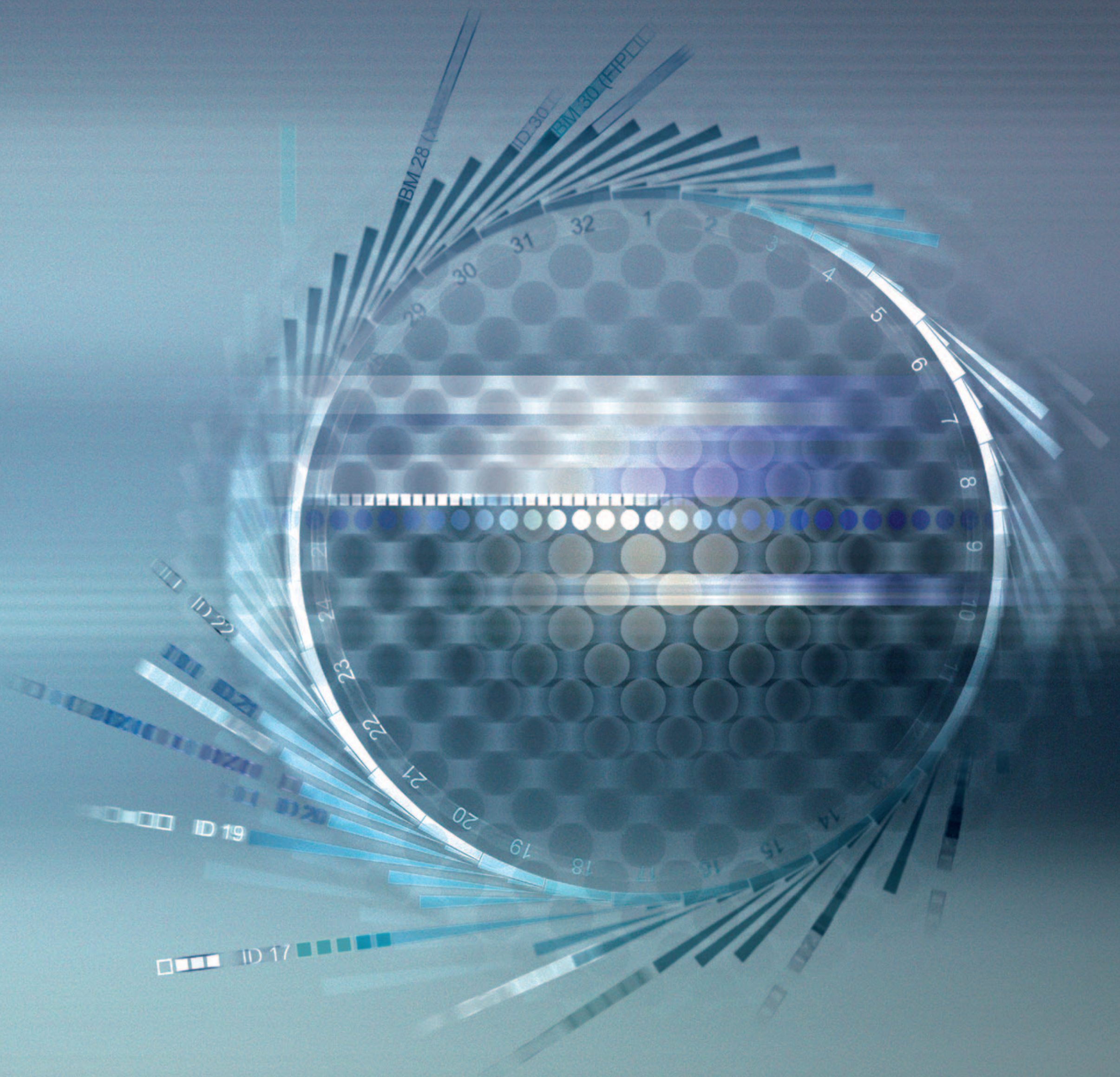
International Topical Meeting on

Nuclear Research Applications and Utilization of Accelerators

Vienna, Austria, 4–8 May 2009



BOOK OF ABSTRACTS

IAEA
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International Topical Meeting on Nuclear Research Applications and Utilization of Accelerators

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Book of Abstracts

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OV

Overview

OV–01

ADS Projects in the World and Perspective for Implementation of MYRRHA/XT–ADS in Europe

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Transmutation of minor actinides (MA) can be completed in an efficient way in fast neutron spectrum facilities. Both critical reactors and sub-critical Accelerator Driven Systems (ADS) are potential candidates as dedicated transmutation systems. However, critical reactors, heavily loaded with fuel containing large amounts of MA, pose reactivity control problems, hence safety problems, caused by unfavorable reactivity coefficients and small delayed neutron fraction. A sub-critical ADS operates in a flexible and safe manner even with a core loading containing a high amount of MA leading to a high transmutation rate. Thus, the sub-criticality is not a virtue but rather a necessity for an efficient and economical burning of the MA. Besides these reactor and core physics considerations, there are other parameters to consider for deciding on the most appropriate technology suitable for the large scale deployment of partitioning and transmutation (P&T) technology for the reduction of the HLW burden.

The implementation of P&T needs the demonstration of the feasibility of several installations at an "engineering" level. The respective research and development activities could be arranged in four so called "building blocks" aiming to:

- demonstrate the capability to process a "sizable" amount of spent fuel from commercial power plants (i.e., LWR) in order to separate Pu and MA,
- demonstrate the capability to fabricate at semi-industrial level the dedicated fuel needed to load a dedicated transmuter,
- make available one or more dedicated transmuters,
- provide an installation for processing of the fuel unloaded from the transmuter which can be of a different type of the one used to process initially the original spent fuel unloaded from the commercial power plants (i.e., LWR).

Since a "once-through" reprocessing is not sufficient, whatever type of transmuter is considered, the fuel unloaded from the transmuter should be processed and new fuel fabricated and sent back to the transmuter in order to complete the transmutation process.

Two main kinds of transmuters can be considered for the second "stratum": critical fast reactors and accelerator driven systems whereas in case of once through or phase-out ADS would be the advisable route.

In this paper we will review the ongoing experimental ADS projects in the world and the rational behind and we will report on the perspective of implementation in Europe of MYRRHA/XT–ADS that will be covered more in detail in the satellite meeting IV of this conference.

OV–02

Status of J–PARC and its Scientific Applications

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The J–PARC, which has being constructed jointly by Japan Atomic Energy Agency (JAEA) and High Energy Accelerator Research Institute (KEK) since April 2001, has started user operation in December 2008 and completed the construction of its Phase I facilities, The J–PARC consists of three accelerators; Linac, 3 GeV synchrotron and 50 GeV synchrotron, and three experimental facilities; Materials & Life Science Facility (MLF), Hadron Facility and Neutrino Facility. Those experimental facilities uses secondary particles from high energy high intensity proton beam such as muons, neutrons, K-mesons and neutrinos. The operation status and the scientific applications which will be conducted using those secondary particles are overviewed.

AP

Accelerator Applications

AP/INT — Introduction

AP/INT–01

The Status of Studies on Structural Materials under High Energy Proton and Neutron Mixed Spectrum

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The R&D of spallation targets with either high power or high proton beam intensity has been stimulated by increasing demands for different applications such as neutron scattering science and nuclear waste transmutation devices. One of key issues in the R&D is the understanding of the behaviors of structural materials in severe irradiation environments in spallation targets. A world-wide effort has been focused on studying the radiation damage effects of high energy protons and spallation neutrons on different structural materials by conducting irradiation experiments in the targets of the Swiss spallation source (SINQ) at the Paul Scherrer Institut. In the last few years, a large number of specimens irradiated in the SINQ targets were examined in several institutions in Europe, Japan and USA. A significant progress has been achieved in the basic understanding of the radiation effects and a large amount data have been obtained from the related post-irradiation examinations. In this report, the present status and main outcome of these studies will be described.

AP/INT–02

Modern Status of Accelerators in R&D of Structural Materials for Nuclear Reactors

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Nuclear energy “renaissance” demands to perform research and development of materials which determine the safe and economical operation of running and developed nuclear facilities.

Unfortunately structural materials in the nuclear power plants undergo degradation due to irradiation influence. Rate of degradation of nuclear materials tends to accelerate due to irradiation.

High irradiation doses and temperatures planned for advanced fission and future fusion reactors will most certainly require the development of new improved materials. The cost of material testing under neutron irradiation for these advanced nuclear systems is continuously increasing while availability of test reactors is steadily decreasing. Last time irradiation possibilities were strongly decreased also due to the shut down of all spectra of nuclear facilities.

The problem of material development for operation in unique conditions of irradiation and evaluation of their radiation resistance consists in the use of existing irradiation facilities for determination of mechanisms of radiation damage and selection of materials with high radiation resistance. Now simulation experiments are very useful for evaluation of radiation behaviour of materials, which work in different facilities with different spectral conditions.

The main advantage of accelerators is not only the obtaining of fast results about radiation properties, but mainly possibility to understand basic mechanisms and separately investigate the influence of different factors on radiation damage. Selection of particles and energies allows researching of factors that can be studied directly under reactor irradiation.

Now need to develop technologies for analyzing and predicting the behavior of nuclear materials as proactive safety management. It can be done by set up the correlation between radiation-induced defects and material degradation mechanism.

It is necessary to say that now really exist a new era (also "renaissance") for studies on ion-accelerators, with high-tech instrumentations and new philosophy.

Understanding of radiation damage mechanism of nuclear materials and development of technology for estimating and predicting the radiation damage are main tasks for accelerators using.

How these tasks are solved now and which instrumentation is useful and needed in ion simulation experiments is a topic of this presentation.

AP/INT–03

Electron Beam Processing — What are the Limits

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Radiation emitted from electron accelerators or γ sources is widely applied in the industry. Up to 200 big γ irradiators and 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. Other still being a challenge is application of the technology in food irradiation. The biggest applications in line regarding the power of machines used type concern environmental protection. The advantage of electron accelerators over γ sources is due to the high dose rate what shortens the processing time. An electron accelerator of the power 15 kW regarding delivered dose is equivalent to 1 MCi of the Co-60. Electron accelerators of the power 150 kW and the energy 10 MeV are available on the market The present situation concerning difficulties in the cobalt delivery due to transport restrictions will promote accelerator applications as a radiation source. However, the penetration range of the γ rays is much larger than those of electron beam, of accepted processing energy up to elements activation limits. The application of e/X conversion is a technical feasibility, however due to the low conversion efficiency this is a first limit of this technique. Other limit concerns reliability of accelerators for in line applications, the 8500 hours continuous operation in the year is required. Therefore, these above mentioned physical requirements are the technical limits. Other limits are created by the presence of other technologies on the market. These technologies are in some cases presented as a cheaper from the operational and investment costs point of view and they are simpler regarding safety and operational conditions. In many cases, they base on not very well specified economical and technical parameters to be compared. All these factors are discussed in the paper.

AP/INT–04

Principles and Applications of Neutron Based Inspection Techniques

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Neutron based explosive inspection systems can detect a wide variety of substances of importance for a variety of purposes from national security threats (e.g., nuclear materials, explosives, narcotics) to customs dutiable goods, to hazardous substances to protect the environment. The inspection is generally founded on the nuclear interactions of the neutrons with the various nuclides present and the detection of resultant characteristic emissions. These can be discrete γ lines resulting from the thermal (n, γ) neutron capture process or inelastic neutron scattering $(n, n'\gamma)$ occurring with fast neutrons. The two types of reactions are generally complementary. The capture

process provides energetic and highly penetrating γ rays in most inorganic substances and hydrogen. Fast neutrons inelastic scattering provide relatively strong γ-ray signatures in light elements such as carbon and oxygen. In some specific important cases, unique signatures are provided by the neutron (n, γ) process in light elements such as nitrogen, where unusually high-energy γ rays are produced. This forms the basis for key explosive detection techniques.

The detection of nuclear materials, both fissionable (e.g., ^{238}U) and fissile (e.g., ^{235}U), is generally based on the fissions induced by the probing neutrons and detecting one or more of the unique signatures of the fission process. These include prompt and delayed neutrons and prompt and delayed γ rays. These signatures are not discrete in energy (typically they are continua) but temporally and energetically significantly different from the background, thus making them readily distinguishable.

The penetrability of fast neutrons as probes, and the γ rays and fission neutrons as signatures makes neutron interrogation applicable to the inspection of large conveyances such as cars, trucks, and marine containers.

Neutron based inspection techniques have a broad applications. They can be used as stand-alone for complete scans of objects such as vehicles, or for spot-checks to clear (or validate) alarms indicated by another inspection such as high-energy x-ray radiography. The technologies developed over the last decades are now being implemented with good results. The principles and applications of neutron-based inspection techniques using accelerator based sources will be reviewed and discussed in the presentation.

AP/AM — Research and Development of Applications for Advanced Materials

AP/AM–01

Influence of Radiation Damage Obtained Under Fast Charged Particle Irradiation on Plasma-Facing Erosion of Fusion Structural Materials

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Selection of the structural materials for the fusion reactor is a very actual problem. Plasma-facing materials (PFM's) in diverter and on the first wall of a fusion reactor will be affected by high heat flux, fast particles and 14 MeV neutron irradiation. All these factors are crucial for the lifetime of the fusion structural materials. Fast neutrons produce a high-level of radiation damage (estimated value is up to hundred dpa) in first wall materials during long operation of the fusion reactor. At the same time, PFM's will suffer radiation erosion induced by the plasma. While important data on the plasma erosion have been collected for non-irradiated materials, it is difficult to qualify PFM's at present taking into account radiation damage effect. This paper is devoted to the experimental results concerning radiation damage effect on erosion of materials under plasma impact. To obtain a high level of radiation damage, we simulated neutron irradiation using fast ion irradiation with energy interval of $1-60$ MeV accelerated on the cyclotron at Kurchatov Institute. Using this method we can accumulate the radiation damage equivalent to fast neutron effect at the dose of up to 10^{26} neutron/m^2 in a few days operation of the cyclotron. Both carbon materials and tungsten were taken for the study as the targets: MPG-8 (Russian graphite), SEP NB-31 (ITER PFM candidate) and W (99.95% wt). Irradiation of these materials on the cyclotron has been performed with 5 MeV carbon ions (for carbon materials) and α particles 3.4 MeV for tungsten. The experiments have been performed on the materials having accumulated $0.1-10$ dpa of radiation damage. Plasma erosion was studied on the linear plasma simulator LENTA. Irradiated samples were exposed to steady-state deuterium plasma at 100 eV (D^+ ions) to dose of up to 10^{25} ion/m^2. The microstructure modification was studied and following comparison has been made on the damaged and non-irradiated materials. Enhancement of the erosion process was detected for the radiation-damaged materials. New experimental approach developed in this work to explore the plasma-facing materials for accounting of neutron effect and the results obtained appear to be important for the further studies of the combined plasma and neutron irradiation effect on fusion PFM's.

AP/AM–02

Application of Accelerators in High Temperature Materials Research

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The paper focuses on the application of ion beams in the field of oxidation protection of materials developed for high temperature environments. Turbine blades in aircraft engines and gas-fired

power generation turbines are often manufactured of Ni-base superalloys because of their good mechanical properties. In contrast to this their oxidation resistance may be insufficient particularly at temperatures above 1000°C. Oxidation of these Ni-base alloys does not form a pure continuous protective alumina scale on the surface, but rather a complex layered structure. This structure is characterized by a non-continuous alumina scale. However the formation of a dense continuous alumina scale without significant internal oxidation would theoretically be possible, if a "critical" Al-concentration is realized by a surface modification by using the halogen effect. After fluorine ion implantation of specimens of the alloy IN 939 with fluences between 1×10^{16} Fcm^{-2} and 4×10^{17} Fcm^{-2} the fluorine depth profiles were measured with PIGE by using nuclear reactions of protons with the F-nucleus. The fluorine implantation profiles were in good agreement with the calculated profiles by using the Monte Carlo software T-DYN. After the subsequent oxidation (60 h/1050°C/air) metallographic cross-sections were prepared. A distinct dense and protective alumina scale was formed on the surface indicating that a change of the oxidation mechanism was achieved. The best results were found for fluences between 5×10^{16} and 1×10^{17} F cm^{-2}. The time behaviour of the implanted fluorine during heating and the early stages of oxidation was studied by using PIGE. The results show the technical potential of the fluorine effect in high temperature applications.

AP/AM–03

Non-Destructive Inspection of SiC_f/SiC Composites Structure

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Fiber reinforced ceramic matrix composites are attractive candidate structural materials for fusion power plant because of their light weight, high temperature capability, high strength and toughness. Ceramic matrix composites made especially with silicon carbide matrix and fibers (SiC_f/SiC) are promising for nuclear and fusion technology due to excellent and endurance under high-energy particle, such as neutrons and α particles. Porosity, which is based on the manufacturing process of the SiC_f/SiC composites, is a critical issue in using of the composites in fission and fusion rector. Internal pores mitigate most of the outstanding properties of the SiC_f/SiC composites such as thermal conductivity, high strength and probability radiation stability. The pores in composites are unavoidable and significantly reduce the life time and performance of the composites under harsh environments.

The aim of the study is to examine the pore structure and high-temperature induced changes within the SiC_f/SiC composite. By means of non-destructive cold neutron tomography (HMI-Berlin), X-ray tomography (HMI-Berlin) and small angle neutron scattering (PSI-Villigen) techniques inner microstructure of the composites have been investigated. The cold neutron and X-ray tomography techniques have been performed in order to gain complementary information for the SiC_f/SiC composites with these methods. X-ray tomography provided information about the microstructure of these samples with high resolution. After heat treatment of the composites at 1300°C, 1400°C and 1500°C for different time the small angle neutron scattering (SANS) measurements have been carried out to understand high-temperature induced pore size changes. The two-dimensional neutron scattering patterns from the composites have been evaluated using sector analysis to determine the structure change over the range $0.002 - 0.35$ Å. Scattering curves have been revealed the pore size change at elevated temperature.

AP/AM–04

MeV Ion Beam Assisted Formation of Pseudo-Crystals

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For the past fifteen years, we have formed nanostructure in the MeV ion beam track in order to fabricate pseudo-crystals consisting of nanostructures. The focus of our work is based on the energy deposited due to ionization in order to produce quantum dots or nano-structures resulting to production of pseudo-crystal consisting of nano-crystals with applications in optical devices as well as with applications in highly efficient thermoelectric Materials. The interacting nanocrystals enhance the electrical conductivity, reduce thermal conductivity and increase the Seebeck coefficient, in order to produce highly efficient thermoelectric materials. Theoretically, the regimented quantum dot superlattice/pseudo-crystals consisting of nanostructures of any materials produces new physical properties such as new electrical band structure, phonon mini-bands, as well as improved mechanical. A proper choice of nanocrystals, host and buffer layer result in production of highly efficient thermoelectric generator (TEG)* with efficiencies as high as 30% which correspond to figure of merit above 4.0. In addition to above such systems are in a unique position to be used both as electrical generation from heat and/or other forms of radiation as well as cooling the structures, thus enhance the applicability of hybrid systems.

The interaction of nanostructures results in phonon mini-bands formation reducing the thermal conductivity, while increasing the electrical conductivity resulted in synthesis of TEG with much higher efficiency than reported to this date. We will review a series of materials selected for investigation some operating at temperatures around 300K and some at about 1000K.

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* Patent filed/Patent Pending.

AP/AM–05

Microstructural Investigation of Zirconium Alloys Subjected to Electron, Light and Heavy Ions Irradiations

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In the present study, microstructures and formation of various phases have been examined in samples of zirconium based alloys irradiated with electron, protons and oxygen ions. In case of oxygen ion irradiation zircaloy-2 have been irradiated by Oxygen with different fluences and the effect of the irradiation has been studied in terms of the defect introduced into the materials. Microstructural investigations on these samples showed the presence of defects and precipitates in the alpha matrix. Composite selected area electron diffraction patterns obtained from the irradiated regions were analysed and it was shown that the precipitate phase was the monoclinic zirconium oxide. Orientation relationship between the oxide and the matrix phase has been determined. In the Zr-20Nb alloy, the formation of the omega phase under electron irradiation has been examined. Samples were exposed to 1 MeV and 2 MeV electrons and SAD patterns were recorded after different durations of irradiation exposure at various temperatures. Detailed post-irradiation examination of the microstructure was subsequently carried out. Thermal treatments as well as irradiation have been found to lead to the formation of diffuse omega maxima. The origin of these maxima has been probed in either case by carrying out high resolution electron microscopy (HREM). The formation of the crystalline omega phase on prolonged irradiation and thermal treatment and its subsequent distribution has also been examined. Irradiation has been found to lead to dissolution of the omega phase in periods of time considerably shorter than those required for thermal treatment. In the

case of proton irradiation, the Zr-1Nb alloy has been irradiated with 8 MeV proton. As this energy of proton was higher than the coulombic barrier of the Zr ions, bombardment of protons led into the transmutation of Zr atoms into Nb atoms. Microstructural examination of such samples revealed interesting morphology of the beta$f$nphase (bcc) in the alpha matrix.

AP/AM–06

Functional Hydrogels Containing Polyaniline Nanoparticles Through E-Beam Irradiation

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The use of ionizing irradiation has been proved to be a valid methodology for the production of biocompatible hydrogels. The continuous demand for more performing, intelligent materials, i.e., able to mimic biological systems, reacting to changes in the environment and providing either a measurable signal or an actuation function, imposes that extra-functionality is added to the crosslinked structure of a polymer gel.

To this aim a possible approach is the design of hydrogel nanocomposites, where the matrix is the hydrogel, thus providing biocompatibility, soft tissue resemblance and high aqueous solutions retention, and a nano-scalar dispersed phase adds up specific functional properties to the assembly.

If the dispersed phase is represented by a conjugated polymer, such as polyaniline (PANI), its unique physical and chemical properties, such as low density, electroactivity, adjustable optical and electrical properties can be exploited to design a material construct that combine both the properties of the water-swellable matrix and the responsiveness of polyaniline, e.g., for highly sensitive optical probes for protein biosensing.

PANI aqueous nanocolloids are synthesised by means of suitable polymeric stabilisers, i.e., water soluble polymers, that may prevent irreversible PANI particles coalescence and precipitation during synthesis. Depending on the nature of the polymeric stabiliser, e.g., polyvinyl pyrrolidone (PVP) or polyvinylalcohol (PVA), PANI can be synthesised in form of rods or spherical particles, respectively. In the present work, e-beam irradiation with a 12 MeV Linac accelerator has been tested, in alternative to γ-rays, as a viable industrial methodology to generate hydrogel nanocomposites via *in-situ* crosslinking of the polymers already used to stabilise polyaniline nanocolloids, at low temperature and with no recourse to further addition of molecular weight chemicals. In these conditions the particles morphology of PANI should be preserved and interesting electro-optical properties can be imparted. The swelling properties of the different hydrogel nanocomposites as well as the corresponding optical properties are discussed at the variance of the chemical structure of the matrix material and the pH of the swelling medium. Furthermore, toxicity studies confirm the benignity of the produced hydrogel nanocomposites.

AP/AM–07

Application of Neutron Transmission Spectroscopic Imaging for Analysis of Texture in Materials for Industrial Use

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Energy dependent imaging can obtained at one measurement in the pulsed neutron source since the neutron energy can be analyzed by time–of–flight method coupled with a 2-dimensional position sensitive detector. Therefore, spectroscopic transmission imaging using an accelerator based pulsed neutron source is very useful for obtaining not only the different contrast imaging but also the information of the texture depending on the position. The total neutron cross section depends on crystal structure, crystallite size, crystallite orientation and so on. They appear as different shapes and value of the cross section around Bragg edge. In the high wavelength resolution measurements we can observe the shift of the Bragg edges, and get the distribution of the strain.

We are now under developing this method and applying to some nuclear materials. Here, we present results we obtained so far. For establishing the method it is necessary to evaluate the correlation between the cross section change and the texture change. Therefore, we performed model experiments to clarify the relations. It became clear that the larger the grain size is, the smaller the cross section around Bragg edges and the anisotropic distribution of grain orientation causes the round shape Bragg edges. By measurements on a bended stainless steel we clearly observed the effect, and also the strain distribution in the stainless steel. As an application of this method we observed the precipitation process of γ-phase of Pb-Bi to study the expansion effect, which is the candidate for coolant of ADS and a spallation target. We observed the spatial dependent distribution of crystal structure and the cooling speed dependence of the expansion.

The transmission spectroscopy method using an accelerator based neutron source has proved to be useful tool for material analysis.

AP/AM–08

On the Direct Characterization and Quantification of Active Ingredients in Commercial Solid Drugs using PIXE, PIGE and TOF–SIMS Techniques

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The quantification of the active ingredient (AI) in drugs is a crucial and important step in the drug quality control process. This is usually performed by using wet chemical techniques like LC–MS, UV spectrophotometry and other appropriate organic analytical methods. In the case of an active ingredient contains specific heteroatoms (F, S, Cl, ...), elemental IBA like PIXE and PIGE techniques, using small tandem accelerator of $1 - 2$ MV, can be explored for molecular quantification. IBA techniques permit the analysis of the sample under solid form, without any laborious sample preparations. This is an advantage when the number of sample is relatively large.

In this work, we demonstrate the ability of the Thick Target PIXE and PIGE technique for rapid and accurate quantification of low concentration of different fluorinated, sulfured and chlorinated active ingredients in several commercial anti-hyperlipidemic and anti-inflammatory commercial drugs.

In this work we will demonstrate the ability of PIXE and PIGE techniques for rapid and accurate quantification of Celecoxib and Atorvastatin active ingredients contained in several solid commercial drugs. The experimental aspects related to the quantification validity are presented and discussed.

In addition, the Time of Flight Secondary Ion Emission using multicharged Ar ions with ~ 10 MeV energy, delivered by a 4 MV Vander Graaf single stage accelerator, was used for structural and chemical analysis for some cases of binary commercial drugs containing two different active ingredients. The aspect of sample preparation and the role of excipient will be highlighted and discussed.

AP/AM–09

Electrostatic Accelerators of IPPE for Nuclear Science and Technology

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The base for experimental research has been created and developed at SSC RF-IPPE with its complex of high-voltage-accelerators for over half a century. Results obtained have become a major contribution to the solution of problems related to nuclear fission physics, solid state physics, and material irradiation studies; to the establishment of nuclear-physics data bases for the modernization of fast-neutron reactors, as well as other areas of fundamental and applied studies.

Nowadays the problem-oriented investigations and research on electrostatic accelerators at IPPE have been underway essentially as a support for creating a new technological platform for nuclear power of Russia, with closed nuclear fuel cycle based on fast-neutron reactors and innovation nuclear technologies. Principal trends of scientific research include the following:

- Nuclear physics of low and intermediate energies. Nuclear data for nuclear power engineering. Closed nuclear fuel cycle. Safe management and disposition of radioactive wastes and spent nuclear fuel.
- Solid-state physics. Physics of radiation damage and material irradiation studies.
- Nuclear micro-analysis. Analysis of material structure and composition.
- Physics of nuclear-excited dust plasma. Direct conversion of nuclear energy in nuclear-pumped lasers.
- Activation analysis. Wear and corrosion monitoring by surface activation method.
- Beam technologies. Nanotechnologies and nanomaterials.
- Nuclear medicine.
- Technologies for manufacturing membranes and catalytic systems.
- Technologies of hydrogen energy.

Results of a short review on state of the art in the area of electrostatic accelerators of multiply charged ions for diverse applications in nuclear science and technologies have been presented, with references to the most important and interesting materials obtained recently.

The discussion covers also the main areas for upgrading and perspectives of the development of analytical complex on the base of the IPPE electrostatic accelerators, including the establishment of a collective-use center on the base of tandem electrostatic accelerator of multiply charged ions with energy levels of $6 - 25$ MeV and intensive beam density up to 50 nA/cm^2 for investigations in the area of nuclear power and nanotechnologies.

AP/AM–10

Accelerator Mass Spectrometry Programme at Mumbai Pelletron Accelerator Facility

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The Accelerator Mass Spectrometry (AMS) programme at the 14 MV Pelletron Accelerator Facility in Mumbai has been initiated with major emphasis on the determination of ^{36}Cl in water samples. As a part of this programme, to cut down the beam intensity by a factor of 20 before injection into the accelerator, a beam chopper has been designed, developed and installed. In order to separate^{36}Cl from the interfering ^{36}S, a multi-anode gas and silicon detector setup has been developed and employed for the AMS measurements. A new terminal potential stabilizer system was procured to operate the machine in the generating voltmeter (GVM) mode. The accelerated beam after passing through the analyzing magnet was bent by a switching magnet and injected into the beam line where the AMS measurements were carried out. Standard and blank samples of Cl from the Prime lab, Purdue were used in these measurements to optimize the beam transmission through the machine. The detector was calibrated using the ^{35,37}Cl ions and ^{32,34,36}S ions, by using the ions directly into the detector by operating the ion source filament at extremely low values. During the calibration, the count rate in the detector was about 1 kHz or less. The background of ^{36}Cl from the blank was determined and it was estimated that the minimum measurable value of the ratio ^{36}Cl/Cl was of the order of 10^{-13} using the present set up. The Purdue standard gave a value of 4×10^{-11} for ^{36}Cl/Cl ratio. We also obtained ^{36}Cl/Cl ratio values from a few old water samples collected from different parts of south India. After normalizing to the Purdue standard, the values were estimated to range between $2 - 5 \times 10^{-12}$. To augment this programme, a multi-cathode ion source is being indigenously developed. It is proposed to extend this programme with measurements for ^{129}I.

AP/AM–11

Search for the Formation of Magnetic Nanoclusters by Ion Implantation into Suitable Insulators

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Ion beams are finding increasing applications in the synthesis and modifications of materials on the nanometer scale. Strict control of ions species, energy and fluence allow one to tailor the ion irradiation conditions to specific applications and circumvent restrictions set to ion solid interactions by thermodynamic effects. We report on our search for the formation of magnetic nanostructures in suitable host matrices, achieved by the implantation of low fluence Fe ions accelerated to $60 - 80$ keV energy. Mass separated Fe^{57} ions were implanted to fluences of 5×10^{15}, 1×10^{16} and 2×10^{16} per cm^2, into ZnO, 3C-SiC and SiO_2 substrates. The search for cluster formation was conducted as functions of thermal treatment of the substrates and implantation dose. Characterization methods included Mössbauer spectroscopy, Rutherford Backscattering Spectrometry, and MOKE and VSM measurements.

The Mössbauer spectra of the Fe implanted ZnO and SiC single crystals, annealed up to 1073K and 973K, respectively, show that the Fe^{3+} ions remain fairly constant in the crystals, while the Fe^{2+} show some reordering. Evidence of formation of ferromagnetic clusters is obtained on ZnO samples implanted with Fe^{57} at several energies giving a plateau distribution. These results will be presented and discussed.

AP/DM — Simulation of Radiation Damage and Testing of Materials for Nuclear Systems

AP/DM–01

Heavy Ion Irradiation Simulation of High Dose Irradiation Induced Radiation Effects in Materials

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Materials used for ADS, ITER, fast reactor, and so on, suffer very high dose irradiations of protons and/or neutrons. The yearly accumulated irradiation doses could reach a couple of hundred dpa in ADS, $\sim$ 40 dpa in fast reactors and $\sim$ 30 dpa in ITER's DEMO, producing severe radiation damage in materials and leading to a breakdown or accident of these installations. Investigation of such high dose irradiation induced radiation damage is a currently interesting topic with great importance. It is deeply hampered for lack of high dose neutron and proton sources. The heavy ion irradiation simulation technique has been developed at HI-13 tandem accelerator to investigate radiation damage encountered in the above mentioned installations. An experiment was carried out to verify the reliability and validity of heavy ion irradiation simulation. A series of experiments were performed by heavy ion irradiation simulation in combination with positron annihilation lifetime spectroscopy to investigate the temperature and dose dependence of radiation damage in stainless steels, tungsten, tantalum, etc. Some experimental results will be presented and discussed.

AP/DM–02

Modeling of Cascades and Sub-Cascade Formation in Materials Irradiated by Fast Charged Particles on Accelerators and by Fast Neutrons using Fission and Fusion

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A new theoretical model is developed and used for the investigation of cascades and sub-cascade formation in fission and fusion structural materials under fast neutron energy spectra corresponding to the fission and fusion reactors and fast charged particle irradiations. The developed model is based on the analytical consideration of elastic collisions between displaced moving atoms into atomic cascades produced by a primary knock atom (PKA) with the some kinetic energy getting from fast charged particles and fast neutron irradiations. The criterion of sub-cascade formation is based on the comparison of two calculated values: mean distance between two consequent PKA collisions and the size of sub-cascade produced by PKA. The Thomas-Fermi interaction potential is used for the describing of elastic collisions between moving atoms. The suggested model takes into account electronic losses of moving atoms between elastic collisions of them during the scattering process. The analytical relations for the most important characteristics of sub-cascade are determined including the average number of sub-cascades per one PKA in the dependence on PKA energy, the distance between sub-cascades and the average sub-cascade size as a function of PKA energy. The developed model allows determining the size distribution function in the

dependence on PKA energy. Based on the developed model the numerical calculations for main characteristics of sub-cascades in different materials are performed using the neutron flux and PKA energy spectra for fusion reactors: ITER, DEMO, IFMIF-Source and fission High Flux Irradiation Reactor (HFIR). So the total numbers of sub-cascades, distribution functions of sub-cascades in dependence on their sizes and generation rate of sub-cascades for different fission and fusion structural materials: Fe, V, W, Be, Cu and C are calculated for these fission and fusion irradiation conditions. The obtained numerical results for main characteristics of cascades and sub-cascade formation under fission and fusion irradiation conditions in these materials are compared with the same results obtained in these materials using different types of fast charged particle irradiations on cyclotron of RRC "Kurchatov Institute".

AP/DM–04

Application of a Plasma Accelerator of the Dense Plasma Focus Type in Simulation of Radiation Damage and Testing of Materials for Nuclear Systems

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We present some results of our experiments with use of a number of plasma accelerators of the Dense Plasma Focus type, namely PF-5M (IMET, bank energy – 5 kJ), PF-6 (IPPLM, 7 kJ), PF-10 (ITEP, 10 kJ), and the largest in the world DPF facility operating with deuterium as a working gas PF-1000 (IPPLM, 1.2 MJ). We use this set of devices for application in the field of radiation material sciences, in particular for Simulation of Radiation Damage and Testing of Materials intended for use in Thermonuclear Reactors (TNR) of both types – with magnetic plasma confinement (MPC) and with inertial plasma confinement (IPC).

These devices can produce *directed streams* of the same types of radiation and having the same parameters (density, temperature, spectrum, energy of fast particles, etc.), which are expected on the walls of the reactors' chambers, independently of their bank energy (it is clear that on different areas of a sample). Power flux density of plasma and fast ion/electron streams on the sample's surface during the experiments, which simulate conditions on plasma-facing components inside thermonuclear fusion reactors [1], may reach on the target's surface (on the face of a specimen under test) as much as 10^{10} W/cm^2. It is about those expected in the reactors with the inertial plasma confinement and much higher than those with the magnetic plasma confinement.

We describe results on the interaction of powerful deuterium plasma and fast ion/electron streams with specimens made of ferritic and austenitic steels, different alloys, tungsten, carbon-fiber-composites, various optical and ceramic materials, etc., which are counted as a candidate materials for use as plasma facing and construction components of TNR with MPC and IPC. In our analysis of the irradiation consequences we apply optical, scanning electron and atomic force microscopy, X-Ray elemental and structure analysis, ERDA, tribological methods, etc. Taking into consideration that the above materials are the main construction and plasma facing resources for I and NIF facilities, the results received are fruitful for estimations of prospects of their use in these reactors as well as in the next generation of nuclear fusion reactors. Some recommendations on the use of these materials will be presented.

1. V.N. Pimenov, E.V. Demina, S.A. Maslyaev, L.I. Ivanov, V.A. Gribkov, A.V. Dubrovsky, Yu.E. Ugaste, T. Laas, M. Scholz, R. Miklaszewski, B. Kolman, A. Tartari, *Damage and Modification of Materials produced by Pulsed Ion and Plasma Streams in Dense Plasma Focus Device*, Nukleonika,**53**, No. 3, (2008) 111-121.

AP/DM–05

Test Simulation of Neutron Damage to Electronic Components and Circuits Using Accelerator Facilities

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Historically, fast burst reactors have been used to test the transient response of electronic systems to displacement damage and ionization. With the shut down of several fast burst reactor facilities, there is an ongoing effort to use alternative facilities and radiation types, such as heavy ions, to simulate the displacement damage of neutrons, and electrons to simulate reactor ionization. The concept of damage between these two types of irradiation is a topic of much interest and controversy. This paper examines the relations between several measured damage metrics of electronic components and circuits after irradiation by reactor neutrons and by heavy ions generated in particle accelerators. Metrics considered include measured early- and late-time gain degradation in silicon bipolar junction transistors, the type and number of defects as measured in deep level transient spectroscopy (DLTS), and voltage output responses of circuits. We will also compare the difference in ionization effects produced by neutron and ion irradiations, as well as electron irradiation. The paper also examines circuit test methodologies required when tests are fielded at diverse facilities, such as a reactor and an ion facility. Reactor facilities used to test electronics include the Sandia National Laboratories Sandia Pulsed Reactor–III (SNL SPR–III) and Sandia National Laboratories Annular Core Research Reactor (SNL ACRR). The ion facility used in this work is the SNL Ion Beam Laboratory (IBL). A 6 MV tandem Van de Graaff and numerous ion sources allow the IBL to provide a wide variety ions and energies. The electron facility addressed is the Little Mountain linear accelerator (LINAC), located at Hill AFB in Utah, operated in electron beam mode. The electron irradiation is used to bound the complex contributions of ionization effects on the device observed at the IBL. Little Mountain has a unique capability among LINACs in that it can provide long pulse widths. Pulse widths can be tailored from 50 μsec to 50 nsec settings with beam currents ranging from 0.1 to 2 Amps. In summary, we will demonstrate that alternate facilities, such as the IBL, have great utility in replacing the use of fast burst reactors to test discrete silicon transistors when the appropriate damage metrics are selected. We intend to expand the approach of using alternate facilities to circuit applications.

AP/IA — Different Aspects of Industrial Accelerator Applications

AP/IA–03

Electron Beam Flue Gas Treatment (EBFGT) Technology for Simultaneous Removal of SO_2 and NO_x from Combustion of Liquid Fuels: Technical and Economic Evaluation

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Among emerging technologies for Environmental Protection, Electron Beam Flue Gas Treatment (EBFGT) technology is the most promising and was already implemented in few industrial plants in different parts of the world. In order to evaluate the potential of implementing BFGT technology in the case of flue gas generated during fuel oil combustion, Saudi Arabian Oil Company (Saudi Aramco) initiated a project entitled “Feasibility Study for Electron Beam Flue Gas Treatment (EBFGT) at Oil Fired Boiler” which was conducted by King Abdulaziz City for Science and Technology (KACST) and Institute of Nuclear Chemistry and Technology (INCT) in Poland. The detailed study of this process was performed in a laboratory by irradiating the exhaust gas from the combustion of three grades of Arabian fuels with an electron beam from accelerator (800 keV, max. beam power 20 kW). SO_2 removal is mainly dependent on ammonia stoichiometry, flue gas temperature and humidity and irradiation doses up to 8 kGy. NO_x removal depends primarily on irradiation dose. High removal efficiencies up to 98% for SO_2 and up to 82% for NO_x were obtained under optimal conditions. Flue gas generated during heavy oil combustion is characterized by high humidity, high sulfur dioxide content and relatively low nitrogen oxides concentration. In spite of this, the process is similar to that of flue gas from coal fired boilers. The flue gas emitted from combustion of high-sulfur fuel oils after electron beam irradiation meets the stringent emission standards for both pollutants.

The by-product, which is a mixture of ammonium sulfate and nitrate can be used as a fertilizer as such or blended with other components to produce commercial agricultural fertilizer. In addition, general concept of EBFGT installation for oil fired boilers and basic operational parameters are presented. On this basis economic analysis of investment and operational costs of the installation is also presented and factors affecting costs of the installation are discussed.

AP/IA–04

Radiation Curing of Composites for Vehicle Component and Vehicle Manufacture

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Some traditional uses of metals in vehicle component and vehicle manufacture, such as steel (specific gravity 7.8) or aluminum (specific gravity 2.7), can be replaced by carbon-fiber composites (specific gravity 1.6) to provide significant weight savings while maintaining structural integrity. The aerospace and aircraft industries have adopted this approach. The auto or motor vehicle industries have explored the use of composites, but have been reluctant to widely adopt this technology because of concerns over manufacturing processes. A typical steel auto body weighing $\sim$ 750 kilos would weigh only $\sim$ 155 kilos if replaced with carbon-fiber composites. Structural members, as the vehicle chassis, could also be fabricated out of carbon-fiber composites. With only 20% of the body weight, smaller, lower horse-power and more fuel efficient engines could be used to power such vehicles. Commercial aircraft manufacturers that have adopted carbon-fiber structures in lieu of aluminum (a 40% weight savings) estimate a 20% savings in fuel costs for large planes. These are still made with conventional materials being used for motors, tires, interiors, and the like. A fuel efficient auto now running at $\sim$ 10 kilometers/liter would more than double its fuel efficiency given the nearly 80% weight savings attainable by use of carbon-fiber composites just for the vehicle body. As with aircraft, conventional systems for propulsion (motors), braking, tires and interiors could still be used.

Radiation curing can simplify the manufacture of carbon-fiber composite vehicle components. Highly penetrating X-rays derived from high current, high energy electron beam (EB) accelerators can be used to cure structural composites while they are constrained within inexpensive molds; thus reducing cure cycles, eliminating heat transfer concerns and concerns over potentially hazardous emissions during the curing process. Since X-rays can penetrate mold walls, the curing process is quite versatile, enabling diverse components with varying designs to be cured using a common X-ray source or multiple parts of the same design could be cured at once. Since the energy output of an EB unit can be tightly controlled, EB processing itself can be used to produce "B" staged fiber-reinforced composite materials for sheet molding (SMC) and prepregs. Such materials can significantly reduce the time-to-cure should alternative energy sources or even subsequent X-ray curing be used. In the EB mode, SMC materials can be made in excess of 100 meters/minute. The matrix systems are proprietary formulations based on common radiation responsive materials used in a variety of radiation curing applications.

AP/IA–05

Focused Ion Beam Writing of Optical Patterns in Amorphous Silicon Carbide

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In the present work we investigate the use of ion beam techniques for properties modification and optimisation of wide-bandgap materials with view of their uses in sub-micron lithography and high-density data storage for archival purposes. We propose scanning near-field optical microscopy as a novel technique for characterizing the ion-implanted patterns fabricated in amorphous silicon carbide (a-SiC:H). Different patterns have been fabricated in a-SiC:H films with a focused

Ga^+–ion beam system and examined with scanning near-field optical microscopy and atomic force microscopy. Although a considerable thickness change (thinning tendency) has been observed in the ion-irradiated areas, the near-field measurements confirm increases of optical absorption in these areas. The observed values of the optical contrast modulation are sufficient to justify the efficiency of the method for optical data recording using focused ion beams.

AP/IA–06

Use of the Accelerators in the Socio-Economic Development in Tunisia

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Tunisia is an agricultural and industrial country located in a strategic position on Mediterranean sea. Economic constraints are forcing Tunisia in adopting certain technologies such as radiation technology which is competitive and its demand for medical and industrial applications is continuously increasing ($5 - 10\%$ per annum). This technology is playing a great role in improving the quality (sanitary) of food stuffs, medical devices and healthcare products mainly dedicated for export to European union countries. According to this purpose, Tunisia began the use of radiation technology in 1999 with the setting up of pilot plant γ irradiation facility located in National Centre for Nuclear Sciences and Technologies (CNSTN) with initial activity of 100 000 Curies. The Centre is completing its irradiation facilities by establishing a semi-industrial electron beam accelerator (variable energy, from 5 to 10 MeV and maximum power of 5 kW expandable to 10 kW) which is planned to be exploitable in the middle of 2009.

This paper will highlight the recently and ongoing promising research and development applications of radiation technology in Tunisia in the fields industry, food irradiation and preservation of art objects.

AP/IA–07

Ion Cancer Therapy in China

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The heavy-ion cancer therapy researches started in 1995 at the Heavy Ion Research Facility in Lanzhou (HIRFL) in the Institute of Modern Physics (IMP). The first vertical beam terminal for the heavy-ion cancer therapy was constructed in 2005 at HIRFL, where a passive beam delivery system of two-dimensional and three-dimensional conformal irradiations has been used. It consists of a pair of orthogonal dipole scanning magnets, range shifter, range modulator (ridge/ripple filter), and a multi-leaf collimator. In November 2006, the first clinical trials of superficially-placed tumor therapy with ~ 100 MeV/u carbon ions delivered from two combined cyclotrons SFC ($K = 69$) and SSC ($K = 450$) were carried out. Up to September 2008, totally 82 patients were treated for different kinds of tumors such as squamous cell carcinoma, basal cell carcinoma, malignant skin melanoma, sarcoma, lymphoma, skin breast cancer, metastatic lymph nodes of carcinomas and so on. The majority of tumors disappeared completely and the local control rates are more than 90%. No obvious side-effects and no local recurrence have been observed.

In 2000, a new ion cooler-storage-ring project was started at HIRFL. It consists of a main ring (CSRm) for accumulation and acceleration as well as an experimental ring (CSRe) for high precise measurement. In November 2008, carbon ions with the different energies were successfully slow extracted from the CSRm to the horizontal treatment terminal served for deep-seated tumor therapy. The first depth-dose distribution for carbon ions in water was measured. The cancer therapy for the deep-seated tumor with carbon ions will be started in the end of 2008. Due to the excellent clinical success of the heavy-ion cancer therapy, up to now more than five heavy-ion facilities are proposed in China.

AP/IA–08

The Proton Engineering Frontier Project

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The Proton Engineering Frontier Project (PEFP) was launched, in 2002, to establish an advanced research facility based on a high power 100 MeV, 20 mA proton linac, and to cultivate and expedite core scientific and industrial R&D programs by utilizing high quality proton beams. The PEFP proton linac consists of a 50 keV ion source, 3 MeV RFQ (Radio Frequency Quadrupole), and 100 MeV DTL (Drift Tube Linac), from which the proton beams can be extracted at either 20 MeV or 100 MeV and delivered to five target stations at each energy with distinguished beam conditions.

The upstream part of the PEFP proton linac, up to 20 MeV DTL, has been successfully developed and commissioned to meet the designed performance in beam energy and peak beam current. The higher energy part is under fabrication and the full system is to be completed in 2012 as scheduled. Along with developing the proton linac, the PEFP has developed a dedicated user program to nurture and foster scientific and industrial R&D by using the proton beams, and made promising progresses.

The paper describes the specifications of the PEFP proton linac and reports the status of the proton linac development and progresses made by the user program. In addition, the future expansion options and related R&D activities will be briefly covered.

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AP/IA–10

Opportunities of Basic and Applied Research at MedAustron

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MedAustron is a planned centre for hadron therapy and diagnosis in Austria. The central unit of this centre is a synchrotron which should deliver beams of protons up to 800 MeV/c and carbon ions up to 400 MeV/c per nucleon with intensities of 10^{10} protons/s and 4×10^8 ions/s, respectively. Although the accelerator is primarily dedicated to clinical application, its use for non-clinical research is foreseen for nights, weekends and holidays. In a recent study we clearly indicated the potential of the facility for basic and applied research in physics and technology. Especially, the wide range of intermediate energies delivered by the foreseen accelerator is of interest. It allows the setup of a proton scattering facility for basic research as well as the use of the beam to perform tests of detectors for nuclear and particle physics. The facility offers also opportunities to implement selected applications, e.g., in materials research and in dosimetry. In this contribution we present the outcome of our study and discuss the most appealing applications and possibilities for non-clinical research at such a synchrotron of a hadron therapy centre. In addition we will also discuss the importance of this infrastructure for education and training of young researchers in Austria.

AP/IA–11

ARRONAX, a 70 MeV Cyclotron for Radiochemistry and Nuclear Medicine

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ARRONAX means: "Accelerator for Research in Radiochemistry and Oncology at Nantes Atlantic". ARRONAX is also a veiled reference to Professor ARRONAX, a character in Jules Verne's novel "Twenty thousand leagues under the sea". Jules Verne was born in Nantes in 1825. This large equipment is being installed at Saint-Herblain, in the outskirts of Nantes, on the campus of the University Hospital and of Cancer Center.

ARRONAX aims at producing innovative radionuclides for research in nuclear medicine and at performing research in radiochemistry on radiolysis (study on radiation effects on living or inert matter). For research in nuclear medicine the main domain of application is diagnostic (PET imaging) and therapeutic (radionuclide therapy) oncology. Another application is PET imaging in cardiology. Radiolysis is the second facet of the research project. ARRONAX will provide a privileged tool, one the one hand, to better determine the confining quality of radioactive waste containers and, on the other hand, to test devices submitted to radiations (like e.g., spatial electronic).

The ARRONAX project leaders are the University of Nantes and the Regional Council of "les Pays de la Loire" in cooperation with CNRS (National Scientific Research Center), INSERM (National Institute of Health and Medical Research), the University Hospital, the Cancer Center and the engineering school "Ecole des mines". The scientific initiators are: Jacques Barbet and Jean-François Chatal (Inserm-University of Nantes), Jacques Martino (Subatech, CNRS, "Ecole des mines", University of Nantes) and Yves Thomas (division of economic development at the University of Nantes). The global cost of 34.5 million Euro has been shared between : the regional and local authorities for 19.5 M€; the French State for 8.6 M€; the European Union for 6.4 M€. The annual operating budget is provided by the funding agencies: CNRS, INSERM, University of Nantes, University Hospital, Cancer Centre, and Ecole des mines; and is supplemented through contracts with industrial partners.

Summer 2009. ARRONAX will be unique through the combination of several characteristics:

- a 70 MeV energy whereas the energy of the majority of biomedical cyclotrons does not exceed 30 MeV;
- a maximal proton intensity of 750 μA whereas the intensity of the majority of biomedical cyclotrons does not exceed 100 μA;
- the possibility to accelerate protons, deuterons and alpha particles whereas the majority of biomedical cyclotrons accelerate only protons.

ARRONAX is built thanks to a joint initiative of Subatech laboratory (CNRS, Ecole des mines, University of Nantes) and Research Center of Oncology in Nantes (Inserm, Université of Nantes) for which it is a major research instrument. But ARRONAX is also open to projects originating from any interested academic research laboratories in Europe and also, under conditions to be defined, to industrial partners. All projects will be evaluated by an international scientific committee which will propose the related priorities.

AP/IA–12

Review of Industrial Accelerators and their Applications

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Of the particle accelerators that have been manufactured by for-profit entities worldwide, about half are used for industrial applications. These industrial systems utilize a wide range of accelerator technologies, including direct voltage systems, RF and microwave linacs, and cyclic accelerators. They accelerate either electrons or ions with energies and currents spanning more than six orders of magnitude. Their numerous applications cover a broad range of business segments from low energy electron beam systems for welding, machining, and product irradiation to high energy cyclotrons and synchrotrons for medical isotope production and synchrotron radiation production. Although industrial accelerator manufacturing is not a high profile business, these systems have a significant impact on people's lives and the world's economy, as so many commonly-used materials and products, both durable and consumable, are processed by charged particle beams. Wide scale industrial use of many of these processing tools has resulted in the rapid growth of the industrial accelerator business. This paper is a review of the current status of this business worldwide, including the technologies, the applications, the vendors and the market sizes.

AP/IE — Interdisciplinary Endeavours

AP/IE–01

Long-Lifetime High-Yield Neutron Generators Using the D–D Reaction

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The Lawrence Berkeley National Laboratory and Adelphi Technology Inc. have developed a series of high-yield neutron generators using the D–D reaction with an axial geometry. They operate with a single ion beam and can have a small source size useful for fast neutron radiography. The generator uses RF induction discharge to efficiently ionize the deuterium gas. This discharge method provides high plasma density for high output current, high atomic species from molecular gases, long life operation and versatility for various discharge chamber geometries. These generators are open systems that can be actively pumped for a continuous supply of deuterium gas further increasing the generator's expected lifetime. Since the system is open, many of the components, including the target, can be easily replaced. Maximum measured peak yield from one of the generators is 2×10^9 n/s and higher yields are expected to 10^{10} n/s. Pulsed and continuous operation has been demonstrated. Several of the generators have been enclosed in moderators and shielded for both neutrons and x-rays. In this mode of operation these generators have been used for Prompt Gamma Neutron Activation Analysis (PGNAA) and Neutron Activation Analysis (NAA). Fast neutron radiography has also been demonstrated using a newly developed camera.

AP/IE–02

Neutron Transmission: A Very Powerful Technique at Small Accelerator-Based Neutron Sources

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The determination of total cross section of a material as a function of neutron energy by means of transmission experiments is rather easy on a pulsed neutron source. The spectrometer and associated instrumentation required may be described as relatively simple, and sound statistical data are achieved even using a small, accelerator-based neutron source. Despite its simplicity, detailed scientific and technological information can be extracted from such measurements, at the cost of fairly elaborate data analysis techniques. These features make this an attractive tool for neutron-based materials research within small research groups.

Different physical properties of a material manifest over the different neutron energy ranges. At our group we have focused on the determination and analysis of the total cross section for thermal and sub-thermal neutrons, which is very sensitive to the geometric arrangement and movement of the atoms, over distances ranging from the "first-neighbour scale" up to the microstructural level or "grain scale".

We will describe our experimental facilities, based on a 25 MeV electron LINAC, together with our current research topics, focused mainly around structural nuclear materials and moderators.

Besides this, we will present current efforts aimed at expanding the variety of problems feasible to be studied by neutron transmission experiments. These efforts comprise experimental work for reducing experimental counting times, and maybe more importantly, theoretical and programming work aimed at producing a powerful data-analysis program for efficient materials characterization.

We will show examples illustrating the use of neutron transmission for the study of crystalline materials. In particular we will present non-destructive studies dealing with the identification and quantification of phases, lattice parameters and preferred orientation in zircaloys, metal hydrides, steels, and copper-based alloys.

AP/IE−03

Nuclear Cross-Section Measurements at the Manuel Lujan Jr. Neutron Scattering Center

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The Los Alamos Neutron Science Center (LANSCE) is a versatile user facility built around a proton linear accelerator. The 800-MeV proton beam is used to generate spallation neutrons in the Weapons Neutron Research (WNR) facility and the Lujan Center (LC) optimized for nuclear physics and materials science research, respectively. Even though the LC facility is used extensively for material research, two out of sixteen neutron flight paths (FP-5, FP-14) are devoted to nuclear physics experiments. The nuclear physics experiments (fission, neutron capture) carried out at these flight paths provide vital contributions to the nuclear data evaluation efforts. Better understanding of the systematic uncertainties of the experiments provides higher-quality data sets to the evaluators and allows for generation of reliable covariance matrices to be included in next releases of nuclear data libraries.

LC facility's target is a rather complex system consisting of many different materials, requiring a very detailed geometry description in our calculation model. We will discuss our extensive Monte Carlo study carried out for the nuclear flight paths of the LC facility. The influence of the time distribution of the primary beam on the final response function of the LC target system will be presented. Our results will be compared to the experimental data showing a direction of actual implementation in the real data analysis.

AP/IE−04

Application of Nuclear Microprobe in Biomedical, Industrial and Fusion Research

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Nuclear microprobe at 2 MV Tandetron accelerator of Jožef Stefan Institute (JSI) was constructed in the year 2000 with the support of IAEA Technical Cooperation Project SLO/1/004. The measuring station is equipped with instrumentation for micro-Proton-Induced-X-ray-Emission (micro-PIXE), micro-Elastic Recoil Detection Analysis (micro-ERDA), micro-Nuclear Reaction Analysis (micro-NRA), Proton Beam Writing (PBW) and confocal PIXE.

Micro-PIXE elemental mapping in biomedical research has been established as routine analytical method at JSI tandetron laboratory for collaborators from biomedical fields. Research results from the last two years include, among others, elemental distribution in the leaves and seed of Cd/Zn hyperaccumulating plant Thlaspi Praecox [1] grown in heavy-metal polluted area, leaves of halophyte plants, elemental distribution of buckwheat seed, elemental contents of wood, lichen arsenate uptake [2] etc. From analytical point of view, some results of elemental mapping measured at thick biological samples, such as wood and plant seed, on the samples of micrometer thickness produced by dedicated procedure of sample shock-freezing, cryotome cutting and freeze-drying,

and even interesting example of brain tissue of mercury miner sampled for pathological depot over a decade ago and recently retrieved for Hg/Se analysis will be presented.

On the other hand, the intensifying research associated with the construction of the future thermonuclear reactor ITER is expressing in the development of the techniques for detection of hydrogen isotopes in the tokamak wall materials. Hydrogen microdistribution in the exposed tokamak wall materials are measured by micro-ERDA using focused 4.5 MeV ^{7}Li beam. Post-mortem micro-ERDA analyses of tokamak plasma-exposed surfaces were combined with simultaneous X-ray emission to understand erosion-redeposition processes in the tokamak walls. Micro-ERDA has been also recently used for determination of hydrogen concentrations in titanium alloys for industrial customers. In addition, micro-NRA for deuterium mapping has been established with ^{3}He beam using nuclear reaction D(^{3}He,p)^{4}He. Carbon fiber composites, the candidate materials for the ITER divertor, were exposed to the deuterium plasma inside tokamak Textor. Deuterium penetration depth was then determined by micro-NRA [3].

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AP/IE–05

A New Positron Emission Particle Tracking Facility at iThemba LABS

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Positron emission particle tracking (PEPT) has become a powerful tool for in-situ characterisation of particulate flow within aggressive industrial environments, such as tumbling mills and powder mixers. PEPT is based on the tracking of a single tracer particle which has been labelled with a radionuclide that decays via β^{+} decay. The location of the particle is obtained by the triangulation of events associated with the detection of pairs of annihilation γ rays in a modified "positron camera". One of the challenges facing PEPT is associated with labelling sub-millimetre sized particles which would allow studies in systems of finer particulate flow, such as flotation cells. The Positron Imaging Centre at the University of Birmingham is currently the only operational PEPT facility in the world. We are presently installing a PEPT laboratory at the iThemba LABS cyclotron facility in Cape Town. Details of this new facility will be presented, together with a flavour of recent PEPT data obtained in Birmingham, and results from our accelerator-based studies at iThemba LABS which are aimed at extending the state-of-the-art in the size and type of labelled tracer particles for PEPT work.

AP/IE–06

Neutron Imaging at Spallation Neutron Sources

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Neutron imaging is a powerful method for non-destructive investigations where the high penetration through metals and the high contrast for hydrogenous materials is exploited in particular. The complementary to X-ray studies is a clever alternative in many cases of scientific and industrial applications. Reactor based neutron sources are becoming less available, caused by the shutdown of aged facilities. Accelerator driven neutron sources, in particular spallation sources, can provide similar performance also for imaging now, when digital imaging systems are utilized. The article shows the properties of imaging beam lines at SINQ, the currently strongest stationary spallation

source. They deliver thermal neutrons as well as cold ones. Several beam line properties such as collimation, field-of-view, neutron energy and spatial resolution can be changed and adapted to the conditions of the various experiments. The imaging methods include transmission radiography and time-dependent studies. In addition, advanced methods like tomography and refraction enhancement are provided. New aspects like quantitative tomography, phase contrast imaging and imaging with polarized neutrons are under consideration and implementation.

A new and challenging aspect will be the use of the pulse structure of newly available large spallation sources like SNS, JPARC or ISIS–TS2 for imaging purposes. Despite the high peak intensity, which can be used for the study of fast repetitive processes, a time–of–flight imaging approach will enable energy resolved investigations. This is of particular interest at energies near the Bragg edges of structural materials, where textural changes (e.g., near welds) become directly visible. First data from this kind of investigations underline the importance of the new methodical approach.

AP/IE–08

Simulation of Light Ion Collisions from Intra Nuclear Cascade (INCL-Fermi Breakup) Relevant for Medical Irradiations and Radioprotection

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An increasing interest is now well established for the treatment of tumors by irradiations with light ion beams (especially Carbon) of a few 100 MeV per nucleons. Similar problems occur at higher energy for the radio-protection of manned spacecraft irradiated by cosmic rays of protons and heavy ions with a wide energy spectra around 1 GeV per nucleon.

A good modelization starts at the nuclear level with codes able to predict the double differential cross sections of the various outgoing channels for a variety of targets and beam nature and energy. Light ions (He, C, O, Ca) are especially important in this context.

The intranuclear cascade code INCL4 has obtained many successes in the frame work of spallation physics, especially for the detailed production of neutrons and of residual nuclei but for rather heavy targets (above aluminium) and with protons or α projectiles. However, it should be noted that α beams were a lot less tested.

We have recently extended the possibilities of INCL4 to light ion induced reactions by adding a more precise treatment of the spectator nucleons from composite projectiles (α now up to C or O) and coupling it to a Fermi break-up model. This Fermi break-up (standard) is used dynamically for the projectile spectators and for the remnant nuclei produced after the cascade. Calculations with thick targets (including a transport of particles) are also possible with this version also introduced as a physics model in GEANT4.

We will present the model and encouraging test calculations on n production, fragmentation of the projectile and residual nuclei production for light projectiles, various targets especially light ones (C to Al) at various energies (90A MeV to 400A MeV).

AP/IE–09

Scientific Program of SESAME Project

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The synchrotron radiations emitted by a charged particle in motion while accelerated or decelerated is a very useful tool in field of research related to various important areas of physical and biological sciences. The board energy spectrum and flux provided by a synchrotron source can be used for various applications. Some of the applications include lithography, food preservation, study of environment, archaeology, and mineral mining using XRF. Synchrotron-light for Experimental Science and Applications in Middle East SESAME is a project, which is established under auspices of UNESCO as intergovernmental organization with following members: Bahrain, Cyprus, Egypt, Iran, Israel, Jordan, Pakistan, Palestine Authority, and Turkey.

SESAME is a third generation light source with beam energy of 2.5 GeV, beam current of 400 mA, emittance 26nm.rad and circumference of 133.2 m. It is under construction close to Amman – Jordan and will become operational end of 2012 or beginning of 2013. SESAME contains 16 straight sections out of which 13 straight sections are available for placing insertion devices such as undulator and wigglers.

An extensive scientific programme has been established with the help of Scientific Advisory Committee (SAC) and the Beamline Advisory Committee (BAC). From the beginning 7 beamlines are planned for Phase — I covering diverse areas of scientific interest such as: SAXS/WAXS, PX, IR, Soft X-ray, Powder Diffraction, XRF/XAFS and Atomic, Molecular spectroscopy (AMO) beamline. SESAME once operational will be a very competitive machine in the category of third generation light sources.

AP/P2 — Poster Session P2

AP/P2–01

The Profiling Measurements on Metal Ion Distribution in CTA Polymeric Inclusion Membranes by Rutherford Backscattering Spectrometry

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Polymer inclusion membranes based on cellulose triacetate polymer, containing 2-nitrophenyloctyl ether as plasticizer and the crown dioctylphosphyl (TOPO) as a fixed carrier were prepared were studied by backscattering spectrometry technique to measure the distribution of the metal ions across the membrane using (p, α) beam from the 3.75 MV VDG accelerator at Nuclear Research Center (CRNA). The sample was mounted at normal incidence with respect to the beam in a scattering chamber of 80 cm diameter. Simulation is done by SIMNRA software. The results of this study suggest that RBS may offer advantages in a wide range of membrane materials analysis applications. The ability to accurately measure the thickness and composition of thin polymeric layers using RBS offered a means of analyzing complex structures in which metals are adsorbed. RBS provided an accurate tool to determine the elemental composition, thickness and roughness of the membrane. The oxygen-to-carbon and the molybdenum to phosphor ratio obtained for CTA membranes were obtained. Changes in physico-chemical properties of the polymers were assessed by model fitting of the RBS spectra, oxygen was found to be the most unstable element in this investigation.

AP/P2–02

A Comparative Study of the On-Surface Diffusion of the Ternary System Au/Pd/Si(111) Under the Influence of Ion Implantation

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A study of the influence of ion implantation on the on-surface diffusion of a ternary system was elaborated by making a comparative study of the same ternary system, which consisted of the deposit of two metal coats (layers), Gold and Palladium, on (111) monocrystalline Silicon substrates, with and without preliminary ion implantation. So, three different series of samples were obtained and subjected to a vacuum heat treatment in temperatures varying from 200 to 800°C and with a time in steps of 200°C and with time of annealing of annealing fixed to 30 min.

The first step consisted of ion implantation of a pair of (111) monocrystalline Silicon substrates which was realized using the ion implanter facility available at the CNRS/STRASBOURG-FRANCE, with two different ions species, Phosphorus and Argon, accelerated to 50 keV and a flux of 1×10^{16} ions/cm^2. The deposits of both metal coats (layers) were successively made without

breaking the vacuum in the evaporator. The substrates of Silicon had undergone beforehand a chemical treatment by the CP_4 method to avoid the effect of Oxygen barrier. Then we proceeded, simultaneously, to the annealing of each group of samples (the first two were implanted and the other one without ion implantation) in order to maintain exactly the same conditions for all of them.

So, we were able to obtain a series of samples, the characterization of which was carried out by the various techniques available in the CRNA among which we selected: the Rutherford Backscattering Spectrometry (RBS), X-rays diffraction (XRD) and the scanning electronic microscopy (SEM) with its incorporated X-rays Energy Dispersal (XED) technique.

These combined analyses allowed us to fulfil a comparative study of the interdiffusion between the various elements included and to follow the thermodynamics transformations that have arisen. The reaction dependence due to the influence of the ion implantation is also shown.

AP/P2–03

Nuclear Reaction Analysis (NRA) of Silicon Samples Doped by Trimethylphosphine $P(CH_3)_3$

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Nuclear reaction analysis (NRA) is well established as one of the methods in ion-beam analysis (IBA) of materials. Complementary to Rutherford backscattering spectrometry (RBS), the NRA technique is suitable for quantitative analysis of light elements in near surface solids (up to about one micron) containing heavy elements.

There are many prominent features of NRA, including high selectivity of isotopes, good sensitivity for many nuclides, capability of non-destructive depth profiling, accurate and quantitative analysis, and possible simultaneous analysis of multiple elements.

Moreover, for many elements (e.g. O, C, N, F, Al) the use of a deuteron probing beam (rather than protons or helium) can give enhanced sensitivity and accuracy, owing, mainly to large nuclear reaction cross sections.

Analysis of carbon and oxygen in the near surface region of solids is of particular importance in many applications. The most important reactions for the determination of concentrations of carbon and oxygen in heavy matrices are the $^{12}C(d,\ p_0)^{13}C$ and $^{16}O(d,\ p_1)^{17}O$ reactions, respectively. The relatively low deuteron energies required, render these reactions especially useful for small accelerators.

The aim of this works is to determine the concentration of carbon and oxygen in thin films of hydrogenated amorphous silicon (a-Si_xC_y:H) deposited on silicon substrate by pulverization DC magnetron. During the pulverization, a trimethylphosphine ($P(CH_3)_3$), carried by argon gas at different pressure, is introduced in the deposit chamber. We obtain a layers of a-Si_xC_y:H doped with phosphorus. In this study we determine the stoechiometry (Si and C) and we tentatively correlate C and the P contents using the reaction $^{31}P(d,p)^{32}P$ at about 900 keV deuteron energy. The P concentration cannot be given at this stage owing to the lack of nuclear cross section data for this reaction. These stoechiometries are equally correlated to the deposition conditions.

AP/P2–05

High Ion Irradiation Tolerance of Multilayered AlN/TiN Nanocomposites

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High strength multilayered metal or composite nanostructures are interesting as radiation protective materials, because of a large number of interfaces that act as obstacles to slip and sinks for radiation induced defects. In the investigations reported to date, mainly multilayers of immiscible metals were studied, such as Cu/Nb, W/Ni, Cu/W or Mo/Cu. This study reports on the stability of nanocrystalline AlN/TiN multilayers upon argon ion irradiation. The AlN/TiN system was chosen because it exhibits high strength and temperature stability, and the constituents are immiscible. Reactive sputtering was used to deposit (AlN/TiN)×5 films on (100) Si, to a total thickness of ∼ 270 nm. Argon ions were implanted at 200 keV, the projected ion range being around mid-depth of the deposited structures. The applied fluences were high enough to induce a marked intermixing in normally soluble or chemically reactive materials. Structural characterizations of the samples were performed by Rutherford backscattering spectrometry (RBS), X-ray photoelectron spectroscopy (XPS) and transmission electron microscopy (TEM). It was found that the investigated AlN/TiN multilayers exhibit a remarkable ion irradiation stability. Ion irradiation induced a slight increase of the mean grain size in individual layers, from ∼ 10 nm to ∼ 20 nm, and small local density changes around the projected ion range. Apart from this, no distinct intermixing of the layers was observed. Also, the interfaces remained sharp after irradiation to all the applied fluences, which is crucial for structural stability of multilayered structures. The results were compared to other systems and analyzed in terms of the existing ion beam mixing models. The net mixing rate found was below the predictions of the ballistic model. In fact, in immiscible systems thermal spikes and chemical driving forces invoke dynamic demixing, when the knocked on particles are driven back across the interface. In conclusion, the results obtained in this study suggest that immiscible metal-nitride multilayers should attract further attention as radiation tolerant materials.

AP/P2–06

Ion Beam Processing of Polymers as Biomaterial

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Our workers have studied the interaction of MeV ion in its track with large number of polymer types in order to tailor their properties for aerospace applications, and medical applications, control cell adhesion, improved surface properties of polymers used for heart-valve, for hip-joint implants, for fabrication of nano-pours used for DNA-sequencing and for filtration, as well as change in the surface properties of bio-compatible polymers for control drug/medication delivery.

Chemical changes are produced in plastics by the ionizing radiation interacting with the polymer material resulting in the liberation of electrons from the atoms of the polymers. Radiation induces modifying processes in the polymer chains that produce chemical changes in the materials' properties. These processes can occur separately or in combination with one another and, depending on the nature of the material, one or more can occur simultaneously. Molecular excitations may be transmitted through the material as phonons or excitons which may cause bonds to break and produce scission, and cross-linking of the polymer chains. In many cases, dissociated hydrogen atoms and other small molecules move through the material and diffuse out as volatile species are formed. Dehydrogenation or the liberation of hydrogen atoms produces dangling bonds which eventually saturate and results in cross-linking. Other molecular emission processes, double bond

formation, triple bond formation, dipole formation and precipitate formation by self clustering of the injected species can also occur. Our studies have revealed the effects on the polymers by radiation using energetic ion beams and have allowed us to modify the polymers as a result. This is a review paper of this work at the Center for Irradiation of Materials of AAMU and resulting applications.

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AP/P2–07

Optimisation of Beam Optics in the Van de Graaff Accelerator Microbeam at iThemba LABS and its Results on the Biomedical Analysis

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To improve the beam quality and intensity of the Van de Graaff accelerator at iThemba LABS, it is important to know the beam optics from the ion source. The ion source characteristics and optimal operating conditions were determined on an ion source test bench. The results of microbeam obtained with different computer codes are compared and discussed. The capabilities of the nuclear microprobe facility were evaluated in the improved beamline, with particular emphasis to biomedical samples such as human hair, kidney stones and teeth. As a result of these improvement applications of PIGE, PIXE and RBS techniques performed and this showed significant sensitivity. As well measurements carried out to compare elemental content and spatial distribution within scalp hair-shaft cross sections of two distinct human population groups, and to assess possible similarities and/or differences, hair samples from Sudan and South Africa were collected. Proton backscattering and Micro-PIXE were used to determine the matrix composition and content of light and middle transition elements. Mapping analysis showed a relatively similar content distribution for S, Cl, K and Ca within each group. However significant differences, particularly for heavier metals, such as Fe and Zn were also found. Correspondence Analysis of the data showed a clear separation between the two groups when the total content over the hair cross section was considered.

AP/P3 — Poster Session P3

AP/P3–06

Magnetism in Rare Earth Nickelates Studied by Muon Spin Rotation

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The metal to insulator transition at T_{MI} and related changes in structure and magnetic behavior in the rare-earth nickelates $RNiO_3$ have been intensively studied in recent years. Evidence for charge disproportiona-tion occurring at Ni in $EuNiO_3$, $NdNiO_3$ [1,2] and $YNiO_3$ [3] comes from Mössbauer spectroscopy using ^{57}Fe substituted for Ni as nuclear probe. For both $EuNiO_3$ and $YNiO_3$ T_{MI} is much higher than the Néel temperatures of T_N = 210K and 150K, respectively. This is in contrast to the nickelates with larger R (like Nd) where T_{MI}, T_N and a structural transition are coinciding.

We have performed muon spin rotation (μSR) experiments at SμS PSI, Switzerland, both for $EuNiO_3$ and $YNiO_3$ to trace the magnetic ordering and also the influence of doping. Whereas in other $RNiO_3$ the magnetic response is dominated by the moments of R, we have here the advantage of vanishing or nearly vanishing contributions from the Y and Eu moments allowing an undisturbed study of the Ni sublattice.

The $EuNiO_3$ susceptibility is untypical for an antiferromagnet. The moment is increasing below T_N and saturating only below about 120K. We relate this to induced moments caused by mixing with higher crystal electric field states to the $J = 0$ ground state of Eu^{3+}. With μSR in zero magnetic field we observe muon spin rotation at several muon sites in completely magnetically ordered surrounding below T_N = 210K. From the frequencies we conclude that the ratio of valence of the disproportionated Ni species cannot be more than about 50% in contrast to the Mössbauer data of the Fe doped samples. For $YNiO_3$ we find similar μSR results with T_N = 150K, yet with significant differences due to the diamagnetism of Y. Notably both compounds reveal significant changes in magnetic response below T_N which will be discussed, as well as the discrepancies with the Mössbauer results.

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AP/P3–08

Transmission Images and Evaluation of Tomographic Imaging Based Scattered Radiation from Biological Materials using 10, 15, 20 and 25 keV Synchrotron X-rays

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Transmission images and tomographic imaging based scattered radiation is evaluated from biological materials, for example, Poly carbonate, Plexiglas and Nylon using 10, 15, 20 and 25 keV synchrotron X-rays. The SYRMEP facility at Elettra in Trieste (Italy) and the associated detection system has been used for the image acquisition. The scattered radiation is detected for each sample at three energies at an angle of 900 using Si-Pin detector coupled to a multi channel analyzer. The contribution of transmitted, Compton and fluorescence photons are assessed for a test phantom of small dimensions. The optimum analysis is performed with the use of the dimensions of the sample and detected radiation at various energies.

Most biological and phantom materials of medical interest contain varying proportions of elements in the atomic region $1 < Z < 20$. From a fundamental point of view, the most intense Compton scattering is produced by the first row elements in the periodic table. The scattered radiation from these materials will provide potential source of information at different energies. The reduction of Compton scattered background will improve the quality of the image. The electron binding energies for those elements (for example carbon) are such that 75% or more of the incident X-rays are scattered into the Compton peak for X-ray wavelengths T 0.8 Ao-1 and for a 90° scattering angle. The choice of 900 geometry will be useful because of the clear voxel determination, in spite of the fact that the difference between Rayleigh and Compton peaks is about half of the difference at 1800. The present study is focused on transmission images at optimum energy and detection of total scattered radiation mainly from biological materials. We have chosen tunable monochromatic energy in the region $10 - 35$ keV. It allows us to study the contribution of scattered radiation on various materials, with special attention to Rayleigh and Compton peaks separately. The study will be extended to higher energies in order to estimate the scattered radiation arises due to Rayleigh and Compton scattering (with inclusion of Doppler broadening).

AP/P3–09

Production of Super-Absorbed Hydrogels Prepared by Electron Beam Irradiation for Agricultural and Industrial Purposes

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Polyacrylamide/sodium alginate (PAAm/Na-alginate) crosslinked super-absorbed hydrogels were prepared by using electron beam irradiation. The gel content and the swelling behavior of the obtained copolymers were investigated. The addition of PAAm/Na-alginate copolymer in small quantities to sandy soil increased its ability to retain water. The growth and other responses of the faba bean plant cultivated in a soil treated with PAAm and PAAm/Na-alginate copolymer were investigated. The growth of the bean plant cultivated in a soil containing PAAm/Na-alginate was better than that cultivated in soil treated with PAAm. The increase in faba bean plant performance by using PAAm/Na-alginate copolymer suggested its possible use in the agriculture field as a plant growth promoter. On the other hand, crosslinked polyacrylamide PAAm and acrylamide–Na–acrylate P(AAm–Na–AAc) super-absorbed microgels were prepared by electron beam irradiation. It was found that the dose required for crosslinking depends on the polymer moisture content, so that the dose to obtain PAAm of maximum gel fraction was over 40 and 20 kGy for dry and moist PAAm, respectively. The structural changes in irradiated PAAm were investigated using FTIR and SEM. The swelling property of such microgels in distilled water and real urine solution was determined and crosslinked polymers reached their equilibrium swelling state in a few minutes. The ability of the microgels to absorb and retain large amount of solutions suggested their possible uses in horticulture and in hygienic products such as disposable diapers.

AP/P3–11

Photoionization Study of Atoms, Molecules and Clusters and their Ions in the VUV and Soft X-Ray Region

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Most of the matter in the universe (> 99.99%) exists in a highly ionized state. However, relatively little experimental data is available on the structure of multiply charged ions and their interactions with photons. Combining a merged ion-photon beam (IPB) endstation, an electron-cyclotron-resonance (ECR) ion source and a third-generation synchrotron radiation source makes possible quantitative studies of photoionization (PI) of multiply charged ions. This apparatus is permanently installed on undulator beamline 10.0.1.2 at the Advanced Light Source (ALS), which provides intense photon beams at high energy resolution range $17 - 340$ eV.

In the soft X-ray region we can study the atomic structure of the inner shells for most of the elements, which has not explored yet for the best of my knowledge. Photoionization of molecular and cluster ions remain essentially unexplored, and will provide new insights into their structure and dynamics. Interpreting such experiments will be a major challenge. So SESAME as a third generation light source similar to the ALS will be the best for such studies, and with similar IPB endstation at the ALS will attract many researchers from the region and all over the world.

PI experiments performed at ALS in collaboration with the Giessen group included multiply charged metallic ions, such as K-like Sc^{2+}, for which complementary measurements of time-reversed process electron-Sc^{3+} recombination have been performed at a heavy-ion storage ring in Europe. PI measurements for the lower charge states of the Fe isonuclear sequence, which are important for astrophysical applications, and present a formidable theoretical challenge. Many other examples will be presented during the meeting and the future look of PI spectroscopy.

AP/P3–12

Overview of Ion Beam Analysis Applications at the Lebanese Accelerator

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The 5SDH tandem accelerator facility was established within the IAEA TC project LEB 1003 at the Lebanese Atomic Energy Commission. Since its installation in 1999, Ion Beam Analysis techniques IBA are performed, in order to provide elemental analysis in a wide range of applications. The main strength of IBA is to be multi-elemental, fast and non destructive analysis and could be performed simultaneously. Hence, they could determine the elemental composition of different kind of samples, covering nearly the whole periodic table, with sensitivity for some elements of ppm level (part per million). Furthermore, they can measure the stoichiometry and thickness of thin films, or multilayer, elaborated on bulk materials with a possibility to perform elemental depth profile. The analytical capabilities available on the facility include particle-induced X-ray emission (PIXE), proton induced γ-ray emission (PIGE), Rutherford backscattering spectrometry (RBS), nuclear reaction analysis (NRA) and elastic recoil detection analysis (ERDA). The most undertaken research activities are related to IBA applications in materials science and archeology, however, other applications in aerosols, pharmaceutical science and biomedicine will also be shown as to summarize the different activities of the accelerator during the past few years.

AP/P3–14

WAXD and FTIR Studies of Electron Beam Irradiated Biodegradable Polymers

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The problem of non-biodegradable plastic waste remains a challenge due to its negative environmental impact. Poly(L–lactic acid) (PLLA) and poly(ϵ–caprolactone) (PCL) have been receiving much attention lately due to their biodegradability in human body as well as in the soil, biocompatibility, environmentally friendly characteristics and non-toxicity. Poly(lactic acid) (PLLA) is a poly(α-hydroxy acid) and poly(ϵ–caprolactone) (PCL) is a poly(ω–hydroxy acid). PLLA is a hard, transparent and crystalline polymer. On the other hand, PCL can be used as a polymeric plasticizer because of its ability to lower elastic modulus and to soften other polymers. To improve some desirable properties two or more polymers can be mixed to form polymeric blends. PLLA/PCL blends have attracted great interest as temporary absorbable implants in human body, but they suffer from poor mechanical properties due to macro phase separation of the two immiscible components, and to poor adhesion between phases. Chemical structure influences the biodegradation of solid polymers. Enzymatic and non enzymatic degradations occur easier in the amorphous region. Morphology of biodegradable polymers affects the rate of their biodegradation. A polymer that has high degree of crystallinity will degrade at a slower rate due to the inherent increased stability. Moreover, both polymers, PLLA and PCL, require a proper sterilization process when used in biomedical applications. Nowadays, the most suitable sterilization method is high energy irradiation. Radiation has been known to alter the physical properties of polymers through main-chain scission and crosslinking. Usually both these processes take place simultaneously in many polymers. The combination of two radicals leads to cross-linking in the amorphous phase or recombination in the crystalline region, whereas chain transfer and the subsequent splitting result in chain scission PCL homopolymer cross-linking degree increases with increasing doses of high energy radiation. On the other hand, the irradiation of PLLA homopolymer promotes mainly chain-scissions at doses below 250 kGy. In the present work, sheets of PCL and PLLA homopolymers and blend with PLLA:PCL weight ratio of 50:50 (w:w) were prepared using a twin screw extruder (Labo Plastomill Model 150C, Toyoseki, Japan) equipped with a T-die (60 mm width and 1.05 mm thickness). Twin screw extruded sheets of PLLA and PCL biodegradable homopolymers and 50:50 (w:w) blend were electron beam irradiated using electron beam accelerator Dynamitron (E = 1.5 MeV) from Radiation Dynamics, Inc. at doses in the range of 50 to 1000 kGy in order to evaluate the effect of electron beam radiation on the blends. Wide-angle X-ray diffraction (WAXD) patterns of non irradiated and irradiated samples were obtained using a diffractometer Rigaku Denki Co. Ltd., Multiflex model, Cu Ka radiation; and FTIR spectra was obtained using a NICOLET 4700, ATR technique, ZnSe crystal at 45°. By WAXD patterns of as extruded non irradiated and irradiated PLLA it was observed broad diffusion peaks corresponding to amorphous polymer. The amorphous phase of PLLA decreased with radiation dose. Although it had been presented in the literature that PLLA crystallinity decreases with radiation dose up to 80 kGy, it was not possible to observe this fact in this study. Furthermore, it was observed that PLLA crystallite size increases with radiation dose above 100 kGy in the studied dose range. Also this occurrence can be observed for the PLLA in the blend. PCL samples, non irradiated and irradiated show the two strongest reflections at Bragg angles $2\theta = 21.4°$ and $2\theta = 23.7°$ that have been attributed in the literature to the (110) and (200) reflections, respectively. For as extruded irradiated PLLA samples it was observed broad diffusion peaks corresponding to amorphous polymer. PLLA samples annealed under temperature of 140°C during half an hour, showed reflections at Bragg angles $2\theta = 16.4°$ and $2\theta = 18.7°$ previously attributed in the literature to distorted 10^3 (α-form) helices. PLLA as extruded samples are amorphous and crystallize by thermal treatment. On the other hand, FTIR results have shown that the ionizing radiation does not promote degradation of the studied homopolymers and blends, also do not affect the miscibility of the blends.

AP/P5 — Poster Session P5

AP/P5–01

A Study of Diffusion Behaviour of Silicon in D9 Steel

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Silicon is an essential solute element in D9 steel, which is envisaged for use as fuel cladding and wrapper materials in the Indian fast breeder reactor (FBR). The effectiveness of silicon in extending the transient regime of void swelling is well known, but an understanding of the underlying mechanism is still lacking. Any quantitative modelling of the irradiation effects in alloys requires knowledge of the diffusion behavior of the constituent atomic species due to their considerable redistribution during irradiation. In this paper we experimentally investigate the thermal diffusion behavior of silicon in D9 steel. D9 steel samples are implanted with 500 keV Si^{30} to a fluence of 3×10^{16} atoms cm^{-2}. The implanted Si^{30} profile which resides at a depth of $\sim$ 280 nm serves as the marker layer and its broadening can be used for following the diffusion of silicon in D9 steel samples. Depth profiling of Si^{30} was carried out by the Resonance Nuclear Reaction Analysis (RNRA) using Si^{30} (p, γ) resonance at 942 keV. The range and straggling of the room temperature implant determined by the RNRA is in agreement with that computed from the TRIM program. The D9 alloy samples were isochronally annealed for 30 minutes at temperatures of 320, 390, 460, and 530K. After every annealing step the sample was quenched and RNRA was carried out to probe the diffusion of silicon atoms. The diffusion constant is obtained from the profile broadening and the Arrhenius plot shows a linear behavior. An activation energy of 0.34 eV for diffusion was obtained. At temperatures of 600K and above there is a tendency for the FWHM of the diffusion profiles to shrink and approach that of the as implanted profile. Also, a shift in the vertex of the diffusion profile towards the peak damage position is observed. From our previous studies on the annealing behavior of D9 alloy using positron annihilation spectroscopy it was found that the vacancies in the alloy start migrating at temperatures above 500K. Therefore at temperatures above 600K silicon atoms may be diffusing by a vacancy mechanism. The movement of silicon atoms in a direction opposite to the direction of the vacancy migration has resulted in the shrinking of the diffusion profile. The above results are discussed in the light of irradiation induced point defects acting as vehicles for solute atom diffusion.

AP/P5–03

Diffusion of Fission Products through Silicon Carbide

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Fuel elements of modern high-temperature nuclear reactors are encapsulated by CVD-layers of pyrolitic carbon and silicon carbide to reduce fission product release. The aim of this study is to obtain information on volume and grain boundary diffusion as well as on the influence of radiation damage. For this purpose relevant isotopes were implanted with a fluence of 2×10^{16} cm^{-2} in poly and single crystalline SiC samples at temperatures ranging from room temperature to 900K. Diffusion coefficients were obtained from the broadening of the implantation profiles after isochronal and isothermal annealing studies up to 1900K, using RBS analysis in conjuncture with

α-particle channeling spectrometry. Structural information on the implanted samples was obtained by scanning and transmission electron microscopy.

As the surface region of the room temperature implants was completely disordered, the initial profile broadening could be used to study diffusion in amorphous silicon carbide. Comparison of profile broadening in annealed single and poly crystalline samples yielded information on the relative importance of volume and grain boundary diffusion. Information on the influence of radiation damage was extracted by comparing results from samples implanted at room and elevated temperatures.

AP/P5–04

Comparison of Monte Carlo Simulations with Proton Experiment for a Thick Au Absorber

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Proton therapy applications deal with relatively thick targets like the human head or the trunk. Therefore, relatively small differences in the total proton stopping power given, for example, by the different models provided by GEANT4 could lead to significant disagreement in the final proton energy spectra when integrated along lengthy proton trajectories. This work presents a comparison of proton energy spectra for 49.1 MeV protons passing through a couple of Au absorbers with different thicknesses obtained by GEANT4.8.2 simulations using ICRU49, Ziegler1985 and Ziegler2000 models. The comparison was made with the experimental data of Tschalar, with TRIM/SRIM2008 and MCNPX2.4.0 simulations, and the Payne analytical solution for the transport equation in the Fokker-Plank approximation. It is shown that the simulations reproduce the experimental spectra with some detectable contradictions. It should be noted that all the spectra lay at the proton energies significantly above 2 MeV, i.e., in the so-called "Bethe-Bloch region". Therefore the observed disagreements in GEANT4 results, simulated with different models, are somewhat unexpected. Further studies for a better understanding and to obtain definitive conclusions are necessary.

AP/P5–05

Applications of Positron Annihilation Spectroscopy

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Positron annihilation spectroscopy techniques are well established nuclear techniques with applications which nowadays range from structural investigations of materials to investigations of biological samples and medical imagining. They have extensively been used more than thirty years, but with constant improvements in measuring methods and with new applications, especially in investigations of technologically important materials. In standard positron annihilation spectroscopy suitable positron source is used, and techniques include positron lifetime measurements, Doppler broadening spectroscopy and angular correlation measurements. In the recent times slow positron beams combined with these techniques are applied as well, providing depth-profiling of the samples.

We are going to present digitized positron lifetime system and a novel system for simultaneous positron lifetime and Doppler broadening spectroscopy developed at the Department of Physics in

Zagreb and measurements with these systems using ^{22}Na as positron source. Their advantages compared to conventional systems and further development of the positron annihilation spectroscopy techniques by employing signal digitizers in multi-detector systems and possible applications will be described.

AP/P5–06

Laboratory of Nuclear Analytical Methods of Nuclear Physics Institute ASCR

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Basic facilities of the laboratory are new Tandetron 4130 MC, installed in 2005, and old 3.5 MV Van de Graaff accelerators. The latter is mostly used for standard analyses by RBS and PIXE/PIGE techniques with protons and helium ions. The laboratory at Tandetron accelerator is equipped with devices for analyses of materials by RBS, RBS-channeling, ERDA, ERDA–TOF, PIXE/PIGE methods. Ion microprobe is under construction. Also available is equipment for ion implantation and several devices for production of nano- and micro-structured systems. The research program is conducted in close collaboration with specialized research institutions in Czech Republic and abroad. Most notable research topics are nano-and micro- structured systems with special optical, electromagnetic and biological properties and processes proceeding within, radiation degradation of materials and environmental research.

AP/P5–07

ITEP Heavy Ion RFQ — Experimental Facility for Reactor Material Investigation under Irradiation

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Development of new materials for future energy facilities with higher operating efficiency is a challenging and crucial task. However, full-scale testing of radiation hardness of reactor materials is quite sophisticated and difficult as it requires long session of reactor irradiation; moreover, induced radioactivity considerably complicates further investigation. Ion beam irradiation does not have such a drawback, on the contrary, it has certain advantages. One of them is high speed of defect formation. Therefore, it provides a useful tool for modeling of different radiation damages. Improved understanding of material behaviour under high dose irradiation will probably allow to simulate reactor irradiation close to real conditions and to make an adequate estimation of material radiation hardness. ITEP heavy ion RFQ HIP-1 provides accelerated beams of Cu^{2+}, Fe^{2+}, Cr^{2+} ions with current up to 4 mA and energy 101 keV/n. The results of beam extraction line adjustment for experiments with reactor materials are presented. The construction of controllable heated target is presented as well. The first experiments will be started at the beginning of 2009. Also, the low energy experiments are carried on at the HIP-1 injector. The construction of target for low energy experiments is presented as well. The main objectives of this work are to study primary damage, cascade formation phenomena, phase stability and self-organization under irradiation. This research is carried out by means of tomographic atom probe and transmission electron microscopy.

AP/P5–08

A Basic Investigation on Low-energy Ion Irradiation Effect on Lives

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Low-energy ions are everywhere, from arrivals of natural cosmic particles at the earth to biological and medical applications of manmade accelerator and plasma generated ions. When the low-energy ions irradiate biological cells, the basic effect is induction of mutation or killing of lives. Because of this effect, low-energy ion irradiation has widely been applied for mutation breeding and sterilization. However, some fundamentals involved in the applications are not yet well understood. Furthermore, biological effects from slow-down space particles and radiotherapy ions on genetic mutations are also not yet very clear. Some critical puzzles include whether the low-energy ion irradiation induced biological effect is a direct or indirect interaction consequence, what changes occur in DNA irradiated by low-energy ions, and what the lowest ion energy limit is to cause mutation. To look for answers, this investigation applies both experimental and computer simulation means, in which ions at energy from keV down to eV are used to bombard naked plasmid DNA, followed by checking DNA structure changes. In the experiment, nitrogen and argon ions at keV energy generated from low-energy ion accelerators bombarded naked plasmid DNA in vacuum to low fluences in orders of $10^{11} - 10^{13}$ ions/cm^2 and the samples were analyzed using electrophoresis and sequencing. Results show that the low-energy ion irradiation of naked DNA can indeed cause DNA damage in the forms of single strand breakage, double strand breakage and multiple double strand breakage, which are the bases of mutation of biological organisms. Lighter nitrogen ions are found more effective in induction of mutation than heavier argon ions. Molecular dynamics simulation of ion bombardment of naked DNA at energy of 2 eV to 200 eV reveals that the DNA double strand separation is base bond dependent, i.e., certain base bonds are more vulnerable to the irradiation than the others, ion energy dependent, i.e., the strand separation is greater when bombarded by ions with higher energy, and irradiation time dependent, i.e. the strand separation is a function of the interaction time between the ion and the molecule. This presentation reports related details.

AP/P5–09

Accelerator Beams for X-Ray-Gamma Lasers

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The relativistic accelerator beams interaction with strong laser fields in different schemes for generation of intense shortwave coherent radiation is investigated. As a new generation of light sources of shortwave radiation, specifically for x-ray and γ-ray lasers, the high brightness ion beams or channelled in the crystals ultrarelativistic electron beams are considered where due to the existence of quantum bound states the ion-photon or channelled electron-photon interaction cross sections are resonantly enhanced by several orders with respect to the Thompson/Compton cross section on the free electrons. The latter means that the coherent radiation generated in such systems will rather exceed by intensity the contemporary Free Electron Laser systems. Hence, the stimulated radiation by relativistic charged particle beams with discrete energy levels is of certain interest as a potential synthesis of the conventional Quantum Generators and Free Electron Lasers in x-ray and γ-ray domains. Besides, the spectral intensity of spontaneous radiation of the channelled electrons/ions well exceeds the intensities of other radiation processes in this frequency range. Hence, the Self-Amplified Spontaneous Emission (SASE) regimes of x-ray laser by means of relativistic

ion beam or channelled in a crystal ultrarelativistic electron beam with the strong counterpropagating pump laser fields are investigated. The consideration is based on the self-consistent set of the Maxwell and relativistic quantum kinetic equations. In the considering schemes the pump wave (optical or strong infrared laser radiation) due to the Doppler up-shifting of its frequency resonantly couples two internal ionic or transverse electronic levels in the channel of a crystal, and the necessity of the initial inverse population of energy levels for lasing in such systems vanishes, which is obligatory for conventional quantum generators on atomic systems. Different regimes of generation of coherent x-ray are considered. It is shown that the SASE power both on the ion and channelled electron beams resonantly enhances by several orders with respect to the x-ray Compton laser scheme on the free electrons.

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ADS

Accelerator Driven System

ADS/INT — National & International ADS Programmes

ADS/INT–01

The Researches of ADS and the Sustainable Development of the Nuclear Energy

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China, as a developing country with a great population and relatively less energy resources, actively emphasizes the development of nuclear energy. To develop nuclear power in such a large scale, long-lived radioactive nuclear wastes have to be safely disposed to reduce the impact on the environment and to eliminate public fear of nuclear power. Considering MA and LLFP transmutation with more efficiency and non-criticality risk for new nuclear application the accelerator-driven sub-critical system (ADS) study has been started in China. The conceptual study of ADS that lasted for about five years ended in 1999 in China. As one project of the National Basic Research Program of China (973 Program) in the energy domain, which is sponsored by the China Ministry of Science and Technology (MOST), a five-year-program of fundamental research of ADS physics and related technology was launched in 2000. From 2007, another five-year 973 Program, Key Technology Research of Accelerator Driven Sub-critical System for Nuclear Waste Transmutation, started. The research activities will focus on HPPA physics and technology, reactor physics of external source driven sub-critical assembly, nuclear data base and material study. For HPPA, a high current injector consisting of an ECR ion source, LEBT and an RFQ accelerating structure of 3.5 MeV has been built and will be improved. In reactor physics study, a series of neutron multiplication experimental study has been carried out and still being done. The VENUS facility has been constructed as the basic experimental platform for neutronics study in ADS blanket. It is a zero power sub-critical neutron multiplying assembly driven by external neutron produced by a pulsed neutron generator. The theoretical, experimental and simulation study on nuclear data, material properties and nuclear fuel circulation related to ADS is carrying on to provide the database for ADS system analysis.

ADS/INT–02

Partitioning and Transmutation Research in Germany

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Based on the presently scheduled operation times for nuclear power plants in Germany, more than 17 500 tons spent fuel containing approximately 175 tons plutonium, 15 tons minor actinides (neptunium, americium and curium) and 700 tons of fission products will be generated until 2022. About 7000 tons have been shipped to France and UK for reprocessing to recover plutonium and uranium. The safe disposal of high-level radioactive waste, i.e., spent fuel and heat producing waste arising from reprocessing, is the responsibility of the federal government.

The safety research for nuclear waste disposal is organised according to three major areas: characterisation and immobilisation of radioactive waste, reduction of radiotoxicity (partitioning and transmutation), and long-term safety of nuclear waste disposal. Here, only the second issue is dealt with.

As far as the reduction of radiotoxicity of the high level nuclear waste is concerned, partitioning and transmutation (P&T) is considered as a way to reduce the burden on geological disposal. The expected impact of P&T on a deep geological repository is related to the reduction of the long-term radiotoxicity associated with nuclear wastes, the reduction of the time period for nuclear waste isolation from the biosphere and the masses to be stored and their associated residual heat load. Independently of a P&T option, the safe disposal of radioactive waste in deep geological formations is indispensable, because of losses during P&T cycles and the HLLW, which is already vitrified.

The work is jointly performed by the Research Centres in Dresden-Rossendorf, Jülich and Karlsruhe.

ADS/INT–03

ADS Programme and Associated Developments in India — Roadmap and Status of Activities

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Large-scale utilization of thorium as nuclear fuel has been a long-term goal in the Indian nuclear power programme. The 3-stage programme for gradual switch over from uranium to plutonium-fueled fast-breeders and finally to Th fuel system has been in place for this purpose. With external neutron source driven ADS, the self-sustainable thorium fuel cycle and growth of nuclear power generation capacity seem distinctly feasible.

Accordingly, India has initiated a programme in 2003 to pursue a roadmap on physics studies & stage-wise technology development for ADS. Under this programme, activities related to reactor concepts & design, spallation target system and technology for high power proton accelerator have progressed.

Reactor design studies were made on some representative schemes of sub-critical reactors to introduce and sustain thorium fuel utilization, development of indigenous reactor calculations codes, application of high-energy particle-matter interaction codes to estimate neutronics in spallation target and its coupling with surrounding reactor core. A reactor physics experimental programme is also underway to couple 14 MeV neutron generator (D–T reaction) with a sub-critical natural uranium-water core. In another reactor studies, a research reactor is being designed with feasibility for future conversion into a spallation neutron source-driven sub-critical ADS reactor.

In the spallation target technology programme, thermal hydraulics analyses were made of liquid metal flows around beam window under various beam-induced heating conditions in target volume. A liquid metal LBE flow loop has been designed for experimental validation of CFD analyses through simulation of proton heating the beam window by using plasma torch and electron beam. This loop would also have corrosion test set up for samples of various materials.

Energy efficient and reliable high power proton accelerator for ADS presents challenges in accelerating low-energy space-charge dominated proton beam, and at high-energy in utilizing superconducting (SC) RF cavities with cryogenics. Design and construction of 20 MeV cw proton linac at BARC and development of techniques to fabricate & characterize high-β SC RF cavities from niobium are progressing.

The above spectrum of ADS-related activities is covered in this paper along with some thoughts on future directions.

ADS/INT–04

Research and Development Programme on ADS in JAEA

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JAEA has been promoting the research and development (R&D) on accelerator-driven subcritical system (ADS) as a dedicated system for the transmutation of long-lived radioactive nuclides. The ADS proposed by JAEA is a lead-bismuth eutectic (LBE) cooled, tank-type subcritical reactor with a thermal power of 800 MW*th* driven by a 30 MW superconducting LINAC. The R&D activities can be divided into two categories: one is the design study and technical development for a future large-scale ADS, and the other is the experimental programme at the Transmutation Experimental Facility (TEF) under the J-PARC (Japan Proton Accelerator Research Complex) project. As for the design study of the future ADS, the reliability of the accelerator is being investigated based on the data analysis of existing LINAC facilities. The coupling mechanism between the accelerator and the reactor is another issue to be carefully considered. As for the technical development of the superconducting LINAC, fabrication and tests of prototype cryomodule were carried out, and its good performance was demonstrated. As for the TEF, conceptual design is being discussed, and some technical developments for the facility construction are under way including the laser charge exchange technique for the extraction of a low power (about 10 W) proton beam for reactor physics experiments from high power beam.

The approval to start construction of the TEF has not yet been decided by the government. Recently, the check and review of the nuclear transmutation technology was begun by the Atomic Energy Commission (AEC) of Japan, and the recommendations on the R&D in this field will be issued by the end of March, 2008. The results for this check and review will be reported in this presentation.

ADS/INT–05

Overview of EU Research Activities in Transmutation and Innovative Reactor Systems within the Euratom Framework Programmes

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European Community (EC) (currently 27 Member States) shared-cost research has been organised in Framework Programmes (FP) of durations of $4-5$ years since 1984. The 6^{th} European Atomic Energy Community (EURATOM) Framework Programme $(2002-06)$ and the current 7^{th} FP $(2007-11)$ have been allocated a fission research budget respectively of 209 and 287 Million Euro from the EC. There are 10 projects (total budget 70 M€, EC contribution 38 M€) in all aspects of transmutation ranging from road-mapping exercise to large integrated projects on accelerator driven systems, lead-cooled fast critical systems for waste transmutation, technology, fuel, accelerator facilities for nuclear data etc. In Innovative Reactor concepts, there are about half-a-dozen projects (total budget 30 M€, EC contribution 16 M€) including High Temperature Reactors, Gas-cooled Fast reactors, road-mapping exercise on sodium fast reactors etc. The main research and training activities in FP7 are: management of radioactive waste, reactor systems, radiation protection, infrastructures, human resources and mobility and training. In the two call for proposals (2007 and 2008) in FP7, 8 projects have been accepted in transmutation and innovative reactor concepts (total budget 53 M€, EC contribution 32 M€). These research projects cover activities ranging from materials, fuels, treatment of irradiated graphite waste, European sodium fast reactor to the establishment of a Central Design Team of a fast-spectrum transmutation device in Europe. The third call for proposals is underway requesting proposals on nuclear data, thermal hydraulics, gas and lead-cooled fast reactor systems with a total EC budget of 20 M€. International collaboration is an important element of the EU research policy. This overview paper will present elements of the strategy of EURATOM research and training in waste management including accelerator driven transmutation systems and Innovative reactor concepts that are being pursued through Euratom Programmes. The paper will also discuss achievements of selected FP6/FP7 research projects.

ADS/ET — Experiments and Test Facilities

ADS/ET–01

The GENEPI–3C Accelerator for the GUINEVERE Project

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GUINEVERE, **G**enerator-of-**U**ninterrupted-**I**ntense-**NE**utrons-at-the-lead-**VE**nus-**RE**actor, is a project of the Domain 2 of the FP6 EUROTRANS Integrated Project devoted to Accelerator Driven System (ADS) feasibility studies. Domain 2, ECATS, is related to specific **E**xperiments for **C**oupling an **A**ccelerator, a **T**arget and a **S**ubcritical core. GUINEVERE will investigate on-line reactivity monitoring, sub-criticality determination and operational procedures in an ADS.

The project consists in coupling a modified VENUS facility at the SCK·CEN site in Mol (Belgium) to an upgraded GENEPI neutron source. SCK·CEN is transforming the water moderated VENUS reactor into a fast lead core facility, the fuel and lead rodlets being provided by CEA.

The **GE**nerator-of-**NE**utrons-**P**ulsed-and-**I**ntense is an electrostatic accelerator generating 14 MeV neutrons by bombarding a high intensity deuteron beam on a tritium target located in the reactor core. CNRS is designing and building a new accelerator, GENEPI–3C, to meet the new requirements of the experimental program: it will be capable of delivering alternatively 1 μs long deuteron pulses with adjustable repetition rate, as well as continuous beam with programmable interruptions.

This paper will describe the design and commissioning of the GENEPI accelerator.

† Deceased.

ADS/ET–02

Application of High Intensity Neutron Generator for the Investigations of ADS Neutronics

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Experimental and theoretical investigations of the neutronics and kinetics for Accelerator Driven Systems have been performed at the Joint Institute for Power & Nuclear Research-Sosny (Minsk,

Belarus) in the frame of State Scientific Programs, the ISTC Project B–1341 and the IAEA Coordinated Research Project "Calculation benchmark on neutronics of a booster (cascade) assembly driven by external neutron sources" and "Analytical and Experimental Benchmark Analysis on Accelerator Driven Systems, and Low Enriched Uranium Fuel Utilization in Accelerator Driven Subcritical Assembly Systems" at the YALINA subcritical facility. YALINA facility consists of a deuteron accelerator, a target unit and subcritical booster assembly with thermal and fast neutron spectra. The assembly consists of a central lead zone (fast zone), a polyethylene zone (thermal zone), a radial graphite reflector and a front and back biological shielding of borated polyethylene. The fast-spectrum lead zone and the thermal-spectrum polyethylene zone are separated by a so called thermal neutron filter, or valve zone, consisting of one layer with metallic natural uranium and one layer with boron carbide (B_4C) which is located in the outermost two rows of the fast zone. Thermal neutrons diffusing from the thermal zone to the fast zone will either be absorbed by the boron or by the natural uranium, or transformed into fast neutrons through fission reactions in the natural uranium. In this way, a coupling of mainly fast neutrons between the two zones is maintained. Experimental and calculated results obtained during the start up of YALINA–Booster after replacement the 90% enriched metallic uranium fuel to 36% enriched dioxide uranium will be presented in this paper.

ADS/ET–03

Subcriticality Measurements in Accelerator-Driven System at Kyoto University Critical Assembly

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Subcriticality measurements in the Accelerator-Driven System (ADS) at the Kyoto University Critical Assembly (KUCA) are described in this paper. The Kyoto University Research Reactor Institute is going ahead with an innovative research project on ADS using a Fixed Field Alternating Gradient (FFAG) accelerator. The goal of the research project is to demonstrate the basic feasibility of ADS as a next-generation neutron source using KUCA coupled with a newly developed variable energy FFAG accelerator. The construction of the accelerator complex has been completed and its beam commissioning is currently being conducted. It is expected that the ADS experiments using the FFAG accelerator could start in February 2009. At the ADS with the FFAG accelerator, the high-energy neutrons generated by nuclear reactions with 150 MeV proton beams in a tungsten target will be injected into a solid-moderated and -reflected core (A-core) in thermal neutron field of KUCA. The maximum power of the A-core and maximum neutron yield at the target are limited to 100 W and 1×10^{10} n/s, respectively, and the average beam current is 1 nA. Prior to the ADS experiments with 150 MeV protons, the ADS experiments with 14 MeV neutrons, which is a conventional pulsed neutron generator of the Cockcroft-Walton type accelerator, have been conducted in KUCA, including subcriticality, neutron multiplication, reaction rate distribution, neutron spectrum, neutron decay constant. Among these reactor physics parameters, an exact measurement of subcriticality is an interesting issue in the ADS studies. At the KUCA A-core, subcriticality measurement experiments the ADS with 14 MeV neutrons are carried out by using several methods: Feynman-alpha, Rossi-alpha, Neutron source multiplication and Pulsed neutron methods. In these subcriticality benchmark problems, these facts are demonstrated experimentally that the dependence of subcriticality on the detector positions is found, and that the measurement precision varies both in accordance with the degree of subcriticality and each measurement technique.

ADS/ET–04

Reactivity Monitoring of a Subcritical Assembly Using Beam-Trips and Current-Mode Fission Chambers: The YALINA–Booster Program

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Transmutation of spent nuclear fuel in Accelerator-Driven Systems (ADS) is considered as a key technology for achieving sustainable nuclear energy. In the design of future ADS facilities, the reactivity monitoring system is of highest importance. An extensive experimental program devoted to reactivity monitoring of ADS has been carried out at the subcritical facility YALINA–Booster in the framework of IP–EUROTRANS. The main objective, besides the qualification of the reactivity monitoring techniques, has been to develop electronic chains that can be used in a full power ADS. For this purpose, YALINA–Booster couples a D–T neutron generator to a flexible zero-power subcritical assembly with a coupled fast-thermal neutron spectrum. The high intensity of the accelerator and the possibility to work in continuous or pulsed mode allowed the study of the current-to-flux relationship, beam-trip experiments and dedicated experiments for loading and start-up procedures. In addition, the experimental facility provided the opportunity to test electronic chains in current mode, which correspond to the most probable condition in a full power ADS. The experimental program has mainly been focused on the current-to-flux and beam-trip methodologies using detectors operating either in current or pulsed mode. However, in order to achieve the reference reactivity values of the different loading configurations, an extensive set of measurements based on pulsed neutron source techniques has been carried out. In addition, neutron noise measurements have also been performed. These studies are presented in separated papers within this conference. At present, the experimental campaign has been finished and, for the first time, the reactivity of a subcritical system has been measured within a single instantaneous beam trip ($\sim$ 20 ms) using fission chambers operating in current mode. The necessary electronic chains to operate the fission chambers in this mode have been developed at CIEMAT. The preliminary results of our analysis show that the reactivity values obtained applying the Sjöstrand method and the slope-fit method using data from current-mode detectors are compatible with those obtained when using standard pulsed-mode detectors (presented also in this conference). The validity of the reactivity determination methods using fission chambers operating in current mode has been stated.

ADS/ET–05

Pulsed Neutron Source Reference Measurements in the Subcritical Experiment YALINA–Booster

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An extensive experimental program devoted to reactivity monitoring of accelerator-driven systems has been carried out at the zero-power subcritical facility YALINA–Booster. The work is a part of a joint collaboration between several European research institutes through the European research programme for the transmutation of high level nuclear waste in an accelerator driven system (IP–EUROTRANS) in the 6^{th} EU Framework Programme. Pulsed Neutron Source (PNS) experiments have been carried out to achieve the reference reactivity values for each configuration studied. In total, four different core configurations at three different subcriticality levels have been studied,

with effective multiplication factors ranging from about 0.85 to 0.975. Two of the configurations have the same subcriticality level, but different source multiplication, thus making it possible to explore possible source multiplication effects. This was achieved by removing highly enriched fuel located close to the target and compensating by adding low enriched fuel at the core periphery until the same reactivity was reached. For each core configuration, except the most deep subcritical configuration, an additional subconfiguration was obtained by inserting the control rods into the core, meaning that in total seven subcriticality levels were studied. The techniques applied were the Sjöstrand method and the prompt neutron slope fitting technique. Reactivity values have been obtained for detector positions in all three regions of the complex YALINA–Booster core: the fast booster zone, the thermal zone and the reflector. It is shown that the experimental results from the Sjöstrand method, without correction factors, carry strong spatial effects. For the first time, possible source multiplication effects on the area ratio technique are shown.

ADS/ET–06

YALINA Booster Conversion Project

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The YALINA Booster subcritical assembly was constructed at the Joint Institute for Power and Nuclear Research (JIPNR)–SOSNY, Belarus to examine the physics of Accelerator Driven Systems (ADS). The assembly has fast and thermal zones to study the coupling between the two zones, the transuranics transmutation, and the ADS kinetics. It is driven by external neutron source located at the assembly center. The central fast zone (the booster zone) consists of high enriched uranium (HEU) fuel rods loaded in a lead matrix and it is surrounded by thermal zone. The thermal zone has low enriched uranium (LEU) fuel rods loaded in polyethylene moderator. Between the two zones, there is a thermal neutron absorber zone.

(JIPNR)–SOSNY has an International Science and Technology Center project in collaboration with Argonne National Laboratory of USA to convert the HEU fuel of YALINA Booster to LEU fuel without penalizing its performance. The first step of this project is to characterize and define the performance of the YALINA Booster subcritical assembly with HEU fuel by performing detailed analytical and experimental studies. The second step is to convert the booster zone to use uranium fuel rods with 21% enrichment. The YALINA Booster configuration is modified to reach the original subcriticality level.

The analytical analyses have developed accurate calculational models without geometrical approximations for performing Monte Carlo and Deterministic calculations. MCNP, MCNPX, MCB, MONK, ERANOS, and PARTISN computer codes with different nuclear data libraries based on ENDF/VI, JEF2.2, and JEF3.1 have been used for static and kinetic analyses. The geometrical details are included explicitly without approximation or homogenization. In the experimental program, the subcriticality has been measured as a function of the number of the fuel rods loaded in the subcritical assembly. Different methods have been used to measure the assembly subcriticality during the fuel loading process. In addition, the spatial neutron flux distribution, spectral indices, and transmutation reactions rates have been measured.

In this paper, the analytical models and the obtained results are presented including the static and the kinetic results. The experimental and analytical results are compared and discussed. The YALINA conversion results are also included.

ADS/ET–07

Deterministic Analyses of YALINA Thermal Subcritical Assembly with DRAGON–PARTISN Software

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This study analyzes the YALINA Thermal subcritical assembly with a deterministic calculation methodology. Within this methodology, the DRAGON code, developed at Polytechnique de Montreal (Canada), has been used to generate the macroscopic cross sections for about 50 different volumes of the assembly. The DRAGON code is linked to a nuclear data library with 179 energy group microscopic cross sections. In the DRAGON code, the geometry of the assembly has been simplified. The generated macroscopic cross sections have been used in the PARTISN code, developed at Los Alamos National Laboratory (USA), which modeled the facility in a detailed three-dimensional geometry.

In order to facilitate the deterministic modeling of the assembly the interface software DRAGON–PARTISN has been developed in C programming language. The DRAGON–PARTISN software reads the ASCII macroscopic cross sections for a specific material from the DRAGON output and it rearranges them into the material section of the PARTISN input. The DRAGON-PARTISN software can utilize multiple DRAGON outputs files and for each of the output file the user can choose which material to process. According to the DRAGON material processing sequence, the macroscopic cross sections are sequentially stored in the material section of the PARTISN input. The DRAGON–PARTISN software also can process the scattering matrix up to the first moment. The DRAGON-PARTISN is a general purpose software and it can be easily applied to any deterministic reactor design analyses.

For a fuel cell calculation, the DRAGON simulations have shown that a simple two-region homogenization of the fuel rod and of polyethylene is not accurate and it results in several thousands pcm difference from the MCNP results. Consequently, a fine subdivision of the moderator volume around the fuel pin has been used for the fuel cell calculation. With this more accurately modelling DRAGON, PARTISN and MCNP provide the same multiplication factor for a fuel cell.

The deterministic analyses have been extended to the full core PARTISN calculation of the YALINA Thermal assembly. The PARTISN results include the multiplication factor and the He-3 reaction rate axial profile in the experimental channels of the facility.

ADS/ET–08

Analysis of Molybdenum-99 Production Capability in the Materials Test Station

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The United States of America currently relies on foreign suppliers to meet all of its needs for molybdenum-99 used in medical diagnostic procedures. The current US demand exceeds 5,000 six-day curies (Ci) per week. A six-day Ci is a unit of measure used by the industry, which is the amount of Mo-99 remaining in the generator six days after delivery to the medical facility. The recent decision by the Atomic Energy of Canada, Limited to close the MAPLE reactors has led to renewed interest within the USA in assessing alternate sources for Mo-99, particularly domestic sources. The proposed Materials Test Station (MTS) could potentially serve this mission.

The MTS will be a fast neutron spectrum irradiation facility for testing candidate fast reactor fuels and materials. It is a spallation source driven by a 1 MW, 800 MeV proton beam, located at

the Los Alamos Neutron Science Center (LANSCE) within Los Alamos National Laboratory. The facility is slated to start operation in 2013.

Two methods of Mo-99 production have been evaluated in this study. The first is through the traditional ^{235}U$(n, f)^{99}$Mo reaction, the second is via the ^{99}Tc$(n, p)^{99}$Mo reaction. The first is best carried out in a thermal spectrum, while the second, which has a threshold energy of 0.58 MeV, requires a very hard neutron spectrum.

Two target material options have been explored for Mo-99 production in the Materials Test Station (MTS): low enriched uranium (LEU) and Tc-99. For LEU, scoping calculations indicate that MTS can supply nearly half of the current US demand with only minor neutronic impact on the MTS primary mission. However, there may be significant impact from an operations standpoint (permitting, safety, and security). For the Tc-99 option, the MTS could produce about one-tenth of the US demand.

ADS/ET−09

The MEGAPIE Operation Synthesis

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The MEGAwatt Pilot Experiment (MEGAPIE) was initiated by six European institutions (PSI, FZK, CEA, SCK·CEN, ENEA, CNRS), JAEA (Japan), DOE (US) and KAERI (Korea) with the objective to demonstrate the safe operation and to fathom the neutronic performance of a liquid metal (lead bismuth eutectic, LBE) target for high power spallation and ADS applications. The MEGAPIE target was operated at the Swiss Spallation Neutron Source SINQ starting mid-August 2006, for a scheduled irradiation period until 21^{st} December 2006. The continuous (51 MHz) 590 MeV proton beam hitting the target reached routinely an average current of 1300 μA, corresponding to a beam power 0.78 MW. The presentation summarizes the main features of the target and the ancillary systems, and reports on the operational experiences made with this target during start-up and routine operation. The general performance is highlighted, including transient reactions after beam trips or interrupts, the performance of new beam and target safety devices, and the functional experience and lessons learned with the ancillary systems.

ADS/ET−10

MEGAPIE on the Way to PIE

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The MEGAPIE target was the first liquid metal target ever operated in the Megawatt regime, at a power level of 0.8 MW. The LBE target has successfully been irradiated in a period from August until December 2006. During this time the spallation target received a beam charge of 2.8 Ah of 590 MeV protons. After the successful operation of the target it has been stored in the target storage facility of PSI, waiting for its post irradiation examination, PIE. In the time since the end of 2006 several campaigns of tests have been conducted by PSI and interim storage facility of Swiss nuclear power plants – ZWILAG – in the hot cells of ZWILAG. In these tests the feasibility of the conditioning of the target and the extraction of sample material for the PIE has been proven. It is planned to start the dismantling of the MEGAPIE target in June 2009. The dismantling campaign will last until the end of 2009. The PIE activities are foreseen to start in late 2009 or early 2010. In this paper we report on the outcome of all cold tests of the dismantling that have

been done. In addition a detailed description of the procedure of dismantling and sample taking of MEGAPIE will be given.

ADS/ND — Nuclear Data

ADS/ND–01

The Nuclear Data Measurement Activities in China

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China, as a developing country with a great number of population and relatively less energy resources, reasonably emphasizes the nuclear energy utilization development. Meanwhile, the application of nuclear technology at different fields plays more and more important role. All these put forward new requirements to nuclear data measurements.

The fast neutron physics laboratory in CIAE is the main base of nuclear data measurement in China. There are more than 40 scientific staff in this laboratory. Different neutron sources ranged from 0.01 MeV to 40 MeV are available. Many kind of detector systems such as three detectors fast neutron time of flight spectrometer, inverse geometry multi-detectors fast neutron time of flight spectrometer, HPGe-BaF_2 anti-Compton suppression spectrometer are available and a few new detector systems are under construction.

The research activities are focused on Fusion and fission related nuclear data measurements, Astrophysics related nuclear data measurements and others. The main results in recent years will be reported.

ADS/ND–02

High-energy nuclear data for ADS

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Accelerator-driven sub-critical reactors that are envisaged for the transmutation of nuclear waste use intense neutron fluxes produced through spallation reactions in a heavy metal target. During the last years, new high-quality experimental data have been collected leading to a better understanding of the spallation reaction mechanism and to the development of more reliable spallation models. Examples of recent experimental data and model improvements will be presented. The impact on target design, radioactivity production and material damage will be discussed.

ADS/ND–03

INC model for hadron-nucleus reactions

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The applicability criteria for the semi-classical INC model are discussed. The various implementations of the INC model in use in the transport codes are described.

ADS/ND–04

Nuclear Data Measurements at the RPI LINAC

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The RPI Linac is a 60 MeV electron accelerator located in upstate New York, USA. A pulsed neutron source is used for a variety of experiments primarily related to nuclear data measurements. This presentation and paper will provide an overview of measurement capabilities and results, with a focus on new work since the 2007 conference. New capabilities include high energy (0.5 − 20 MeV) neutron transmission (at 100 meters) and high energy neutron scattering (at 30 meters) using proton recoil detectors. The scattering system consists of an array of detectors at specified angles around the sample, a digital data acquisition system and internally developed software to discriminate γs and neutrons using pulse shape analysis. A mid-energy (1 eV–400 keV) Li-6 glass transmission detector is currently being constructed and tested at 100 meters. The laboratory also hosts a 66 metric-ton lead slowing down spectrometer (LSDS). In transmission, new measurements include the total high energy cross section of elemental zirconium and titanium which resolve structure not seen in the evaluations. Filtered neutron beams are also being used which enable high accuracy measurements of smooth transmission cross sections in the energy range from 24 keV to 905 keV. Data from beryllium using this method was used to resolve discrepancies between evaluations of total cross section. Scattering measurements on carbon, molybdenum, and beryllium have been completed. Uranium-238 resonance scattering was measured and a new scattering kernel for MCNP was verified. Low epi-thermal transmission (0.01 eV to 2 keV) and capture (1 − 600 eV) measurements of europium-153 and elemental europium were performed in 2008. Resonance parameters of molybdenum have been determined from data using the multilevel R-matrix Bayesian code SAMMY. Other materials which are being studied in the resonance region include rhodium, cadmium, rhenium, uranium-236, and dysprosium-164. The RPI LSDS was used for simultaneous measurements of fission cross section and fission fragments mass and energy distributions as a function of the incident neutron energy. To qualify the system, data for uranium-235 and plutonium-239 were collected and agree with previous data. In addition, (n, α) and (n, p) detectors are being developed for use in the LSDS to measure small samples or samples with small cross sections.

ADS/ND–05

A Study of Pre-Equilibrium Emission in Some Proton Induced Reactions: Measurement of Cross-Sections

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The study of nuclear reactions induced by protons has again attracted the attention of nuclear physicists due to the requirement of precise nuclear data needed for the development of recently proposed accelerator driven sub-critical (ADS) reactors. Apart from several applications of nuclear data for radio-isotope production in medical sciences, environmental sciences, transmutation of nuclear waste etc., one of the main aims has been to enhance the basic understanding of the reaction mechanism. Though, a large amount of data is now available in literature on nucleon induced reactions but, in general the measurements done by different groups have large uncertainties and do not agree with each other. Further, the reaction mechanism of such reactions at different energy regimes is still not well understood. There are indications that equilibrium and pre-equilibrium

reaction mechanisms both play important role at moderate excitation energies. In view of the above, as part of a programme of precise measurement of cross-sections for the production of several radio-isotopes in proton induced reactions, excitation functions for several reactions in ^{63,65}Cu, ^{113,115}In, ^{121,123}Sb, and ^{197}Au isotopes up to 20 MeV have been carried out. The experiments have been carried out using the proton beam from the Variable Energy Cyclotron Centre, Kolkata, India. The analysis of data performed in light of several theoretical model codes clearly indicates the presence of considerable pre-equilibrium component in such reactions. An attempt has been made to determine the pre-equilibrium fraction, which is a measure of the relative strength of equilibrium and pre-equilibrium component and its energy dependence. Further details of the measurements and analysis of data will be presented.

ADS/ND–06

Production of $A+1$ and $Z+1$ Isotopes in Proton-Induced Reaction on ^{A}Z Nuclei. Application to Po production in $p-^{209}$Bi to Bi isotopes in $p-^{208}$Pb reactions

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Most of the isotopes produced in spallation reactions induced by nucleons in the GeV range have a mass and a charge smaller and sometimes sizably smaller than the original mass and charge of the target nucleus, respectively. This is consistent with the current model used to describe these reactions, namely the intranuclear cascade+evaporation model. However, occasionally, the mass of the so-called residue exceeds the target mass number, by one unit. This is possible when the incident nucleon is absorbed and when a non-baryonic particle is emitted. At low energy, the latter could be a photon. But at sufficiently high incident energy, the emitted particle could be a pion. Residues with a charge one unit larger than the target charge can be produced by conventional (p, xn) reactions, except when their mass number exceeds the target mass number by one unit, in which case a (p, π^0) process is at work. An interesting experimental study of the Bi isotopes produced in $p-^{208}$Pb collisions at 1 GeV has been published by the FRS group at GSI in Ref. [1].

This set of reactions are quite interesting, because they involve the emission of a single pion or of a pion with a very low number of nucleons. Production of residues close to the target thus provides with a good test for the pion dynamics of INC models. We have just recently improved this feature in the Liège INCL4 model [2]. In this paper, we want to apply our modified INCL4 model to this problem.

As typical examples, we consider the production Po isotopes in $p-^{209}$Bi reactions and Bi isotopes in $p-^{208}$Pb reactions. We will indeed show that good agreement with the data can be achieved only when the pion potential is introduced and when the energy-dependance of the nucleon potential is properly taken into account. In particular, this is true for the production of ^{210}Po by $p-^{209}$Bi reactions at higher energy when the (p, π^0) mechanism replaces the (p, γ) process. This is still true to some extent for the production of ^{208}Po and ^{209}Po isotopes at any energy, since it that case, the photon capture process is negligible. We also arrive at a similar conclusion for the Bi isotope production in $p-^{208}$Pb reactions at 1 GeV, after comparison with the data of Ref. [3].

We also investigate the influence of our calculations for the radiotoxicity associated with Pb-Bi targets bombarded by high energy protons.

1. A. Kelic et al., Phys. Rev. C **39** (2004) 064608.
2. Th. Aoust and J. Cugnon, Phys. Rev. C **74** (2006) 064607.
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ADS/ND–07

Spallation Reaction with Tin Isotopes

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In the recent past, liquid tin has been proposed as a coolant in fast reactor systems and as a spallation target that exhibits many favourable properties and attractive features, in terms of high boiling point, low melting point and low vapour pressure. With the recent availability of the spallation data for proton induced reactions on $^{112-124}$Sn isotopes at proton energies from 0.66 to 8.1 GeV, it is interesting to compare the production cross sections of light and heavy spallation products with the predictions of the well tested and successful computer code, CASCADE.04. The predictions from this code are consistent with the experimental data, in the mass range $7 - 96$. E.g., In the case of ^{112}Sn and for proton energy of 660 MeV, the production cross sections for the nuclei ^{77}Br, ^{76}Br and ^{74}As are calculated to be 1.32 mb, 2.06 mb and 0.49 mb respectively. The corresponding experimental data are 1.6 mb, 0.8 mb and 0.21 mb respectively. Using this code, we have calculated the neutron yield for the tin isotopes. At proton energy of 1 GeV, the calculated neutron yield for ^{112}Sn to ^{124}Sn varies from 11.5 to 19.0 per proton. These values can be compared with the value of 26.5 per proton obtained for Pb. However, the tin isotopes in general have the added advantage over Pb-Bi eutectic in that they are free from Polonium radioactivity and α emitting rare earth nuclei like ^{146}Sm, ^{148}Gd, ^{150}Gd and ^{154}Dy produced in the spallation reaction on Pb-Bi eutectic. The range values of 1 GeV proton in Pb and Sn are 57 cms and 75 cms respectively. The heat density calculated for Sn is about 500 W/cm^3/mA. The corresponding value for Pb is around 650 W/cm^3/mA. This implies that Sn will be a better coolant from thermal hydraulics point of view.

ADS/ND–08

Low-Energy Photonuclear Reactions — A Review

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The study of photonuclear reactions has a long and rich history, dating back to the 1930s. Indeed, probably no other branch of nuclear physics has such an extensive record of fertilizing others; and its applications are more extensive that of any other field of nuclear physics except for neutron physics. The impetus for these studies was provided since the 1960s mainly by the availability of monochromatic photon beams and efficient neutron detectors. The basic cross sections, both near threshold and in the Giant Dipole Resonance region, for the most part have been known since the 1970s. What is new today is the advent of high-intensity *polarized* monochromatic photon beams, capable of extending our detailed knowledge of photonuclear processes, and the emergence of important applications in medical physics, nonproliferation, and counterterrorism that can best be addressed with their use. Accordingly, this talk will focus on new developments in the study of reactions with polarized photon beams, especially of fewbody nuclei, high-resolution resonance fluorescence, and photofission studies of the uranium isotopes and transuranic nuclei.

ADS/ND–09

The Fission TPC Project

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New high-precision fission experiments have become a priority within the nuclear energy community due to a growing, world wide, interest in nuclear reactors. In particular, the design of the next generation reactors requires a reduction in the errors on a number of cross section measurements. Most of the required nuclear data has been measured over the last 50 years, although improvements in the accuracy of the data appear unlikely with the current technology. A potential breakthrough is the deployment of a detector developed within the particle physics community called the Time Projection Chamber (TPC). A group of 6 universities and 3 national laboratories have undertaken the task of building the first TPC for this purpose. In this talk I will present the fission TPC concept, and why we think we can make an improvement on 50 years of fission study.

ADS/ND–10

Comparative Study of ADS-Burners Efficiency with Thermal, Intermediate and Fast Neutron Spectrum for Transmutation of Minor Actinides

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The problem of minor actinides (MA) in the closed nuclear fuel cycle (NFC) is a one of the most important for future nuclear energetic. There are several approaches for MA transmutation but there are no common criteria for the comparison of their efficiency. In paper [1] we turned out the attention to the importance of taking into account the duration of the closed NFC in addition to a usual criterion of the neutron economy. In accordance with these criteria the different ADS-burners are considered: LBE-cooled reactor (fast neutron spectrum), molten-salt reactor (intermedium spectrum) and heavy water reactor (thermal spectrum). It shown that the time of transmutation of loaded MA in the closed nuclear fuel cycle is more than 50 years. All calculations are normalized to the ADS-burner power 1 GWth.

1. A. Gulevich, A. Kalugin, L. Ponomarev, V. Seliverstov, M. Seregin, *Comparative Study of ADS for Minor Actinides Transmutation*, Progress in Nuclear Energy **50**, March-August (2008) p.358.

ADS/ND–11

Analyses of Transients for 400 MWth-Class EFIT Accelerator Driven Transmuter with the SIMMER–III Code

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European R&D for ADS design and fuel development is driven in the 6^{th} FP of the EU by the EUROTRANS Programme. In EUROTRANS, two ADS design routes are followed, the XT–ADS and the EFIT. The XT–ADS is designed to provide the experimental demonstration of transmutation in an Accelerator Driven System. The longer-term EFIT development, the **E**uropean **F**acility for **I**ndustrial **T**ransmutation, aims at a generic conceptual design of a full transmuter. The EUROTRANS Domain DM1 (DESIGN) developed the conceptual reference design of the EFIT, a 400 MW_{th} ADT, loaded with a CERCER U-free fuel with an MgO matrix. For the cladding, the 9Cr1MoVNb T91 steel has been chosen. The core coolant is pure lead with inlet and outlet temperatures of 400 and 480°C. For the EFIT clad and structural materials, a surface treatment with a GESA type technique is foreseen to prevent the build-up of thermal conductivity reducing oxidation layers. The windowless target for the 800 MeV proton beam also contains pure lead. The EFIT concept is to be optimized towards: a good transmutation efficiency, high burnup, low reactivity swing, low power peaking, adequate subcriticality, reasonable beam requirements and a high level of safety. In the current paper the safety analyses performed with the SIMMER-III code are reported and discussed. In the framework of the SIMMER analyses additional calculations have performed with ERANOS, DANTSYS, and C4PTRAIN to check safety coefficients, burn-up behavior and decay heat.

Basically two different safety areas have been analyzed. Firstly, protected and unprotected transients which are initiated by a mismatch of power-to-flow or resulting from a beam disturbance or overpower situation. Secondly a stream generator tube rupture (SGTR) accident has been investigated with its potential impact on the core region. From the safety point of view all ADTs with a high load of Minor Actinides are characterized with a “zero” Doppler fuel feedback, a high void worth for lead and a very small beta-effective. In addition the massive Helium production from the transmutation process leads to high pressure potentials in the plena. Although the boiling point of Pb coolant is high, voiding may take place via two routes. It can be triggered either by a pin failure with gas release from the plena or the dragging in of steam into the core after a SGTR accident.

The transient scenarios presented here are mostly unprotected (beam-on scenarios): spurious beam trip (BT), unprotected transient overpower (UTOP), unprotected loss of flow (ULOF) and unprotected blockage accident (UBA). As the high temperature and transient behavior of the MgO based fuel and the T91 cladding is connected with large uncertainties, the unprotected accidents with the potential of fuel failure and gas release deserve special attention. Extensive investigations have been performed for the UBA as it represents a route into pin failure and a blockage accident has been reported in the past in a HLM cooled submarine. As fuel and clad might be swept out of the core region after an UBA the release of material and possible re-freezing or deposition on structures was also investigated experimentally, simultaneously validating the SIMMER code.

ADS/P4 — Poster Session P4

ADS/P4 – 01

Modelling of Radiation Effects in Materials for Accelerator-Driven Systems Based on Th-U Fuel Cycle

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The problem of high radioactive nuclear waste reduction has stimulated activity on research and development concerning innovative nuclear reactor systems and accelerator-driven systems based on Th-U fuel cycle. In this paper an investigation on radiation damage of the thorium fuel, modelling the primary knock-on atoms energy spectra for broad energy interval up to several hundred MeV is presented. A method has been developed for primary knock-on atoms energy spectra simulation that utilizes the phase function approach for the recoil atoms in the elastic scattering. For non-elastic scattering, (n, α) and (n, p) reactions a statistical approach in nuclear reactions is applied. For Frenkel pairs the Kinichn–Pease expression in the Lindhard–Scharff–Schiott (LSS) theory is applied. The displacements per atom (dpa) have been calculated and their connection with the neutron flux has been obtained. Our results have been verified applying codes (LAHET, MCNP, SPECTER) typically used in theoretical simulation of radiation effects in materials.

ADS/P4 – 02

Measurement of Cross-Sections in some Reactions in ^{16}O + ^{181}Ta System at Energies ~ 5 MeV/nucleon

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In view of the recent advances in Accelerator Driven Energy Systems (ADES), there is a great need of precise data on reaction cross-sections induced not only by light but also by heavy ions (HIs). The HI-induced reaction data is also needed for environmental and medical applications. Further, the reaction mechanism for HI interaction at energies near and just above the Coulomb barrier (CB) is not well understood. Both complete and incomplete fusion mechanism are likely to compete at these energies. With above view in sight, the excitation functions (EFs) for several reactions ^{181}Ta(^{16}O, $3n$)^{194}Tl, ^{181}Ta(^{16}O, $4n$)^{193}Tl, ^{181}Ta(^{16}O, $5n$)^{192}Tl, ^{181}Ta(^{16}O, $p\,3n$)^{193m,g}Hf, ^{181}Ta(^{16}O, $p\,4n$)^{192}Hf, ^{181}Ta(^{16}O, $p\,5n$)^{191m,g}Hf, ^{181}Ta(^{16}O, $2p\,2n$)^{193m}Au, ^{181}Ta(^{16}O, $\alpha\, n$)^{192}Au, ^{181}Ta(^{16}O, $\alpha\,2n$)^{191}Au and ^{181}Ta(^{16}O, $\alpha\,3n$)^{190}Au produced both by complete and incomplete fusion in ^{16}O + ^{181}Ta system at energies varying from the Coulomb barrier to ~ 5 MeV/nucleon has been measured. The experimental data has been analysed within the frame work of complete and incomplete fusion (ICF) formalisms. The analysis of the data indicates that the experimentally measured EFs for reaction channels produced by the emission of protons or neutrons and/or by both agree well with the theoretical predictions of the code based on statistical model formalisms. However, for α emission channels, the enhancement of the experimentally measured EFs has been

observed in comparison with the theoretical predictions of the model calculations based on CN theory, indicating the significant contribution of incomplete fusion channels. Furthermore, in the present work energy dependence of ICF components has also been deduced. Details of experiments and analysis will be presented.

ADS/P4 – 05

Developmental Studies of a High Current Proton Linac for ADS Program

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A program has been initiated at BARC, Mumbai to design and develop an **A**ccelerator **D**riven sub-critical reactor **S**ystem (ADS) as it will provide an additional route to an efficient and economic nuclear power generation with the abundant Thorium resources.

One of the main sub-systems of ADS is a high energy ($\sim$ 1 GeV) and high current ($\sim$ 30 mA) CW proton accelerator. In contrast to high-energy particle accelerators in use hitherto, the electrical efficiency, reliability and beam loss rate in this system should be improved to a great extent. It is, therefore, planned to take a staged approach towards development of the requisite accelerator technology, dividing it into 3 sections; namely, 20 MeV, 100 MeV and 1 GeV. Developmental studies for such an accelerator architecture were initiated in our institute sometime back.

The most challenging part of these accelerator sections is the front-end low-energy injector, typically up to $10 - 20$ MeV, because of severe space-charge effects at these energies. This section with its stand-alone applications as intense neutron source through $^{9}\mathrm{Be}(p,n)$ reaction, has been taken up for construction at BARC. It consists of a 50 keV ECR ion source, 3 MeV RFQ and a 20 MeV DTL. The LEBT and MEBT lines are used to match the beams from ion source to RFQ and from RFQ to DTL respectively. In order to minimize the emittance growth space charge compensation ($> 95\%$) is planned in the LEBT. Two solenoids used for focusing the beam in the LEBT have been fabricated and are meeting their specifications. The operating frequency is chosen as 352.21 MHz in view of readily available RF power hardware. This would serve as the front end of an ADS set up. The fabrication of various sub-systems is in progress. Measurements on the prototypes validate the design procedures.

Beam dynamics of the high energy part (> 100 MeV) has also been done using superconducting elliptical cavities with a gradient of $\sim$ 15 MV/m. The aperture is more than 16 times the rms beam size in order to restrict the beam loss to less than 1 nA/m required in ADS systems. In this paper, salient features of the project and its status will be discussed.

ADS/P4 – 06

Estimation of Acceptable Beam Trip Frequencies of Accelerators for ADS and Comparison with Experimental Data of Accelerators

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Frequent beam trips as experienced in existing high power proton accelerators may cause thermal fatigue problems in ADS components which may lead to degradation of their structural integrity and reduction of their lifetime. Thermal transient analyses were performed to investigate the effects of beam trips on the reactor components, with the objective of formulating ADS design considerations, and to determine the requirements for accelerator reliability. These analyses were made on the thermal responses of four parts of the reactor components; the beam window, the cladding tube, the inner barrel and the reactor vessel. Our results indicate that the acceptable frequency of beam trips ranges from 43 to 2.5×10^4 times per year, depending on the beam trip duration.

In order to consider measures to reduce the frequency of beam trips on the high power accelerator for ADS, we compared the acceptable frequency of beam trips with the operation data of existing accelerators. The result of this comparison shows that for typical conditions the beam trip frequency for durations of 10 seconds or less is within the acceptable level, while that exceeding 10 seconds should be reduced to about 1/15 to satisfy the thermal stress conditions.

ADS/P4 – 07

Application of ITEP TWAC Accelerator Beams for Diagnostics of Fast Process

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Parameters of the proton radiographic facility which constructed on the ITEP TWAC accelerator for diagnostic static objects and fast process are reported. Time structure of ITEP TWAC accelerator beam is able to make a diagnostic of dynamic process with characteristic speed up to 20 km/s.

In paper shown that the facility spatial resolution on the sharp edge of the dense object with step up to 4.5 g/cm^2 will be 8 μm with contrast factor ~ 0.67.

ADS/P4 – 08

Reactivity Monitoring with Imposed Beam Trips and Pulsed Mode Detectors in the Subcritical Experiment YALINA–Booster

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Reactivity monitoring is one of the urgent problems that require a solution in order to achieve a license for a future full-scale ADS. As a part of the EUROTRANS experiments at the YALINA–Booster facility, presented in this conference, a set of measurements with imposed beam-trips has been performed. Traditionally, the source jerk method has been used in subcritical systems to obtain the reactivity by comparing the total neutron flux before the neutron source removal to the semi-stable delayed neutron flux after the source removal. The deuterium-tritium neutron source of the YALINA–Booster facility can, in addition to pulsed mode operation, operate with continuous beam with short imposed millisecond-scale interruptions, thus providing the possibility to monitor the reactivity at each beam trip in the source jerk manner. In order to test the validity of the beam-trip reactivity values determined by using detectors operating in current-mode (also presented in this conference), the reactivity values of the YALINA–Booster assembly obtained through the beam-trip technique using pulsed-mode detectors is presented in this work. In these experiments a beam-trip frequency of 1 Hz and an interruption time of $\sim$ 20 ms have been chosen and two different subcriticality levels (with effective multiplication factor around 0.975 and 0.95, respectively) have been investigated. Moreover, the flexible core layout has allowed for two different loadings with close to equal subcriticality but different source multiplication characteristics, thus making it possible to explore the effect of the different source multiplications. In addition, the response of the imposed beam-trip reactivity monitoring technique to reactivity insertions and removals has been studied through control rod movements. Experimental data from fission chambers have been acquired from all three zones of the core: the fast booster zone, the thermal zone and the reflector.

ADS/P4 – 09

Current-to-Flux Experimental Results in the YALINA–Booster Subcritical Assembly

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As a part of the IP-EUROTRANS experimental program at YALINA–Booster, presented in this conference, a set of measurements concerning the current-to-flux techniques has been performed. In a subcritical assembly coupled to an accelerator operating in continuous mode, the power of the reactor is related to the accelerator beam current and the external neutron source strength. It is generally assumed that by monitoring the ratio between the accelerator beam current and the neutron source intensity as well as the ratio between the neutron source intensity and the core power, any change in the system can be detected. With this methodology, changes in the system caused by reactivity transients can be isolated. However, it has been observed that this is only true for transients in the time scale of seconds. At CIEMAT, an acquisition system capable of monitoring the core power, the accelerator beam current and the neutron source intensity in the millisecond scale has been developed. It has been observed that, in these short time ranges, the proportionality relationship between these three quantities is not always fulfilled.

ADS/P4 – 10

Neutron Noise Measurements in the YALINA–Booster Experiments

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Measurement of neutron fluctuations plays an important role in determining reactor kinetic parameters. In addition to the pulsed neutron source measurements and the continuous source beam-trip measurements performed in the YALINA–Booster facility, also presented in this conference, a set of neutron noise measurements has been performed to achieve a complete characterization of the core. The neutron noise measurements have been performed in three different configurations covering a subcriticality range from 0.85 to 0.975. The Feynman-alpha and Rossi-alpha neutron noise techniques have been applied to detector counts from both the fast booster zone and the thermal zone. The neutron noise results are compared to the experimental prompt neutron decay constants obtained from the pulsed neutron source measurements.

ADS/P4 – 12

Optical Restoration of Irradiated Lead Fluoride Crystals

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Due to its relatively high resistance to high radiation, lead fluoride (PbF_2) crystals are becoming an increasingly popular material of choice for electromagnetic calorimetry, such as for experiments

requiring the measurement of high-energy photons in Hall A of Jefferson Lab. For our studies we irradiated the PbF_2 crystals using an electron linear accelerator (LINAC) followed by exposing the crystals to blue light so as to restore the nominal optical properties. This technique of optical bleaching with blue light affords an efficient and low-cost means for reversing the deleterious effects of optical transmission loss in radiation-damaged lead fluoride crystals. Whereas earlier experiments irradiated the PbF_2 samples with 1.1 and 1.3 MeV γs from ^{60}Co, we used pulsed beams of energetic electrons from the tunable 25-MeV LINAC at Idaho Accelerator Center of Idaho State University in Pocatello, Idaho. A 20-MeV beam of electrons was targeted onto four separate 19 cm length samples of lead fluoride over periods of 1, 2, and 4 hours yielding doses between 7 kGy and 35 kGy. Samples were then bleached with blue light of wavelength $410 - 450$ nm for periods between 19.5 and 24 hours. We performed this process twice – radiation, bleaching, radiation, and then followed by bleaching again – for each of these four PbF_2 samples. We shall discuss the efficacy of blue light curing on samples that have undergone two cycles of electron irradiation and optical bleaching.

ADS/P4 – 14

Deterministic Model for the Analysis of YALINA–Booster Experiments with the ERANOS code System

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The YALINA experimental program has been launched by the Joint Institute for Power and Nuclear Research–SOSNY (Belarus) to study the physics of ADS.

The present work focuses on the analysis of the YALINA–Booster subcritical assembly by the use of deterministic codes. The YALINA–Booster couples a fast zone of two U-235 enrichments (90% and 36%) in a lead lattice, and a thermal zone with 10% enrichment of U-235 in a polyethylene moderator. The two zones are separated by an absorbing layer of B4C and natural uranium rods. The active core is surrounded radially by a graphite reflector and axially by borated polyethylene.

A deterministic model for YALINA–Booster has been created with the ERANOS code package. Cross-sections have been processed with the ECCO code using JEF2.2, JEF3.1 and ENDF/B-VI.8 data. The VARIANT module has been used for reactivity and flux calculations in XYZ geometry and the KIN3D code is used for the analysis of dynamic measurements.

A meticulous analysis was devoted to the existing empty spaces in the original YALINA–Booster configurations (beam tube, experimental channels, etc.), that required to be homogenized with other materials, due to the code difficulties to perform in presence of void regions. Additionally, due to the current limitations of the existing cell codes, another major difficulty associated with the use of deterministic codes consists in the impossibility to reproduce all the details of the reactor geometry. As consequence, local effects can not be simulated as they really are and a physical approach is then required to correctly reproduce the global effects in the selected regions where the cross-sections are processed so that the results can be obtained without any loss of accuracy. For instance, for YALINA–Booster significant efforts had to be also devoted to process accurate cross-sections for the B4C absorber rods between the fast and thermal zones. The selection of the reactor zones associated with the material homogenization and cross-section processing is in general the most delicate phase when creating a deterministic model. Details of the deterministic model created for YALINA–Booster with the ERANOS code system will be given in the full paper. The calculated results, showing a good agreement with the measurements, confirmed the ERANOS capabilities for the analysis of complicated systems such as YALINA–Booster.

ADS/P4 – 15

Study of Subcriticality Control by Hf and Gd Hydrides for Accelerator Driven System

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A major example of the Accelerator Driven System (ADS) is proposed by Japan Atomic Energy Agency (JAEA). The ADS is a hybrid system that consists of a high intensity proton accelerator, a spallation target of a heavy metal such as Lead-Bismuth Eutectic (LBE) and a sub critical core. The ADS has been researched for transmuting Minor Actinides (MA) and Long-Lived Fission Products (LLFP) in a High Level Waste (HLW). Subcriticality of the ADS is expected to be stable for keeping the thermal power constant. However, the subcriticality varies with the burn-up of fuel. The thermal power of the ADS must be kept by controlling the proton beam intensity. In the case of the ADS proposed by JAEA, the beam intensity is required to change it between about 20 to 30 mA in one operation cycle of 600 EFPD. The accelerator performance has been intense. At the high beam intensity, the irradiation damage is enhanced at the beam windows in the ADS. Therefore, subcriticality decrease should be moderated in one operation cycle of the ADS. In this paper, the control is studied by using a control rod (CR) or a burnable poison (BP) of metallic hydrides composed of Hf-hydride or Zr-Gd-hydrides. The CR of the Hf-hydride is expected as a long life-time in a fast reactor core. On the other hand, the BP of the Zr-Gd-hydrides is hopeful to keep the subcriticality constant without a control mechanism. Thus, the subcriticality control method by using the Hf and Zr-Gd hydride will be useful for controlling the subcriticality of the ADS. We supposed the absorber pins of the Hf-hydride or the Zr-Gd-hydride coated by stainless steel. The pins are set in a hexagonal assembly. The CR or BP assembly are arranged triangularly in an ADS core. For the CR and BP the analysis of core characteristics are performed for by using the continuous-energy Monte Carlo code, MVP, and the burn up calculation code, MVP-BURN. The evaluated nuclear data library, JENDL-3.3, is employed. As the result, the specification of the pins and the assemblies are designed adequately and the CR and BP assemblies can control the subcriticality in the ADS.

ADS/P4 – 16

Precisions Improvement of Dynamic Calculation Code for Accelerator Driven System

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An Accelerator Driven System (ADS) has been widely studied for transmuting Minor Actinide (MA) and Long-Lived Fission Product (LLFP) in High Level Waste (HLW). An ADS has high efficiency for transmuting those. There are many R&D (Research and Development topics about ADS. Dynamics of ADS is one of the topics. However, it has been studied few since there are no dynamics calculation codes which are able to treat dynamic changes of spallation neutron source and accelerator parameters (beam intensity, energy, diameter, etc.).

The ADS dynamics calculation code DSE (Dynamics calculation code system for Sub-critical system with External neutron source) was developed in our laboratory. The DSE code consists of a neutronics calculation module and a thermal-hydraulics calculation module. The DSE code can calculate time variations of thermal power, neutron flux, fuel temperature, cladding temperature and coolant temperature distributions by treating the dynamic changes of the accelerator parameters directly.

The improvement of precisions is needed to study dynamics in more detail. The purpose of this study was to improve precisions of each module. For the purpose of this study, some improvements were conducted. In the neutronics calculation, the transport code was employed instead of diffusion one to consider angular distributions of neutron flux. The transport code is efficient to improve

the precision of neutronics calculations. In the thermal-hydraulics calculation, databases of the temperature correlations for thermal properties of core structures (Pb-Bi, etc.) were improved. They are useful to improve the precision of thermal-hydraulics calculations.

Calculation results by the improved DSE code were evaluated using experimental results and the other calculation results. The results of a sub-critical transient experiment at TRACY (TRAnsient experiment Critical facilitY) were compared to verify neutronics calculations. The OECD/NEA dynamics benchmarks about beam-trip transients on 80 MWt XADS were also compared to verify thermal-hydraulics calculations. As a result, calculations agreed well with each comparison data. These results indicate that precisions of calculations are improved in each module.

ADS/P4 – 17

A Neutron Booster for the SINQ Neutron Source Using Thin Fissile Layers

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The possibility of using thin fissile layers to improve the flux of the SINQ spallation neutron source at the Paul Scherrer Institut is studied. Two concepts are considered: a local booster, placed between two beam ports where at present a water scatterer is placed, and a global booster, consisting of a fissile layer placed around the spallation target. Neutronic calculations have been performed with MCNPX, and the complete SINQ facility has been modeled, using two types of target: liquid metal (MEGAPIE) and a solid Pb target cooled by heavy water. Fissile layers of pure ^{235}U of variable thickness, up to 0.5 mm, have been considered. The following quantities have been calculated: neutron fluxes at the beam lines, power deposition, keff. The results indicate that large flux increases can be achieved. The limitation appears to be on the power deposited in the fissile layer, which is of the order of the MW. Some considerations on the coolability of the system will be made.

ADS/P4 – 19

Practical Use of Atomic-Scale Simulations for MYRRHA/XT–ADS Evolutionary and Innovative Nuclear Fuels

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The driver fuels today considered for MYRRHA, namely enriched UO_2 and MOX, can be considered as evolutionary fuels in view of their wide use, but with much lower enrichments, in conventional nuclear power plants. However, the foreseen operating conditions in MYRRHA will go much beyond the validation range of empirical correlations still used in some of parts of fuel performance codes, and will therefore require evolving towards mechanistic models, based on a true description of the physical processes at play. This is particularly true for the fission gas release process which, in view of the high temperatures expected, and the high He production, could be one of the most penalizing phenomena in terms of fuel performance.

In this paper, we will discuss the possible practical contribution of atomic-scale computer simulations in order to better understand and model different phenomena at play during the fission gas release process. We will show the progress made at SCK·CEN in terms of atomic-scale fuel modelling, by covering both atomic scale diffusion and irradiation effects (enhanced diffusion, trapping, re-solution of intragranular bubbles, ...).

In addition to modelling the driver fuel, the work performed also open the road for studying other compounds such as the IMF targets (MgO, ZrO_2, Mo) which suffer from limited data in terms of in-pile behaviour. These studies are conducted in the framework of the fuel R&D programme for Gen-IV & ADS systems at SCK·CEN.

ADS/P4 – 20

Progress and Advancements in Fuel Performance Modelling for MYRRHA/XT–ADS

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Transmutation of the higher actinides (Np, Pu, Am and Cm) in either a fast reactor (FR) or a fast accelerator-driven system (ADS) is currently considered as one of the most promising options. The current reference fuel for the MYRRHA transmuter is MOX (driver fuel) and oxides targets such as (Cm, Am, Pu)O_2 diluted in MgO, ZrO_2, and Mo matrices. Prognosis of the in-pile behaviour of MYRRHA fuels and targets is still difficult because of limited information on their thermal and mechanical properties. This paper will summarize the main results of calculation assessments and design studies performed for MYRRHA ADS driver fuel and targets by means of the SCK·CEN fuel performance code MACROS specifically developed to cope with the fast and intermediate energy neutron spectra. The main attention is paid to integral behaviour of fuel rods as needed for design qualification and verification purposes for the foreseen fuel cycles with emphasis on reliability issues and safety margins. These studies are conducted in the framework of fuel R&D programme for fast reactor systems at SCK·CEN.

ADS/P4 – 21

Complex Particle Production by CEM03.03

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The coalescence, preequilibrium, evaporation, fission, and Fermi breakup models used by the last versions of our Cascade-Exciton Model event generator CEM03.03 have been extended recently to improve description of complex particles production from nuclear re-actions. Here, we test how CEM03.03 describes complex particle spectra and yields from all reactions included in the Mandatory List of the International Benchmark of models organized in 2008 under the auspices IAEA and discussed in details at the Satellite Meeting "Nuclear Spallation Reactions", as well as from many other reactions not covered by the Mandatory List. On the whole, CEM03.03 describes reasonably well many measured data on production of d, t, He^3, and He^4 from various reactions. However, we identified several problems to be solved for a better description of complex particles emission from some re-actions, and we see a necessity to extend the preequilibrium emission for fragments heavier than He^4, currently neglected by CEM03.03.

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ADS/P4 – 22

Benchmarking the CEM03.03 Event Generator

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Following an increased interest in intermediate-energy nuclear data for many applications, the US Department of Energy has supported during the last decade our work on the development of improved versions of the Cascade-Exciton Model (CEM) which has led to our event generators CEM03.03 for transport codes MCNPX, MCNP6, and MARS15. Here, we benchmark CEM03.03 against all reactions included in the Mandatory List of the International Benchmark of models

organized in 2008 under the auspices IAEA and discussed in details at the Satellite Meeting "Nuclear Spallation Reactions", as well as against some other reactions not covered by the List. On the whole, CEM03.03 describes reasonably well most of the tested reactions. Therefore, it can be employed with confidence as a reliable event generator in transport codes used as "working horses" for ADS and other applications. However, our benchmark identified several problems to be solved to improve the predictive power of CEM03.03. Open questions on reaction mechanisms and future necessary work are outlined.

This work was partially supported by the US Department of Energy at Los Alamos National Laboratory under Contract No. DE–AC52–06NA25396.

AT

Accelerator Technology

AT/INT — Accelerator Technology – Introduction

AT/INT–01

Active Inspection Fission Signatures for the Detection, Quantification and Identification of Fissionable Materials

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Recently there has been heightened interest in active inspection techniques that can nondestructively detect, identify and quantify fissionable materials for security, nonproliferation and nuclear forensics applications. These active techniques use a source of neutrons or high energy photons to stimulate nuclear reactions in the inspection object and then monitor the emitted secondary radiation for unique fissionable material signatures. These signatures are based on detecting emissions from fission reactions (e.g., prompt and delayed neutrons) and/or non fission reactions (e.g., nuclear resonance fluorescence). In this presentation, the authors will present recent experimental results using prompt neutrons, delayed neutrons and delayed γ rays as fissionable material signatures. The research first focused on how to detect these emissions in an intense radiation environment and the algorithms required to produce unique fissionable material signatures. The sensitivity, accuracy, speed and isotope specificity of each signature was then explored. Current work is focusing on how to effectively combine multiple signatures.

AT/INT–02

Multi-Purpose Accelerator-Accumulator ITEP–TWAC for Nuclear Physics and Practical Applications

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The ITEP-TWAC facility consisting of proton injector I2, ion injector I3, booster synchrotron UK and accelerator-accumulator U10 is now in operation delivering 4000 hours per year of proton and heavy ion beams in several modes of acceleration and accumulation using multiple charge exchange injection technique. A new design of laser ion source with 100 J CO_2-laser has been started to use for high current Al- and Fe-ion beam generation for experiments with particle energy of several hundreds MeV/u. Experimental area of ITEP-TWAC facility includes now five zones of beam utilization. Two fast extracted beams from U10 ring to the target hall and to the building for nuclear physics and practical applications. The 25 MeV beam of linac I2 is used in parallel for both injection to synchrotron U10 and different applications. Some progress is achieved also in extension of experimental area and multi-purpose utilizing of machine to be used in a time sharing mode and running in parallel of several experiments and routine operation with various beams for a number of users. The machine status analysis and current results of activities aiming at both subsequent improvement of beam parameters and extending beam applications are presented.

This work is supported by ROSATOM.

AT/INT–03

The 600 MeV EUROTRANS Proton Driver Linac

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Accelerator Driven Systems (ADS) for nuclear waste transmutation require proton drivers with energies between 600 and 800 MeV and beam currents of several mA for demonstrators and several 10 mA for a large industrial systems. The required operation is continous wave (cw) which prefers superconducting cavity technology. One major issue of these accelerators is reliability and fault tolerance to reduce the number of unwanted beam trips. Additionally, beam losses have to be minimized to avoid activation of the machine. The European activities are focused in the EUROTRANS project. The EUROTRANS driver linac has to deliver a 600 MeV proton beam with a maximum beam current of 4 mA but it is capable to accelerate up to 25 mA. In order to improve the overall reliability two 17 MeV, 352 MHz injectors are foreseen. Each injector consists of a 3 MeV RFQ, a r.t. CH-cavity and four s.c. CH cavities. The intermediate energy section (17 – 100 MeV) consists of independently phased superconducting spoke cavities.

It is followed by a high energy section with two groups of superconducting elliptical 5-cell cavities (704 MHz). The paper describes the present status of the reference design with respect to beam dynamics issues, prototype development and fault tolerance.

AT/INT–04

China High-Intensity Accelerator Technology Developments for Spallation Neutron Source and Accelerator Driven Systems

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During the recent years, there have been aggressive developments in China on the technology of high intensity hadron accelerators for the spallation neutron source, accelerator driven systems (ADS), and related programs including hadron therapy. For example, the China Spallation Neutron Source (CSNS) is a newly approved project to be constructed in Guangdong, China. The CSNS complex consists of an H- linear accelerator, a rapid cycling synchrotron accelerating the beam to 1.6 GeV, a solid tungsten target station, and five instruments for spallation neutron applications. The facility operates at 25 Hz repetition rate with an initial design beam power of 120 kW and upgradeable beam power of 500 kW. The primary challenge is to build a robust facility at a fraction of the "world standard" cost. Benefiting from a close collaboration with world leading institutes and facilities, tremendous efforts were made in China to develop domestic vendors to comprehend the technology for key systems of high intensity ion source, linear accelerators, and rapid cycling synchrotron. Goals of such facilities include spallation-neutron-based, muon-based, and proton-based platforms for multi-discipline science and industrial applications, fast-neutron-based platform for nuclear science and applications, and parasitic apparatus for medical therapy and ADS tests. This paper attempts to summarize the R&D efforts, key component prototyping and vendor development experience, and user development efforts during the past several years in China.

AT/INT−05

Commissioning of the New Spallation Target for the n_TOF facility at CERN

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The neutron Time of Flight (n_TOF) facility at CERN is a source of high flux of neutrons obtained by the spallation process of 20 GeV/c protons onto a solid lead target and the remarkable beam density of the Protons Synchrotron (PS). From Nov 2008 the n_TOF facility resumed operation after a halt of 4 years due to radio-protection issues. It features a new lead spallation target with a more robust design, more efficient cooling, separate moderator circuit and most important without any loss of the unique neutron performances of the previous target. The outstanding characteristics of this facility: high neutron flux 10^6 n/cm^2/s.c. at 185 m, wide spectral function from thermal up to GeV, low repetition rates 1.2 s^{-1} and the excellent energy resolution of 2×10^{-4} open new possibilities for high precision cross section measurements, using radioactive samples of modest mass. Moreover the separate moderator circuit will permit in the future the use of borated or heavy water instead of normal water to reduce the 2.2 MeV γ background for the neutron capture measurements. The facility has been commissioned in Nov. 2008, with performances similar of the previous target and predicted by Monte Carlo simulations.

AT/OC — Operation, Instrumentation and Control

AT/OC–01

Development of a Tandem-ElectroStatic-Quadrupole Facility for Accelerator-Based BNCT

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In this work we describe the present status of an ongoing project to develop a Tandem-ElectroStatic-Quadrupole (TESQ) accelerator for Accelerator-Based (AB)-Boron Neutron Capture Therapy (BNCT) at the Atomic Energy Commission of Argentina in Buenos Aires. The project goal is a machine capable of delivering 30 mA of 2.4 MeV protons to be used in conjunction with a neutron production target based on the ^{7}Li$(p,n)^{7}$Be reaction slightly beyond its resonance at 2.25 MeV. These are the specifications needed to produce sufficiently intense and clean epithermal neutron beams, based on the ^{7}Li$(p,n)^{7}$Be reaction, to perform BNCT treatment for deep-seated tumors in less than an hour. An electrostatic machine is the technologically simplest and cheapest solution for optimized AB-BNCT. The machine being designed and constructed is a folded TESQ with a terminal at 1.2 MV. This machine is theoretically shown to be capable of transporting and accelerating a 30 mA proton beam to 2.4 MeV, using a 3D selfconsistent Poisson-Lorentz simulation code. The general geometric layout, its associated electrostatic fields, and the acceleration tube from ion source to neutron production target are calculated using a 3D finite element procedure. The design and construction of the ESQ modules is discussed and their electrostatic fields are investigated. Beam transport calculations through the accelerator are briefly mentioned. Likewise, work related to neutron production targets, strippers, beam shaping assembly and patient treatment room is briefly described.

AT/OC–02

New Detector for Neutron Beam Monitor

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For high precision of the neutron cross-section measurement, one of a very important and fundamental parameter is the knowledge of the neutron flux during the measurements. The detector

dedicated for this measurement must be placed in the entrance of the experimental area before the different detectors for the neutron-cross section measurement. That means the device used for this detector should present a mass as small as possible, in order to minimize the perturbation on the neutron beam and, especially, the background produced by the device itself.

According to these considerations a new neutron detector equipped with a small-mass device based on micromegas microbulk technology has been designed for monitoring the CERN n_TOF neutron beam.

In order to cover the full range of the neutron energy from thermal to several MeV two neutron/charged particle converter (^{235}U and ^{10}B) have been used. The $^{235}U(n,f)$ is suited above a few 100 eV. Below that energy the resonance structure of $^{235}U(n,f)$ does not allow a precise determination of the neutron flux. To fill this gap the $^{10}B(n,\alpha)$ is simultaneously used.

After a description of the innovative detector concept, we present the result obtained in the IRMM Geel neutron beam facility and the preliminary commissioning of the new device of the CERN n_TOF facility.

AT/OC–04

Shielding and Activation Analyses of the SNS Accelerator Facility in the Early Stage of Operations

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The Spallation Neutron Source (SNS) is an accelerator driven neutron scattering facility housing a world-class suite of neutron scattering instruments that benefit material and life science research. During all phases of SNS development, including design, construction, commissioning and operation, extensive neutronics work was performed in order to provide adequate shielding and optimize performance of the accelerator facility. In the early stage of operation, the power ramp up phase reaching at present one third of the nominal power level of 1.4 MW, the accelerator shielding holds up comfortably to the design predictions for all sections of the accelerator. Although the accelerator construction is finished and the facility is in neutron production mode there is still demand for shielding and activation analyses to support redesign of parts of the accelerator, facility upgrades, designing additional structures, designing test stands for accelerator structures, and evaluation of measured residual dose rates inside the accelerator tunnel.

AT/OC–05

Radiation Protection Commissioning of the Electron Line of the Linac Coherent Light Source

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The Linac Coherent Light Source (LCLS) is a cutting-edge facility at the SLAC National Accelerator Laboratory (operated by Stanford University for the US Department of Energy). This new machine uses high energy electrons delivered by the two-mile linac to create ultrafast and brilliant X-ray pulses, able to take stop-motion images of atoms and molecules. LCLS is a pioneer machine and, as such, its design has encountered unprecedented challenges, the solutions to which will benefit future facilities of its kind across the globe.

This article describes the radiation protection aspects of LCLS electron beamline, summarizing the main issues and the corresponding protection systems. Special emphasis is made about the successful commissioning of LCLS electron line, where for all examined loss sources the measured prompt and residual dose rates are both in good accordance with or below the values predicted through detailed Monte Carlo simulations, used earlier for the design of the shielding.

AT/RD — Research and Development

AT/RD–01

Recent High Power RFQ Development

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RFQs as injectors for high power linacs have to deliver high current ion beams at cw operation. The development of the 4-rod RFQ structure has led to interesting solutions, which will be discussed with actual projects as examples. The properties and limits of our designs will be discussed.

AT/RD–02

Utilization of Variable Energy Radio-Frequency Quadrupole Linear Accelerator Systems

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Radio-frequency quadrupole (RFQ) accelerators are utilized worldwide in a variety of applications but invariably are restricted in their individual diversity due to fixed energy and ion-species constraints. In collaboration with industry Necsa has been developing systems utilizing RFQ accelerators in such a way as to provide for greater diversification of applications. A major development has been the routine operation of combining two RFQs in tandem and using the extracted beam to generate intense, pseudo mono-energetic, neutron beams with energies ranging from 3 to 8 MeV and energy spread of less than 600 keV. Such neutron beams are extremely useful when performing studies of materials with elements exhibiting resonance reactions in the applicable neutron energy range. The greatest challenge in developing the neutron source has been the beam target. The only viable nuclear reaction to use for generating mono-energetic neutrons, in the $3 - 10$ MeV regime, is the $d(d,n)^3$He reaction. This necessitates the use of a gas target and the challenge then is how to inject an intense ion beam from the accelerator high vacuum environment into the gas target, with minimal ion beam energy degradation. Two types of pseudo-differential pumping systems have recently been developed and their performance under various conditions will be presented.

With the systems in operation at Necsa a selected cluster of applications is being developed in collaboration with academia and international partners, so as to create a sustainable research and development environment having identifiable socio-economic impact.

AT/RD–03

Design, Modeling and Simulations of a Cabinet Safe System for a Linear Particle Accelerator of Intermediate-low Energy by Optimization of the Beam Optics

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As part of an accelerator based Cargo Inspection System, studies were made to develop a Cabinet Safe System by Optimization of the Beam Optics of Microwave Linear Accelerators of the IAC–Varian series working on the S-band and standing wave $\pi/2$ mode. Measurements, modeling and simulations of the main subsystems were done and a Multiple Solenoidal System was designed. This Cabinet Safe System based on a Multiple Solenoidal System minimizes the radiation field generated by the low efficiency of the microwave accelerators by optimizing the RF waveguide system and by also trapping secondaries generated in the accelerator head. These secondaries are generated mainly due to instabilities in the exit window region and particles backscattered from the target. The electron gun was also studied and software for its right mechanical design and for its optimization was developed as well. Besides the standard design method, an optimization of the injection process is accomplished by slightly modifying the gun configuration and by placing a solenoid on the waist position while avoiding threading the cathode with the magnetic flux generated.

The Multiple Solenoidal System and the electron gun optimization are the backbone of a Cabinet Safe System that could be applied not only to the 25 MeV IAC-Varian microwave accelerators but, by extension, to machines of different manufacturers as well. Thus, they constitute the main topic of this paper.

AT/RD–04

Ruling Factors in the Impact of Collision Debris on the LHC High Luminosity Insertion Magnets

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The Large Hadron Collider built at CERN now enters a starting-up phase in order to reach the present design luminosity (L_0) of 10^{34} cm^{-2}s^{-1}. A possible upgrade of the machine to a luminosity value of $10L_0$ requires a new design of some insertion region magnets, and will be implemented in essentially two phases. The energy from collision debris is deposited in the insertion region magnetic elements and in particular in the superconducting magnet coils with a possible risk of quench. The role of the key parameters (such as the magnet aperture, the crossing plane, the thickness of a possible shielding liner, ...) is pointed out, in order to optimize the design of the new insertion regions for the Upgrade phase I aiming to reach $2 - 3\,L_0$.

AT/RD–05

Charged Particle Collisions for Particle Simulation Methods

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Macroparticle simulation plays a invaluable role in the design and optimization of advanced light sources,electric propulsion systems and modern accelerators. In devices like nuclear fusion systems or highly rarefied plasma flows, collisions between charged particle strongly influence their behaviour, for example in the target part. To describe elastic charged Coulomb collisions it is

convenient to start form the Boltzmann collision integral with the classical Rutherford differential cross section. Taylor series expansion up to second order in velocity of the postcollision distribution functions and cutoff value for the impact parameter permits the final integration of the Boltzmann integral to obtain the Fokker–Planck equation. The keys to compute the friction and diffusion coefficients in the Fokker–Planck equation are the Rosenbluth potentials which are complicate integrals of the field particle distribution function and the relative velocity between test and field particles. Since the Rosenbluth potentials are convolution integrals, the use of fast Fourier transform techniques to calculate these quantities and their derivatives rapidly frees from any additional assumptions. Such a determination the Rosenbluth potentials is the basis to model collisional relaxation in a complete selfconsistent manner. In order to fit the 3D Fokker–Planck equation of the scattered distribution function into a particle based framework,the equivalence with the stochastic differential equation (SDE) is exploited. The stochastic variable $\mathbf{C}(t)$ is later identified with the charged particle velocity. The friction force vector and a diffusion matrix play the central role. By means of Ito–Taylor expansion and Ito calculus the stochastic differential equation is discretised and numerical schemes are derived. Weak Ito–Taylor schemes together with the Fourier transform method and particlemesh interface techniques represent a remarkable simulation tool to study collisional relaxation processes from first principles. By means of which, a more realistic evaluation of the time scales can be provided since the classical testparticle approach is not necessary anymore. The introduced intraspecies charged particle modelling can be adapted for interspecies electron-ion collisions. Finally, the structure of the developed PICbased method to solve the Fokker–Planck equation also allows to perform coupled simulations.

AT/RD–06

In-Target Yields for RIB Production with EURISOL

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EURISOL DS (Europe Isotope Separation On-Line Design Study) project is the European common effort in planning a next generation RIB factory able to deliver secondary beams up to 10^{13} pps at energies up to 150 MeV u^{-1}.

The proposed schematic layout of the facility is based on four target stations, three direct targets of 100 kW of beam power and one multi-MW target two stages assembly.

Being produced via spallation the RIBs produced in the direct targets are mainly proton rich. While in the multi-MW target high intensity RIBs of neutron rich isotopes are produced by fission in actinide targets placed in the fast neutron spectrum given by a liquid metal spallation source.

The purpose of this paper is to summarize the work carried out within Task 11 “Beam Intensity Calculations” with special emphasis to the estimation of the in-target yield intensities produced in the various target configurations.

Benchmark studies were performed initially in order to verify the accurate description of the spallation models used by the MCNPX2.5.0 code and to choose the best options to be used for the present work requirements. The predictions of the code tested against measured data are presented.

Several calculations using MCNPX2.5.0 combined with the evolution code CINDER’90 were carried out to assess the performance of the direct targets. A complex analysis was performed to study the in-target production RIB intensities varying with various parameters: target dimensions, materials and incident proton beam energies. The optimized configurations for the targets together with the corresponding quantitative estimates of the production rates for all interested nuclei resulted from this investigation are discussed.

The production rates in the case of the MMW-fission targets were obtained in two steps as follows. Fission rate energy distributions were firstly estimated with MCNPX2.5.0 using the geometry model previously optimized to reach 10^{15} fission s^{-1}. Then individual production rates were further calculated based on the evaluated tables of yields for the fission products. Results for various fissile materials (^{235}U (99.99%), ^{235}U (20%), ^{235}U (3%), Natural Uranium, Depleted Uranium and ^{232}Th) are also presented.

AT/RD−07

Proton LINAC for the Frankfurt Neutron Source FRANZ

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The Frankfurt Neutron Source at Stern - Gerlach - Centre will use the ^{7}Li(p, n) reaction to produce a intense neutron beam. The planned experiments require a variable neutron energy between 10 and 500 keV. Hence the energy of primary proton beam should be adjustable between 1.8 MeV and 2.2 MeV.

The FRANZ beam line consists of two branches to allow different methods of neutron capture measurements. The compressor mode offer time of flight measurements in combination with a 4π BaF_2 detector array. The proton beam of about 150 mA will be compressed to a 1 ns pulse with a peak current of about 8 A at the repetition rate of 250 kHz. The activation mode uses a continuous neutron flux. The primary cw proton beam with a low current up to 30 mA will be focussed onto the production target.

FRANZ is not only a neutron generator but also a test bench for new accelerator and diagnostic concepts for intense ion beams. The planned proton beam properties on the target leads into a challenge accelerator design to overcome the space charge forces. This presentation emphasises on the ongoing construction of the proton injector.

AT/RD−08

The ALTO Facility for the Production of Rare Nuclei

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The ALTO facility (Accélérateur Linéaire et Tandem d'Orsay) at Institut de Physique Nucléaire d'Orsay is under commissioning. The aim of this facility is to provide neutron rich isotope beams for both nuclear physics study (away from the valley of stability) and developments dedicated to next generation facilities such as SPIRAL2. The neutron rich isotopes are produced by photofission of ^{238}U induced by the 50 MeV electrons from the linear accelerator. The isotopes coming out of the fission target effuse towards an ion source to form a beam that is analyzed through the on line separator PARRNe. Additional experimental beam lines are currently under construction. Experimental data will be presented and compared to simulations.

AT/RD–09

Powerful Industrial Electron Accelerators Type ILU for Energy up to 10 MeV

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The industrial electron accelerators type ILU are developed and produced by the Budker Institute of Nuclear Physics. The ILU accelerators are working in many countries in the industrial lines as well as in some research establishments starting from the beginning of 70-s. These machines are the pulse RF type accelerators with relatively low working frequency – 120 MHz for ILU-6 and ILU-10 and 180 MHz for ILU-8. Their energy range is from 0.8 MeV (ILU-8) to 5 MeV (ILU-10), beam power is up to 50 kW.

The ILU machines are working in various technological processes – radiation modification of polymer tubes and films, polymer pipes for hot water supply, wires, cables, sterilization of single use medical products (syringes, hospital and operation gowns, sets for operations, etc.), decontamination of the medicinal raw.

The ILU accelerators are very compact machines because they do not need the big high pressure vessel filled with insulating gas. The height of the ILU-10 machine (with energy up to 5 MeV) is less than 3 meters. The ILU-8 machine with energy range $0.8 - 1$ MeV can be installed inside the local shield with height of 3.24 m. The local shield can be placed in the ordinary industrial shops.

The ILU accelerators are equipped with several beam extraction devices – linear scanner and scanners with 4 windows permitting to organize the irradiation of the long products (tubes, cables, wires, pipes) from 4 sides. The rewinding devices providing the twist-free transportation of the long products in the irradiation zone are also designed and produced by the Institute.

The new ILU-14 machine for energy range $7.5 - 10$ MeV is under development. This machine is very good for radiation sterilization.

AT/RD–10

Performance of the PSI High Power Accelerator

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PSI operates a 590 MeV proton accelerator that drives a neutron spallation source and delivers a high average beam power of up to 1.3 MW. In 2008 the Ring Cyclotron, which represents the major component in the accelerator chain, was upgraded by installing the remaining two out of four new and more powerful accelerating resonators.

This paper describes the performance of the facility achieved with these new resonators in terms of beam power, grid-to-beam power transfer efficiency, beam losses and activation, statistics of beam trips and run durations as well as overall reliability.

AT/P5 — Poster Session P5

AT/P5–01

Development of Superconducting CH-Cavities for the EUROTRANS and IFMIF Project

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The superconducting CH-cavity is an excellent candidate for the efficient acceleration in high power proton and ion drivers like EUROTRANS (**EURO**pean Research Programme for the **TRANS**mutation of High Level Nuclear Waste in an Accelerator Driven System, 600 MeV 352 MHz) and IFMIF (The **I**nternational **F**usion **M**aterial **I**rradiation **F**acility, 40 MeV 175 MHz). The CH-structure is a superconducting cavity for the low and medium energy range operated in the H_{21}-mode. A prototype cavity has been developed and tested successfully with a gradient of 7 MV/m. Presently a new superconducting CH-cavity with improved geometry for these high power applications is under construction. The status of the cavity development related to EUROTRANS and IFMIF is presented.

AT/P5–02

Control of Amplified Spontaneous Emission in the Laser System for Intense Laser Plasma Acceleration Research

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One of the emerging trends in new accelerator techniques is the laser based acceleration of particles, known as laser – plasma acceleration. Interaction of intense ultra short laser pulse with matter generates oscillations in hot plasma and the subsequent acceleration of electrons in a wakefield. Electrons can be accelerated to around 100 MeV within 1 mm distance. Ion beams can also be produced by laser plasma acceleration, though with a broader energy spectrum than achieved with electrons. Since laser–plasma acceleration offers the potential of compact accelerator technology, at BARC work has begun on the development of a 20 TW pulsed laser system based on Nd:glass. Whether the laser plasma accelerator can produce high quality particle beams, depends on the characteristics of the laser pulse itself. These laser systems generally use the technique of chirped pulse amplification, where, after amplification the laser pulses are recompressed to obtain the high intensity required for laser plasma acceleration. The recompressed laser pulse temporal profile is very crucial for the best particle acceleration. The pulse should be free of a pedestal and prepulse, giving a high intensity contrast ratio (ratio of intensity of the short pulse to the intensity of the pedestal) for the recompressed pulse. The pedestal and pre pulse contains enough energy to create a plasma when the laser pulse is focused on target, before the arrival of the powerful femtosecond range pulse. Amplified spontaneous emission (ASE) in the amplifier stages give the main contribution to the harmful pedestal. The optical scheme used in the front end amplifier stage that has been designed and developed to reduce the ASE is described. A detailed numerical analysis using Frantz & Nodvik rate equation model was done for the amplifier. We have found that by introducing an angular misalignment, inducing a differential loss for the main pulse to be amplified and the spontaneous emission, it is possible to increase the intensity contrast ratio by two orders of

magnitude in the recompressed pulse. In the experimental set up too, for the amplification of the laser pulse, we have incorporated this method of misalignment to reduce amplified spontaneous emission by 85%. This should improve the temporal profile of the final compressed pulse.

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AT/P5–03

New Technology of Nuclei Stuffing for High Power Beam Generation in ITEP–TWAC Facility

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The ITEP-TWAC accelerator complex is well in progress now for acceleration and accumulation of high current and high power ion beams. Modified Non-Liouvillian multiple charge exchange injection technique is being employed for accumulation of fully stripped ions in a storage ring by means of particles density increase in a small phase space separatrix area. This technique allows formation of $\sim$ 170 ns compressed beam bunch, its fast extraction and focusing down to a target spot of $\sim$ 1 mm size in order to obtain maximal energy density of irradiated matter. Activities are focused on development of new experimental tools for investigations into the physics of high-brightness beams generation opening wide opportunities for variety of practical application.

AT/P5–04

Innovative Powerful Pulsed Technique, Based on a Plasma Accelerator, for Simulation of Radiation Damage and Testing of Materials for Nuclear Systems

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Innovative technology of a plasma accelerator of the Dense Plasma Focus (DPF) type based on modern elements of high-current nanosecond electronics is presented. This technology ensures operation of the devices having capacitor bank energy 1 through 10 kJ with a high repetition rate (up to tens cps) and a long life-time (on the level of 10^6 "shots"). These devices can operate with different gases, including deuterium-tritium mixture. They may produce plasma streams having velocity $1-5\times10^7$ cm/s and density about 10^{18} cm^{-3}, fast ion and electron beams with particle's energy about 100 keV, soft and hard X-Rays, and 2.5 and 14.0 MeV neutrons [1] during $0.1-1.0$ μs pulse durations.

DPF phenomenon been discovered in 50's is the most well diagnosed observable fact. It is usually characterized by a number of diagnostics with nanosecond temporal, micrometer spatial and very high spectral resolution. The same statement can be applied to the secondary plasma parameters' measurements as well as to the transient events appeared on the surface and inside the specimens' bulk under tests. A number of such diagnostics used in the simulation and test experiments together with the results received will be described.

Power flux density of plasma and fast ion/electron streams on the sample's surface during the experiments simulating conditions on plasma-facing components inside thermonuclear fusion reactors may reach as much as 10^{10} W/cm^2. It is about those expected in the reactors with the inertial (IPC) plasma confinement and much higher than those with the magnetic plasma confinement (MPC).

Pulse durations of *primary* irradiating streams are in the limits from 10^{-7} s up to a few microseconds. It is quite similar to those expected in the IPC reactors. Discussion of a so-called "damage factor" will be presented in the connection with MPC reactors. However the life-time of secondary plasmas produced by the above streams on the sample's surface and by current flowing during $4-5$ cycles of the oscillating discharge is $30-100\,\mu$s, which simulate heat loads appeared in tokamaks during transient events (ELMs, disruption instability, etc.) in a perfect way also by the pulse's durations.

1. V.A. Gribkov, A.V. Dubrovsky, M. Scholz, S. Jednorog, et al. *PF-6 – an effective plasma focus as a source of ionizing radiation and plasma streams for application in material technology, biology and medicine*, Nucleonika **51** No.1, (2006) pp. 55-62

AT/P5–05

H^- Ion Source with Inverse Gas Magnetron Geometry for SNS Project

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At the Institute of Applied Physics of National Academy of Sciences of Ukraine the plasma dual-chamber source of H^- ions having a rapid starting, reliable and long-time operation and also simplicity in service was designed for the injector of a high energy accelerator. In more details design of this source can be found in reference [1]. It is a non-cesium ion source working on the basis of tubular discharge. For plasma generation the inverse gas magnetron is used. The dual-chamber design of a source allows receiving rather easily necessary vacuum conditions, using pumps with average speeds of pumping.

In plasma volume of non-cesium H^- ion source the conditions for obtaining of increased density of H^- ions in the field of adjoining to the emission aperture were realized. It was made due to increase of flow of slow electrons to plasma adjoining to the emission aperture and their retention in this volume, and also due to decrease of gas pressure in an accelerating interval of a source.

The value of density of H^- emission current 440 mA/cm^2 is obtained. The designed source has high operating characteristics. It has rapid starting. The current of H^- ions with nominal parameters is usually reached in $1-2$ minutes after achievement of necessary vacuum conditions and supply of high voltage.

In the paper the results of optimization of emission and optical properties of the ion source will be presented. Earlier version of non-cesium source worked in the structure of RFQ accelerator for a long time. Adding cesium to an uncesiated source promises an increased H^- current output with a reduced beam emittance. Therefore, the paper also examines cesiated version of the source. H^- ion source represented in the paper can be used as an alternative version of injector for the Spallation Neutron Source accelerator complex, presently under construction at Oak Ridge National Laboratory.

1. Yu.V. Kursanov, P.A. Litvinov, V.A. Baturin, *H^-- Source with the Volume-Plasma Formation of Ions* AIP Conference Proceedings **763**, American Institute of Physics (2005) pp. 229-234.

AT/P5–06

Design and Construction of a New Ion Beam Analysis (IBA) Facility at the 3 MV Van de Graaff Accelerator of Bangladesh Atomic Energy Commission

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A new beam line and ion beam analysis (IBA) facility has been designed and constructed at the left beam line of the 3 MV Van de Graaff accelerator of Atomic Energy Centre Dhaka (AECD). The goal is to perform standard ion beam analysis such as proton induced X-ray emmission (PIXE), proton induced gamma emmission (PIGE, Rutherford Back Scattering spectrometry(RBS), Nuclear Reaction analysis (NRA), etc. with a millimeter size beam. A number of equipments such as new detectors,data acquisition system, data analysis software, vacuum systems, etc were procured and installed. Different necessary attachments were designed and fabricated at AECD workshop to install the new equipments. To be able to perform multiple IBA techniques simultaneously a special, large chamber was designed with computer control sample movement facility. A good control of the size of the beam spot and the current has been achieved with a combination of slits, ion source focusing and quadrupole magnets. The chamber was constructed under a IAEA-TC project BGD/4/023 funding at Ruder Boscovic Institute, Jagreb, Croatia. In the new ion beam analysis (IBA) facility a fine homogeneous beam spot size of 3 or 5 or 7 mm diameter and beam current in the range of $3 - 100$ nA are achievable using slits and quadrupole magnets. The beam line and the experimental chamber are described in this paper.

AT/P5–07

Halo and Tail Generation Study in CLIC

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Halo particles contribute very little to the luminosity but may instead be a major source of background and radiation. Even if most of the halo will be stopped by collimators,the secondary muon background may still be significant. We study halo production with detailed simulations and analytical estimates in the CTF3 Test Beam Line (TBL), CLIC drive beam and Beam Delivery System. We calculate and simulate particle scattering process like beam-gas elastic and in-elastic scattering.

AT/P5–08

Improvements of the Ion Beam Quality of the Magurele FN Tandem Accelerator

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The Pelletron charging chain has been installed in 2007 at the Tandem accelerator of the National Institute of Physics and Nuclear Engineering, Magurele. The chain does not limit the ultimate terminal potential, and it is in use in electrostatic accelerators up to 9 MV, and has excellent voltage stability; no spark damage, intrinsically protected; high efficiency; isolation from line voltage ripple.

A new generating volt meter was developed to get more accuracy for the terminal voltage measurement and tandem stabilization, running under GVM control only. The GVM consists of two signal plates and a grounded rotating plate. Alternatively the rotating plate covers and uncovers the signal plates so that, due to the alternating field, a current is induced to the signal plates.

This current I follows the equation: $I = U_T\, dC/dt$, where U_T is the terminal voltage and C is the terminal-signal plate capacitance.

The rotating plate covers more than the area of one signal plate, resulting in a capacitance, C_1 and C_2 respectively. Therefore the readout signal i_1 and i_2 is shaped in that way that its derivative is zero at zero crossing. So the readout electronic can be slow and there is enough time to control the electronic switches. The motor axe is grounded via a massive collector.

Position holes in the rotating plate are read out by a photo-logic sensor to control the complete read out electronics. The positive and negative half cycles of the input signals i_1 end i_2 are integrated in different capacitors and in the next state they are sampled. An output amplifier makes the difference of the sampled voltage. The output voltage, representing the terminal voltage, is independent of the revolution speed. Only the temperature coefficient of the integration capacitors influences the accuracy of measurement.

A stability of the tandem voltage better than 1 kV is achieved. To eliminate the effect of the temperature drift of the capacitors it is planned to use the integrators as comparators. Current pulses, representing the nominal value of the terminal voltage, with inverse polarity to the input signals, will be fed to the integrators. At the output we will get the voltage error that controls the voltage stabilizer circuit.

AT/P5–09

Activation Method for Measuring Ranges of Heavy Ions in Solids

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Recently, experimental studies on the residual activity induced by U ions in Cu targets have been carried out at GSI Darmstadt. During the data handling procedure we came across an interesting "spin off" leading to a new method of stopping range determination for fast U ions. In the preformed experiments, heavy ion beam delivered by SIS–18 synchrotron has been used to irradiate so-called "stacked-foil" targets. Precise gamma-spectrometric measurements for element identification has been performed with a HpGe detector by coupling with the 4096 multi-channel analyzer (resolution of 1.8 keV for the 1332 keV ^{60}Co γ line). Analyzing the gamma-spectra of the activated foils has allowed us to identify the radioisotope concentration in each foil and to resolve depth profiles for each individual isotope. One of the radioactive nuclides detected only in the foils located around the range of primary ions was ^{237}U. This nuclide can be produced in the reactions ^{238}U(X, ^{237}U). From the nuclear kinematics to a good accuracy, it can be assumed that the total stopping ranges of the of ^{237}U and ^{238}U isotopes have to be almost identical. Using the experimental data, the concentration of ^{237}U ions which have been stopped in each foil was deduced, so the range distribution of U ions was determined.

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AT/P5–10

Tandem Accelerator Beam Tests of New Fast Neutron Scintillators

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There is an intense search of new no organic scintillators for the neutrons detection in last years. There are KDP-crystals (KH2PO4) very interesting for these goals with their wide transparency band from UV up to IR-regions. These crystals do not take up γ-quanta (density – 2.34 G/cm^2 and effective atomic number $Z = 14$).

In this paper there were obtained on EGP–10K tandem accelerator beam the comparison characteristics of the irradiation detection efficiencies in mixed (n, γ)–fields.

AT/P5–11

Alternative On-Line Cyclotron Beam Intensity and Exposure Rate Levels Operative Monitoring

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Charge particle accelerator laboratories and, more important, non-nuclear physics centres are still in-crescendo and expected to play a key role upon diverse fields such as research, materials, safety, analytical applications, industrial-probe probing and other distinguishable non-destructive machine capabilities in addition to cosmological endeavours. Everyone uses commercially available accelerators for radionuclide production, new/modification materials, ion beam applications; PIXE on elemental analysis is a well recognized multidisciplinary tool ranging from forensic medicine to art. Human health and patient's life quality being likely the most sensitive non-invasive ambulatory, molecular, clinical diagnostic contribution; and later, although expensive by any standards, charged-particle beam-therapy with high energy machines are becoming a serious choice if affordable.

Low and medium energy accelerators for applications like these are found all over the word and not under a nuclear physicist or nuclear related specialist operation necessarily. Accelerator operators are highly trained professionals skilled to plump for and to adopt fast and correct decisions when needed. Therefore, new approach and techniques are always sought to make accelerators operation more reliable and safe under routinely work. We present a method to take advantage for using exposure detectors and operational figures recorded when running an accelerator to track beam intensity on target from indirect data.

Cyclotron operators considers advantageous and always necessary to have alternative and indirect ways to track irradiations parameters such beam intensity on target. In this work we will show how in our laboratory we have developed a method to provide additional exposure rate data to be used as beam indirect probe and vice versa. By monitoring the exposure rate data we obtain irradiation radiological profile. Several trials were performed to achieve best radiological rate data detector-target geometry. A detector (Ludlum Survey Meter Area Monitor) was located on the inside vault inner wall a 1.5 m over floor and 1.8 m distance from irradiation target. The exposure rate curve as a function of irradiation time

AT/P5–12

PIN Photo-Diodes as Radiation Detectors in Accelerator Applications

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We have been using PIN photo-diodes originally suited for light detection as radiation detectors in several applications: photon monitoring in X-ray machines in industrial and medical applications, X-ray spectroscopy for identification of radioactive materials and XRF, and charged particles spectroscopy. The versatility of these devices as radiation detectors has led us to apply it in several accelerator experiments. This work presents an overview of the results obtained in several experiments: the measurement of charged particles up to 12 MeV in a Tandem accelerator, the measurement of the Bremmstrahlung radiation obtained in an experimental electron accelerator in the range from 70 keV to 470 keV, the direct measurement of the intensity of the electron beam; also the application of PIN photo-diodes in the measurement of the intensity of photons in lineal accelerators used in radiotherapy up to 18 MeV. The front end conditioning electronics associated with the detectors is also described for every application: low noise charge sensitive preamplifiers and current amplifiers are used. The PIN diodes are a good choice for radiation detection in several accelerator applications with the advantage of a good position resolution due to its small size, good sensitivity for different radiation fields and low cost, and can be used to build a wide variety of detection systems around accelerator experiments.

AT/P5–13

Thermal Stress Analysis of a 3 MW Rotating Solid Target

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The structural feasibility of a rotating solid target for potential use at the SNS second target station was evaluated for a beam power of 3 MW. The solid target concept consists of a water cooled, segmented, and cladded tungsten disc contained within a stainless steel shroud rotated to distribute energy deposition from a long pulse proton beam. Finite element analysis was used to simulate temperature distributions caused by different beam profiles and cooling configurations, and again to evaluate the stress fields resulting from the combination of thermal expansion and mechanical constraint of the tungsten segments. If the segments are split both angularly and vertically, cooling on the top, bottom, and center surfaces can maintain temperatures below 155°C. This cooling configuration, combined with a system of spacers and springs to avoid over constraint, results in stresses well below allowable. A detailed shroud design, incorporating a concave window in order to minimize material in the beam path, results in acceptable stresses with respect to both thermal and internal pressure loads. Although further hydrodynamic evaluation is required to analyze the coolant flow system in detail, the rotating solid target concept is structurally feasible for a beam power of 3 MW.

AT/P5–14

Design of Proposed DC Low Voltage Acceleration System

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Design of proposed DC low voltage acceleration system has been done by using SIMION computer program. An assumption is made that the ion beamexit from the ion source at a distance 20 mm

from the input of the accelerating tube, beam width is 10 mm; beam divergence angle is 0.0°, singly charged argon ions. The constant gradient is made through accelerating tube with equal value of the voltage applied on the successive gapes of 10 mm. Two different kinds of the extraction systems have been studied with the aid of the SIMION computer program version 7. The ion beam parameters are determined by the geometrical parameters of the extraction system, the applied voltages and the plasma parameters. This study is made to reveal the influence of accelerating tube diameter, the influence of the space charge, the input energy of the ion beam, on both beam emittance and output radius. Beam emittance was deduced at distance of 60 mm from the exit of the accelerating tube.

AT/P5–15

Lay-out of the EURISOL Experimental Hall

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The EURISOL project is aimed at the design of the next generation European ISOL radioactive ion beam (RIB) facility able to deliver high intensity beams of 10^{13} pps at energy up to 150 MeV u^{-1}. The RIBs of 21 MeV u^{-1} and 150 MeV u^{-1} will be extracted to a number of experimental halls, where they interact with secondary targets. The purpose of this study is to configure the shielding and the management of the access to the controlled areas inside the beam experimental halls. In agreement with physics case of the project it was decided to investigate six target materials: CH_2, Be, C, Cu, Ni and Pb at two possible thicknesses of 1 mg cm^{-2} and 10 mg cm^2. The experimental hall hosting the AGATA germanium array detector was selected as the conservative case. The conceptual model for the beam dump system to be placed at the end of the post-accelerator beam line, whose feasibility was previously demonstrated, was used here also to examine safe operation conditions inside the experimental hall. Therefore the geometry model used in simulations contains

a) a simplified AGATA detector placed in the centre,
b) a typical experimental target positioned inside AGATA, and
c) a V-shaped beam dump configuration with a water-cooled graphite core and a subsequent iron block downstream of the beam line. A test case of $^{132}Sn^{25+}$ RIB was used in simulations.

Neutron production yields from the physics targets, dose rate estimates in the experimental area and behind the shielding walls and energy deposition on the beam dump were calculated and analysed in this study. Dedicated simulations were performed by means of the PHITS Monte Carlo computer code. In order to characterise the residual radiation environment inside the experimental halls the following procedure was developed. Induced radioactivity in the targets, AGATA equipment, concrete wall and the air inside were estimated using DCHAIN–SP–2001 code. Ambient dose equivalent rates due to the residual radiation were calculated with the MCNPX code using photon sources resulted from DCHAIN activation calculations. The lay-out of the experimental area was schematically configured by preliminary sizing of concrete shielding walls. The paper provides also the magnitude of the radioactive material inventory generated inside this zone and the associate dose rate estimates.

AT/P5–16

A Regulated High Voltage Power Supply for Accelerator Driven System

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This paper discusses a regulated high voltage power supply (RHVPS) developed for accelerator driven systems to drive a klystron. The RHVPS uses a large no. of small voltage choppers. These choppers are switched in tandem by a novel technique to regulate output voltage.

Various parts of the system are novel. The front end is a pair of transformer with 40 secondaries each. Each secondary feeds a switched power module (SPM) which has a rectifier-filter unit followed by an IGBT switch to get 1.3 kV. All 80 SPMs are connected in series. The final output is taken from the two end SPMs. A central controller uses voltage sample from each SPM and generates switching pulses for each IGBT switch. IGBTs of all SPMs are switched with a fixed phase lag from each other, resulting in purely constant voltage with ripple limited to one SPM voltage. The frequency of ripple is high and can be filtered out with a simpler filter.

The system can turn off for protection of the load in less than 2 μs, the essential attribute for a power supply to be used with klystrons. The results of wire burn tests measure the low stored energy at fault turn off (less than 10 J). The power supply (rated for 100 kV at 2.5 MW) will be used for a continuous duty with the klystron for accelerator driven system at BARC (India). A power supply giving 80 kV. 75 A is being used with an accelerator system for extraction of beam along with a Neutral Beam Injector. This paper discusses the technology and experimental results of the system. It also discusses various other options with similar power supply.

AT/P5–17

High Intensity ECR Proton Source Development for LEHIPA–ADS

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A 50 keV, 50 mA microwave based ECR (Electron Cyclotron Resonance) Proton Source have been designed, developed and commissioned for the 20 MeV, 30 mA high power proton accelerator LEHIPA.

In the ion source, the plasma discharge is initiated by cw magnetron of 2 kW at 2.45 GHz in the presence of axial magnetic field of 875 G. The microwave power is transmitted through a waveguide launcher and delivered to the plasma load through a circulator, 4-stub auto tuner, dual directional coupler, waveguide break, ridge waveguide and microwave window. The magnetic field in the ion source is generated by two solenoid magnets that are independently energized and have been designed using POISSON code to obtain optimum field configurations.

Two types of ion extraction i.e., in triode and pentode geometry have been designed and fabricated. The design of the ion extraction has been performed using PBGUNS and the electrode shape, separation and aperture diameter have been optimized.

The plasma discharge has been obtained for hydrogen gas at flow rates of 1 SCCM to 9 SCCM and microwave powers of $300 - 900$ W. The measured plasma electron density and temperature using Langmuir probes were found to be in the range $10^{11} - 10^{12}$ cm^{-3} and $2 - 7$ eV respectively. The variation of plasma density and electron temperature with microwave power for hydrogen gas at a fixed flow rate 1.5 SCCM were studied. It has been observed that as the microwave power is increased the plasma density increases due to increased ionization of the neutral gas, and the electron temperature decreases due to enhanced collisions with charged and neutral particles. Similar trend has been observed at other flow rates in the range of 3 SCCM to 9 SCCM. The variation of plasma density with gas flow rates was also studied.

The maximum proton beam current extracted from the three electrode configuration was 42 mA at 40 kV measured using the Faraday cup located at a distance of 36 cm from the plasma electrode for 600 W of forward microwave power, 875 G of axial magnetic field and 5 mbar of gas pressure in the plasma chamber. The variation of beam current with gas pressure, microwave power and magnetic field has been studied. The proton beam diameters recorded for residual gas pressure of 8×10^{-6} mbar and 1×10^{-5} mbar on SS flange located at 75 cm from the plasma electrode were 13 cm and 10 cm respectively.

AT/P5–18

Development of Quadrupole Focussing Lenses for Drift Tube Linac

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A linear accelerator comprising of Radio frequency quadruple (RFQ) and drift tube linac (DTL) is being developed by BARC. The alvarez type post-coupled cw DTL accelerates protons from an energy of 3 MeV to 20 MeV. The drift tube linac is excited in TM010 mode, wherein the particles are accelerated by longitudinal Electric fields at the gap crossings between drift tubes. The particles are subjected to transverse RF defocusing forces at the gap crossings due to the increasing electric fields in the gap. The transverse defocusing is corrected by housing magnetic quadrupole focussing lenses inside the drift tubes. The permanent magnet quadrupoles are placed inside the hermetically sealed drift tubes and provide constant magnetic field gradient in the beam aperture.

The drift tubes are mounted concentrically inside the resonating DTL tank and are attached to the tank body with stems. Rare earth permanent magnets have been used to achieve the high field gradient. The drift tube body is subjected to RF heating due to eddy currents and hence the sealed drift tubes are to be cooled from inside. The temperature rise of the drift tube assemblies has to be limited to avoid demagnetization of permanent magnets and also to limit thermal expansion of the tubes. This paper discusses various aspects of magnetic design, selection of magnetic materials and the engineering development involved in the assembly of the drift tubes.

AT/P5–19

Development of the High-Brightness Ion Source

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A helicon and a multicusp version of a radio-frequency ion source with compact permanent magnet systems for accelerator applications have been developed and tested to show the following performance data: plasma density of $10^{11} - 9 \times 10^{12}$ cm^{-3}, pressure of $2 - 10$ mTorr, beam current densities of $10 - 130$ mA/cm^2, brightness ~ 100 A/(m^{2}rad^2 eV), energy spread $8 - 30$ eV, and an rf power input into the plasma of $40 - 400$ W. The design of a gas field ion source (GFIS) of the needle-in-capillary type operating at room temperature is proposed. A field ion emitter made on the nanostructured carbon basis is planned to be used in the source.

SM
Satellite Meetings

SM/SR — Nuclear Spallation Reactions

Spallation reactions are nuclear reactions playing an important role in a wide domain of applications ranging from neutron sources for condensed matter and material studies, transmutation of nuclear waste and rare isotope production to astrophysics, simulation of detector set-ups in nuclear and particle physics experiments, and radiation protection near accelerators or in space. The simulation tools developed for these domains use nuclear model codes to compute the production yields and characteristics of all the particles and nuclei generated in these reactions. The codes are generally Monte-Carlo implementations of Intra-Nuclear Cascade or Quantum Molecular Dynamics models followed by de-excitation (principally evaporation/fission) models.
This Satellite Meeting will help experts and competent practitioners to better understand the physical basis, approximations, strengths and weaknesses of the currently used spallation models and codes. In addition, presentations of relevant basic experimental data with emphasis on accuracies, detector efficiencies, filters and thresholds will be planned.
The IAEA and the Abdus Salam International Centre for Theoretical Physics (ICTP) have recently organised an expert meeting on model codes for spallation reactions. The experts have discussed in depth the physics bases and ingredients of the different models in order to understand their strengths and weaknesses. Since it is of great importance to validate on selected experimental data the abilities of the various codes to predict reliably the different quantities relevant for applications, it has been agreed to organise an international benchmark of the different models developed by different groups worldwide. Therefore, a second important objective of the meeting will be to discuss the results of the recently launched Benchmark Exercise on Spallation Models. Details on this initiative are posted on the website:

http://www-nds.iaea.org/spallations

During the Satellite Meeting, a first assessment of the results obtained from the benchmark initiative will be discussed. The main topics to be addressed at the Satellite Meeting are:

- To review the status of the benchmark exercise on spallation models recently launched;
- To assess the preliminary results of the benchmark in terms of respective successes or deficiencies of the different models;
- To define the figures of merit to compare the different models;
- To present basic experimental data relevant for the benchmark with emphasis on accuracies, detector efficiencies, filters and thresholds;
- To promote the exchange of information among researchers in the field;
- To identify areas of international cooperation in the field.

Complementary, the main objective of the Satellite Meeting is to promote exchange of information among IAEA Member States representatives and delegates, and to discuss new trends in neutron spallation reactions for applications in the relevant fields. It is also aimed at enhancing research collaboration between Member States and promoting education on topics related to the AccAp-09 Conference, emphasising the potential of nuclear based technologies.

The Organizing Committee of the Satellite Meeting is composed of:

- *Jean-Christophe David, CEA, Saclay, France*
- *Detlef Filges, Forschungszentrum Jülich, Germany*
- *Frank Goldenbaum, Forschungszentrum Jülich, Germany*
- *Sylvie Leray, CEA Saclay, France*
- *Guenter Mank, IAEA, Vienna*
- *Alberto Mengoni, IAEA, Austria*
- *Yair Yariv, NRC Soreq, Israel*

SM/SR–12

Tools for Benchmarking of Spallation Models — First Results

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Early in 2008 an expert meeting [1] on model codes for spallation reactions had been organized by IAEA and ICTP. The experts had discussed in depth the physics bases and ingredients of the different models and the available experimental data as well. Since it is of great importance to validate on selected data the abilities of the various codes to predict reliably the different quantities relevant for applications, it has been agreed to organize an international benchmark of the different models developed by different groups in the world.

This benchmark is organized under the auspices of IAEA and the analysis of the results is done with the help of an International Advisory Board. Necessary tools have been developed to do a comparative study of the calculated and experimental data. Preliminary results have been obtained from the comparison of different models with experimental data to better understand the physical basis, approximations, strengths and weaknesses of the currently used spallation models and codes.

1. http://nds121.iaea.org/alberto/mediawiki-1.6.10/index.php/Benchmark:Documentation

SM/AE — Particle Accelerators in Analytical and Educational Applications

Particle Accelerators have become important tools both, for basic and applied research for the generation of fresh knowledge as well as for applications in a large variety of fields including advanced training and education for new generation of scientists. Industrialized and developing nations have benefited from this technology to advance their knowledge based technology not only of the industry, but also in material sciences and analytical applications in a large variety of substrates. The applications in medicine are well known and widely used.

Although accelerator technology is already well advanced, it continues to be developed with the aim of improving performance, lowering the cost and, producing specialized design for specific purposes. For instance, small accelerators are ideal tools for advanced basic and applied research in universities that covers a wide range of practical analytical applications in environmental sciences, exploration and exploitation of natural resources and materials of cultural and historical value, through techniques such as PIXE, PIGE and micro-beams, in addition to playing a fundamental role in education and training of scientists.

A large number and variety of accelerators ranging from small linear proton accelerators a few MeVs, and single or dual cyclotron accelerators have been installed in the laboratories of many developing nations. With the experience gained thus far, scientists managing these machines are today eager to increase the utilization time by expanding the spectrum of relevant analytical applications to a truly multidisciplinary one, and making efforts to establish collaborative research with other centers around the world. In these regard, scientist from these regions see the IAEA as the central or focal point to nurture and facilitate such international collaboration. International scientific meetings of the type organized by the Agency can proactively provide the right atmosphere where scientists from advanced and developing nations can meet. One has to remember of the few opportunities that the scientists from developing countries have to meet with other scientists and thus, interact and exchange fruitful experience.

The focus of this Satellite meeting is on reviewing and discussing the potential utilization programmes of small accelerators in physical and chemical analytical applications as well as an invaluable tool for research and high level university education and training of young scientist.

The main topics to be addressed at the Satellite Meeting:

– General analytical applications of accelerators
– Micro beams in physical and chemical analytical applications
– Accelerators as an advanced tool for education and training
– Networks for collaborative research and training

The Organizing Committee of the Satellite Meeting is composed of:

– *Hernan Vera Ruiz, Bolivia*
– *Mohammad Haji-Saeid, IAEA, Vienna*
– *Françoise Mulhauser, IAEA, Vienna*
– *Claudio Tuniz, ICTP, Trieste, Italy*
– *Pierre van den Winkel, Belgium*
– *Stjepko Fazinic, RBI, Croatia*
– *Matthias Rossbach, FZJ, Germany*

SM/AE–01

Materials Science and Engineering Research and Education at the Center for Irradiation of Materials of Alabama A&M University

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The Center for Irradiation of Materials @ AAMU (http://cim.aamu.edu) established in 1990 to serve the University in its research, education and services the need of the local community and Industry. CIM irradiation capabilities oriented around two tandem type ion accelerators with seven beam lines providing high resolution Rutherford backscattering spectrometry (RBS), MeV focus ion beam, high energy ion implantation and irradiation damage studies, particle induced x-ray emission (PIXE), particle induced gamma emission (PIGE), and ion induced nuclear reaction analysis in addition to fully automated ion channeling. One of the two tandem ion accelerators designed to produce high flux ion beam for high fluence MeV ion implantation and high fluence ion irradiation damage study. The facility is well equipped with variety of surface analysis systems, such as SEM, ESCA, as well as scanning micro-Raman analysis, UV-VIS Spectrometry, luminescence spectroscopy, Thermal conductivity, electrical conductivity, IV/CV systems, Mechanical test systems, AFM, FTIR, Voltmetry analysis as well as low energy implaters, Ion Beam Assisted Deposition and MBE systems. In this presentation we will demonstrate how the facility provides services to schools, industries and how CIM has contributed to the recent invention of fabrication of highly efficient thermoelectric materials.

Sponsors: Supported in part by AAMU Research Institute, NASA, DOE, NSF and industries.

SM/AE–02

An Undergraduate Ion Beam Analysis Laboratory

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Hope College (in Holland, Michigan) purchased a 1.7 MV tandem pelletron with nuclear microprobe capability with funding from the US National Science Foundation in 2004. The purpose of this facility is to perform publishable research in a variety of applied fields, and to provide educational opportunities and sophisticated technical training for undergraduates that will enter the workforce in science, technology, engineering and mathematics. Hope College has two senior investigators with experience in nuclear science and expertise with accelerators, and an institution with approximately 3200 undergraduates. The college also has a rich history of involving undergraduates in research and producing future Ph.D. scientists. The facility was installed and commissioned in October, 2004 and since that time hundreds of separate ion beam analysis experiments have been performed in fields as diverse as solid state physics, biochemistry, forensic science, electrochemistry, environmental science, mineralogy and palaeontology. Over 90% of the work has involved on-campus collaborations between different faculty members, and there are already over 50 different undergraduate research students that have been involved in ion beam analysis research. There are six manuscripts published or in press from this facility, with more than two dozen undergraduate co-authors. During the first four years, the facility has been operated entirely with undergraduates and a single technician who was trained to help maintain the facility. We have recently added a post-doctoral fellow to our research group to help with the large number of students that are interested in the research projects that have become possible with the new ion beam analysis facility. A brief tour of our facility and an overview of some of the successful research projects will be presented, plus some insights into best operating practices we have learned for maintaining a productive an ion beam analysis facility at an undergraduate institution.

SM/AE–04

Educational Applications on Particle Accelerators in Brazil

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The Brazilian production of radiopharmaceuticals and radioisotopes for medical usage dates back to the 70's, since the beginning up to 2006; it was a monopoly of the government-owned corporations. After the market was open for the private enterprise, the quantity of small particle accelerators is increasing. The difficulties are many, from industry installation to the hard time on finding qualified personnel. The lack of investment on this area brought few trained people and the trained ones keep working in the government laboratories. Facing this issue, a strong program was started on training and educating people on universities, businesses enterprises and at hospitals in order to increase the human resources capabilities in the country. Activities such as laboratory research and lectures are being made as well in order to adapt Brazil to the renascence of the nuclear technology and increase the knowledge in the field of particle accelerators. These investments on education are preparing professionals in several areas, such as: physics, engineering, pharmacy, medicine, administration, among others. It started on the universities not only with lectures and workshops, but also with research partnerships on the stand-by time of the particle accelerators. At clinics and hospitals the efforts are focused in the improvement and training of the particle accelerator product applications. One of the private enterprise corporations has trained more than 30 people from five different states and established partnership with five different universities, qualifying people on installation, operation, maintenance and administration of the whole process of implementation of a particle accelerator site. It's also collaborating with the universities and researchers in the development of new techniques: the irradiation of other material targets or the use of non-usual particle beams, allowing the study of the nuclear activation of the concrete walls of the particle accelerator's bunker and the radionuclide capture on the filters of the air conditioning system in the factories.

SM/AE–05

Nuclear Microprobe Facility at iThemba LABS in Multidisciplinary Applications — Key Elements of a Success Story

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Nuclear microprobe at Materials Research Group of iThemba LABS (earlier National Accelerator Centre) has been operational since 1991. Ion beams are provided by the 6 MV CN single-ended Van de Graaff accelerator (High Voltage Engineering USA) installed in 1963. Voltage range is between 0.6 and 6 MV. Several old components were replaced and the accelerator operation has been partly computerized in 2003 – 2006. The microprobe uses a standard magnetic quadrupole triplet (OM 150) and experimental chamber manufactured by Oxford Microbeams. Modifications including implementation of digital scanning system and computer-controlled changes of specimen position using stepper motors were made locally. The most often used techniques are PIXE and RBS. Other ion beam techniques (NRA, PIGE, STIM, IBIC) were also occasionally used. Protons and α particles were the only focused ion beams used. Since commissioning the microprobe has been serving the South African research community and industry, often hosting students and researchers from other African countries. It operates as a national and effectively regional facility, without fees charged for its usage by the academic community. Instead, rigorous collaboration protocols have been established and implemented with the goal of maximizing scientific outputs. Initially microbeams have been used in materials science and geological applications, which were typically forming part of M.Sc. or Ph.D. projects done in collaboration with local universities. An important factor in successful collaborations was the availability of auxiliary equipment for on-site specimen preparation, in particular the establishment of specialized cryo-preparation laboratory, with some equipment unique in Africa and skilled personnel being part of our research group. At present this is the only microprobe worldwide with analytical capabilities of biological specimens in frozen-hydrated state. This has been the key of success, especially in research projects related to plant physiology, ecophysiology, agriculture and environmental studies.

Selected applications of finalized research projects will be presented.

SM/AE–06

Educational and Research Aspects of Homemade Modular PC-Controlled Radiochemistry Systems for the Processing of Irradiated Electroplated Solid Cyclotron Targets

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Homemade modular PC-controlled radiochemistry systems, used to separate the non-carrier added radionuclide of interest from irradiated electroplated solid cyclotron target layers such as ^{203}Tl, ^{67}Zn, ^{111}Cd and ^{64}Ni, illustrate that classical analytical separation and sampling techniques can be carried out remote-controlled with a minimized risk of operator errors and with excellent processing yields ($> 95\%$) and resulting in chemical and radiochemical purity levels that meet the requirements of the Pharmacopoeia. As VUB Cyclotron Laboratory developed such systems for the production of ^{201}Tl, ^{67}Ga, ^{111}In and ^{64}Cu, the ^{111}In manifold, the interface and the VB program will be presented from educational point of view. Emphasis will be placed on analytical techniques such as selective dissolution of the target layer (heated flow-through stripper), re-dissolution of a precipitate (reversed-filtration, rotating magnetic field in the precipitation-filtration unit), extraction (mixing by inert gas bubbling, phase separation by micro-conductivity cells), volume monitoring of the bulk volume (micro-conductivity assembly) and sampling prior to chemical, radiochemical and radionuclidic analysis (micro-conductivity drop counter). A limited slide show will illustrate the system.

SM/AE–07

Utilization of the RBI Tandem Accelerator Facility for Analytical Applications

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Through its Division of Experimental Physics, Rudjer Boskovic Institute (RBI) has a long-standing tradition in accelerator science, technology and applications. In 1956 the first Cockroft-Walton accelerator was built and used as a source of fast neutrons (neutron generator) for nuclear physics experiments. In 1971 new neutron generator was commissioned and is still in use as a source of neutrons for applied research. Between 1954 and 1962 a cyclotron was built, which during its best years produced up to 75 GBq of radio-nuclides per year used for production of radiopharmaceuticals. This cyclotron was decommissioned, and the new one is under installation to be used mostly for the production of PET pharmaceuticals.

Through the Laboratory for Ion Beam Interactions (LIBI), the Division of Experimental Physics of the Rudjer Boskovic Institute (RBI) operates and maintains the Tandem Accelerators facility that physically consists of the 6 MV Tandem Van de Graaff and 1MV Tandetron accelerators, associated beam lines and measurement end-stations, including ion microprobe, Time–of–Flight Elastic Recoil Detection Analysis (TOF-ERDA) end-station, general purpose Ion Beam Analysis (IBA), High-Resolution Particle Induced X-Ray Emission (PIXE), and in-air end stations. The facility is used for research and applications in a range of fields, including nuclear and atomic physics, ion beam modification and characterisation of materials by a variety of ion beam analytical methods. Interdisciplinary research is performed at this facility as a collaborative effort between different RBI laboratories from several departments, and between RBI and other institutions from

Croatia and abroad. Capabilities of the RBI Tandem accelerator facility for analytical applications will be presented, illustrated with several examples of recent interdisciplinary collaborations.

SM/AE–P01

Swift Heavy Ion Irradiation Induced Alteration in Infrared Vibrational Modes for Ti-Substituted Li-Al and Li-Cr Ferrite systems

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The swift heavy ion-irradiated Li-Ti-Al and Li-Ti-Cr spinel ferrite systems have been studied with the X-ray diffraction and infrared absorption spectroscopy. The polycrystalline samples of $Li_{0.5(1+x)}Ti_xAl_{0.1}Fe_{2.4-1.5x}O_4$ [LTAF] and $Li_{0.5(1+x)}Ti_xCr_{0.1}Fe_{2.4-1.5x}O_4$ [LTCF]($x = 0.0, 0.1, 0.2$ and 0.3) systems were synthesized using a solid state reaction technique. The spinel cubic structure of these ferrites was confirmed by powder X-ray diffraction technique. The powdered samples were irradiated with a 50 MeV Li^{3+} ion beam at fluence of 5×10^{13} ions/cm^2. The IR spectra revealed two absorption bands along with the shoulders/splitting in the wave number range of $400 - 800$ cm^{-1} arising from interatomic vibrations in the tetrahedral and octahedral coordination compounds. The intensity of all absorption bands and their shoulders decrease whereas bands become broader with substitution of titanium, which is ascribed to the chemical disorder brought about by the Ti-substitution. On SHI- irradiation appreciable changes are observed in IR spectra in both the systems which are explained on the basis of generation of micro-structural defect states.

SM/AE–P02

IAP Accelerator Based Microanalytical Facility for Material Science Studies

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Modern analytical facility developed at the Institute of Applied Physics (IAP) is based on a single-ended 2 MV Van de Graaf accelerator. It consists of 4 beamlines to fulfill materials science tasks using following techniques: Rutherford backscattering, nuclear reaction analysis, ion luminescence and particle induced X-ray emission. Rutherford backscattering beamline is equipped with magnetic spectrometer with double focusing and resolution of 3 keV. A scanning nuclear microprobe is implemented in one of the beamline. Proton beam focusing is realized with two doublets of precision magnetic quadrupole lenses of a new design. Both doublets are made of single piece of the soft iron using electrical-discharge machining system. Resolution of 2 μm with current about 100 pA is obtained. The microprobe is used for investigation of the impurity segregation to the grain boundary in the structural materials of the nuclear power systems. Article presents a description of the facility and its applications.

SM/EB — Applications of Electron Accelerators: Prospects and Challenges

Electron beam (EB) accelerators are used in diverse industries to enhance the physical and chemical properties of materials and to reduce undesirable contaminants, such as pathogens or toxic by-products. Electron beam accelerators are reliable and durable equipments that produce ionizing radiation without relying upon radioactive isotopes. EB equipment can be turned on and off as any other industrial electrical equipment. These electron accelerators can be used as tools in basic and applied research, but also in pilot plants for demonstration of the feasibility of a certain radiation processing technology, as well as in industrial-scale facilities. Different end-use areas need accelerators with different energies as well as different under-beam handling systems. For example, wire and cable insulations, heat-shrinkable tubing, and the emerging use of EB cross linked polyethylene tubing for water distribution rely upon a multiple-pass system referred to as a "race-track" system, while EB units for surface curing are installed on printing presses and coatings lines. Service centers often rely upon cart-type conveyor systems that handle diverse product forms and items. Most of the heat-shrinkable films used for food packaging are cross linked before the film is blown into its finished dimensions. Some heat-shrinkable films and tire components are irradiated as sheets. Market surveys indicate that there are more than 1400 high-current EB units in commercial use providing an estimated added value to numerous products of more than 85 billion USD.

The main objective of the Satellite Meeting is to promote exchange of information among the IAEA Member States representatives/delegates and to discuss the expansion of industrial applications using electron beam accelerators in developing countries focusing on the technology transfer, the availability of low cost, reliable electron accelerators, energy saving and environmental protection by using electron accelerators ant the role of the IAEA for promotion of electron accelerator applications.

The focus of this Satellite meeting is on the development of reliable electron beam accelerators for industrial processes and preservation of the environment, as well as on the development of new processes and applications.

The main topics to be addressed at the Satellite Meeting are:

- Accelerator Development for Industrial Applications: low, medium and high energy, X-ray Accelerators
- Application of Electron Accelerators in Industry, Food and Agriculture Sector
- Electron Accelerators for tackling environmental pollutants (gases, liquids and solids)
- Advanced Materials produced by Electron Accelerators
- Clean and Energy Saving Surface Coating and Printing Technique by Electron Accelerator

The Organizing Committee of the Satellite Meeting is composed of:

- *Sueo Machi, Japan*
- *Anthony Berejka, USA*
- *Andrzej Chmielewsky, Poland*
- *Mohammad Haji-Saeid, IAEA*
- *Agnes Safrany, IAEA*
- *Maria Helena de O. Sampa, IAEA*

SM/EB–01

Prospects and Challenges for the Industrial Use of Electron Beam Accelerators

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A panel discussion will be held with the invited speakers to address the opportunities and challenges that face the industrial use of electron beam (EB) technology. Topics to be covered include:

1. the expansion of existing markets into developing countries: as in the use of high-current EB for the crosslinking wire and cable jacketing and heat shrinkable films and tubing, for the curing of elastomers for tires and sheeting, and for medical device sterilization, and of low-energy EB for the elimination of volatile organic compounds (air pollutants) in the curing of inks, coatings and adhesives;

2. the use of low-cost, high-current EB equipment for materials and biological research and new product development, in lieu of gamma cells, in academic, national and industrial laboratories;

3. the emergence of innovative end-use applications, such as the use of low-energy EB for surface decontamination; and the commercial use of high-energy EB and X-rays for medical device sterilization and food irradiation and other uses;

4. the industrial viability of environmental applications, such as stack gas and waste water treatment, including infra-structure and investment impediments; and

5. the understanding of and access to high-current EB and X-ray processing by academic institutions and industrial engineers and the need for the development of trained personnel in this area of technology.

SM/EB–02

Needs and Emerging Opportunities of Electron Beam Accelerators on Radiation Processing Technology for Industrial and Environmental Applications in South America

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The radiation processing technology for industrial and environmental applications has been developed and used worldwide. In South America there are 17 industrial electron beam accelerators with energy from 200 keV to 10 MeV, operating in private companies and governmental institutions to enhance the physical and chemical properties of materials. However, there are more than 1400 high-current electron beam accelerators in commercial use throughout the world. The major end-use markets for these EB units are R&D, wire and electric cables, heat shrinkable tubes and films, foams, tires and components, semiconductors and multilayer packages.

In addition, *the Brazilian Technical Association for Radiation Curing* was foundered in 1993. The knowledge on EB technology has been sharing with the associated industries and partners in Brazil, since that time. In 2006, an agreement with RadTech International North America and this Brazilian association promotes the *RadTech South America*, which has its headquarter in IPEN–CNEN/SP.

Nowadays, the emerging opportunities in South America are paints, adhesives and coatings cure; disinfestations of seeds; films and multilayer packages irradiation for low-energy EBA (150 − 300 keV). For mid-energy EBA (300 keV–5 MeV), they are flue gas treatment (SO_2 and NO_X

removal); composite materials and carbon fibers irradiation; irradiated grafting ion-exchange membranes for fuel cells application; natural polymers irradiation and biodegradable blends production. For high-energy EBA ($5-10$ MeV), they are sterilization of medical, pharmaceutical and biological products; gemstone enhancement; treatment of industrial and domestic effluents and sludge; preservation and disinfestations of foods and agricultural products; sugarcane bagasse irradiation as pretreatment to produce ethanol biofuel; decontamination of pesticide packing; soil remediation; organic compounds removal from wastewater; treatment of effluent from petroleum production units and liquid irradiation process to treat vessel water ballast.

On the other hand, there is a growing need of mobile EB facilities for different applications, as well as, an emerging opportunity of using low-energy electron beam accelerators for the curing of inks, coatings and adhesives in order to eliminate VOC's, and for less energy use than thermal process in South America.

SM/EB–04

Growing Industrial Applications of Electron Accelerator in Japan

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Japan is a pioneer for application of electron accelerators. There are 248 electron accelerators used for industrial applications and 148 for research/development in Japan. The first commercial production of radiation cross-linked heat resistant wires was started in 1971. All major wire and cable companies are using several electron accelerators each for production of heat, flame and chemical resistant wires. More than 90% of automobile tires are produced by partial cross-linking of rubber using electron accelerator. Electron beam cross-linked heat shrinkable tubes and sheets are also extensively produced. More recently commercial production of electron beam cross-linked PVA hydrogel wound dressing has been commercialized. Only Japan is applying radiation grafting by using accelerator for commercial production of battery separator and deodorant, and further developing new applications. Curing of surface coating and printing inks by low energy self shielded accelerator is increasing in Japan because of better quality of products, non emission of VOC and energy saving. Efficient sterilization of medical products and food packages including PET bottles is new and growing application of accelerator in Japan. Accelerator application for cleaning environment is an important challenge. Removing SO_2 and NO_x by using electron accelerator was first developed in Japan and successfully being used industrially in Poland and China. Moble electron accelerator is used for removing smell from drying of sewage sludge at waste water treatment plant in Japan. Major R/Ds for electron accelerator applications in Japan are (1) radiation grafted absorbent for recovery of uranium from sea water and rare metals from hot spring water, (2) cross-linked hydrogel, (3) VOC removals from flue gases for environmental protection, and (4) processing natural 2 polymers to value added products such as plant growth promoter or elicitor. Challenges of electron accelerator application are (1) expansion of commercial application in developing countries to enhance of industrial development through technology transfer, (2) improvement of accelerator design and production in terms of reliability and cost, (3) enhancement of R/D of new technology and application to meet social needs, such as environmental protection and energy saving.

SM/EB–05

Evaluation on Physical Properties of Irradiated Cabbage (*Brassica Oleracea* L. var. *Acephala*)

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The Brassica family is well known all over the world, and among their species, the cabbage (*Brassica* *oleracea* L. var. *acephala*) is the most consumed in Brazil, as an ingredient of salads and also usual in preparation of a typical Brazilian dish called *feijoada*. Food irradiation is a world wide spread technology used to improve the quality of vegetables extending the shelf-life and reducing microorganisms present in leafs. Color is the first sensorial aspect realized by consumers, being an important factor of refuse. The objective of this paper was to analyze the color of irradiated cabbage treated by electron beam from a linear accelerator at different radiation doses. The cabbage samples were irradiated at IPEN–CNEN/SP in an electron accelerator (Radiation Dynamics Inc. USA, 1.5 MeV, 25 mA) at doses of $1.0-1.5$ kGy and also a control sample. Statistical analysis was done to compare the efficacy of different radiation doses. Slight differences in color measurement were observed in the irradiated samples, although the quality of cabbage was maintained until the 7^{th} day of storage.

SM/EB–06

Advances of E-beam Processing for Food Preservation in Brazil

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Food irradiation is a well known process in which food products are exposed to a controlled amount of ionizing radiation to kill harmful microorganisms, to delay ripening and also to inhibit sprouting. During last years the demand for this technology had increased in order to reduce losses all along food chain supply. E-beam processing trends to be the future's choice, once besides the possibility of being disconnected when not in use, is easily available, does not need reloading and streamlines the process, reducing logistics costs. In Brazil, the use of this technology is gaining importance day by day, mainly due to the necessity of food industry on guarantee food assurance and enhances its shelf-life. Although only few industries has already installed e-beam accelerators to its processing systems and also not many provides irradiation services to local companies, this scenery trends to change due to knowledge diffusion, high cost effectiveness relationship and government support.

SM/EB–07

Electron Beam Irradiation Effects on Some Packaged Dried Food Items

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For radical sports practitioners, small nutritious snack foods are needed. At the same time, food preparation must guarantee long shelf life and be compact or lightweight for easiness of carrying. Commercial individually packaged foods can be used either for sports practitioners like adventure racing or eventually as military rations. Irradiation processing of foods is an important preservation technology. High-voltage electron beams generated from linear accelerators are an alternative to radioisotope generators as they require much shorter exposure times (seconds vs. hours for γ irradiation) to be effective and are currently used to pasteurize meat products among others food items. This work describes the application of electron beam irradiation on some food items used in sport training diets: fiber rich cookies, fruit cereal bars, instant dehydrated asparagus soup and instant Brazilian corn pudding. Each kind of sample contained 3 groups of 15 units each. Irradiation was performed with an electron beam accelerator Dynamitron (Radiation Dynamics Inc.) model JOB 188, with doses of 5 and 10 kGy. For the evaluation of irradiated samples a methodology based on the Analytical Norms of the Instituto Adolfo Lutz, one of the South America Reference Laboratories was employed. The microbiological and sensory analyses of the diverse irradiated samples are presented. Electron beam irradiation resulted in significant reduction of the fungus and yeast load but caused dose dependent differences of some sensory characteristics.

A careful dose choice and special irradiation conditions must be used in order to achieve sensory requirements needed for the commercialization of these irradiated food items.

SM/EB–08

New Applications for Accelerators in Pharmaceutical Processes

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In-line sterilization tunnels using electron beam have become a reality since the development of low energy and medium energy accelerators small enough to fit into self-shielded units which can be integrated into production lines. These systems have many advantages for the health care industry since they provide fast continuous room temperature sterilization which is simple to validate and traceable. Economies are apparent in terms of time, logistics, fixed assets costs, labour costs etc. Environmental impact is considered low. Medium energy systems for core sterilization of medical devices, syringes or vials have already been installed. The low energy surface sterilization systems which have been installed on 19+ pre-filled syringe lines have recently benefited from technology improvements which increase efficiency. The presentation will introduce electron beam sterilization technology and its practical aspects for pharmaceutical manufacturers, i.e., dosimetry, validation, interfaces, monitoring and recording.

SM/EB–12

Developments in Electron Beam Processing in Polymer and Petroleum Industries

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Recent estimates show that out of about 1400 electron accelerator units currently in use for industrial applications throughout the world, 1200 are being used for plastics and rubber processing. Commercial availability of new low, medium and high energy electron accelerators with varying powers and innovative formulations for better radiation processing of polymers have brought a synergy into electron beam processing in polymer industry. The objective of this paper is to highlight recent developments and emerging applications of radiation processing in polymer and petroleum processing technologies. The emphasis will be made on the preparation of fuel cell membranes for low temperature fuel cells, specialty adsorbents for recovery of useful metals/removal of toxic chemical species from aqueous systems, nanostructuring of surfaces for tissue engineering, modification of fluorinated polymers as solid lubricants, advanced materials for biomedical applications, composites for automotive and aviation industries and upgrading of heavy oil.

SM/EB–13

E-beam Irradiation of "In Natura" Palm: Texture and Color Evaluation

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In the last decades, palm tree (Bactris gasipaes Kunth) cultivation is gaining impetus to produce palm heart not only because its potential economic value but also due to its high mineral content. Food irradiation is a worldwide technology that aims to improve the product quality, in order to eliminate diverse microorganisms that can spoil the food. Irradiation processing, in the recommended doses, causes very few chemical alterations in foods, nutritional losses are considered insignificant and some of the alterations known found in irradiated foods is not harmful or dangerous. The objective of this work was to evaluate shelf-life and physical characteristics of "in natura" palm, such as color and texture, after combination of e-beam processing and refrigeration. Samples were irradiated with 0 (control), 1.0 kGy and 2.0 kGy using an electron beam irradiator (Radiation Dinamics Co. model JOB 188, New York, USA). Colour analysis results showed a significant change mainly with samples irradiated with 2.0 kGy after 14 days of storage, while non-irradiated samples and those irradiated with 1.0 kGy did not show any alteration. Similar results were obtained to texture profile, non-irradiated and 1.0 kGy samples did not differ each other, although 2.0 kGy demonstrated lower firmness.

SM/EB–14

Radiation Processing for Synthesis of Structural Materials

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Radiation processing has given rise to more and more interest in the production of structural materials because of the several advantages that it can offer. Besides the economic considerations, concerning energy saving due to the short processing times, radiation curing provides a non thermal process way, thus reducing mechanical stresses in the final product. On the other hand epoxy resins matrices for advanced composites, used in the aerospace and automotive applications, cured by ionizing radiation, generally suffers from poor fracture toughness. This mechanical property can be enhanced by the introduction of engineering thermoplastics, but is significantly affected by the morphology and by the distribution of residual stresses in the material. Considering that radiation curing can cause an increase of temperature, due to both the exothermic polymerization reactions and the absorption of radiating energy, depending upon process and system parameters, a right choice of operating conditions has to be done in order to obtain the thermal profile which could provide the desired final properties. In this work epoxy resins toughened blends, for use as matrices for advanced composites, have been cured by electron beam with a moderate temperature profile. The samples cured in different operating conditions, including a post irradiation thermal treatment out of the mould, have been characterized in terms of both thermal behaviour by DMTA analysis and mechanical properties by fracture toughness test. The results, discussed also in the light of the morphological analysis investigated by SEM, indicate that the required properties for such applications (in terms of Tg and KIC) can be achieved by a dual cure process consisting of irradiation at moderate temperature followed by a slight thermal treatment. The use of a second treatment is needed in order to complete the cure, overcoming vitrification effects due to the low temperature during irradiation.

SM/EB–15

Effect of Electron Beam in Viscosity Properties of Inverted Liquid Sugar

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The great advantage of inverted liquid sugar in food and pharmaceutical industries related to powder sugar is its sweetness once its main composition is a mixture of sucrose, glucose and fructose. Samples of this raw material were submitted to irradiation by an accelerator type Dynamitron-job 188, from Radiation Dynamics, Inc, at IPEN. The samples were delivered in Petri dishes with 3 mm thickness. The samples have received the following absorbed dose from the middle-energy of 1.44 MeV electron beam: 5 kGy and 10 kGy (current of 2.74 mA and dose rate of 11.19 kGy/s); 20 kGy, 30 kGy and 50 kGy (current of 5.48 mA and dose rate of 22.39 kGy/s). Viscosities were measured in a Brookfiled rheometer, model LV–DVIII, spindle SC4–34, at temperature 24.6±0.1°C.

Results confirmed the Newtonian rheological behavior of inverted liquid sugar for irradiated and control samples. Viscosity varied from 2799 ± 15 cP (for control) to 2918 ± 16 cP (for 50 kGy). Irradiated samples at 5 kGy and 10 kGy presented lower values than control, being respectively 2507 ± 18 cP, that could represent a potential break of sugar molecules. Indeed, irradiation can lead to a breakage of molecules of sucrose with release of glucose and fructose and still, the break of this monosaccharide with formation of compounds containing chains of six or less carbons. Samples irradiated at 20 kGy and 30 kGy presented viscosities close to the control ones. Samples irradiated at the higher dose obtained the highest viscosity average (2918 ± 16 cP), that could show a possible grade of polymerization. This latter became with an intense color after irradiation.

Anyway, the alterations due to irradiation were lower than the viscosity range encountered in different batches of sugar. This indicates that irradiation by electron beam did not impair the rheological properties that are essential in designing pumps, valves and equipments for processing facilities.

SM/EB–16

Changes in Physicochemical, Morphological and Thermal Properties of Electron-Beam Irradiated Ethylene–Vinyl Alcohol Copolymer (EVOH) as a Function of Radiation

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In the present work the changes in physicochemical, morphological and thermal properties of electron-beam irradiated ethylene–vinyl alcohol copolymer (EVOH) resin and EVOH resin reinforced with piassava (Attalea funifera Mart) fiber as a function of radiation dose were investigated. The EVOH resin was irradiated up to 90 kGy using a 1.5 MeV electron beam accelerator, at room temperature in presence of air. The changes in properties of the EVOH resin and of the reinforced EVOH resin after irradiation were investigated using scanning electron microscopy (SEM), differential scanning calorimetry (DSC), thermogravimetric analysis (TGA) and sol-gel analysis. The correlation between the properties of the EVOH resin and of the EVOH resin reinforced with piassava fiber, both irradiated and non-irradiated sample, were discussed.

SM/EB–17

Radiation Induced Modification of Silica And Fillosilicates for Rubber-Fillers Composites with Enhanced Compatibility and Radical Reactivity

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Ionizing radiations have been used for modifying the surface properties of silica based fillers by grafting polybutadiene olygomers . The materials were found to have enhanced compatibility with elastomer matrices and are now being tested for sulphur and radiation induced vulcanization with the expectation of obtaining improved yield of chemically bound rubber and enhanced reinforcement mechanism. The modified silica samples were characterized by Inverse Gas chromatography (surface energy properties), granulometry, FTIR and Raman spectroscopy; the mechanism of the grafting reaction was exploited by matrix EPR spectroscopy. Under irradiation the initiating paramagnetic centres are generated prevalently within the silica matrix but rapidly migrate at the surface where the reaction with the organic coating takes place. This process is characterized by a low activation energy since experiments performed with samples irradiated at 77K and subsequent stepwise warming up to room temperature have shown that the silica species disappear giving rise to the polybutadiene crosslinking radical between 77K and 110K.

The double bond content, as measured as a function of the radiation dose by Raman spectroscopy, was not significantly affected by irradiation under vacuum up to 30 kGy. A different situation applies to the irradiation under air which led to > 90% decay of unsaturations in the same dose range. The relative reactivity of the vinyl double bond was found to be about 5 times greater with respect to that of cis and trans $1-4$ double bonds.

Parallel experiments are now being carried out with organo fillosilicates of the bentonite and montmorillonite class.

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2. D. Dondi, C. Palamini, F. Pepori, A. Buttafava, P. Gallinetto, A. Faucitano, *Radiation Curing of Silica for Silica-Rubber Composites* International Meeting on Recent Advances in Nuclear Technologies, (2008) Bialowiecza, Poland.

SM/EB–18

Energy Monitoring Device for Electron Beam Energy Monitoring

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An easy-to-use and robust "energy monitoring device" has been developed for reliable detection of day-to-day small variations in the electron beam energy, a critical parameter for quality control and quality assurance in industrial radiation processing. It has potential for using on-line, thus providing real-time information. Its working principle is based on the measurement of currents collected by two aluminium absorbers of adequate thicknesses, insulated from each other and positioned in a faraday cup-style aluminium cage connected to the ground. The device has been extensively tested in the energy range of $2-12$ MeV under standard laboratory conditions at Aérial, Institute of Isotopes and CNR–ISOF using different types of electron accelerators; namely, a Van Der Graaf accelerator (0.5 to 2.4 MeV), a TESLA LPR-4 LINAC (3 to 6 MeV) and a L-band Vikers LINAC (7 to 12 MeV), respectively. This device has been also tested in high power electron beam radiation processing facilities, one equipped with a 7-MeV LUE-8 linear accelerator used for crosslinking of cables and for medical device sterilization, and the other equipped with a 10-MeV Rhodotron TT100 recirculating accelerator used for in-house sterilization of medical devices. Based on our tests, we suggest that such a device is capable of detecting deviation in the beam energy as small as 40 keV.

SM/EB–19

How EB Radiation could affect the Mechanism of PAH Formation

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Polycyclic aromatic compounds (PAH) are a family of volatile and semi-volatile organic compounds with at least two fused aromatic rings. Their volatile property makes them highly mobile throughout the environment and facilitates their partitioning between air, soil and water. Some of them have been listed as priority pollutants by the US-EPA due to their carcinogenic/mutagenic characteristics. Their origin is mainly anthropogenic, being transport and electricity their main sources. On the other side, EB treatment, proven treatment for NO_x and SO_x removal at energy generation, could affect the PAH formation and emissions mechanisms. The abundance of radicals involved in any thermal process at energy generation could be affected by the EB irradiation and therefore, the radicals nucleation and condensation step to reach a more stable species, it is to say, the PAH formation, could be influenced. Therefore, the goal should be to try to control the PAH formation by attaining bulky radicals associations addressed to the Coronene formation, which is a very stable and a non-pollutant PAH.

SM/EB–20

Study of the Effects of Electron Beam on Heavy Metals in Presence of Scavengers for Decontamination and Purification of the Municipal and Industrial Wastewater

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Radiation processing technology has been proven to purify and decontaminate the textile industrial wastewater. The research work undertaken that has overall goal to better understand the EB processing of wastewater containing heavy metals. This research have conducted our study to examine the effects of Electron Beam on laboratory made samples and real samples containing heavy metals such as Pb and Cd in the presence or absence of rice bran as metal scavenger. A 10 MeV Rhodotron accelerator system of Yazd Radiation Processing Center with the beam power of 100 kW was used for irradiation. The concentration of metal ions in the samples before and after irradiation was measured by graphite furnace atomic absorption spectrometry. Samples of Lead and Cadmium in distilled water or in solution containing either Sodium acetate (0.01 M) or Ethylene diamine tetra- acetate (0.01 M) were prepared. It was found that, the capability of rice bran for sorption of metal ions in the presence of sodium acetate and ethylene diamine tetra-acetate is lowered. Then, the effect of electron beam irradiation with different doses of 1, 3, 6, and 9 kGy on the laboratory made samples, the wastewater samples taken from the Yazd municipal wastewater plant and textile industry was considered. Results showed that in the presence of scavengers, the concentration of metal ions in solutions irradiated by electron beam has significantly decreased.

SM/EB–22

On the Possibility for Application of Electron Accelerators for EBFGT Installation at TPS Sviloza

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The electron beam flue gas treatment process is one of the most promising technologies in the modern environmental protection. The technology allows the simultaneous removal of acidic pollutants such as SO_2 and NO_x with high efficiency and decomposition of VOC (volatile organic compounds) without generating any wastes. These pollutants are named “acid gases” that cause acid rain and damage forests, agriculture fields and flora as well as public health.

After successfully put in operation of Electron Beam Flue Gas Treatment Pilot Plant at Maritsa East 2 TPS, the Bulgarian Ministry of Economy and Energy take decision for implementation EB Technology like Industrial scale at “Sviloza” TPS in Svishtov, Bulgaria.

The Industrial Electron Beam Flue Gas Treatment Plant (IEBFGTP) covers 100% of the flue gases generated from all units of TPS “Sviloza” JSC, Svishtov. This Thermal Power Station generate flue gases from all boilers $-600\,000$ Nm^3/h, with emission of $SO_2 \rightarrow 2800-4800$ mg/Nm^3, $NO_x \rightarrow 1200-1600$ mg/Nm^3 and dust $\rightarrow 200-1400$ mg/Nm^3.

One of the main equipments for IEBFGTP at “Sviloza” TPS was electron beam accelerators. Correctly determination of technical parameters is very important procedure.

The major objective of the Electron Beam project is to reduce harmful emissions of SO_x, NO_x and VOC by 85%.

The by-product generated by the Electron Beam Plant is ammonium sulfate and ammonium nitrate and it can be used as fertilizers in the Bulgarian agriculture sector and abroad.

SM/EB–23

Cost Assessment of e-Beam Wastewater Treatment

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Electron beam treatment of wastewater leads to purification by the decomposition of pollutants as a result of their reactions with highly reactive species formed from water radiolysis: hydrated electron, OH free radical and H atom. Sometimes such reactions are accompanied by the other processes, and the synergistic effect upon the use of combined methods such as electron beam with biological treatment, adsorption and others improves the effect of electron beam treatment of the wastewater purification. In the process of electron-beam treatment of wastewater there are utilized chemical transformations of pollutants induced by ionizing radiation. The key to the successful implementation of electron beam process in environmental protection depends on how to manage the economics in its application. To compete with other processes in economic evaluation, the electron beam system should be operated with cost-effective manners. To result in complete decomposition of the pollutants, sufficiently high absorbed doses are required. However, in real conditions of rather high content of pollutants in wastewater, high absorbed doses are not economically acceptable, and it is better to utilize the partial decomposition of pollutant as well as transformations of pollutant molecules that result in improving subsequent purification stages. To apply electron beam process to the treatment of industrial wastewater and disinfection of effluent from municipal wastewater plant, we accomplished the cost assessment together with the laboratory irradiation experiments. Cost assessments of industrial e-beam treatment plant for treating textile dyeing wastewater were carried out for the treatment capacity of 10 000 m^3 per day. The total construction cost for this plant was USD 4M and the operation cost was not more than USD 1M per year and it was about USD 0.3 per each m^3 of wastewater. Another study on the disinfection plant designed for the flow rate of 100 000 m^3 effluent per day showed the overall cost for plant construction as approximately USD 4M, and the operation cost as around USD 1M per year. It is approximately USD 0.12/m^3 for construction and USD 0.03/m^3/yr for operation of above plant, and is quite applicable when compared to other advanced oxidation techniques such as Ozonation, UV techniques etc.

SM/EB–24

E-Beam Flue Gas Treatment Plant for “Sviloza Power Station” AD

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The problems of environmental damage and degradation of natural resources are receiving increasing attention throughout the world. The increased population, higher living standards, increased urbanization and enhanced industrial activities of humankind are all leading to degradation of the environment. Increasing urbanization has been accompanied by significant air pollution, and the activities to produce heat and electrical energy are responsible for emitting a large number and amount of pollutants. Electrons interact with such pollutants in stack gases containing sulphur oxides (SO_2 and SO_3), nitrogen oxides ($NO_X = NO_2 + NO$) and volatile organic compounds to create divergent ions and radicals including oxidizing radicals and excited species. These excited species react in a various ways of neutralization reactions to convert SO_2 and NO_X into a dry product containing $(NH_4)_2SO_4$ and NH_4NO_3 that was usable as a fertilizer.

After the successful operation of e-beam flue gas treatment pilot plant in Maritza East 2 power plant equipped with three electron accelerators (0.8 MeV, total power 90 kW) with a gas flow rate of 1.0×10^4 m^3/h containing 5600 ppm SO_2 and 390 ppm NO_X, the feasibility study for an industrial scale EBFGT facility for a 120 MW power plant in "Sviloza Power Station" AD in Svishtov, Bulgaria, treating a flue gas flow of 6.0×10^5 m^3/h (NTP) has carried out with a comprehensive engineering and cost study. The power of accelerators required is 4×350 kW, and expected efficiency of removal for SO_x is 85% and 40% for NO_x. There are two reaction chambers each equipped with two accelerators, which have two irradiation windows each, installed in series irradiate each chamber. The applied dose is around 4 kGy, and the by-product will be collected for fertilizer. This study showed that the large-scale EB plants for flue gas cleaning have cost advantages over conventional technologies.

SM/EB–25

Design of Electron Beam Sludge Hygienization Plant

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Digested sludge from municipal wastewater treatment has long been used directly in agriculture in Israel. However, owing to the infection by pathogenic microorganisms, the sludge must be processed to reduce the number of pathogens. The high energy ionizing radiation has the ability to inactivate the pathogens with a very high degree of reliability and in a clean and efficient manner. The ionizing radiation interacts with matter both directly and indirectly. Direct interaction takes place with critical molecules like DNA and the proteins present in the microorganisms, thus causing cell death. During indirect interaction, radiolysis products of water result in the formation of highly reactive intermediates that then react with the target biomolecules, culminating in cell death.The laboratory scale studies had been carried out regarding the possibility of electron beam application for sludge hygienization. Experimental system with nozzle type sludge feeder and stainless steel belt conveyor was constructed for irradiation under continuous feeding conditions of sludge cakes with electron beam of dose rate of 40 kGy/s. Survival curves of microbial population for total coli-forms, fecal coli-forms, E. coli and Salmonellae sp. in dewatered anaerobic digested sludge cake deceased as a function of radiation absorbed doses. Based on laboratory data, an industrial scale plant with the capacity to treat 7000 m^3 of dewatered sludge per month (18% solid contents) with 10 kGy has been planned. This plant will be equipped with an electron accelerator (2.5 MeV, 100 kW) and handling facilities, and is expected to be more economical than other sludge disposal processes, such as incineration, lime stabilization, etc.

The utilization of electron beam on sludge will necessitate the development of technologies that can treat the sludge in a reliable, efficient and cost effective manner.

SM/EB–27

High Precision Dose Delivery Using Electron and X-ray Beam Lines

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In this paper the design and detailed qualification process of an industrial irradiator based on an

10 MeV TT–100 Rhodotron electron accelerator is presented. The system provides 2 beam lines: a 10 MeV mono-energetic electron beam line and a 6.6 X-ray source using a tantalum target. The system is designed to provide a wide range of doses with very high precision which are required e.g., for advanced applications in medical device sterilisation or semiconductor modification.

The paper focuses on the design process which includes 3D mathematical modelling and the extensive validation program including IQ, OQ and PQ. Preliminary results of the characterisation of the radiation field are presented together with comparison between model predictions and dosimetry.

SM/EB–28

Electron Linacs for Cargo Inspection and Other Industrial Applications

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Cargo inspection is one of important part of homeland security. Most of the cargo inspection systems adopt low energy linacs as their x-ray sources. And cargo inspection has becoming a more and more important application area of the electron linacs. Unlike the electron linacs for high energy physics and SR & FEL light sources, most of the low energy linacs adopt magnetrons as their RF power sources, because of their compact size, cheap price and their high efficiency. And s-band (2998 MHz or 2856 MHz) RF power sources are mostly used, although x-band structures are more compact and L-band linacs can deliver more electron beam power. For a low energy electron linac used for industrial application, once its performance meets the requirements, reliability and stability are the most important things.

Low energy electron linac development at Tsinghua University was begun from more than 30 years ago. The first one developed in Tsinghua Univerisy cooperating with several other universities and factories was BJ–10, which was a 10 MeV traveling wave linac for cancer therapy. From that time on, we developed different kinds of linacs for medical and industrial applications. Hundreds of standing wave electron accelerating tubes (with electron gun, target or titanium window and RF window) have been produced in the accelerator lab of Tsinghua University.

Together with NUCTECH company, kinds of cargo inspection systems have been developed and more than two hundred sets have been installed and used all over the world. These years, material identification and 100% inspection of the containers at the ports bring new challenges to the cargo inspection techniques and low energy linacs. We successfully developed several kinds of dual energy and fast beam on linacs for material identification and fast scan cargo inspection systems. Beside the above linacs for cargo inspection systems, linacs for high energy x-ray industrial CT and mail sterilization are also will be introduced in this paper.

SM/EB–29

Low Voltage, Hermetically Sealed Electron Beam Accelerator for Industrial Applications

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Three types of hermetically sealed, low voltage electron beam accelerators and novel solid state power supply/control systems have been developed by Advanced Electron Beams. These accelerators produce uniform, unscanned electron beams through the unique management of the thermionic emitter profile and vacuum body shape. The power density of the accelerators range from 0.02 to 0.2 kW per square centimetre with accelerating voltages ranging from 60 to 150 kV and extracted electron currents of 1 to 30 mA. A wide variety of in-process-line industrial applications have been implemented and continue to be developed for these accelerators including: curing of high

density and/or high opacity thin films; cross-linking or chain scission of thermoplastic films; pre-fill disinfestation of food and beverage packaging; sterilization of medical devices and pharmaceutical container surfaces; and the active treatment of air streams for pollution abatement and bioburden remediation. This paper will describe the design of the three emitters and the methods of application implementation.

SM/EB–30

High Power ELV Electron Accelerators for Research and Industries

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Beginning from 1971, the Budker Institute of Nuclear Physics Siberian Branch of Russian Academy of Science (SB RAS) is manufacturing of electron accelerators of the ELV-type. The ELV electron accelerators are DC machines purposed for wide application in various technological processes. ELV accelerators are the most popular Russian accelerators. Over 110 accelerators are operating both inside Russia and abroad. ELV accelerator can be equipped with a wide set of supplementary devices extending the application range. There are systems of ring and double side irradiation, 4-side irradiation system, extraction device for concentrated electron beam, transportation systems for cable, film and grain. ELV accelerators very easy can be integrated in technological processing due to excellent control system based on PC computer. The different models of accelerators are covering the energy range from 0.3 to 2.5 MeV with a power of accelerated electrons beam up to 400 kW.

SM/EB–31

Electron Accelerator for Radiation Sterilization and R&D Study

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Upgrading of radiation facility located at Institute of Nuclear Chemistry and Technology in Warsaw has been initiated, with support of IAEA TC Project, towards higher technical and economical effectiveness, better operational characteristics suitable for radiation processing and research programs in order to promote in Poland the radiation technologies for sterilzation medical devices and tissue grafts as well as food product hygenization and other radiation processes where high energy electrons are required. The objective of the project is 10 MeV, 15 kW linear electron accelerator equipped with microwave source based on modern klystron device TH2158 operated at frequency 2856 MHz and standing wave accelerating section. The following stages of the project have been described: electron gun construction, design of microwave system of accelerator including pulse power supply, completion and installation of necessary systems including klystron stand, pulse power supply stand, driving generator stand and waveguide system. The klystron modulator was designed with high power semiconductor HV transistor. Electron beam alignment, beam parameters evaluation and accelerator commissioning are foreseen in the final stage of the project. The better accelerator availability, more stable beam parameters, better spare parts availability, reduced exploitation costs and higher beam power are expected after successful project implementation. Implementation of the project will provide opportunity to develop skills and knowledge of the personnel engaged. It will make also possible to apply the results to another facility in Poland and other central European countries.

SM/ADS — European Fast Neutron Transmutation Reactor Projects – (MYRRHA/XT–ADS)

According to the projections published by the Intergovernmental Panel on Climate Change (IPCC), the median electricity increase till 2050 will be by a factor of almost 5. It is reasonable to assume that nuclear energy will play a role in meeting this demand growth. However, there are four major challenges facing the long-term development of nuclear energy as a part of the world's energy mix: improvement of the economic competitiveness, meeting increasingly stringent safety requirements, adhering to the criteria of sustainable development, and public acceptability. Issues linked to meeting the sustainability criteria define the scope of this Satellite Meeting. While not involving the large quantities of gaseous products and toxic solid wastes associated with fossil fuels, radioactive waste disposal is today's dominant public acceptance issue. In fact, small waste quantities permit a rigorous confinement strategy, and mined geological disposal is the strategy followed by some countries. Nevertheless, public opposition arguing that this does not yet constitute a safe disposal technology has largely stalled these efforts. One of the primary reasons that are cited is the long life of many of the radioisotopes generated from fission. This concern has led to increased research and technology development efforts to establish a technology aimed at reducing the amount of long lived radioactive waste through transmutation in fission reactors or hybrid systems like the Accelerator Driven System (ADS).
The main focus of this Satellite Meeting is on the European projects implemented in the area of fast-fission reactor concepts and fuel cycles that offer the flexibility needed to contribute decisively towards solving the problem of growing "spent" fuel inventories by utilizing fissionable isotopes and greatly reducing the volume of high-level waste that ultimately must be disposed of in long-term repositories.

The Organizing Committee of the Satellite Meeting is composed of:

- *Hamid Aït Abderrahim, SCK·CEN, Belgium*
- *Alexander Stanculescu, IAEA, Vienna*

SM/ADS–02

From MYRRHA to XT–ADS: Lessons Learned and Towards Implementation

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The EUROTRANS project is an integrated project in the $6th$ European Framework Program in the context of Partitioning and Transmutation. It aims to deliver an advanced design of a small-scale Accelerator Driven System (ADS), XT–ADS, as well as the conceptual design of a European Facility for Industrial Transmutation, EFIT. The comparison between those two machines is described in another contribution.

Since 1998, SCK·CEN has been designing a multipurpose ADS for R&D applications – MYRRHA – which consists of a proton accelerator delivering its beam to a windowless liquid Pb-Bi spallation target that in turn couples to a Pb-Bi cooled, sub-critical fast core.

The EUROTRANS partners have accepted the SCK·CEN offer to use MYRRHA as a starting basis for the XT–ADS design. Instead of starting from a blank page, this allowed optimizing an existing design towards the XT–ADS needs within the limits of safety requirements.

In this paper we discuss the evolution from MYRRHA to XT–ADS, the lessons we have learned in this process and the perspectives for the future developments starting from the present XT–ADS design.

SM/ADS–03

XT–ADS & EFIT: Two Machines not so Different for the Same Goal

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Within the EURATOM Sixth Framework Program, the EUROTRANS integrated project, funded by the European Community, is expected to provide a significant contribution to the demonstration of the industrial transmutation through the Accelerator Driven System route. The domain DESIGN, of the EUROTRANS integrated project, has the task to provide the pre-design of an European Transmutation Demonstrator (ETD) able to demonstrate the feasibility aspect of the nuclear waste transmutation/burning in ADS at industrial scale. This occurs in a two-phase approach running in parallel:

- a *conceptual* design of the industrial scale Pb-cooled system, called European Facility for Industrial Transmutation (EFIT) and
- a *detailed* design of an experimental ADS, called eXperimental demonstration of the technical feasibility of Transmutation in an Accelerator Driven System (XT–ADS), the construction of which can be started within the next eight years.

The XT–ADS should be as much as possible serving as a technological test bench of the main components of EFIT (Pb). Nevertheless divergence in the choices of components or parameters of the two machines to be designed is allowed. This divergence is even necessary as the time scales of realisation of the two facilities are different.

In the present paper the general configuration and the main characteristics of the two systems are presented. Taking into account the respective objectives, the paper highlights the characteristics that are common to both machines, despite their sometimes diverging objectives, and presents the divergent characteristics and justifies the rationale behind the choices.

SM/ADS–04

The XT–ADS Core Design

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The XT–ADS core has to be able to fulfill several objectives. First of all, the XT–ADS machine should be a relevant prototype for an industrial ADS. This means that the power of the core should be sufficiently high in order to be representative. Second, the XT–ADS machine is foreseent to be an irradiation facility for EFIT, the large scalle industrial transmuter under design in the same FP6 IP–EUROTRANS project. This require that XT–ADS can reproduce irradiation conditions which are similar to the operating conditions for EFIT. For example, the ratio of damage in structural material and burn-up in the fuel is such a parameter that is important when we want to use XT–ADS as the irradiation facility that hosts the EFIT fuel qualification programme. In order to accommodate these programmes, and of course also other irradiation programmes, 8 positions in the XT–ADS core are kept free. These positions also have a penetration through the reactor lid which allows the positions to have in-pile loop types of experiments and/or extensively monitored experiments.

The constraints in which the design of the core of XT–ADS is done are quite strict. The basic idea is to use existing technology as much as possible. Also, the design did not start from scratch: SCK·CEN offered the preliminary design of MYRRHA Draft 2 as a starting point for the XT–ADS machine.

Some major design options for XT–ADS are the fuel, the choice of coolant and inlet/outlet temperatures and the core geometry. The fuel in the core is MOX (albeit with a high plutonium enrichment) and not an innovative minor actinide fuel. The coolant is lead-bismuth eutectic. This allows us to lower the working temperatures compared to the lead cooled EFIT and as a consequence the requirements on the structural materials are not that high (corrosion, erosion, ...). The damage caused by neutron irradiation (dpa) on some components was also a driving force behind some significant changes in the core compared to the MYRRHA core.

This paper will give an overview of the current state of the design of the XT–ADS core, motivate how we got there from the initial MYRRHA core and present a look at the future.

SM/ADS–05

The Reliability Requirements of the XT–ADS & EFIT Accelerator

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An Accelerator Driven System (ADS) for transmutation of nuclear waste typically requires a 600 MeV – 1 GeV accelerator delivering a proton flux of a few mA for demonstrators (XT–ADS), and a few tens of mA for large industrial systems (EFIT). Such a machine belongs to the category of the high-power proton accelerators, with an additional requirement for exceptional "reliability": because of the induced thermal stress to the subcritical core, the number of unwanted "beam-trips" should not exceed a few per year, a specification that is far above usual performance. To reach such reliability levels, several guidelines have been followed during the conceptual design phase of the ADS accelerator, including in particular derating of components, redundancy for critical systems, and capability to sustain operation during most of the RF breakdowns ("fault tolerance"). Dedicated R&D is performed on this topic within the EUROTRANS programme, and the main results obtained so far will be briefly presented.

SM/ADS–06

Feedback to the Designers from Research and from Safety

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Within the EUROTRANS project, the design activities have started from the very beginning while R&D activities were running in parallel either within the same project (like the other domains related to fuel – AFTRA – and to materials – DEMETRA) or outside. Once a first version of the design was made available, the safety calculations could then also start (most of the time at least one year after the start of the design).

Only at the very end of the project R&D results and safety calculations become available. No room is available (be it in time or in manpower) to perform a complete iteration within the EUROTRANS project. But this will occur within the CDT project described in another contribution. So it becomes the duty within the finishing EUROTRANS project to provide a list of both the *verified* assumptions and the required *modifications*.

In this paper we present the different assumptions that the engineering teams have taken and the possible consequences for the design, should those assumptions be inaccurate. We list also preliminary results from the materials studies and from the safety calculations.

SM/ADS–07

ISOL@MYRRHA: an Application of the MYRRHA Accelerator for Nuclear Physics

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In order to explore new research opportunities offered by the MYRRHA proton accelerator, a preparatory feasibility study was initiated within the framework of the "Belgian Research Initiative on eXotic nuclei" (BriX) network. This study investigates unique possibilities for fundamental research using high intensity proton beams.

One of the possible interesting approaches for fundamental research using the 600 MeV proton accelerator is the installation an Isotope Separator On-Line (ISOL) system to produce intense low-energy radioactive ion beams (RIB) available for experiments requiring very long beam times. From technical point of view this so-called ISOL@ MYRRHA project will follow closely the RIB production schemes that are developed and successfully used at the ISOLDE–CERN (Switzerland) and TRIUMF (Canada) facilities. ISOL@MYRRHA will be equipped with simplified and ruggedized target-ion source systems, including laser ionization sources, that allow the use of a selection of target materials that can withstand the proton beam power. By using a part (between $100 - 200\,\mu$A) of the 600 MeV proton beam this new facility will produce a wide spectrum of intense and pure radioactive ion beams at energies around 50 keV. The rationale behind the choice for simplified and ruggedized target-ion source systems is that the facility should deliver RIB for experiments needing very long beam times up to a few months. The long beam times will be available for high-precision experiments, experiments hunting for extremely weak signals or experiments with an inherently low efficiency. In this sense ISOL@MYRRHA will be complementary to other existing or planned facilities. Different physics cases are currently under investigation.

The prospects with ISOL@MYRRHA will be discussed and a limited number of possible physics cases will be presented. The latter might include detailed decay studies of exotic nuclei, weak interaction studies through precise nuclear β decay experiments in ion traps, laser spectroscopy studies of interest to atomic physics as well as implantation and detection of specific radioactive probes in different host materials, a topic of interest to solid state physics and applications in nanotechnology.

SM/ADS–08

GUINEVERE: Construction of a Zero-Power Pb Fast ADS at Mol

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The GUINEVERE project is running since 2007 and is part of the EUROTRANS Integrated Project of the 6^{th} EURATOM Framework Programme. It consists first in the construction of a lead fast ADS mock-up at SCK·CEN Mol (Belgium) for the purpose of ADS subcriticality monitoring experiments, and beyond in support to the design of a Transmutation Experimental Facility (MYRRHA/FASTEF). To do so the VENUS reactor (SCK·CEN) will be coupled with a new GENEPI neutron source under construction by CNRS (France).

To accommodate this new source (a 250 keV deuteron accelerator) in a vertical coupling configuration, the VENUS building is being heightened. In parallel the reactor core is being modified to be loaded with fuel assemblies made of enriched Uranium and solid Lead moderator pins, and hold radial and axial Lead reflectors. A new safety and control rod system is also under development.

The new GENEPI-3C neutron source is designed to be operated in pulsed mode but also in continuous mode to investigate the current-to-flux reactivity indicator in representative conditions of a powerful ADS. In this latter mode it will be also possible to make short beam interruptions at a fixed frequency to have access to the neutron population decrease as a function of time. The vertical beam line will have the distinctive feature to be retractile, allowing target changing or complete removal (for critical configuration for example). The accelerator will be first completely assembled at LPSC Grenoble for beam characterization before to be transferred in Mol.

We will present in this paper the status of this experimental facility assembling, and foreseen experimental programmes in the framework of fast transmutation system studies.

SM/ADS–09

The next step for MYRRHA: the Central Design Team FP7 Project

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SCK·CEN in association with 18 Europeans partners from industry, research centra and academia, responded to the second FP7 call to establish a Central Design Team for the design of a **FA**st **S**pectrum **T**ransmutation **E**xperimental **F**acility (**FASTEF**) able to demonstrate efficient transmutation and associated technology through a system working in subcritical and/or critical mode. The proposal prepared by the consortium coordinated by SCK·CEN was accepted for funding and the project will start 01 April 2009 for a period of 3 years.

MYRRHA/FASTEF is proposed to be designed to an **advanced engineering level** for decision to embark for its construction at the horizon of 2012 with the following objectives:

- be operated as a flexible and high-flux **fast spectrum irradiation facility**;
- **be an experimental device to serve as a test-bed for transmutation by demonstrating the ADS** technology and the efficient transmutation of high level waste;
- contribute to the demonstration of the Lead Fast Reactor technology without jeopardizing the two above objectives

The paper will discuss in more detail the objectives and the work programme of CDT that is subdivided in one coordination work package (WP) plus 4 technical WP's: Definition of specifications and detailed work programme of FASTEF (WP1), Design of the FASTEF in sub-critical & critical mode (WP2), Plant Requirements (WP3) and Key issues towards realisation (WP4).

SM/EN — Neutron Based Techniques for the Detection of Illicit Materials and Explosives

There is a worldwide need for improved technologies for the efficient inspection of cargo containers, especially in the transportation sector. The main objectives are the detection of contraband such as illicit drugs, fissile materials, explosives and weapons and the verification of declared manifests. Technology capable of detecting explosives and drugs has a vital role to play in protecting society. Presently, the detection of concealed contraband is based mainly on the use of X-rays, vapour detection and sniffer dogs. X-rays are widely used since they have many advantages, particularly their high speed and their high resolution images. However the limitations of X-ray inspection techniques have stimulated the need to develop additional methods, including those based on the use of neutrons. Neutron based techniques offer a powerful tool for the detection of illicit materials and bulk explosives, particularly because of their ability to determine composition combined with good penetration. In addition, many neutron based techniques use accelerators, including neutron generators.

The main focus of this Satellite Meeting is on the development and application of neutron techniques for the detection of illicit materials and explosives. Both new emerging applications and novel techniques in established fields will be presented. In addition, methods and facilities for the production of fast neutrons will be discussed.

The main topics to be addressed at the Satellite Meeting:

- Accelerator technologies, particularly those suited to neutron generation outside the laboratory, including developments in neutron generators
- Neutron-based techniques for the improved detection of illicit materials (such as illegal drugs, explosives and special nuclear materials)
- Research into components of neutron analysis systems, including neutron sources, detectors, signal processing, data processing, imaging and data presentation
- The development and demonstration of complete scanning systems
- Modelling aspects of proposed systems; e.g., radiation transport calculations, signal processing, imaging, validation, radiation dosimetry, shielding design, etc.
- Consideration how proposed techniques could best be integrated into a complete system to be used by non-specialists.

The main objective of the Satellite Meeting is to promote exchange of information among IAEA Member States representatives/delegates and to discuss new trends in neutron applications for the detection of illicit materials and explosives. It is also aimed at enhancing research collaboration between Member States and promoting education on topics related to the conference, emphasising the potential of nuclear based technology for solving a wide variety of societal issues.

The Organizing Committee of the Satellite Meeting is composed of:

- *Brian Sowerby, CSIRO, Australia*
- *Christopher Franklyn, NECSA, South Africa*
- *Françoise Mulhauser, IAEA Vienna*

SM/EN–01

Recent Developments in Fast Neutron Radiography for the Interrogation of Air Cargo Containers

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There is a worldwide need for improved methods for the scanning of consolidated air cargo for contraband such as illicit drugs and explosives. Ideally, cargo containers must be imaged without unpacking and with scan times of less than a few minutes. Fast neutron radiography techniques are particularly attractive for screening cargo. Neutrons have the required penetration, they interact with matter in a manner complementary to X-rays and they can be used to determine cargo composition.

The Commonwealth Science and Industrial Research Organisation (CSIRO) has developed a scanner for fully-loaded air cargo containers. The scanner combines fast (14 MeV) neutron and γ-ray (or X-ray) radiography, using intense radiation sources and custom high-efficiency detector arrays. The ratio of the transmissions of neutrons and X-rays provides a measure of material composition that is much more sensitive than alternative dual high-energy (MeV) X-ray systems.

A full-scale prototype scanner was used by Australian Customs Service to screen incoming air cargo at Brisbane International Airport in 2005/6. The trial of the scanner at Brisbane demonstrated the material discrimination capability of the technology and its ability to make hidden organic materials more obvious. Consolidated cargo was scanned in less than two minutes allowing high volumes of cargo to be screened rapidly.

CSIRO is working directly with Nuctech Company Limited, Beijing, China to develop and commercialise the next generation in air cargo scanning technology. A commercial version of the airport scanner being developed by Nuctech and CSIRO is expected to be commissioned by January 2009. The commercial scanner combines a 14 MeV fast neutron radiography system with Nuctech's dual-energy X-ray technology that uses a 6 MeV LINAC X-ray source and Binocular Stereoscopic imaging technology. The commercial scanner will have much better spatial resolution than the Brisbane scanner. The improved resolution, combined with Binocular Stereoscopic imaging, will allow complex cargo images to be separated into multiple layers, making it easier to identify threat items. We will present initial results from the new scanner and also discuss future potential applications of the technology for the detection of special nuclear materials and for the scanning of sea cargo containers.

SM/EN–02

Active Neutron Interrogation to Detect Shielded Fissionable Material

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Portable electronic neutron generators (ENGs) may be used to interrogate suspicious items to detect, characterize, and quantify the presence fissionable material based upon the measurement of prompt and/or delayed emissions of neutrons and/or photons resulting from fission. The small size (< 0.2 m^3), light weight (< 12 kg), and low power consumption (< 50 W) of modern ENGs makes them ideally suited for use in field situations, incorporated into systems carried by $2-3$ individuals under rugged conditions. At Idaho National Laboratory we are investigating techniques and portable equipment for performing active neutron interrogation of moderate sized objects less than $\sim 2-4$ m^3 to detect shielded fissionable material. Our research in this area primarily relies upon the use of pulsed deuterium-tritium ENGs and the measurement of die-away prompt fission neutrons in-between neutron bursts. Fissionable materials used for this work include enriched uranium and plutonium in > 1 kg quantities. This paper will summarize recent results from our

research including descriptions of detectors and interrogation profiles together with a discussion of detection performance evaluations for a variety of shield scenarios.

SM/EN–04

Identification of Materials Hidden behind or in front of a Dense Organic Goods

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It was already shown in the previous work that the tagged neutron inspection system (TNIS) was able to detect the explosive in the sea-going cargo container filled with the iron matrix with density 0.2 g/cm^3 [1]. It was shown also the possibility of TNIS to detect the explosive in the organic matrix with density $\leqslant 0.25$ g/cm^3 [2]. In this work the possibility of TNIS to identify the materials hidden behind or in front of dense organic goods is investigated. Paper target, which is a good explosive simulant, is put close to the flour surroundings. Triangle diagram is made from the number of counts in the carbon peak, number of counts in the oxygen peak and the number of counts in the transmitted neutron peak. Identification of the paper target is possible if some appropriate knowledge about the surroundings is known.

1. D. Sudac, S. Pesente, G. Nebbia, G. Viesti, V. Valkovic, Nucl. Instr. And Meth. B **261** (2007) 321.
2. D. Sudac, D. Matika, V. Valkovic, Nucl. Instr. And Meth. A **589** (2008) 47.

SM/EN–05

Air cargo inspection using Pulsed Fast Neutron Analysis

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A powerful tool for air cargo inspection exists at the George Bush Intercontinental Airport in Houston, Texas USA that utilizes the Pulsed Fast Neutron Analysis (PFNA) technology. Funded by the Transportation Safety Administration under the United States Department of Homeland Security, a system has been developed to detect explosives at the threat level in a wide range of cargoes. The system utilizes a tandem Van de Graaff accelerator operating at 3.5 MHz that produces pulses of deuterons with a FWHM of 1.5 ns. Neutrons of several nanosecond duration are created through the d,D reaction at an energy of around 8 MeV at a deuteron beam intensity of up to 140 micro-A. A neutron collimator near the deuteron gas target produces a neutron beam spot 9-cm wide by variable (typical) 12-cm tall at the center of the container. This neutron beam oscillates vertically by moving the collimator. Translational motion of the air cargo is provided by a constant-velocity conveyor system. The inspection volume is surrounded by a large array of 14-cm cube NaI detectors to collect the γ-rays from the neutron inelastic scattering reactions occurring within the volume. Using the time–of–flight technique to determine the position in the container in which the neutron inelastic scattering reactions occur, the data acquisition system and the image reconstruction engine produce a three dimensional image of the cargo contents. The images have a typical volume element granularity of 6.3 cm wide $\times$ 6.3 cm wide $\times$ 8 cm deep. The latest signature measurements from the 4.44-MeV γ-ray from carbon, the 6.13-MeV γ-ray from oxygen, and the 1.63-MeV, 2.31-MeV, and 5.55-MeV γ-rays from nitrogen of threat and non-threat material, as well as images demonstrating the capabilities of this unique inspection tool, will be presented. In addition, alternate applications; including, nuclear material detection, and other uses for neutron beams of various energies will also be presented.

SM/EN–06

Environmental Security of the Coastal Sea Floor

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The coastal sea floor is littered with many of man made objects and materials including a variety of ammunition. In addition, sediments in ports, harbors and marinas have increased concentrations of chemicals used as biocides in antifouling paints. Therefore, one has to develop capabilities of measuring concentrations of chemical elements in the sediments, determining the content of different containers, establishing the presence of threat materials, identifying the material within sunken ships.

In this report the activities related to the development of capabilities for the evaluation of environmental security of the coastal sea floor are summarized.

Several hundred coastal sea sediment samples have been collected and analyzed for 18 chemical elements by using EDXRF as an analytical tool. Contour maps of antifouling biocide elements (Cu, Zn, As and Pb) have been generated for the entire eastern coast of Adriatic Sea indicating the locations of "hot spots" in the distribution of chemical elements used as biocides (Cu, Zn, As, Pb).

In order to be able to establish if an object on the sea floor contains some sort of threat material (explosives, chemical warfare) a system using neutron sensor installed within an unmanned underwater vessel has been developed and tested. When positioned above the object such a system can inspect the object for the presence of the threat material by using α particle tagged neutrons from the sealed tube $d + t$ neutron generator.

While the commonly used military explosives are characterized by the presence of only four chemical elements (C, H, N, O) chemical warfare agents usually have in addition one or more chemical element (P, S, Cl, F, As or Br). The results from the laboratory tests for the detection of the presence of these chemical elements are presented.

It is often required to inspect ship hulls, either to detect potential anomalies attached to the hull, or to determine the nature of materials within hull, especially of sunken ships. We have performed tests with our system submerged in the test basin filled with sea water with targets being: 10 liters of diesel fuel, 5 kg of explosive and different chemicals (expected components of chemical warfare agents) placed behind 16 mm steel plate in the first measurement and behind sandwich 18 mm steel plate – 10 cm air bag – 16 mm steel plate in the second measurement, respectively.

SM/EN–07

Acquisition of Neutron-Induced Gamma Signatures of Chemical Agents

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The detection of special chemical elements that could be used by terrorist in improvised explosive devices (IED) can be performed by the spectroscopic analysis of neutron-induced γ rays.

Capture γ-ray detection is optimally performed by thermal neutron analysis (TNA), between the pulses delivered by a fast neutron generator. During this inter-pulse period, the ratio between thermal and fast neutrons reaches a maximum.

On the other hand, γ rays induced by fast neutrons, e.g., in inelastic scattering reactions, can be optimally detected by using the associated particle technique (APT), which allows to improve the signal-to-noise ratio by selecting γ rays induced by fast neutrons inside a specific volume of interest.

In the frame of the French CBNRE R&D program, which aims at developing new detection technologies and systems to improve the fight against chemical, biological, nuclear, radiological and explosive threats, we propose to use both TNA and APT in a portable inspection system. The goal is to identify the largest possible panel of chemical elements of interest: fluorine, sodium, phosphorus, sulphur, chlorine, arsenic, bromine, iodine, mercury, ...

TNA and APT signatures of these elements are currently being acquired with low background measurement systems and long acquisition times, to constitute a reference database that will be used to process the inspection data of the future portable system.

The paper will present the status of this experimental database, which will provide indications about the interest to couple TNA and APT in a single inspection system. Measured signatures will be compared with γ-ray spectra calculated with MCNPX and ENDF/B–VII.

SM/EN–08

Low Dose Transmission Radiography for Detection of SNM using Monoenergetic Gamma Rays

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Active detection of nuclear materials (SNM) requires both the localization of the potential threat and confirmation of its nuclear properties. By selecting nuclear reactions with large positive Q values, small accelerators producing 4 to 10 MeV protons or deuterons can simultaneously produce fast neutrons and high energy (greater than 10 MeV) monoenergetic γs. A significant benefit of such monoenergetic γs lies in the greatly reduced radiation dose as compared to bremmstrahlung sources. These multiple energy monoenergetic γ rays can be used to image the material and also to confirm its nuclear properties by detection of delayed γs and neutrons from photofission. One such reaction is $d(^{11}\mathrm{B}, n)^{12}\mathrm{C}$. Using 3 MeV deuterons, this reaction produces fast neutrons peaking at around 12 MeV (with a broad distribution at lower energies) and intense γ rays at 4.4 and 15.1 MeV as well as others at 10.7 and 12.7 MeV. Scaled for beam currents of 100 μA, the experimental production rates are 6×10^9 photons/sr/s at 4.4 MeV, 6.6×10^8 photons/sr/s at 15.1 MeV and 2×10^{10} n/sr/s fast neutrons. Using just the 4.4 and 15.1 γs in transmission imaging, threat quantities of SNM in benign material such as 40 cm equivalent of iron may be detected in seconds with doses of 1 mrem or less. We are also investigating the development of ultra-compact cyclotrons as sources for this application.

SM/EN–09

Detection of Concealed Fissionable Material by Delayed Neutron Counting

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One of the greatest challenges in detecting concealed nuclear material by non-contact means is the measuring of uranium, especially highly enriched uranium, particularly if it is surrounded by additional shielding material. Hence, γ detection is not a promising option. However, neutrons provide a high probability to penetrate typical shielding materials well. Whereas plutonium emits enough neutrons from spontaneous fission to be measured by passive methods in most of the

cases, highly enriched uranium, particularly in casings, does not emit sufficient neutrons to be detected passively. Therefore, we investigated in the active interrogation with a neutron generator in particular. A clear proof of the existence of special nuclear material is the emission of delayed neutrons after induced fission, e.g., by a neutronn generator.

We performed measurements with a small, light-weight neutron generator, which can be carried by one person. The time structure of delayed neutrons was measured in order to detect and identify hidden or shielded nuclear material in geometrical configurations whereof only the outer shape is known but little or no information is available on the inner structure. A small block of depleted uranium was irradiated repeatedly by a sealed neutron tube of a 14 MeV neutron generator for different time intervals. The delayed neutrons were measured by a neutron "slab" counter consisting of 6 He-3 tubes moderated by high density polyethylene. After the end of each interrogating neutron pulse we analyzed the delayed neutrons in different time intervals, ranging from 3 s to 300 s and thus recorded the "decay curves" of the delayed neutrons. We optimized neutron irradiation and measuring time to gain information on the existence of fissionable material in a short time.

These experiments show that fissionable material can be detected clearly and easily in a suspicious object without any information on the inner geometry and the surrounding moderating material within a very short time (several minutes).

SM/EN–10

Active Neutron Interrogation Approach to Detect Special Nuclear Material in Containers

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Cargo interrogation in search for special nuclear materials (SNM) like highly-enriched uranium (HEU) or Pu-239 is a first priority issue of international borders security. In this experimental work we present a thermal pulsed neutron based approach which combined with time–of–flight (TOF), demonstrates capability to detect small quantities of SNM shielded with moderate thicknesses of high or low Z materials providing, in addition, a manner to know the approximate position of the searched material. As many efforts are currently under way to exploit fast neutron penetration through cargo material, this work probes into the applicability of the complementary use of slow neutrons, taking advantage of the higher reaction cross sections, aimed at the usual cases of cargo with low neutron moderation capacity. If the surrounding merchandise were a highly moderating medium, the alternate fast neutron beam should be allowed to impinge on the object and undergo moderation in it, at the expense of loosing TOF information.

The actual work employed a 25 MeV electron linac with a refrigerated lead target and a polyethylene neutron moderator as the pulsed source, although the technique is not restricted to that combination which, it must be said, is not the most favourable one. A wide area neutron detection moderating array (shielded from thermal background) was devoted to the detection of fission fast neutrons.

Results are presented concerning the detection of an irradiated volume of SNM comprising some 11 grams of isotope U-235 (in aluminum matrix), although when hidden in a moderating surrounding, the whole 27 grams sample can be taken into account. The sample was detected, placed behind 3 mm steel wall and was also hidden under lead 5 cm thick and within a moderating environment provided by high density polyethylene 5 cm thick. As to position sensitivity, a 100 cm movement of the U-235 sample along the irradiation axis shifted the TOF neutron spectrum 300 μs. This movement is close to the approximate distance difference between a lateral positioning and a central one, within a standard shipment container.

SM/EN–11

Detection of Explosives and Other Illicit Materials by Nanosecond Neutron Analysis

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Experimental results in the detection of explosive and other hazardous materials by Nanosecond Neutron Analysis (NNA) technique are presented. The detecting device SENNA is based on a portable DT neutron generator with built-in segmented detector of associated α-particles, up to 12 BGO-based detectors of γ-rays, and fast data collection electronics. The following detection scenarios are explored:

a) identification of liquids in sealed containers;
b) detection of explosives in small packages;
c) inspection of UXO;
d) detection of explosives in luggage.

The ability of the SENNA system to identify sealed liquids by their C/N/O ratio is demonstrated. Results of measurements with samples of liquids weighting from 40 g to 1 kg are discussed. The possibility of tuning SENNA's decision-making algorithm to automatically determine the necessary measurement time is discussed. Examples of the dependence of the number of successful and unsuccessful detections of 200 g and 500 g samples on measurement time in a particular geometry are presented. The procedure of tuning the decision-making algorithm for the detection of small amounts of explosives concealed inside heavy luggage is described. Methods of handling the distorted measured values of concentrations of major chemical elements obtained due to presence of large masses of benign materials close to explosives are discussed. Current and planned research activities in the field of further NNA development are briefly presented.

SM/EN–12

Operation of a Variable Energy RFQ Accelerator System to Produce Intense Beams of Neutrons for Cargo Interrogation

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Two radio-frequency quadrupole (RFQ) linear accelerator systems have recently been commissioned at Necsa, near Pretoria, South Africa. These accelerator systems are unique in their design, construction and mode of operation. Although of different design, both accelerator systems can operate over the same energy range, but with different intensities and duty cycles. To extract a variable energy ion beam a system consists of two RFQ acceleration cavities, which operate at a selectable phase between one another, thus facilitating an acceleration or deceleration of the ion beam within the second cavity. Molecular hydrogen or atomic deuterium ions can be accelerated (1.9 to 2.5 MeV or 3.8 to 5.0 MeV respectively) and targets of deuterium gas or solid targets, such as a thin beryllium foil, have been used to generate a range of neutron distributions which, through appropriate selection criteria, can then be used to perform radiographic imaging of various objects. The primary focus of this work has been to set up a system producing intense (greater than ten to power ten neutrons per second) beams of neutrons of pre-determined energy and energy spread, to interrogate typical cargo containers for traces of illicit material and/or explosives. The methodology has been to develop a neutron radiography system that can be used to scan large volumes, such as cargo containers in a relatively short time span and provide an indication as to whether the contents tally with the cargo manifest. The current status of this project will be presented.

SM/EN–13

A Dual-Purpose Ion-Accelerator for Nuclear-Reaction-Based Explosives and SNM-Detection in Massive Cargo

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We present a dual-purpose ion-accelerator concept, to serve as radiation source for radiographic cargo inspection systems detecting Special Nuclear Materials (SNM: ^{239}Pu & enriched-^{235}U) and explosives. Such systems would be cost-effective, employing largely-common hardware, but different nuclear reactions and data acquisition modes. For SNM-detection, Dual-Energy Radiography (DER) using 15.11 & 4.43 MeV γ-rays from ^{11}B(d,n) is envisaged [1]. Explosives are detected via Gamma Resonance Absorption (GRA) in ^{14}N [2], the probe being 9.17 MeV γ rays produced at the $E_p = 1.747$ MeV ^{13}C(p,γ) resonance.

If the DER deuteron energy is selected to be precisely double the GRA proton capture resonance energy, namely 3.494 MeV, both reactions are accessible with an accelerator operating at this energy, by alternately bombarding ^{11}B and ^{13}C targets with mass-2 beams of d and H_2^+, respectively. Nitrogen-rich liquid scintillators could serve as common detectors, data acquisition modes alternating between γ-ray pulse-height spectra (DER) and internally-produced photo-proton spectra (GRA). Pulse-shape discrimination (PSD) is employed throughout, to reject undesired particle-species events.

The viability of this dual-purpose system concept is non-trivial, since an appreciable contribution of proton-proton repulsion in H^{2+} ions to emission-line broadening of resonant 9.17 MeV γ rays at the resonant angle $\theta_R = 81.6°$ could prove detrimental to GRA-system performance characteristics. This contribution was hitherto unknown, but has recently been measured at the PTB Van-de-Graaff accelerator and found to be small compared to the emission-line broadening observed when the resonance is populated by protons. The latter was consistently measured as $\sim$ 500 eV [3], the total nuclear level width being $\Gamma_{tot} \sim 130$ eV [3,4]. Presumably, the broadening is due to proton-induced inner-electron-shell excitation concomitant with nuclear capture [5].

The absence of appreciable emission-line broadening with H^{2+} ions is probably related to the well-known "wake" effect [6], whereby the two correlated projectiles progressively align themselves along the beam direction while traversing the target medium. Thus, the Coulomb repulsion between them exhibits an appreciable longitudinal component, that manifests itself primarily by broadening the resonance excitation yield curve [7]. However, it does not exhibit a large transverse component and thus, produces little 9.17 MeV line-broadening.

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SM/EN–14

New Developments in Pulsed Fast-Neutron Transmission Spectroscopy and Imaging

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Fast-Neutron Transmission Spectroscopy (PFNTS) is a radiographic imaging method that exploits the isotope-specific energy-dependence of total neutron cross sections to measure elemental distributions in inspected objects. Fast-neutron transmission, as opposed to X-ray transmission, depends only weakly on absorber Z and thus, neutrons readily penetrate high-Z materials. In particular, the method is well suited to quantitative measurements of the elemental distributions of light elements, such as C, N and O, even if these are embedded in complex matrices of high-Z materials. This is advantageous, since the latter would strongly attenuate low-E (sub-MeV) X-rays and γ-rays. Moreover, more penetrating electro-magnetic radiation, namely, high-E (few-MeV) X-rays and γ-rays, would fail to provide contrast for low Z-elements. On these grounds, PFNTS is considered to be a very promising method for fully-automatic detection and identification of explosives concealed in luggage and cargo.

In the late 1990s, Tensor Technology Inc. constructed an advanced PFNTS evaluation prototype. In a comprehensive series of blind tests, this system demonstrated the power of the method for detecting bulk explosives. However, its poor performance in detecting thin-sheet explosives and the relatively high false-alarm rates indicated that significant improvements on the detector side were called for, particularly with regard to spatial resolution, which was no better than several centimetres.

In this contribution we present the concept of a high-spatial-resolution fast-neutron imaging system with multiple-energy TOF-spectrometry capability. This is a further development of our Time-Resolved Integrative Optical Neutron detector (TRION), which, in its present version, is able to capture simultaneously up to 8 image frames at different neutron energies. A 4-energy TRION variant will be evaluated in the fast-neutron beam at the PTB accelerator facility in December 2008. Updated results on its position resolution, contrast sensitivity and elemental imaging capability will be presented.

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SM/EN–15

Signal and Noise Analysis in TRION Detector

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TRION is a sub-mm spatial resolution fast neutron imaging detector, which employs an integrative optical time–of–flight technique. The detector was developed for fast neutron resonance radiography (**FNRR**), a method capable of detecting a broad range of conventional and improvised explosives. A more detailed description of the system can be found in another contribution to this conference by our group. (see Mor paper, SM/EN–14).

In this paper we have analyzed in detail, using Monte-Carlo calculations and experimentally determined parameters, all the processes that influence the signal and noise in the TRION detector. In contrast to event-counting detectors where the signal-to-noise ratio is dependent only on the number of detected events (quantum noise), in an energy-integrating detector additional factors, such as the fluctuations in imparted energy, number of photoelectrons, system gain and other factors will contribute to the noise. It is shown that, even under ideal light collection conditions, a fast neutron detection system operating in an integrative mode cannot be quantum-noise-limited due to the relatively large variance in the imparted proton energy and the resulting scintillation light distributions.

SM/EN–16

The Doppler-Broadening of Gamma-Ray Spectra in Neutron-Based Explosives Detection Systems

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Neutron-induced γ-ray reactions are the primary means used in the nondestructive analysis of materials. Since 9/11, there is an expanded interest in using these reactions to detect explosives. Simultaneously, there have been great advances in the cooling systems of semiconductor γ ray detectors which make their deployment more practical. The high resolution of this type of γ ray detectors shows great promise in increasing the signal–to–noise ratio which has plagued neutron-based explosives detection systems in the past. γ-ray analysis using these high-resolution detectors relies heavily on dependable resolution curves so that the software can calculate the full-width half-maximum for any peak based on a given energy. These curves fail if the γ ray peak is Doppler-broadened. Due to momentum considerations, Doppler-broadening occurs primarily with γ-rays from neutron-induced inelastic scattering. The recoiling nucleus of interest must have excited states whose lifetimes are much smaller than the time of flight in the material. We have been examining C, N, and O nuclei when bombarded by 14 MeV neutrons. We have calculated the period of time for the kinetic energy to drop from its maximum value to a value under 100 keV. We are utilizing this slowing period to predict if the peak shape of a γ ray emitted from these nuclei under these conditions will be Doppler-broadened. With this knowledge, we can more accurately measure the intensity of the γ ray in question and employ this information in determining the threat potential of a given object.

SM/EN–17

ULIS: A Portable Neutron Device for Explosive and Chemical Detection

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We are developing a new device for explosive and chemical detection using the Associated Particle Imaging (API) technology and based on a new Associated Particle Sealed Tube Neutron Generator (APSTNG) which specifications comply with one of the basic requirements of a portable device: it must be light. Our objective is to have a total weight lower than 25 kg. This includes the neutron generator, its VHV supply, the detectors, the data acquisition system and all the electronics. Everything is in a suitcase that can be put near an object the content of which one wants to know. Few minutes are enough to identify what is inside and to detect illicit materials as explosives or chemicals. The device will be globally described and the first laboratory results will be presented.

SM/EN–18

Applications for Gas-Plasma Target Neutron Generators

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The NSD-Fusion GmbH commercial development of Inertial Electrostatic Confinement fusion devices as neutron generators started in 1996. Technical progress was positive but business and finance circumstances where the delay factors. Today equipment sales and further development projects are at last filling the order book. For commercial success the NSD neutron generator has to deliver approximately ten times longer operational lifetime or endurance and ten times greater output for the marketable price. There are additional characteristics which users deem to be advantageous. The complete set of equipment is remarkably compact. High density high voltage and high current per pulse power technology has been adopted for the pulsed neutron variants. This enables both pulsed neutron PGNAA applications but also boosts neutron yield by exploiting super linear scaling of Inertial Electrostatic Confinement fusion. Sealed tube operation was developed whereby a gas storage technology is integrated with the automated regulation of neutron output in a central sub-system. The lack of a solid target mitigates ageing effects of sputter erosion deposits causing short circuits and thermal cycle fatigue. The adoption of a linear electrode configuration enables easy adaptation of the neutron emission unit to a wide range of applications. A specific of 1 kW of input power per 20 mm of cage electrode length is the design rule. With 115 kV and 15 mA of DC power a steady and stable Deuterium-Deuterium yield of 2×10^7 n/s is achieved. By lengthening the electrode more input power can be accepted. A Deuterium-Tritium gas mixture gives a factor of approximately 80 yield gain. The variable neutron emission length parameter can be utilized for neutron illumination of large objects such as containers on scrap metal trucks for PGNAA assay of the alloy elements. The ContainerProbe-Net concept is being advocated to address the requirement for 100% risk screening of inter-modal containers. Radiography utilizing the neutron source topology within the plasma and image deconvolution is proposed. A range of conceptual applications are described with the intent to alert innovative applications developers to the potential of the NSD neutron generator family of products.

SM/EN–19

Powerful Nanosecond Single-Shot Technique for Detection of Illicit Materials and Explosives

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In the report results of several tests of the Nanosecond Impulse Neutron Investigation System (NINIS) intended for a *single-shot interrogation technique* of characterizing of hidden illicit materials and explosives are presented. The NINIS method is based on use of time–of–flight (TOF) procedure of measuring of neutron energy after their elastic and inelastic scattering on nuclei of elements composing hidden materials [1]. As a neutron source a Dense Plasma Focus device is applied. Very powerful pulses of neutrons (10^7 through 10^{11} neurons per pulse having duration about 10 ns) give an opportunity to produce full characterization of the elemental content of a hidden object during just a single pulse of the device (so during about a 1 μs period of the interrogation time of an object) and at the TOF base of only a few meters. Numerical simulation of the technique will be presented. We shall describe results of experimental tests of the operation of his technique:

1. With pure deuterium DPF chamber's filling when only 2.5-MeV neutrons are generated.
2. With deuterium-tritium mixture DPF chamber's filling when both 2.5-MeV and 14-MeV neutrons are generated.

3. Examples of elemental characterization of test materials at a high neutron yield with a large TOF base (18 m) and at a low neutron yield with a short one (2 m).
4. Examples of elemental and dimensional characterization of test materials having small and large sizes.
5. Examples of elemental characterization of test materials having in its content some fissile components.

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SM/EN–20

Fast Neutron Imaging for SNM Detection

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Special Nuclear Materials (SNMs) are difficult to detect because the γ emission are weak and are being absorbed by surrounding cargo, while the neutron emissions of p.e. 1 kg weapon grade plutonium ($\sim$ 2 MeV) fall below the natural back ground beyond a stand off distance of one meter. The application of direction sensitive imaging techniques to reduce the back ground, thereby taking advantage of the isotropy of the back ground, is therefore mandatory for passive as well as active interrogation methods. A fast neutron imaging detector for the detection of SNMs in containers is being developed to be applied in the harbor of Rotterdam in cooperation with Customs Rotterdam. The detection principle is based on two subsequent elastic neutron-proton scatterings in one single large organic scintillator block. The direction cone of an incident fast neutron can be determined by observing the event locations, their time difference and the first recoil proton energy. The scintillator material must have a very short decay time because the time difference is in the nano second regime. The angular resolution of the detector is estimated from simulations to be better than 10 degrees, allowing to pinpoint a container holding 1 kg plutonium from a distance of 70 m in 6 minutes. The detector will be applied on the Rotterdam harbor terrain for monitoring containers in the stack, but would also make possible for instance checking of the full container load of a ship in one go.

SM/EN–P03

Low Cost Combined Systems for Detection of Contraband Hidden in Cargo Containers

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The fruitful cooperation between Egypt and the International Atomic Energy Agency IAEA through the Coordinated Research Project (Contract No.13497/RO) which is concerned with the use of neutron based techniques for the detection of illicit materials and explosives tends to design and construct combined systems to search the contents of cargo containers for illicit trafficking. The systems consist of a scanner based on using γ rays emitted from ^{60}Co source to locate the position of contraband hidden within the payload and an identifier based on using neutrons emitted from Pu-α-Be source to distinguish the suspected object through elemental analysis by fast and thermal neutrons. The systems include as well a especially mechanical system to move the inspected container between the radiation sources and detector. The mechanical system is equipped with an electrical controller unit to adjust the movement increment of the inspected container and time of measurement.

A γ ray measuring system with NaI(Tl) detector is used to measure the γ rays transmitted through the container during the scanning process. The same γ detector is used to measure the γ spectrum resulting from neutron interrogation. The measured γ rays are fed to two counting stations, the first station is used to count γ rays transmitted through the container during the scanning process, while the second one is used to record the spectrum of γ ray emitted from the suspected object during the identification stage.

Results obtained from the primary tests are presented in the form of 2D image for the suspected object and in the form of displayed γ spectra for γ rays emitted from the suspected objects by neutron interrogation analysis. The constructed 2D images and γ-ray spectra measured for different hidden illicit materials clearly indicate that the system is of low scanning cost, very fast and efficient for detecting contraband screened by steel shield of 1 cm thick. In addition, the system weight is very low compared with other scanners and therefore can be used as mobile or fixed system and can be easily installed at different locations.

SM/EN–P04

Portable Search Devices of Wide Application on the Basis of Radioisotope Switchable Neutron Source

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Existing designs of radioisotope neutron search devices and indicators do not meet modern requirements of radiating safety to devices of wide application. Last decade was reached essential progress in working out of switched off sources of neutrons - Radioisotope Switchable Neutron Source (RSNS) and portable D–D neutron generators. Their use in portable search devices will provide radiating safety in a non-working position. It can become a basis for development of new generation of search devices of wide application.

In work the comparative analysis of application radioisotope SNS and tiny D–D neutron generators in search devices intended for prevention of illegal circulation of explosives, drugs, and also for detection of Highly Enriched Uranium (HEU) is carried out. Simple designs of radio isotope sources are offered and specifications on injector and target manufacturing are formulated. For maintenance of an exit of neutrons 10^5 n/s the contact area of an injector-target should make 110 cm^2 for Am-Be pairs and 40 cm^2 for Pu-Be pairs. In both cases a thickness the alpha of a radiating layer makes $0.1 - 0,2\,\mu$m.

For manufacturing of laboratory breadboard model of device on the basis of RSNS it is necessary to have access to nuclear technologies. We welcome interested persons possessing radiochemical technologies for cooperation.

SM/EN–P06

ContainerProbe-Net

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ContainerProbe-Net is a global system concept for high throughput Risk Screening of inter-modal containers while they are in motion. It will have the following detection capabilities:

1. Mis-declared hazardous materials:
   - illegal waste exports or imports
   - hazardous materials causing many annual maritime insurance claims
   - accumulated pest poisons

2. Contraband materials:
   - smuggled and counterfeit goods to avoid import duties and restrictions
   - narcotic drugs
   - weapons for criminals
   - illegal immigrants
3. Terrorism materials:
   - explosives and precursors
   - Weapons of Mass Destruction
   - fissile materials

The demand for this type of detection capability with high throughput has been declared by the EU, USA and other nations as a consequence of the rising policy of Civil Security. Efforts to advocate ContainerProbe-Net to both U.S.A. and EU security research administrators are progressing as the private investment base grows. ContainerProbe-Net directly addresses the 100% Risk Screening of containers requirement.

Neutron interrogation of each container on a train or on an automated vehicle passing through the ContainerProbe portal will provide information about the bulk elemental composition of the contents. A burst of pulsed neutrons for a combination of prompt γ and secondary neutron emissions can provide a measured "fingerprint" which will remain constant from the start to the end of the container's journey. A period of two seconds is available per container in order to capture data for each container on a moving train. Contents of containers are already, to some extent, registered in the export logistics databases. However these disparate systems have evolved with computer science and the needs of ports and customs authorities. Today such systems are far from complete. The global access to such registered container data and the fusion of this information with actual physical measurement data is the Network part of the concept. Risk screening implies that anomalies are detected; both physically measured and filtered from the globally accessible container logistics data that is accessed by new information search tools and network infrastructure. Anomalous containers can then be sorted for further examination with high resolution but low throughput systems. ContainerProbe is able to be implemented because a linear geometry or line source neutron generator with intense pulse.

SM/EN–P07

Explosive Detection Using 14 MeV Neutron Generator

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Trafficking of explosive materials through various routes is a threat to international security. The neutron based explosive detection technique is found to be one of the promising non-destructive techniques to detect concealed explosives. Explosives are special type of material consisting of hydrogen, carbon, oxygen and nitrogen. The elemental analysis of these elements can be done by the neutron activation analysis method where characteristic prompt γ are produced from interaction of fast or thermal neutrons. Fast neutrons produce prompt γ in carbon and oxygen where as the thermal neutrons do it through capture in hydrogen and nitrogen. 14 MeV neutrons from D–T generator is a good choice for both the purposes. To create a database for different type of explosive materials we are carrying out various experiments in our laboratory. We have one compact neutron generator that can produce 14 MeV neutrons with neutron yield of 1×10^{10} neutrons per second. We are creating databases for the explosive like ammonium nitrate and melamine (equivalent to TNT) using the compact neutron generator and various type of detectors like HPGe, NaI, and BGO. Here in this paper some of the results of these experiments will be presented.

SM/EN–P09

Current Research Activities for Landmine Detection by Nuclear Technique in Libya

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This paper gives a description to the current research activity carried by the research team which is concerned with the application of nuclear techniques for landmine detection. The activities are technically and financially supported by the IAEA through a TC project Lib/1/006. The IAEA has provided the project with two ^{3}He detectors and some electronic equipment to install a detection system based on measuring thermal neutrons backscattered from the buried object. Also a detection system based on measuring the γ rays emitted from the hidden object through the interrogation of its elemental nuclei by fast and thermal neutrons will be installed.

Theoretical and experimental studies are performed when neutrons of different energies are used. Calculations are performed using a Monte Carlo MCNP or Geant–3 Code. This code is used to assess the thermal neutron flux backscattered from plain soil and soil embedded with landmines of different amount of explosive. Measurements are performed to measure the backscattered thermal neutrons from a landmine with different amount of explosive material which is buried in ground at different depths.

The obtained results are presented in the form of displayed spectra for γ rays and thermal neutron fluxes of landmines buried at different depth in ground. The analyses of the obtained data can be used to show the strength and weakness of the applied methods for landmine detection in different environmental conditions.

SM/EN–P10

Monte Carlo Modelling of Fast Neutron Scattering by Various Compounds in View of Elaboration of a Single Shot Inspection System

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Modern, portable or transportable neutron generators, based on the Plasma-Focus principle, are capable to produce a flash of the very intense (up to 10^9 of 2.45 MeV neutrons from D–D and up to 10^{11} of 14 MeV neutrons per shot from D–T reactions) and very short neutron pulses ($\sim$ 10 ns). Taking advantage of these capabilities it is possible to determine the elemental content of unknown samples from information existing in a field of scattered neutrons. It allows proposing an alternative approach to the detection of explosives and other illicit materials. The time–of–flight method can be involved in the identification procedure due to the short neutron pulse duration. It is expected that a single shot inspection system can be elaborated on the basis of the proposed method, limited in time only by computer data processing.

Results of the Monte Carlo simulations of the scattered neutron field from several compounds (explosives and everyday use materials) are presented in the paper. The MCNP5 code has been used to get info on the angular and energy distributions of neutrons scattered by the above mentioned compounds assuming the initial neutron energy equal to 2.45 MeV (D–D). A new input has been elaborated that allows modeling not only a spectrum of the neutrons scattered at different angles but also their time history from the moment of generation up to detection. Such an approach allows getting approximate signals as registered by hypothetic scintillator+photomultipler probes placed at various distances from the scattering object, demonstrating a principal capability of the method to identify an elemental content of the inspected objects.

SM/EN–P11

Tagged Neutrons from Portable Neutron Generator for Detection of High Explosives and Fissile Materials in Cargo Containers

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Two prototypes of measuring inspection systems created in VNIIA and intended for active interrogation of cargo containers to detect high explosives (HE) and fissile materials (FM) are presented. Both systems are based on 14 MeV tagged neutrons (API) method.

The first system (for HE detection) includes:

– VNIIA portable neutron generator ING-27 with built-in segmented 9-pixel semiconductor α-detector (30×30 mm^2),
– 12 scintillation γ-detectors based on bismuth germanate crystal (BGO) with size of $\varnothing 63 \times 63$ mm^2,
– γ-detector shielding from primary neutron flux (borated polyethylene + iron),
– electronics for data acquisition and processing system.

Experimental results on detection of 50 kg of HE simulator melamine ($C_3H_6N_6$) are presented for wood and iron matrix as container mock-up with average density of 0.4 g/cm^3 and for different distances of HE simulator from container front wall.

With increase of distance from container wall to melamine the excess of signal over background decreases. This is conditioned both by measurement geometry and attenuation of probe neutron beam and produced inelastic γ-quanta by container filling. Various decision-making algorithms and improvements are discussed.

The second system (for FM detection) includes the same neutron generator, six plastic (polystyrene) large square ($120 \times 9 \times 9$ cm^3) scintillators for detection of multiple coincidences of prompt neutrons and fission γ-quanta from FM. Radiation types were distinguished according to time of flight.

Measurements were conducted for depleted uranium (8 kg) arranged in container filled with wood and iron of 0.4 g/cm^3 average density at the distance of 60 cm from container front wall.

Excess of two- and three-fold coincidences from uranium over the corresponding background value was observed both in neutron and γ-channels. The best signal/background ratio was revealed for container filled with iron.

SM/EN–P13

Neutron Tests of a Microchannel Plate Detector and Amorphous Silicon Pixel Array Readout for Neutron Radiography

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High-performance large area imaging detectors for fast neutrons in the $5 - 14$ MeV energy range do not exist at present. The aim of this project is to combine microchannel plates or MCPs (or similar electron multiplication structures) traditionally used in image intensifiers and X-ray detectors with amorphous silicon (a-Si) pixel arrays to produce an intensified position sensitive imaging system. This detector will provide an order of magnitude improvement in image resolution when compared with current millimetre resolution limits obtained using phosphor or scintillator-based hydrogen rich converters. In this study we present the results of the experimental evaluation of the prototype system. This study was carried out using a thermal neutron source. The hybrid detector described in this study is a unique development and paves the way for large area position sensitive detectors consisting of MCP or microsphere plate detectors and a-Si or polysilicon pixel arrays. Applications include neutron and X-ray imaging for terrestrial applications. The technology could be extended to space instrumentation for astronomy and planetary science.

SM/EN–P14

Studies of Polarized Photofission

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Idaho State University and the Idaho Accelerator Center are developing a polarized photon facility using the off axis bremsstrahlung technique. Initial tests have been performed using the high analyzing power of the photodisintegration of the deuteron to measure the beam polarization. A program is currently underway to measure potential angular asymmetries of fission neutrons which are a consequence of the angular distribution of the fission fragments from photofission with linearly polarized photons. In this talk, we will describe the Idaho State University Polarized Photon Facility, present the results of its commissioning run, and describe potential application of polarized photofission in detecting actinides for homeland security and safeguards applications.

SM/EN–P16

Algorithmic Classification of Active/Inactive Unexploded Ordnance Using Neutron Analysis Data

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For over a decade, the Applied Physics Institute at Western Kentucky University has been assisting the U.S. Army to determine the active/inactive status of unexploded ordnance (UXO) using a Pulsed Fast/Thermal Neutron Analysis (PFTNA) technique that indicates the elemental composition of the test item. Typically, their methods require a skilled analyst to interpret the spectral data collected. The author has developed a wavelet-based algorithm that automatically interprets the spectral data and makes a determination as to the substance being tested. The basis being used is a smooth scaling vector and multiwavelet developed by the author with approximation order 4, along with a prefilter developed by the author. Preliminary results from its usage on PFTNA data in UXO determination applications are described.

SM/EN–P17

A Fast Pulsed Neutron Source Driven by a Pulsed Current Transformer

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Pulsed neutron accelerators have been considered for active interrogation of special nuclear materials and also for location and imaging of explosives using PFNA. Alameda Applied Sciences Corporation is developing a < 40 ns pulsed neutron source for these applications, based on the dense plasma focus (DPF). The DPF benefits from well established scaling laws that cover a wide range of outputs from 10^4 up to 10^{12} n/pulse. The strong scaling of neutron output with discharge

current (as the fourth power of the current) and the fact that the voltage required is relatively low ($\sim$ 10 kV for a small source), allows the use of a pulsed current transformer architecture to efficiently drive the DPF. This paper describes the performance of a unit module of such a transformer driven neutron source. A single Thyratron switch is used to transform a 30 kV/13 kA pulse on the primary side of a metglas transformer into a 10 kV/40 kA pulse on the secondary. This secondary pulse drives a DPF at rep-rates from $10 - 100$ Hz, to produce $\sim$ 20 ns neutron pulses. Optimization of the DPF head and its electrical coupling efficiency to the transformer driver are discussed. Conceptual designs for 100 kA and 300 kA versions of the pulsed transformer are presented, that are capable of driving DPF sources to 10^{12} n/s (D–T) output with 14.1 MeV neutrons in $<$ 40 ns pulse widths.

SM/EN–P18

Dynamic Temporal Enhancement of Material Signatures in a Pulsed Neutron Source Application

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Extracting unique signatures from γ-ray spectra form the foundation for detecting various threats (explosives, narcotics, chemical weapons) in sea containers, trailers of trucks, air cargo, and luggage for systems that employ the Rapiscan VEDS (Vehicular Explosive Detection System) technology. The application of focus for this paper is a portal VEDS for detecting explosives inside of the trailer of a truck for infrastructure protection. Due to its pulsed operations, a 14-MeV neutron generator accelerator source allows for the measurement of different elemental signatures through three primary neutron-induced reactions. Synchronized time windows in reference to the creation of the neutron pulse allows for the extraction of γ-ray spectra dominated by different nuclear reactions. This paper will present the latest data from a study of optimizing the time windows used to collect the fast (during the neutron pulse), the thermal (immediately following the neutron pulse), and activation (after the die-away of the thermal neutron population) spectra. With the understanding that the characteristic die-away time of the thermal neutrons is determined by the type of cargo in the trailer being inspected, the time windows can be chosen to account for this effect. The study shows that the signature strength improves when cargo dependent dynamic time windows are chosen. The data acquisition system employed allows for real-time dynamic control of these time windows. As the cargo type(s) can be determined by the very same detector system, this technique provides a simple method to extract the maximum possible signal.

SM/SA — Applications of Synchrotron Radiation in Natural and Applied Sciences

This satellite meeting is aiming at the applications of synchrotron radiation in the field of natural and applied sciences. The special attention and focus of the meeting is the light source in Middle East. The Synchrotron-light for Experimental Science and its Applications in Middle East (SESAME) is under construction in Amman (Jordan). SESAME is a project under the auspice of UNESCO and it is an inter-governmental organization. Bahrain, Cyprus, Egypt, Iran, Israel, Jordan, Pakistan, Palestine Authority and Turkey are the members.

The Organizing Committee of the Satellite Meeting is composed of:

- *Hafeez Hoorani, SESAME, Jordan*
- *Françoise Mulhauser, IAEA, Vienna*

SM/SA–01

Scientific Program of SESAME Project

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Synchrotron-light for Experimental Science and Applications in Middle East SESAME is a project, which is established under auspices of UNESCO as intergovernmental organization with following members: Bahrain, Cyprus, Egypt, Iran, Israel, Jordan, Pakistan, Palestine Authority, and Turkey. The German Government as a gift has donated the injector and booster for SESAME after dismantling of BESSY in Berlin. The SESAME team will build the storage ring.

SESAME is a third generation light source with beam energy of 2.5 GeV, beam current of 400 mA, emittance 26 nm.rad and circumference of 133.2 m. It is under construction close to Amman (Jordan) and will become operational end of 2012 or beginning of 2013. SESAME contains 16 straight sections out of which 13 straight sections are available for placing insertion devices such as undulator and wigglers.

An extensive scientific programme has been established with the help of Scientific Advisory Committee (SAC) and the Beamline Advisory Committee (BAC). From the beginning 7 beamlines are planned for Phase I covering diverse areas of scientific interest such as: SAXS/WAXS, PX, IR, Soft X-ray, Powder Diffraction, XRF/XAFS and Atomic, Molecular spectroscopy (AMO) beamline. SESAME once operational will be a very competitive machine in the category of third generation light sources.

SM/SA–02

The Canadian Light Source: A Novel Tool in the Search for Environmental Sustainability

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As applied research moves into the 21^{st} century, industry is discovering that traditional analytical techniques are not answering all of their questions. For example, new materials are being developed daily that may have significantly different properties but are chemically indistinguishable using current analysis techniques. It is important for industry to understand these differences and be able to go back to the laboratory and impart those unique properties to a new product. Therefore, today, industry is turning to new tools to shed light on old and new questions. In a similar manner, environmental waste management is motivating many proactive industries to move toward new technologies that will provide answers to environmental questions yet to be asked. Within the mining sector, the ability to understand and predict the long-term stability and future bioavailability of metals (e.g., arsenic) in mine waste is critical for operation and absolutely essential to their capacity to decommission that site in the future. Currently, the environmental impact of tailings is monitored and stability is predicted by combining thermodynamic models with powder x-ray diffraction data to determine material composition and with assorted wet chemistry techniques to determine total species concentrations. Although these techniques have supplied a significant amount of important ecological information, increasing pressure from environmental groups demand more detailed information beyond the range of these procedures. To obtain this increasing level of detail, scientist are turning to more sophisticated analytical tools such as such as synchrotron radiation-based x-ray absorption spectroscopy (XAS) for insight. XAS is a powerful probe that can directly determine the oxidation states and local chemical surroundings of a metal and thereby increase our understanding of its long term environmental impact.

With environmental stewardship being of global concern, the Canadian Light Source (CLS), a 2.9 GeV synchrotron facility located at the University of Saskatchewan, is taking a leadership in role in the area of mine waste characterization. This presentation will discuss various mine impacted sites and the role facilities like the CLS play in our search for environmental sustainability.

SM/SA–03

Diamond Light Source: Status and Applications in Life Sciences

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Diamond Light Source is the UK's 3^{rd} generation synchrotron radiation source which has been operational for 18 months. A number of operational beamlines are dedicated to Life Sciences including macromolecular crystallography and circular dichroism and biologists have access to other experimental techniques such as spectroscopy and solution scattering whose beamlines are shared with the physical sciences. Additional Life Science beamlines are at various stages in the construction process including, as part of Phase 3 of Diamond, a full field X-ray microscope dedicated to biology. To support the science on the beamlines we have biological laboratories adjacent to the beamlines around the periphery of the ring including the Membrane Protein Laboratory which is a collaboration between Diamond and Imperial College London aimed at providing facilities and expertise in the solution of membrane protein structures. In my talk I will present the current status of Diamond, focussing specifically on the provision for the life sciences, highlighting some of the results already obtained. I will end with a vision for the future of life science and synchrotron radiation.

SM/SA–04

The Elettra and FERMI: two Accelerator-based Radiation Sources in Trieste

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Elettra is the Italian third generation synchrotron radiation laboratory located on the Triestinian Carso plateau. It is built around a medium energy electron storage ring operated between 2 and 2.4 GeV. The Elettra beamlines cover a wide energy range, from the far infrared to the hard x-rays, as the photon energy ranges between 2 meV and 40 keV, i.e. wavelengths between 0.6 mm and 0.3 Å.

Moreover, an existing LINAC, previously used as injector for the storage ring is being upgraded and converted into a Free Electron Laser (FEL), FERMI @ ELETTRA (Free Electron laser Radiation for Multidisciplinary Investigations at Elettra) FEL.

Both sources are built and operated by the Sincrotrone Trieste public no profit company. Beamlines are often built in collaboration with external partners from different scientific institutions, both Italian and from other countries.

Together with the synchrotron radiation activity, Elettra hosts several support and complementary laboratories, which makes it a multidisciplinary Research and Service center, competitive at the international level by employing advanced micro/nano analytical, photolithographic and radiographic techniques. Researchers at Elettra are active in fields as diverse as genomics, pharmacology, biomedicine, catalysis and chemical processes, microelectronics and micromechanics.

This wide range of applications makes the site an international crossroad where researchers, coming from different countries and disciplines and from academic and applied research, interact and exchange in a competitive, yet friendly, atmosphere, producing new knowledge and training junior researchers. Training of younger generations of scientists and engineers for research and industry is indeed one of the missions of the Sincrotrone Trieste public company. to be sent

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