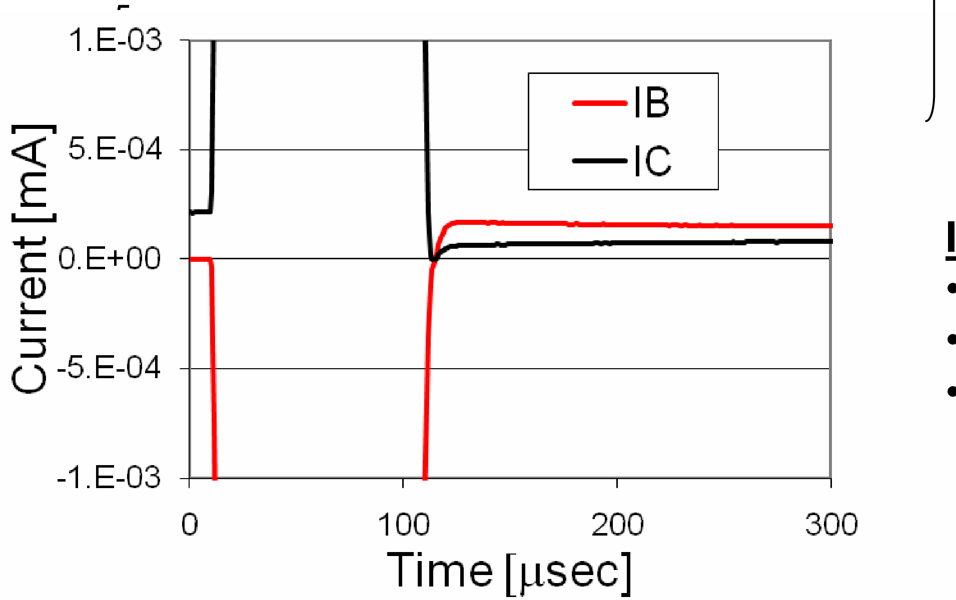


AP/DM-05: "Test Simulation of Neutron Damage to Electronic Components using Accelerator Facilities" by D.B. king et al. (Sandia Nat. Lab., USA)

- Radiation damage in transistors was studied using irradiations of various ions beams at different energies and compared with that of pulsed neutrons. **The results show that the ion irradiation can well simulate neutron irradiation for such applications.**

Si ions create a response in transistors similar to neutrons





SPR fast neutron

- 3E14 n/cm^2 1 MeV Si Eqv
- 1E9 rad(Si)/sec
- 90 µsec pulse width FWHM

Displacement damage increases base current and decreases collector current

IBL

- 10 MeV Si
- 3E14 n/cm^2 1 MeV Si Eqv
- 100 µsec pulse width FWHM

- **07.05.09. 16:10 – 18:00, Different Aspects of Industrial Accelerator Applications**

- 1. ***KRAIEM M. Tunisia, Use of the Accelerators in the Socio-Economic Development in Tunisia (Responsible for an irradiation unit at the National Center for Nuclear Science and Technology, Tunisia)***

Dr. Kraiem discussed about the history and current status of the irradiation facilities in Tunisia. The facility consists of two gamma irradiation devices of electron accelerator with variable energy up to 10 MeV and beam power up to 5 kW. This program started in 1999 with main applications on agriculture and sterilization. There has been continuous increase (5 – 10% per annum) in the demand of applications in fields including art, biology, environment. However, there seems to be no definite plan of expanding the accelerator based facility.

- ***2. KIM K. Korea, The Proton Engineering Frontier Project (PEFP Project, KAERI, Korea)***

PEFP is a proton application facility based on high-intensity, high-duty proton accelerator. The current project costs about $100 M lasting 10 years until year 2012. There are two application platforms, one at 20 MeV and the other 100 MeV of proton beam energy. The 20 MeV platform has been successfully commissioned at KAERI. PEFP team has also developed a 45 MeV facility at KIRAM. In this talk, Dr. Kim provided an overview of the status of the PEFP project, emphasizing on the extensive user programs and future perspectives. Areas of applications include nano-science, biological and medical applications, and material (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). Dr. Kim also discussed R&D efforts including the development of (beta=0.42, 700 MHz) superconducting RF cavity, (700 MHz, 1 MW cw) klystron power source, and neutron target (collaboration on MEGAPIE).

- ***3. LEEB H. Austria, Opportunity of Basic and Applied Research at MedAustron (Vienna University of Technology, Nuclear Theoretician)***

The MedAustron is mainly a proton/carbon therapy facility proposed to be constructed at Vienna. This proposed facility is similar to the cancer treatment built at Heidelberg of Germany. The proton beam will be accelerated to an energy of 60-250 MeV at up to 1 Hz repetition rate with up to 10^10 protons per pulse. The carbon beam will be accelerated to 400 MeV/u at up to 1 Hz rate with 10^8 ions per pulse. As this is the only major accelerator facility in the region, Dr. Leeb and his colleagues intend to propose programs to support radiation physics, biology, and experimental physics. It was proposed to extend the beam energy to 800 MeV to facilitate various physics programs. It was realized that the bottleneck to such programs is potentially due to the low beam intensity. It is indeed true that extra shielding and a variable-intensity ion source is needed but such efforts may be worthwhile and necessary to realize the intended programs especially interests of neutron scattering and ADS are pursued.

Electron Beam Satellite Meeting

- **Non-technical market barriers inhibit the growth of proven EB technologies such as:**

  Food Irradiation

  Environmental Remediation

- **Cost-effective, low energy equipment has been integrated into systems that decontaminate the surfaces of packaging materials to be used in aseptic packaging.**

Electron Beam Satellite Meeting

- **End-use applications involving low-energy EB equipment is the fastest growing market segment.**

- **Very powerful, 300 kW to 700 kW, EB accelerators have made X-ray processing a commercially viable alternative to the use of isotopes.**

Materials Science & Engineering Research &Education at the Center for Irradiation of Materials of Alabama A&M University (CIM) (http://cim.aamu.edu)

Daryush ILA, Executive Director

CIM is well equipped:
SEM, AFM, ESCA, scanning micro-Raman, FTIR, UV-VIS and luminescence spect., thermal and electrical conductivity, mechanical test systems, cyclic voltammetry, L/H energy implanters, IBAD, NRA, PIXE, PIGE, μ-Probe, XPS, AES, and Magnetron spottering, MBE, EELS, UPS, CVD, …

Research results:
Fundamental topics in ion interactions in polymers, ion beam induced ordered quantum dots, non linear optics & waveguides, surface hardening & roughness of materials, high temperature carbon composites, bio-materials, chem-/bio-sensors, ceramics and polymers.

Applications:
Medicine, forensics, aerospace domestic industry: thermoelectric materials, surface enhanced Raman detectors, sensors in extreme environments, cell adhesion, high T tough composites, nanopores, filters & DNA sequencing, IBA of water, air, soil, & paint, & Ind. Support, ….

Research & Education @ the CIM.aamu.edu

Education component:
CIM contributes to the national requirements for engineers and scientists, especially from the under represented minorities.
A one semester advanced undergraduate/graduate Special Topics Course (**STC**: 3-6 credit hours) is 30% laboratory work at CIM, with staff and advanced student mentors for each student. Individual projects terminate with an abstract and manuscript submission to a significant national topical conference.

Summer Training Program (STP):
8-12 week summer course for off campus visiting graduate and undergraduate students, and an occasional exceptional high school student, is entirely conducted in the CIM laboratories. As in the **STC** each student is expected to make weekly presentations, prepare samples, design an experiment, analyze data, submit an abstract to a topical conference. Our presentation will provide numbers of higher degrees awarded, publications and conference contributions with student first authors, supervised by CIM staff, dissertation defenses on the AAMU, as well as foreign university, campuses, all a consequence of the strong education component at CIM-AAMU

Graduate Degree program:
BS,
MS Thesis,
And
PhD
Dissertation