Book of Abstracts

DAE-BRNS TWO-DAY THEME MEETING ON Strategic Planning for Enhancing Research Reactor Utilization (RRU-2022)

Jointly Organized by
Reactor Group and Radiochemistry & Isotope Group
Bhabha Atomic Research Centre

May 6-7, 2022
DAE Convention Centre, Anushaktinagar, Mumbai-400094

Editors
Tej Singh, Kunal Chakraborty, C G Karhadkar, Reactor Group
and
Raghunath Acharya, P.K. Pujari, Radiochemistry & Isotope Group

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Bhabha Atomic Research Centre

Board of Research in Nuclear Sciences

Jointly Organized by

Reactor Group and Radiochemistry & Isotope Group

Bhabha Atomic Research Centre

Sponsored by

Board of Research in Nuclear Sciences

सार पुस्तक

अनुसंधान रिएक्टरों के उपयोजन वृद्धि हेतु कार्यनीतिक आयोजना

पर दो दिवसीय पऊवि-बीआरएनएस थीम गोष्ठी

(आरआरयू-2022)

दिनांक 6-7 मई, 2022

पऊवि सम्मेलन केंद्र

अणुशक्तिनगर, मुंबई-400094

संकलन

कमलाकान्त सिंह *शान्तनब बनर्जी* *अभिषेक मिश्र*

अभिजीत दास *तनय मजुमदार* *परितोष पाण्डेय*

जैनेन्द्र कुमार *यशपाल सिंह राणा*

तेज़ सिंह

भाभा परमाणु अनुसंधान केंद्र **नाभिकीय विज्ञान अनुसंधान बोर्ड**

रिएक्टर वर्ग तथा रेडियोरासायनिकी एवं आइसोटोप वर्ग
भाभा परमाणु अनुसंधान केंद्र
द्वारा संयुक्त रूप से आयोजित

प्रायोजक

नाभिकीय विज्ञान अनुसंधान बोर्ड

DAE-BRNS TWO-DAY THEME MEETING ON

Strategic Planning for Enhancing Research Reactor Utilization

RRU-2022

May 6-7, 2022

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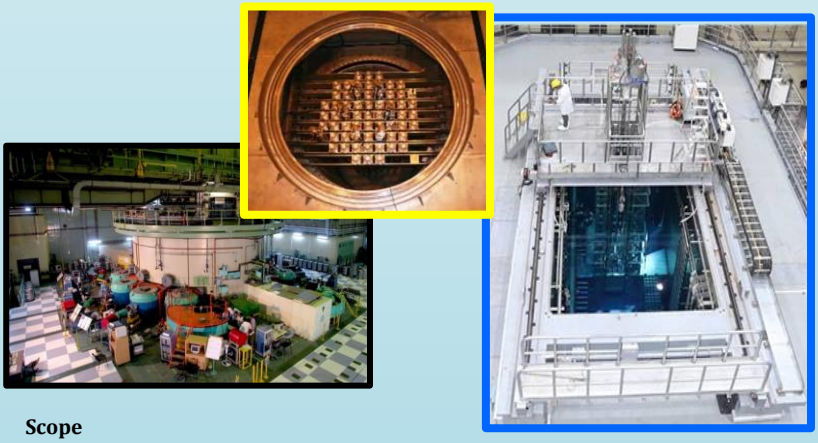
DAE Convention Centre

Anushaktinagar, Mumbai-400094

Bhabha Atomic Research Centre has state of art research reactor facilities at Dhruva and Apsara-U for radioisotope production as well as various R&D works. There is a need as well as scope to enhance the utilization of neutrons from research reactors by various R&D communities and users from various organizations for materials characterization, nuclear reaction & fission, health care and various societal applications. In this regard, a DAE-BRNS sponsored Two-Day Theme Meeting on "Strategic Planning for Enhancing Research Reactor Utilization (RRU-2022)" is being organized to commemorate Azadi Ka Amrit Mahotsav. The main objective of this Theme Meeting is aimed at interaction with the potential users of research reactors at BARC, other units of DAE as well as non-DAE government and private organizations including industries, research and academic institutes and Institutes/Universities that are pursuing projects under BRNS, UGC-DAE CSR , CSIR and other schemes.



Scope

a) Research Reactor Facilities at BARC, Mumbai
b) Radioisotope Production & Various Societal Applications in Healthcare, Industry, Food & Agriculture
c) Neutron Scattering Studies utilizing Neutron Beams
d) Neutron Imaging (Radiography/Tomography) for Non-destructive Testing
e) Neutron Activation Analysis for Chemical Characterization of Materials
f) Nuclear Physics Studies (Neutron Capture Gamma-ray Spectroscopy, Fission Studies etc.)
g) Development and Testing of Radiation Detectors
h) Development and Testing of Shielding Materials for Neutron and Gamma-rays
i) Studies related to Materials Science, Reactor Materials, Ores, Minerals, Forensic Sciences, Industrial Applications, Geochronology
j) Reactor Physics Experiments
k) Neutron Transmutation doping studies for semiconductor devices
l) Education and Training for Human Resource Development

Jointly organised by

Reactor Group and Radiochemistry & Isotope Group, BARC

In association with

UGC-DAE CSR, Mumbai Centre and Society for Positron Annihilation and Nuclear Probes (SPAN) C/o. RCD, BARC

Website: http://www.barc.gov.in/symposia/RRU-2022

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के. एन. व्यास
K. N. Vyas

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Government of India

अध्यक्ष, परमाणु ऊर्जा आयोग
व
सचिव, परमाणु ऊर्जा विभाग
Chairman, Atomic Energy Commission
&
Secretary, Department of Atomic Energy

MESSAGE

I am happy to know that the DAE-BRNS sponsored Two-Day Theme Meeting on "Strategic Planning for Enhancing Research Reactor Utilization (RRU-2022)" is going to be organized jointly by Reactor Group and Radiochemistry & Isotope Group during May 6-7, 2022 at DAE Convention Centre, Anushaktinagar, Mumbai.

Since commissioning of India's first nuclear reactor Apsara in 1956, DAE has been actively involved in utilization of research reactors for societal applications by producing medical radioisotopes as well as encouraging cutting-edge research with neutrons as probes in the field of condensed matter physics, nuclear physics, reactor materials, etc. Presently, research reactors at BARC – namely, Dhruva and Apsara-U are being extensively used by both DAE and non DAE users for a variety of applications in the field of reactor engineering, materials research, agriculture, material characterization, neutron imaging, etc.

I am delighted to know that about 200 delegates from DAE and Non-DAE institutes will be participating in this theme meeting. I am sure that the meeting will provide guidance and awareness among users for the effective utilization of these important research facilities. The two-day deliberations will inspire the researchers from academic institutes to take up new challenges by utilizing research reactors in India.

I wish the Theme meeting a grand success.

(K. N. Vyas)

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डॉ. अजित कुमार मोहान्ती
Dr. Ajit Kumar Mohanty

भारत सरकार
Government of India

निदेशक, भाभा परमाणु अनुसंधान केंद्र
Director, Bhabha Atomic Research Centre
सदस्य, परमाणु ऊर्जा आयोग
Member, Atomic Energy Commission

FOREWORD

On behalf of Bhabha Atomic Research Centre, I extend my gratitude to Reactor Group (RG) and Radiochemistry & Isotope Group (RC&IG) for organizing a DAE-BRNS sponsored Two-Day Theme Meeting on "Strategic Planning for Enhancing Research Reactor Utilization (RRU-2022)" to commemorate 75 years of Indian Independence - "Azadi Ka Amrit Mahotsav".

BARC is a premiere nuclear research centre under Department of Atomic Energy, which symbolizes an organization of multidisciplinary and broad-spectrum R&D excellence in the advanced domain of Nuclear Science, Engineering and Basic Sciences. It was none other than Dr. Homi Jehangir Bhabha, who conceptualized and laid the foundation of the research reactor programme in India by setting up Apsara in 1956 in order to commence beam tube research in nuclear physics, condensed matter physics and material science and production of radioisotopes for wide range of applications starting from medicine to industry to agriculture and research.

Presently, BARC has state-of-the-art research reactor facilities at Dhruva and Apsara-U for radioisotope production as well as various R&D activities. These Research Reactors are being well utilized by DAE and non-DAE organizations for Radioisotope production, Neutron Scattering and Spectroscopy experiments in beam tubes, Neutron Activation Analysis, Neutron imaging and its applications etc.

The main objective of the theme meeting is to enhance collaboration with potential users of research reactors at BARC including industries, research and academic institutes and thereby utilize the research reactors to their full potential.

I again wish to extend my heartfelt thanks to the organizers and the participants, who contributed to this programme and wish RRU-2022 a great success.

Ajit Kumar Mohanty

(Ajit Kumar Mohanty)

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डॉ. आर. चिदंबरम

Dr. R. Chidambaram

सत्यमेव जयते

भारत सरकार
Government of India

पऊवि-होमी भाभा पीठाचार्य,
DAE - Homi Bhabha Chair Professor
भारत सरकार के पूर्व प्रधान वैज्ञानिक सलाहकार
पर्व अध्यक्ष, परमाणु ऊर्जा आयोग एवं
पर्व निदेशक, भाभा परमाणु अनुसंधान केंद्र
Former Principal Scientific Adviser to GOI,
Former Chairman, Atomic Energy Commission
Former Director, Bhabha Atomic Research Centre

The DAE BRNS Theme Meeting on Strategic Planning for Research Reactor Utilization (RRU-2022) is timely. The activities in BARC in neutron beam research for condensed matter physics and materials research, radio-isotope generation, etc. have been growing, and the experimental facilities have been made available to other units and universities in the country also.

The power reactor program in the country and that of the research reactors at BARC are closely intertwined. These research reactors have been providing our scientists and engineers much sought-after insights into the intricacies of design and construction of nuclear power reactors.

Since inception, our nuclear programme has been characterised by a holistic approach. Thus, while power generation is indeed a matter of priority, non-power applications of nuclear energy in areas such as medicine, agriculture and industry are given emphasis in our R&D programme. DAE has also extensively encouraged the university-BARC collaboration in the area of neutron beam research.

A new High-Flux Research Reactor is also coming up at the BARC campus at Vishakhapatnam, where our aim should be to build a robust R&D program, with the best-in-class neutron beam research instruments.

I believe the deliberations in the meeting would definitely lead to fruitful interactions amongst the participants and help in advancing research reactor utilisation in the country.

I extend warm wishes to all the participants and wish the conference all success.

R. Chidambaram
29.4.22

(R. Chidambaram)

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भाभा परमाणु अनुसंधान केंद्र, छठी मंजिल, सेंट्रल काम्प्लेक्स, ट्रॉम्बे, मुंबई - 400 085, भारत
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सी. जी. कऱ्हाडकर

C. G. Karhadkar

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Government of India

उत्कृष्ट वैज्ञानिक एवं
निदेशक, रिएक्टर वर्ग
Outstanding Scientist &
Director, Reactor Group

MESSAGE

Research Reactors are an important platform for supporting research pertaining to material characterization using neutrons as probes, testing and qualification of reactor materials and related components under neutron flux environment and production of large variety of radioisotopes for health care, agriculture, industry and environmental related programme.

These reactors have provided a valuable support in development of the Indian Nuclear Power Program in many ways, viz. testing of materials, fuel, equipment, shielding experiments, validation of codes etc.

Presently BARC has state-of-the-art facilities, with neutron flux as low as 10^6 n/cm^2/sec to as high as 2.2 x 10^{14} n/cm^2/sec at Dhruva, Critical Facility and Apsara-U reactors. These Research Reactors are being utilized by DAE and some Non-DAE organizations for radioisotope production, Neutron Scattering experiments, Neutron Activation Analysis (NAA), Neutron Imaging, Material Research, Nuclear Reactions and Fission studies, Development and testing of detectors, Neutron Transmutation Doping (NTD)-Si, Reactor Physics experiments, Education and Training for Human Resources Development.

With a goal to enhance the collaboration with potential users of research reactors, Reactor Group (RG) and Radiochemistry & Isotope Group (RC&IG) are organizing a DAE-BRNS sponsored Two-Day Theme Meeting on ***"Strategic Planning for Enhancing Research Reactor Utilization (RRU-2022)"*** on May 6 & 7, 2022. I sincerely hope that this meeting will strengthen the bonds between the BARC-Reactor community, Non-DAE Government Industry, Private Industry & Academia and pave way for creation of a platform for regular interactions and enhancing research reactor utilization.

26.4.22

(C. G. Karhadkar)

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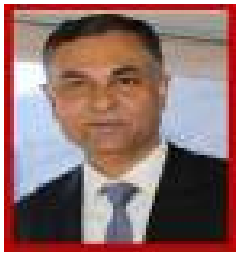

Message

I am glad that **DAE-BRNS sponsored Two-Day Theme Meeting on 'Strategic Planning for Enhancing Research Reactor Utilization (RRU-2022)**' is being jointly organized by Reactor Group and Radiochemistry & Isotope Group of BARC in association with UGC-DAE CSR Mumbai Centre and Society for Positron Annihilation and Nuclear Probes (SPAN) during May 6-7, 2022 at the DAE Convention Centre, Anushaktinagar, Mumbai to commemorate "**Azadi Ka Amrit Mahotsav**". The Theme Meeting will provide forum for interaction of Scientists and Engineers from BARC and researchers and potential users from non-DAE and private organizations including Industry. I am happy that 200 delegates will participate in this Meeting. The technical program of RRU-2022 consists of keynote and invited talks by experts as well as oral and poster presentations by more than 200 researchers from BARC, DAE, faculties from academic institutes, R&D personnel from Industry and research scholars.
Radiochemistry and Isotope Group of BARC is one of the beneficiaries of research reactors ever since the commissioning of Apsara reactor. In addition to various R&D works utilizing neutrons, RC&I group has very strong activities linked to societal applications in health care, industry as well as physical and chemical research. State of art facilities utilizing neutrons for studies in nuclear fission, neutron activation analysis, radiopharmaceuticals as well as isotope hydrology are in place at BARC. It is necessary to have enhanced utilization of neutrons from Dhruva and Apsara-U reactor facilities in key areas having societal importance and frontier areas of research like neutron radiography, imaging, non-destructive assay, PGNAA, neutrino research as well as intense positron facilities for materials characterization. BARC encourages users from Industry, academic institutes and government organizations for utilizing available research reactor facilities.

I am thankful to BRNS, DAE for the financial support and UGC-DAE-CSR and SPAN as organizing bodies. I wish the theme meeting RRU-2022 a grand success.

Date: 20th April 2022 (P.K. Pujari)

FAX : +91-22-2550 5151/2550 5345
Phone No.25593933, 25593604

Dr. S. Kannan

Director, RC&I Group,
BARC, Trombay, Mumbai 400085.
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सत्यमेव जयते

भारत सरकार
Government of India
BHABHA ATOMIC RESEARCH CENTRE
Radiochemistry & Isotope Group

April 21, 2022

Message

I am happy that the **DAE-BRNS sponsored Two-Day Theme Meeting on 'Strategic Planning for Enhancing Research Reactor Utilization (RRU-2022)'** is being jointly organized by Reactor Group and Radiochemistry & Isotope Group of BARC in association with UGC-DAE CSR, Mumbai Centre and Society for Positron Annihilation and Nuclear Probes (SPAN) during May 6-7, 2022 at the DAE Convention Centre, Anushaktinagar, Mumbai - 400094 to commemorate "**Azadi Ka Amrit Mahotsav**". The main objective of this Theme Meeting is aimed at interaction of experts from BARC, DAE with Potential Users of research reactors from non-DAE government and private organizations including academic and research institutes and Industries. It is heartening to note that more than 200 delegates will participate from various organizations having interest in utilizing research reactors and reactor produced radioisotopes and present their work plan. The technical program of RRU-2022 consists of keynote and invited talks by experts, Oral presentations by existing and prospective users and Poster presentation by researchers, faculties, R&D personnel and research scholars.

Radiochemistry and Isotope Group of BARC has been utilizing research reactors since 1956 for various R&D as well as applied works having applications in the area of health care, industry and research. R&D studies in the fields of Nuclear Fission, Neutron Activation Analysis and Radiopharmaceuticals are the key areas, where reactor neutrons have been extensively utilized by our group and also through collaboration with academic and research institutes under various schemes of BRNS and UGC DAE CSR. RC&I Group has a long-term R&D work plan aimed towards departmental as well as societal applications utilizing reactor neutrons and thermal neutron beam via Radioisotopes for health care and industry as well as Prompt Gamma-ray NAA and Positron Annihilation Spectroscopy for materials characterization utilizing Dhruva as well as Apsara-U reactor facilities.

I congratulate the organizers of RRU-2022 and wish the theme meeting a grand success via fruitful interaction among experts and users of research reactors.

(S . Kannan) 22/4/22

Dr. A. K. TYAGI
(FRSC, FNASc, FASc)
Director, Chemistry Group
Bhabha Atomic Research Centre
Mumbai-400 085

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भाभा परमाणु अनुसंधान केंद्र
BHABHA ATOMIC RESEARCH CENTRE

MESSAGE

I am happy to know that the DAE-BRNS sponsored Two-Day Theme Meeting on "Strategic Planning for Enhancing Research Reactor Utilization (RRU-2022)" is being organized jointly by Reactor Group and Radiochemistry & Isotope Group during May 6-7, 2022.

The research reactors are important national facilities for supporting research and development in the areas of material characterization using neutrons as probes; testing of reactor materials, related components under neutron environment and production of a large variety of radioisotopes for societal applications including health care, agriculture, industry and environment. There are numerous industrial applications for research reactors. Another important application is in the area of neutron radiography/tomography of various objects utilizing neutron beam tubes of nuclear reactors.

Since late fifties, Chemistry Group, BARC has been utilizing reactor based neutron activation analysis (NAA) techniques for various applications including geological exploration, forensic investigations, archaeological studies and high purity material development program. Lunar samples made available to BARC were also analyzed by NAA. There was strong collaboration with Central Forensic Science Laboratory and Geological Survey of India for the specialized analyses for forensic exhibits and analysis of rock samples for precious metals respectively using NAA technique. With the availability of high flux research reactors the utilization of this technique will be extended to every branch of science and technology.

I am delighted to know that about 200 delegates including 80 participants from academic institutes will be attending this theme meeting. I am sure, RRU-2022 will provide an excellent platform for effective interaction among various users of research reactors and experts from DAE and Non-DAE. The two-day meeting will create awareness about the wide utility of existing facilities and inspire the young researchers to take up new challenges utilizing these research reactors.

I wish the Theme Meeting a grand success and fruitful time to all the delegates during RRU-2022.

Dated: 18-04-2022

(A. K. Tyagi)

डॉ. एस. एम. युसुफ
Dr. S.M. Yusuf, D.Sc (Hon.), FASc, FNASc
निदेशक, भौतिकी वर्ग
Director, Physics Group

सत्यमेव जयते
भारत सरकार
GOVERNMENT OF INDIA
भाभा परमाणु अनुसंधान केंद्र
BHABHA ATOMIC RESEARCH CENTRE
भौतिकी वर्ग
PHYSICS GROUP
Mumbai – 400085

भाभा परमाणु अनुसंधान केंद्र
BHABHA ATOMIC RESEARCH CENTRE

Message

It is my immense pleasure to be associated with the organization of "DAE-BRNS Theme Meeting on Strategic Planning for Enhancing Research Reactor Utilization (RRU-2022)". The Theme meeting is being held during May 6-7 at Bhabha Atomic Research Centre, Mumbai, jointly organized by Reactor Group and Radiochemistry & Isotope Group, BARC.

Research reactor utilizations for neutron scattering, imaging and nuclear physics studies form a significant and unique implementation of radiation to probe and explore the properties of matter. Neutron scattering, in particular, has influenced many branches of science, ranging from fundamental physics to polymer science, nano-materials to soft matter, and biological systems to energy materials. The neutron scattering facilities, available at the National Facility for Neutron Beam Research at the Dhruva reactor, are enthusiastically used by faculty and students of many universities and other academic institutions in the country. These facilities are made available to users through research projects funded by various agencies.

The inter-disciplinary character of this Theme meeting would definitely lead to fruitful deliberations and birth of new ideas amongst the participating scientists and young researchers, not only in the field of basic research, but also in the application sector. Advancement of research reactor utilization is the need of the hour and in this respect, this Theme meeting is a step forward in this direction.

I extend my warm greetings to all the delegates and wish a grand success of this "DAE-BRNS Theme Meeting on Strategic Planning for Enhancing Research Reactor Utilization (RRU-2022)".

Md. Yusuf

(S. M. Yusuf)

प्रो. अम्लान जे. पाल
निदेशक
Prof. Amlan J. Pal
Director

विश्वविद्यालय अनुदान आयोग–परमाणु ऊर्जा विभाग वैज्ञानिक अनुसंधान संकुल
UGC-DAE CONSORTIUM FOR SCIENTIFIC RESEARCH
[Centres: Kolkata, Mumbai, Indore; Node: Kalpakkam]
प्रधान कार्यालय: विश्वविद्यालय परिसर, खण्डवा रोड़, इन्दौर–452001, भारत
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Message

I am happy to know that the **DAE-BRNS sponsored Two-Day Theme Meeting on 'Strategic Planning for Enhancing Research Reactor Utilization (RRU-2022)'** is being jointly organized by the Reactor Group and Radiochemistry & Isotope Group of BARC in association with UGC-DAE CSR, Mumbai Centre and Society for Positron Annihilation and Nuclear Probes (SPAN) during May 6-7, 2022 at the DAE Convention Centre, Anushaktinagar, Mumbai - 400094 to commemorate "**Azadi Ka Amrit Mahotsav**". The Theme Meeting will provide a forum for interaction of scientists and engineers from BARC and researchers and potential users from non-DAE and private organizations including universities and Indian industries. I am happy that about 200 delegates will participate in this meeting. I noted that the technical program of RRU-2022 consists of keynote and invited talks by experts as well as contributed abstracts for oral and poster presentations by younger researchers from BARC, DAE, and faculties from academic institutes and universities, R&D personnel from industries, and research scholars.

UGC-DAE CSR, Mumbai Centre is already coordinating the use of neutron scattering facilities by researchers from colleges, universities, and other research institutes for the last three decades. More than 300 collaborative research schemes have been completed. About 70 research scholars have obtained their Ph.D. degrees with their theses containing a significant amount of neutron data recorded from Dhruva and/or CIRUS reactors. In addition to CRS projects, many one-time users have also accessed these neutron facilities. Neutron diffraction of crystalline and amorphous systems and small-angle neutron scattering on soft matters remained the conventional techniques envisaged by the researchers. Users are gradually applying other neutron techniques as well.

A national facility for Research Reactor Utilization could be a useful idea for effective and enhanced utilization of research reactors for various R&D works and societal applications including human resource developments.

I wish the theme meeting a grand success.

Amlan J. Pal.

(Amlan J. Pal)

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DAE-BRNS TWO-DAY THEME MEETING ON
Strategic Planning for Enhancing Research Reactor Utilization

(RRU-2022)

May 6-7, 2022

Preface

Research Reactors are made for multifaceted application like radioisotopes production for medical, industrial and agricultural uses, neutron beam research, material characterization, imaging etc. In India, the journey of research reactors was started with the commissioning of Apsara in August, 1956. At present, Bhabha Atomic Research Centre (BARC) at Trombay has state of the art research reactor facilities like Dhruva and Apsara-U for radioisotope production, as well as various R&D works. Since 1985, Dhruva, which is a 100 MW_{th} reactor, remains one of the potential sources of radioisotope production and neutron beam research. 2 MW_{th} Apsara-U, which went critical in 2018, is the latest entry into the list of Indian research reactors. There is a need, as well as scope, to enhance the utilization of neutrons from research reactors by various R&D communities and users from various organizations for their intended applications. In order to do so in an organized manner, a DAE-BRNS sponsored Two-Day Theme Meeting on "Strategic Planning for Enhancing Research Reactor Utilization (RRU-2022)" is going to be organized jointly by Reactor Group and Radiochemistry & Isotope Group during May 6-7, 2022 at DAE Convention Centre, Anushaktinagar, Mumbai-400094. The main objective of this theme meeting is aimed at interaction with the potential users of research reactors at BARC, other units of DAE as well as non-DAE government and private organizations including industries, research and academic institutes and Institutes/Universities that are pursuing projects under BRNS, UGC-DAE CSR, CSIR and other schemes. In this meeting, a strategic plan will be developed for long-term sustainability in terms of 'marketing' the R&D facilities associated with the research reactors.

Over the years, research reactors are serving as precursor for wide variety of radioactive isotopes for use in many fields, including nuclear medicine, industry, agriculture and research. Globally, the use of radioisotopes for medical purposes is rapidly increasing. Every year, more than 30 million examinations and cancer treatments are being carried out worldwide. Radionuclides, which are produced at research reactors, are used in both diagnostic techniques and therapeutic treatments.

Sealed radioisotope sources such as ^{60}Co, ^{192}Ir, etc find also applications in level gauging, density monitoring, thickness gauging, radiometric scanning, gamma radiography, topography, blockage detection, etc. Some radioisotopes are also used as radiotracers for leak detection in pipelines and heat exchanger, residence time distribution, etc. Like ^{60}Co used for radiation processing in industry such as sterilization of medical appliances, hygienization of waste products and so on.

Through beam holes, neutron beam lines are utilized outside the reactor for research in nuclear physics, condensed matter physics and material science. Thermal neutrons have a typical wavelength ~ 0.1 nm (nanometres), which is perfect for studying crystalline structures through diffraction because of its similar order of magnitude as the interatomic spacing inside the crystals. Also, the order of energy of thermal neutrons allows to measure atomic/molecular dynamics in the system. The high penetrating power of neutrons, along with their magnetic moment and their unique sensing capabilities of light atoms, make them a unique probe. The nuclear structure studies employing prompt (n,γ) reactions using thermal neutrons and fission fragment spectroscopy are being carried out to investigate the properties (shape and structure) of the neutron-rich fragment nuclei. Dhruva reactor is best suited for such studies.

The research reactors are also serving as the facility for studying and qualifying nuclear fuels, structural materials and components used in power reactors (vessels, internal equipment, neutron absorbers, etc). Being a reliable source of high intensity fluxes of neutrons, gammas, neutrinos and other types of radiation, these reactors are used to determine the effect of radiation on materials, components and instruments in view of their performance in radiation environment.

Neutron activation analysis (NAA) is a qualitative and quantitative analytical technique for the determination of trace elements in a variety of complex sample matrices. It can be performed in a variety

of ways depending on the element and its levels to be measured, as well as on the nature and the extent of interference with other elements present in the sample. This is worthy to mention here that many of the trace element identification can be directly linked to potential economic benefits. Therefore, NAA should be considered as a key component in the strategic plans of Dhruva and Apsara-U research reactors. In one of the Apsara-U thermal neutron beam tubes, PGNAA facility is also going to be set up. Typical applications of PGNAA include analysis of samples in geological and atmospheric sciences. The technique is useful for analysing elements like H, B, C, N, P, S, Cd, Pb, Sm, and Gd.

There are numerous industrial applications for research reactors. Few of them, which are very common, are mentioned below. Firstly, neutron radiography/tomography of various objects is used for non-destructive testing in the aeronautical and space industries, nuclear sector, etc. Such facility has been commissioned in one of the Dhruva neutron beam tubes. Secondly, positrons are considered suitable probe to detect low concentrations of defects in materials. Thirdly, neutron transmutation doping of silicon (NTD-Si) through the formation of ^{31}P in silicon ingot upon its irradiation under thermal neutron flux is considered superior than the conventional doping technique. This method is used to achieve an excellent distribution of resistivity in silicon ingots, which is desirable in manufacturing components for the electronics industry, such as diodes, thyristors etc.

Research reactors have also established their legacy in education field in terms of manpower training in various branches of science and engineering, including the nuclear power plant staff. For safety and accessibility reasons, low power research reactors like Apsara-U are best suited for such training activities, which include neutron measurements and radiological protection measurements and characterization of reactor cores by establishing the neutron-absorbing rod worth curve and measuring the temperature coefficient etc. This type of reactor also enables trainees to acquire knowledge and practical experience of operating a nuclear reactor like approach to criticality, divergence etc.

This book is a compilation of about 200 abstracts, including 16 invited talks and 10 oral talks, contributed to the theme meeting and covers a whole gamut of the different aspects of utilization of research reactors.

It is quite evident that a theme meeting of this scale would not be possible without the support from many corners. On behalf of RRU-2022 Organizing Committee and Technical Programme Committee, we would like to thank the members of Trombay Council, BARC; Reactor Group and Radiochemistry & Isotope Group. We wish to express our sincere gratitude to Dr. K. N. Vyas, Chairman, AEC & Secretary, DAE; Dr. A. K. Mohanty, Director, BARC; Dr. R. B. Grover, Chairman, BRNS for their support and encouragement. We are indebted to all Unit Heads of DAE; Group Directors and Head of Divisions of BARC; Dr. S. Adhikari, Head, SIRD, BARC and his colleague Dr. M. Singh; all Advisory, Organizing, Technical and Local Organizing Committee members for their continuous and whole-hearted support. We thank Shri H. G. Gujar, Chairman, LOC for his untiring efforts for making RRU-2022 a grand success. Thanks are due to all Distinguished Guests, Session Chairs etc. We thank Director, DCSEM; Security Officers (DAE/BARC/DCSEM), Manager, DAE Convention Centre; AO (III), BARC Guest House for their cooperation. Thanks are also due to all Office and Technical Staff of Chairman, AEC; Director, BARC; BRNS Secretariat; Chairman, BRNS; Reactor Group; Radiochemistry & Isotope Group and concerned Divisions of BARC towards successful organization of RRU-2022.

Looking forward for fruitful scientific discussion in the RRU-2022 Theme Meeting.

Dr. Tej Singh
Convener, RRU-2022

Dr. Raghunath Acharya
Co-convener RRU-2022

Shri Kunal Chakraborty
Chairman, Technical Programme Committee, RRU-2022

DAE-BRNS TWO-DAY THEME MEETING ON
Strategic Planning for Enhancing Research Reactor Utilization
(RRU-2022)

DAY-1 **Friday, May 06, 2022**	
8:00-9:30	Registration of Participants
9:30-10:15	Inaugural Function
	Chief Guest: **Director, BARC**
10:15-11:00	**Keynote Talk-1:** *Neutron Beam Research* **Dr. R. Chidambaram, Former Chairman, AEC, Former Secretary to the Govt. of India, DAE, Former Principal Scientific Adviser to the Govt. of India**
11:00-11:45	**High Tea**
11:45-13:00	**Technical Session I:**
11:45-12:10	**Invited Talk-1:** *Irradiation and experimental facilities at research reactors of BARC, Mumbai* **Shri Kunal Chakrabarty, BARC**
12:10-12:35	**Invited Talk-2:** *Reactor Physics Aspects of Research Reactor Irradiation Facilities at BARC* **Dr. Tej Singh, BARC**
12:35-13:00	**Invited Talk-3:** *Production and radiochemical processing of radioisotopes for use in healthcare utilizing research reactors at Trombay - Present scenario and future prospects* **Dr. S. Chakraborty, BARC**
13:00-13:45	**Lunch Break**
13:45-15:00	**Technical Session II:**
13:45-14:10	**Invited Talk-4:** *Clinical applications of indigenous ^{177}Lu: a decade of experience* **Dr. Sandip Basu, BARC**
14:10-14:35	**Invited Talk-5:** *Neutron Imaging for Aerospace Applications – past, present & future* **Dr. M. Nallaperumal, ISRO, Thiruvananthapuram**
14:35-15:00	**Invited Talk-6:** *Applications of Radioisotopes in Industry* **Dr. H. J. Pant, BARC**
15:00-16:30	**Poster Session-I** **Tea (Floating)**
16:30-18:30	**Technical Session III:**
16:30-16:55	**Invited Talk-7:** *Physics using Neutrons at Dhruva* **Dr. S. M. Yusuf, BARC**
16:55-17:20	**Invited Talk-8:** *Utilization of Neutron Scattering Facilities at BARC by Indian Universities and Institutes* **Dr. P. D. Babu, UGC-DAE CSR**
17:20-18:30	**Users' contributed presentation:**

DAE-BRNS TWO-DAY THEME MEETING ON
Strategic Planning for Enhancing Research Reactor Utilization
(RRU-2022)

DAY-2 **Saturday, May 07, 2022**	
9:15-11:15	**Technical Session IV:**
9:15-10:00	**Keynote Talk-2:** *Medical Applications of Radioisotopes* **Dr. Sudeep Gupta, ACTREC**
10:00-10:25	**Invited Talk-9:** *Basics of Neutron Imaging and its applications* **Dr. Y. S. Kashyap, BARC**
10:25-10:50	**Invited Talk-10:** *Functional Testing of Neutron detectors: Role of Research Reactors* **Dr. V. Balagi, BARC**
10:50-11:15	**Invited Talk-11:** *Chemical Characterization of Materials by NAA and PGNAA utilizing Research Reactors at BARC* **Dr. R. Acharya, BARC**
11:15-11:35	**Tea Break**
11:35-13:15	**Technical Session V:**
11:35-12:00	**Invited Talk-12:** *Utilization of Research Reactors for testing of Fusion Reactor Materials* **Dr. Shashank Chaturvedi, IPR**
12:00-12:25	**Invited Talk-13:** *Applications of Radioactive Particle Tracking Technique for Flow Visualization in Industrial Process System* **Dr. Rajesh Upadhyay, IIT (BHU)**
12:25-12:50	**Invited Talk-14:** *Enhancing the Efficiency of Chemical Processes: The Triad of Radiotracing, Radioactive Particle Tracking (RPT) And Computational Fluid Dynamics (CFD)* **Prof. Shantanu Roy, IIT Delhi**
12:50-13:15	**Invited Talk-15:** *Nuclear structure studies with thermal neutron induced reactions* **Dr. Bency John, BARC**
13:15-14:00	**Lunch Break**
14:00-16:00	**Technical Session VI:**
14:00-14:25	**Invited Talk-16:** *Ionizing Energy for Food Security, Safety and Promotion of International Trade of Agri-produce* **Dr. S Gautam, BARC**
14:25-15:50	**Users' contributed presentation:**
15:50-17:15	**Poster Session-II** **Tea (Floating)**
17:15-18:15	Panel Discussion
18:15-18:30	Valedictory session

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Key Note Talk

Medical Applications of Radioisotopes

Sudeep Gupta, MD, DM

Professor of Medical Oncology
Director, ACTREC
Tata Memorial Centre
(Email: sudeepgupta04@yahoo.com)

Diagnostic and therapeutic radioisotope based techniques have gained increasing importance in cancer related healthcare in recent years. While radio-iodine scans and treatment of thyroid cancer is well known, many other applications of radioisotopes are now in routine clinical use. Increasing sophistication of techniques of conjugating radioisotopes to targeting molecules has enabled the new age radiopharmaceutical drugs to enter the molecular age of precision medicine for imaging, treatment and sometimes for both. An excellent example of such molecular targeted imaging is PSMA-PET for prostate cancer.

Radioimmunotherapy (RIT) is a technique wherein a radioisotope and a monoclonal antibody are administered as a conjugate with an intention to achieve synergy for tumor kill. This modality emerged about two decades ago, and at present there are two such radioimmunoconjugates (RIC) which are commercially available for human use – Bexxar and Zavelin for the treatment of Non Hodgkin's Lymphoma (NHL). Many investigators have now tried to develop RICs for other indications including breast cancer. While RICs offer several advantages, a single or limited dose administration being the most appealing, the complexities associated with formulating the conjugate as well as the cost had hitherto precluded widespread use of this modality in India. In India, Bhabha Atomic Research Centre (BARC) has the skill and expertise to make these conjugates. Coupled with the advent of biosimilars of important monoclonal antibodies such as rituximab and trastuzumab, the time is now most appropriate for the development of indigenous RICs. Tata Memorial Centre in collaboration with BARC has undertaken this project. Biodistribution studies in xenograft models of NHL and breast cancer has been completed. 131I-Rituximab and 131I-Transtuzumab RICs were evaluated in two separate studies using Raji cell xenograft (CD20+) bearing nude mice and MDA-MB-361 cell (Her2+) xenograft bearing NOD-SCID mice, respectively. More recently, human study of Lu-trastuzumab has been started in TMC.

Other radiopharmaceutical including alpha emitters will also be discussed during the presentation.

Invited Talk

Irradiation and experimental facilities at research reactors of BARC, Mumbai

Vikas Jain*, Sanjit Pal, Prasit Mondal, Kunal Chakrabarty

Reactor Group, Bhabha Atomic Research Centre, Mumbai-400 085
(Email: vikasj@barc.gov.in)

Since the inception of Indian nuclear program, a number of research reactors and facilities were commissioned and utilized with emphasis on societal benefits. These research reactors have played vital role in developing India's nuclear energy program and establishing the safety basis for the related activities. Research reactors located at Trombay site i.e. Dhruva, Apsara-U and Critical Facility are presently serving the nation in a number of ways. Diverse design of these reactors expands the scope of utilizing research reactor at Trombay site in the field of beam tube research, radioisotope production, neutron activation analysis, material irradiation, neutronic detector testing and reactor physics studies. Dhruva is a high power (100 MW_{th}) research reactor fuelled with natural metallic Uranium and high thermal neutron flux (Max 2.0 X 10^{14} $n/cm^2/sec$). During the last 35 years, Dhruva remains a workhorse for isotope production, neutron beam studies, material irradiation experiments and Neutron Activation Analysis. Newly commissioned pool type Apsara-U ($2MW_{th}$) is now ready with its full capacity for its utilization. The new reactor offers additional features in terms of high epithermal flux, accessible lattice positions for in-core material irradiation, facility for shielding experiments, neutron detector testing and neutron activation analysis at thermal column. Zero power Critical Facility is being utilized for reactor physics studies of experimental fuel assemblies having different pitch and geometries. The facility is also being extensively utilized for neutron activation analysis and neutron detector testing. In all of these research reactors, safety managements are in place for ensuring safety during irradiation at these facilities. This paper describes about basic design feature of research reactors and their irradiation and experimental facilities and scope of their utilization.

References:

1. S.K. Agarwal et al., Dhruva: Main design features, operational experience and utilization, Nuclear Engineering and Design 236 (2006) 747
2. Kunal Chakrabarty & C.G. Karhadkar, "Research Reactors in BARC History, Development & Utilization" BARC Newsletter Jan-Feb 2021

Reactor physics aspects of Research Reactor (RR) Irradiation facilities in BARC

Tej Singh* and Shantanab Banerjee

Research Reactor Services Division, BARC, Mumbai, 400085
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Research Reactors around the world are being used for various important endeavours such as radioisotope generation, fundamental research, testing various nuclear & structural materials etc. Currently, in BARC, there are three functional research reactors: Dhruva, Critical Facility (CF) and Apsara-U. Continuous technical support from reactor physicists is essential for safe and efficient utilization of research reactors. Analysing all irradiation requests for feasibility and safety is a part of the responsibilities of operational reactor physicists. In typical research reactors (RR), various options are available for sample irradiation, namely the in-core irradiation facilities like tray rods and beam-tubes. In-core irradiation facilities are specialised positions available within the core wherein the samples can be inserted/removed while reactor is operating mode (online) or in shutdown mode (offline). It can be designed to suit both short and long duration of irradiation, depending upon the half-life of the radioisotope, intended application and the target specific activity. Beam-tubes, on the other hand are specialised positions providing neutron source for carrying out research work in the area of neutron radiography, neutron based scattering studies etc..

To properly estimate radioactivity generated during sample irradiation, it is important that available neutron flux as well as spectrum is known beforehand. Both stochastic and deterministic method-based codes have been employed to generate neutron flux and spectrum distribution at all the irradiation facilities. These estimations, as needed, are also verified using experimental means. Various safety assessment requests for irradiation, as well as their high frequency, make it necessary to use computer codes in order to simplify the task and to increase overall productivity. A software named "ORPAC-Operational Reactor Physics Analysis Code", which is an amalgamation of different computer codes on a single platform, has been developed in this regard. Recently, the software was upgraded to solve generalized Bateman equation for neutron transmutation reactions e.g. (n, γ), (n,p), (n,α), (n,2n) etc. Capability to account for radioactive decay such as isomeric decay, β-, β+, electron capture and alpha decay etc are also considered in the newly developed module. It has the capability to generate spectrum averaged cross section library using PREPRO-19 and ENDF/B-VIII library for Apsara-U and Dhruva irradiation position. In addition, spectrum-averaged cross-section libraries for PWR and PHWR as well as decay data library, photon data library and fission yield data library as used in point depletion code ORIGEN-2, have also been incorporated. The code also provides shielding and cooling requirements for irradiated sample. Other ORPAC modules are used in various scenarios: such as xenon estimation in equilibrium and non-equilibrium state of the reactor, generation of startup curve, output power fractions etc.Moreover, in some cases, to assess the safety implication of an irradiation assembly on reactor operation, it may be necessary to estimate and verify the reactivity worth of the shut-down/control devices. The measurement may be done by a number of experimental methods like reactor period measurement method, compensation method, inverse kinetics method, subcritical method etc. This paper discuss the operational ascepts of Research Reactors.

Production and radiochemical processing of radioisotopes for use in healthcare utilizing research reactors at Trombay – Present scenario and future prospects

Sudipta Chakraborty

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Production, radiochemical processing and utilization of radioisotopes for their use in societal and economic development has come a long way since its inception in India after the commissioning of Apsara reactor in 1956. Commissioning of Radiological Laboratories at Trombay in 1969 and availability of CIRUS reactor were major milestones in the production of radioisotopes at a routine commercial scale. Availability of 100 MW Dhruva research reactor from 1985 had resulted in a significant augmentation of radioisotope production capacity. Radioisotopes produced in research reactors find extensive applications in several fields that include human healthcare, industry, agriculture and research. Production of radioisotopes in research reactors to service different sectors of economic significance constitutes an important ongoing activity at Bhabha Atomic Research Centre (BARC). Radiochemicals Section of Radiopharmaceuticals Division, BARC shoulders the responsibility to ensure the steady availability of reactor produced radioisotopes in suitable radiochemical formulation as per their requirement in India.

Last couple of decades have witnessed phenomenal growth in the use of reactor produced radioisotopes in nuclear medicine both in diagnostic and therapeutic applications in India. Augmentation of production capability and introduction of new radioisotopes after extensive research and development mainly contributed to this accelerated growth of nuclear medicine. The science and technology of production, processing and purification of radioisotopes suitable for use in human healthcare is being continuously improvised and new applications are being demonstrated.

Currently, around 3000 Ci quantity of radioisotopes are produced using Dhruva research reactor at BARC exclusively for use in human healthcare. These radioisotopes, namely, ^{131}I, ^{99}Mo, ^{153}Sm, ^{166}Ho, ^{125}I and ^{177}Lu, are radiochemically processed to obtain radiochemical formulations suitable for their use in preparation of 'radiopharmaceuticals' for nuclear medicine applications. Radiochmical processing involves the use of various techniques such as dissolution, distillation, solvent extraction, column chromatography and so on depending on the specific requirement for a specific radioisotope.

One of the notable recent development toward the use of new reactor produced radioisotope in India is the production and clinical utilization of ^{90}Y produced in Dhruva by ^{89}Y(n,γ)^{90}Y route. Our group at Radiopharmaceuticals Division, BARC is the first in the world who have successfully demonstrated clinical utility of ^{90}Y produced by (n,γ) route for treatment of inflamed knee joint using [^{90}Y]Y-hydroxyapatite microparticles formulation. Further, based on their growing importance in nuclear medicine, production and subsequent radiochemical separation of new radioisotopes (NCA ^{161}Tb, ^{169}Er) or new radiochemical formulations (NCA ^{177}Lu) are being extensive investigated using Dhruva.

Introduction of 2 MW Apsara-U research reactor is another major milestone in production of new radioisotopes for nuclear medicine. Fast neutron flux available in Apsara-U have been successfully utilized in the production of NCA ^{64}Cu by ^{64}Zn(n,p)^{64}Cu route. Our group has developed and demonstrated a robust method of radiochemical separation of no-carrier-added ^{64}Cu from the bulk of

irradiated ZnO target. Required regulatory approval have been obtained for use of [^{64}Cu]$CuCl_2$ formulation thus produced for imaging different types of cancer such as, glioblastoma, prostate carcinoma and colorectal cancer by positron emission tomography. It is worthy to mention that, we are the first in the world to demonstrate clinical use of reactor-produced ^{64}Cu. Apart from this, extensive research is in progress on production and radiochemical purification of some other potent radioisotopes such as, ^{47}Sc, ^{89}Sr and ^{117m}Sn for cancer management using the fast neutron flux of Apsara-U.

Acknowledgements: I gratefully acknowledge the sincere efforts and dedicated services of all my colleagues of Radiopharmaceuticals Division and Reactor Operation Division, BARC, and Board of Radiation and Isotope Technology associated production, processing and deployment of radioisotopes for societal use.

Clinical Applications of indigenous ^{177}Lutetium: a decade of experience

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Targeted radionuclide therapy and Nuclear Theranostics in India have been greatly boosted by the production of ^{177}Lu from enriched ^{176}Lu targets via the direct (n,γ) route in the medium-flux Dhruva reactor and its successful radiolabelling with various ligands, either directly or through bifunctional chelating agents, in the Radiopharmacy units of the country. Based upon this, 3 targeted therapies have been developed over the last decade that has been widely employed clinically for treatment of cancer patients: (a) ^{177}Lu-DOTA-TATE Peptide Receptor Radionuclide Therapy (PRRT) in metastatic/advanced neuroendocrine neoplasms (NENs) (b) ^{177}Lu-PSMA-617 peptide receptor radioligand therapy (PRLT) in metastatic castration resistant prostate cancer (mCRPC) and (c) ^{177}Lu-EDTMP for painful skeletal metastasis from different cancers. The physical characteristics (Max β=497 keV, t1/2=6.7 days, γ=208 keV and half-life of 6.7 days) and relatively easy radiolabeling (related to the chemistry of the radiolanthanide Lu^{3+}) of ^{177}Lutetium makes this a preferred and popular therapeutic radionuclide in the field of Nuclear Medicine.

The two major success stories in targeted radionuclide therapy in cancer over the past decade have been development of a variety of cell-surface receptor targeted peptide-based radiopharmaceuticals, ^{177}Lu-DOTA-TATE and ^{177}Lu-PSMA-617. Of these, [^{177}Lu] Lu-DOTATATE (DOTATATE = $DOTA^0$-(Tyr^3)-octreotate) for treatment of metastatic or advanced Neuroendocrine tumors, is directed towards somatostatin receptor subtype 2 ($SSTR_2$) in the NENs while ^{177}Lu-PSMA-617, a radiopharmaceutical based upon overexpression of prostate-specific membrane antigen (PSMA), a type II membrane glycoprotein, in prostate cancer cells. With years of successful use & promising results, both these treatments have made inroads into the main clinical treatment algorithms of metastatic neuroendocrine tumors and metastatic prostate cancer respectively and frequently being considered in the oncological parlance. We need to state here that India had been one of the frontrunners in these treatments, and the clinical PRRT & PRLT services in this country was a result of joint combined effort by the Radiation Medicine Centre (RMC), Bhabha Atomic Research Centre (BARC), and Gastrointestinal services of Tata Memorial Hospital (TMH) at the TMH-RMC premises, with strong support from the Reactor Group and Radiopharmaceutical division, Bhabha Atomic Research Centre and BRIT. The indigenous production and availability have enabled these very specialized therapies to be delivered at a very affordable cost in RMC (BARC) which could be viewed as a major societal contribution of the Department of Atomic Energy (DAE) to this country.

^{177}Lu-EDTMP has been developed as an attractive alternative to ^{153}Sm-EDTMP for systemic radionuclide therapy of bone pain palliation in view of the logistical advantage of relatively longer half-life of ^{177}Lu and possibility of rationing it for other radiopharmaceuticals prepared with other ligands such as DOTATATE and PSMA-617.

Basic dosimetry work is currently in progress in the area of radioimmunotherapy (RIT) after tagging monoclonal antibodies with ^{177}Lu. The two such successful examples include, (I) radiolabelled anti-

CD20 antibodies against lymphoma cells, where ^{177}Lu/^{131}I-Rituximab has been used for therapy of relapsed refractory lymphoma and (II) HER2/NEU receptor targeting on breast cancer cells by ^{177}Lu-trastuzumab for metastatic, advanced breast carcinoma.

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Neutron Imaging for Aerospace Applications – past, present & future

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Neutron imaging has been extensively used by Indian Space Research Organization (ISRO) for imaging and quality assurance of explosive laden pyrotechnic devices used in Indian space programme. NR of pyro components for launch vehicles application started during the initial days at APSARA reactor at BARC. The first NR facility in Indian Space Research Organization (ISRO) was developed at Satish Dhawan Space Centre, SHAR, Sriharikota using 15 MeV LINAC. Subsequently, neutron imaging activity was shifted to reactor-based neutron imaging at KAMINI reactor facility of IGCAR Kalpakkam, India. In recent years, due to increased production of pyros to meet the tight launch schedules of various types of launch vehicles / satellites as well as difficulty in transportation of explosive loaded pyro devices to IGCAR each time, there was a strong requirement to have an in-house neutron radiography facility. This led to setting up a neutron radiography facility using a Deuterium–Tritium-based neutron generator with the technical support of BARC, Mumbai.

The Neutron Radiography facility established at VSSC with the expertise of BARC Team has been used for clearance of pyro components for all important missions of ISRO since 2016. But the system uses D-T based Neutron generator bought from M/s. Sodern, France. As a part of "Make in India" policy, it is essential to have an indigeneous Neutron Generator of similar size and easiness of operation like the present Neutron Generator. In future, it will be difficult to depend upon a single source for meeting ISRO's NR requirements. It is essential to consider the above requirements and develop neutron generators which are very compact and of sufficient flux close to nuclear reactor source. D-D or D-T based compact Neutron Generators with flux as high as 10^{12} to 10^{14} n/cm^{2}s will be the need of the hour considering the increased number of launches in the coming years as ISRO is under a trasnformation stage with increased participation of private players in the Space sector. The neutron generator shall be user friendly and simple to operate without the support of a nuclear expert. Since the flux levels in such systems will always be less than nuclear reactor based NR facilities, suitable provisions of carry out NR of pyro components containing explosives also shall be planned in the future. Above mentioned facilities do not have sufficient penetartion to detect explosives in Pyro components in its assembled stage. In such typical scenarios, NR facilities at BARC/IGCAR only could offer support. IGCAR, Kalpakkam permits entry of ISRO flight components in KAMINI reactor for NR but do not have digital NR systems. BARC, Mumbai has expertise in digital NR which needs to be made available for pyro devices from ISRO that can support radiography as well as studies related to failure analysis during new development of pyros etc in future.

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Applications of Radioisotopes in Industry

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Radioisotope techniques are widely used in industry for troubleshooting, measurement of hydrodynamic parameters, process visualization and optimization of design of process equipment. The applications are broadly classified into two categories i.e. radiotracer and sealed source applications. In radiotracer applications, the radioactive material in a suitable physo-chemical form similar to that of the process material is instantaneously injected into the system at the inlet and its passage is monitored at the outlet or along the system at strategically selected locations using collimated radiation detectors. The monitored radiotracer concentration data is plotted as a function of time and interpreted to obtain information about process parameters, hydrodynamic behavior of the system and occurrence of malfunctions, if any. The commonly carried out applications of radiotracers in industry include leak detection in buried pipeline and industrial systems, residence time distribution in process vessels, flow rate measurements, mixing time measurements, sediment transport investigations in ports, effluent dispersion studies in water bodies, wear rate measurements, radioactive particle tracking technique for flow visualization and flow tracing in oil fields.

In second category of applications, a radiation source is encapsulated in a metal capsule that never directly comes in contact with either process material or equipment. The penetrating radiations from the source capsule are directed at the desired location in the equipment under investigation or material of interest and the intensity of transmitted or scattered radiation intensity is measured, and analysed to obtain information about content of the system or physical properties of the material. The commonly carried out applications of sealed sources include radiography, radiometry or gamma scanning, tomography, nucleonic gauges and radiation processing applications.

Since early sixties, Bhabha Atomic Research Centre (BARC), Mumbai has made pioneering contribution in the development and promotion of radioisotope technology in India. Today, India has fairly advanced infrastructure/facilities and good expertise in application of radioisotope technology in industry. Isotope and Radiation Application Division (IRAD), BARC alone has carried out large number of radioisotope applications to benefit the Indian industry during last five decades. The level of application, though growing, is still not commensurate with the level of technology development for a country of India's size and economy. Considering the size of the Indian industry, there is good scope for wider applications of radioisotope technology to minimize the shutdown times of industrial plants and improve industrial productivity and product quality thus leading to increased revenues for the industry.

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Physics using Neutrons at Dhruva

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Neutron was discovered by Chadwick in 1932. It is a charge less particle with magnetic moment. Neutrons are useful for technological developments as well as fundamental science. In this regard, the National Facility for Neutron Beam Research (NFNBR) at Dhruva reactor has contributed immensely in condensed matter physics research in the subject domain of advanced magnetic materials, structure and dynamics of functional materials, soft matters, quantum materials, thin films and multilayers, and nano structures. Neutron beams have also been used in the area of nuclear physics and imaging technology.

In my talk, I shall present a brief overview of current neutron beam research program at Trombay using the thermal research reactor Dhruva. I will then elaborate few specific examples of recent studies. My talk will also include some selective examples of collaborative research with national users.

Utilization of Neutron Scattering Facilities at BARC by Indian Universities and Institutes

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UGC-DAE Consortium for Scientific Research (UGC-DAE CSR), formerly known as Inter University Consortium for DAE Facilities came into existence following an MOU (and MOA) between University Grants Commission (UGC) of MHRD, GOI and Dept. of Atomic Energy (DAE) with a mandate to promote and coordinate the use of major DAE facilities by university research community. The Mumbai Centre of UGC-DAE CSR coordinates the use Neutron Scattering Facilities available at various Reactors inside BARC under aegis of Nation Facility for Neutron Beam Research (NFNBR). Mumbai Centre has been promoting use of neutron scattering among university research community for last three decades by organizing neutron schools/workshop different parts of the country and imparting hands on training in neutron scattering instruments with the help BARC scientists. Over a period of time, more than 500 university users from all over country have been trained in the use of neutron scattering. The consortium also supports university research community through long term (3 year) collaborative schemes (CRS) through which many university groups have utilized the neutron facilities over the years. Till date more than 300 collaborative research projects have been completed. At any given time, there are 30 to 40 ongoing CRS projects per year utilizing the neutron scattering facilities. In addition to long term usage, UGC-DAE CSR also supports university groups to perform one-time experiments where a single or series of samples are studied using neutrons. On an average about 30 to 40 publications arise out of these university collaborations per year and has also led to large number Ph.D. degrees being awarded using the Neutron Facilities.

Fig.1. Neutron Powder Diffractometer (PD-III) developed by UGC-DAE CSR, Mumbai Centre. (above) Schemetic of beamline and (below) actual instrument

Powder neutron diffraction and small angle neutron scattering are the most popular techniques which attract bulk of the university community. Study of glasses/amorphous materials, single crystal diffraction, quasi-elastic and inelastic neutron scattering are other experimental probes used by the university community.

With large demand for powder diffraction, Mumbai Centre has designed, development and commission a Tandem Neutron beamline with focusing crystal based high resolution and high intensity neutron powder diffractometer as shown in Fig.1. Different wavelengths can be accessed with simple rotation of monochromator. This instrument is also equipped with unique sample environment facilities like low temperature and high magnetic fields. This talk will bring out the salient features of university collaborations in utilizing the neutron scattering facility with some statistics and some unique examples to show how neutrons were employed by university groups to resolving certain material property relations and develop the basic understanding.

Basics of Neutron Imaging and its Applications

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Neutrons are non-invasive probes with a wide range of benefits, including high penetration depth, isotopic sensitivity, magnetic interaction owing to intrinsic magnetic moments, and so on. They have been widely employed in identifying the microscopical characteristics of materials that are difficult to probe using other radiations such as X-rays because to their unique features. Because neutrons are more sensitive to lighter elements, they've been frequently employed to investigate hydrogen migration in Zr-alloys or hydrogen-based fuel cells, as well as water transport in plants. Similarity, the large interaction cross-section of neutrons with Lithium makes them a useful tool for investigating the kinematics of Lithium-based battery charging and discharging cycles.

Furthermore, because of the wave-particle duality, we may regard neutrons as both waves and particles, allowing us to simulate the neutron-matter interaction using complex refractive index. The real part of the complex refractive index contributes in the phase shift as the neutron pass through the materials. Therefore, in order to improve the sensitivity of tradition neutron imaging techniques different forms of neutron phase contrast imaging techniques have been developed in the recent years, allowing researchers to examine diverse properties of materials under examination. These include visualization of distribution of magnetic field in the superconductors, measurement of atomic stresses under externally imposed force, phase contrast tomography for materials with similar absorption characteristics, and so on.

In 2016, a new Neutron Radiography and Tomography Facility was commissioned at Dhruva. Dhruva is also India's main neutron beam research center, with digital neutron radiography and tomography capabilities. At the Beam-hole HS-3018, a dedicated neutron imaging beam line has been built up for real-time neutron imaging and neutron tomography.

The digital imaging detector system used for experiments consists of a scintillator (LiF/ZnS(Ag)), a front coated mirror and a high resolution CCD camera kept inside a light tight box. A 170µm spatial resolution has been achieved with the 100µm scintillator and the optics used in the camera. The sample manipulator is kept in front of the imaging system for mounting the samples. The material is directly imaged for Neutron radiography using CCD based digital detector or off-line neutron sensitive Films. Tomography involves rotating samples in stages of 180/360^{o} and recording the radiography projection image data to rebuild the distribution of components in the sample.

This paper provides overview of the fundamentals of thermal neutron imaging, as well as recent advancements and its various applications.

Functional Testing of Neutron detectors: - Role of Research Reactors

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Nuclear Power provides a viable and cleaner alternative to fossil-fuel based power plants by harnessing clean energy generated through nuclear fission and helping in decarbonisation of the environment. A nuclear reactor is at the heart of a Nuclear Power Plant, which is engineered to carry out a controlled nuclear chain reaction for generating heat to be converted to electrical power. Nuclear reactor instrumentation (NIS) is a sine qua non for any nuclear reactor and its importance cannot be over emphasized. By reactor instrumentation is chiefly meant the systems deployed in any nuclear reactor for the control and safety of the core during all the stages of operation and otherwise. Apart from the electronics, the neutron detector, which detects the neutrons is an integral part of any NIS.

The detectors and the electronics needs to be tested for performance and adequacy for the intended purpose. The tests include functional tests at operating environment conditions. Among the functional tests are the neutron sensitivity, linearity of response and the range of operation. These tests are carried out in the various research reactors as the reactors provide the necessary conditions for the functional tests.

Among the reactors that were/are used for these kinds of tests are Apsara, CF, KAMINI, FBTR and Apsara-U. Where necessary suitable modifications have been carried out the meet the environmental requirements also. The projects for which these reactors have provided the necessary tests bed include, P4, PRP, LWRs, PHWRs, PFBR etc.

The present paper covers the some of the detectors and the testing methodology adopted for these in establishing the suitability of the detectors for various projects.

Chemical Characterization of Materials by NAA and PGNAA utilizing Research Reactors at BARC

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Chemical characterization of materials is the most important step under chemical quality control (CQC) exercise and it involves quantification of major, minor and trace elements present in the sample. Presently, atomic and mass spectroscopic techniques are widely used for this purpose. Radioanalytical techniques in general and Nuclear Analytical Techniques (NATs) in particular like Neutron Activation Analysis (NAA) and Ion Beam Analysis (IBA) have added advantages in analyzing direct solid samples without chemical dissolution for obtaining simultaneous multi-elemental determination from major to trace elements. NAA is a powerful isotope specific nuclear analytical technique for simultaneous determination of elemental concentrations of major, minor and trace elements in diverse matrices. The technique has many advantageous properties including inherent accuracy and precision and it is capable of yielding high analytical sensitivity and low detection limits (ppm to ppb) due to availability of high thermal neutron flux from research reactors. Due to higher penetration power of neutrons and gamma rays, NAA experiences negligible matrix effects in the samples of different origins. Depending on the sample matrix and element of interest NAA technique is used non-destructively, known as instrumental neutron activation analysis (INAA), or through chemical dissolution methods. This technique in combination with on-line NAA (PGNAA) is capable of analyzing about 2/3rd of the elements (~ 70 elements) in the periodic table. The NAA and PGNAA have been applied almost all fields of Science and Technology. It has been applied for multielement analysis in the fields like environment, biology, geology, archaeology, material sciences, nuclear technology and forensic sciences as well as industrial samples like coal, cement and gemstones. Under our R&D programs of the department as well as collaborative work utilizing research reactors, NAA has been extesively applied for multielemental determination in samples like sediments, ores, manganese nodules, cereals, medicinal / edible leaves, wheat, milk, packaged foods, renal calculi, ancient pottery/bricks, precious stones, gunshot residues, viscera samples, automobile windshield glasses, alloys such as stainless steel, zircaloys, coal, coal ash, catalysts and dross. This is possible because of availability of high flux (about 10^{14} n/cm^2/s) research reactors like 100MW$_{th}$ Dhruva and 2MW$_{th}$ upgarded Apsara (Apsara-U) at BARC, Trombay. On the other hand, PGNAA is a truly non-destructive technique capable of determining elements like H, B and other neutron poisons (like Cd, Gd, Sm, Eu , Dy and Hf) as well as almost all elements at minor or trace concentration levels. A dedicated PGNAA facility will find vast applications to finished reactor materials, archaeology/museum smaples, forensic specimens/evidences as well as glass, ceramics and alloys that are difficult to destroy and samples can be returned after analysis is over as there will be not much gross activity since it is an online measurement method with low neutron flux from thermal neutron beam lines (10^5 to 10^8 n/cm^2/s).

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Utilisation of Research Reactors for testing of Fusion Reactor Materials

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Fusion reactors have a range of components/sub-systems that are exposed to 14 MeV neutrons. These include the superconducting/copper magnets, structural materials, plasma-facing components, breeding blankets, etc.

Superconducting magnets are a key element of fusion reactors. These magnets involve superconducting materials, insulation and support structure. Superconducting materials belong to two categories – low-temperature materials like NbTi and Nb_3Sn and high-temperature (HTS) materials like BSSCO. When these materials are subjected to 14 MeV neutron irradiation, it leads to changes in electrical and mechanical properties due to transmutation, e.g. critical current, critical temperature, electrical resistivity and microstructural properties. For example, beyond a certain neutron fluence threshold, Nb_3Sn ceases to be superconducting. For insulating materials like FRP Tapes, Epoxy Resin, Bisphenol, Cyanate Ester, Kapton Film and superinsulation, there are changes in Electrical Resistivity, Voltage Breakdown, Flexural Strength, Compressive Strength and Inter-laminar shear strength. In structural materials like SS316LN and SS304, there are changes in mechanical properties like creep strength, thermal properties, etc. Apart from these areas, there can be changes in properties of sensors and instrumentation cables used in these magnets. Fusion reactor blankets must necessarily breed tritium to ensure self-sufficiency. Different kinds of lithium ceramics serve as breeder material. Neutron irradiation affects the mechanical stability of the pebbles and also the tritium release properties.

Since an intense D-T neutron source relevant to fusion reactor conditions is not yet available, these properties need to be studied in fission research reactors.
A range of fusion-blanket materials has been developed at IPR and their physical & thermo-mechanical properties have been measured, such as yield strength, specific heat, thermal conductivity and grain-size distribution. The same properties now need to be measured after different levels of neutron irradiation. A preliminary irradiation study has been conducted in FBTR on IPR-supplied GFRP materials for cryogenic applications, with irradiation up to 10^{21} n/m^2 neutron fluence. The effect of irradiation on tensile, shear and electrical breakdown strength was studied in the irradiated material. IPR has recently set up an accelerator-based D-T neutron facility with a design yield of $5x10^{12}$ n/s. It is planned to use this for neutron activation studies, neutron diagnostics development and low-fluence irradiation studies such as performance degradation of electronics. A range of computational studies have been performed on fusion-relevant materials, using Molecular Dynamics simulations, for determination of DPA & helium production.

This talk will report on theoretical and experimental work done so far at IPR, including collaborative studies with other institutions. Possible areas of Research Reactor utilisation for fusion-relevant studies will also be identified.

Applications of Radioactive Particle Tracking Technique for Flow Visualization in Industrial Process System

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Multiphase flow reactors are the heart of many industries. However, even after decades of their use for many industrial processes, the design and scale-up of such reactors are still based on some heuristics rules. This is mainly due to the poor understanding of their complex flow physics, which is mainly due to the lack of suitable measurement technique. The radioactive particle tracking (RPT) technique is a state-of-the-art non-invasive velocity measurement technique which can measure the flow field for variety of multiphase flow system with same fidelity at all the scale. In RPT, motion of a single radioactive particle which is the marker of the phase of interest is tracked for long time. NaI (Tl) detectors are placed around the vessel of interest to record the photon counts emitted by the tracer particle. This count time series data recorded on each detectors are used to reconstruct the position-time series of the tracer particle. The reconstructed data is further post processed to calculate the complete flow filed of the phase of interest. The different flow quantities like instantaneous velocities, mean velocities, rms velocities, kinetic enrgy of turbulance and turbulent intensities are calculated. The current contribution discusses the details of RPT techniques and its implementation for investigation of different multiphase flow systems at different scale. The data for laboratory scale gas-solid bubbling fuidized bed and pilot plant scale gas-solid circulating fluidized bed are presented to establish the accuracy of RPT at two different scales.

Enhancing the Efficiency of Chemical Processes: The Triad of Radiotracing, Radioactive Particle Tracking (RPT) and Computational Fluid Dynamics (CFD)

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The design and scale-up of chemical reactors is a problem of continuing interest to chemical and process engineers. While many problems and challenges in the design and scale-up of multiphase reactors have been addressed, the emergence of novel (and typically difficult) feedstocks as well as the need to reduce the environmental footprint of process units continues to open and evolve new challenges in this field. Many of these challenges relate to the inherently complex and scale-dependent nature of these dispersed multiphase flows. Other transport effects in reactors, in turn, get determined by the nature of these flows.

Radiotracer techniques are widely used for measurement of hydrodynamic parameters, troubleshooting and process optimization in full-scale industrial reactors because of their many advantages such as high detection sensitivity, on-line detection and availability of a wide range of compatible radiotracers for various applications and utility in harsh industrial environments. Built on the legacy of classical reactor engineering and residence time distribution (RTD) theory, radiotracer imaging involves the injection of radioactive material in a suitable physico-chemical form similar to that of the process material. The passage of these radiotracers in their sojourn through the system of interest is monitored at strategically selected locations using radiation detectors. In spite of their wide use in the industry, radiotracer techniques have several limitations in their interpretation, not often widely discussed, and thus their use for scale-up and scale-down of multiphase flow reactors and validation Computational Fluid Dynamic (CFD) models is limited.

The other end of the spectrum of radiation-based imaging techniques is represented by single-particle radiotracing methods, such as Radioactive Particle Tracking (RPT), Positron Emission Particle Tracking (PEPT) and X-Ray Particle Velocimetry (XPTV). For instance, RPT, which has been widely discussed in the open literature, is based on the principle of following a single gamma-ray emitting tracer particle through its many realizations in the process vessel of interest, and then back-projecting the photon counts time series to yield a Lagrangian velocity time series. From the latter information, many flow quantities of interest are evaluated, including ensemble averaged profiles of velocity, turbulence and flow regime information, and dispersion coefficients. In that sense such techniques come close to other "optical" velocity measurement methods like PIV and LDA. Such single particle radiotracer data thus yields rich databases for benchmarking CFD models, but the issues related to both experimenting with such techniques at large scales and well as having grid-converged CFD models at large scales essentially limits such validation research to small-scale laboratory systems.

This presentation will dwell on the challenges in "bridging this gap" in radiotracer techniques between these scales.

As an illustrative application, the talk will focus on coal gasification as an application, where all these techniques have been applied. The talk will show how having a judicious application of these three apparently diverse expertise can help to aid chemical processing and reduce the environmental footprint of chemical reactors.

Nuclear structure studies with thermal neutron induced reactions

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The renaissance in low energy nuclear physics during the past couple of decades is credited largely due to the technological revolutions in terms of radioactive ion beam accelerators and high-resolution high-efficiency radiation detector systems. Along with the experimental developments, a qualitative change in theoretical modeling due to the progress in computer technologies and numerical algorithms is taking place, particularly in the areas of theoretical nuclear structure. Exploration in a selected section of thermal neutron induced reactions using a high resolution detector setup can be stimulating in this background as we found in experiments carried out using the DURGA facility (Dhruva Utilization for Research using Gamma Array) at DHRUVA reactor.

The primary aims of the DURGA facility are to conduct nuclear structure investigations in neutron rich fission fragments produced in thermal neutron induced fission of fissile isotopes, and thermal neutron capture reactions in medium to heavier mass nuclei. The facility has a near-4π array frame for installation of HPGe and ancillary detectors. If all the detector positions in this frame are occupied with the HPGe clover-detectors, there will be 32 such detectors and a highly detailed prompt gamma coincidence spectroscopy can be performed over a wide range of nuclei, allowing detection of γ transitions as weak as approximately 10^{-4} of the total reaction cross section. However, at present, the number of HPGe clover detectors in DURGA are limited to six, and in near future it will be enhanced to eight detectors. Even with these many detectors, data on spins and parities of the excited states were deduced with technique known as γ-ray angular correlation. To obtain data on the excited states' lifetimes, and hence on nuclear moments, it is required that the HPGe clover detectors are coupled to suitable ancillary devices. The $LaBr_3$(Ce) fast scintillator detectors serve this purpose and the DURGA setup is equipped with 11 such detectors.

First experiment with this facility has been conducted recently on neutron capture reaction ^{163}Dy(n_{th}, γ)^{164}Dy*. Two-phonon gamma-vibration in ^{164}Dy* nucleus had been predicted theoretically to occur with the presence of $K^{\pi}=0^{+}$ and $K^{\pi}=4^{+}$ bandheads at more than twice the energy of the single phonon $K^{\pi}=2^{+}$ band. This brings certain difficulty in experimental observation of the same, such as $K^{\pi}=0^{+}$and $K^{\pi}=4^{+}$ bandheads are close to the pairing gap, and hence under influence of an enhanced density of levels. As a result, the experimental vibration strength function may turn to be a fragmented one. Due to these difficulties, the two phonon gamma vibration states have remained rather elusive in nuclei. In the present experiment, hitherto unknown levels with decay properties matching that of elusive $K^{\pi}=4^{+}$ two-phonon gamma-vibrational band were detected [1] in ^{164}Dy*. The results have been communicated to a reputed physics journal. It may be noted that these interesting observations have significance for the search for 'door-way states' in this and in nuclei of similar structure. Locations of door-way states among nuclear levels are important for devising methods for production of certain nuclear isomers in high specific activity, using high intensity photon facilities for medical and other applications.

Further enhanced utilization of this facility, which is unique in the country for nuclear structure investigations using thermal neutron beams, will be discussed.

Acknowledgements: Author gratefully acknowledge the able support of colleagues from DHRUVA, Gas and Movement Section, EmAID, and NPD in accomplishing the measurements. Special thanks to Dr. S. Mukhopadhyay for help in preparing the manuscript.

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Ionizing Energy for Food Security, Safety and Promotion of International Trade of Agri-produce

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In India food losses range around 30% for grains and nearly 40% for fruits, vegetables and other perishables, which can be drastically reduced through the intervention of modern technologies such as ionizing energy. FAO, IAEA, WHO, and the Codex General Standard of Food approved Cobalt-60, Cesium-137, X-rays (energy <5 MeV) and Electrons (<10 MeV) for processing of food. At very low doses, the radiation treatment helps in inhibition of sprouting in potato and onion and delay in the ripening and senescence in certain fruits and vegetables. The alternate treatment such as use of chemical sprout inhibitors like maleic hydrazide (MH) and isopropyl-N (3-chlorophenyl) carbamate (CIPC) has been found to negatively affect health and environment. Grains including cereals and pulses are often infested with insect pests leading to huge post-harvest losses during storage. Current existing practices of using fumigants such as ethylene dibromide (EDB), methyl bromide (MB), and ethylene oxide (ETO) are deleterious to the health as well as environment. Therefore, use of such chemicals has been recommended to be phased out by the statutory bodies including WHO. Due to inadequate handling and processing conditions, spices often get contaminated with insect eggs and microbial pathogens. An average absorbed dose of 10 kGy brings microbial decontamination of spices while retaining the natural characteristics. The treatment at higher doses can be used for complete microbial decontamination of diets for immune compromised patients, military, astronauts as well as for calamity affected people. A nutritious and safe Ready to Eat product 'Stuffed Baked Food (SBF)' was supplied by DAE as a good will gesture for flood and land slide affected people of Himachal Pradesh in the year 2018. Radiation technology has also helped in overcoming quarantine barrier of trade enabling export of Indian mango to USA from 2007 after a gap of 18 years. Recently class-based approval of radiation processing of food has been endorsed by the Food Safety and Standard Authority of India (FSSAI) and subsequently Gazette notified by the Government of India in 2016. Currently 25 gamma irradiation plants are operational in the country treating food and allied products. Existing numbers of food irradiation plants are minuscule compared to the quantum of produce. Therefore, India is in absolute need of many more food irradiation plants coupled with pack houses, and cold chain storage to cater the huge domestic and export requirements.

Contributed Abstract

Utilization facilities in High Flux Research Reactor

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Research reactor is an important tool for supporting research and development in a wide range of scientific aspects such as neutron scattering, neutron activation analysis (NAA), material testing, education and training. The upcoming 40 MW High Flux Research Reactor (HFRR) at Visakhapatnam is an open tank pool type reactor fueled with uranium silicide dispersed in aluminium matrix and cooled by upward flow of demineralized light water. The reactor core is surrounded by heavy water reflector which provides a large irradiation volume around the core. The main objective of HFRR is to provide the extensive neutron beam tube research facility to the researchers in the basic sciences. There are six beam tubes in HFRR including a Cold Neutron Facility(CNS). Out of five, four are thermal neutron beam tubes equipped with H-Q diffractometer, single crystal diffractometer, magnetic material diffractometer and Inelastic neutron scattering spectrometer. These beam tubes are used to do structural studies on single crystals, disorder materials, glasses and liquid characterization as a function of temperature, electric field and pressure and for investigations of magnetic materials with potential industrial applications and photons studies and lattice dynamical studies of functional materials. Thermal guide tube in GT (Guide Tube) lab will host polarization analysis spectrometer, time of flight spectrometer, powder diffractometer, residual stress analysis diffractometer and neutron radiography facility. Cold neutron guide line in GT lab will have Small Angle Neutron Scattering (SANS) facility, triple axis spectrometer, quasi elastic neutron scattering spectrometer, neutron reflectometer, spin echo spectrometer, Ultra Small Angle Neutron Scattering (USANS) facility, prompt gamma NAA and detector testing setup. HFRR will also be used to produce Neutron Transmutation Doping (NTD) Silicon which will be used in power electronics applications. The reactor will also facilitate advance research in radio-isotopes, fuel and material testing, irradiation of samples for isotopic analysis and also production of Fission Molly. This paper describes various utilization facilities provided in HFRR.

Design of new neutron guides for DHRUVA reactor

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Neutron guides are essential at research reactor/spallation sources for transporting neutron beams with little loss in intensity to areas of smaller background, and to enable greater space between beam lines and instruments. The existing neutron guides at Dhruva research reactor are 30 years old and are almost at the end of their lifetime. The objective is to replace the old neutron guides (m=1, Ni coated guides) with a superior supermirror (m=2, Ni/Ti based) guides at Dhruva to facilitate more neutron flux at the sample positions, faster measurement times and also to allow more neutron instruments in GT lab. The design and development of these guides are being carried out indigenously at BARC. Comprehensive calculations and McStas Simulations to optimize the neutron guide performance have been carried out. The extent at which intensity is gained/lost along a guide depends strongly on the guide geometry, supermirror coating as well as the source properties (ie. energy, divergence and spatial extent). These parameters have been optimsed to arrive at the optimal guide design for GT Lab at Dhruva for a beam of 2.5 cm (horizontal) X 10 cm (vertical) cross section of neutron guides. Neutrons emerging from the end of the curved guide have an asymmetric spatial distribution, with higher number of neutrons at the outer wall of the guide especially at short wavelengths, and a non-uniform angular distribution. Both the geometry and the reflective coating of the walls of the curved guide dictate these distributions. The spatial–angular correlations induced by the curved guide has been corrected by the addition of appropriate length of straight guide sections in conjunction with the curved guide section. The homogeneous neutron intensity distribution across beam cross section was optimised by McStas simulation. The Figures (a) and (b) depict the planned lay out of the two new neutron guides, G1 and G2, and the simulated results from McStas of the expected neutron flux from the these neutron guides, respectively.

The guide G1 is 21 m long with 10 m being curved having a radius of curvature of 479 m, followed by straight section. It has a cut-off wavelength of 3Å and having the provision for 2 instruments. The guide G2 consists of 14 m of curved section with radius of curvature of 863 m, followed by 16 m of straight sections having provisions for 4 instrument and a cut-off wavelength of 2.2 Å. These guides are being constructed completely in-house at BARC.

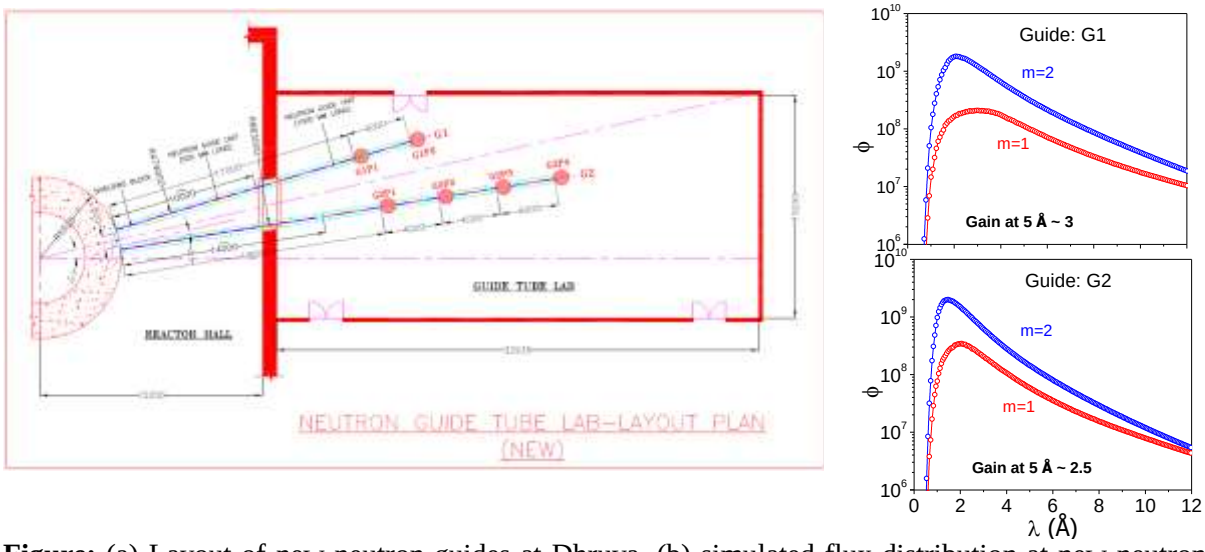

Figure: (a) Layout of new neutron guides at Dhruva, (b) simulated flux distribution at new neutron guides G1 and G2

Isotope Production and Handling in Dhruva

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Dhruva is a 100 MW(t) research reactor fuelled with natural metallic Uranium and has high thermal neutron flux (Max achivable 2.0 X 10^{14} n/cm^2/sec). Due to this feature, Dhruva produces a number of radioiotopes of high specific activity for use in applications for societal benifits. Post its criticality in 1985, Dhruva has been consistantly meeting most of the nations' demand for radioisotopes for use in healthcare, industry, agriculture and enviornmental studies. Out of a number of Isotopes produced in Dhruva, isotopes such as Mo^{99}, I^{131}, Sm^{153}, Lu 177, Ir 192, Co-60 are being produced in large volumes . Based on excess reactivity in core, target material can be loaded in to the core using special carrier rods (commonly called Tray Rod) for mass production of radioisotopes. As Irradiation time can vary from few days to few years, a number of special Tray rod assemblies/Slug rods are being used for loading them in Pile as per requirments. A dedicated hot cell inside Reactor Building and other handling equipmets ensure safety during loading of radioisotope in to shielding casks and its delivery to RPhD for Radiochemical processing.

Newly commissioned adjuster rod will also provide radioisotope such as cobalt-90. Trials are in advanced stage for production of Mo-99 of very high specific activity by fission route.

A well defined administartive procedure is being followed for irradiation of capsule containing target material to ensure safety of capsule and target material. Isotopes are loaded in to the reactor after an estimation of reactivity load, heating rate, activity developed and shielding requirement post irradiation.

The poster will give an Insight of administrative and Technical procedure for production of radioisotopes in Dhruva, Irradiation of target material, handling of In-Core Isotope carrier assemblies and handing and delivery of Radioisotope to RPhD.

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Pneumatic Carrier Facility of Dhruva Reactor and its utilization

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Dhruva is a 100 MW(t) research reactor fuelled with natural metallic uranium and cooled and moderated with heavy water. Alongwith other irradiation facilities available in Dhruva, Pneumatic Carrier Facility (PCF) is a widely used faciliy for carring out in-core irradiation of samples for neutron activation analysis. It is used for short-term irradiation of samples of the order of few seconds to few minutes. The facility is specially meant for irradiation of short-lived samples which require minimum transit time between the completion of irradiation and counting. It is a unique facility in the research reactor in which sample capsule is sent into reactor core and retrieved back to the experiment room located outside reactor building using pneumatic force. Its design features ensure safety of sample during irradiation as well as during anticipated operational conditions.
A wide variety of samples were irradiated in PCF for application in material sciences, environmental and life sciences, forensic science and archaeology.
The poster will describes the Pneumatic Carrier Facility of Dhruva Reactor, procedures for irradiation of samples, safety issues and an overview of its utilization.

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Utilization of Self Serve Facility in Research Reactor Dhruva

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Dhruva, 100 MW_{th} high flux vertical tank type research reactor joined research reactors fleet of BARC Trombay in the year 1985 and proved its versatility by rendering various experimental/irradiation facilities. One of the irradiation facility is Self Serve Facility which is designed to facilitate irradiation of small samples of material having intermediate half life ranging from few hours to a few days. Irradiation is aimed from radio-isotope production having inttermittant half life as well as for Neutron Activiation Analysis (NAA). The sample is being send in to Reflector region of the reactor for irradiation using a special setup. Self serve facility consists of two state of the art and well engineered Self serve units (i.e. SS-1, SS-2) which are located on either end of upper through tube which passes through Calandria. Presently SS-2 unit is in use and it provides three positions for irradiation. For irradiation, target sample is placed in aluminium sealed container which is in turn placed inside a spherical aluminium ball having lid. The spherical balls are rolled into required position by gravity though inlet channel made in to biological shield of the reactor. After predefined irradiation period, sample is rolled out from outlet channel after completion of irradiation by gravity. A wide variety of samples are being irradiated in Self serve facility for research application.This poster describes overview of Self serve utilization along with operational procedures , operational experiences and safety enhancements.

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Feasibility of Measurement of N-16 in Apsara-U Research Reactor

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Apsara-U is a swimming pool type Research Reactor having maximum capacity of 2 MW_{th}. This reactor is used for production of radioisotopes, material shielding experiments, neutron activation analysis and scattering experiments. As part of core management, many a times configuration of the reactor core is changed leading to a change in the overall neutron flux pattern. This necessitates for calibrating the nuclear channels in accordance to thermal power of the reactor.

Conventionally in a pool type research reactor, for measurement of thermal power, two methodologies are adopted. The first method is based on heat balance wherein the heat transferred to different components of the reactor is estimated using associated temperature changes with time. This method requires shutting down of secondary cooling water system and hence puts a limitation on the reactor power level and measurement time. The second method makes use of the formation of N-16 by the neutron activation of O-16 contained in the primary coolant. The N-16 content in the coolant is a direct measure of fission rate and thereby a direct measure of the total power generated. The decay of N-16 produces 6 MeV gamma rays which can easily be measured outside the coolant pipes. An N-16 power monitoring has several advantages over the ΔT and excore power measurements; one of them being faster time response.

In view of the above, an N-16 based reactor power monitoring system is being attempted in Apsara-U. Two Gamma Ion Chambers (GIC) (GIC-1 & GIC-2) with nominal sensitivity of $1.25x10^{-09}$ A/R/hr, have been mounted on the coolant outlet header at suitable locations. The HV module & electrometer and log amplifiers for the measurement of the signal current are located in accessible area. The outputs of detectors are measured with operating voltage of 600V DC applied to chambers at various power levels during reactor operation and shut down. The GIC outputs are connected to 6 decade log amplifiers and are interfaced to COIS for further analysis.The log-amplifiers outputs are measured & compared with outputs of online neutronic channels. A correlation will be established between the difference (to account for the background) of GIC outputs and reactor power, which are expected to be repeatable for various reactor operating conditions.

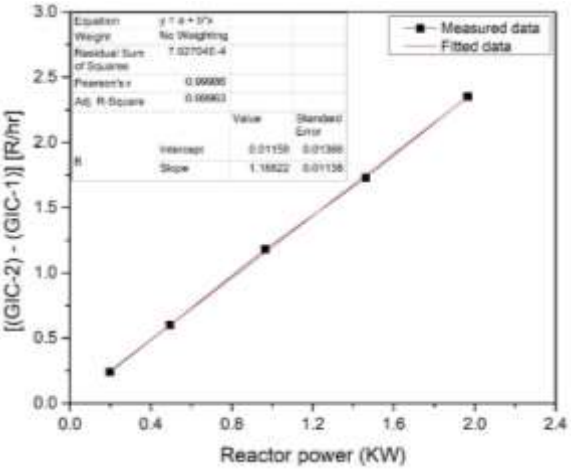

Fig. 1: Preliminary measurement results

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Research Reactor Utilization - Critical Facility

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Critical Facility (CF) is a low power reactor built as a part of the over-all technology development program to validate the physics design of the thorium based Advanced Heavy Water Reactor (AHWR).

Salient Design Features:
Nominal Power: 100 Watt.
Thermal Neutron Flux: ~ 108 n/cm2/sec.
Reactor Tank: 330 cm Φ, 500 cm Ht , vertical, Cylindrical, Aluminium.
Lattice pitch: Variable (minimum 215 mm)
Moderator: Heavy water
Shutdown system: 6 Cadmium shut-off rods & Moderator Dump

Facility Utilization:

- Facility is being utilized for validating the physics design parameters of AHWR Type Fuel.
- The reactor has facilities for testing neutron detectors and also to activate samples (Soil, Geological rock, Biological sample and Metallic alloys) for neutron activation analysis (NAA). On an average nearly 30 neutron detectors were tested and 150 samples were activated yearly.

Special Campaign Jobs:

(i) Following are a few important activities/experiments conducted in CF:
(ii) Worth measurement of Hafnium absorber section of SOR and CSR for new Apsara-U reactor before installation in the Apsara-U reactor.
(iii) Activation of DM water, dye and absorbent used in DP testing of welded joints for analysis of Chlorine and Br-82.
(iv) Measurement of fission products of Uranium Silicide, type of fuel used in Apsara-U reactor.
(v) Sensitivity checking of Modified Critical Accident Dosimeter badge.
(vi) Activation of medicine samples to see radiation damage on the medicine carried by astronauts during long term space missions.
(vii) Activation of articles (P4 Fuel Assembly & Fuel Pin) for testing and commissioning of the axial & integral gamma scanner and establish the procedural steps for bulk gamma scanning of the activated articles at P-4 facility

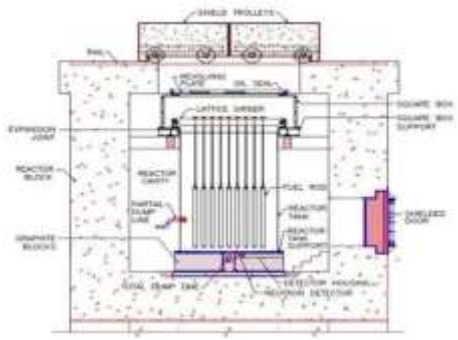

Fig. 1: Reactor block

Fig. 2(a): Core

Fig. 2(b): Core Map

Fast & thermal neutrons as novel mutagens for inducing mutations and improvement of crop plants

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Plant mutation breeding uses mutagenizing agents like radiation sources to create variability in crop species leading to development of novel improved traits, which may be further utilized for breeding desired varieties providing economic benefits to farmers. BARC is engaged in full spectrum mutation breeding research for India, involving utilizing different mutagen sources, developing varieties and using modern biotechnological tools for crop improvement. Conventionally gamma rays are the most commonly used mutagen for crop breeding. However, neutrons, having very high Linear Energy Transfer (LET) are another potent mutagen that can be explored for mutation induction in breeding experiments. High LET neutron based sources provide opportunity to create novel spectrum of mutations both qualitative and quantitatively, with minimal background mutation's in genome. Both energies i.e. thermal and fast neutrons, interact differently with biological material, consequently having potential to cause different types of mutation. However, neutron based irradiation for mutation breeding is limited only to few countries viz. China, Japan & Korea, where use of neutron sources, irradiation condition and reported literature are not standardized. Especially in case of thermal neutrons, there is no well documented report for its application in mutation breeding applications. To utilize neutron source for mutation breeding program in India, as a preliminary study we initiated, thermal neutron based irradiation of wheat and rice using thermal neutron imaging beam line facility of Dhruva reactor. Radio sensitivity studies were conducted at five different doses for wheat and rice variety HI-1605 & TCDM-1 respectively. HI-1605 had GR50 dose of 17.7 Gy while GR30 dose of 9.1 Gy, TCDM-1 had GR50 at 22.5 Gy and GR30 at 14.9 Gy. Wheat variety HI-1605 had LD50 dose of 17.4 Gy compared to 17.6 Gy of TCDM-1. In future the study will be extended to other varieties and extended to field based mutation breeding experiments leading to development of improved mutants. In collaboration with Physics and Reactor Group BARC, the study will be also being extended to utilize fast neutrons from Research Reactor(s) at BARC, for mutation breeding application in all important crops. In addition, neutron sources, will be exploited for other application in agriculture viz. neutron imaging for studying physiological process like root development, water utilization in plants as well as neutron activation analysis (NAA) for quantifying important elements like Fe, Zn, Mn, Se in crops. Overall, the study will provide platform for use of novel mutagens like neutron irradiations for plant mutagenesis for improvement of crop plants.

Centre of Excellence on Nuclear Energy for Food Security and Rural Development

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The vision of Prime Minister Narendra Modi is to transform India in to a modern, prosperous, strong and secure country, which he has termed as "New India". The latest and presumably the most favourite of PM Modi's mission is *to double the farmer's income by 2022*. Agriculture plays a crucial role in India's economic and human development, nearly 50% of India's workforce depends on agriculture for their livelihood. Agriculture income is not only based on food grains but there are various other components such as fruits, vegetables, pulses, poultry, milk etc. Enhancing the farmer's income will depend not only on increasing the yield per hectare of land but preventing crop loss due to pests / bacteria/ diseases and lengthening the ripening process through radiation treatment will provide more value for the same farm products. Varanasi and adjoining area is hub of vegetables and other perishable products. A Centre equipped with all modern state of the art technologies seems essential to be established in this region to reduce the post harvest losses which eventually accrue not only the pecuniary benefit to the farmers but also motivate them to work for more days to ensure the sufficient availability of food at reasonable price and thus it would avoid distress sale during glut. Keeping in mind the aforesaid vision of our Hon'ble Prime Minister, IIT (BHU) Varanasi has decided to set up **the "Centre of Excellence" on *Nuclear Energy for Food Security and Rural Development.*** The R & D organizations which may come forward to support the centre or may be affiliated are BARC, AERB, BRNS, ICAR, DAE, NIFTEM, DFRL etc. These organizations may support the centre in various ways. BARC is likely to help the centre by providing know-how in establishment of the Centre.

Scope of the centre:

1. Setting up a demonstration cobalt-60 gamma irradiation unit of 100-300 kCi.
2. Setting up ancillary units (solar dryer, cold storage, and packaging)
3. Encouraging farmers, traders and industry of adjoining areas to use the technology
4. Carrying out interdisciplinary R&D on the engineering, technological and economic aspects

Validation of ^{131}I yields from fission and irradiation of ^{130}Te

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^{131}I, a radioactive ($T_{1/2}$ ~8 days) isotope of element Iodine, is an important isotope due to its wide applications especially in the field of healthcare. It is used in medical therapies for diagnosis as well as treatment, especially of ailments related to thyroid. It is also used as an industrial tracer. ^{131}I is produced in nuclear reactors by neutron irradiation of ^{130}Te. ^{131}I also appears as a product in fission of heavy nuclides.

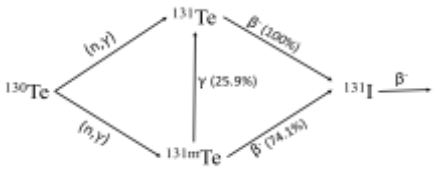

Fig. 1(a): Production of ^{131}I from ^{130}Te

Fig. 1(b): Production of ^{131}I from fission

In order to get the maximum specific activity of ^{131}I, it is required to have a suitably optimized irradiation scheme for the specific reactor system and an efficient extraction methodology to deduce maximum ^{131}I from irradiated samples. The optimization of activation and decay procedures requires an accurate estimation of the yield of ^{131}I as a function of time during the generation process and subsequent radioactive cooling. Unfortunately, the literature contains inconsistent and erroneous results of the ^{131}I yield as a function of neutron fluence, target mass, irradiation time and post-irradiation decay [1]. We have developed an analytical model to calculate the yield of ^{131}I produced either in fission or by irradiation of ^{130}Te as a function of irradiation time, cooling time, sample mass and neutron flux [2]. Our model is based on general and mathematically exact solution of governing rate equations and does not build upon the approximations on which conventional analytical methods are based. We have tested our model by comparing its results with those from other studies and found it satisfactory.

Estimation of activity calls for a careful and judicious selection of cross-section data as they are found to vary widely across different studies. To estimate the activity for Dhruva, we calculated the flux depression factor and microscopic cross-section using the neutronic code DRAGON [3] by simulating the actual target sample geometry and properties in Dhruva fuel matrix. Flux depression factor was also estimated by a diffusion theory-based model and was found close to that obtained from DRAGON. We have used our model with thus obtained cross-section and flux depression factor to estimate ^{131}I activity produced in Dhruva at different tray rod locations and found them in agreement with the measured values.

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Production of Radioisotopes in Indian Research Reactors

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Research Reactors are made for multifaceted application like radioisotopes production for medical, industrial and agricultural uses, neutron beam research, material characterization, imaging etc. In India, the programme of radioisotope production was started with the commissioning of Apsara in August, 1956. Commissioning of 40 MW CIRUS in 1960 brings the programme to the next level by commencing radioisotope production on industrial scale. Further, the quality and quantity of radioisotope production considerably improved with the operation of 100 MW research reactor Dhruva since 1985. Apsara and CIRUS being permanently shutdown in 2010 left Dhruva the only source of radioisotope production on large scale for some time. Total isotope production was further augmented by 2 MW Apsara-U, the revamped version of Apsara, which went critical in 2018. Currently, a 40 MW High Flux Research Reactor (HFRR) is being designed for BARC, Vizag site to maintain the pace of radioisotope programme in future days [1]. Irradiation facilities in the present/proposed research reactors and the radioisotopes produced/expected to be produced therein due to the irradiation of various target materials are described below. In Dhruva, there are 3 tray rod positions (2 on-power and 1 off-power) for long term irradiation (months to years), where important radioisotopes like ^{99}Mo, ^{131}I, ^{192}Ir, ^{32}P, ^{60}Co etc. are produced. Each of the tray rods is capable to accommodate upto 90 capsules. There is a self serve unit, which can accommodate upto 3 capsules for short term irradiation (hrs to days). At 100 MW reactor power, maximum thermal and fast neutron fluxes are about 2.2×10^{14} and 2.8×10^{12} n/cm^2/sec (for tray rods); 1.3×10^{13} and 5.0×10^{11} n/cm^2/sec (for self serve), respectively. At 100 MW operation, specific activities of ^{99}Mo, ^{131}I, ^{192}Ir, ^{32}P (from Sulphur) and ^{60}Co are 800 mCi/gm, 800 mCi/gm, 300 Ci/gm, 40 mCi/gm and 5-300 Ci/gm, respectively. In Apsara-U reactor, there are 8 tray rods (1 in-core and 7 in reflector) for radioisotope production. The in-core tray rod can accommodate only 5 capsules, while each tray rod in reflector can accommodate 15 capsules. At 2 MW reactor power, maximum thermal and fast neutron fluxes are about 6.1×10^{13} and 1.5×10^{13} n/cm^2/sec (for in-core tray rod); 4.4×10^{13} and 7.8×10^{12} n/cm^2/sec (for tray rods in reflector), respectively. Relatively higher ratio (than Dhruva) of fast to thermal neutron flux for in-core tray rod enhances fast neutron induced reaction like ^{32}S(n, p)^{32}P. In reflector region, 3 tray rods (near to the core) will be used to irradiate samples like MoO_3, Te, Ir, $LuCl_3$, Sm_2O_3, Red P, Y_2O_3 etc. and remaining 4 tray rods (periphery of the reflector) will mainly be used to produce short lived radioisotopes. At 2 MW operation, yields of ^{99}Mo, ^{131}I, ^{192}Ir, ^{177}Lu, ^{153}Sm, ^{32}P (from sulphur) and ^{90}Y are expected to be 150 mCi/gm, 180 mCi/gm, 200 Ci/gm, 2500 Ci/gm, 400 Ci/gm, 160 mCi/gm and 6 Ci/gm, respectively. In proposed HFRR, there is 1 in-core and about 30 out of core irradiation positions. The in-core irradiation position, at core centre, will be used for capsule based tray rod under a maximum thermal and fast neutron flux of about 1.0×10^{15} and 2.5×10^{14} n/cm^2/sec, respectively. Out of core irradiation positions are situated in the heavy water reflector tank around the core for bulk production of radio isotopes like ^{60}Co, ^{99}Mo, ^{131}I, ^{32}P, ^{135}I, ^{197}Hg, ^{192}Ir, ^{177}Lu, ^{153}Sm, fission molly etc. under a maximum thermal neutron flux ranging from 7.1×10^{13} to 5.0×10^{14} n/cm^2/sec [2].

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Clinical Grade ^{90}Y-acetate for Therapeutic Applications obtained from Ultra-Pure ^{90}Sr Recovered from HLLW of spent fuel from DHRUVA

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Research Reactors have been the backbone of India's Nuclear Power Program providing vital information regarding reactor design, fuel performance etc. They are also primary sources of neutrons, which find wide applications in the field of production of radioisotopes for medical as well as industrial use, neutron beam research and material characterization etc. At present BARC is having two operating research reactors such as Dhruva and Apsara-U. Dhruva is Uranium metal fuelled 100 MW_{th} research reactor employing D_2O as the coolant and moderator. The spent fuel generated from Dhruva is reprocessed in FRD, PP, which results in the separation of Pu for strategic applications. The high level liquid waste generated during the reprocessing of spent fuel from DHRUVA is a rich source of various useful radioisotopes like ^{137}Cs, ^{90}Sr, ^{106}Ru etc. These radioisotopes find various societal applications. Beta decay of ^{90}Sr leads to the formation of ^{90}Y, a pure β-emitter (E_{max} = 2.28 MeV, $T_{1/2}$ = 64.1h), which is a potential therapeutic radionuclide. Different potential radiopharmaceutical applications of ^{90}Y include treatment of hepatocellular carcinoma (HCC), leukemia, and lymphoma, as well as a range of tumors. However, the application prospect of ^{90}Y based radiopharmaceutical is strongly dependent on the separation of clinical grade, carrier-free ^{90}Y which depends on high purity ^{90}Sr separated from HLW.

Extensive efforts carried out by NRG resulted in the separation of high purity ^{90}Sr capable of producing clinical grade ^{90}Y product. For this purpose, product stream obtained from the 'Third Cycle' of 'Actinide Partitioning' process carried out at WIP, BARC was purified employing multi step separation techniques consisting of liquid-liquid extraction, solid-liquid extraction, carrier precipitation and supported liquid membrane technique to obtain ultra pure ^{90}Sr. Supported Liquid Membrane (SLM) technique based ^{90}Sr-^{90}Y generator system developed in-house has been utilized for milking carrier-free ^{90}Y from the separated ^{90}Sr product [Fig. 1]. The SLM technology is primarily based on the extraction and stripping behaviour of two organic extractants namely, 2-ethyl hexyl 2-ethylhexyl phosphonic acid (KSM-17) and octyl phenyl-N,N-diisobutyl carbamoyl methyl phosphine oxide (CMPO) towards Y and Sr. The optimized conditions were obtained after extensive studies in the laboratory scale. Both the rate of transport as well as purity of the obtained ^{90}Y product was optimized. The generator is consisting of two stages where KSM-17 is used as carrier in the first stage for the transport of ^{90}Y from pH 1-2 to 4 M HNO_3 medium. In the next stage, CMPO is used as the carrier for the transport of pure ^{90}Y from 4M HNO_3 into 1M CH_3COOH. The final product after two-stage separation is meeting the required product specifications as per European Pharmocopia (^{90}Sr content of < 10^{-6} Ci/ Ci of ^{90}Y and gross α-activity of < 10^{-9} Ci/Ci of ^{90}Y). Thus, the obtained carrier-free ^{90}Y-acetate is of clinical grade and is supplied regularly in lots of ~140 mCi are regularly (about 20 lots per year) to Radiation Medicine Centre (RMC), Parel for cancer therapy following BSC approved transport guidelines [2]. A typical molecular representative structure of ^{90}Y-Dotatate that is used for cancer treatment is shown in Fig. 2. The feedback received from RMC on the purity and effectiveness of the separated ^{90}Y was excellent. In view of this, the demands for supply of clinical grade ^{90}Y have been increasing and to meet the demand, developmental studies for scaling up are under progress.

Fig. 1: ^{90}Sr-^{90}Y generator

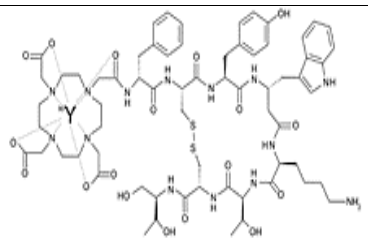

Fig.2.Molecular structure of ^{90}Y-DOTATATE

Acknowledgements
The Authors very humbly acknowledge dedicated workforce of Nuclear Recycle Group who are contributing to recovery of ^{90}Y for therapeutic applications.

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Development, Deployment and Performance Feedback of Ruthenium Brachytherapy (RuBy) Plaques for Treatment of Eye Cancer

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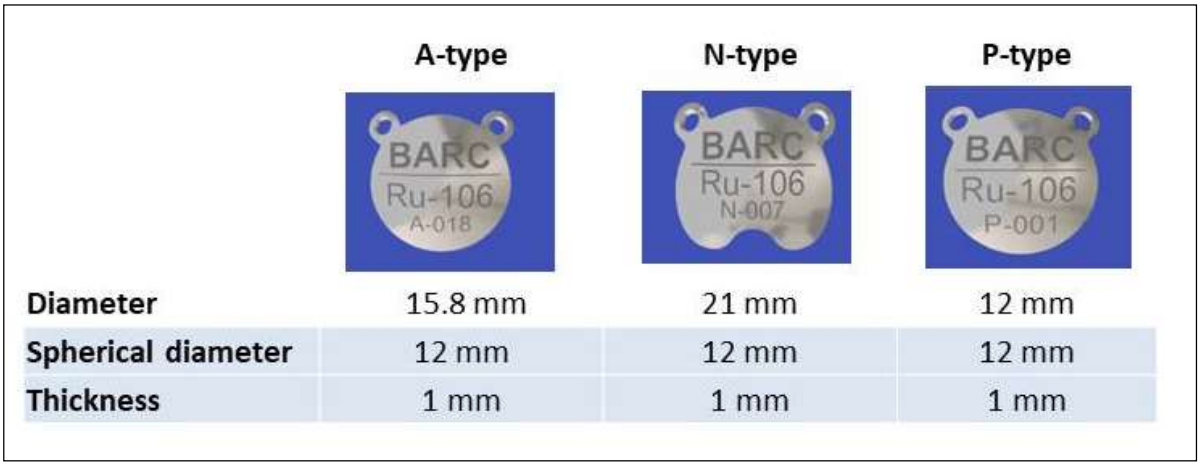
Bhabha Atomic Research Centre (BARC) has indigenously developed Ruthenium Brachytherapy (RuBy) Plaque utilizing fission produced Ruthenium-106 radioisotope. RuBy plaques of three different configurations (Figure 1) and plaque simulation software have been deployed to treat eye cancers. The design of these plaque configurations is based on the interactions with the leading ophthalmologists of the country. It is estimated that about 90% of the eye cancer patients of the country can be treated using these three configurations. The journey of plaque development was started with the deployment of A-type plaque in July 2019. The other two configurations are then added to the list. The P-type plaque is the tiniest (12 mm dia) designed for the treatment of retinoblastoma, which is more prevalent in eye cancer of paediatric patients. The N-type plaque is suitable for treating eye cancers located adjacent to the optic nerve.

The A and N-type plaques have already been used in treating more than a hundred patients in seven hospitals of India. The supply of P-type plaque has started recently. The performance feedback received from doctors is very encouraging both with regard to ease of use and post-treatment results. All post-treatment results are satisfactory, with no evidence of local tumour recurrence and well-maintained and complete vision. These plaques have gained the trust of doctors and patients of the country.

Indigenous development of RuBy Plaques and the Plaque Simulator are breakthroughs in the area of AtmaNirbhar healthcare and providing affordable treatment to eye cancer patients in India.



	A-type	N-type	P-type
Diameter	15.8 mm	21 mm	12 mm
Spherical diameter	12 mm	12 mm	12 mm
Thickness	1 mm	1 mm	1 mm

Fig. 1: BARC developed Ruthenium Brachytherapy (RuBy) Plaques for treatment of eye cancers

Enhancement of specific-activity of ^{192}Ir for use in Brachytherapy

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Dhruva, 100 MW research reactor, is been used for the production of ^{192}Ir. Natural Ir target is irradiated in the regular tray rod position, observed specific activity of which is about 300 -400 Ci/gm. High Dose Rate (HDR) source of ^{192}Ir can be used for brachytherapy, specific activity of which should be about 650 Ci/gm and total radioactivity greater than 15 Ci per target (weight of each target is about 22.5 mg). In order to increase the specific activity of ^{192}Ir produced, enriched Ir sample should be irradiated in the reactor. In this regard, ^{191}Ir enriched to about 80% was irradiated in Dhruva reactor at two tray rod locations. In the tray rod location K-9, tier 15 (PIR-4667) two disc shaped (0.6 mm dia and 3.5 mm height) enriched sample of mass of 22.25 mg each, was irradiated for about 1450 RMWD while at the tray rod location H-7, tier 21 (PIR-5104) three similar samples, was irradiated for about 4500 RMWD. It may be noted that since ^{191}Ir is having high capture cross-section, self-shielding effect becomes dominant and due to depression in neutron flux inside the sample it is difficult to obtain high specific activity of ^{192}Ir. Also, effect of depletion of target has to be taken into account for radioactivity estimation. For the estimation of radioactivity, the effective thermal neutron capture cross section of ^{191}Ir and effective thermal neutron flux in the target have been calculated using Monte Carlo computer code. The estimated thermal neutron flux depression factor is about 0.35 and the thermal neutron capture cross section is about 650 b. Actual irradiation history was used in the simulation and calculated using ORPAC-2 code which uses the cross-section library valid at the actual irradiation location. The radioactivity of ^{192}Ir in each disc comes to be about 7.3 Ci (PIR-4667, after 7 days of radioactive cooling) and 13.0 Ci (PIR-5104, after 10 days of radioactive cooling). The corresponding observed value of the same is about 7 Ci and 13.2 Ci respectively. Thus the theoretical and measured value matches satisfactorily. Simulation was carried out to extend the irradiation upto 10000 RMWD with the assumed reactor operation history of 11 days' reactor operation at 80 MW and 4 days' shutdown and so on for the PIR-4667. It was seen that after 10000 RMWD reactor operation activity per disc reaches to about 17-18 Ci with a specific activity of about 750 Ci/ gm of initial Ir (Fig. 2). It is also noted that the maximum radioactivity is reached at about 7000 RMWD irradiation (with the assumed irradiation history). The reduction in radioactivity after further irradiation is due to depletion of target (^{191}Ir).

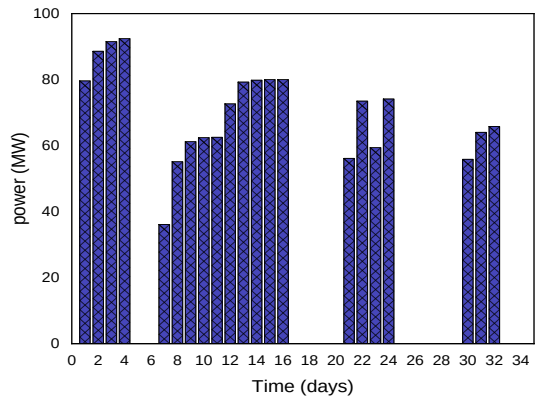

Fig. 1: Actual irradiation history

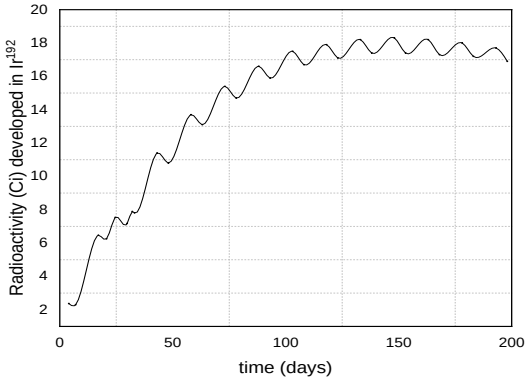

Fig. 2: radioactivity developed with time (with extrapolated operation history)

Enhancement of specific-activity of ^{60}Co for use in Teletherapy

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Dhruva, 100 MW research reactor is also used for ^{60}Co production. Quality and quantity of the radioisotopes produced depends upon duration of irradiation, available neutron flux level, geometry of the target, etc. In particular, low specific-activity (<100 Ci/gm) ^{60}Co is used in industrial application. Optimization study is aimed at obtaining a specific-activity of 300 Ci/gm in Dhruva reactor which is useful for teletherapy. It may be noted that sample can be accommodated in the reactor only after clearing the safety analysis: reactivity load and temperature is within limits. Cooling requirement in post irradiation handling is also required to be within acceptable limits.

Initial design irradiated at Dhruva was solid Co slug of dia 6mm (Fig. 1). The resulting maximum specific-activity for which is about 90 Ci/gm. The target sample is natural Co in pellet form. To increase the specific-activity, the geometry of Co sample was changed to annular form with pellet size reduced to 1 mm (Fig. 2). This leads to increased flux level seen in the target (lower depression of neutron flux in the target) and hence increase in specific-activity. The annular geometry will further increase the surface area and hence aid in cooling and hence in limiting temperature of target while the target remains in the core. Optimized target mass to be irradiated is about 40 gm in annular geometry for a period of 2-3 years to obtained specific-activity of about 250-300 Ci/gm (Fig. 3). This annular Co samples were arranged and formed Adjuster Rod (AR) for Dhruva reactor [1]. The AR installation served dual purpose of helping in reactor operation and production of radioisotope ^{60}Co. The total yield of Co^{60} is about 60 kCi/ 3 years with reactor operation at NP100%. Comparison of properties of Co-slug and Annular Co is given in Table-1.

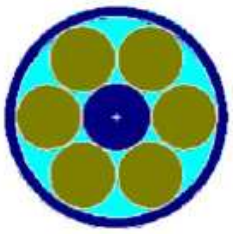

Fig. 1: 6 pellet design (6mm dia pellet)

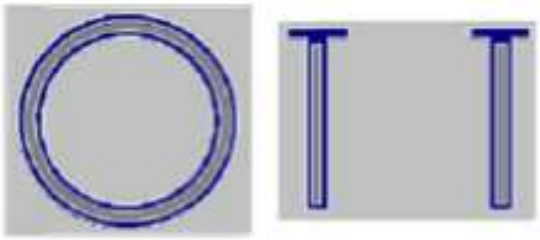

Fig. 2: annular arrangement of 1 mm dia pellet

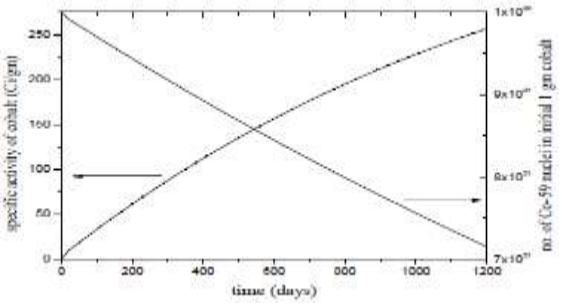

Fig. 3: buildup of specific activity in Co sample with time

Table 1. comparison of data

property	**6 mm**	**1 mm**
Mass/capsule	36 gm	40 gm
Depression factor	0.4	0.6
Max. power	NP90%	NP100%
Specific activity	90 Ci/gm	250 Ci/gm
Irradiation time	40 GWD	70 GWD

References: Paritosh Pandey et al., BARC Report, BARC/2016/I/007.

Quantification of Light Elements in Baby Food Samples Using PCF at Dhruva Research Reactor

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Food product like baby foods are subjected to fraud. Various food supplements for infants are available in the market. A sufficient amount of nutrition intake is very necessary to ensure proper growth, development, and health of the infant. Ca, Cu, Fe, Mn, Se, and Zn are considered to be essential micro-nutrients for infants. It is essential to evaluate elemental profile in the baby foods to confirm whether these are as per specifications or not. Not only that, various toxic elements may present in the samples as per reports in literature due to adulterations. In this regards, analytical techniques are very useful to evaluate the presence of toxic elements and harmful chemicals in baby food supplements [1]. Instrumental Neutron activation analysis (NAA) could be one of the efficient nuclear analytical technique for the analysis of baby foods as part of food forensic study [2]. Various branded baby foods were collected and eight baby food samples along with two INCT CRMs were analyzed using PCF at Dhruva research reactor for quantification of light elements as part of quality assurance work. Cl, Mn, Na, K were determined in various baby food samples using PCF facility at Dhruva reactor [**Fig. 1**]. It is observed that Cl, Na and K were present in the range of 0.41-1.63 % (mean 0.70 %), 0.12-0.29 % (mean 1.05 %) and 0.76-0.19 % (mean 0.18 %) for baby food samples respectively. Mn is found in the range of 5.4-20.2 mg/kg (mean 9.91 mg/kg). In one of the brand, Cl is found to be higher than permissible limit as per FSSAI and K is found to be higher than permissible limit as per FSSAI and the value specified by the brand.

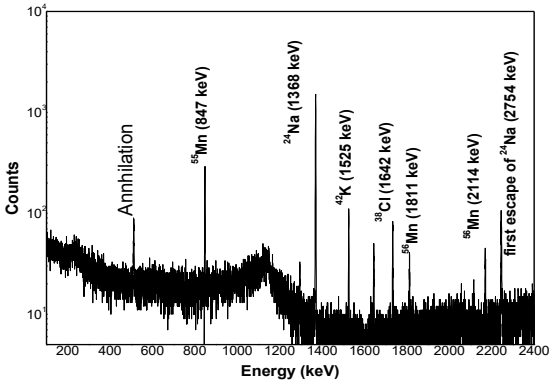

Fig 1: Gamma ray spectrum of neutron irradiated baby food sample in DHRUVA reactor

Acknowledgements: Sincere thanks to Operation Crews of Reactor Group, BARC. This work is a part of project UGC DAE CSR (Mumbai Centre) of AINST, Amity University. Ms. Gupta thanks UGC-DAE-CSR for the financial assistance as a project fellow during her tenure at Amity University. Mr. V. Sharma is thankful to Dr. P.K. Pujari, Director, RC&IG and Head, RCD and Dr. H.K. Bagla for encouraging him. He also wants express his gratitude to CSIR, New Delhi for providing senior research fellowship (SRF).

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Application of the Artificial Intelligence in Radioactive Particle Tracking (RPT) Technique

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RPT is a non-invasive technique widely used for the hydrodynamics study of various multiphase reactors. This technique is based on tracking the motion of a single radioactive particle (which mimics the phase of interest) as the Lagrangian marker of the point velocity [1]. RPT technique meets the challenge of reconstructing tracer particle positions in conventional reactors like bubble columns, fluidized beds, or newer applications once the volume of interrogation increases or there is a presence of internals. Due to these computational limitations, RPT is mostly only used for small-scale operative vessels without the presence of internals. These challenges mentioned can be overcome by Artificial Intelligence (AI). AI and RPT combined contributions in an application will be present here, taking two case studies. The first case shows, Algorithm used for the reconstruction of tracer particle position is the classical Monte Carlo (MC) Algorithm, which is significantly improved using AI [1]. It boosts computational speed and convergence using Genetic Algorithm (GA) optimization with real-time coding. In an earlier RPT experiment, "distance Count Map" is inherently needed, eliminating the need for the same [2]. The second case is proposed to a Machine learning (ML)-based reconstruction methodology. Three ML algorithms, namely Relevance Vector Regression (RVR), Support Vector Regression (SVR), and Artificial Neural Network (ANN), were used for RPT position reconstruction [2]. Results of this study show that the accuracy of SVR was near for all cases and that RVR was nearly as accurate as SVR for large training data sets [2]. RVR outperforms SVR by a wide margin due to the sparser RVR model regarding reconstruction speed.

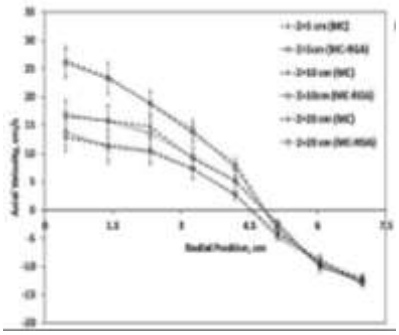

Fig. 1: Comparison of the typical axial liquid velocity plot using MC and MC-RGA method.

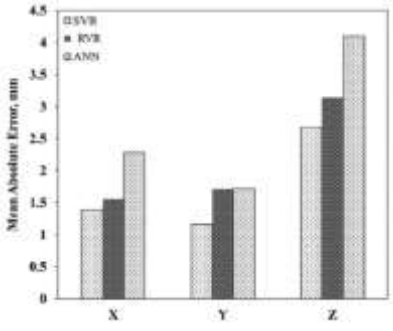

Fig. 2: Comparison of mean error (mm) in X, Y, and Z direction using machine learning algorithms.

Acknowledgments:
The author would like to acknowledge Prof. Shantanu Roy, Department of Chemical Engineering, IIT Delhi, for his support and guidance.

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Radiotracer investigation in cross flow reactor using bromine-82 and technetium-99m

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Hydroprocessing is the most promising secondary refining process for treatment of heavier feedstocks. A cross flow reactor (CFR) are most promising reactor to carry out these rection more efficienctly than conventional trickle bed reactors. However, it difficult to scale up these reactors due to complex hydrodynamics of the liquid phase in the CFR. The time spent by the process fluid in the reactor, thier holdup and degree of mixing are critical parameters for designing and operation of the CFR [1]. Therefore, a residence time distribution (RTD) measurement in a pilot-scale cross flow trickle bed reactor was carried out to investigate fluid flow dynamics using radiotracer. Various stpes involved in the implementation of the radiotracer techniques to measure the RTD of the liquid phase are selection of the radiotracer, estimation of the amount of the radiotracer, radiotracer injection, selection of the monitring locations, data analysis and flow modelling. One of the most important aspect of accurate meaurement is selection of the radiotracer and evaluation of the tracer to know wheather the tracer truely represents the tracing phase or not.

Table 1: Resuts of the radiotracer measurements carried out in the CFR

Sr. No.	Q_l (L/h)	Q_g (m^3/h)	P (bar)	τ (min)	$\bar{t}$ (min)		% of V_D		H_t	
					^{82}Br	^{99m}Tc	^{82}Br	^{99m}Tc	^{82}Br	^{99m}Tc
1	12000	1200	2	6.0	9.0	5.7	--	5.0	60	34.7
2	12000	600	2	6.0	8.0	5.9	--	11.7	53	37.3
3	6000	1200	2	12.0	13.8	9.3	--	22.5	46	31.0
4	6000	600	2	12.0	14.4	10.0	--	16.7	48	33.0

In this study two different radiotracers, such as, ^{82}Br [$t_{1/2}$: 36h, γ: 0.55 MeV(70%), 0.776MeV (85%)] as ammonium bromide and ^{99m}Tc [$t_{1/2}$: 6h, γ: 0.14 MeV(87.7%)] as sodium pertechnatate were used to trace the aqueous phase. Sufficient amount of the radiotracer was instananeous injected into the column and its movement was monitered at inlet and outlet of the bed using collimated NaI(Tl) detectors. The results of the study are given in Table 1. The mean residence time of the liquid phase measred by the Br-82 was found to much larger than the theoritical estimated parameters. It is due to presence of the long tail in the RTD curve incase of ^{82}Br as comapred to the ^{99m} Tc. The long tail was due to adsorption of Br-82 in the inner walls of the oputlet section. Hence ^{99m} Tc was found to be an ideal tracer in the present study.

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Application of bromine-82 for leak detection in a bridge-lock type heat exchanger system in a refinery

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A hydrotreater unit in a refinery was designed for conversion of fresh feed i.e. mixture of Coker gas oil (CGO), Total cycle oil (TCO) and Coker kerosene (CK) to diesel. The hydrotreater unit has two sub units, such as a reactor and a high-pressure heat exchanger (HX) system. The HX system consisting of seven bridge-lock type HXs connected in series, i.e. E-2A, E-2B, E-2C, E-3A, E-3B, E-8A and E-8B. These exchangers were suspected to be leaking as sulphur in the product was found on the higher than 20-50 ppm. Therefore, radiotracer investigation was carried out in the heat exchanger system with an objective to identify the leaking heat exchanger (s).

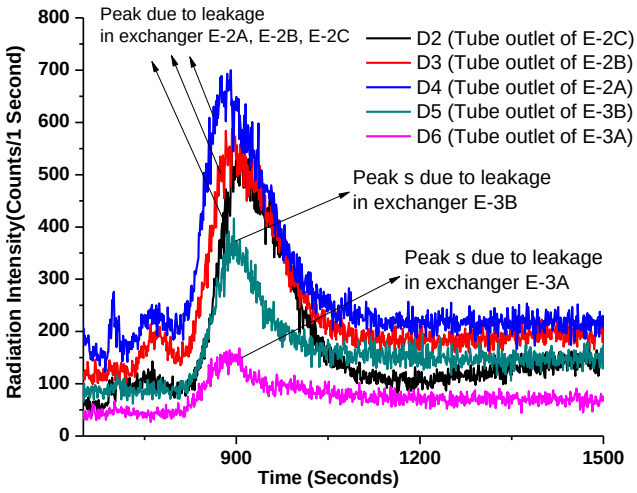

Fig. 1: Radiotracer concentration monitored at tube outlet of different exchangers

In this investigation, about 1.85 GBq of ^{82}Br [$t_{1/2}$: 35 h, γ: 0.55 MeV (70%), 0.77 MeV (85%), 1.32 MeV (24%)] as dibromobiphenyl was injected into the heat exchanger system and its movement was monitored at nine locations using collimated scintillation detector [1]. All the detectors were connected to two independent data acquisition systems (DAS) set to record tracer concentration data at a preset time interval of one second. The results of the radiotracer study indicated that out of seven heat exchangers, E-2A, E-2B, E-2C, E-3A and E-3B were found to be leaking [Fig 1]. The leak rates in individual heat exchangers were found to be ranging from 4-22 %.

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Residence time distribution measurement in pulse extraction column using radiotracer

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The pulsed extraction columns (PEC) are used for fuel reprocessing in nuclear industry. The PEC provides high turbulence which assist to breakdown of process fluid into droplets. Consequently, the large interfacial area is offered to achieve high separation efficiency of the meatl ions.The knowledge of the axial mixing in PEC is necessary for understanding the complex flow processes involved during extraction [1]. Several mathematical models have been developed to predict the separation efficiency of the PEC. However, theses correlations are specific to the geometry, design and operating conditions of PEC. Therefore, it is essential to estimate the axial dispersion, while PEC is operating in single phase and two phase flow. These measurements will help in understanding of complex flow of process fluids in fuel repossessing plants. Therefore, in the present work single phase axial mixing characteristics in an industrial scale PEC has been studied using radiotracer technique.

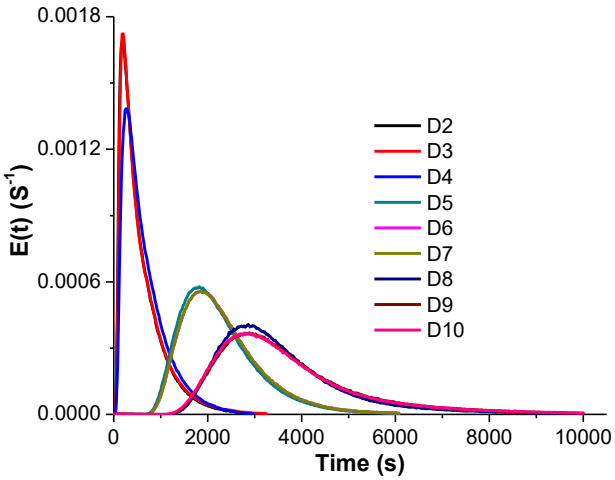

Fig. 1: Typical radiotracer curved monitored in the PEC

A series of radiotracer measurements were carried out at different operating conditions using Br-82 ($t_{1/2}$: 36 h, γ: 0.55 MeV, 0.77 MeV) as NH_4Br as radiotracer. About 37MBq activity was used in each run. The radiotracer was injected into the system and its movement in the column at three axial locations using nine NaI(Tl) detectors. The typical treated radiotracers curves obtained in the radiotracer studyis shown in Fig. 1. From the measured radiotracer curves mean residence time and degree of axial mixing in the different sections of PEC was also estimated.

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Multi Responsive, Self-healable and Injectable Ionic Liquid based Polymeric Hydrogel for the Treatment of Breast Cancer

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To ameliorate the limitations of traditional cancer therapies, scientists are working to produce safer, more effective and targeted drug carriers that increase its efficiency, reduce the drug's negative effects on healthy cells, and aid in the prevention of cancer recurrences. In this paper, we developed self-healable, injectable, temperature and pH-responsive ionic-liquid based polymeric hydrogel as the local drug delivery system that exhibited sustained release of the antitumor drug, 5-Fluorouracil (5-FU). Poly (vinyl alcohol) and worm like micelle of choline oleate are cross linked with each other due to borax that form the hydrogel. Mechanical properties of the hydrogel were improved through the addition of glycerol and dextrose. Morphology, mechanical strength of hydrogel and interaction within the molecules are characterized via different analytical techniques, including ATR-FTIR, small-angle neutron scattering (SANS), SEM and rheological measurement. The in vitro cytotoxicity (MCF-7) and in vitro drug release study indicated that hydrogel can be used as the targeted delivery of 5-FU at physiological condition and more effectivity killing the cancerous cells. Overall, the study shows the effectiveness of the hydrogel system by determining that whether hydrogel formulation supported or hampered total cellular 5-FU trafficking.

Acknowledgements:
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Cholesterol Mediated Stable Vesicles of Functionalized Ionic Liquid Based Surfactant: Formation and Appication As Nano Drug Delivery Vehicle for Anti-cancer Drugs Curcumin and 5-Fluorourecil

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Vesicular nanoaggregates that are thermodynamically stable have shown great interest in myriad of applications including but not limited to the preparation of nanomaterials and drug delivery. In the present investigation, we show the ability of the ester functionalized ionic liquid based surfactant (ILBS) to synergistically interact with the cholesterol, the natural sterol and form the vesicular nano-aggregates with outstanding stability with dilution, pH, salt solution and temperature. The molecular self-assembly formed were studied through state of the art analytical techniques including small angle neutron scattering and FRET upon varying the ILBS/cholesterol ratio. The thermodynamically stable vesicular nanoaggregates further checked for their antimicrobial activity against gram-positive and gram-negative bacteria. These biologically active aggregates were then used as the nano-vehicles for the encapsulation of the anticancer drugs, curcumin and 5-Fluro uracil. Sustained release study was carried out for the drug encapsulated vesicular nanoaggregates. The composition dependent molecular level investigations towards transition of the supramolecular organization of ILBS/cholesterol could overcome the limitations related to lipid vesicle systems.

Acknowledgements:
NM acknowledges the financial assistance of UGC-DAE for the Collaborative Research Scheme (UDCSR/MUM/AO/CRS-M-276/2017). The authors are thankful to Dr. Arvind Kumar (CSMCRI, Bhavnagar) for useful discussion. The authors are thankful to Dr. Sugam Kumar for useful discussion and SANS analysis.

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Evaluation of Mo-99 and Lu-177 Radioisotopes Production in 14 MeV Neutron Generator Facility

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A high yield and high energy neutron generator which is based on deuterium and tritium fusion reaction has been developed at Institute for plasma research India. This generator is based on the linear accelerator concept where the deuterium ion beam impinged to the tritium target to produce neutrons [1-3]. It is designed to produce the neutron yield of $2x10^{12}$ n/s. To extend the utilization of the neutron generator, assessment of the radioisotope production capabilities and set-up is done. The evaluation is conducted to generate the radioisotopes especially ^{99}Mo and ^{177}Lu which are having a vast application in the medical and pharmaceutical industries [4,5]. ^{99}Mo can be produced using neutron incident reactions ^{98}Mo(n, γ)^{99}Mo and ^{100}Mo(n, 2n)^{99}Mo. The cross-section of ^{98}Mo(n, γ)^{99}Mo is high in the thermal energy range whereas ^{100}Mo(n,2n)^{99}Mo occurs at a high energy range. ^{177}Lu can be produced using the reactions ^{176}Lu (n, γ)^{177}Lu and ^{176}Yb (n, γ)^{177}Yb. The cross-section for both ^{177}Lu production reaction is higher at thermal and intermediate energy range. The flux level near to the target is around 10^{10} n/cm^2/s. In order to enhance the production capabilities, the neutron energy spectrum optimizer is used. The materials chosen for the optimizer is made of flux attenuator and reflector such as beryllium, graphite, water, lead, etc. It enhances the capabilities of medical isotope production in neutron generator. This work is conducted to demonstrate the capability of neutron generator for medical isotope production.

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Microsensing of water dynamics in root architecture under abiotic stress and role of rhizobacteria

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There are many methods to study the water dynamic flux in plants. but major problems arise when it comes to uprooting the plant without causing damage to its root architecture. Hence to resolve these problems radiations are prefered mostly to study plant dynamics of water. In our lab (Gujarat University) our work is focused on abiotic stress tolerance in plants by plant growth promoting rhizobacteria (PGPR), investigations to date have been largely focused on PGPR-root/plant interactions and related plant responses to PGPR activities that induce drought, salinity and high temperature tolerance. Water flux through the soil-plant-atmosphere continuum is mediated by hydraulic conductivity of soil, plant roots, stems and leaves, which vary widely in their ability to facilitate water transport along with this water potential energy gradient. Earlier from our lab experiments has been carried out with NR imaging techniques and EPS extracted from PGPR *Klebsiella* SSN1, showing us a promising result for the relative water content of EPS compare to water and non-EPS producing bacteria**.** This was the first-ever experiment where we have presented application NR imaging with bacterial EPS in the sand. After accomplishing the best results in the sand, we want to apply the NR technique to study the relative water content of plants treated with PGPR strain. Based on the hypothesis, our outcomes will deal provide a new direction in biophysics. A mechanistic explanation for increased water retention and reduced evaporation rate from bacteria treated soil samples, which is mainly attributed to the production of extracellular polymeric substances (EPS) by PGPR, due to EPS' hygroscopic and chemical properties (viscosity and surface tension). This hypothesis can be documented with evidence suggesting the beneficial impacts of rhizobacteria. These findings shall have practical implications in "rhizosphere engineering" to improve/restore soil structure, support sustainable agricultural production, and mitigate climate change.

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Application of Gamma-Ray Densitometry Technique in Gas-Liquid Reactors

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The multiphase flow reactors are used in many industries like petroleum, petrochemicals, fine chemicals, water treatments, mining, power industries, etc. The design and scale-up of these reactors are still based on some heuristic rules rather than the science. This is mainly because of the poor understanding of the system due to the lack of suitable measurement technique. In this work, gamma-ray densitometry technique is used to decipher the phase fraction distribution of each phases inside the two different gas-liquid reactors, gas-liquid stirred tank and gas-liquid bubble column with vibrating internals. The gamma-ray densitometry is a non-invasive technique in which both gamma-ray source and scintillation detectors are mounted at a moving carriage at 180° apart. The carriage has facility to move in radial as well as axial direction to scan the complete section. Both detector and source are placed outside and medium attenuation coefficient are measured based on transmission principle. The Beer Lambert's law is used to measure the medium attenuation coefficient by scanning the empty column and column at in-situ condition. The information is further processed to measure the phase distribution inside the reactor by using Eq. 1 and 2.

$$I = I_o e^{-\mu L} \quad (1)$$

$$\mu = \mu_l \varepsilon_l + \mu_g \varepsilon_g \quad (2)$$

Here μ is the medium attenuation coefficient and μ_l, μ_g, ε_l, and ε_g are liquid and gas attenuation coefficient and phase fraction. In current work Cs-137 of 5 mCi activity is used as a source.

The gas distribution profiles are measured in a 19 cm ID gas-liquid stirred tank reactor for different impeller configuration, impeller speed and gas inlet velocities. The chordal average gas fraction is measured at two different axial locations for all the conditions. It is found that the gas fraction is high at the center of the column. However, with increase in impeller speed the distribution becomes more uniform. The situation remains same for all the impeller configuration investigated in the current study.

In the second case, the densitometry experiments are performed in a gas-liquid bubble column with vibrating internals. Springs are used as vibrating internals which breaks the large bubbles in to the small bubbles and enhances the gas fraction. The experiments are performed for different number of springs, different side and thickness of the springs for different gas inlet velocities. For all the conditions chordal average bubble fraction is measure at three different axial locations. It is found that bubble distribution is uniform in case of vibrating internals compared to without internal system. Hence, the contribution shows the importance of gamma-ray densitometry technique in investigation of multiphase flow systems.

Hydrodynamics Studies on Sidewall Nozzle Assisted Gas-Solids Fluidized Bed

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The gas solid interaction plays a very important role in the mixing and segregation processes. The hydrodynamics of the gas with solids in nozzle assisted gas-solid fluidized bed is still under investigation [1]. In the current work, the effect of secondary air injection through single/multiple sidewall nozzles on the solid distribution is investigated by measuring the chordal averaged solid hold-up via a non-invasive, gamma-ray densitometry measurement technique. The investigation is conducted in a laboratory-scale cold flow model setup of 210 mm diameter and 2250 mm height cylindrical column by studying: single nozzle injection with two different sizes (6 mm and 1 mm) at same/different planes, and multiple injections of 6 mm diameter nozzle at same/different planes. The result provides useful information on the effect of different configurations of nozzles for optimizing the design consideration of the reactor.

The solid flow field parameters, characterizing the hydrodynamics of the solid phase (glass beads or Geldart B type (density 2500 kg/m3 and mean size of 0.6 mm) are measured via a non-invasive, radioactive particle tracking (RPT) technique [2]. The investigation is carried out with same cold flow model by studying: single nozzle injection with two different sizes (6 mm and 1 mm) at same planes, and multiple injections of 6 mm diameter nozzle at same planes. All RPT experiments with multiple sidewall injections has been performed in a 6 mm diameter nozzle under fixed fluidization conditions. The radioactive particles, Cs-137 and Sc-46 are used in the gamma densitometry and radioactive particle tracking techniques respectively. The experimental results show that the symmetric arrangement of injection at the sidewall of the bed does not only reduce the axial mean velocity of the solid but also bring the system in a condition similar to the normal fluidization. The data obtained from this work will be important in optimization, designing and troubleshooting of sidewall nozzle assisted fluidized bed.

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Towards Improved Cancer Treatment Through Boron Neutron Capture Therapy

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Boron neutron capture therapy (BNCT) has emerged as a non-invasive therapeutic strategy for the treatment of invasive malignant tumors. It employs the reaction of ^{10}B species with thermal neutrons for the generation of alpha particles which destroy cells within the tumor, but not in the surrounding tissue. Various efforts have been made globally to develop ^{10}B containing drugs or formulations to improve the efficiency of this therapy. In our efforts to demonstrate multimodal theranostic applications, we have developed the zinc gallate based nano-formulation containing ^{10}B species as well as tagged with a tumor targeting, in-house synthesized pH-(low)-insertion peptide. It was characterized with TEM, ^{11}B NMR and FT-IR spectroscopy. It was studied for its persistent luminescence *in vitro* as well as *in vivo*. The persistent luminescent zinc gallate nanoparticles improved the therapy due to providing the facility for imaging by photon imager to detect the tumor location as well as evaluating the time required to accumulate a ^{10}B formulation in tumor and further monitoring the progress of treatment. Additionally, the nano-formulation was found to be non-toxic to non-cancerous cells as well as it exhibited fast internalization to cancer cells. The studies using photon-imager demonstrated that the formulation was accumulated in tumors developed in mice within 2 hours. Finally, the formulation was evaluated against the melanoma as well as fibrosarcoma induced in C57BL/6 and BALB/c mice respectively. The results revealed about 75-80% reduction of tumor volume during studies over 15 days. The overall results in therapy have indicated that the zinc gallate based ^{10}B containing nano-formulation is beneficial as a novel theranostic approach and it can be investigated further.

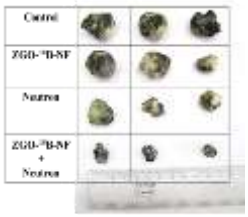

Fig. 1: Treatment of tumors by BNCT

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Production of intrinsically radiolabeled [^{90}Y]Y-glass microsphere "BhabhaSphere" for treatment of liver cancer in India

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Intrinsically [^{90}Y]Y-labeled glass microsphere is a widely used radiotherapeutic agent for Selective Internal Radiation Therapy (SIRT) of unresectable liver cancer. The radiolabeled microspheres lodge in the vasculature of malignant hepatic cells in the hepatic artery and the cytotoxic dose of ionizing radiation is deposited from ^{90}Y [$T_{½}$ = 64.1 h, E_β(max) = 2.28 MeV] on the cancer cells. [^{90}Y]Y-glass microsphere (Therasphere™) is a US FDA approved product for the treatment of liver cancer. The prohibitively high cost of commercially available ^{90}Y-labeled glass microspheres severely restricts its affordability in countries like India. We have successfully accomplished indigenous production of [^{90}Y]Y-labeled glass microsphere (BhabhaSphere) utilizing Dhruva reactor irradiation facility that is compatible for human use and for treatment of liver cancer at an affordable cost for patients in India.

Yttrium alumino silicate (YAS) glass of composition wt.% $40Y_2O_3$-$20Al_2O_3$-$40SiO_2$ prepared by melt-quench process is converted into glass microsphere (with >95 % of sphericity) by flame spherodization process. SEM confirmed uniform and spherical monodisperse glass microspheres having 20-35 µm particle size range. Intrinsically ^{90}Y-labeled glass microspheres were produced by thermal neutron irradiation of cold glass microspheres at a flux of 1.5×10^{14} n.cm^{-2}.s^{-1} for 7 days duration in Dhruva research reactor. [^{90}Y]Y-YAS produced was dispersed in 0.6 mL sterile saline solution and radioactivity content ascertained by measurements in a dose calibrator.

Intrinsically ^{90}Y-labeled glass microspheres yielded a specific activity of 200 ± 15 MBq/mg of glass microspheres at end of irradiation. Radionuclide purity of the product was 99.94 ± 0.02 %. The formulation exhibited excellent *in vitro* stability at room temperature in physiological saline and human serum. Leaching of ^{90}Y activity from the labeled microspheres was found to be insignificant (<0.2 %) even after 15 days. Biodistribution studies of the product developed carried out in normal Wistar rats by administering through portal vein showed that >97 % of the injected radioactivity was retained in liver of the animals for entire duration of study post-administration. Customized doses of the formulation were administered through right hepatic artery with superselective approach in human patients with hepatocellular carcinoma after autoclaving. Post-therapy image showed targeted localization of the formulation in the cancerous site of the liver without any leaching of activity to any other organ.

The indigenously prepared [^{90}Y]Y-YAS glass microsphere has properties comparable to the commercially available TheraSphere™ for HCC, is safe, effective and can be made available at affordable cost.

Acknowledgements: Authors express their sincere thanks to Dr. P. K. Pujari, Director, Radiochemistry and Isotope Group, Bhabha Atomic Research Centre for keen interest and valuable support to this program. The authors acknowledge Dr. S. V. Thakare RPhD, BARC for coordinating neutron irradiation of targets in Dhruva research reactor.

Growth in production and deployment of ^{177}Lu utilizing Dhruva reactor for nuclear medicine applications

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Carrier added Lutetium-177 [$T_{½}$ = 6.65 d, $E_{\beta max}$ 0.497 MeV, E_{γ} 0.113, 0.208 MeV], produced by direct neutron activation of isotopically enriched [^{176}Lu]Lu_2O_3 target is successfully used in therapeutic nuclear medicine, thanks to decay characteristics of ^{177}Lu, excellent feasibility of large-scale production and its facile chemistry. India is one of the pioneering countries where ^{177}Lu-therapy had started.

Presently, ^{177}Lu is produced by irradiation of Lu_2O_3 (enriched in ^{176}Lu, 74.5%) at the highest available thermal neutron flux position of Dhruva reactor for 21 days. Post irradiation, the target is dissolved in 0.02 M HCl (Suprapur®) by gentle heating to obtain a clear solution of [^{177}Lu]$LuCl_3$, which is used for formulation of radiopharmaceuticals. Impurity assessment and yield calculations of ^{177}Lu is done by gamma ray spectrometry using a HPGe-MCA system and measurements in dose calibrator. Present scale of production is about 925 GBq (25 Ci) per batch, the specific activity of ^{177}Lu achieved under optimized conditions is 740 ± 74 GBq/mg (20 ± 2 Ci/mg).

Last decade has seen a steady rise in the use of ^{177}Lu in nuclear medicine therapy across the country, which was possible thanks to the enhancement of regular production and processing of [^{177}Lu]$LuCl_3$ radiopharmaceutical precursor (Fig 1). Availability of Dhruva research reactor operating round the year, robust radiochemical processing facility were the key factors behind these achievements. From a modest beginning of 18.5 GBq (0.5 Ci) production of ^{177}Lu per batch in 2007, to upscaling it to 185 GBq (5 Ci) in 2012, a milestone of average production and deployment of 925 GBq (25 Ci) of [^{177}Lu]$LuCl_3$ per batch was accomplished in 2021. Annually, about 5000 patients are receiving treatment of ^{177}Lu-radiopharmaceuticals prepared using [^{177}Lu]$LuCl_3$ radiochemical precursor produced and supplied from Radiopharmaceuticals Division, BARC.

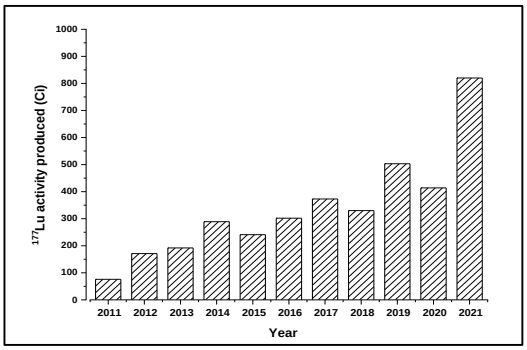

Fig. 1: Growth in production of ^{177}Lu for nuclear medicine applications in the last decade

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NF_3 based Plasma Etching Facility for Surface Modification/Cleaning

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NF3 based plasma generates more flourine species at lesser power than other flurinated gases. A typical 13.56 MHz radio-frequency (RF) glow discharge plasma drives highly mobile electrons to collide with neutral gas atoms and molecules, resulting in ionization and dissociation of a reactant gas.
This plasma etching process is used for modification of surfaces at microscopic level, removal of oxide layers and etching of semiconductors. Plasma etching can also be used in the decontamination of the depleted Uranium Oxides from the Stainless steel surfaces.
A Facility of NF_3 RF glow plasma discharge is developed at Institute for plasma Research. Primary objective of this facility to support semiconductor device appliaction. Moreover, it could be utilised for radioactive waste removal form the metallic surface such as Uranium Oxide cleaning from stainless steel surafces. In this plasma etching system, the substrate is placed in a vacuum chamber on the cathode of the plasma generator and gases are introduced to produce the reaction. NF_3 gas in plasma generates many Flurine atoms (free radicals), which are highly reactive and spontaneously react with substrate (Si or SiO_2) to produce volatile product (SiF_4) which will be pumped away by the vacuum pump. NF_3 is selected as reactive gas because bond dissociation energy of various dissociative reactions in NF_3 is much lower than other fluorinated gases like CF_4, SF_6 etc. The basic operating parameter of this facility are pressure (5 to 80 Pa) and RF power from 50-150 Watt.

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Application of radiotracer technique to analyze flow dynamics of gas-solids reactors

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Various experimental techniques are available to characterize the granular flow in a gas-solids system. The quality of information collected varies widely from technique to technique. The most commonly used methods are invasive (i.e. fibre optical, probe capacitance probe) in nature. This kind of probe changes the local flow structure of the granular bed at the point of measurement itself and hence suffers the accuracy. Non-invasive techniques do not involve direct contact with particles. The non-invasive techniques are further classified in mainly two categories, photographic techniques and radiation based techniques. The photographic techniques can be used only in transplant system with low discrete phase fraction. Therefore, radiation based techniques are preferred. In current work, radioactive particle tracking (RPT) technique is used to map the flow field inside the gas-solid reactors. In RPT, motion of a single radioactive particle is tracked by using the NaI (Tl) scintillation detectors which are placed outside the reactor. These detectors acquire the photon counts emitted by the tracer particle during its path. The same is used to reconstruct the position of the tracer particle by using suitable reconstruction algorithm. A detailed flow quantity like mean velocities, rms velocities, granular temperature, solid diffusion, turbulent intensities, etc. are calculated by post processing the obtained data.

In this work, RPT is implemented in a gas-solid binary fluidized bed (semi batch system) and gas-solid circulating fluidized bed (continuous system). For batch system experiment is carried out in a 3.5-inch Perspex cylindrical column. Flow dynamics of monodispersed bed is compared with the binary bed. A small amount (3, 5, and 8%) of fine glass beads (150μm) is mixed with 500 μm glass beads and fluidized at gas velocity of 1–1.8 U_{mf}. Mean and fluctuating velocity profiles are reported at different gas velocities and bed compositions. Similarly, the solids phase flow field of circulation fluidized bed is mapped by using RPT technique. Glass bead of the diameter of 500 μm is used as a solid phase and air is used as a gas phase. Experiments are performed in a laboratory scale riser of diameter 5 cm. RPT experiment is conducted at the fully developed section of the riser and investigated the effect of gas velocity and solids flux. The current work shows the details of the RPT implementation in a gas-solid system.

Food Irradiation as a model preservation technique for the food industry

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Food irradiation is a method of sterilizing and prolonging the shelf life of fresh foods by exposing them to a regulated amount of ionizing radiations such as gamma rays, X-rays, and accelerated electrons to enhance microbiological safety and stability. Irradiation disturbs those biological processes that cause food quality to deteriorate. The most common radioactive source of irradiation energy is ^{60}Co, which decays to non-radioactive nickel via γ-rays and emitting α particle emission. The γ- rays destroy fast developing cells (microorganisms), but they do not render food radioactive. It may be utilized to deal with food enclosed inside a packaging because to its high permeability and deep penetration. It is an effective non thermal process to reduce food borne pathogens and microorganisms to extend the shelf life. Irradiation of foods is very useful for sterilization of products that are prone to microbial attack, especially that are sold without pretreatment such as raw poultry, meat and sea food. Use of Irradiation for post-harvest disinfestation for various fruits and vegetables has shown a great promise since it sterilizes microbial organisms at low doses that are not enough to be detrimental to most fruits and vegetables. It also has the ability to decontaminate dried foods to prevent storage losses as well as fruits and vegetables to fulfil quarantine regulations for export commerce. Its application in natural fruit juice processing has a promising future, particularly in a fruit-rich region like Kashmir. As a physical method for extraction and preservation, gamma irradiation has proven to be more effective than other thermal preservation techniques, and it is known to retain the quality of fruit juices and its effects on various fruit juices in terms of the changes induced in phenols, anthocyanins, flavonoids, and antioxidants. It also includes how gamma irradiation affects microbial inactivation, colour changes, sensory qualities, and the shelf life of treated juices.

Use of Nuclear Reactor in Geochronological Applications: ^{40}Ar-^{39}Ar Dating

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The $^{40}Ar/^{39}Ar$ dating technique is an analytical conversion of the conventional K–Ar method and is based on the formulation of ^{39}Ar during irradiation of potassium-bearing samples. In this method, the sample to be dated is irradiated with fast neutrons in a nuclear reactor to convert a portion of ^{39}K atom to ^{39}Ar through nuclear reaction $^{39}K(n,p)^{39}Ar$, followed by measuring the abundances of argon isotopes on a Noble Gas Mass Spectrometer (NGMS). Hence, as due to the the direct result of neutron irradiation, ^{39}Ar serves as a proxy for potassium since it is produced from ^{39}K by fast neutron bombardment.

During the neutron irradiation of the sample, interfering nuclear reactions, for examples, $^{40}Ca(n,n\alpha)^{36}Ar$, $^{40}Ca(n,\alpha)^{37}Ar$, $^{42}Ca(n,\alpha)^{39}Ar$, $^{40}K(n,p)^{40}Ar$, etc, also occur that require corrections to be made to the observed data. The samples dated in the Geochronology Laboratory, KDMIPE, ONGC, are irradiated in the DHRUVA Reactor at Tray Rod positions K-09 or H-07, in order to receive maximum fast neutron flux with minimum interferences. Further, the effect of thermal neutrons leads to the production of significant amount of ^{40}Ar by the $^{40}K(n,p)^{40}Ar$ reaction through interaction with thermal neutrons, which would lead to significant amount of corrections and are unwarranted. To minimize this, a Cadmium shielding of ≥0.5 mm is utilized for the elimination of thermal neutron interference that can reduce the corrections which could be significant in younger samples. To determine $(^{40}Ar^*/^{39}Ar)_K$ ratio to be used in the age calculation, the $^{40}Ar/^{39}Ar$ ratio measured in the mass spectrometer needs to be corrected for atmospheric, calcium and potassium derived interfering isotopes.

The measured argon isotopes representing the cumulative effect of various interferences are:

$$^{36}Ar_m = {}^{36}Ar_{atm} + {}^{36}Ar_{Ca}$$
$$^{37}Ar_m = {}^{37}Ar_{Ca}$$
$$^{39}Ar_m = {}^{39}Ar_K + {}^{39}Ar_{Ca}$$
$$^{40}Ar_m = {}^{40}Ar_{atm} + {}^{40}Ar_K + {}^{40}Ar^*$$

Where: subscript 'm' stands for measured, 'Ca' for calcium derived, 'K' for potassium derived, 'atm' for trapped initial component and '*' for radiogenic argon component

For correction for atmospheric, Ca and K derived interfering isotopes, the correction factors $(^{36}Ar/^{37}Ar)_{Ca}$, $(^{39}Ar/^{37}Ar)_{Ca}$ and $(^{40}Ar/^{39}Ar)_K$ are used, which are determined by measuring the relative production rates of these isotopes in pure calcium and potassium salts i.e. CaF_2 and K_2SO_4 after neutron irradiation. The correction factors for 06 irradiation batches calculated in the Geochronology Laboratory, KDMIPE, ONGC are given in Table 1.

Table 1. Correction factors for K and Ca produced interfering isotopes:

$(^{40}Ar/^{39}Ar)_K \times 10^{-2}$ Salt: K_2SO_4	$(^{39}Ar/^{37}Ar)_{Ca} \times 10^{-3}$	$(^{36}Ar/^{37}Ar)_{Ca} \times 10^{-3}$	Irradiation Batch No.
	Salt: CaF_2		
9.07740	0.105262	4.344500	IRRN # 1
10.8968	1.385085	0.437918	IRRN # 2
2.54983	1.291745	0.310007	IRRN # 3
2.17031	1.412901	0.420692	IRRN # 4
2.17031	1.108567	0.566156	IRRN # 5
6.43173	1.193020	0.177959	IRRN # 6

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Quality Control of Radiopharmaceuticals for Metastatic Bone Pain Palliation: BRIT Experience

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Skeletal metastases remain a major cause of morbidity and mortality in 65–75% of patients with advanced prostate, breast and lung cancer and result in intolerable pain which also adds to the financial and social burden on the patients' families. ^{153}Sm-EDTMP and ^{177}Lu-EDTMP are excellent radiopharmaceuticals for bone pain palliation with minimum side effects (1) and are regularly supplied by BRIT to Nuclear Medicine Centres all over India. These products undergo stringent Quality Control (QC) testing prior to despatch and our experience over the past few years is documented herein.

Methods: QC tests are performed as per specifications approved by the Radiopharmaceuticals Committee and include testing several parameters *viz.* Appearance, pH, Radio Chemical Purity (RCP), Radio Active Concentration, Radio Nuclide Identity, Sterility Test and Bacterial Endotoxin Test. RCP is a very important parameter since it is the radiochemical form which determines the biodistribution of the radiopharmaceutical. RCP evaluation of all batches was done by Ion exchange column chromatography method (^{153}Sm-EDTMP) and Paper chromatography method (^{177}Lu-EDTMP).

Results:

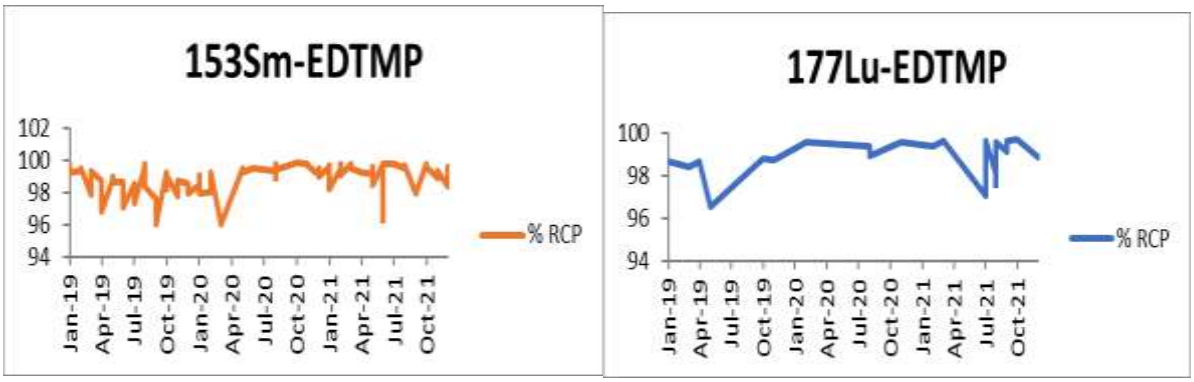

Fig. 1: % RCP values of ^{153}Sm-EDTMP and ^{177}Lu-EDTMP

All batches passed all QC tests and as seen in Fig. 1, RCP values were well within the limit specified (≥ 95%). The dependable availability of the β− emitting ^{153}Sm and ^{177}Lu isotopes from Dhruva reactor (BARC) enabled timely production and despatch of these high-grade radiopharmaceuticals from BRIT. This has resulted in significantly effecting an overall improvement in quality of life of terminally ill cancer patients in India.

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Fission molly production in Dhruva reactor

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Dhruva is a 100 MWth, tank type thermal research reactor at Trombay, has been significantly contributing towards production of radioisotopes. Technetium-99m, the daughter product of molybdenum-99 (^{99}Mo), is one of the most commonly utilized medical radioisotope. ^{99m}Tc (half-life=6 hrs) is very much suited for medical diagnostic applications because of its soft gamma (140-keV). ^{99}Mo can be produced either by irradiating ^{98}Mo through (n,γ) reaction in the reactor or by fission route. However, the specific activity of ^{99}Mo is very low in case of direct irradiation route because of low neutron capture cross section of ^{98}Mo and only 24% natural abundance. In fission route, very high specific activity of ^{99}Mo can be produced. For the production of high specific ^{99}Mo activity, a tray rod with two fission targets assemblies each with 6 LEU plates and 19.75 % enrichment of ^{235}U has been designed for irradiation in Dhruva. This paper presents, the physics and safety analysis for the fission molly target carried out for Dhruva reactor. Estimations for heating in two fission moly targets in Dhruva Tray Rod[Fig.1] were carried using Monte Carlo code. For reactor power of 100 MW, heating due to fission at in-core irradiation position are estimated to be ~ 48 KW in upper target and ~ 39 KW in lower target at F-11 position. After 5 days' irradiation and 8 days cooling ^{99}Mo activity is estimated to be ~ 360 Ci for reactor operation at 100 MW in two targets. The analysis was carried out using ORPAC-2.

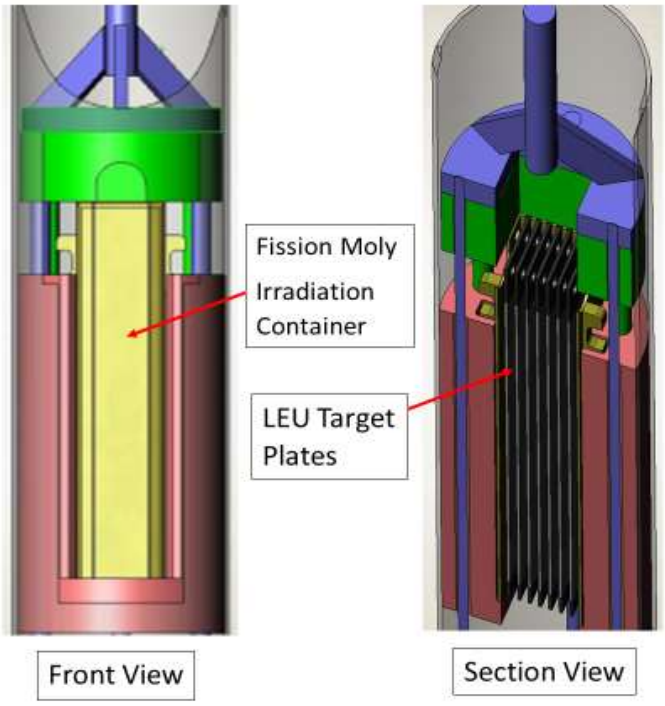

Fig.1: Schematic Sketch of Fission Moly Tray rod

Utilization of indigenously produced Lutetium-177 for development of theranostic agents

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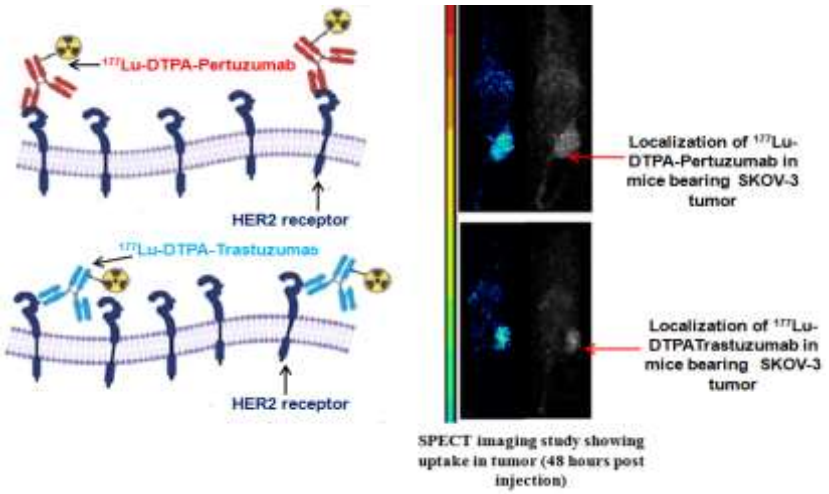
Lutetium-177 exhibits strong potential for theranostic applications in the field of nuclear medicine. Lu-177 with suitable nuclear decay characteristics and half-life of 6.73 days offers an excellent prospect to carry out imaging and dosimetry evaluation along with therapy. It decays by emission of beta particles for therapy along with emission of suitable γ photons for simultaneous scintigraphic studies. Also, its relatively long half-life gives an opportunity for preparation, quality control (QC) and safe transport of the radio formulations to nuclear medicine centres. Convenient and economic availability of ^{177}Lu with high radionuclidic purity and acceptable specific activity is an added advantage for wider applicability of this radioisotope. ^{177}Lu is being regularly produced in Dhruva reactor and is successfully been utilized for preparation of a number of radiopharmaceuticals.

Monoclonal antibodies (mAbs), trastuzumab and pertuzumab have been explored for targeting HER2 positive tumors overexpressed on breast, ovarian and a number of other tumors. Radioimmunotherapy (RIT) with ^{177}Lu has several advantages over other radionuclides such as deposition of energy to smaller metastatic sites. Additionally, the longer physical half-life of ^{177}Lu more appropriately matches with the biological half-life of intact mAbs (6–26 days). To demonstrate the potential of ^{177}Lu labeled trastuzumab and pertuzumab for targeting HER2 receptors, mAbs were conjugated with p-SCN-Bn-CHX-A"-DTPA and subsequently radiolabeled with ^{177}Lu. ^{177}Lu-DTPA-pertuzumab and trastuzumab could be prepared with >95% radiochemical purity (% RCP) as ascertained by chromatography techniques. Extensive studies were conducted in cancer cells and their tumor xenografts in SCID mice with trastuzumab and pertuzumab. *In-vitro* binding studies revealed high affinity and specificity of the formulations towards HER2 receptors. SPECT imaging in tumor bearing mice revealed specific tumor uptake and prolonged retention of radioformulations in HER2 positive tumors. The results of the studies revealed that these radioformulations could serve as effective radioimmunotherapeutic agents for management of HER2 overexpressing cancers. Further studies are underway to obtain the regulatory clearance for translating^{177}Lu labeled formulations to clinics.



Substrate Selection for Product deposition in the enrichment of Lanthanides for Medical applications

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The Lanthanide isotope, viz., ^{177}Lu has application in the medical field as a nuclear medicine with high specific activity. One route for obtaining this isotope is by irradiation of highly enriched ^{176}Yb in the nuclear reactor followed by chemical separation[1]. Enrichment of this naturally occurring isotope viz., ^{176}Yb, by Laser Isotope Separation (LIS) based on selective photo-ionization is being pursued by BTDG, BARC. In the LIS process, the target isotope from the atomic vapour of the natural ytterbium feed, is excited from ground state to higher energy states, and subsequently photoionized using combination of high-power dye lasers. The photo-ions of the targeted isotope are collected on a negatively biased collector substrate[2]. The product, deposited as solid, is recovered from the substrate by acid elution to bring it in to aqueous phase and analyzed for quantity and quality by ICPOES and TIMS methods respectively[3]. This work addresses the selection of the substrate for product collection.

Some of the criteria for substrate selection are (a) material shall be conducting and hence suitable for ion collection, (b) the sticking coefficient of the product to the substrate should be high to ensure complete adhesion, (c) sputtering of deposited product from the substrate shall be minimal, (d) substrate shall be non-reactive to the product being deposited, (e) it shall be inert to the acid used for recovering the product making it re-usable and shall also not introduce impurities in to the aqueous product, (f) it shall have minimum outgassing when being evacuated to high vacuum of around 1×10^{-5} mbar with other components in the LIS separator, and (g) it should be amenable to standard fabrication techniques. Metallic substrates generally meet most of the above criteria. For the current study, two metallic substrates, tantalum and stainless steel were tested for their suitability as substrate collectors in the LIS process. Tantalum being benign to most acids does not introduce impurity in to the product and can be re-used in multiple LIS experiments. Hence, it was chosen as one of the candidates for testing. Stainless steel was available, cheaper compared to tantalum and was selected because of the low out gassing rate inside the evacuated separator system and also the ease of fabrication by standard techniques, which is the case for tantalum as well. The surface finish of both the materials was not changed and taken as received.

Two equal-sizes ((105 mm × 50 mm), symmetrically placed product collector segments made of stainless steel and tantalum sheets were mounted on the base plate as shown in the Fig 1.

Fig 1: Product collector segments made of stainless steel and tantalum mounted on base plate

During the LIS the photo-ions were collected on the product collection segment mounted on the negatively biased base plate. It is assumed that the profiles of photo-ion are also symmetric along the direction of laser and hence flux of photo-ions on tantalum and stainless steel is similar. The two halves of the plates were disassembled after the two-hour experiment, individually eluted in nitric acid[3]. The product obtained in aqueous form was separately analyzed for quantity and isotopic composition. The analysis results are presented below. Tantalum substrate collected marginally more product (RSD of quantity is ±10%) than the stainless steel. Several factors could influence the differential collection of Yb ions on the composite collector of tantalum and steel *viz*. difference in the electrical conductivity of substrate, sputtering due to ion impact, embedding of ions and hence non-removal during acid leach, surface finish of each plate and any variation in the photo-plasma.

Table 1: Experimental data

Fraction		Quantity (mg)	^{168}Yb	^{170}Yb	^{171}Yb	^{172}Yb	^{173}Yb	^{174}Yb	^{176}Yb
			(%age)						
Collector Segment (Tantalum)	5.73mg @96.53%^{176}Yb	3.07±10%	0.00	0.12	0.54	0.84	0.64	1.30	96.55
Collector Segment (S. Steel)		2.65±10%	0.00	0.12	0.56	0.85	0.65	1.32	96.50

Based on the vapour distribution of the ytterbium in the photo-interaction zone, significant difference in the photo-plasma density is less probable. Surface binding energy (BE) of tantalum substrate is 8.1 eV which is nearly two times of stainless steel's value of 4.3 eV[4,5]. Hence it is expected that tantalum substrate is less prone to sputtering of energetic ions reaching substrate during Yb ion collection. Self sputtering of Yb after few mono layer deposition is also expected to influence total collected Yb metal due to its low surface BE (~1.75 eV). Difference in the electrical conductivity of tantalum and stainless steel may not exhibit any pronounced effect on the collection of the ions as the electric field variation is negligible. The effect of embedding of the Yb ions may result in incomplete removal of collected product, which is to be verified by further dissolution studies.

Conclusion: The quantity of collection of photo-ions on the product collection segment is ~16% more on the tantalum substrate than on the stainless-steel substrate. As this minor variation in collection can be due many factors mentioned in paper, it can be concluded that there is no predominant effect of the selected substrate material of the collection of photo-ions of the chosen lanthanide for the separation of isotopes through LIS. Selection of tantalum as a substrate is however advantageous, as compared to stainless steel, due to excellent inertness to acid used for product recovery and hence nearly nil elemental impurity addition to the product.

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Commercial Deployment of Gamma Radiation Technology for Extended Storage of Onion and Potato

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India is the second largest producer of potato and generally, chemical sprout suppressants are routinely employed for preventing sprouting during commercial storage of potatoes. Improved post-harvest technology intervention is needed to provide a physical preservation approach with retention of quality attributes. Therefore, the prime objective of this commercial trial was to assess the efficacy of gamma radiation (from Cobalt-60) treatment as a superior physical alternative in maintaining keeping quality of potato during extended storage. Three different commercial cultivars utilized namely: 'Santana', 'Frysona' and 'HYSM' were included. Potato (approx. 28 tons) were irradiated [Dose (*Dmin*: 73 Gy)] at the Irradiation Facility Centre (IFC), Maharashtra State Agriculture and Marketing Board (MSAMB), Vashi followed by storage in a cold storage facility, Mehsana, Gujrat. Within 100 days of storage, complete sprouting was observed in all the non-irradiated potatoes whereas, no sprouting was noticed in irradiated samples. Irradiated samples were found to be in good condition including texture till 8 months of storage after harvest. After 8 months, these irradiated potato samples were further successfully channelized to a processing industry for the manufacturing of end products including chips and French fries.

In case of onions, weight loss, microbial spoilage and sprouting are the key limitations that significantly affect their commercial storage. The prime objective was to assess the efficacy of radiation processing in extending shelf-life of onion with minimal weight loss. Onion ('Rabi' variety; approx. 15 tons) was subjected to radiation treatment [Dose (*Dmin:* 60 Gy)] at KRUSHAK, Lasalgaon and shifted to a cold storage facility, Shahpur, Maharashtra under customized storage conditions. As compared to the significant (approx. 40%) weight loss that was observed in onions stored under ambient storage conditions, weight loss in irradiated onions under the above specified conditions was found to be approx. 5% until storage (7.5 months). After storage, the samples were further sorted, packaged in gunny bags and successfully marketed to a vendor in APMC, Mumbai. This R&D work was completed under a Memorandum of Understanding (MoU) titled 'Shelf Life Extension R&D For Onion And Potato' between BARC, DAE, Mumbai and Natural Storage Solutions Private Limited (NSSPL), Gandhinagar, Gujarat.

These Commercial trials thus contribute to the 'Operation Greens' scheme of the Ministry of Food Processing Industries, Government of India for integrated development of Tomato, Onion and Potato (TOP) value chain.

Gamma radiation treatment as an effective eco-friendly non-thermal alternative for pest disinfestations in wheat grains thus ensuring food security

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India is recognized as the second largest producer of food grains and even though the production quantum is quite huge, per capita availability is low owing to many factors including increased population and high losses of food. To sustainably and effectively accomplish the target of food security, food availability needs to be strengthened through reductions in the post-harvest losses across the supply chain during post-harvest operations. Minimizing cereal losses in the supply chain through policy intervention could be one of the most efficient ways that can help in strengthening food security. Among all the biotic factors, insect pests are considered most important and cause huge losses in the grains (30%-40%). Management of stored product without insect infestation is a major concern in grain processing and storage industries. Several common and effective fumigants are facing usage restrictions and deregistration in many parts of the world.

As the pest-free products have greater demands in the market therefore the current study was aimed at elucidating the effectiveness of gamma radiation (from Cobalt-60; *Dmin* dose: 650Gy) technology for pest disinfestations in wheat grains (packaged in high density polyethylene) during storage for 1 year. Non-irradiated samples displayed extensive pest-infestation leading to significant loss of structural integrity. As compared to radiation processed samples, the non-irradiated samples displayed 21-25 % weight loss due to pest infestations after 112 days of storage under ambient storage conditions. This weight loss further increased to ~29% after 138 days of storage. However, in samples subjected to gamma radiation processing no structural loss was observed and the samples were significantly superior as compared to the non-irradiated ones. Pest identification further confirmed that wheat grains were infested with rice weevil (*Sitophilus oryzae*). Eventually after a period of 12 months, weight loss was observed to be~95% as compared to irradiated samples wherein weight loss was insignificant. Radiation processing was not found to impact the surface topography of the wheat grains and the surface topography was found to be similar to non-irradiated wheat grains under different magnifications as observed through SEM. Following phenolic acids namely gallic acid, ferulic acid, sinapic acid, p-hydroxybenzoic acid, p-coumaric acid, vanillic acid and syringic acid were detected in wheat samples. Upon gamma radiation treatment, a significant increase in the level of phenolics was observed for most of the phenolic acids. Furthermore, maximum phenolics content was observed for the bound fraction with ferulic acid relatively in the highest concentration followed by sinapic acid. The redox behavior by the wheat extract was found to be similar even during storage period of 12 months. Current study thus provides credible evidences establishing radiation technology as an effective modality in the preservation of wheat grains.

Development of Imidazo[1,2-a]pyridine Based Radiopharmaceuticals

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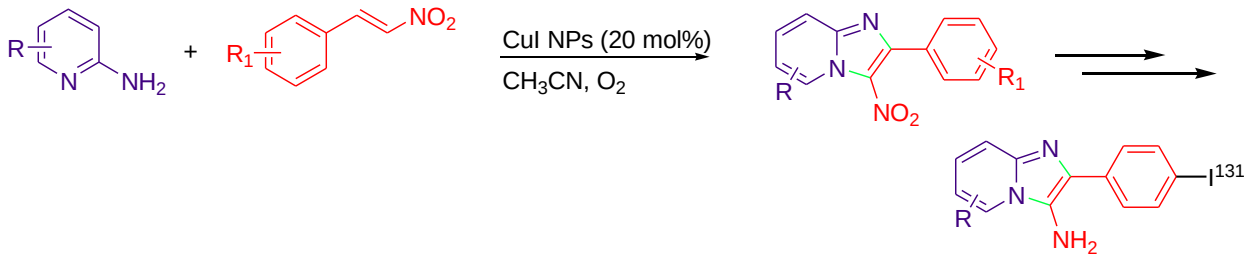
Substituted imidazo[1,2-a] pyridines form an important class of compounds in the pharmaceutical industry. Particularly 2-aryl substituted imidazo[1,2-a]pyridines which constitute the core structure of several marketed drugs such as Zolpidem, Zolimidine, Alpidem, Nicopidem, Saripidem and Miroprofen made this heterocycle a popular target for synthetic chemist.[1] A mild, efficient and stable copper iodide nanoparticle (CuI NP)-catalyzed regioselective synthesis of 3-nitro-2-arylimidazo[1,2-a]pyridines was developed. Substituted 2-amino pyridines successfully reacted with both electron-rich and electron-deficient β-nitro styrenes to produce the desired products in good to excellent yields. Hot filtration tests confirmed the heterogeneous nature of the CuI NPs. The Nano catalyst showed good reusability up to three consecutive cycles without any significant loss in its activity and product yield, confirmed by high-resolution transmission electron microscopy (HR-TEM) analysis. Use of molecular oxygen as oxidant is advantageous from an economic and environmental point of view. Studies will be carried out using 131I or 125 I radiotracers obtained from neutron irradiation in research reactors like Dhruva or Apsara-U at BARC. Further investigation towards the synthesis of radiolabeled compounds may be carried out.



Acknowledgements: The author acknowledges the technical advice of Dr. R. Acharya, Radiochemistry Division, BARC and it is proposed to be carried out under a BRNS Project with a PC from BARC, DAE.

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Research Reactors Contributing to Societal Benefits – Cs^{137} based Blood Irradiators

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Research reactors (RRs) in BARC have been the forerunners for the nuclear energy programme of the country. They are primarily meant to provide neutron source for research and applications in healthcare, neutron imaging, neutron activation studies, neutron scattering experiments etc. RRs have always been central to the production of radioisotopes of high specific activity. Apart from this, spent nuclear fuel from these reactors is a rich source of useful fission products such as Cs-137, Sr-90, Ru-106 etc. Technological advancements in back-end of nuclear fuel cycle, especially in the field of spent fuel reprocessing and radioactive waste management, has enabled selective recovery of these valuable radionuclides from waste and its deployment for societal applications, thereby redefining the nuclear waste as a material of resource.

The high-level liquid waste (HLLW) generated from reprocessing of the spent fuel contains useful radioisotopes in significant quantities. Towards utilization of these radioisotopes, India has taken the lead role for their bulk scale recovery. Separation and recovery of these fission products not only reduces the waste burden to the environment but also gives value addition to drive social impact. Selective recovery of Cs-137 from HLLW and production of Cs-137 based blood irradiators is one of the examples of the successful deployment of radioisotopes recovered from waste in medical industry. With this advent, India has become the first country in the world to deploy Cesium in non-dispersible glassy form as the source in blood irradiators. This will eventually replace the existing Co-60 based blood irradiators in the country and abroad. The use of Cesium in blood irradiators is advantageous due to the its longer half-life, which reduces source replenishment frequency and man-rem consumption. Further, it is possible to build compact irradiators due to lower shielding requirement.

Recovery of Cesium from HLLW is accomplished through a novel solvent extraction-based process utilizing 1, 3-di-n-octyloxy Calix [4] arene-Crown-6 (CC6) in isodecyl alcohol (IDA)-dodecane solvent system. Stripping of Cs from the loaded organic phase is carried out using dilute nitric acid. The cesium rich product stream is further concentrated and subsequently immobilized into a specially formulated glass matrix. Such non-dispersive glassy form of cesium is then metered into the small-sized stainless-steel pencils and sealed by remote welding. Post sealing, pencils are subjected to overpacking, surface decontamination and stringent quality assurance checks, at par with international standards. Each pencil contains about 200 gm of Cs-glass, amounting to about 300 Ci of Cs-137. More than 250 numbers of Cs-glass pencils have been produced successfully till date. Qualified Cs-pencils are transported to BRIT for deployment in blood irradiators and subsequent supply to different hospitals. Each blood irradiator houses ten such pencils in a circular cage. This provides a dose-rate of about 11 Gy/minute, suitable for irradiating a standard blood bag within 3 minutes, with an estimated absorbed dose of about 30 Gy. Such irradiation of blood before its transfusion helps to prevent Transfusion Associated–Graft Vs Host Disease (TA-GVHD). At present, more than fifteen such irradiators are in use at leading hospitals of the country.Apart from blood irradiation, other potential applications of Cs-137 includes its usage for irradiation of foodstuffs, sterilization of medical supplies and radiation processing of sewage sludge.

Challenges In The Indegenous Production Of Selenium-75 Source For Use In Industrial Radiography

Rajesh Kumar Yadav

Atomic Energy Regulatory Board
Mumbai

Selenium-75 (Se-75) is a radioactive source used for industrial radiography worldwide and also in India, since about two decades. This is a promising source for radiography of low thickness materials due to its low energy spectrum and low radiation output, which makes it safe from radiological safety view point for the open field work. The sensitivity of the radiograph obtained using this source is comparable with that of X-rays. Over the last two decades, the use of Se-75 sources in Indian industries have increased, presently there may be around 100 Nos. of Se-75 sources being used in India, these sources are imported. Due to increasing demand, there is a need for production of these sources in India, in the range of 1 TBq-3 TBq. It is the time again to review the indigenous production of Se-75 source in India, to meet the demand and to save revenue.

This paper discusses about the need for use Se-75 source over Ir-192 for low thickness of materials w.r.t. image quality, sensitivity and radiological safety; and the future challenges anticipated in these areas for production of the sources viz. enrichment of Se-74, irradiation in the high flux reactor and welding for encapsulation, which need to be focused to facilitate use of Se-75 sources in India.

Design and development of Cs-137 based Agro Irradiation Facility

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Infestation of grain primarily due to insects is a common problem for long term storage which accounts for around 2-4% post harvest losses of food grains i.e ~3-5 million tons. Gamma irradiation provides a new method of grain dis-infestation. The main advantages are its effectiveness, instantaneous treatment and zero residue of any type. It is a physical method of insect control, by which grain in motion is treated with a prescribed dose of ionizing radiation to inhibit insect reproduction and to kill them. Low dose irradiation (0.25 to 1 kilo Gray) completely kills or sterilizes the common grain pests.

Cesium-137 (Cs-137) is an alternate gamma source in place of Co-60 which can be used for grain irradiation. It is currently being used in blood irradiators. Cs-137 has higher half-life i.e. 30.17 years, hence, it will require less frequent source replenishment to maintain the throughput. As photon energy of Cs-137 is low i.e. 0.66 MeV, it requires lesser shielding. As Cs-137 is freely available from spent nuclear fuel reprocessing, use of Cs-137 for radiation processing of grains is planned to be explored which may be useful for societal benefit applications. Hence, to demonstrate the use of Cs-137 as gamma source for radiation processing of food grains, a small scale Agro Irradiation Facility (AIF) has been designed and built at BARC, Mumbai. The facility will be used to demonstrate the effectiveness of radiation for grain disinfestation using Cs-137 source pencils developed by BARC from spent fuel reprocessing. This facility is designed for 21 kCi of Cs-137 source pencils which will give a throughput of around 50-60 kg/hr. This facility is first of its kind in terms of radiation treatment of food grains under gravity flow and using Cs-137 as gamma source.

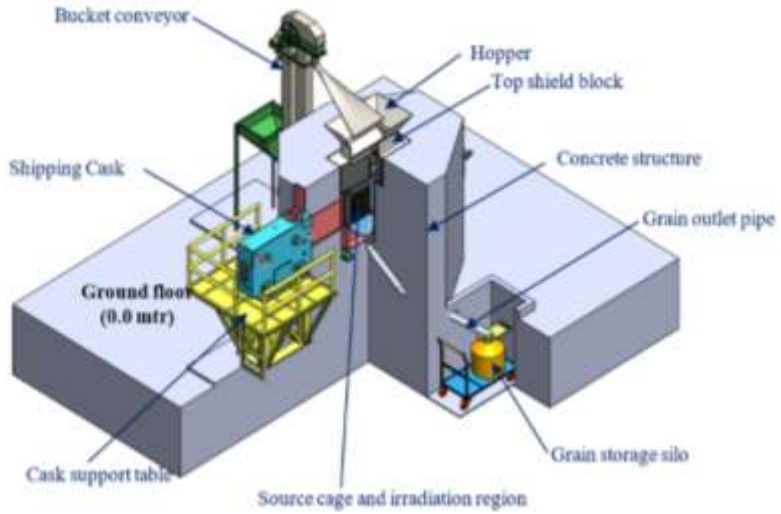

Figure 1: Schematic of Cs-137 based Agro Irradiation Facility (AIF)

Acknowledgements: We acknowledge contribution of team members of RDDG, ESG, NRG, HSEG, BSG, RPD, PDD, RPNES of BARC and BRIT for development of AIF at BARC, Mumbai. We acknowledge the guidance of BSC/ DSRC-AIF for providing regulatory clearance.

Neutron diffraction studies of pristine HfO_2 and Ta-doped HfO_2

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Hafnia is a material of technological interest as it is being considered as a replacement of SiO_2 in microelectronics. But, following reports on HfO_2 systems exhibiting ferroelectric properties [1], interest in orthorhombic phase of HfO_2 renewed. Under application of external pressure, it undergoes phase transformation to an orthorhombic-I phase at ~ 3.7 GPa, that subsequently transforms to orthorhombic-II at ~ 8.2 GPa. The space group of the orthorhombic-I phase was determined to be *Pbcm* from Rietveld refinement and peak decomposition of high-pressure X-ray diffraction data [2]. Based on simulations studies, it was realized in the study [2] that *in situ* neutron diffraction data at high pressure has the potential to detect space group of the high-pressure orthorhombic-II phase of HfO_2. Thus performing an *in situ* high pressure neutron diffraction experiment is a requirement understanding the high pressure phase of HfO_2.

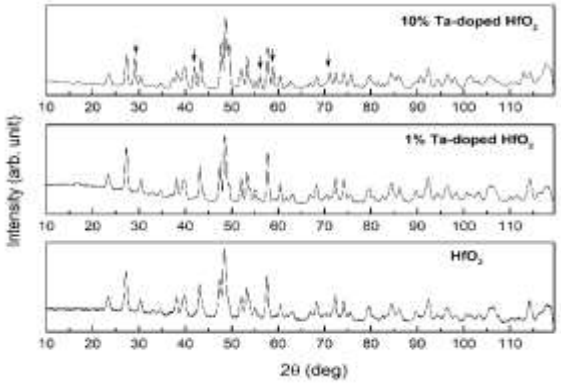

Figure 1 Neutron diffraction pattern of undoped, 1% Ta-doped and 10% Ta-doped HfO_2 .

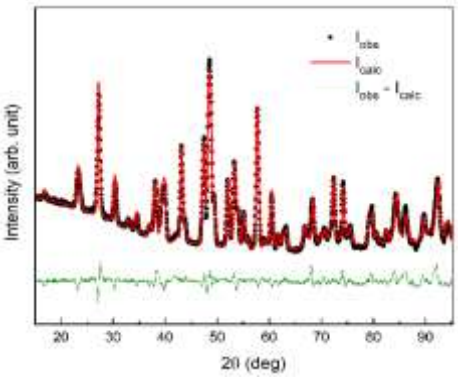

Figure 2 Rietveld refinement of neutron diffraction pattern of 1% Ta-doped HfO_2.

In a recent study on Ta-doped HfO_2 samples under ambient conditions, an orthorhombic-I phase formation similar to the high pressure phase of undoped HfO_2, was observed on increasing the doping concentration beyond 1% [3]. Neutron diffraction data for pristine, 1% Ta-doped and 10% Ta-doped HfO_2 were taken in powder diffractometer (PD-3) of BARC and the diffraction patterns are shown in Fig. 1. The newly emerged peaks for 10% doped sample are shown with arrows in this figure. The neutron diffraction pattern of 1% Ta-doped HfO_2 [Fig. 2] confirmed orthorhombic phase formation in doped samples. The neutron diffraction pattern for 10% Ta-doped HfO_2 sample was low statistics and could not be fitted with the mentioned two phases. As oxygen position can be determined with better precision with neutron diffraction studies [4], further studies are planned with higher Ta-doping concentrations for understanding different phase formation in doped HfO_2 samples.

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Understanding the origin of magnetoelectric coupling in G-type antiferromagnetic Fe_2TeO_6 through Neutron diffraction

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Fe_2TeO_6 (FTO) is a magnetoelectric (ME) G-type antiferromagnet with tetragonal trirutile structure (*P2/mnm*).[1, 2] The magnetic susceptibility and the specific heat of FTO show broad anomaly around 233K before the sharp fall at $T_N \sim 210$K. We observed nonlinear ME behavior above and below T_N. This nonlinear behavior signifies the presence of magnetostriction and/or magnetoelasticity in FTO. The analysis of temperature dependent Neutron diffraction (ND) data (fig. 1(a)) reveals the local noncentrosymmetry at the Fe site due to d^5 off-centering of Fe^{3+} with asymmetric *p-d* hybridization in different Fe-O bonds causing ME coupling in FTO. Crystal and magnetic structure (fig. 1(b)) of FTO reveal the possibility of multiple competitive exchange interactions (Fe^{3+}-O-Fe^{3+}).[3, 4]

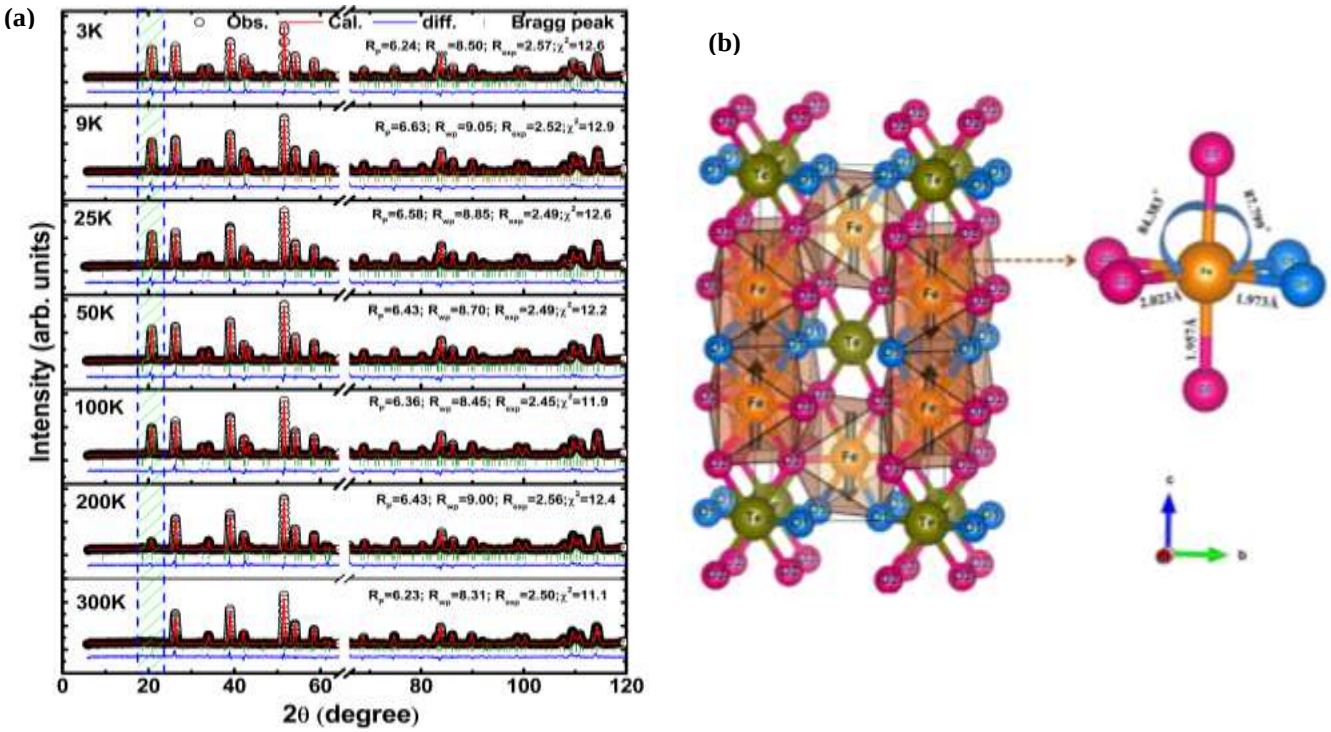

Fig. 1: (a) ND Rietveld refined fitted pattern at various fixed temperatures with reliability parameters. (b) Crystal and magnetic structure obtained from ND data at 3K.

Acknowledgements:
We acknowledge the Board of Research in Nuclear Science (BRNS), Mumbai (Sanction No: 2012/37P/40/ BRNS/2145), and UGC-DAE-CSR Mumbai (Sanction No: CRS-M-187, 225) for funding.

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High-*Q* neutron diffraction studies of glasses at Dhruva reactor

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Glasses are non-crystalline materials which have an atomic structure that is indistinguishable from those of liquids but possess rigidity like solids. The structure of glasses is characterized by short-range order without a long-range order of the constituent atoms that exists in crystalline solids. The short-range order properties of glasses and liquids such as bond lengths, co-ordination environments and bond angle distributions can be determined by pair distribution function analysis of the X-ray and neutron diffraction studies. Neutron diffraction technique is more useful as compared to the X-ray diffraction, since neutrons can provide an accurate study of oxygen-oxygen atomic pair correlations which are the dominant species in oxide glasses. During the last two decades, the present investigators have studied the short-range structure of borate, silicate and tellurite glasses at the high-Q neutron diffraction beamline of the Dhruva reactor and analyzed B-O, Te-O co-ordination and bond lengths as a function of glass composition. Reverse Monte Carlo simulations of the diffraction datasets reveal significant disorder in the tellurite glass network due to the existence of wide range of Te-O bond lengths. The understanding of glass short-range structure is useful for making structure-property correlations and for modeling the mechanical, thermal and optical properties of glasses. High-*Q* neutron diffraction beamline at Dhruva reactor is a unique national facility that is used for total scattering studies of glass, liquids and disordered crystalline materials. In this talk, we will present results on the structural studies of lead borate, bismuth borate, tungsten tellurite and molybdenum tellurite glasses carried out Dhruva reactor [1-3]. The quality of diffraction data is comparable to that measured on the high flux reactors in the world. Presently neutron diffraction studies at this beamline can be carried out upto *Q* (momentum transfer function) value of 15 $Å^{-1}$, an enhancement in the neutron flux and in the *Q*-value will provide higher real space resolution of structural studies of materials.

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Probing Nanoporous Materials by Neutron Scattering

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In the past few decades, the design of novel nanoporous materials with isolated/connected pores has led to materials with great potential. Their excellent porous properties can be tailored through their pore structures to suit particular applications. Mechanical strength, density and thermal conductivity of such materials are associated with their isolated pores while connected pores relate to the processes of absorption and flow of fluid from the bulk to the surface. In addition, the confined environment of pores enhances chemical reactions within them. Connected pores have the property of only letting through certain substances while blocking others. In a neutron scattering measurement, neutrons are scattered simultaneously by both connected and isolated pores - which is not possible by other pore characterization methods. In the present study we used the neutron contrast variation method to determine pore structure, pore connectivity and micellar aggregation in the pore structure. Measurements were carried out at SANS and MSANS instruments at the Guide tube laboratory of Dhruva Reactor (BARC, Mumbai)

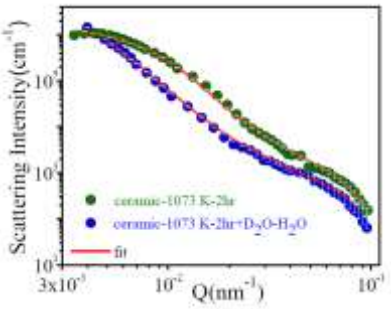

Fig. 1: Scattering profile of ceramic sintered at 1073 °K and loaded with a H_2O-D_2O mixture

A porous ceramic prepared from derived silica, consisted of a wide size-range of irregularly shaped particles. The distribution of nanopores was found to be bimodal with modes at ~ 170 nm and 35 nm in the compacts and it was found that the densification of the matrix occurs by annihilation of smaller pores. The next higher level of complexity was found in bentonite clay. In the latter, particles were not only of differing sizes and shapes but could absorb water to form a swollen porous mass. A micellar solution within the pore matrix of sodium saturated clay was also studied. Changes of the micellar aggregation number and the effective charge for the confined solution were determined. We note that the quantification of; nano-porous structures in increasingly complex porous materials; estimation of isolated pores and; the effect of confinement of water and the aggregation of micellar solution has all been studied. These neutron scattering techniques may also be extended to the study of low-density materials such as aerogels and composite aerogels

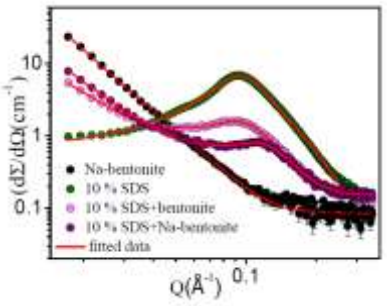

Fig.2: 10wt% SDS induced bentonite and Na saturated bentonite

Acknowledgements:
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Neutron Scattering Studies of 2D layered Transition Metal Dichalcogenides and it's Composite for High Performance Supercapacitor Application

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In order to address the energy needs in the present scenario, energy storage technologies have get significant attention among research community. There are different types of energy storage technologies are developed such as batteries, but it possesses a lower lifetime, lower energy and power density. In the past years there exist very large efforts on batteries in order to produce a steady current to recharge it. But the results from this were found that it requires a larger time period to fully charge it, when it is discharged. The slower charging rate introduces a necessity for alternative energy storage technologies. Thus the importance of supercapacitors is come forward. An electrode material is an important parameter for supercapacitor device fabrication [1]. Here in the present study we are going to develop an electrode material based on highly active 2D layered Transition Metal Dichalcogenides (TMDs)[2] and its composites. But it is necessary to study the properties such as ion diffusion rate, diffusion jump rate and length in the atomic and nanometer scale. Thus we need a proper tool for study the properties of materials in the molecular level inorder to produce a fine tuning of them to improve its device efficiency. Thus we like to employ the neutron scattering studies to evaluate the defects, ionic diffusion rate etc to illustrate the properties such as pore size distribution, pore volume etc to demonstrate a highly efficient supercapacitor device [3-5]. Also we need material characterization facilities such as XPS, FESEM, AFM and HRTEM.

Table 1. Experimental Data

Sample Name	**Data**	**Remarks**
MoS_2	XRD,UV-Visible Spectrum, FESEM	The MoS_2 sample is confirmed by these analysis technique and found that it possesses a layered hexagonal structure with a bandgap of 1.8eV
MoS_2-ZnS composite	XRD,UV-Visible Spectrum, FESEM	The composite was exhibits a bandgap of 2.1eV with an intercalation of ZnS to MoS_2 layers
MoS_2-ZnS-CNT composite	XRD,FESEM	The sample is confirmed by using XRD and FESEM it possess a layered structure itself
MoS_2-TMO composite and its ternary with MXene and conducting polymer	Works under progress	After synthesizing it like to do the basic characterization

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Lattice dynamics in the ferroelectric medium at and around phase transition using Neutron Spectroscopy

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The energy loss (EL) of 6 MeV electrons and 25 MeV protons in the ferroelectric $BaTiO_3$ (BT) was measured as a function of the temperature of the target medium with an accuracy of ±1%. The results show an anomaly in the EL of electrons in BT near the phase transition temperature. whereas, the EL for the proton beam shows broad fluctuations with a peak-to-peak variation of 5% around phase transition. It is suggested that the observed variations in EL are indicative of a new mode of interaction of particles with the ferroelectric medium that is not yet included in the standard stopping power mechanisms. As the beam traverses the medium, it produces a transverse electric field and also increases localized lattice temperature by a transit thermal process acting in the electronic and atomic subsystems. The estimated field produced by the 6MeV electrons is ~184MV/cm and for 25MeV proton is ~15MV/cm at a radial distance of 1 nm from the rectilinear path is sufficient for fast domain switching. The localized temperature due to the passage of 25 MeV proton in the BT is ~6000 K in the time interval of 10^{-15} s to 10^{-9} s estimated using the inelastic thermal spike model. This short duration temperature may excite the soft mode phonons. Hence, the interaction of particles with the phonons may explain the observed anomaly in the EL mechanism.

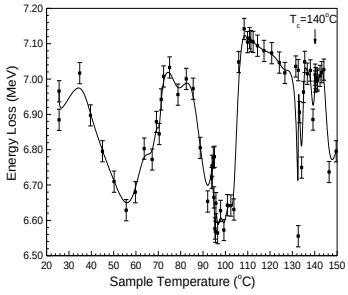

Fig 1. ΔE of protons in BT

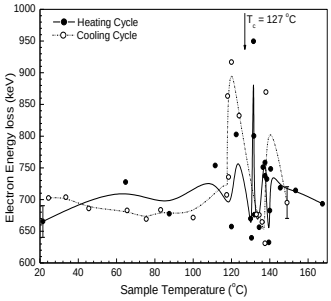

Fig 2. ΔE of electrons in BT

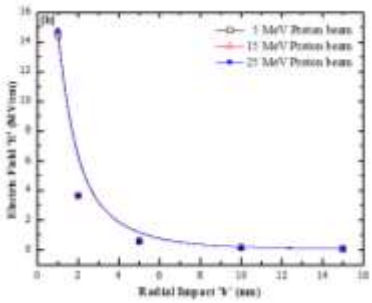

Fig 3. E v/s b for protons.

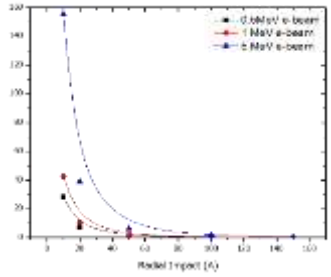

Fig 4. E v/s b for electrons.

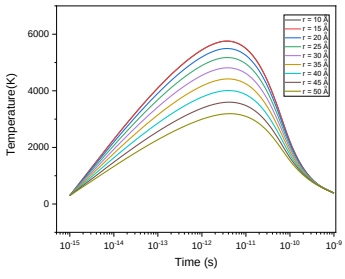

Fig 5. Temperature rise in BT due to the passage of protons

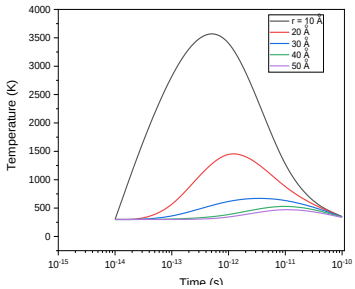

Fig 6. Temperature rise in BT due to passage of electrons.

The neutron scattering facility of BARC is the best tool to understand the excitation of soft mode phonons due to the lattice dynamics of the ferroelectrics at and near the phase transition to account for the observed energy loss mechanism.

Acknowledgements: The Authors are grateful to IUAC, New Delhi, and Pune University for having provided the beam time for the EL measurement.

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Multipurpose Test Facility for Neutron Detectors at Guide Tube Laboratory, Dhruva Reactor

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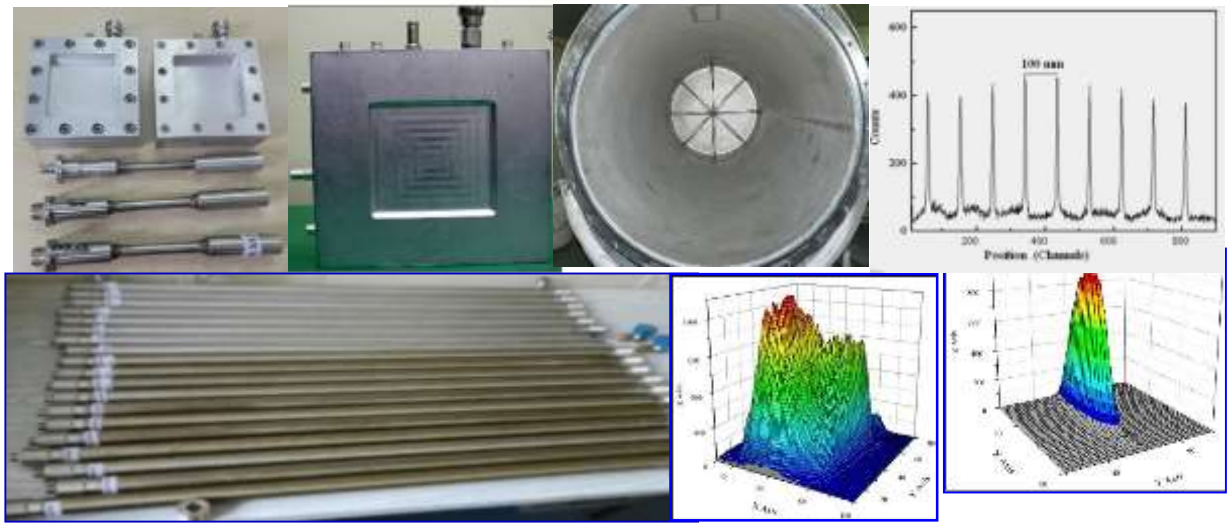
National Facility for Neutron Beam Research (NFNBR) at Dhruva comprises of twelve neutron scattering facilities in the reactor hall and Guide Tube Laboratory, for condensed matter research. The users are from Department of Atomic Energy, national laboratories and various universities. All these instruments are supported with indigenously developed durable neutron detectors, such as neutron beam monitor, proportional counters and one-dimensional and two-dimensional position sensitive detectors (PSD), which are tailor-made for the beam size and intensity. These detectors are quality tested using a Pu-Be portable neutron source as well as collimated neutron beam from Dhruva reactor. Analytical study of gas kinetics is useful in design stage of various complex geometry detectors. Neutron beam flux counting monitor [1] and imaging monitor are designed and used for the beamlines as per the geometry requirements. Imaging monitor is useful to evaluate the intensity profile and mount neutron optics in high in tensity regions. MultiPSD array [2] and multiPSD fanlike 2D arrangement [3] have been successfully implemented at the spectrometers. Figures 1 and 2 show the various detectors



developed and characterised using the Multipurpose Test Facility neutron beamline at Dhruva reactor.

Fig.1. Neutron beam counting monitors, Beam Imaging monitor, Multiple linear PSDs in a near 2D arrangement and PSDs for TOF spectrometer at Dhruva reactor

Fig.2. Position scan of a PSD using 2 mm fine neutron beam with shift of 50 mm and beam images at sample position of spectrometers

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Probing nanostructure using SANS towards development of membrane based CO_2 capture in India

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Current practice of CO_2 capture via chemisorption by aqueous amine solution poses serious concerns of inefficient, cost-intensive process and environmental pollution by toxic amines. To this end, the focus objective is on fabrication of CO_2 selective membrane that selectively adsorb and permeate CO_2 instead of other gases under ambient condition. The first task is to design and synthesize porous, functionalized and chemically robust porous material for high CO_2 uptake and then to tailor polymer chain stiffness and interaction within the membrane by introduction of porous material to systematically improve and fine-tune separation performance of the membranes. Figure 1 depicts the fabrication of composite membrane. The polymer nanostructures due to aggregation of polymer chains were probed using small-angle neutron scattering (SANS). The expression of the intensity of scattering I(Q) is directly related to the form factor P(Q) and structure factor S(Q). P(Q) gives the size distribution of the scattering particles while S(Q) is related to the correlation of scattering particles in the surrounding medium. I(Q) is contributed from the both P(Q) and S(Q) factors for correlations of position or orientation between the scattering units. An approach is applied to describe such correlation using the Lorentzian term from Ornstein–Zernike model and a Lorentzian-squared term from Debye–Anderson–Brumberger model of the scattering intensity to estimate the correlation length, which is average distance between the interacting macromolecular segmental units of a cross-linked polymer. The difference in the neat polymer and composite nanostructures were evident from their SANS profiles as shown in Figure 2.

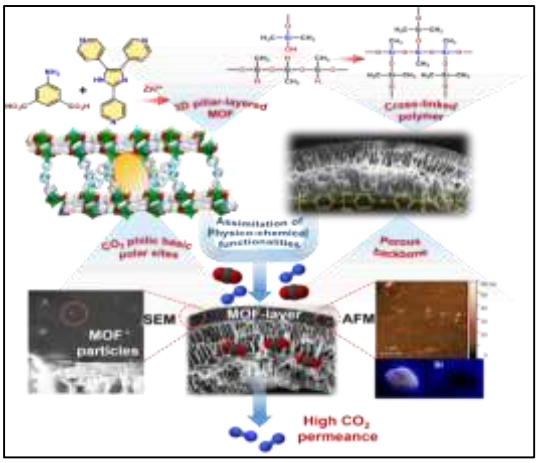
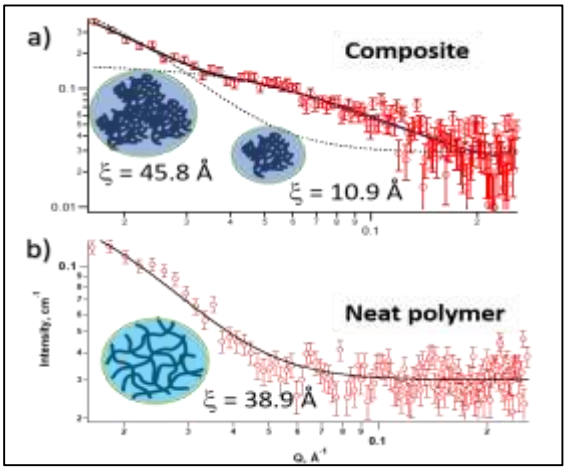


Fig. 1. Fabrication of CO_2 selective membrane Fig. 2. SANS profiles of composite (a) and neat polymer (b)



Acknowledgements:
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Small Angle Neutron Scattering: A Tool to Understand the Aggregation Behaviour of Solvents with Rare Earth Elements

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Rare earth elements are used in various hi-tech devices such as smart phones, digital cameras, light emitting diodes, smart displays, electronic gagdets and computers. Rare earth elements need to be in ultra pure form for their applications in these devices. However, it is challenging to separate individual rare earth elements due to lanthanide contraction. Nevertheless, several novel solvents have been developed to enhance the separation of individual rare earth elements. Most of these solvents are prone to aggregate which induces physico-chemical changes during the extraction of rare earth elements and leads to third phase formation. This is an undesirable phenomenon during solvent extraction process. Hence it is crucial to investigate the aggregation behaviour of recently developed novel solvents in order to improve the extraction behaviour of rare earth elements.

Small angle neutron scattering (SANS) is an excellent technique used to probe aggregation of macromolecules. It provides information on size and shape of colloids as well as interactions among the aggregated molecules. This helps us to understand the behaviour of molecules with change in various parameters such as pH, temperature, solvent, solute, metal and ionic strength. Several investigators have used SANS as a powerful tool to understand the phase splitting and aggregation behaviour of solvents during the extraction of metal ions. Hence, it is worthwhile to utilize SANS technique to understand the molecular level interactions among solvents in order to enhance the separation factor for the extraction of rare earth elements.

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Small Angle Neutron Scattering Probing of the Effect of Nanoparticles with Liquid Crystals

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Small-angle X-ray and neutron scattering measurements are used to investigate the structural transitions and alignment of the nanoparticle-liquid crystal system. The small-angle neutron scattering (SANS) technique is a valuable method for the characterization of morphology and inhomogeneities in the sample at a length scale from the atomic size (nanometers) to the macroscopic (micrometers) size. Using SANS measurements, effect of nanoparticles on the phase transition properties, stability of the mesophases, role of functional groups and substituents molecules present at the liquid crystal core and alignment of different layers at the molecular order in such systems can be studied. Such information is very fruitful in enhancing the applicability of different nanocomposites in sensors, memory devices, electro-optic applications, and one-dimensional charge carrier conduction. In pure liquid crystals, attempts have been made to elucidate the molecular interaction at the liquid microscopic level [1-2]. The structure of liquid crystals is determined by the X-ray diffraction technique, wherein the specimen is enclosed in a glass capillary and hence no information is obtained about the structure in the bulk-free from the glass surface effect. In a neutron diffraction experiment, however, a thick sample (e.g., 10 mm in diameter) can be used. The only difficulty is that liquid crystals contain many hydrogen atoms, and the incoherent neutron scattering cross-section of hydrogen is so large that the signal-to-noise ratio is very poor. This difficulty is removed, if all the hydrogen atoms are substituted by deuterium. The ability to substitute deuterium for hydrogen in macromolecular complexes makes SANS a unique technique for probing macromolecular conformations in synthetic and biological polymers.

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Probing of the interaction of natural dye with transition metal oxide nanoparticles using small angle neutron scattering

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Different transition metal oxide nanoparticles such as zinc oxide, copper oxide, titanium dioxide, iron oxide etc posses the advantage of being used in biomedical applications, solar energy conversion, field emission emitters. Zinc oxide nanoparticles are used as catalysts, nanosensors, ultraviolet absorber; copper oxide nanoparticles have antibacterial and antioxidant properties, iron oxide is used as contrast material in bio-imaging and titanium dioxide nanoparticles are widely used in optoelectronic devices, photo-catalysis, protective coating and photovoltaic devices to energy accumulators. It has been reported that all such nanoparticles have the capability of interacting with biochemicals and molecular constituents of biological origin such as chlorophyll, carotenoid, anthocyanin, betalain etc. Chlorophyll functions as a photocatalyst in plants as well as a photo-sensitizer in dye-sensitized solar cells and organic photovoltaic devices. Similarly carotenoids functions as light harvesting as well as photo-protective agents. They also have high extinction coefficient and hence act as sensitizers. Overall, the sensitization process involving natural dye molecules like chlorophyll, carotenoids, anthocyanin, betalain etc and semiconductor nanoparticles like zinc oxide, copper oxide, titanium dioxide, and iron oxide are highly fruitful for photoelectric energy conversion processes in dye sensitized solar cells (DSSCs) [1, 2]. However, the performance of the DSSC is based mainly on surface structure of visible light absorbing dye/sensitizer. Hence, in order to understand the conformation structure and aggregation behaviour of natural dyes in solution, neutron scattering technique such as small angle neutron scattering (SANS) can be used. The technique can be used to probe the structure and dynamics of dye aggregates in solutions. This will help in understanding the nanoscale organization of molecular aggregation in solutions of these conjugated molecules at atomic level resolution and provide the mechanism for the enhancement of the efficiency of the photo-conversion devices.

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Characterization of Polymer Micelles using Small Angle Neutron Scattering

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The advances in the synthetic approaches in polymer chemistry have facilitated the development of amphiphilic block copolymers with desired number of monomers with each having distinct hydrophilic and hydrophobic characteristics. The variation in the number of blocks and chemically distinct block types generates a collection of unique copolymers, where each creates a specific nanosized structure in aqueous solution. The self-assembling properties of block copolymers are strongly affected by the primary and secondary factors in the solution. These copolymers are capable of self-assembling in a wide range of nano-sized structures in aqueous solution. Nanoparticles, polymersomes and micelles (spherical, cylindrical, and worm-like) are some of the examples. The external factors In addition to primary and secondary factors which emphasis on the structure of block copolymers, external factors such as temperature, ionic strength, and pH also play an essential role in the self-assembly of particular block copolymers. As soon as the desired block copolymer assemblies are formed in the aqueous solution, detailed characterization becomes necessary for these assemblies to be suitable for specific biosensing and biomedical applications. The morphology and dimensions of highly swollen micelles of copolymers can be investigated employing small-angle neutron scattering (SANS) for various applications. The present study is based on the self-assembly of various EO-PO based amphiphilic block copolymers and the effect of different additives on the size and shape of micelles was confirmed using SANS.

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A study on the effect of different solvents on the star block copolymeric micelles

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The influence of 2,2,2- trifuoroethanol (TFE) and ethanol (EtOH) was checked on the self assembly of commercially available ethylene oxide-propelene oxide (EO-PO) octa block copolymers, Tetronics® 1304 and 1307 using small angle neutron scattering (SANS) and fluorescence. The critical micelle temperature (CMT) for the both the copolymers as determined by fluorescence, significantly decreased in the presence of TFE while EtOH increased it. For T1304 aqueous solutions, micellar growth is observed as a function of TFE concentration and temperature (for a fixed concentration of TFE) while a decrease is noted in the presence of EtOH as evident from SANS.

Influence of different Ionic Liquids on the amphiphilic star block copolymers

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Here we have reported an inclusive analysis of physicochemical properties of an ethylene oxide-propelene oxide (EO-PO) star block copolymer Tetronic® 1304 (T1304)with the total mol. Wt. 10,500 and the % PEO is 40%, for the influence of of 1 alkyl-3-methylimidazolium based ionic liquid (ILs) using the plethora of techniques such as cloud point(CP), viscosity, dynamic light scattering (DLS), small angle neutron scattering (SANS), high sensitivity differential scanning calorimetry (HSDSC), Fluorescence measurement and 1H NMR spectroscopy. With different anions ILs showed identical effect on T1304 micelles at lower concentrations, but significant change was noticed at higher concentrations. ILs formed smaller mixed micelles with longer alkyl chains while remained in the bulk with shorter chain. Moreover, the CP significantly increased with the increased in the alkyl chain length while the apparent hydrodynamic diameter (Dh) of micelles decreased. The presence of NaCl suppressed the effect of IL on T1304 micelles. In the presence of different ILs the microstructural changes as observed for T1304 micelles are explained by SANS data. Fluorescence studies with coumarin-481 as probe showed shifts in the emission spectra and enhancement in the fluorescence decay, suggesting incorporation of the IL in micelles. The penetration of ILs with longer alkyl chains in T1304 micelles was further confirmed by 1H NMR spectroscopy. The present study provides important information on tuning solution behavior of T1304 by ILs that may prove to be beneficial for different industrial applications.

Effect of Various Metal Salts onto Micellization of Amphiphilic Block Copolymer for Energy Storage Devices

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The overwhelming scientific research focus onto the aqueous electrolyte modifications is noticed in recent years due to rapid growth of alter sustainable energy storage devices which can possibly replace the lithium ion batteries. Though, many challenges need to resolve to use the aqueous liquid electrolyte including dendrite formation, anode corrosion, cathode dissolution, uncontrollable side reactions till date. Amongst the alternative strategies, polymer based electrolytes identified as the excellent candidate as they improve the electrochemical performance, suppress the Zn dendrite formation, alleviate the dissolution of active materials due to their limited water content. [1] Simultaneously, Amphiphilic block copolymers (ABC), with common repeating units of poly (ethylene oxide)-poly (propylene oxide)- poly (ethylene oxide) (PEO-PPO-PEO) received indispensable amount of research focus due to their unique ability of micellar arrangements leading to wide application areas. [2] The alteration in micellar arrangements after the salt addition is exclusive characteristic governed by the ABC due to the fundamental changes occurring at molecular levels which influencing electrolytic behavior for the energy storage devices. Here, in this contribution, we report comprehensive study of micellization behavior of ABC under the influence of various salts with a specific groups involving effect of various metal salts with common triflate anion and effect of various anions of zinc metal. The small angle neutron scattering (SANS) method was utilized for the detailed investigations of micellar parameters and quantitative fitting analysis were undertaken to notice the change in key parameters such as core radius (R_c), hard-sphere radius (R_{HS}), volume fraction (ϕ) and aggregation number (N_{agg}). The suppoprtive proofs were collected usign nuclear magnetic resonance (^{1}H-NMR) and dynamic light scattering (DLS) investigations. The extensive electrochemical measurements were also pursuied to understand the potential applicability of the prepared electrolytes using electronic impedance spectroscopy (EIS), DC polarization and cyclic voltammetry (CV). As a result, series of electrolytes were made applicable in the zinc-iodine device fabrication resulting high performance.

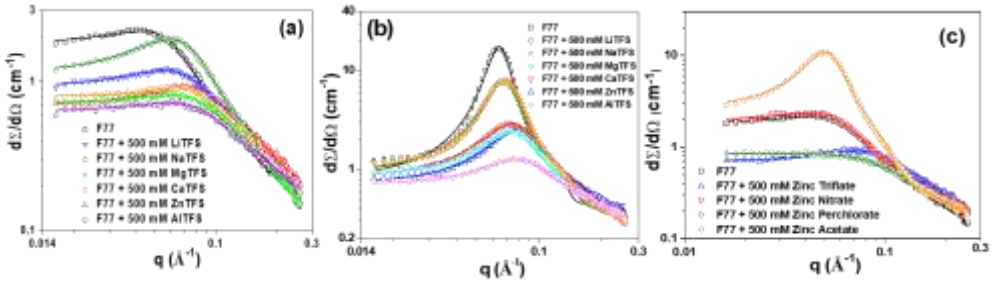

Fig. 1: SANS profiles of 15% ABC mixed with various metal salts at 30 ℃.

Acknowledgements:
Authors, SSS, and HKM are highly obliged to UGC-DAE (Sanctioned letter No. UDCSR/MUM/AO/CRS-M-290/2017/587) for financial support.

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Exploring the structural and physical properties of Tb_2NiMnO_6 through Neutron diffraction

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Phase pure double perovskite Tb_2NiMnO_6 (TNMO) have been prepared by solid state reaction method. The earlier study on TNMO reported presence of secondary phase. The prepared sample was subjected to X- Ray diffraction (XRD) and neutron diffraction (ND) at ambient temperature. The analysis by Rietveld refinement confirmed the phase purity. The sample was found to crystallize in the monoclinic structure with $P2_1/n$ space group.). In order to further ascertain the phase purity, the neutron diffraction pattern was recorded at focusing crystal diffractometer (PD-3) at Dhruva, India [1] using neutron beam of wavelength 1.48 Å. The crystal structure has been plotted with the help of VESTA from the analysis of ND pattern and shown in adjacent to the spectra in fig 1. We can observe that the Ni and Mn polyhedral are alternatively interlinked. The refinement of ND pattern gives Mn-O and Ni-O interatomic bond distances which were found to be ~2.035 Å and 1.94 Å which are closer to the reported values [2].

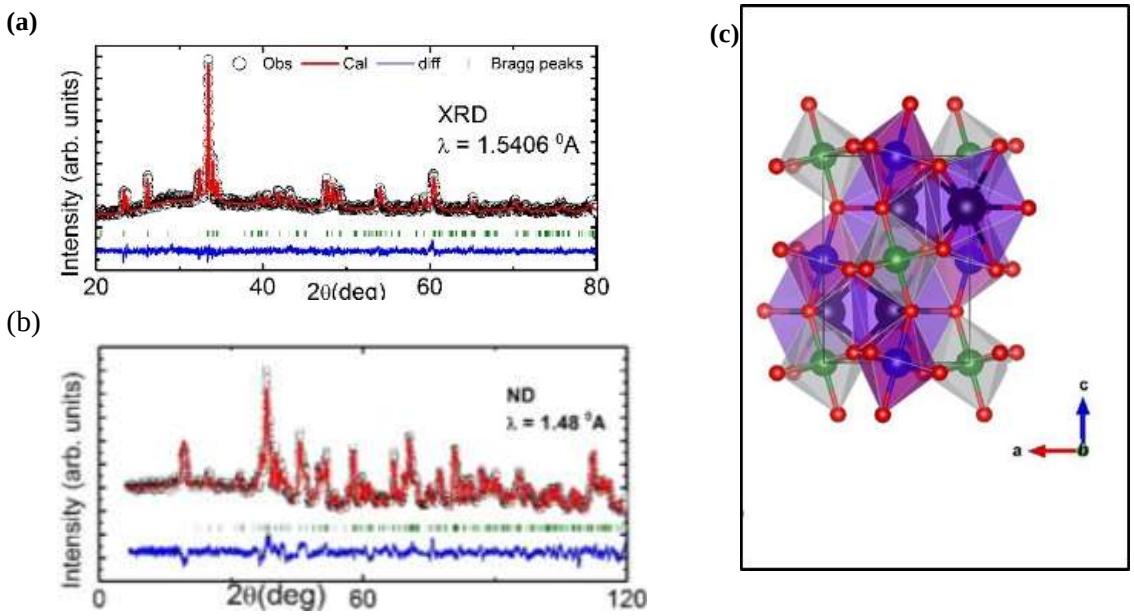

Fig. 1: Room temperature Rietveld refined (a) XRD and (b) ND fitted patterns. (c) Crystal structure obtained from neutron data

Acknowledgements:
We would like to Acknowledge Dr. S. Rayaprol from UGC-DAE CSR Mumbai Centre for XRD data at room temperature.

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Exploring nuclear structure at extreme spin and isospin using neutron beams

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The atomic nucleus is a fascinating and one of the most challenging quantum system that has been studied for the last sixty years. Some of the important discoveries that have been made during this time is that the nucleus can exhibit a variety of excitation mechanisms which include single particle, collective-rotation and vibration and intermediate which include magnetic and anti-magnetic rotations [1,2,3]. The other excitation mechanisms that are being explored widely these days is chirality and wobbling [1,4]. Shape co-existence and the emergence of new magic numbers [5,6] around the neutron and proton driplines are other interesting features that are being explored.

When nuclei are populated using accelerators like that in TIFR, Mumbai or IUAC, New Delhi, it's not possible to populate the nuclei around the dripline as both the target as well as the beam used in the accelerators involve stable nuclei. There are two possible ways to populate the nuclei around the driplines: using radioactive ion beam or a neutron (proton) beam. Since we do not have the radioactive ion beam facility available in India as of now, the neutron beam is the only possibility to populate the nuclei around high isospin. Since the neutrons are produced in abundance at Dhruva Research Reactor, the neutrons can be harvested to populate the high isospin nuclei and investigate the nuclear structure at the extremes of spin and isospin. A strong Coriolis interaction acting on the orbitals with high-*j* values transforms particle-unbound nucleonic configurations i,e resonances into particle-bound ones with increasing spin [7]. The point of the transition manifests the birth of particle-bound rotational bands. I would like to explore this phenomenon by populating nuclei around the neutron dripline using the neutron beam along with the study of the emergence of new magic numbers.

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Inelastic neutron scattering measurements at Dhruva reactor: Materials of interest in nuclear reactors

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Beryllium oxide (BeO) is a high temperature ceramic nuclear material that possesses good neutron scattering properties and plays a significant part in the design of nuclear reactors and nuclear power plants. In particular compared to graphite, BeO moderates fast neutrons to thermal range more efficiently [1,2]. On the other hand, silicon carbide is the most promising material for next generation fusion and fission reactors to be used as structural material and cladding material [3]. The phonon density of states (PDOS) gives the number of modes per unit frequency per unit volume of real space and can be used to calculate the experimental heat capacity and test lattice dynamical models.The PDOS for BeO and SiC are computed using a lattice dynamics code, Quantum Espresso (QE) [4]. Figure 1 shows the PDOS curves computed using QE software. The technique of inelastic neutron scattering provides a way of probing the phonon density of states. Measurements of the phonon density of states at room temperature have been performed employing the Triple axis spectrometer available at DHRUVA reactor in BARC. The theoretical calculations and data from measurements show good agreement. The phonon density of states is further employed to compute the specific heat and other thermodynamic properties, including phase transitions.

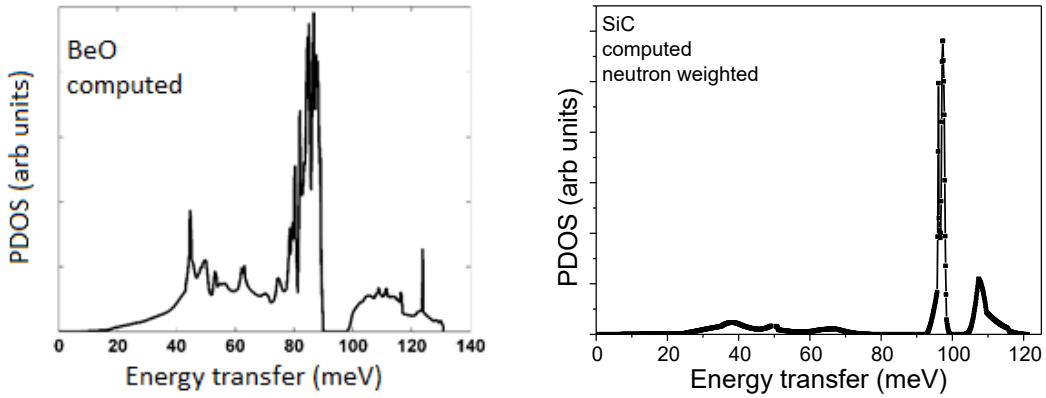

Fig 1: Computed phonon density of states for BeO, and SiC

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Sodium salt-Tetronic binany system as a proposed polymer gel electrolyte: A SANS study

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High ionic conductivity is offered by electrolytes present in batteries in aqueous environment. These are non-flammable, economic and propose high energy density. Though, the seepage of water and its restricted thermodynamic electrochemical stable potential window overpowers the use of these batteries. To address these problems, development of a polymer-based electrolyte system is an upcoming area of research. Even, due to the abundance and economic feasibility of sodium salts, the uses of sodium salts in battery electrolytes are gaining importance over lithium salts. The present study explains the self-assembly of block copolymer Tetronic® 1107 in the presence of sodium salts viz. sodium chloride, sodium fluoride, sodium nitrate, sodium hexafluoro phosphate and disodium hydrogen phosphate with different anions by cloud point (CP), gelation, dynamic light scattering (DLS) and small angle neutron scattering (SANS) [1, 2] in aqueous medium. Conductivity measurements are also performed for the block copolymeric system in the presence and absence of sodium salts. The gelation behaviour of the block copolymer to decrease leakage problems and appropriate ionic conductivity of the system in the presence of sodium salts make the system a reliable choice as a polymer gel electrolyte (PGE).

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Ordering of clay in chitosan films

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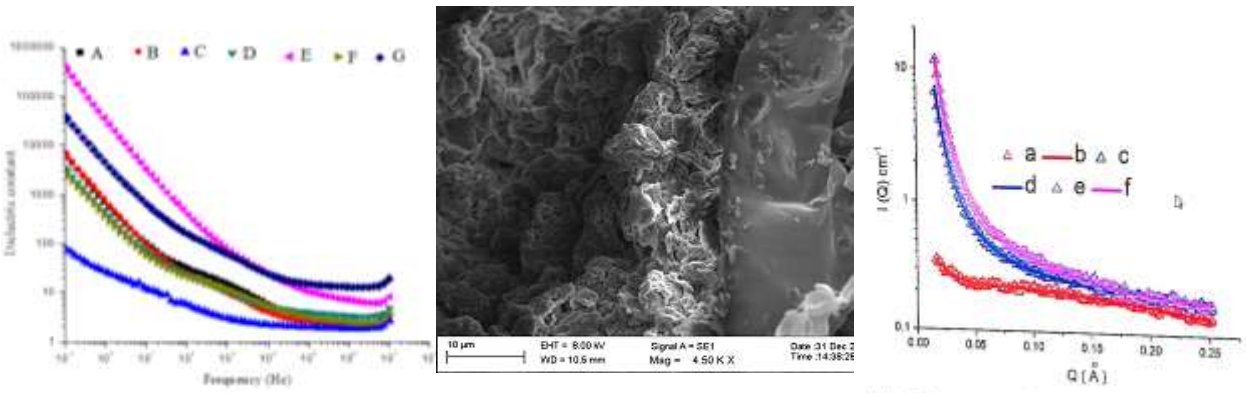
Inclusion of fillers in polymers is an active area of research. In this research we have studied the dielectric and SANS analysis of clay (bentonite) included chitosan films. Chitosan is an abundantly available biopolymer and it has advantageous properties such as biocompatibility, nontoxicity, and excellent film forming capacity. Clay minerals have several applications such as fire retardant materials, fillers, purifiers and adsorbents [1]. Bentonite is an abundantly available clay mineral and it possesses a 2-to-1 layered structure with a single octahedral aluminum layer located between two layers of tetrahedral silicon. In this research, characterization of Chitosan/Bentonite Nanocomposites was done using Broad band Dielectric Spectroscopy (BDS), Scanning Electron Microscopy (SEM), and Small angle neutron scattering (SANS). SANS measurements showed that Bentonite arranged as fractals in the chitosan membranes. The radius of gyration (R_g) value for the chitosan polymer is found to be $\sim 6.0 \pm 0.5$ nm. When Bentonite was added to chitosan in the ratios 1:1 and 1:2 the fractal dimension was observed to be 2.60±0.02 and 2.63±0.01. Chitosan-bentonite in the ratio 1:2 showed conductivity value of 6.03×10^{-8} S/Cm. The Conductivity of the sample increased with increasing bentonite concentration. Our investigations show that inclusion of Bentonite affects morphology, dielectric and electrical characteristics of the chitosan films. SEM images showed that the clay nanoparticles were embedded inside the film with smooth surface. This research could benefit our understanding of ordering of ceramic fillers in polymer composites. It could benefit research in using clay minerals for battery technology.

(I) (II) (III)



Figures: (I) dielectric constant for (A) chitosan (B) chitsan bentonite (1:1), (C) chitsan bentonite (1:2), (D) chitsan bentonite (1:1.5), (E) chitsan bentonite (1:4), (F) chitosan 1gm – Rhodamine 5mg, (G) chitsan 1gm – bentonite 1 gm – Rhodamine 5 mg (II) SEM for chitsan bentonite (1:4) film. Scale bar is 10 µm, and (III) SANS data (I(Q) vs Q) for (a) chitosn film (b)chitosn film fitted, (c) chitosan bentonite (1:1), (d) chitosan bentonite (1:1) fitted,(e) chitosan bentonite (1:2) and (f)) chitosan bentonite (1:2) fitted.

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Inelastic neutron scattering studies and simulations on stoichiometric and Li deficient $Li_{1-x}FePO_4$ (x = 0, 0.25, 0.5)

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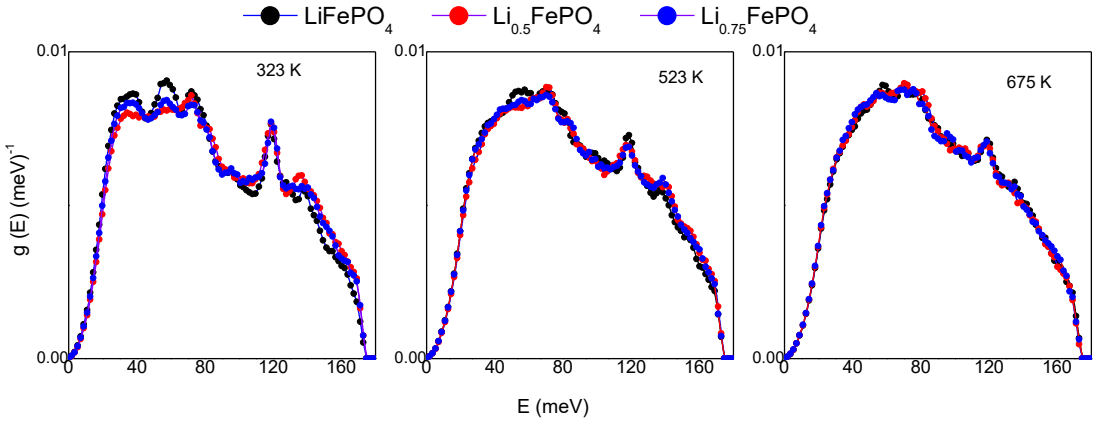
Lithium ion batteries find widespread use in portable electronic devices and a promising material for electric vehicles. Due to its good thermal stability, low cost, safety, environment friendliness $LiMPO_4$ (M = Fe/Mn) are important cathode materials for lithium batteries. Here we report our neutron inelastic scattering studies to understand the vibrational properties of these materials with increasing temperature in conjunction with theoretical molecular dynamics simulations. These simulations using AIMD (ab-initio molecular dynamics) have been used as a central tool for understanding interactions and dynamics of lithium atoms. The process of delithiation and lithiation form the crux of these batteries during operation. Our aim is to understand the process of lithium diffusion microscopically and understand the role of phonons, vacancies and host dynamics in this process. We have measured phonon density of states in stoichiometric and Li-deficient $Li_{1-x}FePO_4$ (x=0,0.25,0.5) from 323 K to 675 K. Our studies aim to investigate the Li diffusion processes and role of phonons in stoichiometric and Li-deficient $Li_{1-x}FePO_4$ (x=0,0.25,0.5).

Fig. 1: Experimental Data of the phonon density of states in stoichiometric and Li-deficient $LiFePO_4$.



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Stabilization of Ferroelectric Phase in Sodium Niobate: A Powder Neutron Diffraction Study

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Materials having antiferroelectric property possess a unique opportunity in the energy storage application due to the electric field-induced phase transition. Room temperature antiferroelectric phase of sodium niobate can be suppressed and ferroelectric phase could be stabilized by structural engineering of materials lead free materials with perovskite structure gained great deal of attention because of their wide range of applications [1,4]. We have structurally engineered ferroelectric phase in $NaNbO_3$ by the application of chemical pressure. The neutron powder diffraction data have been recorded on sample in the 2θ range of 4°–138° with a step of width of 0.05° using neutrons of wavelength of 1.2443 Å on a medium resolution position sensitive detector based powder diffractometer at the Dhruva Reactor in Bhabha Atomic Research Centre. The temperature dependent measurements from 6 K to 300 K are carried out using a cryomagnet in zero field. In order to explore phase stability of this ferroelectric phase with temperature, we analyzed the temperature dependent powder neutron diffraction data upto cryogenic temperatures (see figure 1). Temperature dependent neutron diffraction patterns do not show appreciable change either in intensity or appearance/disappearance of the observed peaks down to 6 K, ruling out any structural transition in the entire temperature range of 300 K to 6 K. All lattice parameters and volume exhibit regular thermal expansion behaviour, indicating no abnormal structural changes with increasing temperature. From the linear fitting of lattice parameters, the coefficient of thermal expansion (a/K) of compounds along the principal crystallographic axes and volume were found to have values of 10.6×10^{-6}, 9.40×10^{-6}, 8.30×10^{-6} and 28.3×10^{-6} K^{-1} respectively. The small difference among these three values suggests that it is almost thermally isotropic material. Total spontaneous polarization was estimated using refined structural data to be ~ 3.2 μC cm^{-2} at 6 K.

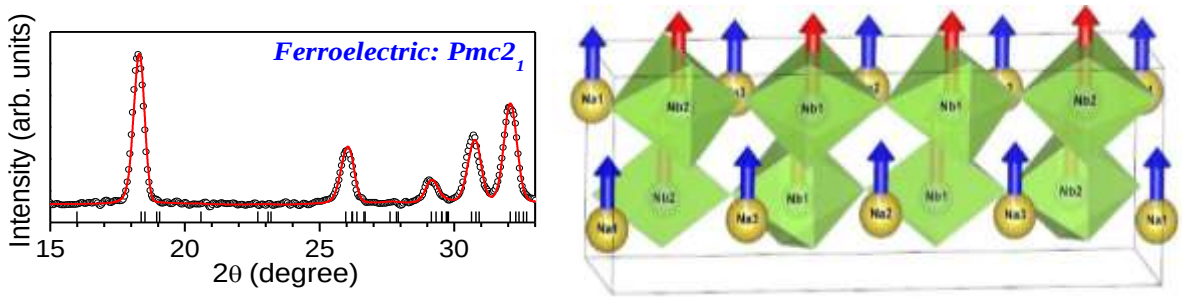

Fig. 1: (Left side) Observed (dot), and calculated (continuous line) profiles obtained after the Rietveld refinement using ferroelectric (*$Pmc2_1$*). Crystal structure of ferroelectric phase ((Pmc21) is shown on right side.

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Neutron as a probe to investigate magnetization reversal phenomenon in spinel compounds, $CoCr_{2-x}Fe_xO_4$

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The magnetization reversal phenomenon, where the net magnetization of a sample changes its sign at compensation temperature (T_{Comp}) when sample temperature is lowered below the magnetic ordering temperature (T_C), is very important from fundamental as well technological aspects [1]. We have observed a temperature dependent reversal of field-cooled magnetization in the x = 0.1 and 0.15 compounds [Fig. 1 (a)] of the series, $CoCr_{2-x}Fe_xO_4$. Neutron depolarization and neutron diffraction techniques have been employed to investigate the origin of magnetization reversal in this series. The $x \leq 0.15$ compounds crystallize in a face centered cubic (space group: Fd-3m) structure where Co^{2+} and $(Cr_{2-x}Fe_x)^{3+}$ ions occupy the tetrahedral and octahedral sites, respectively. For $x > 0.15$, a distribution of Co^{2+} and Fe^{3+} ions at both the sites is observed. The neutron depolarization study, that probes magnetic correlations at mesoscopic length scales, infers that the average magnetization of each domain becomes zero at the T_{Comp} for x = 0.1 and 0.15 [Fig. 1(b)]. The ordered tetrahedral and octahedral moments, deduced from temperature dependent neutron diffraction study [Fig. 1(c)], reveal that the unequal growth of the antiferromagnetically coupled tetrahedral and octahedral site moments plays an important role in realizing the magnetization reversal in the $CoCr_{2-x}Fe_xO_4$ series [2,3].

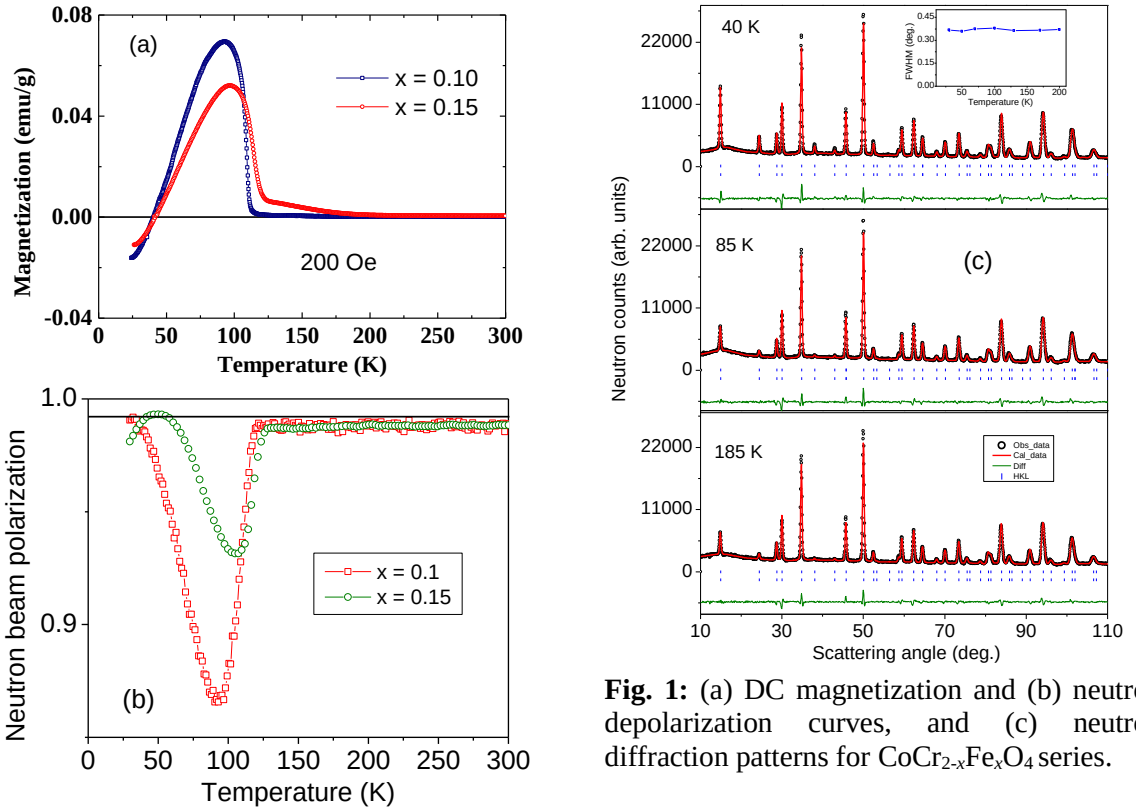

Fig. 1: (a) DC magnetization and (b) neutron depolarization curves, and (c) neutron diffraction patterns for $CoCr_{2-x}Fe_xO_4$ series.

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Modulation of Diffusion Mechanism and it's Correlation with Hydrogen Bond Dynamics in Aqueous Deep Eutectic Solvents

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Aqueous mixtures of deep eutectic solvents (DESs) have gained traction recently as an effective template to tailor their physicochemical properties. But detailed microscopic insights about the effects of water on molecular relaxation phenomena in DESs are not entirely understood. DESs are strong network forming liquids due to the extensive hydrogen bonding between their species and therefore water can behave as a controlled disruptor altering the microscopic structure and dynamics in DESs. In this study, we investigate the role of water on the diffusion mechanism of acetamide in the aqueous mixtures of DES synthesised using acetamide and lithium perchlorate. Quasielastic neutron scattering (QENS) experiments have been carried out on DES sample with and without 20 (*w/w*) % D_2O using MARX spectrometer [1] in Dhruva reactor located at BARC, Trombay, India. The spectrometer has an energy resolution of 200 μeV and energy transfer range of ±1 meV, which is suitable to observe dynamics in range of 1 ps to 20 ps. D_2O was chosen instead of H_2O in order to avoid the scattering contribution of water-hydrogen in the DES and enhance solely the contribution from acetamide-hydrogen in the system. To gain microscopic insights, classical molecular dynamic simulations have also been carried out on DES with different concentrations of D_2O. The acetamide dynamics comprise localised diffusion within transient cages and jump-diffusion process across cages [2]. The jump-diffusion process is observed to be strongly enhanced as the water content in the system is increased, showing almost a ten-fold increase [3]. Meanwhile, the geometry of the localised dynamics is unaltered by the addition of water but the localised diffusion becomes significantly faster and more heterogeneous with increasing water concentration. The accelerating effects of water on localised diffusion are also substantiated by QENS experiments. The hydrogen bond relaxation dynamics in the DES is investigated to establish its correlation with the diffusive processes in the system. The addition of water is found to decrease the lifetime of hydrogen bond complexes, indicating that the addition of water can provide a mechanism to control the structural relaxation in the DES. A power-law scaling relationship is obtained between the diffusivities and hydrogen bond lifetimes surmising a decoupling phenomenon similar to viscosity-diffusivity decoupling inferred from the fractional Stokes-Einstein relationship. This study sheds light on the role of water on the diffusion landscape of DES and establishes a correlation between hydrogen-bond dynamics and diffusion processes.

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Utilization of neutron diffraction technique to determine the microscopic structure of Th-U-Mo alloys

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Thorium-Uranium alloys are considered to be potential nuclear fuel materials. With the incorporation of Molybdenum, the Uranium stabilizes in the gamma (γ-U) phase [1]. This gamma phase of Uranium is desired in fuel materials due to its isotropic thermal expansion character and irradiation stability. To optimize the amount of Mo in the alloy it is essential to determine the correct phase fraction of Uranium as a function of Mo concentration. Also the Th metal gets oxidized and forms ThO_2. In these materials it is essential to quantify phase fraction of Thoria (ThO_2). For this we have made use of both x-ray diffraction and neutron diffraction techniques and also drawn a comparison between the two.

Neutron diffraction experiment has been performed at Powder Diffractometer 2 (PD-2) at Dhruva research reactor, BARC. The wavelength of monochromatic neutrons was 1.2443 Å. Data collections were performed with Debye-Scherrer geometry in the 2θ range 6˚-135˚ with a step size of 0.1˚. To obtain structural model, Rietveld refinement of the neutron and X-ray diffraction data was carried out using FullProf Suite software.

With the addition of Mo in the system, the α-U changes to γ-U crystalline phase. γ-U exists in bcc crystal structure and show isotropic thermal expansion behavior. With temperature the changes in the lattice are equal in all three directions and this is a desired property to make nuclear fuel more stable. We have performed x-ray and neutron diffraction experiments to quantify the phase fraction of γ-U with respect to Mo concentration. For $Th_{0.67}U_{0.30}Mo_{0.03}$ systems, we observed that most of the U is present in gamma phase. With incorporation of only 3% Mo we were able to achieve complete γ-U phase. For $Th_{0.67}U_{0.30}Mo_{0.03}$ systems, we observed different values of ThO_2 crystalline phase fraction in x-ray and neutron diffraction studies. As the oxidation of Th is more prominent on surface and Cu k-α x-rays probe the heavy z-element materials on the surface so we observed a larger fraction (15%) of ThO_2 phase. Whereas neutrons with large penetration depth will give us the more accurate information of the bulk. From neutron diffraction we observed the ThO_2 phase fraction around 3% and this is in agreement with chemical analytical techniques. We propose that for such materials, neutron diffraction can be utilized which is non-destructive in nature.

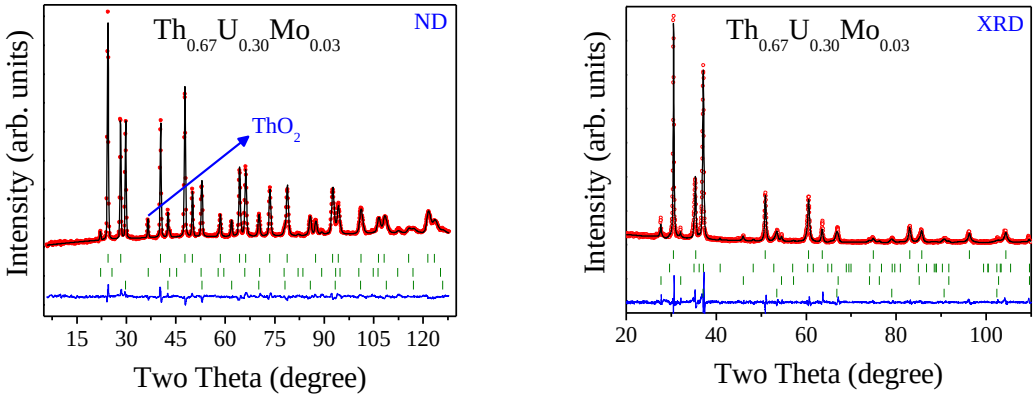

Figure 1. Rietveld refinement fit of Th-U-Mo alloy: Neutron and X-ray Diffraction.

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Origin of enhanced leaching resistance in Lead Phosphate glasses: A neutron diffraction study

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Lead iron phosphate (LIP) glasses are used for the immobilization of radioactive nuclear waste materials. Addition of 10 weight % of Iron Oxide into the lead phosphate matrix causes the leaching resistance to increase by a factor of 10^4 in comparison to binary lead phosphate glasses. This large increase in the leaching resistance is unusual and in order to evaluate the effect of iron oxide on the structural stability of Lead Phosphate glasses, Reverse Monte Carlo modelling of the total neutron diffraction has been performed.

Glass samples of lead iron phosphate of compositional formula [1-x] $Pb(PO_3)_2$ + [x] Fe_2O_3{x = 0, 0.06, 0.09, 0.20} were prepared. Powdered form of the glasses was used for total neutron diffraction experiment using the GEM diffractometer, ISIS, RAL, UK. Figure shows the RMC fit of the experimental structure factor for all compositions. By utilization of RMC modelling, a 3D model of the atoms have been created and from there partial pair distribution functions of each atomic pair have been calculated. For P-O atomic pair, first neighbor distribution shows a characteristic peak around 1.50 Å with covalent bond length distribution ranging from 1.4 Å to 1.8 Å. The presence of shoulder to the peak indicates the two different types of P-O bond contributions. The peak around 1.43 Å corresponds to double bonded terminal oxygen atoms and the peak around 1.56 Å is due to single bonded bridging oxygen atoms. This is in consistency with the bond lengths present in threefold linked PO_4 units.

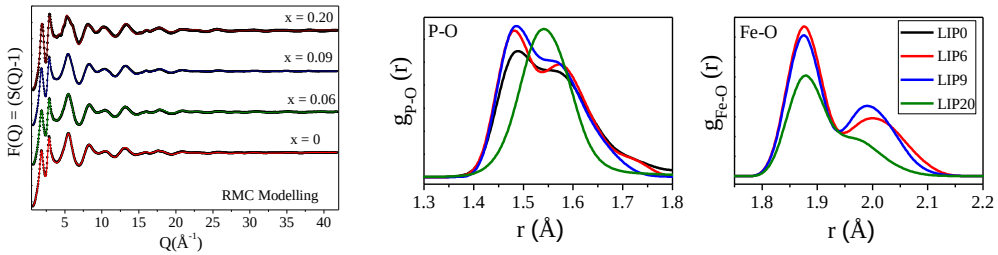

Fig.: Experimental neutron diffraction structure factor (dots) along with RMC modelling (solid line). The partial pair correlation functions for P-O and Fe-O atomic pairs are also shown.

For LIP0, two types of bonds can be clearly distinguished whereas for LIP20 only single peak is observed and the peak center is also shifted to higher values. As the Fe^{2+}/Fe^{3+} ions enter the glass matrix, they tend to break the P=O bond and form a 3-D network. Accordingly, as the concentration of Fe_2O_3 is increasing more and more terminal oxygen atoms are getting converted into bridging atoms. This can be associated with increase in leaching resistance property with Fe_2O_3 concentration. Terminal oxygen atoms are susceptible to aqueous corrosion as OH^- ions can easily combine with it. Hence, conversion of terminal oxygen into bridging oxygen and developing a 3-D network in the presence of Fe_2O_3 is essential for improved leaching resistance. The metal ions bond with non-bridging oxygen atoms of each PO_4 tetrahedra and establish cross linking between two polyphosphate chains.

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Emergence of quantum behavior in $CaHFO_3$

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Calcium hafnate ($CaHfO_3$) based ceramics have potential applications in Microwave resonators which are essential components for wireless communication devices. At room temperature, it has orthorhombic structure (space group *Pnma*) with a = 5.731 Å, b = 7.981 Å and c = 5.570Å which is analogous to widely studied $CaTiO_3$. Considering the structural similarity and congeneric character between $CaTiO_3$ and $CaHfO_3$, it will be of interest to investigate occurrence of non-polar phase at cryogenic temperature.

A polycrystalline sample of $CaHfO_3$ has been synthesized by using solid state reaction method. The neutron powder diffraction data in the temperature range of 2 K to 300 K have been recorded on Powder Diffractometer-2 (PD-2) at the Dhruva Reactor in BARC.

At ambient conditions, structure of $CaHfO_3$ can be described as a combination of two kinds of HfO_6 octahedron tilts: two out-of-phase tilts along <100> and <001> directions, and one in-phase tilt along <010> direction. It can be expressed as $a^-b^+c^-$ tilt system in Glazer's notation. Figure shows the Rietveld refinement results of neutron diffraction patterns at 2K and 300K. It is evident from this figure that the orthorhombic phase (space group *Pnma*) accounted for all the reflections in the entire temperature range of 2 K- 300 K. The Bragg peaks appearing at 2θ ~ 25.5˚, 30.1˚, 36.3˚ are indexed as main cubic perovskite peaks $(110)_{pc}$, $(111)_{pc}$ and $(200)_{pc}$ respectively whereas the peaks appearing around 2θ ~ 28.7˚, 30.01˚, 32.6˚ are superlattice reflections arising due to cationic displacement, M-point modes (in-phase tilting) and R-point modes (anti-phase tilting) respectively. It is interesting to note that volume is decreasing on lowering temperature from 300 to 100 K and then becomes nearly temperature independent up to 2K. Classically, a linear relation ($V(t) = V_0 + \alpha t$) in unit cell volume and temperature is expected, but the deviation from this behaviour indicates the emergence of quantum behaviour at low temperatures. It can also be observed that spontaneous strain, orthorhombicity and tilt angle increase in the temperature range 2 K≤ T≤75 K and then decrease in the temperature range 100 K≤ T≤ 300 K.

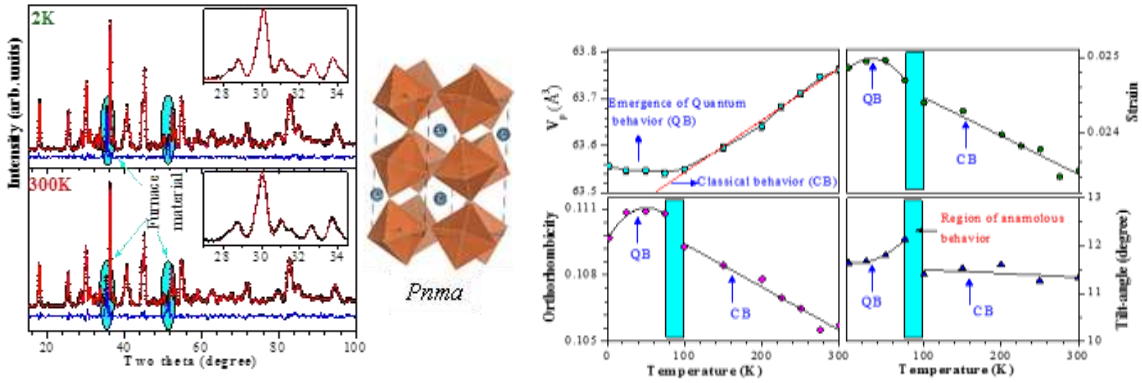

Fig. Rietveld refinements of neutron data. Schematic of tilted HfO_6 octahedra is shown. Variation of structure parameters: volume, strain, orthorhombicity and tilt-angle with temperature is also shown.

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Interlocking Dendritic Fibrous Nanosilica into Microgranules by Polyethyleneimine Assisted Assembly: In-situ Neutron Scattering and CO_2 Capture Studies

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Amine-based solid nano-adsorbents have shown tremendous potential for mitigating the CO_2 emissions from fossil fuel-based power plants. The conventional approaches for achieving nano-adsorbents utilize the loading of the amines in well-defined mesopores which face several challenges including, pore blocking, slow adsorption kinetics, and pressure drop in the temperature swing adsorption/desorption cycle. These challenges were resolved by using dendritic fibrous nano-silica (DFNS), with unique fibrous morphology consisting of both mesopores and macropores1. However, the nanosized particles of DFNS did not allow efficient use of these sorbents for CO_2 capture with required stability and kinetics. In this work, we report the synthesis of DFNS microgranules using the one-step evaporation induced assembly of the nanometer-sized DFNS particles and polyethyleneimine (PEI), keeping textural properties of the DFNS intact. Two-dimensional fast Fourier transform (2D FFT) of the high-resolution micrographs shows an intriguing order to disorder transition in the jamming of DFNS in presence of PEI. This disordered jamming of DFNS led to the formation of voids causing increased accessibility of DFNS internal pores. Further, the interstices between the jammed DFNS provides additional space to immobilize PEI therefore PEI loading capacity of DFNS microgranules remains inherently higher compared to bare DFNS particles. The PEI incorporated DFNS microspheres show fast CO_2 adsorption kinetics of ~6.5 mmol min^{-1}/g with good adsorption capacity that was attributed to the connectivity between mesopores and macropores as evident from in-situ neutron diffraction measurements at high pressure CO_2. In-situ neutron diffraction provided crucial experimental evidence of the connectivity of mesopore and macropores for the first time refining the enigmatic DFNS structure. PEI-loaded DFNS microgranules showed good CO_2 capture and cyclic stability over 20 cycles is found to be excellent caused by strong immobilization of unabsorbed PEI in the interstices of the microgranules.

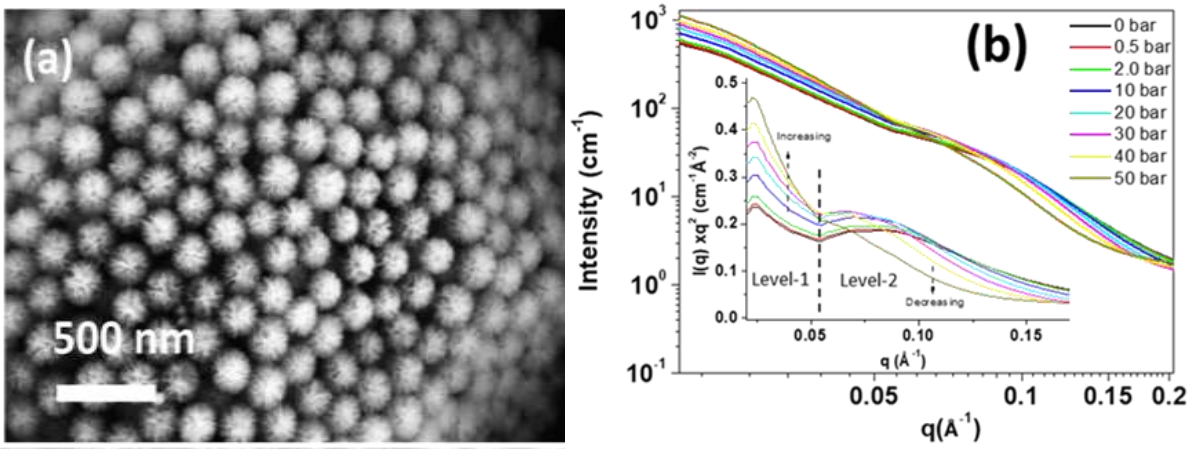

Figure 1 (a) The interlocked PEI incorporated fibrous silica (b) SANS profiles at different CO_2 pressure.

Correlating Cation Distribution to Magnetic Properties of Ni-Zn Ferrites through Neutron Diffraction

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Mixed spinel Ni-Zn ferrite with high resistivity and good magnetic properties has been considered as one of the potential candidate for its multifunctional application potentiality. Its degree of inversion basically depends on the cation distribution which in turn affects its magnetic as well as other properties. Determination of cation occupancy along with position is one of the important features to detect the composition dependent properties in Ni-Zn ferritesystem. The presence of oxygen vacancies in such materials plays the crucial role in controlling the magnetic as well as other properties. The detection of the same can easily be noticed employing neutron diffraction (ND) technique. Hence, the determination of cation distribution using ND technique and its correlation to various properties of Ni-Zn ferrites are of essential.

The work is proposed to be carried out using thermal neutron beam at research reactor facility like Dhruva reactor with help of Scientists from BARC (SSPD). In addition chemical composition of materials will be pursued using NAA and other techniques in a collaborative basis under a suitable project with BARC.

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Evolution of Magnetic Structure in $La_{0.35}Bi_{0.35}Sr_{0.3}MnO_3$: A Neutron Diffraction Study

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The evolution of magnetic structure in $La_{0.35}Bi_{0.35}Sr_{0.3}MnO_3$ has been studied by neutron powder diffraction recorded as a function of temperature in the range 50 – 300 K and also in the presence external magnetic fields up to 5 Tesla. The composition $La_{0.35}Bi_{0.35}Sr_{0.3}MnO_3$ represents a case where *A*-site is occupied with an equal atomic percentage of La^{3+} (35%) and Bi^{3+} (35%). The compound also exhibits multiple magnetic ordering as a function of temperature. The sample undergoes a paramagnetic (PM) to ferromagnetic (FM) transition at T_C = 286 K followed by FM to antiferromagnetic (AFM) transition at 270 K. In addition to the above, a hump in ZFC and FC curve of magnetic susceptibility, has been noticed between the temperature range 260 – 180 K, which is followed by an upturn in magnetization below 100 K. The magnetic isotherms recorded at 100 K demonstrate field induced metamagnetic transition, suggesting coexistence of FM and AFM interactions in the compound [1-2]. The thermo-diffractograms obtained reveal the appearance of new reflections on cooling the sample below 150 K. These reflections increase in intensity with a decrease in temperature. The new peaks are indexed considering two propagation vectors namely, [k1= 0 0 0] and [k2 = 0 0 ½] [3]. The magnetic structure is found to be a complex mixture of A-type [k1 = 0 0 0] and canted pseudo-CE type (pCE) [k2 = 0 0 ½] at T = 100 K which transforms to be canted A-type AFM and canted pCE-type at T = 55 K. The detailed study of the neutron diffraction data have been presented and discussed to understand the evolution magnetic structure under the influence of temperature and external magnetic fields.

Acknowledgement: ADS is thankful to DST, India for INSPIRE fellowship (IF 170553). Authors thank Dr. S. D. Kaushik for neutron diffraction data.

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Development of nanoformulations for boron neutron capture therapy using thermal neutron beam from research reactors at BARC

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Boron neutron capture therapy (BNCT) has evolved as a powerful alternative cancer therapy platform by delivering ^{10}B rich compounds to the tumor and irradiating with thermal neutrons. For successful implementation of this therapeutic approach, it is necessary to specifically deliver such boron compounds to the target site. Nanoformulation with specific functional groups or receptor molecules could as a delivery platform for site specific targeting. It is proposed to develop novel nanoparticles with sufficiently high boron loading and investigate its therapeutic potential by irradiating with thermal neutron from the research reactors at BARC. This proposal aims to utitlise the thermal neutron beam lines to investigate the in-vitro and in-vivo efficacy of various boron containing formulations for cancer therapeutics. PEG coated micelles, metallic and magnetic nanoparticles with tumor specific receptors will be employed as a novel carrier for the delivery of the BNCT agents. The experiments will be performed in collaboration with SSPD and RCD and utilizing the reactor facilities in BARC.

Design proposal of India's first intense positron facility

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Design parameters of an intense positron beam to be installed in R3002 beamhole of Dhruva Research Reactor will be presented. Thermal neutrons from the reactor core will be intercepted by a thin cadmium sheet where they will undergo ^{113}Cd (n, γ)^{114}Cd reaction. This nuclear reaction will result in a bright capture gamma source with roughly ~1 photon in forward direction above the electron-positron pair production threshold per thermal neutron. The capture gamma photons will interact with a suitably designed tungsten moderator assembly placed in a vacuum enclosure along with beam conditioning aluminum lenses. The high energy positrons that are pair produced in the tungsten foils will be self-moderated resulting in an intense flux of slow positron beam. The slow positron beam is transported outside the biological shield through a ~3 m long solenoid tube which maintains a uniform axial magnetic field of ~5mT- 7mT. After exiting the biological shield, the positron beam will be bend through a 2m x 2m x 2m neutron and gamma layered shield to filter the streaming radiation from the reactor core. Our simulations suggest an intensity of ~1x10^7 e^+/s positrons in a ~10 mm diameter which is comparable to the various other similar sources operating worldwide [1-3]. The intense positron beam will be used to study defect evolution in nanosecond time scale and will be complimentary to the time resolved Laser induced pump-probe experiments.

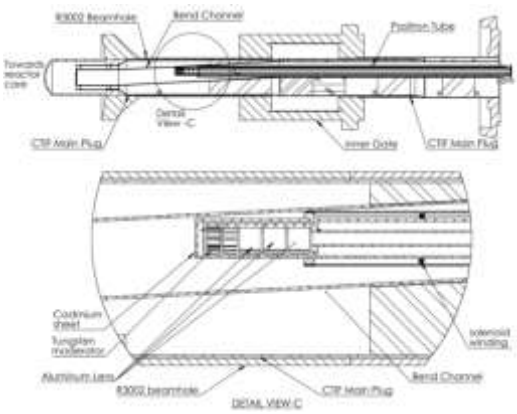

Fig. 1: Schematics of the positron tube placed in R3002 beamhole. The preexisting Controlled Temperature irradiation facility (CTIF) [4] assembly will not be removed and is considered as fixed part of R3002 beamhole.

Acknowledgements:
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Non-destructive and non-invasive neutron imaging probing of the change in biochemical profile of the maize seedlings upon the treatment of transition metal oxide nanoparticles

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Due to unique properties of nanoparticles like greater surface area, large surface energy, high reactivity, large ultraviolet radiation absorption, strong light scattering, anti-corrosion, and photocatalysis, microscopic quantum tunnelling effect, low melting point etc, these are widely used nowadays in various field of science like agriculture, biomedical, chemical industries, pharmaceutical industries, horticulture etc. The large consumption and increasing use in the products lead to the discharge of nanoparticles in atmosphere (soil, water, air). Therefore, interaction of the nanoparticles with biotic components of the environment is expected. In the current study, potential of the different spectroscopic techniques has been explored for the assessment of the change in pigments of the leaf of the maize seedlings due to the treatment of the different concentration of the transition metal oxides nanoparticles. For this, the maize seedlings have been grown inside the laboratory under the controlled conditions such as light flux, temperature and humidity. Various spectroscopic probes like laser induced fluorescence, Raman, ultraviolet-visible measurements have been used for the assessment of the alteration of the biochemicals due to the treatment of different concentration of the transition metal oxide nanoparticles. Since the plant tissues like root, stem, leaf, flower and fruits are heterogeneous in the distribution of the various biochemical and mineral elements. Therefore, imaging techniques are expected to yield more fruitful results regarding the uptake, distribution and biochemical formation.
Therefore, we have decided to apply imaging techniques for the assessment of the change in biochemicals and mineral elements using neutron scattering based imaging techniques. The use of non-invasive methods such as X-ray and neutron scattering provides an attractive complimentary source of information to direct imaging because in vivo systems can be probed in near-natural conditions. The study will also provide the better information about the uptake, distribution and chemical states of the treated nanoparticles in different parts of the maize seedlings.

Molybdenum sulphide integrated mesoporous carbon derived from wood sand for fuel cell & Neutron imaging of fuel cells

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Fuel cell is one of the alternative sources of energy compared to traditional energy sources. Oxygen reduction reaction (ORR) is one of the complementary reactions of the fuel cells [1, 2]. Generally, Platinum and palladium are the most common commercial electrocatalyst for fuel cells. The high cost and low abundance of these commercial catalysts restrict the wide availability of commercial fuel cells. So, it is necessary to replace these catalysts with cheaper and more efficient catalysts. Mesoporous carbon (MC) has a wide range of applications in supercapacitors, batteries, fuel cells, etc. [1-3]. In this work, MC was developed from the wood sand of the Teak Plant using chemical activation, thermal pyrolysis, and hydrothermal reactions. The electrocatalytic activity of the MC was further enhanced with the composite of MoS2 (MC/MoS2). The modified electrode of MC/MoS2 coated on GC (GC/MC/MoS2) exhibits the high electrocatalytic activity for ORR. The modified GC/MC/MoS2 could be a suitable alternative to replace the commercial electrocatalysts. In addition, neutron imaging of fuel cells was used to visualize the water distribution in operative polymer electrolyte fuel cells. It also monitors the different issues related to the water management [5, 6]. Neutron imaging of the proposed fuel cells would be analyzed in the next step of this work.

Acknowledgements: PKS acknowledges the University Grant Commission (UGC, No.F.30-431/2018 (BSR)) and Institute of Eminence (IoE), Seed Grant, Banaras Hindu University (scheme number: 6031), India for financial support.

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Recent results from ISMRAN experiment for reactor based anti-neutrino studies

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Indian Scintillator Matrix for Reactor Anti-Neutrinos (ISMRAN) is an above-ground reactor anti-neutrino experiment at very short baseline located at Dhruva reactor facility in Bhabha Atomic Research Centre, Mumbai. A moderate ~1 ton detector by volume to very close distances from reactor core can address the physics of sterile neutrino searches and anti-neutrino spectra anamoly [1]. The ISMRAN detector setup consists of 90 plastic scintillator (PS) bars, each having a dimension of 10cm x 10cm x 100cm and wraped with Gadolinum foils, arranged in a matrix of 9 x 10 inside a passive shielding of 10 cm lead and 10 cm borated polyethylene.

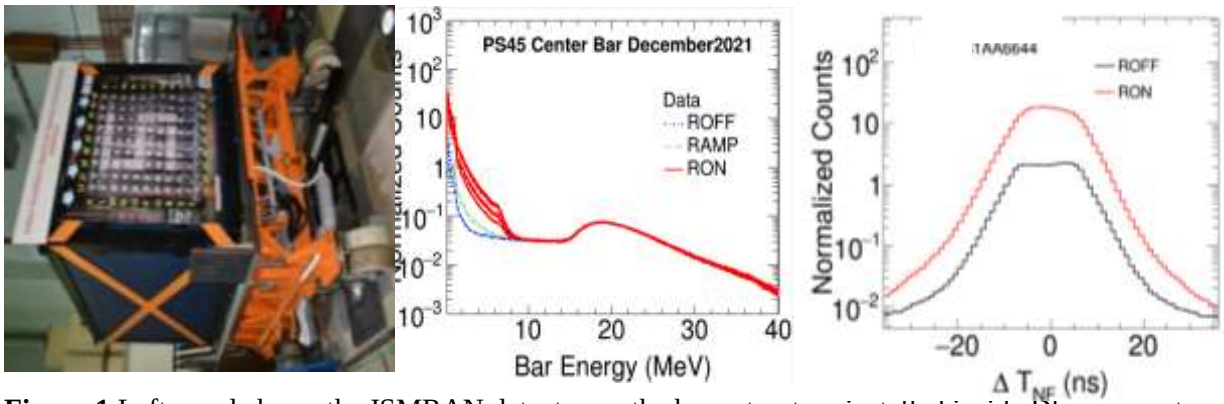

Figure 1 Left panel shows the ISMRAN detector on the base structure installed inside Dhruva reactor hall. Right panels shows the energy and timing spectra from one PS bar.

The complete setup for ISMRAN, as shown in Figure 1 left panel, is housed on a movable base structure and placed at a distance of ~13m from the Dhruva reactor core. Anti-neutrinos are indirectly detected by measuring the response of positron and neutron signals, produced by inverse beta decay, inside the ISMRAN volume. A first analysis from a proto-type detector, mini-ISMRAN, which was 1/16 of the volume of the full scale ISMRAN was installed and took data in year 2018. The analysis of the data from mini-ISMRAN lead to an observation of total of 218±50(stat.)±37(sys.) anti-neutrino events from 128 days of RON data [2]. ISMRAN experiment will provide, for the first time, the measurement of anti-neutrino energy spectra from a natural uranium fueled core. Sensitivity studies involving the searches for sterile neutrinos will be another interesting aspect to explore with ISMRAN data.In this talk, we will present results for the measurements of anti-neutrino candidate events from a prototype detector, mini-ISMRAN, which is 1/16 of the volume of ISMRAN. We will also discuss the ongoing efforts on the measurements of the anti-neutrino signals from the full scale ISMRAN setup which is currently installed, comissioned and taking data in Dhruva reactor hall since November 2021.

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Neutrino physics studies using ISMRAN detector at Dhruva reactor

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Neutrinos are the second most abundant particles in the universe. In the standard model (SM) of particle physics, there exist three flavours of neutrinos such as ν_e , ν_μ , and ν_τ associated with correpsonding leptons viz. e, μ and τ . These neutrinos are considered to be massless in the SM. It is established that neutrinos have non-zero masses by using solar, atmospheric and reactor neutrinos. Nuclear reactors are copious source of electron antineutrinos (ν_e). About 10^{20} ν_e's produce per second from a reactor of thermal power of 1 GWth . A wide range of physics goals can be addressed such as, exploration and validating the existence of sterile neutrino and remote monitoring reactor thermal power measuring the ν_e's from the reactor. There are several short-baseline measurements that have observed an anomalous and unexplained excess of the reactor ν_e's flux. This is known as the "reactor antineutrino anomaly". To address this anomaly, at present several short-baseline experiments are going on all over the world. An overground one-ton Indian scintillator matrix for reactor anti-neutrino (ISMRAN) detector has been installed in Dhruva reactor hall to explore some of the above physics goals.

In this presentation, we will discuss the feasibility of measuring sterile neutrino using the ISMRAN detector setup by varying both the reactor and detector related parameters. Further, to reduce the systematic uncertainties due to reactor as well as detector, we have considered various possible combinations of near and far positions for the same detector which will be placed for a period of six months at each distance that will constrain the active-sterile neutrino oscillation parameters with good sensitivity.

Lifetime measurements in neutron rich fission fragments

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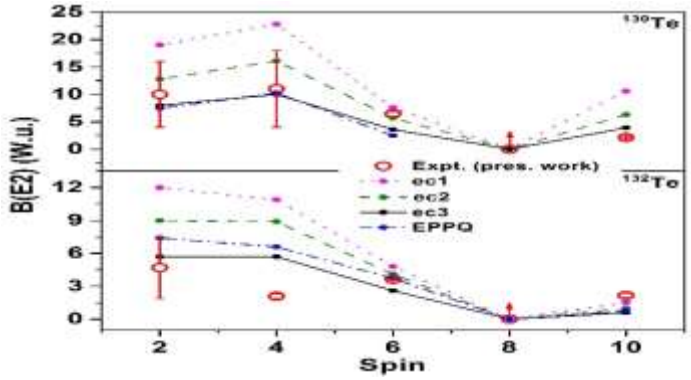
The lifetime measurements in the low lying levels of Sn and Te nuclei close to N = 82 are of extreme importance to understand the n-n interaction in the vicinity of double shell closure of ^{132}Sn [1]. However, the availability of spectroscopic information around ^{132}Sn is very scanty as there is experimental difficulty in reaching this region by compound nuclear or transfer reactions using the available target-projectile combinations. With the availability of detectors having moderate energy resolution along with very good time resolution in recent times, viz., $LaBr_3$(Ce) and $CeBr_3$, improved timing measurement techniques in picoseconds range have been proposed. A timing array (VENTURE) with 8 numbers of 1"x1" CeBr3 detectors has been developed at VECC, Kolkata [2]. Several experiments for lifetime measurements around ^{132}Sn has been carried using this array and other collabotrative setups.

In one such measurements, the low lying excited states of ^{130,132}Te have been populated from the IT decay of higher lying μs isomeric levels in these Te viz. 10^+, 1.9 μs in ^{130}Te, 10^+, 3.7 μs in ^{132}Te. The neutron rich Te were produced through neutron induced fission at Institut Laue-Langevin (ILL) research reactor, Grenoble, France. The recoiling fission fragments were separated in mass and kinetic energy using the Lohengrin recoil fragment separator and were detected with an ionisation chamber (IC) placed at the focal plane. An array of four 1.5" X 1.5" $LaBr_3$(Ce) fast scintillator detectors placed at 90 degrees to each other and coupled with two Clover HPGe detectors were used for the detection of de-exciting γ radiations. Lifetimes have been measured using Generalised centroid difference techniques and slope method. Transition probabilities have been obtained using measured lifetimes and compared with Shell model calculations (**Shown below**).



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Exploration of two-phonon γ-vibrational states in deformed nuclei

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Multi-phonon vibration of atomic nuclei has been a subject of intense discussion among experimental physicists and theoreticians over the last few decades. However, the existence of collective two-phonon vibrations of the type $\beta\beta$, $\beta\gamma$ and $\gamma\gamma$ remains an open question in nuclear structure physics. Although the single-γ vibration is a firmly established feature of deformed nuclei, the double-excitation of two-γ-phonons were observed only in a few nuclei. The existence of two-phonon γ-vibration in a deformed nucleus manifests itself in the presence of $K^{\pi} = 4^{+}$ and $K^{\pi} = 0^{+}$ bands at excitation energies more than twice the bandhead energy of the single-phonon $K^{\pi} = 4^{+}$ band.

An experiment has been carried out using the **DURGA** facility at Dhruva reactor to investigate the presence of two-phonon γ-vibrational states in the deformed ^{164}Dy nucleus in the rare-earth region. Data were recorded at multiple thermal powers of the Dhruva reactor, ranging from 40 to 70 MW, and enriched $^{163}Dy_2O_3$ powder, sealed in a Teflon-made capsule, was used as target. During the experiment, DURGA was comprised of six Compton-suppressed clover Ge detectors, out of which, three were mounted at 90°, and the other three were at 60° with respect to the incoming thermal neutron beam. The data were acquired using state-of-the-art, multi-frequency digitizers based data acquisition system, which was conceptualized and implemented in-house [1].

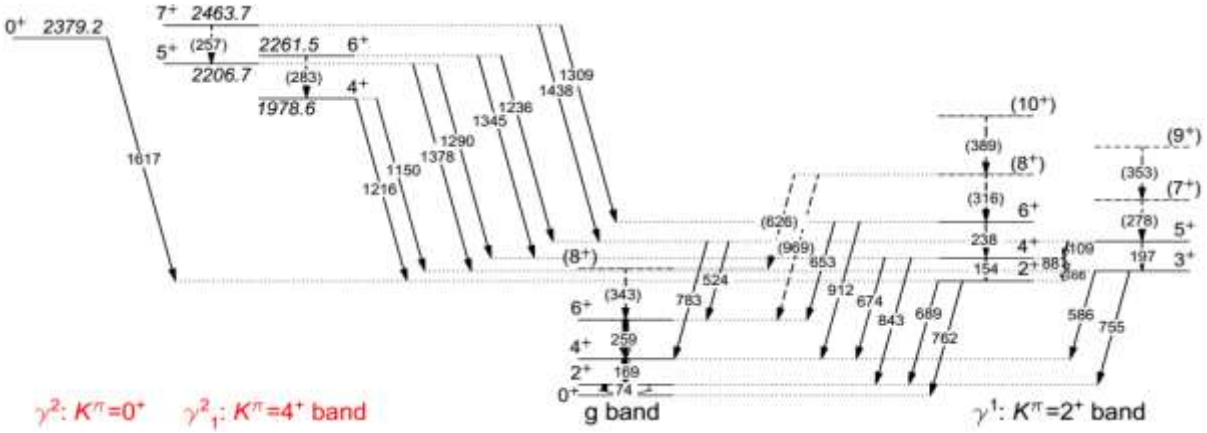

Fig. 1: Partial level scheme of ^{164}Dy nucleus, as obtained from the present experiment.

Following offline analysis of the acquired data, the lowest lying intrinsic $K^{\pi} = 4^{+}$ state at 1978.6 keV was observed. This state, along with the three other newly observed states at E_x = 2206.7, 2261.5 and 2463.7 keV decay exclusively to the states in the 1-phonon γ-band, thus possibly forming together the elusive $K^{\pi} = 4^{+}$ 2-phonon γ-vibrational band structure in this nucleus. A state at E_x = 2379.2 keV has also been observed, which can potentially be the first instance for a $K^{\pi} = 0^{+}$ two-γ-phonon state in a well-deformed nucleus after ^{166}Er [2]. Results and interpretation of the data will be presented in detail during the meeting.

Acknowledgements: The authors gratefully acknowledge the operation staff, shift-engineers, beam-port operators and RHC personnel at Dhruva reactor.

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A novel digital signal processing based data acquisition system for DURGA facility at Dhruva

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The advent of high-efficiency γ ray spectrometers with multiple types of detectors, coupled with digital signal processing based data acquisition system, and the availability of a wide range of projectiles, ranging from thermal neutrons to heaviest stable beam to RIBs, are driving the low-, medium-, and high-energy nuclear structure physics into the path of exciting exploration. In order to cater to the crucial scientific need of quality and quantity of data, digital signal processing based data acquisition system are being developed and implemented worldwide. The main advantages of such system over the conventional analog one are (i) high throughput of time-stamped data; (ii) reduction in size, cabling, power consumption, and cost per channel; (iii) high reliability, reproducibility and flexibility to load different algorithms into the same hardware.

Nuclear structure studies in the low- and medium-spin/excitation energy regime using capture gamma and fission reactions provide a lot of new information in a large number of otherwise inaccessible nuclei using thermal neutron beam from reactor. With this in consideration, a hybrid gamma detector array, DURGA, consisting of multiple types of detectors, has recently been made operational at Dhruva reactor facility, BARC. The heart of the DURGA facility is a multi-frequency digitizer-based, trigger-less data acquisition system that has been conceptualized and developed in-house. The acquisition system has been designed for an array of eight Compton-suppressed clover Ge detectors and sixteen $LaBr_3$(Ce) fast scintillators.

Fig. 1: The digital data acquisition system coupled with DURGA spectrometer at Dhruva reactor.

The pre-amplifier signals from clover Ge detectors are digitized by four 8-channels 100 MHz 14-bit digitizers, whereas the fast signals from the $LaBr_3$(Ce) scintillator detectors are sampled by a single 16-channel 500 MHz 14-bit digitizer board. The signals from the BGO anti-Compton shields were also digitized by one 8-channel, 250 MHz 12-bit digitizer board which is operated in the same crate/chassis. The anti-coincidence logic for Compton suppression is generated by a logic board which implements a programmable delay along with a signal fan-out of 1 to 4, and generates the veto signals for the clovers. The system was thoroughly characterized with radioactive sources. Recent in-beam measurements also validated the potential and usefulness of the aforesaid system.

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From order to chaos: Complete mapping of nuclear excitations

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In 1981, Davidson *et al.* [1] published the results of a comprehensive study of excited states in ^{168}Er that were populated by the (*n*,γ) reaction. The resulting level scheme was based on extensive data from the GAMS (Gamma Spectrometer) facility at ILL, France and ARC (Average Resonance Capture) measurements at BNL, USA and provided a fertile testing ground for many nuclear models, especially the IBA (Interacting Boson Approximation). Later, Davidson and Dixon [2] attempted to extend the level scheme with additional data, and by searching for additional energy sums that could give rise to states beyond the pairing gap. They could extend the knowledge of the level scheme up to about 2.5 MeV excitation. Those studies were basically carried out using singles measurements and either one Ge(Li) or one Ge detector were used. The level schemes were built mainly from the observation of primary transitions and the subsequent secondary transitions were placed on the basis of Ritz combination principle. Later on, Jungclaus *et al.* [3] collected a substantial amount of γ-γ coincidences (at the BNL HFBR facility) data using three, non-Compton-suppressed, Ge detectors. The data of Jungclaus *et al.* [3] showed that without either the ultra high precision γ-ray energy measurements possible with GAMS, or the use of γγ-coincidences, assignments based solely on energy sums must be viewed with skepticism. This is especially true for nuclei (such as ^{168}Er) with a large number of excited states around and above the pairing gap region, which can lead to many accidental energy sums. The limited coincidence measurements of Jungclaus *et al*. [3] led to the proposal of 19 new levels above 2 MeV excitation. Also, Jungclaus *et al*. [3] pointed out that about 25% of the levels proposed in Ref. [2] is no longer unique and there are lot of issues that are suspicious. Even the work of Jungclaus *et al.* [3] could not settle out many of the issues related to the level scheme. The follow up ^{167}Er(n,γ) experiment were carried out using the High Flux Beam Reactor (HFBR) facility at BNL using the TESSA array [4] consist of 16 Germanium detectors with BGO shielding. Very clean γγ-coincidence data were obtained because of the suppression of the unwanted Compton events. The success of this campaign points towards the fact that the employment of a large array for the study of neutron capture reactions is a vital tool.

The proposed investigation would be carried out using the (n,γ) probe and the DURGA facility stationed at Dhruva Reactor beam line at BARC will be used. The sensitivity of this array would be about four times more than the TESSA array. The main objectives of the proposed investigation would be: (a) Complete Characterization of multiphonon states in ^{168}Er; (b) Study of the onset of chaos at excitation energies above the pairing gap; (c) Study and testing of models of statistical decay of the capture state, and, eventually, the extension of nuclear structure interpretations into the region above the pairing gap.

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Pulse Height Spectra (PHS) and Efficiency Simulation of a Cadmium Zinc Telluride (CZT) Detector

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Use of monte carlo simulation is becoming increasingly important in the domain of detector development for radiation detection application recently. In this paper, 3D continuous energy code MCNP [1] was used to validate the experimentally obtained Cadmium Zinc Telluride (CZT) detector pulse height spectra and efficiency over an energy range of 40 keV to 1400 keV. A coaxial CZT (45% Cd, 5% Zn, 50% Te) detector of crystal dimension 10x10x5 mm, diameter 24 cm, relative efficiency of 23%, resolution of 10.3 keV and peak to Compton ratio of 7.5 for the ^{137}Cs gamma ray at 661 keV was used for the study. The geometry of the detector was modelled in MCNP, ensuring minimum approximations. F8 (pulse height) tally and appropriate Gaussian Energy Broadening (GEB) constants were used to generate the detector response to the incident photon (Fig:1). This yielded the intrinsic response characteristics of the CZT crystal for various gamma sources [2].

The pulse height spectra were obtained for various known gamma sources positioned at 5 cm along the axis of the detector and validated using the theoretically obtained results. A set of four standard sources e.g. ^{152}Eu, ^{60}Co, ^{137}Cs and ^{241}Am were used. After gathering enough counts by a MCA for each source, pulse height spectra were generated for each isotope (Fig:1). Full energy peak efficiency (FEPE) ε(E) was calculated using the following formula,

$$\varepsilon(E) = \frac{N_p(E)}{A.\ I_\gamma(E)} \quad \ldots (1)$$

where, $N_p(E)$ = no. of counts in the full peak, A= source activity, I_γ = gamma yield.

The simulated and experimentally obtained detector efficiency were compared and plotted in log-log scale (Fig:2). The Figure shows good agreement between the experimental and simulated results, with an average discrepancy of about 8-15% in all energy range.

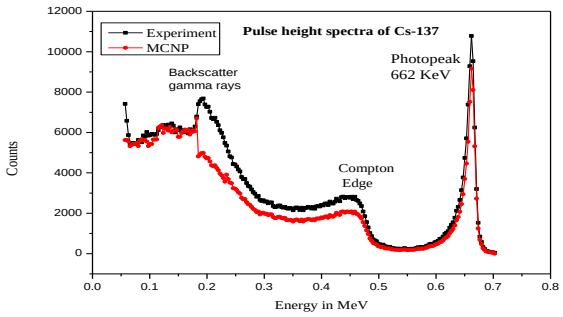

Fig:1 Pulse height spectra comparison

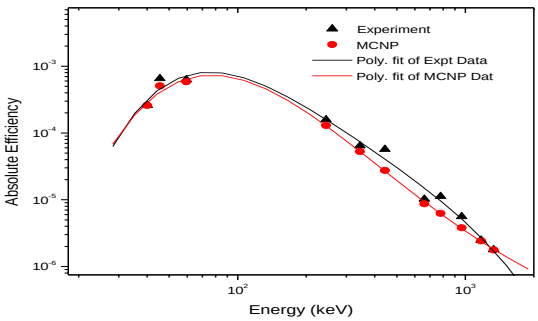

Fig:2 Detector FEPE comparison

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Application of Neutron Irradiation to Study the Reliability of Semiconductor Devices

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Semiconductor devices such as HBTs, BJTs and MOSFETs are the backbone of high tech systems employed in high energy physics, defense and space applications and are often exposed to various types of radiation. Therefore, it is very important to evaluate the hardness of semiconductor devices to different ionizing and non-ionizing radiations.

The high energy radiation produces ionization and displacement damages in the semiconductor devices and thereby degrade the electrical characteristics. The ionizing radiations such as gamma and electrons produce ionization in the semiconductor material to a greater extent compared to the displacement damage whereas, the protons and heavy ions produce both ionization and displacement damage. This leads to an increase in threshold voltage shift in the MOSFETs and degradation of current gain in the BJTs. The high energy neutrons can create only displacement damage which reduce the minority carrier life time and inturn degrade the electrical characteristics of semiconductor devices. Therefore, it is very important and interesting to compare the effect of Co-60 gamma radiation and neutron irradiation on electrical characteristics of different semiconductor devices such as BJTs and MOSFETs.

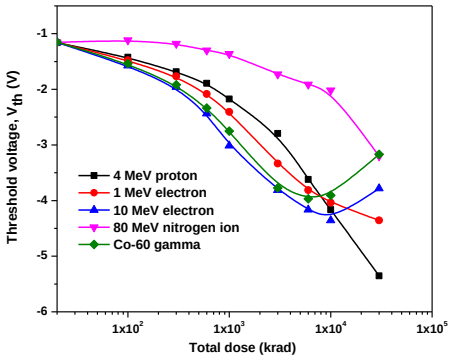

Fig. 1: Variation in threshold voltage after proton, electron, ion and gamma irradiation

We have extensively investigated the effects of gamma, electrons, protons and high energy ions on SiGe HBTs, PIN diodes, BJTs and MOSFETs and published in reputed journals [1-2]. However, the literature on the effect displacement damage due to neutron irradiation on the BJTs and MOS devices is sparse. Therefore, we propose to study the effect of neutron irradiation on NPN transistors and N-channel MOSFETs using deep level transient spectroscopy (DLTS) technique and I-V characterization.

Acknowledgements: The author thank DST-SERB & IUAC, New Delhi, DAE-BRNS, Mumbai and UGC-DAE-CSR, Kolkata for providing funds to carry out the above mentioned research work.

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Sensitivity of Vanadium detectors for use in PHWR

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The neutronic decoupling in large PHWRs requires the widespread use of Self Powered Neutron detectors (SPNDs) for in-core monitoring. SPNDs are the only feasible or practically possible in-core neutron detectors, due to their small compact size, rugged design, better resistance against radiation, adequate life for use inside the reactor core and many more properties. SPNDs are mainly used to determine the neutron flux at specific location or integrated flux over a region. These flux readings can be used to produce a 3D flux map as well as for control and protection functions. There are two different characteristics of a SPND which should be understood in detail, viz. the variation of sensitivity with time due to continuous exposure to neutron or gamma field and second the response of SPND signal in varying flux known as the dynamic response of SPND. Thus not only the overall signal of SPND is important but also the dynamic response of the detector signal is also important.

The vanadium detectors used for flux mapping are accurate with respect to the steady state response to the neutron flux. Therefore 30 cm long vanadium SPNDs are used in IPHWR (540 MWe and 700 MWe) for flux mapping system. Therefore, if the maximum benefit is to be obtained from using these flux detectors in power reactors, a thorough understanding of the factors that affect the detector's response such as, sensitivity, burnout, prompt and delayed fraction of detector's signal etc. is required.

A computer code, based on model proposed by Warren et. al. [1], is developed to estimate the sensitivity of SPNDs. In the present paper, the sensitivity of Vanadium SPND used in IPHWR is estimated and compared with experimental values. For 700 MWe 10 nos. of SPNDs have been tested at Dry Tube-1 location of KAMINI [2], IGCAR reactor at ~ 30 KW power and thermal neutron flux measured at test location was ~7.28×10^{10} nv.

Considering the difficulty to maintain stability of point neutron flux and estimation of thermal neutron flux at KAMINI reactor, the measurements of the sensitivities of V detectors can also be obtained from research reactor at BARC. This would help in the improvement of the present computer code and also establishing the accurate sensitivity for thermal neutron and gamma.

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Utilization of research reactors for characterization of Boron lined proportional counters

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Thermal neutron monitoring is carried out in a number of applications, which include reactor power control, area monitoring in health physics instrumentation, neutron scattering studies, neutron energy spectroscopy, neutron radiography etc.Boron lined proportional counters are the most popular choices for monitoring low thermal neutron flux because of their high sensitivity to thermal neutrons, tolerance to ambient gamma background; ease to fabricate them, as boron is non-toxic and non-radioactive; its reaction products are also non active and have long life in hostile reactor environment. Boron lined proportional counters are extensively used in nuclear reactors for fuel loading and reactor start-up. The detectors and associated instrumentation used for reactors undergo rigorous qualification testing to ensure reactor worthiness. Tests are required to be conducted in neutron fields ranging from 0.1nv to $10^{\wedge 12}$nv. The research reactors are the only facilities where the required range of radiation fields are available, provide flexibility and availability of experimental locations for characterization of detectors and associated instrumentation.

Electronics Division has been developing for more than three decades and delivered large number of boron lined proportional counters and processing instrumentations to various important reactor facilities. Table 1 gives the main specifications of some of the detectors developed and deployed in various Indian nuclear reactors which are subjected to following performance evaluation and testing in research reactor facilities:

1. Optimization of operating parameters.
2. Signal linearity over the operating range and signal stability at the highest operation range.
3. Accelerated life test in high fluence and life test with operating bias on or off.
4. Neutron sensitivity tests by estimating thermal flux with gold foil irradiation.
5. Long term irradiation life test at lower flux.

Table 1: Design specifications of Boron-10 lined proportional counters

Detector	Out-core Detector for LWR	In-core Detector for LWR	Start-up detector PWR	Start-up detector LWR	Cold start-up PFBR	Start-up PFBR
Cathode Outer diameter	63 mm	13mm	34mm	30mm	54mm	25.4mm
Anode wire diameter	25 µm diameter tungsten					
Overall length	930mm	330mm	450mm	200mm	1000mm	735mm
Sensitive length	740mm	190mm	300mm	100mm	700mm	378mm
Gas fill &pressure	Ar (95%) + CO2 (5%) gas mixture at 20 cm Hg					
Neutron sensitivity	17 cps/nv	1.0 cps/nv	4 cps/nv	1.1 cps/nv	12 cps/nv	4 cps/nv
Gamma tolerance	1 R/h	3000R/h	500R/h	2000 R/h	200mR/h	200R/h

The poster delineates characterization of different ^{10}B lined proportional counters carried out research reactor and test results.

Silicon Radiation Detector Development: Application of Neutron Transmutation Doped (NTD) Silicon

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Silicon based solid state radiation detectors have several advantages, such as compactness, fast response, low voltage operation, operation at room temperature and high energy resolution. The well established microelectronic fabrication technology allows batch production resulting in lower costs, good uniformity, and high position resolution with the fine segmentation as microstrips or pixels. Today mega science experimental physics facilities such as CMS Detector at LHC-CERN employ several thousands of silicon detectors with millions of readout channels for measurement of various subatomic particles in proton-proton collisions at a few GeV energies.

In nuclear or particle physics research, identification of charged particles is an important objective for which different techniques such as Times of Flight (TOF) and energy loss (ΔE-E detector telescope) are generally employed [1]. However, these techniques have several disadvantages such as requirement of long flight path length, complex/large detector setup, difficulty to identify particles having high-Z with low energy and low-Z with high energy, etc.. These difficulties could be overcome by utilizing pulse-shape discrimination (PSD) method which is being recently adopted in mega science experiments such as HYDE (HYbrid DEtector ball array) at FAIR facility (Darmstadt, Germany) and future mega science experiments such as GASPARD [2]. In PSD, particle discrimination is carried out by analyzing the pulse shape, which requires a very uniform electric field in the bulk of silicon detectors. The resistivity fluctuations in the bulk silicon become crucial for these detectors as the charge-collection time and hence the particle resolution will depend on the point of impact [3]. Therefore, for the PSD technique, the detectors require neutron transmutation doped (NTD) silicon wafer, which provide minimum possible resistivity variation [4].

We have developed fabrication technology for several types of silicon detectors such as pad detectors and large area single sided or double sided strip detectors which are suitable for nuclear physics experiments [5-6]. For particle identification, we have realized ΔE/E telescope based on novel concept of integrating two detectors on the same silicon wafer [6]. The development NTD silicon has been recently initiated at BARC for various applications. Using the developed fabrication technology and indigenously developed high resistivity NTD wafers, we will be developing silicon detectors suitable for particle identification using PSD technique. An overview of the current status of silicon detector development and activity of NTD silicon based detector development for PSD/DPSD will be presented.

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High sensitivity Helium-3 proportional counters for reactor applications

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High sensitivity neutron detectors are required in reactors for control and safety instrumentation. At out-core locations of reactor where gamma radiation is below 1 R/h, ^{3}He proportional counters fulfilling the specific requirement are better choice than conventional detectors. As compared to ^{10}B lined proportional counters and fission counters, for a given size,^{3}He detectors have respectively 20 times and 200 times higher neutron sensitivity. ^{3}He gas is non-corrosive and non-reactive makes it better choice compared to $^{10}BF_3$ proportional counters. A high sensitivity ^{3}He proportional counter is developed for critical facility of light water reactors. Table 1 gives salient specifications of the developed detector. With these detectors, the reactor criticality can be attained by monitoring the flux at the out- detector locations without external neutron source. The physics experiments can be conducted at lower reactor powers thus reducing the induced activity in reactor fuel.

High sensitivity ^{3}Hedetectors developed to be used in reactor applications for the first time are characterized in research reactor. Therefore, the detector was subjected to rigorous tests for confirming reactor worthiness. The research reactor facilities played vital role in testing these detectors at Critical Reactor facility in regard to the following features:

- Discriminator Bias characteristics & HV characteristics
- Linearity, Sensitivity, Count stability
- Response repeatability, Response time
- Count loss at high neutron flux
- Performance immediately after exposure to high nvt at high flux

The testing ascertained thermal neutron sensitivity of the detectors at given operating parameters (Avg. sensitivity~150cps/nv). The linearity of detector operation was established within +/-10% up to a count rate of 30Kcps. The response of the detectors after being exposed to neutron flux of $4x10^{6}$nV and high gamma field of 10R/hr was found to be repeatable within +/-10%. The counts were observed to be stable exhibiting acceptable statistics when the detectors were kept in operation at constant reactor power. The detector followed the changes in the neutron flux with acceptable response time.

Table-1: Specifications of ^{3}He detector

Outer Housing	S.S.
Overall dimensions	Dia 54 mm X 1 m long
Sensitive dimensions	Dia 51 mm X 908 mm long
Sensitive volume	1854 cc
Gas fill	65% He3 + 35%Kr
Pressure (partial)	He3: 1500 mm of Hg & Kr: 1210 mm of Hg
^{3}He content	5.6 ltr
Total Pressure	3.61 bar (g)
Operating Voltage	1500V-1800V

The poster describes methodology adopted & results achieved in testing high sensitivity ^{3}He detector at research reactor.

Optimized utilization of ^{3}He for neutron detectors

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Helium-3 (^{3}He) filled proportional counters are historically being used for detection of neutrons in wide range of application including nuclear safeguards [1] and flux monitors [2]. However due to limited and continually decreasing supply of ^{3}He, alternative techniques such as BF_3 detectors and, plastic scintillators etc. are employed to meet the requirement. Alternatively, the use of ^{3}He can be reduced by using the detectors at lower fill pressure with increased number of detectors.

Present work illustrates the characteristics of one-meter-long, 40 mm diameter ^{3}He detectors at different fill pressure. We have used 1.5 bar krypton gas to enhance the stopping power of the residual nuclei's in the detector. A Pu-Be neutron source of 10^5 n/s strength placed at 10 cm was monitored for 1 minute. The pulse height spectrum has been obtained at each fill pressure at various anode voltage.

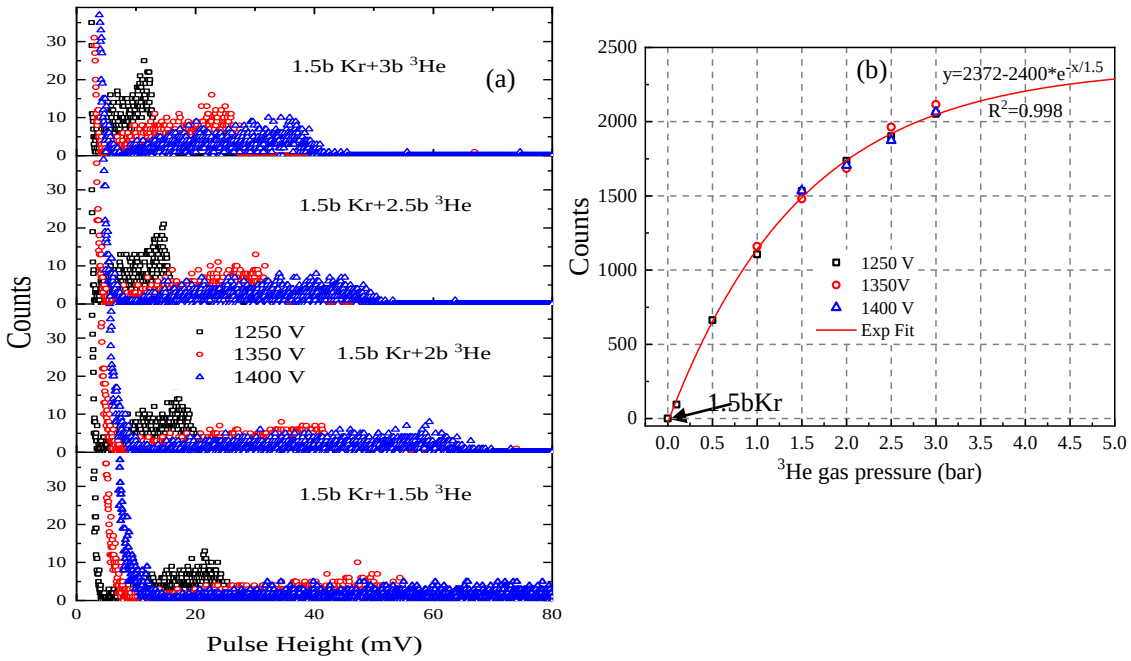

Fig. 1. (a) Pulse height spectrum and (b) counts in detector for different fill pressure with Pu-Be neutron source of intensity 10^5 n/s for 60s.

The pulse height spectrum shows that the pulse height of the neutron signal reduces exponentially with the fill pressure and increase with the applied anode voltage. The count profile of the detector shows that an increase in gas pressure from 0.5 to 3 bar (6 times) could enhance the efficiency only up to three times. Further, it may be noticed that the efficiency corresponding to 3 bar filling pressure can also be achieved by three detectors each filled with lower pressure of only 0.5 bar, i.e. reducing the amount of required gas substantially.

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Efficiency Calibration of HPGe using Monte Carlo Simulation

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In nuclear reactors various samples are radiologically characterized quantitatively using HPGe (High Purity Ge) detector. Full energy peak efficiency (FEPE) of p-type co-axial HPGe was simulated using Monte Carlo for a specific source geometry in water matrix for which standard reference source is unavailable. FLUKA Monte Carlo package was used to model the detector geometry (figure 1) and to simulate its spectral response. The detector's geometry was modelled on the basis of specifications provided by the manufacturer. However, many publications have shown that detectors actual specifications may deviate from that provided by the manufacturer. The deviations may be associated with: a) dead layer thickness b) active volume of Germanium crystal c) thickness of detector cap d) core-hole diameter. However, computational constraints limited the study varying only the thickness of the dead layer and computing the associated FEPE. A comparison has been shown in Table 1 between the simulated and experimental FEPE at various energies for different dead layer thickness using standard reference gamma disc sources.

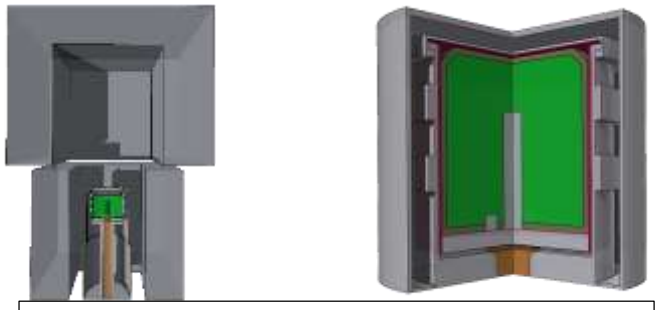

Figure 1: Detector model in FLUKA

Table 1: FEPE values for different Germanium dead layer

Energy (keV)	Experimental FEPE	FEPE Values for Simulated Ge dead layer (mm) thickness					
		0.7 mm	**0.8 mm**	**0.9 mm**	**1.0 mm**	**1.1 mm**	**1.2 mm**
276.4	0.002804	0.0035	0.0032	0.0029	0.0026	0.0023	0.0020
383.85	0.002335	0.00257	0.00254	0.00251	0.00248	0.00245	0.00242
661.7	0.001285	0.00138	0.00136	0.00132	0.00130	0.00128	0.00126
1173.5	0.001053	0.00104	0.00103	0.00102	0.00101	0.00100	0.00099
1332.3	0.000935	0.000940	0.000939	0.00938	0.00937	0.00936	0.00935

Simulated FEPE showed good agreements with those measured experimentally. Model with 1.1 mm dead layer thickness was used to simulate cuboidal liquid source of Cs-137 of 500 ml volume 2.2 Bq/ml specific activity with tolerance of 5% in activity. The experimental efficiency for the volumetric source is 0.001027 while the simulation computed 0.001063, hence a deviation of 3.5 % was observed. The same model was also used to compute FEPE for ^{60}Co, ^{137}Cs in metal dust, system samples etc. in cylindrical geometry. Hence, Monte Carlo simulation of an HPGe detector with optimized parameters can generate FEPE curve precisely and may not require the use of many standard radioactive sources.

Acknowledgments: HASL, IGCAR for providing international standard sources

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Boron lined Ionization Chambers for reactor applications

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Boron lined Ionization Chambers are required in reactors for control and safety instrumentation during intermediate and power range operation. These neutron detectors are installed at out-core locations. In PHWR the out-core locations are provided with lead shield and uncompensated ionization chambers are employed. In cLWR, gamma dose rate is high at installed location and no lead shielding is provided, hence, Gamma Compensated Ionization Chambers (GCIC) are deployed. Boron lined GCIC facilitate reactivity worth measurement during cold and hot physics experiments and power operation in cLWR. Upcoming cLWR generating more power with relatively less neutron flux at designated out-core detector locations require high sensitivity GCIC to meet the safety as well as reactivity worth measurement requirements. Prototype high sensitivity GCIC have been developed to meet these requirements. Table 1 gives salient specifications of the developed boron lined GCIC.

Boron lined GCIC developed for use in cLWR for the first time are characterized in research reactor. Therefore, the detector was subjected to rigorous tests for confirming reactor worthiness. The research reactor facilities played vital role in testing these detectors at Critical facility in regard to the following features:

- Determination of V/I characteristic of GCIC
- Uncompensated gamma sensitivity of the GCIC
- Gamma Compensation factor
- Compensated Gamma Sensitivity
- Linearity and neutron sensitivity of the GCIC
- Variation in log power due to change in amplifier temperature

The tests at research reactor confirmed the above-mentioned critical specifications of the developed GCIC which are described in the poster along with the prototype high sensitivity GCIC developed for upcoming high power cLWR.

TABLE-1: Specifications of boron lined GCIC detector

Overall Dia (mm)	85
Length of the detector housing(mm)	315
Electrodes	Cylindrical and Aluminum
Outer housing	SS
Electrode spacing	2.5mm
Sensitive length (mm)	264.5
Coating thickness	0.75mg/cm^2
Surface Area	945cm^2
Boron content	700mg of 40.5% enriched ^{10}B
Gas fill	N2 at 128cm of Hg
Nominal neutron sensitivity	$7*10^{-15}$A/nv
Nominal compensated gamma sensitivity	$1.8*10^{-12}$A/R/hr

Fission Counters / Chambers for Reactor Applications

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Fission Counters / Chambers operated in ionization chamber region are capable of detecting individual neutron interaction giving pulse signal thereby enabling low neutron flux measurement during source range of reactor operation. In presence of intermediate to high neutron flux during intermediate & power range of reactor operation, the pulses from the detector overlap giving DC output. These detectors exhibit excellent gamma tolerance. The detector signal when processed employing Campbell technique offers enhanced signal to noise ratio thus making it an attractive choice for neutron flux measurement during intermediate power range operation of reactor in presence of high gamma background.

Detectors are designed, developed & fabricated using different construction material viz. 1S-Al, SS, Inconel 600 for PHWR, research reactors, LWR & PFBR respectively. Table 1 gives salient specifications of the developed detectors.

These detectors developed for the first time are extensively characterized in research reactor, subjected to rigorous qualification for confirming reactor worthiness. The research reactor facilities significantly contributed in testing & performance evaluation of these detectors.
The poster describes the tests conducted at research reactor and the results confirming the specifications of different detectors developed.

Table-1: Specifications of Fission Counter / Chamber

Specification	Detector Type			
	High Temperature Fission Counter	High Temperature Fission Chamber	Parallel Plate Fission Chamber	1S-Al Fission Counter
Overall Dia	63 mm	63 mm	63 mm	48mm
Overall Length	398 mm	679 mm	980 mm	380mm
Electrodes	2 nos	2 nos	198 plates	3 nos
Electrode spacing	0.8 mm	0.8 mm	1 mm	2 mm
Sensitive length	63 mm	280 mm	600 mm	193mm
Coating thickness	~ 1.5 mg/cm^2	~ 1.5 mg/cm^2	~ 1.5 mg/cm^2	~1.2mg/cm^2
Surface Area	76 cm^2	730 cm^2	1200 cm^2	640 cm^2
SNM content	~ 0.11 gm	~ 1.1 gm	2.0 g	~0.77gm
Gas fill	97% Ar + 3% N_2 at 6 bars (abs)	97% Ar + 3% N_2 at 6 bars (abs)	97% Ar + 3% N_2 at 5 bars (abs)	97% Ar+3% N_2 at 2.5 bars (abs)
Capacitance	225 pf	450 pf	450 pf of each section	185 pf
α/leakage current	1-2 nA	3-5 nA	6 nA	10.5nA
Neutron Sensitivity	~ 0.15 cps/nv	~ 0.3 cps/nv	~ 0.6 cps/nv	~ 0.6cps/nv
Connector	Triax female, Teflon insulated	Triax female, Teflon insulated	Triax female, Teflon insulated	HN female, 1S-Al, PEEK insulted with SS thread insert

Automated Test Equipment for neutron detectors

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Neutron detectors developed for reactor applications have to undergo extensive characterization and performance evaluation for establishing their reactor worthiness before actual deployment. This involves carrying out experiments in a research reactor at different reactor power levels, for generation of baseline data for H.V. & Discriminator Bias performance of Fission Counter / Chamber, ^{10}B lined Proportional Counter (BPS) or gamma compensation factor of GCIC; and to establish the optimum operating parameters of the detector-counting channel. The baseline data recorded during this characterization is also used to establish the linearity and sensitivity of the neutron detector over its intended dynamic range of neutron flux spanning 5 to 7 decades. Automated Test Equipment (ATE) for neutron detectors automates the performance evaluation of Neutron Detectors operating in pulse mode viz. Fission Counter / Chamber & BPC or operating in DC mode viz. Gamma Compensated Ion Chamber (GCIC).

The ATE comprises two channels of analog outputs generated using a quad 16-bit DAC and 4 multiplexed analog input channels using 16-bit ADC; along with read-back provision. The ATE also has a built-in FPGA based SCALER/TIMER with 8-digit LED display and user settable counting time. The ATE is powered and interfaced to PC through USB port. A LabVIEW based program is executed from the PC, which provides GUI for automating and executing the test sequence, runtime plotting of the test data and saving the test data in excel format for offline analysis.

Integrated testing of ATE along with FC detector & Fast pulse amplifier and GCIC detector & Intermediate Range Monitoring (IRM) channel has been successfully carried out at Critical Facility. For characterization of fission counter operating in pulse mode, the onboard DACs were configured for setting the Disc. Bias and H.V. bias and the set value were read back via the onboard ADCs. The TTL output generated by the pulse amplifier was interfaced to the onboard SCALER/TIMER. For characterization of GCIC detector operating in DC mode, the onboard DACs were configured for setting the +/- HV values and the onboard ADCs were used for reading back the set +/- HV as well the Log. P generated by the IRM channel. The ATE was interfaced to a laptop via USB port and the LabVIEW based program provided GUI for automation and execution of the test sequence, runtime plotting of the test data and saving the test data in excel format for offline analysis.

TABLE-1: Salient features of the Automated Test Equipment

Operating power supply	USB B type port
Overall dimensions	185 mm X 90 m X 85 mm (Height)
Input pulses	TTL / Optical (selectable thru' onboard jumper)
SCALER / TIMER Display	8-digit LED display
Onboard DACs	quad 16-bit DAC; 2 channels
On board ADCs	16-bit ADCs; 4 channels multiplexed
Graphical user interface	LabVIEW based program for automation, execution of test sequence, runtime plotting and saving of test data in excel format.

The poster describes design and development aspects of ATE and test results achieved during testing of FC and GCIC detectors at Critical Facility.

Analysis of plant extract for the synthesis of nanoparticles

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The green chemistry routes are used to prepare nanoparticles [1]. One of the methods is used of plant extract. Phytochemicals that obtained in the extract of some selected medicinal plants contain reducing or oxidizing molecules along with many traces elements. These wide ranges of phytochemicals present in the plant extract can be used as capping agent or to reduce metal ions or metal oxides to its nanoparticles or nancomposites such as Ag [2], Au, Ni, SnO_2 and Fe_3O_4 etc. Examples of commonly used medicinal plants are Neem (*Azadirachta indica*) and Tulsi (*Ocimum tenuiflorum*), Gotu kola (*Centella Asiatica*), Brihati (*Solanum Indicum*), Skunkvine (*Paederia Foetida*) and Lemon plant etc. Not only these, many plants which are in Rhizome family also contain reducing or oxidizing molecules along with many traces elements which also able to work as capping agent to get of nanoparticles.

However, analysis of trace elements and compounds extracted from plants (leaves, shoot, flower, seeds, rhizomes) are necessary so that which are responsible for the formation of nanoparticles and the reduction of agglomeration among particles. In order to perform experiment to the better ways, it needs nuclear reactor utilizations. The following techniques are needed:

1. Neutron activation analysis (NAA) for trace elements analysis
2. Small angle neutron scattering for shape and size determination

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Investigation of qualitative trace elemental analysis of Seeds and Pods of *Parkia roxburghii*

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One of the most popular legume species extensively used as food source in North-Eastern India, particularly in Manipur, is tree legume, commonly known as Tree bean (*Parkia roxburghii*) or 'Youngchak'. Various parts of the plant such as inflorescence, tender pods, seeds are consumed in the various forms of foods items such as salads, curries etc. Curries prepared from pods and seeds of *Parkia* are favourite and special dishes of Manipuris for their peculiar tastes. Moreover, the pods and seeds of the plant are considered as much valued and nutritional and available during winter season every year in the region (December-March)**.** Besides, tree bean has medicinal properties also such as insecticidal, antibacterial, alleopathic. And the seeds and the tender pods are used to cure stomach disorders and regulate liver functions. Parkia has pungent smell due to the presence of thioproline, a cyclic sulphur containing amino acid, which is anticancer agent, the bark decoction to treat diabetes. The green pods are a good source of crude proteins and energy.

However, analysis of trace elements and mineral content in the different parts of the plant viz. inflorescence, tender pods, seeds which are consumed as favorite dishes of the region are necessary to investigate with an advanced technique so that people will consume the food items without adverse effect. In order to perform elemental analysis of inflorescence, tender pods, seeds of *Parkia roxburghii* with precise and better result, nuclear reactor utilizations are needed. The techniques needed are:

3. Neutron activation analysis (NAA) for trace elements analysis
4. Prompt Gamma- ray NAA for elemental analysis

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Trace element analysis of soil samples using NAA for future proton accelerator projects at RRCAT

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Pre-operational survey of any site before commencing the construction of a particle accelerator facility is important for generating the baseline radiological data for that site. For the future Proton accelerator projects at RRCAT, Indore, soil samples were collected from five locations within the site for various types of analyses. In the work reported here, concentration of trace elements capable of producing long lived neutron induced gamma radioactivity in these soil samples was determined using the relative method of Neutron Activation Analysis (NAA).

For carrying out the neutron irradiation, nearly 50 mg of each soil sample was wrapped in aluminium foils alongwith two standard reference materials (IAEA-SL-1 & IAEA-336). The packet of samples and reference materials were co-irradiated at the same position in Dhruva research reactor at BARC, Trombay and the neutron flux at the irradiation position was of the order of 10^{13} n cm^{-2} s^{-1}. Since we were interested in estimating the trace elements that give rise to long lived radionuclides, the samples were allowed to cool for more than six months after the stoppage of irradiation to allow all the short lived activity to decay down to insignificant levels. After six months, the aluminium foils were removed and samples were re-weighed and wrapped in plastic pouches. These samples and standards were then counted for 4000 seconds each on a 50% relative efficiency p type HPGe gamma ray spectrometer having a resolution of 1.9 keV for 1332.5 keV. The results of the trace element concentrations in the soil samples obtained are given in Table 1.

Table 1: Trace element concentrations of Soil Samples from RRCAT obtained by NAA

S. No.	Sample Code	Trace Element Concentration				
		Cs (mg kg^{-1})	Sc (mg kg^{-1})	Fe (g kg^{-1})	Co (mg kg^{-1})	Eu (mg kg^{-1})
1	A-27 (SS-R-I)	0.48 ± 0.01	32.40 ± 0.06	107.1 ± 0.6	49.20 ± 0.20	2.00 ± 0.02
2	A-28 (SS-R-II)	0.58 ± 0.01	35.10 ± 0.06	102.4 ± 0.6	48.30 ± 0.20	1.95 ± 0.02
3	A-29 (SS-T-I)	0.56 ± 0.01	34.70 ± 0.06	105.2 ± 0.6	49.00 ± 0.20	1.84 ± 0.02
4	A-30 (SS-T-II)	0.50 ± 0.01	31.90 ± 0.06	105.7 ± 0.6	41.20 ± 0.20	1.31 ± 0.01
5	A-30 (SS-T-III)	0.48 ± 0.01	31.40 ± 0.06	101.4 ± 0.6	47.30 ± 0.20	1.85 ± 0.02

Quality control analysis to test the accuracy of the measured results were realized by using two certified reference materials (IAEA-SL-1 & IAEA-336), treating one as a standard and the other as a sample. The calculated values were found to be within the 95% confidence interval given by IAEA and the ratio of the calculated to IAEA quoted values (for the certified reference material treated as unknown sample) varied from 0.99 to 1.01 for all the elements of interest.

It is reported that the range of Cs, Sc, Fe, Co and Eu in topsoil are (< 0.5 – 69.1 mg kg^{-1}, median: 3.71 mg kg^{-1}), (< 0.5 – 54.1 mg kg^{-1}, median: 8.21 mg kg^{-1}), (1.6 – 223 g kg^{-1}, median: 35.1 g kg^{-1}), (< 3 – 249 mg kg^{-1}, median: 7.78 mg kg^{-1}) and (0.05 – 6.99 mg kg^{-1}, median: 0.77 mg kg^{-1}) respectively. The concentrations of Sc, Fe, Co & Eu in the soil samples sudied in this work were found to be higher than the median values reported in literature for these elements in topsoil [1].

The trace element concentrations capable of generating long lived gamma emitting radionuclides like ^{134}Cs, ^{60}Co ^{152}Eu ^{154}Eu, ^{46}Sc and ^{59}Fe in the 5 soil samples collected from RRCAT, Indore have been determined using neutron activation analysis.

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Utilization of Research reactors for Instrumental Neutron Activation analysis of geological material in REE exploration activities of Atomic Minerals Directorate, Hyderabad, India

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The Instrumental Neutron Activation analysis (INAA) technique is extensively used for determination of the REE elements (La, Ce, Nd, Sm, Eu, Tb, Tm, Yb, Lu), other trace elements (Sc, Cr, Co, Zn, Ga, As, Rb, Sb, Cs, Ba, Hf, W, Ta, Au, Ag, U, Th) and major elements (Na, Ca, Fe and K) for more than four decades in AMD on variety of geological material and from different geological domains to support the geochemical studies in the Directorate. The nondestructive technique along with other analytical techniques is capable of yielding the elemental concentrations with high sensitivity and low detection limits (ppm to ppb) making good interpretation of the data. The REE patterns obtained are critical in the interpretation of the physico-chemical and redox conditions prevalent at the time of minerals crystallisation and rock emplacement. In the present studies the irradiation of eight Ultramafic samples from Um Sohryngkew river area, Jaintia Hills, Meghalaya has been done in DHRUVA Reactors in BARC, Mumbai with a thermal flux of 10^{13} n cm^{-2} s^{-1}. Samples and certified reference standards are packed in aluminium foil of high purity. The irradiated samples and standards spectrums were analysed at RSA Laboratory, Hyderabad using a p-type (PGC-3018) High Pure Germanium (HPGe) coaxial semiconductor detector- RE 30%, DSG detector systems, GmbH which is coupled to the target dMCA-pro-digital MCA. WinTMCA32 software was used for the analyses of the spectrums. The Chondrite normalised REE pattern (Fig.1) studied, indicate negative Eu anamolies with Eu/Eu* ranging from 0.41 to 0.58 which indicates oxidising conditions prevalent at the time of formation of the rock. The REE content (∑ REE from 176.7 to 252.5, n=8) point towards mineralised nature of the ultramafic rocks.

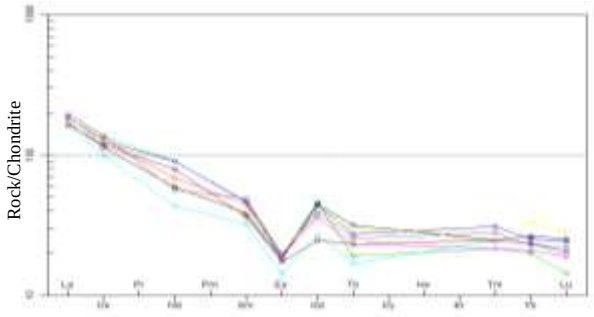

Fig.1 REE pattern of Ultramafics, Jaintia Hills, Meghalaya

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Characterization of Size Fractionated Atmospheric Particulate Matter Using Instrumental Neutron Activation Analysis

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Ambient air pollution is an ever-increasing environmental issue in major cities of Asia and has attracted attention from variety of corners with a proven direct impact on health & ecosystem. In urban air pollution, Particulate Matter (PM) is one of the key air pollutant noted for its potential adverse health effects. A comprehensive study is being carried out for the past 20 years on size fractionated particulate matter at Trombay and Navi Mumbai to study the impact of emissions from anthropogenic activities. Coarse (10–2.5 μm) and fine (≤2.5 μm) fraction PM was collected using 'Gent' sampler and Instrumental Neutron Activation Analysis (INAA) was used to characterize the trace elements [1]. Filter papers were co-irradiated with the standard for 7 hours in Apsara reactor, when the reactor was in operation at a flux of 1×10^{12} neutrons/cm^2/s. Subsequently 14 elements were measured in two sequential steps. Elements such as Na, K, As, Br, Sm and La were measured after one day cooling and again after 20 days of cooling period Sc, Cr, Fe, Co, Zn, Ce, Se, Sb and Eu were measured to avoid the inteference of abundant Na and Br.

Typical elemental concentrations are depicted in Fig. 1. Results show concentrations of Fe, Na, K and Zn in both the size fractions found to be higher than other elements. Mass contribution of Fe was about 5% in both the size frations. Na contributed 0.5 to 0.8 % of the mass in both the fractions, whereas K is showing marginally higher percentage value with 1.3% in fine and 0.6% in coarse mass. Concentrations of Sm, La, Eu, Sc, Co, Sb, Cr, As, Ce and Br are in the range of 0.1-187 ng/m^3 in the coarse fraction and 0.05-150 ng/m^3 in the fine fraction. Results were further used in the study for source apportionment and risk related studies[2]. In the size fractionated samples particulates collected is very less (<15mg). In such cases determination of wide range of elements with low substrate induced background was achieved using INAA with low detection limits as compared to other analytical tecniques. In air pollution monitoring and abatement studies speed and reliability are vital where, INAA has played an important role. The multielemental character, the ease with which it can be applied to a large number of samples and the high sensitivity made INAA as an outstanding technique in the current study. The ongoing study will be conducted at Apsara (U) with more efficiency in the future.

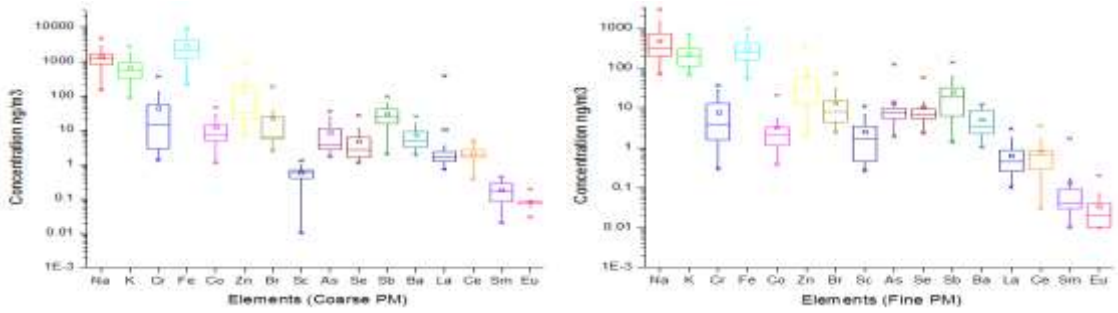

Fig.1 Box-Whisker plot of elemental concentrations in Coarse and Fine PM

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Application of Research Reactor for the Estimation of Elements at Ultra Low Levels in Environmental Samples by Neutron Activation Analysis (NAA)

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The prime use of research reactors is to provide a neutron source for diverse range of applications, such as materials research using neutron scattering and diffraction, materials characterization by activation analysis and radiography, isotope production for peaceful uses, neutron irradiation for materials testing for fission and fusion reactors, neutron transmutation doping of silicon, gemstone coloration, as well as for the education and training in nuclear technology for the students and researchers. Neutron Activation Analysis (NAA) is powerful analytical technique used for qualitative and quantitative determination of elements based on the measurement of characteristic radiation from radionuclides formed by irradiating materials by neutrons in research reactor. Using this information, it is possible to study spectra of the emissions of the radioactive sample and determine the concentrations of the elements [1]. A special advantage of this technique is that it is very sensitive, accurate, non-destructive and useful for measurement of trace element in the range of parts per billion (ppb) level in all types of environmental samples [2]. Radiochemical Neutron Activation Analysis (RNAA) & Instrumental Neutron Activation Analysis (INAA) technique are generally applied in the elemental/radionuclide analysis of environmental samples. NAA is especially useful for analysis of long lived alpha emitting radionuclides like U-238 and Th-232 having extremely low concentrations in presence of large quantities of other interfering elements. The technique is especially applicable for vegetation and biota samples where the equilibrium between these primordial radionuclides and their daughters is disturbed and the option of gamma spectrometry is not feasible. Using NAA one can detect I-129 an anthropogenic radionuclide at environmental levels which is an element of concern due to its long half-life and impact on environment. Multielemental analysis of nutrients concentrations were determined in vegetation samples collected from Trombay site using, INAA. The samples and standard were irradiated for 5 hrs. in the core of Dhruva Research Reactor at a thermal neutron flux of 1×10^{11} $ncm^{-2}s^{-1}$. The mean concentration values for heavy metals i.e Cr, Zn and Fe were 2.4 $mgkg^{-1}$, 27.8 $mgkg^{-1}$ and 235 $mgkg^{-1}$ (dry wt.) respectively. The order of mean concentration in leaves was found to be Fe > Zn > Cr. NAA using research reactors has proved to be an effective method of analysing trace levels of elements.

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Is YPO_4 or YPO_4: 20% Ce Nanoparticle, Good for Sorption of Eu^{3+} Ions?

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The presence of rare earth (RE) ions in aqueous medium causes severe health problems due to their toxicity. Hence their removal is necessary. In this research, we have used a concept of Host-Guest Interaction which helps in removing of RE ions by choosing the host as YPO_4 nanomaterial and the guest as Eu^{3+} ions. The host with tetragonal structure (pure YPO_4) and hexagonal structure (20 at % Ce doped YPO_4) are used for comparison studies.

Different ppm solution like 80, 60 and 40 ppm of Eu^{3+} ions were prepared by dissolving in de-ionized water of a 250 mL volumetric flask. At different conditins like pH = 3, 10 ml of 80, 60 or 40 ppm solution was added to 50 mg of Host (YPO_4 or YPO_4: 20% Ce) and kept under sonication for 15 min. Complete mixture was kept for 1 day and it was centrifuged at 6000 rpm for 10 min. The supernatant was transferred into the solution bottle, whereas the residue remained in the centrifuge tube was washed with 10 ml of acetone. The residue was kept under the IR lamp for 30 minutes to get dryness. Triplicate experiment is done.

Similar experiments were carried at different pH = 7 and 12. Also, sorption of a fix amount of solution of Eu (III) with host (100, 200 mg) was studied. The loading capacity of host was studied using neutron activation analysis (NAA) and luminescence experiments. NAA studies show the order of uptake of Eu^{3+} ions over nanoparticles: acidic < neutral < basic medium. In acidic medium (pH = 3), luminescence peaks at 590 and 615 nm could not be observed due to low sorption of Eu^{3+} over host, whereas in alkaline medium (pH = 12), their emission peaks are observed.

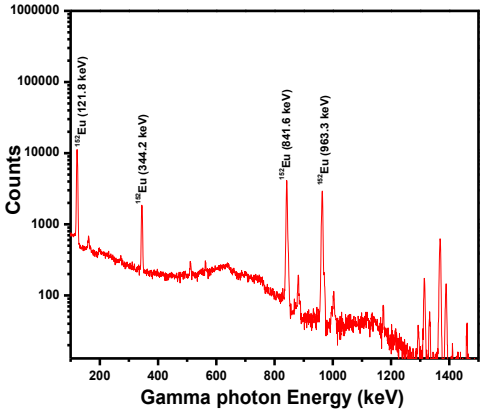

Fig. : Typical INAA Spectrum of Eu^{3+} remained in supernatant

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Irradiation based Non-thermal Approach for Decontamination and Enzyme Inactivation of Cereal and Cereal based Raw Materials

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Cereal grains are food staples and represent the primary source of carbohydrates worldwide. The Food and Agriculture Organization (FAO) forecasts that world grain utilization will reach a record level of 2646 million tons in the coming years [1]. Quality deterioration of cereal and cereal-based raw materials (flour, grits etc.) is a serious post-harvest concern in the packaging, supply, and storage of such food materials. External and Intrinsic factors such as microbial load and enzyme activity (lipase) respectively, are the major causes for such quality deterioration [2]. Microbial contamination is a general problem in cereal and cereal-based raw materials however, the enzymatic quality degradation is specific to only some cereals such as brown rice, maize flour, millet flour etc. The action of detrimental microbes and enzymes results in the development of off-flavour, bitter taste, loss in cooking properties, etc. [3]. Thermal approaches such as infrared heating have been extensively explored for eliminating such problems in the cereals. However, the application of thermal treatment has many limitations with respect to non-uniform thermal distribution and high-temperature gradient to achieve the target temperature. To achieve microbial and enzyme (lipase) inactivation in cereals by exposure to thermal treatments results in undesirable changes such as starch degradation, color changes etc. Therefore, the application of irradiation based non-thermal treatment will have great potential in comparison to the thermal approach for decontamination and stabilization of cereal and cereal-based raw materials [4]. The proposed research will focus on evaluating the potential of gamma irradiation using gamma irradiators with gamma radiation from ^{137}Cs or ^{60}Co in inactivating quality degrading microbes and enzymes in cereal and cereal flours. The reactors for Radioisotope production (for healthcare, industry, agriculture and food processing) available at BARC Mumbai will be used. The effects of the treatment on quality parameters will be evaluated and the lethal dosage required (kGy) will be evaluated by studying kinetic modelling for enzyme and microbial inactivation. The treated samples will be further stored in different packaging under different storage conditions (relative humidity, temperature) to evaluate the efficacy of the treatment during the storage of the product.

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Trace elemental fingerprinting of Triphaladi Curna and other ayurvedic formulations using NAA

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Traditional medicine from herbs and herbal formulations are is becoming increasingly popular, as indigieious medicines and source of primary health care, with many chronic conditions responding to it well. However, a scintific approach for precise reference standard to ensure the quality and efficay of these formulations is yet to be evolved. The trace elements present in the herbals play a vital role in the formation of active chemical constituents present and mediating vital biochemical activities [1-5]. Hence herbal can be characterized in terms of the trace elements present in them. Qualitative and quantitative analysis of trace elements in various herbs and herbal formulation can generate a reference data set, for quality control and standardization of herbal medicines.

Very limited studies have been conducted on trace elemental analysis of herbs using PIXE [1], XRF [2-4], ICPMS [3,4], NAA [2,5], AAS [5], etc. and a few analyses on compound formulations [5,6,7]. In the present work, we report the trace elemental analysis of some of the compound ayurvedic formulations like Thiphala, Nishakatakadi and their constituent herbs, using NAA. The activation was done at KAMINI reactor, IGCAR. The activities induced in the sample were followed using HPGe detector coupled with multichannel analyzer. From the observed intensities of characteristic gamma rays, the yield of specific isotopes was estimated from which the concentration of specific trace elements was determined. We have employed combination techniques for trace elemental analysis covering wide range of elements effectively [4,5,6].

Though NAA is high sensitive, the technique is limited to isotopes of measurable half-lives. Prompt Gamma Neutron Activation Analysis (PGNAA) can provide information on entire range of nuclei and hence is a better approach. Though accumulation of large number of gammas, particularly that the sample contains large number of isotopes make data collection and analysis complex and intricate, the information derived, qualitatively and quantitatively, supersedes the intricacies.

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Study of Ecological and Radioecological Impact of Coal using Nuclear Analytical Technique

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Coal is still the major source of electrical energy production in India in spite of strides being made to generate energy from different renewable sources of energy. Coal and its residues after burning namely coal ash and flue gas comprise of elements such as Si, Al, Ca, Cr, Pb, Se, Hg, Ra, Th, U, Fe, Cd, B, As, S etc. some of which have detrimental effect on the local environment leading to public health issues in the long run.

It is proposed to determine the concentration of metallic toxicants in coal from different regions in India employing Instrument Neutron Activation Analysis (INAA) and Prompt Gamma Neutron Activation (PGNAA) through utilization of thermal neutron beam and reactor neutrons respectively from Dhruva and Apsara Research Reactors.

The potential of INAA has been successfully demonstrated in determination of concentration of essential/toxic elements in soil, plant, fossils, kidney stones etc.earlier (1-3) by our research group. In a preliminary study elements such as Ca, Na, Li, Mg, B, Al, P, F, Mn, Cl and Si present in coal and coal residue samples collected from different thermal power plants of Punjab and Haryana which could have ecological and radioecological impact on the local environment were found to be present in significant amount (4) using External Proton Induce Gamma Emission Technique (PIGE). Table 1 shows the concentration of elements determined in the preliminary work.

Table 1. Determined concentrations (% or in mg kg^{-1}) in coal and coal residue samples by PIGE method using Tantalum as an external current normalizer

Element	Coal 1 (Mean±SD**)	Coal 2 (Mean±SD)	Coal residue 1 (Mean±SD)	Coal residue 2 (Mean±SD)
Si (%)	14.8 ± 0.2	15.1 ± 0.2	24.5 ± 0.2	23.9 ± 0.2
Na (mg kg^{-1})	49 ± 2	35 ± 1	67 ± 2	59 ± 2
Mg (%)	0.41 ± 0.02	0.39 ± 0.02	0.59 ± 0.02	0.64 ± 0.02
Al (%)	4.8 ± 0.2	5.1 ± 0.3	10.2 ± 0.6	9.82 ± 0.06
B (mg kg^{-1})	33 ± 1	43 ± 1	35± 1	34 ± 1
F (mg kg^{-1})	381 ± 8	328 ± 8	269 ± 6	178 ± 4

**(where SD is standard deviation, n=4)

It is proposed to extend the present work with the nuclear analytical set ups coupled with reactor facilities being offered through UGC-DAE Consortium to the University researchers in the near future.

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Precious Metals Quantification in Industrial Waste Matrices using Nuclear Reactor based NAA Methodologies

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The precious metals gold (Au) and silver (Ag) are present at trace levels (parts per million, i.e., mg kg^{-1}) in various copper based industrial waste matrices. Accurate assessment of concentrations is the stepping stone for devising appropriate separation /beneficiation strategies, essentially aiming at these precious metals. Method for the determination of the noble metals after separation from copper based materials was elaborated by Remya et.al. [1]. One of the most sensitive methods for the analysis of noble elements in ores/waste is neutron-activation analysis (NAA) [2,3].

Au and Ag were determined in various copper based industrial waste matrices like copper concentrate, dross and Cu metal by NAA, using appropriate neutron irradiation facilities such as Dhruva, AHWR Critical facilty and earlier in Apsara reactor. Based on the sample amounts, expected precious metal contents and the neutron fluxes in various irradiation facilities, sample matrices were separated either before (Chemical NAA: CNAA) or after irradiations (Radiochemical NAA: RNAA). Quantifications were done by relative as well as internal monostandard NAA methodologies. Fig. 1 shows the flow chart of the entrie analysis procedure.

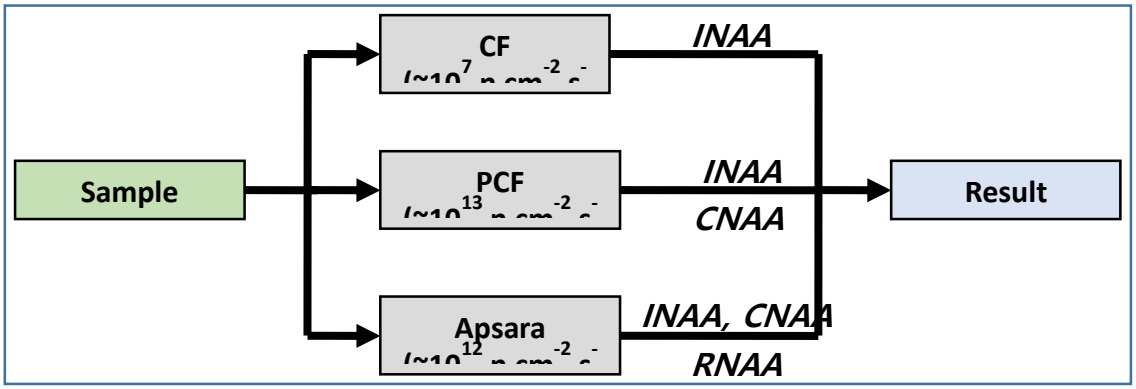

Fig. 1: Flow chart Steps involved in the NAA determinations

Table 1. NAA determination of Au and Ag in three matrices

Element	Copper concentrate			Cu scrap		Dross
Methodology	**INAA**	**CNAA**	**RNAA**	**INAA**	**CNAA**	**INAA**
Au (mg kg^{-1})	19.3 ± 1.5	18.2 ± 1.0	19.9 ± 2.8	-	8.7 ± 0.2	353 ± 15
Ag (mg kg^{-1})	32.8 ± 3.4	-	33.5 ± 2.8	618 ± 40	-	1455 ± 91

Acknowledgements: The authors acknowledge the support of operation crew of nuclear reactors at BARC during sample irradiations.

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Utilization of Low/High Flux Nuclear Reactors: NAA of Herbal/ Ayurvedic Products

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Herbal/Ayurvedic materials are common in India / Asia for treatment of various diseases, cosmetics and perfumeries. Inorganic trace elements play a vital role in the efficacy of such materials, and are hence to be quantified [1]. Neutron Activation Analysis (NAA) is one of the most sensitive analytical techniques for the simultaneous multi element determination in such complex matrices [2]. For herbal/ayurvedic formulations, NAA is having advantage due to low matrix effects and simultaneous multi element determinations.

Various samples, namely Rudraksh, Javyad, Sniffing material and tooth powder were characterized by NAA using relative as well as single comparator methods. Research reactors namely, Apsara and PCF of Dhruva reactors were used for neutron irradiation purposes. The main advantage of this approach is control over blank. Analytes were determined in the above mentioned matrices and their correlation for medicinal use / properties have been evaluated. Table 1 shows the analysis results of few herbal / ayurvedic products using nuclear reactor based NAA.

Table 1. Concentrations of analytes in Various Herbal / Ayurvedic Products

Element	Rudraksh Powder	Javyad Powder	Tooth Powder	Sniffing Material
Fe (g kg^{-1})	1.62 ± 0.08	2.21 ± 0.11	19.7 ± 0.9	1.10 ± 0.05
K (g kg^{-1})	2.93 ± 0.14	7.42 ± 0.37	8.31 ± 0.41	26.4 ± 1.3
Na (g kg^{-1})	0.42 ± 0.02	0.61 ± 0.03	0.42 ± 0.02	0.80 ± 0.04
Mn (g kg^{-1})	0.13 ± 0.01	0.11 ± 0.01	0.53 ± 0.03	0.42 ± 0.02
As (mg kg^{-1})	0.72 ± 0.03	-	1.10 ± 0.05	-
Co (mg kg^{-1})	0.72 ± 0.03	32.6 ± 1.6	2.61 ± 0.13	1.60 ± 0.05
Cr (mg kg^{-1})	4.42 ± 0.22	4.90 ± 0.24	10.1 ± 0.5	4.81 ± 0.02
Hg (mg kg^{-1})	0.20 ± 0.01	-	-	-
Rb (mg kg^{-1})	7.22 ± 0.35	9.60 ± 0.48	19.3 ± 0.9	14.6 ± 0.7
Zn (mg kg^{-1})	19.1 ± 1.0	16.6 ± 0.8	30.4 ± 1.5	13.8 ± 1.0

Mean±1s (n=4) reported

Results showed the presence of traces of toxic constituents, in addition to essential elements in the materials analyzed. Thus, chemical characterization is required prior to their use especially when used for tratment purposes. It is being planned to do extend such analyses using high flux research reactors such as Apsara-U to obtain improved sensitivity and detection limits.

Acknowledgements: The authors thank the operation crew of Apsara and Dhruva reactors, BARC for their support during sample irradiations.

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Non-destructive Determination of Pt, Pd and Co Based Catalysts using NAA Methodologies

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Catalysts are being developed for various applications in the Department of Atomic Energy [1-2]. Important applications of these catalyst include hydrogen mitigation during loss-of-coolant accident conditions in nuclear reactors. The size and shape of these catalysts (powder, bead, disc and plate) are designed as per the requirements of specific applications. Platinum (Pt), Palladium (Pd), Cobalt (Co) are the active ingredients of most of the catalysts and the determination of these is crucial for assessing the catalytic efficiency.

For the non-destructive determinations, neutron activation analysis (NAA) is the most powerful tool. Appropriate irraidation facilities can be chosen, based on sample geometry, the concentration of analyte, the nature of the substrate, nuclear properties [3] of both the analyte and matrix. Matrices analysed include carbon, silica, titania, zirconia, ceria in different forms (Fig. 1). All the analyses were carried out, without significant physical /chemical modifications of the samples. For the neutron irradiations, nuclear reactors at BARC, viz. the AHWR critical facility (CF) reactor (~ 10^7 n $cm^{-2}s^{-1}$) and the pneumatic carrier facility (PCF) of Dhruva reactor (~ 5 x 10^{13} n $cm^{-2}s^{-1}$) were utilized [4]. Gamma spectrometric measurements were carried out using high purity germanium (HPGe) detector, coupled to 8k channel analyzer. Relative method of NAA was used for arriving at the concentrations. The results of few samples are shown in Table 1.

Table 1 Concentrations of Pt, Pd, Co in catalyst samples

Matrix	Pt (%)	Pd (%)	Co (%)
Alumina-1	0.33 ± 0.01	--	--
Alumina-2	--	0.45 ± 0.04	--
Ceria	0.92 ± 0.05	--	--
Zirconia	2.19 ± 0.07	--	--
Carbon fibre-1	0.17 ± 0.01	--	--
Carbon fibre-2	--	0.13 ± 0.03	--
Carbon powder-1	15.27 ± 0.59	--	3.17 ± 0.31
Carbon powder-2	6.93 ± 0.06	--	4.90 ± 0.08

Fig. 1: Analysed catalyst samples in powder, bead, disc and plate forms

Acknowledgements: The authors thank the operation crew members of Dhruva and AHWR CF reactors at BARC for their support.

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Application of NAA for Chemical Characterization of Geological Materials

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Neutron Activation Analysis (NAA) is a nuclear analytical technique, suitable for simultaneous multielemental determination in variety of geological matrices. Geological matrices being complex in nature, involves tedious sample dissolution procedures for complete compositional characterization. For last five decades, Analytical Chemistry Division at BARC, Mumbai is routinely involved in analysis of various geological samples such as rocks, ores, minerals, sediments, soils, employing non-destructive techniques such as NAA [1-2]. Research reactors at BARC, namely Apsara, CIRUS, Dhruva, Critical facilty and KAMINI reactor at Kalpakkam were used for those analyses.

In this work, soil samples were analysed for major, minor and trace elements. The samples were homogenized and representative aliquots were irradiated alongwith reference standards (CRM's). The duration of irradiation and flux were chosen judiciously, to encompass the complete characterization of soil. The irradiation facilities used were: graphite reflector position in the critical facility (CF) reactor (~10^7 n cm^{-2} s^{-1}), the pneumatic carrier facility (PCF) and tray rod facility of Dhruva reactor (~$5x10^{13}$ n cm^{-2} s^{-1}). After sufficient cooling, gamma ray measurements were carried out using high purity germanium detector. Quantification of the analytes was done using relative method of NAA and the validation was using IAEA CRM. The results few soil samples are shown in Tables 1 and 2.

Table 1. Major and minor constituent concentrations in soil samples (mg g^{-1})

Sample	K (%)	Fe (%)	Mn	Na	Rb	Ce
Soil-1	2.2 ± 0.1	2.5 ± 0.4	0.42 ± 0.01	0.90 ± 0.03	0.10 ± 0.02	0.14 ± 0.01
Soil-2	2.5 ± 0.1	1.7 ± 0.2	0.37 ± 0.01	1.36 ± 0.05	0.07 ± 0.01	0.15 ±0.04
Soil-3	1.7 ± 0.1	4.8 ± 0.6	0.36 ± 0.01	0.45 ± 0.02	0.33 ± 0.03	0.07 ± 0.01
Soil-4	1.7 ± 0.1	1.6 ± 0.1	0.20 ± 0.01	0.82 ± 0.03	0.06 ± 0.01	0.33 ± 0.03

Table 2. Trace constituent concentrations in soil samples (μg g^{-1})

Sample	Co	Sc	Cs	Eu	Hf	Ta	Th
Soil-1	12.8 ± 1.4	11.1 ± 0.9	5.5 ± 0.9	1.4 ± 0.2	19.1 ± 5.0	1.2 ± 0.1	47.2 ± 6.3
Soil-2	10.1 ± 2.3	7.5 ± 0.8	2.1 ± 0.3	1.1 ± 0.2	18.2 ± 4.1	1.1 ± 0.2	36.0 ± 4.2
Soil-3	12.5 ± 1.6	16.8 ± 0.8	3.2 ± 0.2	1.1 ± 0.1	9.0 ± 2.4	1.6 ± 0.8	21.1 ± 2.3
Soil-4	5.8 ± 0.4	7.1 ± 1.0	2.5 ± 0.3	0.9 ± 0.3	21.0 ± 2.5	1.0 ± 0.3	111.1 ± 2.6

Mean±1s (n=4) reported

Acknowledgements: The authors acknowledge operation crew of the research reactors for their help during sample irradiations.

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Compositional characterization of materials using neutron induced chain reaction based NAA methodologies

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The concept of thermal neutron induced in-situ chain reactions is less explored for compositional analysis of materials. One such methodology (Equation I and II) was utilized for the production of ^{18}F ($t_{1/2}$: 109 min, β^+ emitter) with high specific activity for medical purpose using enriched lithium hydroxide or lithium carbonate [1].

$$^{6}Li + n \rightarrow {}^{4}He + {}^{3}H \quad (\sigma_{th}: 950\ b,\ Q: 4.78\ MeV) \qquad (I)$$

$$^{3}H + {}^{16}O \rightarrow {}^{18}F + n \quad (\sigma: 0.094\ b,\ V_C: 1.4\ MeV,\ E_{th}: 1.65\ MeV) \qquad (II)$$

Therefore, it is quite evident that if a material has elements such as Li and O, the measurement of ^{18}F can provide information on Li and O contents based on the nuclear chain reaction. The presence of both Li and O is required for the generation of ^{18}F and the activity depends both on the numbers of Li and O atoms present in the sample. This concept is recently employed for the determination of Li and O content in lithium titanate (LTO) which is used as anode material ($Li_4Ti_5O_{12}$) in lithium ion battery and solid breeder blanket material (Li_2TiO_3) for tritium production in International Thermonuclear Experimental Reactor [2]. For complete characterization, determination of Ti in the material was carried out using fast neutron activation. The standards for Li and O were prepared by mixing known quantity of lithium and oxalic acid di-hydrate. The effective range of ^{3}H (E: 2.75 MeV) was found to be in the range of 60 - 73 μm, which is much higher (> 500 times) compared to the grain size of the LTO samples. Thermal neutron and fast neutron irradiations were carried out at AHWR Critical Facility Reactor and at PURNIMA Neutron Generator Facility, BARC, Mumbai. The activity generated upon neutron irradiation, was measured using HPGe detector (EG&G ORTEC, relative efficiency: 30 %; resolution: 1.9 keV at 1332 keV of ^{60}Co) coupled with 8k channel analyzer. The compositions of LTO samples are shown in Table 1.

Table 1. LTO composition obtained by NAA [2]

Sample/LOD	Li (wt. %)	O (wt. %)	Ti (wt. %)
LTO-1	13 ± 1	44 ± 3	43 ± 2
LTO-2	5.8 ± 0.4	41 ± 2	53 ± 2
LOD	0.44	0.52	0.45

The limits of detection (LOD) of Li and O are given in Table 1, which are inferior compared to other existing methods. With the utilization of high neutron flus nuclear reactors (>10^{13} cm^{-2} s^{-1}) such as Apsara-U instead of currently used facility with neutron flux ~10^{7} cm^{-2} s^{-1}, there will be many fold improvement in LOD and ppm (mg kg^{-1}) level analysis can be done using neutron induced chain reaction. The method developed, can also be utilized for the compositional determination of lithium zirconate, lithiun niobate, lithium silicate and also for the determination of oxygen in various kinds of samples (high melting oxides) in which traditional methods face difficulty. The method developed for Li and O, require no special arrangement, can be performed offline and the associated radiation hazard is negligible compared to that of the existing methods available based on neutron activation.

Acknowledgements:
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Determination of Silicon in Apsara-U fuel by using Gravimetry

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There has been a worldwide move from use of high enriched uranium (HEU > 90% ^{235}U) to low enriched uranium (LEU < 20% ^{235}U) fuels for research reactors. The reduced fissile atom content in LEU compared to HEU is beign compensated by increasing the fissile atom density in the fuel meat. The low-enriched uranium-silicide (U_3Si_2) is one of the preferred advanced nuclear fuels with reliable performance at high burn-ups [1]. The brittle nature of this intermetallic compound demands its dispersion in aluminium matrix with uranium densities maximum up to 4.8 g cm^{-3}. The Indian research reactor APSARA underwent an upgrade from its previous HEU-based UAl_3 dispersed in Al fuel to LEU based U_3Si_2-Al fuel. Like any other reactor fuel the new APSARA-U fuel also requires its chemical characterization as a indispensable part of chemical quality assurance (CQA). In this work we have focoused on quantifying the silicon content in LEU-based U_3Si_2-Al fuel. The digestion of U_3Si_2-Al in the HCl medium dissolves U and Al as UO_2Cl_2 and $AlCl_3$ respectively leaving Si in the solution as undissolved black particles [2]. Further, the addition of conc. HNO_3 in the solution converts Si into black silicon oxide (SiO). Then, treatment of this mixture with conc. H_2SO_4 converts SiO into a white SiO_2 which precipitates out. The precipitate is dried in a Muffle furnace at 900°C. The treatment of SiO_2 with conc. HNO_3 and HF results in evaporation of Si as its volatile compound silicon tetrafluoride (SiF_4). The wight differerence gives the amount of Si present.

Table 1. Analysis of synthetic solutions and real U_3Si_2-Al samples sample (n=3)

Samples	Added Conc. (mg mL^{-1})			Analyzed value (%)	Recovery (%)
	U	Si	Al		
Synthetic solution 1	70.7	5.7	23.6	5.66±0.05	99.3
Synthetic solution 2	71.4	5	23.6	4.95±0.05	99.0
Synthetic solution 3	71.9	4.5	23.6	4.48±0.04	99.6
Sample 1	-	-	-	4.65±0.04	---
Sample 2	-	-	-	5.13±0.05	---
Sample 3	-	-	-	4.72±0.05	---

The proposed analytical methodology demonstrates sequential steps of using various mineral acids to selectively separate Si simultaneously from U and Al. This method has been validated by analyzing three synthetic solutions which contain the elements in the same ratio as in actual sample. The results of these analyses and three actuals samples are given in Table 1. Elemental recoveries of more than 99% validates the proposed procedure. The relative standard deviations (RSDs) on the determined quantities are observed within 1%.

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Synthesis and Characterization of Selected Cu(II)-Ln(III) Complexes by Utilizing Enhanced Research Reactor

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In general, nuclear techniques and their neutron-based characterization methods have played a vital role in material science for R&D. Research reactors have played a pivotal role in the development of nuclear technology. Attempts have been made to synthesise selected Cu(II)-Ln(III) complexes of hetero donor ligands. Development of newly synthesised Cu(II)-Ln(III) complex characterization can also be used for the extension of the R & D as well as for nuclear reactor utilization. The heteronuclear copper(II)-Ln(III) compounds have commonly been synthesizing with hetero donor ligands where N,O/N,N coordinated to copper and lanthanide atoms. This newly synthesized Cu(II)-Ln(III) complex can also be characterized by the different nuclear techniques such as Chemical characterization by Neutron Activation Analysis and different studies related to material science. Research at reactor should lead to new and improved structural materials. The properties of the sample complexes under study can be analysed on the crystallographic or chemical structure, hardness, anisotropy in thermal and electrical conductivity, response to external mechanical and thermal loads and to magnetic fields and radiation resistance. These different tools help in materials characterization ranging from the atomistic level to the macroscopic scale. In fact, ultimate goal for utilizing research reactors play a crucial role for testing and characterization of new materials and structural materials. Neutron beams play a unique role both in the characterization and development of materials.Neutron-based techniques are being used in a variety of fields such as physics, chemistry, metallurgy, polymer science, biology, medicine etc. The field of magnetism, superconductivity, low-dimensional systems as well as nano-science and technology has been enriched with the availability of neutron scattering techniques, which provide complementary information to other characterization techniques. In many cases, these techniques provide information that cannot be obtained otherwise.

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Neutron activation analysis of archaeological ceramics of NnorthEast India

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Northeast India has been a region of cultural diversity for ages. This diversity can also be seen in the cultural materials of the area. A contemporary cultural material, i.e. ceramic, can be easily characterised or differentiated based on their visible characteristics, associated literature, and present knowledge inherited from the past generations. However, identifying qualitative material characteristics of past or archaeological ceramic remains of Northeast India is still a relatively unsolved task. The prominent archaeological ceramics of the region are handmade cord-impressed [1], basket impressed [2], carved paddled potteries [3], wheel made potteries, etc.

Qualitative identifications and associated provenance studies of ceramics such as potteries and artefacts of Neolithic and later periods can only be made by their accurate compositional material analysis and comparison with the raw materials present in the nearby and far regions. Neutron activation analysis (NAA) is required in the current situation to investigate archaeological ceramics due to its better accuracy than other analytical techniques.

The NAA and Prompt Gamma-ray NAA can help us in the identification of major, minor, and trace elements and their respective compositions present in archaeological and contemporary indigenous ceramics and their raw materials allied to their origin [4]. NAA can also be used to trace the origins of the raw materials utilised in the manufacturing process tracing [5]. These methods will also assist in identifying compositional variations in the visually similar ceramics of different assemblages [6]. NAA can fulfil the goal of identification of material variations in ceramic artefacts of sub-regions or various sites of a specific region of Northeast India for further investigation of manufacturing and patterns of artefact distribution in past cultures of the area.

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Application of Neutron Activation Analysis for I-129 Estimation in environmental Matrices

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I-129 and I-131 are the most important radioisotopes of Iodine released from nuclear facility and will have impact on the environment. Radio-Iodine (I) can disperse quickly in the air and water. In soil system, however, it combines easily with organic materials and moves more slowly in the environment. I-131 with a short half-life of 8 days will decay completely in a couple of months, however, I-129 released will last for millions of years in the environment. Atmospheric testing in 1950s and 60s released radioactive iodine to the atmosphere, I-129 has dispersed around the globe and is currently found in extremely low concentrations in the environment. Also, I-129 is one of key radionuclides in the nuclear waste depository [1]. Currently, I-129/I-127 ratio has increased from 10^{-12} (pre nuclear era) to 10^{-10}-10^{-4} in the environment [2]. I-129 emits β-particle (154.4 keV), γ-ray (39.6 keV), and X-rays (29–30 keV). It can therefore be measured by using γ/X ray-spectrometry and β-counting using liquid scintillation counters (LSC). Neutron activation analysis (NAA) is another radiometric method for the determination of I-129. The method is based on neutron activation of I-129 to I-130, a short-lived radionuclide, emitting high-energy γ-rays (536 keV (99%), 668.5 keV (96%), and 739.5 keV (82%). Using NAA, I-129 can be determined with a better sensitivity compared with the direct measurement due to the high specific radioactivity of I-130 and gamma of high energy. This method is widely used for estimation of I-129 in environmental matrices besides Accelerator Mass Spectrometry. I-129 measurement in environmental matrices is a regulatory requirement for nuclear industries. Considering the importance of the issue it is planned to estimate I-129 by NAA technique at DHRUVA Reactor and APSARA-U facilities available in Bhabha Atomic Research Center (BARC), Mumbai in collaboration with Radio Chemistry Division, BARC.

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Utilization of Dhruva and Apsara-U research reactors for the chemical characterization of samples important for forensic studies

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Chemical characterization of trace evidences (hair, paint, glass, ceramics etc.) has importance in forensic investigations. Trace elements including transition elements and rare earth elements (REEs) are source specific and capable of finding similarity or difference among the samples. There are various conventional wet chemical and nuclear analytical techniques are available for estimating the trace elements in various matrices. Nuclear analytical techniques using research reactors have various advantages over other competent techniques like small sample size, reagent blank, direct solid sample analysis etc along with good accuracy and precision make it suitable for analysis of forensically important samples. In the present work, forty-eight different automobile windshield glasses of ten different brands were analyzed by irradiated with high flux reactor neutrons (~10^{13} n $cm^{-2}s^{-1}$) for 5 hr in the self-serve facility of Dhruva and tray-rod facility of Apsara-U reactor, BARC. A total of 19 elements including 3 major (Na, Ca and Fe) and 16 trace elements (Sc, Cr, Co, Zn, Rb, Zr, Cs, Ba, La, Ce,Eu, Yb,Hf, Ta, Sm and Th) have been quantified using relative NAA method. Method has been validated by analyzing glass reference material i.e. NIST 610 as control sample. The obtained concentration results were found to be in good agreement with the certified or literature values with the %deviation within ±3%. Trace elemental concentration results obtained by INAA were utilized for grouping studies using PCA. Results confirmed that 48 windshield glasses fall into 10 groups, which indicated the potential of PCA as the glasses actually belong to ten different car brands/manufactures. The study indicated potentials of INAA, trace elements and PCA for grouping/provenance studies relevant for forensic applications. In future, more samples including commercially available packed baby food, biological samples will be analyzed. Beside this, NAA method using reactor neutrons will be utilized for the preparation of sodalime in house glass reference material for the application in the glass forensics.

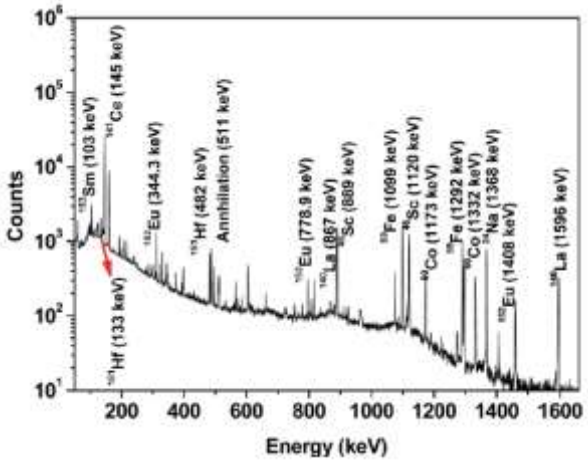

Fig. 1: Typical gamma-ray spectrum of a neutron irradiated automobile glass sample.

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Colorimetric detection of lead ions via functionalized polydiacetylenes

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Poly-di-acetylenes (PDA's) have been extensively utilised as chemosensors for their unique chromatic properties.[1] PDA's bear an alternating ene-yne structure that on exposure to UV irradiation (254 nm) display characteristic blue colour. When subjected to external stimuli such as temperature and pH change, metal ions, anions, surfactants, and other biologically important molecules PDA's show visible colour change from blue to red that arises from the change in molecular structure of the polymer.[2] Additionally, the blue-phase of PDAs are non-fluorescent while the red phase display fluorescence allowing their use as chromofluoremetric sensors. Since they possess such contrasting colorimetric change PDA's have been greatly favoured as sensory materials. Lead is one of the most abundant and toxic substance often encountered in the environment due to its use in batteries, gasoline, and pigments, etc.[3] Lead pollution is a persisting problem and a long-lasting danger to human health and the environment, as even very low levels of lead exposure can cause neurological, reproductive, cardiovascular, and developmental disorders.[4] In continuation of our ongoing research in the field of molecular sensors in this endeavour, we utilised alendronate modified PCDA for the detection of lead ion in aqueous medium. The suspended vesicle solution of alendronate-PCDA displayed blue color on UV irradiation and the addition of lead solution prompted colorimetric response. The sensing system displayed selective detection of lead in presence of competing ions indicating a viable assay for detections of lead ions. The validation of the sensing system will be carried out by NAA.

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Luminescent nanoparticles for anti-counterfeiting applications: Determination of dopant concentrations

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Counterfeiting of documents and currency is an enhancing high-tech crime which requires high-tech solutions to inhibit counterfeiting. In present data detailed study on synthesis of $NaYF_4$-Yb-Er (core), $NaYF_4$-Yb-Er (core)@$NaYF_4$ (shell), $NaYF_4$-Yb-Er (core)@$NaYF_4$-Yb-Nd(shell-1) @$NaYF_4$(shell-2), $NaGdF_4$-Yb-Tm (core)@$NaGdF_4$-X(shell-1, X = Ho^{3+}, Eu^{3+}, Tb^{3+}, Dy^{3+})@$NaYF_4$(shell-2) will be performed. X-ray diffraction (XRD) and transmission electron microscopy (TEM) will be used for structural morphology and microstructural characterization of synthesized nanoparticles. FullProf program employed for Rietveld refinement will be used to refine simultaneously the structural parameters such as lattice constants, atomic positions, occupancies and micro structural parameters as crystallite size and strain present in the crystal and for the determication of dopant amounts in host lattice. Surface functionalization and elemental compositional will be carried out using Fourier transform infrared spectroscopy (FTIR) and energy dispersive X-ray spectroscopy (EDX). Thermogravimetric analysis (TGA) and Differential thermal analysis (DTA) to measure the change in sample weight as a function of temperature (and/or time) under controlled gas atmosphere and temperature will be used. Study of up-conversion (UC), down-conversion (DC), optical heating behavior and energy transfer (ET) mechanism photoluminescence studies will be performed. The characterizations of lanthanide doped UCNM for the fabrication and design of luminescent security inks for their anti-counterfeiting applications, surface and morphological characterizations, ink designing and electroluminescence and chemiluminescence properties will be reported. The synthesized LA doped UCNM based inks can be formulate and produce the accurate color rendering index only for specific excitation power densities, which will make them harder to copy.

However, determination of dopant concentration is required to understand properties of materials. Dopant concentrations in nanoparticles will be deterimined by nuclear techniques such NAA, PIXE, PIGE, etc.

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Mobilization of Toxicants in Terrestrial and Aquatic Bodies of Imphal Valley using Nuclear Analytical Technique

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Loktak Lake in Manipur is the biggest freshwaterlakeinNorth-Eastern India and a wetland of International Importance under the Ramsar Conventiondue to its rich biodiversity, ecohydrological and socio-economic importance.The presence of floating vegetation masses is the major characteristic of Loktak lake, formed by the proliferation of weeds and vegetation, locally known as '*Phumdis*'. The Keibul Lamjao National Park, situated in the southern part of the lake constitutes a thick contiguous mat of *Phumdis* and isthe only floating national park in the world, which is home to the endemic species of brow-antlered deer known as *Sangai*, classified as an endangered species in the Red Book of the International Union of Conservation of Nature (IUCN). The lake is known to be fed by streams, rivulutes and rivers, some of which have been found in recent years to carry significant anthropogenic pollutants load which could be damaging to biodiversity and ecohydrologicalhealth of the aquatic and terrestrial environment.The major feeder rivers include Nambul, Nambol, Moirang, Irumbi, Phubala, Sanathoibi, Thinungei, Ningthoukhong, Thongjaorok, Nachou, and Narakhongoriginate from the western hills of the lake catchment and flows through various habitations in the catchment carryingnumerous amounts of anthropogenic wastes. According to WISA and LDA (2004), the majority of the water accumulated in the lake comes from the western catchment (52 %), followed by 25 % from direct precipitation and 23 % from other linked channels.

Physicochemical and heavy metal pollution studies so far carried out using conventional analytical techniques (which are cumbersome and time-consuming)indicate that the ecohydrological health of the lake is worsening with the passage of time. The groundwater of the valley districts of Manipur is also known to be severely contaminated with Arsenic (Chakraborty et al, 2007, Devi etal., 2012,2016, Alam et al, 2020). It has been reported using Atomic Absorption based study (AAS)that out of the 628 borewells investigated nearly three out of five wells were observed to have Arsenic levels greater than the recommended limit of 10 ppb by the World Health Organization. It is well known that the severity of Arsenic a pro-oxidant can be efficiently countered by Selenium which is an antioxidant. Therefore it becomes imperative to study Selenium too along with Arsenic.

It is proposed to carry out further investigations to identify, characterize and understand the nature of polluting sources besidesthe mobilization pattern of toxic elements present in aquatic and terrestrial bodieslocated in the Imphal valley region of Manipur using Nuclear Analytical Techniques such as Neutron Activation Analysis (NAA), Proton induced X-ray Emission (PIXE) and Proton InducedGamma-Ray Emission (PIGE) techniques.The investigators have carried out a similar study using different analytical techniques to understand the mobilization behaviour of toxicants in Dal Lake of Kashmir, Harike Wetland of Punjab States (2,3) details of which will be provided in the theme meeting.

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Application of INAA to Assess Rare Earth Distribution in Uranium and Copper Tailings from Singbhum Thrust Belt

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The demand for Rare earth elements (REEs) has increased significantly over the last decade due to the need in high-technology equipment, auto catalysts and digital technologies. As demand increases, an emphasis on the extraction of REEs as a by-product from active mining activities or through reclamation of historic mine waste is anticipated. Reprocessing of the tailings after uranium, iron, copper etc. extraction hold a good potential as a source of REEs.

As a preliminary study, uranium mill tailings from Jaduguda and copper mill tailings from tailings disposal facility of Hindustan Copper Limited at Mosabani region of Singbhum Thrust Belt were collected and analyzed for REEs using Instrumental Neutron Activation Analysis (INAA). The results have a high degree of reliability due to the high degree of accuracy and precision of the technique [1]. Homogenised representative samples alongwith standards and blanks (50 mg each) were characterised using INAA technique. The samples were irradiated with suitable neutron flux at the research reactor facility at BARC. After allowing appropriate cooling time, the specific gamma ray spectra were analyzed under identical conditions by a 50% p-type HPGe detector. Quality control was done using IAEA Soil 7 [2]. The distribution of analysed REEs in uranium and copper tailings are shown in Fig-1 a and b.

This study revealed that the U mill tailings from Jaduguda contain average concentrations of 54.7 ± 38.1, 148 ± 23.1, 4.8 ± 4.1, 10.5 ± 1.3, 166 ± 133, 0.5 ± 0.3 and 4.3 ± 1.6 ppm of Sm, La, Eu, Yb, Ce, Lu and Tb, respectively. Uranium mill tailings were observed to contain higher concentrations of La and Ce compared to copper tailings and similar range of concentrations for Sm, Eu, Yb, Lu and Tb. Total REE concentrations were higher in U mill tailings.

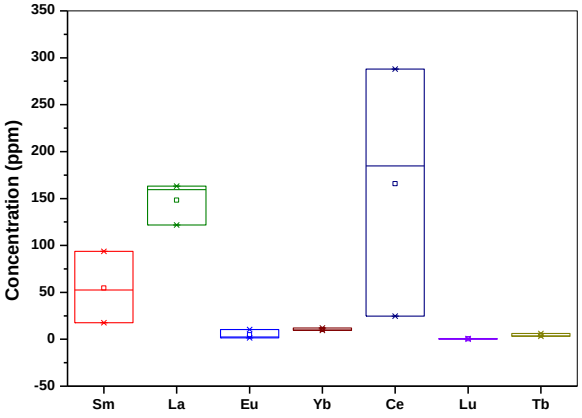

Fig. 1-a: REE concentration in Uranium Tailings

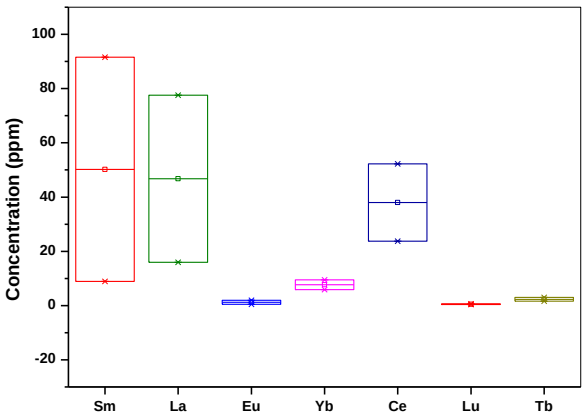

Fig. 1-b: REE concentration in copper Tailings

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A study on bioaccumulation of heavy and radioactive metals in the vital organs of amphibians of Chatrapur beach placer deposits, Odisha utilizing NAA technique at BARC

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There are a few regions in the world known to be high background radiation areas (HBRA) and Chatrapur placer deposits in Odisha are one of them. The major metal ores available in these areas are ilmenite, garnet, sillimanite, rutile, zircon, monazite and ores of other heavy metals. Fauna of this area are thus suspected to be affected by the chronic exposure to these radiations and there is also a possibility of accumulation of radioactive metals and other heavy metals in the body of animals through bioaccumulation and biomagnification. Amphibians are important bioindicators of environmental changes in an ecosystem and probably respond to natural background radiations as well. It is possible that chronic exposure to radiations as well as bio-accumulation of heavy metals may cause physiological, developmental, and behavioral changes in the animals which in turn, may have adverse impacts on the overall dynamics of the ecosystem. The study aims to have an assessment of accumulation of radioactive metals along with other heavy metals in the organs of selected amphibian species in the Chatrapur HBRA. We propose to use the neutron activation analysis (NAA) technique for quantifying thorium, zirconium and uranium along with heavy metals mercury, chromium, arsenic and titanium in the bone and kidney tissues of amphibians in the Chatrapur HBRA. NAA will be also used for quantifying the above metals from the soil and water samples of the study area. For this proposed work, reactor neutrons from Dhruva or Apsara-U reactor will be utilized and the proposed work on NAA will be carried out in collaboration with Radiochemistry Division, BARC.

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Adsorptive remediation of Cr (VI) by magnetite based composite nanomaterials and concentration determination by Instrumental Neutron Activation Analysis (INAA) and Particle Induced X-ray Emission (PIXE)

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Among the toxic heavy metals, chromium is tremendously responsible for pollution in aqueous environment. It mainly exists as Cr (III) and Cr (VI) in aqueous medium. Cr (VI) is genotoxic, mutagenic and carcinogenic towards living organisms. Most of the Indian tannery industries prefer chrome tanning process and discharge untreated waste water into nearby aquatic bodies, thereby elevating Cr (VI) level. For example, Cr (VI) concentration in The Ganges River at Kanpur city of Uttar Pradesh is 12.5 mg L^{-1} and that of surface water in the Ranipet industrial area of Tamilnadu varies from 2.1 to 214 mg L^{-1} as a number of tanneries are being operated in and around of these areas. In addition, Cr (VI) contamination also occurs due to the accidental leakage and improper disposal at mining sites . When ingested above the permissible limit, it causes skin, liver and kidney diseases to the downstream users. Therefore, it has been placed in the priority list of toxic pollutants by the US Environment Protection Agency (USEPA) and the maximum permissible limit for Cr (VI) in potable water is fixed at 50 μg L^{-1} . Adsorption is considered as most effective among the existing techniques to remove Cr (VI) from contaminated water due to its pliancy, simplicity, ease of applicability and scalability. Various nanomaterials such as layered double hydroxides, titanate nanotubes and metal organic frameworks have been used as adsorbents for removal of Cr (VI). However, use of these adsorbents is restricted due to difficulties in separation process. Magnetic nanoparticles (MNPs) have aroused considerable interest for their facile separation property. Among multitudinous MNPs, Fe_3O_4 nanoparticles are considered as most efficient adsorbents owing to their outstanding features such as biocompatibility, non-toxicity, large specific surface area and lack of superficial atomic site. Moreover, their magnetic nature enables them to be easily separated from the treated solution under the influence of an external magnetic field. However, the adsorption capacity might further be improved by combining these materials with advanced materials like graphene, MCM-41 etc. Radioanalytical techniques namely Particle Induced X-ray Emission (PIXE) and Instrumental Neutron Activation Analysis (INAA) with gamma ray spectrometry are recognized as advanced, simple and accurate techniques for identification and determination of adsorbed Cr (VI) directly from solid adsorbents. In this proposal, we have planned to fabricate various magnetite based composite nanomaterials such as magnetite-graphene and magnetite-MCM-41 using different synthesis protocols followed by their characterisation using instrumental techniques like XRD, FTIR, XPS, BET, SEM and TEM. Studies involving sequestration of Cr (VI) will then be investigated by using these synthesised adsorbents. Quantification of Cr (VI) in the solid adsorbents will be carried by Instrumental Neutron Activation Analysis (INAA) using neutron flux from Dhruva research reactor followed by gamma ray spectrometry and Particle Induced X-ray Emission (PIXE). The plausible mechanism for sequestration of Cr (VI) will be presented in form of a model.

Acknowledgements: The management of S'O'A (Deemed to be university), Bhubaneswar, Odisha, India is thankfully acknowledged for the inspiration to carry out the present work.

Studies on agricultural soil quality for improvement in crop products utilizing Nuclear Analytical Techniques: A comparison between chemical and bio fertilizers

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In recent years, the quality of soil in Punjab is significantly degraded and Punjab is also on the list of largest consumers of chemical fertilizer. A study conducted in the Nawanshahr–Hoshiarpur region of Punjab, India shows that the agricultural area of more than 1000 hectares is affected by the high levels of Se which is absorbed by the crop plants such as wheat grain, maize, mustard, mustard pods, rice, rice husk and hence comes into the human diet (Sharma et al., 2009). Farmers are using different agricultural practices to obtain high crop yield but due to lack of awareness about the nutrient profile for the crop, they end up using a higher amount of fertilizers which significantly degraded soil quality. Two main agricultural practices are prevalent in Punjab, organic and chemical. The effect of chemical (inorganic) fertilizers and manure (Biofertilizers) on soil quality and crop yield will be examined. In this study, elemental analysis of soil and crop (wheat, rice, maize) will be done to check the role of nutrients in the crop mentioned above. Nutrients such as Fe, Mn, Zn, & Cu are essential for crops (Alloway, B.J., 2008). It was observed that the application of fertilizers (NPK) with the above-mentioned nutrients increases grain and straw yield but no data is available which shows how much amount of fertilizer is important for sustainable & higher crop production (Bameri et al., 2012, Barnes et al., 1976). Our main focus in this study will be on soil quality and the effect of both chemical and organic fertilizers on the quality of soil and crop yield. The samples of soil and crops will be investigated for elemental analysis with the help of INAA and IBA (such as PIXE/PIGE). For more accuracy samples will also be analyzed with the help of ICP-MS. Obtained information from the study will be used to find out the precise amount of fertilizer needed for a particular crop in a particular type of soil. This will help farmers to get a high-yield crop at marginal cost without affecting soil fertility.

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Characterization of the irradiation positions of Apsara-U reactor and applications of k_0-based NAA for multielemental determination in diverse samples of various fields

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Apsara-U reactor at BARC is operating with low enriched uranium fuel and natural water as coolant and moderator and it has got several tray rod positions for isotope production and research work including Neutron Activation Analysis (NAA). The irradiation positions are shown in **Figure 1** below. The epithermal neutron flux shape factor (α) and the sub-cadmium to epi-thermal neutron flux ratio (f) are usually determined for each irradiation positions (both inner and outer core) in a reactor for standardization of k_0-based NAA. Experimentally, the parameters can be evaluated using cadmium ratio method [1]. The α value can be evaluated using dual monitors (^{197}Au and ^{94}Zr) and f value can be obtained from ^{197}Au. One of the position of Apsara-U (G4, inner core) was characterized previously and f and α values are found to be 19.94 ± 1.02 and -0.027 ± 0.003, respectively, which indicates hard neutron spectrum with about 5% epithermal/fast neutron component (importance of Apsara-U) [2]. It is planned to characterize all core irradiation positions of Apsara-U along with thermal column and selected beam tubes.

k_0-based NAA or single comparator NAA is a suitable and simple method for determination of trace to ultra-trace elements in various kinds of samples without any prior knowledge of constituents of samples. Radiochemistry Division has active R&D programs in various fields and also has a few collaborative projects with Universities/academic institutes. Several samples such as environmental, geological, forensic, food or archaeological origins are planned to be analyzed by k0-based conventional or internal monostandard NAA for various studies.

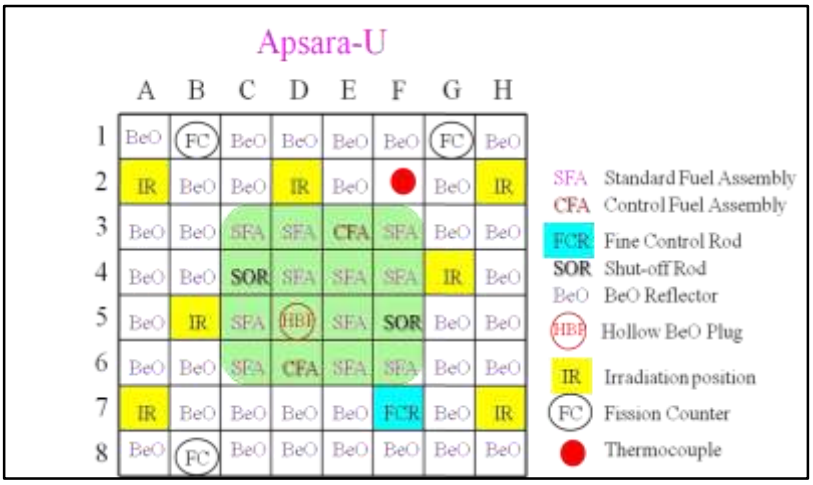

Figure 1. *Apsara-U reactor with all irradiation positions*

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Authors would like to thank Director, Reactor Group, Head, ROD, RS/ARS of Apsara-U, Head, RPNES, Head, RPhD and all Apsara-U operating crew members for their support and encouragement for utilization of the new research reactor.

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Large Sample Analysis using k_0-based internal monostandard NAA and PGNAA methods

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The idea of using an internal monostandard instead of external one in k_0-NAA method is promising for analyzing large and irregular geometry samples. The method utilizes *in situ* relative efficiency using gamma lines of activation products produced in the sample. The *in situ* efficiency takes care of attenuation and geometrical effects of sample and thus makes the method geometry independent. This approach gives relative elemental concentration of element (x) with respect to the monostandard (y) as given below [1,2],

$$\frac{m_x}{m_y} = \frac{\left((S.D.C).(f + Q_o(\alpha))\right)_y}{\left((S.D.C).(f + Q_o(\alpha))\right)_x} \cdot \frac{P_{Ax}}{P_{Ay}} \cdot \frac{(\varepsilon_\gamma)_y}{(\varepsilon_\gamma)_x} \cdot \frac{k_{0,Au}(y)}{k_{0,Au}(x)}$$

In the case of PGNAA, the concentration ratio calculation is very simple compared conventional IM-NAA as given below.

$$\frac{m_x}{m_y} = \frac{P_{Ax}}{P_{Ay}} \cdot \frac{\varepsilon_y}{\varepsilon_x} \cdot \frac{k_{0,H}(y)}{k_{0,H}(x)}$$

The relative concentration is converted to absolute values by using mono standard mass (or concentration) obtained by any other method or by NAA using a sub-sample analysis. Various kinds of large sized "as received" samples such as archaeological artefacts, potteries, bricks, alloys and ores have been analyzed using IM-NAA in conjunction with in situ detection efficiency. In special cases like in metals and alloys, where all major and minor elements are amenable to NAA, absolute concentrations can be arrived by mass balance.

As the samples are large in size, low neutron flux (10^6–10^8 n/cm^2/s) from thermal columns from AHWR Critical Facility and Apsara-U at BARC are proposed be used. Samples are mainly glass, ceramics, alloys and various environmental samples. In addition, ores and minerals including uranium ores are very good samples to be analyzed in large size to get better analytical representativeness. IM-PGNAA is advantageous compared NAA as, it is truly non-destructive and can do faster analysis for multielements including H and B.

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Application of NAA technique for quantification of trace elements in Health Sciences

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Evaluation of blood samples is necessary for evaluating the health condition of an individual. It has been known that Fe, Zn, Cu, Mn, I, Co, Mo, Cr, Ni and Se are the essential elements whose biological functions are rather well studied. In India, many groups are involved in determining the relationship between trace element concentration in serum and human diseases. In BARC Hospital, Mumbai an effort to identify the relation between the trace elements in serum and Asthma in pediatric age group was undertaken. Among other techniques, the Instrumental Neutron Activation Analysis (INAA) is considered to be a powerful and reliable technique for trace elemental analysis. INAA was used to quantify the concentrations of seven trace elements in the blood serum samples of healthy children whose age ranged from 2 to 10 years using INAA.

Freeze dried blood serum samples were irradiated at APSARA reator at a neutron flux 1.0 x10^{12} n/cm^2/sec. The irradiated samples were analysed using HPGe detector based high resolution gamma spectrometry system. The reliability of the method was tested by the analysis of standard reference materials orchard leaves, Apple leaves and citrus leaves. The results obtained were within 5% of the certified values. Table-1 summarises the quality control of the method and the range of elemental concentration obtained and compared with the reported literature range. Self serve facility of 2 MW Apsara-U currently under operation at BARC, Trombay can be successfully used for irradiation of samples for quantification of trace elements in blood samples.

Table 1. Quality control and range of elements in blood serum samples (n=16)

Element	Elemental concentration (µg/g)						Range of elemental concentration (ng/ml)	
	SRM-1572 (Citrus leaves)		SRM 1515 (Apple leaves)		SRM-1571 (Orchard leaves)			
	Certified	Calculated	Certified	Calculated	Certified	Calculated	Blood serum	Literature
Fe	90	87.5±2.8	300	287±15	83	81±4	1479 – 3038	240 – 5070
Zn	29	29.5±1.6	25	23±2	12.5	13±0.8	593 – 1393	660 – 3500
Co	0.02*	0.023±0.002	0.2*	0.18±0.02	0.09*	0.08±0.02	1.1 – 2.8	0.3 – 400
Se	0.025*	0.04±0.01	0.08	0.07±0.01	0.05	0.048±0.008	23.2 – 54.4	21 – 210
Cr	0.8	0.7±0.1	2.6	2.7±0.4	0.3*	0.28±0.02	3.8 – 11.5	1.8 – 400
Rb	4.84	4.9±0.9	12	12.5±0.9	10.2	10.1±0.5	173 – 526	40 – 2000
Sc	0.01	0.01±0.001	-	-	0.03*	0.02±0.005	0.23 – 0.45	0.15 – 6.0

*information values

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Neutron activation Analysis Technique for development of Nuclear Forensic signatures for nuclear materials

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Any Nuclear Material (NM) that is found or seized out of regulatory control should to be analyzed and proper attribution of the material under examination should be done to establish the provenance and process route of the material. Examination of NM involves nuclear forensics analysis of the characteristics of the material under investigation and comparison of the measured information with reference information (Fig.1). Therefore, it is required to have a National Nuclear Forensics Library (NNFL) of the elemental and isotopic composition, also called as signatures, of the nuclear material encountered in nuclear fuel cycle starting from Uranium ore. Establishment of library is prerogative in strengthening nuclear security systems for any nuclear empowered country. Moreover, IAEA recommends establishing NNFL for inventory of nuclear material. [1]

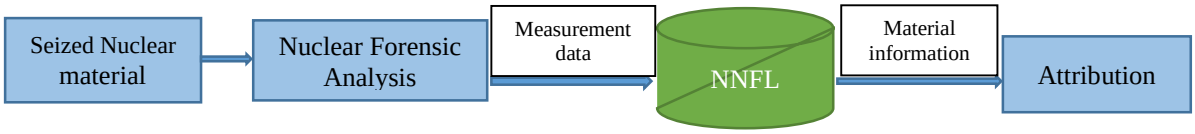

Fig.1 Stages of nuclear forensic analysis

Various analytical methods are used for elemental and isotopic characterization of materials. Most popular methods are spectrophotometric, Mass Spectrometric and Nuclear Analytical methods. Neutron activation Analysis (NAA) and Particle induced Gamma Emission (PIGE) are primarily high sensitive nondestructive techniques unlike other methods.

Chondrite-normalized rare earths elements (REE) pattern of Uranium Ore concentrates(UOC) remains unchanged from that of the feed ore. So information on Uranium ore elemental characteristics will support in deducing the source of the material. Australian Nuclear Science and Technology Organization (ANSTO) had used data of REE in uranium ore that was generated using NAA for Nuclear forensics analysis of interdicted UOC. [2]

NAA is a competent method for analysis of trace element and many REEs in Uranium ore samples. By varying the irradiation and cooling time, a range of elements can be easily analyzed. Na, Sc, Cr, Mn, Zn, Fe, Co, Sb, Cs, La, Ce, Nd, Sm, Eu, Tb, Yb, Lu, Hf, Ta and Th can be analysed using instrumental NAA and Pr and Er requires RNAA. [3]

To develop and strengthen the NNFL, effort is being made to include characteristics of nuclear materials encountered in front end nuclear fuel cycle namely uranium ore, mill feeds and UOC. It is proposed to utilize irradiation facilities at Dhruva and APSARA-U research reactors for analysis of samples from each mine using NAA. The results will serve as an important input for NNFL.

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Utilization of NAA and Conventional Techniques for Trace Metallic Assay in Nuclear Reactor Materials

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Chemical quality control (CQC) of nuclear fuel, structural and other associated materials, is one of the inevitable steps to achieve their desired performance in the nuclear reactor as their thermophysical and metallurgical properties are highly influenced by the presence of trace metals. Analytes (B, Cd, Eu, Sm, Gd, Dy) with high neutron absorption cross-section have very stringent specification limits due to neutron economy point of view. Analytes (Zn, Al etc) with low melting point can lead to liquid metal embrittlement. The highly refractory analytes may lead to creep resistance in the fuel. Hence there is a need of efficient, precise, simultaneously multi-elemental analytical technique to serve the purpose. Direct Current Atomic Emission Spectrometry is being routinely used for trace metallic characterization. However, due to arc wandering and other intrinsic phenomena, the precision of D.C.Arc carrier distillation is very poor (15-20% RSD). The arc not being an optically thin source, chances of self-absorption is more. The analytical zone temperature for the arc is moderate (3500 K), only lead to atomic line emission. Hence, the linear dynamic range as well as sensitivity of D.C.Arc AES are only moderately good. Therefore, there is always a thirst of finding more sensitive, reliable, simultaneously multi-elemental analytical technique with wide linear dynamic range and better precession. Neutron Activation analysis (NAA) is one of such analytical techniques, which can fulfil the above criteria. NAA has been proposed for trace metal assay in nuclear materials including UO_2, ThO_2, U_3Si_2, U-Zr or U-Al based alloys, MSBR fuel, AHWR fuel; reactor materials like nuclear grade graphite, alumina, BeO, Ziraloys, Zr-Nb alloy, Ni-alloy and stainless steel. The samples, where neutron irradiation would lead to the fission reaction, suitable prior separation strategy would be optimized in order to avoid such undesired fission reactions. Statistical evaluation will be performed to evidence the reliability of the measurement compared to the conventional techniques.

Acknowledgements:

Authors would like to thank Director, RC & I G, Head RCD, and all Dhruva and Apsara-U operating crew members for their support and encouragement for utilization of the new research reactor.

Assessment of heavy and radioactive metals for risk of chronic kidney disease in Odisha, India

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Chronic kidney disease (CKD) is a global public health problem of significant morbidity and mortality. Although the classic causes of kidney disease involve prior morbidity with diabetes, hypertension, and glomerular disease; CKD of unknown aetiology [CKDu] is the second most common CKDs after diabetic nephropathy in India. Of the several factors associated with CKD, genetic basis of the disease and environmental factors are important. However, despite an unusual high occurrence of CKDs in Odisha in recent years, there is paucity of information available on the risk of CKD epidemiology and progression in this region. Therefore, in the proposed study, we aim to investigate the predisposing genetic factors in CKD patients and certain important environmental factors of potential risk such as heavy metals including radioactive metals (lead, cadmium, arsenic, mercury, uranium, thorium) in drinking water and soil in the living areas of these patients. Confirmed CKD patients having estimated glomerular filtration rate (eGFR) 15–60 mL/min/1.73 m^2, or >60 mL/min/1.73 m^2 with proteinuria will also be evaluated for bio-accumulation of heavy metals and agricultural chemicals above the permissive limit in their blood). Quantification of heavy metals including radioactive metals will be done using neutron activation analysis (NAA) and other spectrometry techniques. Risk factors for CKDu being region specific, the findings of this study will help strategic management of CKD and prevent irrational exploitation of environmental factors of potential risk to CKDs.

Acknowledgements: The author acknowledges the collaboration with Dr Raghunath Acharya, Bhabha Atomic Research Centre under BRNS Project.

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Utilization of Neutron Activation Analysis (NAA) and Prompt Gamma ray Neutron Activation Analysis (PGNAA) facilities at Apsara-U for material characterization

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The Prompt Gamma-ray Neutron Activation Analysis (PGNAA), based on the online measurement of prompt gamma rays emitted following the neutron absorption through (n,γ) & (n,αγ) reactions, is complementary to conventional decay gamma ray neutron activation analysis (NAA) [1]. PGNAA is useful for the analysis of samples containing low Z elements, and elements like B, Cd, Dy, Gd, Sm and Hg which have extremely good analytical sensitivity due to their large neutron absorption cross-section. These elements due to their high thermal neutron absorption cross section are difficult to analyze by conventional NAA. Most of the elements in the periodic table can be analyzed nondestructively by these techniques under ideal circumstances. These methods have been applied in various fields like geological, biological and environmental samples and they are also useful for reactor technology materials like neutron poisons B, Dy, Gd etc.

A PGNAA facility was set up using neutron beam from Dhruva research reactor for analytical applications. Reflected neutron beam of energy 0.018 eV, intensity $1.4x10^6$ n cm^{-2} s^{-1} and dimension of 10mm x 30mm was available at the sample position in our PGNAA facility at Dhruva, BARC. Boron in in house prepared enriched B_4C (w.r.t. ^{10}B) samples were determined using this set up after correcting shelf shielding effect due to the high thermal neutron absorption cross section of ^{10}B [1]. Instrumental Neutron Activation Analysis (INAA) was used to characterize the compositions in Zirconium based reactor materials (Zr-1% Nb alloys) [2]. Zr-Nb alloys along with reference standards were irradiated for 1 min irradiation at PCF of Dhruva reactor at a neutron flux of $5x10^{13}$ n/cm^2/s. Concentration of Nb and Zr were determined by measuring short-lived activation product ^{94m}Nb (6.26 min, 871 keV) and ^{97}Zr (17 h, 743 and 1148 keV) using HPGe detector. Typical spectrum for boron quantification in boron carbides by PGNAA and Zr-1% Nb alloy are shown in the Fig. given below.

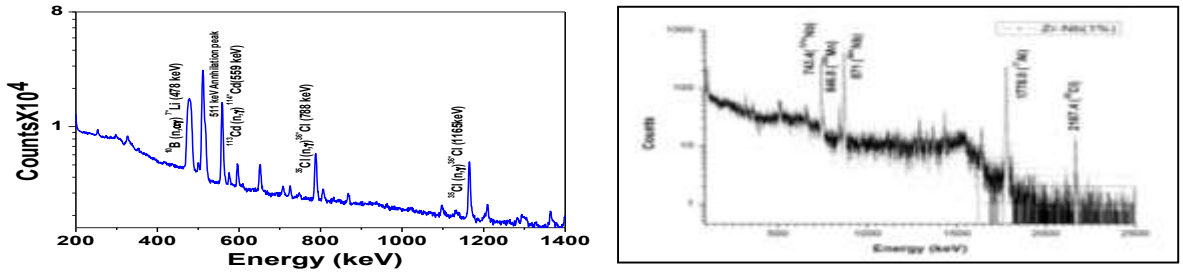

Fig.: PGNAA spectra of B_4C and NAA spectra of Zr-1%Nb alloy samples

As PGNAA is very sensitive to B and an accurate, rapid and quantitative nondestructive analysis of B at trace levels, i.e., in the ppm range in solid and aqueous solutions is possible using PGNAA. Proposals are given for non-destructive quantification of B in reactor materials like alloys and ceramics, H and Cl in Zircaloy etc. using the upcoming PGNAA facility at Apsara-U.

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Trace elemental fingerprinting of some ayurvedic formulation using Prompt Gamma Neutron Activation Analysis

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Throughout the history of mankind, traditional medicine has been considered the primary source of health care because of its effectiveness, availability, preservation, quality, absence of adverse side effects, safety and regulation concerns. Concerning the quality and safety of herbal products, quantitative estimation of elemental concentration of herbs and their formulation is a primary concern. The trace elements present in the herbals play a vital role in the formation of active chemical constituents present in these plants [1]. These elements mediate vital biochemical reactions by performing as centers for stabilizing structure of enzymes and proteins [2]. Their deficiency or excess can lead to disruption of *various* metabolic activities and to various diseases consequently. The herbal can be characterized in terms of the trace elements present in them. Qualitative and quantitative analysis of trace elements in various herbs and herbal formulation, reference data set, for quality control and standardization of herbal medicines, can be generated.

Limited studies have been conducted on trace elemental analysis of herbs using PIXE [3], XRF [4,5,6], ICPMS [4,5], NAA [6,7], AAS [7], etc. and very few analyses on compound formulations [5,6,7]. We have employed combinational techniques for trace elemental analysis covering wide range of elements effectively [4,5,6]. Prompt Gamma Neutron Activation Analysis (PGNAA) is considered very sensitive and is therefore used to analyze trace elements. Also, this method allows identification of more than one isotope and multiple gamma rays for the same element ensuring better consistency for elemental analysis.

The present work focusses on the elemental analysis of selected medicinal herbs using PGNAA along with other analysis techniques, which will produce elemental fingerprint of the herb and the compound formulation and can be used as a standard reference for fingerprint profile. The data can act as reference finger print for quality assurance of the herbs and herbal formulations.

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Estimation of cubic zirconia in diamond powder by using ED-XRF and NAA

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Cubic Zirconia (CZ), ZrO_2 is the most common simulant of diamonds. CZ in a crystal form is reliably identified and measured using FTIR and Raman spectroscopy. A trained Diamond Grader can identify CZ among diamonds lot. Diamond powder has various industrial applications. It is often adulterated with CZ powder. For specific applications, CZ is coated with diamond powder. This mixture can be detected qualitatively by FTIR and Raman spectroscopy. However, determination of CZ is difficult if powder form of CZ is mixed with diamond powder. EDXRF is one of the reliable analytical techniques used in GII to determine various elements present in gemstones. However, determination of Diamond and CZ in a powder mixture is difficult. Diamond (carbon), due to its low Z, is not amenable to determine by EDXRF as well as NAA.

GII developed a quantitative method to determine CZ in the mixture. Sugar powder which has nearly same average Z and comparable density as that of diamond powder. was used as a substitute for diamond powder and mixtures were prepared by adding known amounts of AR grade ZrO_2 powder to sugar powder. A series of samples of sugar and zirconium oxide mixtures were prepared keeping total weight to about 15 mg. Zirconium was determined by EDXRF technique. Amount of ZrO_2 in each mixture was calculated from the peak intensity under Kα Xray line of Zr (15.7 KeV) measured by EDXRF. A calibration plot was made between peak intensity and weight of zirconia. Slope and R^2 values are 16525 and 0.999 in the weight range of 0.075 to 0.75 mg.

Entire methodology was validated by determining Zr using NAA with the same set of samples.Zirconium from the neutron activated samples, was estimated using the peak area under 756.7 keV. Results thus obtained are in good agreement with the values obtained by EDXRF method. In both EDXRF and NAA, zirconium oxide was also estimated by standard addition method. There was no significant difference between results obtained by the two techniques

This method was applied to estimate Zirconia in three sets of diamond powder coated by zirconia by NAA and EDXRF. Reproducible results were obtained Average % of Zirconia obtained by NAA is 0.17% and 0.19% by EDXRF. By standard addition, actual amount was also determined.

Theoretical study on Gamma shielding parameters using a new Monte-Carlo code, MCBLD

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Radiation shielding is essential in various nuclear installations like nuclear reactors, fuel re-processing plant, isotope handling facilities, etc. A Monte Carlo method based gamma transport code MCBLD [1] has been developed to estimate various gamma shielding parameters like, build up factors and dose rate in single, multi-layer shielding arrangements. Various gamma photon interactions like photo electric effect, bound electron coherent scattering (Thomson), bound electron incoherent (Compton) scattering, pair production and annihilation gamma photons have been considered. Different gamma photon interactions like photo electric effect, bound electron coherent scattering (Thomson), bound electron incoherent (Compton) scattering, pair production and annihilation gamma photons have been considered. In this code, along with this survival weight technique, the exponential transform method is applied. This technique is quite useful in case of deep penetration shielding problems where a particle history may get terminated near to the shield boundary before it gets detected. BFs evaluation for different shielding materials like Iron (Fig.1), Lead (Fig.2), ordinary (2.5 g/cm$^{3)}$ and Ilmenite (3.5 g/cm^3) concrete (Fig.2) have been done and compared with other codes. Study has also been done for relative surface dose rates (Fig.3) evaluation in three layers, having different sequence of materials. Other than mono energetic source, provison is also there to take care of gamma spectrum as a source. Further this code is being coupled with neutron transport code to take care of the capture gamma.

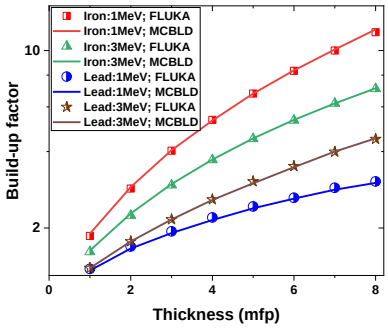

Figure 1. BFs comparison [2] in Iron and lead

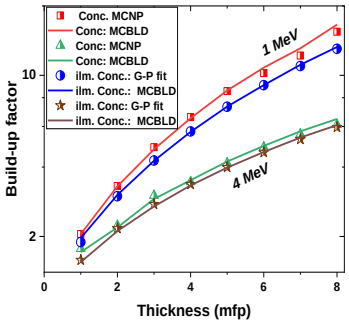

Figure 2. BFs comparison in different concrete

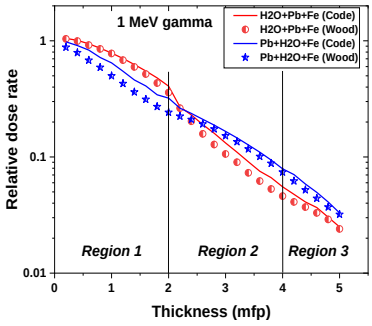

Figure 3. Relative dose rate variation with shield thickness

So far, therotical validation of gamma shielding parameters for common shielding materials is done using this code. The scope is still there, for the experimental validation (using the gamma produced in the reactor) of the physical parameters for different new shielding materials (boron doped glass, heavy metal alloy, polymers etc.) obtained using the code.

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Note on High Purity Mono-Crystalline Silicon Production at BARC

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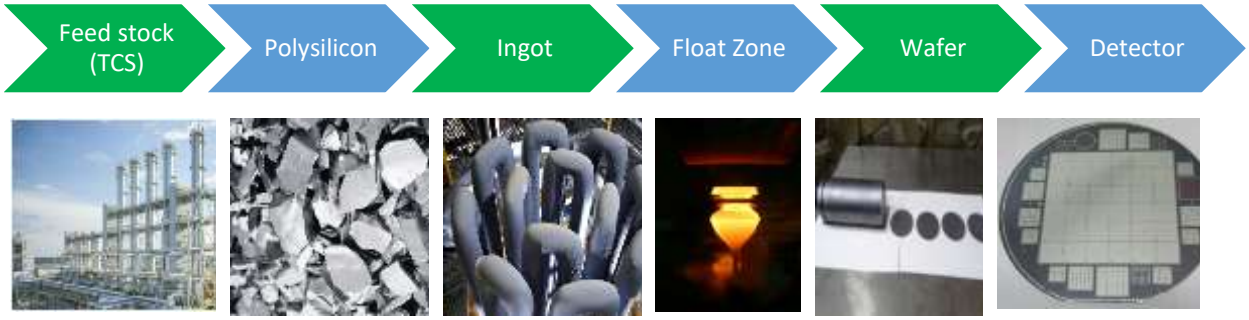
The Ultra High Purity Silicon industry is closely guarded and material supply is also restricted in the open international market. To produce defect free crystal and to make thin wafers thereafter is a technological challenge. Over 90% of the semiconductors produced worldwide are based on crystalline silicon wafers thus high purity silicon technology becomes an obvious choice for indigenous development. In addition, silicon can be purified to much higher levels than any other semiconductor material and thus can be transformed to very high resistivity - near intrinsic semiconductor material. Although sufficient industrial expertise for wafer to devise fabrication is available in the international domain, but for High purity Silicon wafer production, very little information can be extracted. In such a scenario, one has to develop and built their own facility for self-reliance, even though internationally REC (Norway), Wacker Chemie (Germany), Komatsu (Japan) and China have already established the technology.

High purity Silicon is produced from MG Silicon (~99% pure) in a three step process. First a volatile pre-cursor TCS (Tri-Chloro Silane) is produced in a Fluidized Bed Reactor. TCS is then purified by distillation process and Polysilicon is produced in Chemical Vapor Deposition (CVD) reactor to obtain high purity Silicon. BARC has developed all these steps by indigenous effort. Thereafter, Mono-crystalline Silicon is produced from Polysilicon via Czochralski or Float Zone crystal puller. Subsequently Mono-crystalline Silicon wafers can be produced from Single crystalline ingots and BARC also has got nearly all the machineries for this purpose. BARC has demonstrated production and characterization of Silicon wafers, which require dedicated clean rooms (upto Class 10).



High Purity Mono-Crystalline Silicon is used for fabrication of semiconductors, Integrated Circuits, High power device and radiation detectors. High purity silicon technology is denied to the country mainly because of its strategic applications in space, like intrinsic far-infrared detector fabrication for satellite use. In semiconductor foundries, normally doped Silicon wafers are used, instead of intrinsic Silicon. Conventionally gas doping is used to control resistivity and minority carrier life time of the base silicon wafers. But where radial uniformity in carrier concentration improved product quality (like CMOS application), Neutron Transmutation Doping (NTD) has advantages over gas doping. Intrinsic In this direction, few high purity crystals were exposed inside the APSARA-U reactor to produce NTD Silicon.

All the Chemical Process right from Feed Precursor Production (~10kg/day) to Purification via Distillation (~250kg/day) followed by Chemical Vapor Deposition Reactorfor polysilicon production has been demonstrated at BARC. Recently, 25 nos of 4" dia wafers were sent to BEL Laboratories for fabrication of PAD type radiation detectors. The architecture of these detectors was designed in-house by Electronics Division of BARC. The performance of indigenously produced Si PAD detectors is comparable to commercially available detectors. The packagings of these detectors are under process.

Production of neutron transmutation doped silicon (NTD-Si) in Apsara-U reactor

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Conventional semiconductor doping methods in silicon usually results in a non-uniform distribution of impurities in the grown crystals which may lead to formations of hot spots and undesirable variations in the parameters. For the fabrication of high power semiconductor devices like power rectifiers and thyristors, it is required that Si wafers have high conductivity along with uniform resistivity over large areas to achieve the requitred high current carrying capability [1]. In Neutron transmutation doping (NTD) of Si, n-type phosphorus (^{31}P) dopant atoms are produced by transmutation of ^{30}Si by thermal neutron capture reaction. The concentration of dopant atoms will depend upon the thermal neutron fluence. The plot of thermal neutron fluence ($\phi \cdot t$) against inverse of resistivity ($1/\rho_{eff}$) gives a linear behaviour: $\phi \cdot t = \boldsymbol{K} \cdot \frac{1}{\rho_{eff}}$. The slope of the line gives the value of doping factor, or resistivity-fluence correlation constant, called $\boldsymbol{K}$.

A number of trial Si samples were irradiated in Apsara-U research reactor, followed by decontamination and cleaning. The samples were annealed to recover back neutron damage under an inert atmosphere. Parameters like resistivity and minority carrier life time (MCLT) were measured. Theoretical study as well as experimental observations indicate that irradiation of Si ingot of size upto 8" diameter and 10" length may be feasible in a location just outside the core of Apsara-U.

Table 1. Experimental Data of Si wafers irradiated at the outside core position

Expt. ID	**IR-3**		**IR-4**	
S. No.	1	2	3	4
Thermal power (MW)	1.8			
Thermal neutron fluence (n cm^{-2}) (×10^{17})	7.2	2.0	11	3.4
Irrd. time (Hr)	50		70	
Initial resistivity (Ω-cm)	~ 6000			
Final resistivity (Ω-cm)	38.9	141.3	24.3	82.1
MCLT (μs)	50	55	-	-

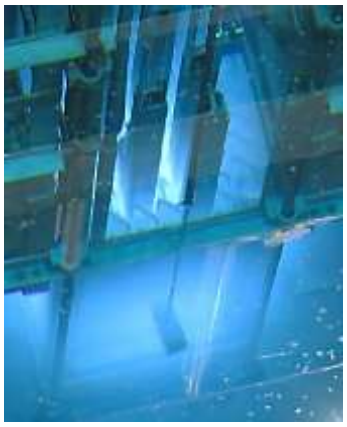

Fig. 1: Trial irradiation of silicon wafers at out-of-core

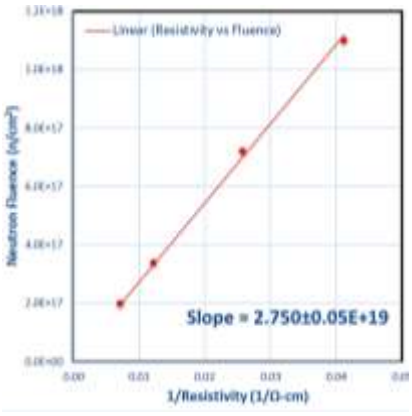

Fig. 2: Resisitivity fluence correlation curve

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Reactivity Meter Algorithm Based On Inverse Kinetics Method

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Reactivity meter is a device to measure reactivity instant to instant using real time computation based on inverse kinetics equation (IK). It finds application in control rod worth evaluation, calibration of reactivity devices and indication of point of criticality during reactor start up. To calculate reactivity in real-time specifically for Apsara-U (in the regime where source term can be neglected), a code has been developed based on IK equations using the power profile from neutron detectors [1]. It has been tested for the real time data from Apsara-U. Table-1 gives calculated reactivity values of CSR-1&2 drop from 6 detectors using the power profile (Fig-1 shows power and reactivity profile for one detector channel). In Apsara-U, photoneutron source occur in the BeO reflector region and the same can be accounted for measuring reactivity in the sub-critical region (reactor going sub-critical from critical state) as proposed by Tamura [2]. Further, for measuring reactivity when reactor goes to subcritical state from another subcritical state, in case of unknown source, the new subcriticality and source term (photoneutron source contribution in this case) can be estimated as given in [3]. The two mentioned type of calculation have been done and validated for simulated data. It will be extended for real time data.

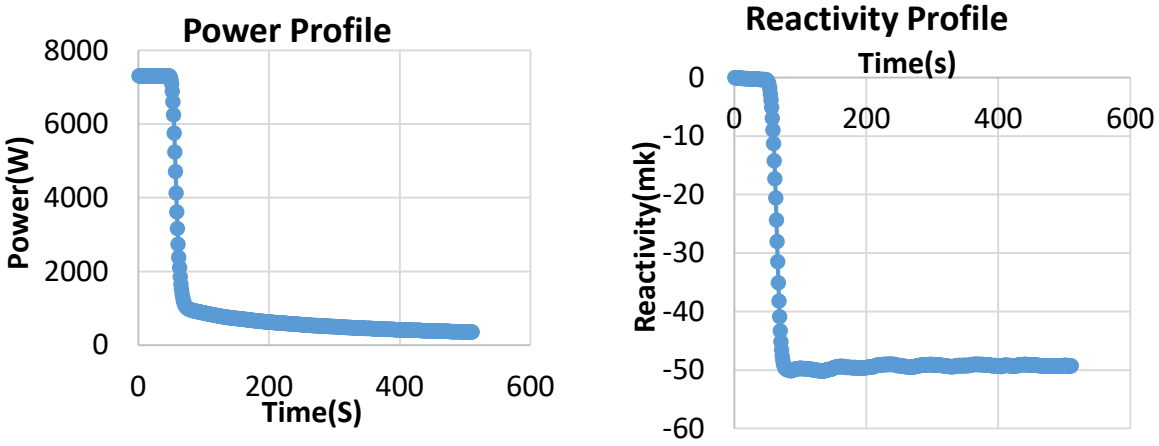

Fig. 1: Power profile and calculated Reactivity profile for CSR1 CSR 2 rod drop in APSARA-U

Table 1: Calculated reactivity for CSR 1 CSR 2 rod drop

Reactivity (mk)	Safety1 ChA	Safety1 ChB	Safety1 ChC	Safety2 ChA	Safety2 ChB	Safety2 ChC
IK	-49.32	-52.96	-49.37	-49.51	-49.11	-49.15
IKT	-50.37	-52.33	-50.37	-50.01	-49.63	-49.82

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Flux measurement at irradiation positions inside reflector of Apsara-U reactor

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The 2 MW Apsara-U reactor [1] is an upgraded version of the 1 MW Apsara reactor. The reactor core is replaced with Low Enriched Uranium (LEU) in the form of U_3Si_2 dispersion fuel. The core is surrounded by two layers of beryllium oxide (BeO) reflectors. Given the relatively small size of the reactor core, the number of irradiation positions that can be provided inside the core is rather limited. BeO reflector elements provide a large radial volume with high thermal neutron flux level and most of the experimental/irradiation positions (IR) are accommodated in reflector region which can be used for isotope production & material testing. Accurate estimation of neutron flux and neutron energy spectrum is necessary for proper utilization of these IR positions. The neutron flux at all irradiation positions have been estimated theoretically by Monte-Carlo method based code. Subseqently experimental measurements were performed to validate the results. Foil activation method was employed to measure neutron flux at two reflector region IR positions, namely G-4 and H-7, which are representative of inner and outer layer of reflector zone IR positions, respectively. Bare zirconium (Zr), bare gold (Au) foils, along with cadmium covered Zr and Au foils were used to measure thermal neutron flux. Sulphur pellet and nickel foils were used to measure neutrons in the fast regime. It may be noted that during the flux measurement experiment, the reactor was operating with only ten standard fuel assemblies and four control fuel assemblies along with a dummy fuel assembly in E-6 position.

Table 1. Experimental Data of foil irradiation and estimated neutron flux

Experimental/Irradiation position	**Experimental value**				**Estimated value**	
	G-4	**H-7**	**G-4**	**H-7**	**G-4**	**H-7**
Reactor power (KW)	15	200	2000 (extrapolated)		2000	
Thermal neutron flux (<0.5 eV) (n cm^{-2} s^{-1})	3.2×10^{11}	9.0×10^{11}	4.3×10^{13}	9.0×10^{12}	4.6×10^{13} (±1%)	1.2×10^{13} (±1%)
Fast neutron flux (>1.2 MeV) (n cm^{-2} s^{-1})	6.2×10^{10}	4.1×10^{10}	8.3×10^{12}	4.1×10^{11}	7.4×10^{12} (±2.6%)	3.9×10^{11} (±4%)

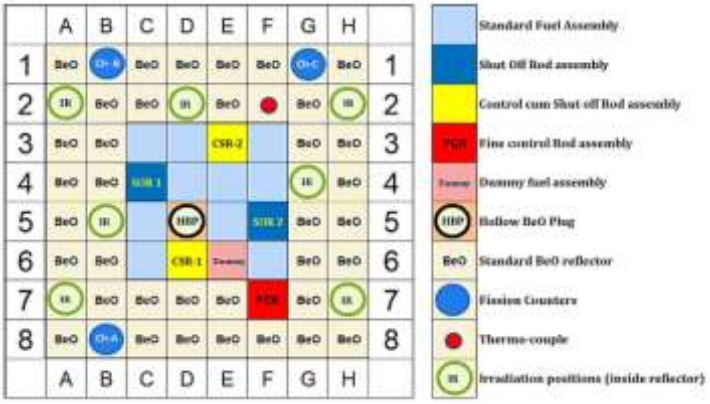

Fig. 1: Irradiation positions of Apsara-U along with the core configuration

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Application of noise technique for reactivity measurement in research reactors

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Reactor noise is an important technique for measurement of kinetic parameters such as prompt neutron lifetime and reactivity of nuclear reactors. With an objective to develop a noise based reactivity measurement system for research reactors, we have carried out experiments [1] in Critical Facility and Apsara-U. The required nuclear instrumentation and associated data acquisition system for the experiments has been developed in-house. The nuclear instrumentation consists of neutron detectors, front end nuclear electronic modules such as pre-amplifier, shaping amplifier, etc. and neutron time stamp measurement and data logging module. In-house made ^{3}He and BF_3 filled neutron detectors, of sensitivities 1- 100 cps/nv, are used for recording time of neutron events and show good counting statistics. The data acquisition system stores time stamps of neutrons in the form of a time series of events. A computer code has been developed for off-line analysis of the time series data to obtain reactivity and other kinetic parameters. Rossi alpha, Feynman alpha, correlation function and power spectral density are some of the commonly used methods for reactor noise analysis [2]. The measurements in Critical Facility have shown good results. The future course of work invoves modification of computer code for on-line analysis of the noise data and measurements in Apsara-U for its validation.

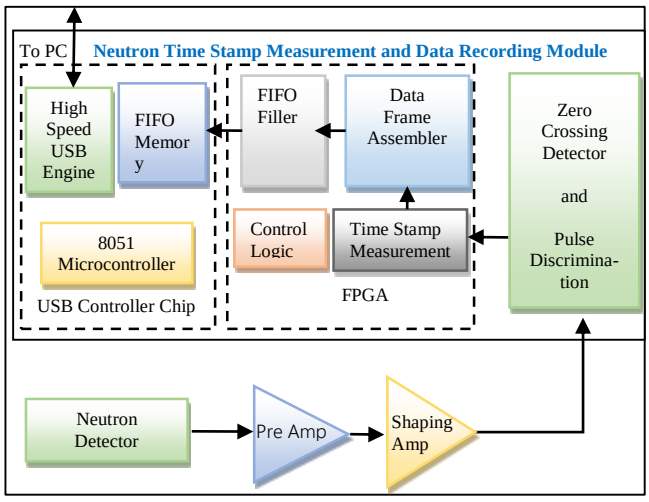

Fig.1. Measurement Setup and Block Diagram of Data Acquisition System

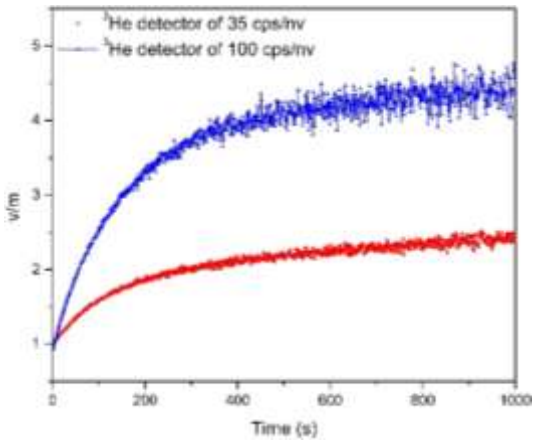

Fig.2. Measured variance to mean ratio for a given sub-criticality

Acknowledgements:

The authors are thankful to Shri C.G. Karhadkar, Director, Reactor Group, Dr. S.M. Yusuf, Director, Physics Group and Shri H.G. Gujar, Head, RRSD for their encouragement in carrying out the work.

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Experimental measurement of open loop transfer function for AHWR-CF: Theoretical perspective

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The time response of reactor power output to any input reactivity perturbation is dependent on reactor kinetics parameters like prompt neutron generation time (ʌ) and delayed neutron fraction (β). The direct measurement of 'ʌ' is considerably difficult. However, through transfer function technique, it can be measured through experiments [1]. An experiment is being planned to measure the 'ʌ' for advanced heavy water reactor critical facility (AHWR-CF) by plotting the Open Loop Transfer function (OLTF).The ratio of Laplace transform of output power and input reactivity is called OLTF. The analytical form of OLTF is given in equation 1.

$$G(p) = \frac{\delta n(p)}{\rho(p)} = \frac{\lambda + p}{p \cdot \Lambda\left(p + \lambda + \frac{\beta}{\Lambda}\right)} \quad (1)$$

The OLTF can be measured experimentally by plotting the power response of a reactor to known input perturbation. In this experiment, it is planned to insert a known reactivity perturbation and variation in output power can be measured. In the theoretical analysis, the response is simulated using point kinetics code MRIF [2]. The Laplace transformation for input reactivity perturbation and output power can be estimated using equation 2 & 3.

$$\rho(p) = L[\rho(t)] = \int_0^\infty \rho(t) e^{-pt} dt \cong \Delta t \sum_{i=i_0}^{N} \rho_i \exp[-p\Delta t(i - i_0)] \quad (2)$$

$$\delta n(p) = L[\delta n(t)] = \int_0^\infty \delta n(t) e^{-pt} dt \cong \Delta t \sum_{i=i_0}^{N} \Delta n_i \exp[-p\Delta t(i - i_0)] \quad (3)$$

The theoretically estimated form will be ratio of equation 3 and 2. This form of OLTF is compared with analytical curve obtained using equation 1. Different intervals for Δt have been considered. It has been observed that for Δt> 0.1 sec, the OLTF observed is of significantly different form compared to analytical eq. 1. The kinetics parameters of AHWR-CF are given in table-1. A case step reactivity of 1.03 mk has been added in 0.1 sec and another case for ramp reactivity insertion of 1.03mk (through movement of adjuster rod) in 17.9 sec has also been studied.

Table-1 AHWR-CF parameters	
Effective delayed neutron fraction (β)	0.00749
Prompt Neutron generation Time (l or Λ), sec	0.00058
1 group decay constant (λ), sec^{-1}	0.088

Here, reference core of AHWR-CF with 55 fuel assemblies has been considered. We have considered the movement of AR with speed of 2.1 cm/s. Figure 1 shows the plot of OLTF and its comparison with analytical form for all the cases studied.

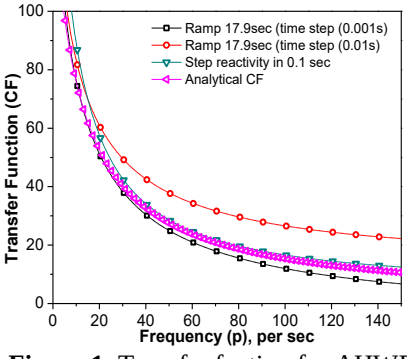

Figure 1: Transfer fuction for AHWR-CF

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Neutron Flux and Gamma Dose-rate Mapping at Beam-Hole 5R of Apsara-U Reactor using Criticality Badge Foils

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An experiment to measure total thermal, thermal, epi-thermal, intermediate and fast neutron fluence rates along with gamma dose rate was carried out using activation foils and TLD 700 (^{7}LiF:Mg,Ti) discs of Criticality Accident Dosimeter (CAD badge) at different distances in the beam hole no- 5 Radial (BH-5R) near Zircaloy plate with reactor core at B location and reactor power at 180 kW of APSARA-U reactor for an irradiation time of 66.63 min. The irradiation was done at different distances (0 to 300 cm) with respect to the Zircaloy plate. For the measurement of lower energy neutron fluence up to 1 keV, gold foil activation technique ^{197}Au(n,γ)^{198}Au with and without cadmium (Cd) cover was used. For fast neutron fluence rate measurement, sulphur pellets ^{32}S(n,p)^{32}P and for gamma dose measurement TLD-700 (^{7}LiF:Mg,Ti) discs were used. Results are given in Table-1.

Table-1: Results of neutron & gamma mapping of BH-5R of APSARA-U at 180 kW reactor power

Location of sample from Zircaloy Plate (cm)	Total Thermal (Westcott) Neutron Fluence-rate ($n.cm^{-2}.s^{-1}$) (0-1000eV)	Pure Thermal Neutron Fluence-rate ($n.cm^{-2}.s^{-1}$) (<0.4eV)	Epi-thermal Neutron Fluence-rate ($n.cm^{-2}.s^{-1}$) (0.4 eV-1keV)	Intermediate Neutron Fluence-rate ($n.cm^{-2}.s^{-1}$) (1keV-100 keV)	Fast Neutron Fluence-rate ($n.cm^{-2}.s^{-1}$) (>1.5 MeV)	Cadmium Ratio (Au-bare/Au (Cd)	Gamma dose rate (Gy/h)
0	(1.09 ±0.02) x10^{8}	(9.41±0.03) x 10^{7}	(9.92±0.05) x 10^{5}	(4.57±0.04) x 10^{6}	(1.57±0.09) x 10^{8}	6.99±0.03	48.55±2.13
80	(6.94±0.03) x 10^{7}	(6.38±0.03) x 10^{7}	(3.39±0.06) x 10^{5}	(1.56±0.05) x 10^{6}	(5.84±0.02) x 10^{7}	12.94±0.02	6.18± 0.47
160	(6.24±0.04) x 10^{6}	(5.41±0.04) x 10^{6}	(5.19±0.08) x 10^{4}	(2.39±0.06) x 10^{5}	(1.00± 0.02) x 10^{7}	7.58±0.03	2.13±0.13
240	(2.16±0.05) x 10^{6}	(8.66±0.05) x 10^{5}	(5.53±0.08) x 10^{4}	(2.55±0.06) x 10^{5}	(2.66±0.06) x 10^{6}	1.67±0.05	1.03±0.03
300	(2.89±0.05 x 10^{6}	(2.51±0.05) x 10^{6}	(2.46±0.09) x 10^{4}	(1.13±0.07) x 10^{5}	(1.15±0.07) x 10^{6}	7.46±0.03	0.77±0.06

Acknowledgements: The authors are thankful to Dr. D.K. Aswal, Director, HS&EG for his keen interest and encouragement in publishing the research work. Thanks are also due to Shri Shibu Thomas, reactor superintendent, Shri Sanjit Pal, ARS and all other staff of APSARA-U who helped us to carry out this work.

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Pre-experimental assessment of TRISO particles fuel irradiation in research reactor Dhruva

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High temperature Reactors (HTRs) are Generation-IV reactor concepts to enable technology for several process heat applications of nuclear energy like efficient production of green hydrogen. An indigenous high-temperature reactor programme is being pursued at BARC. The envisaged design of Indian HTRs, e.g. 100kWt CHTR and 20MWt IHTR, are being investigated and analyzed [1]. The HTRs are fuelled with accident tolerant fuel known as TRISO coated particles (dia. ~0.9 mm), which contains the kernel of nuclear fuel elements encapsulated by three ceramic coatings of pyro-carbon and SiC. The SiC coating act as a micro-pressure vessel and is the main leak-tight barrier for radioactive fission products. These tiny particles are embedded in either spherical pebbles or cylindrical compacts of graphite-matrix as HTR fuel elements. The TRISO fuel particles can withstand up to 1600ºC temperature during operation and accidents in the core with deep burn-up.

An experiment is being envisaged to irradiate the TRISO-particles based fuel compact (dia. 1 cm & length 3.5 cm) as a coupon at the tray rod location in Dhruva reactor at BARC. The experiment aims to study the fuel performance with burnup and validate the physics tools for computing the burnup of TRISO fuel particles in Indian HTRs. As a pre-experimental assessment, the irradiation of LEU based fuel coupon has been simulated with in-house code ADWITA [2]. It is investigated to estimate the irradiation time to achieve burnup up to about 10% FIMA in the coupon during irradiation in the reactor operating at ~80% FP. The build-up (%ww) of fission products such as Cs-137 & Cs-134, their activity and specific power due to fission in the coupon are estimated during time intervals of irradiation and post-irradiation. The results are found to be as in Fig. 1 & Fig. 2. The burnup of the irradiated coupon will be measured by Gamma spectrometry of the fission products [3].

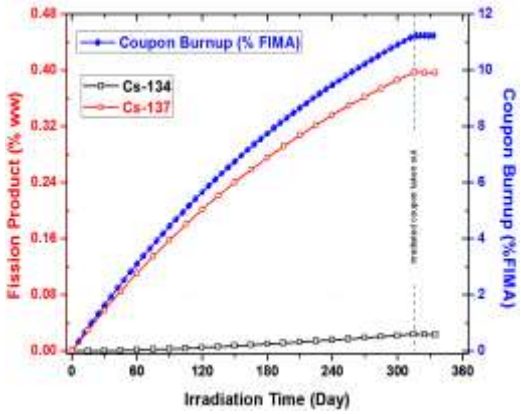

Fig. 1: Fission product build-ups and burup of the TRISO fuel coupon during irradiation

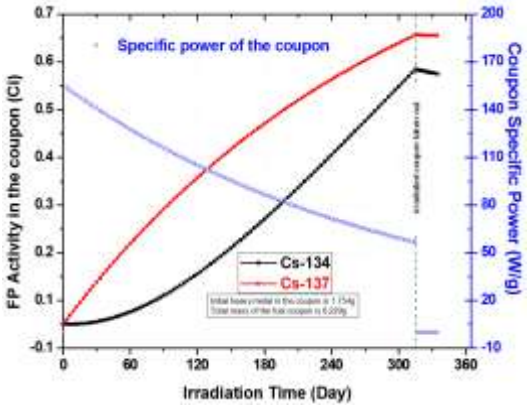

Fig. 2: fission product activity and fission power in the TRISO fuel coupon

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ACTYS: State-of-Art Computer code suite for Neutron-Induced Nuclear Activation Analysis

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ACTYS is an indigenously developed well-validated code suite for neutron-induced nuclear activation analysis. The codes are based on the linear chain method [1,2]. The algorithm is tailored for fast and accurate simultaneous calculations for many points with different material compositions and spatially varying neutron fields [3]. The code is equipped with detailed visualization techniques and can be coupled with neutron transport codes [4]. ACTYS can also be used for a first-level material composition optimization for favorable residual nuclear responses [5,6]. **A**ll the codes are well-validated in various levels such as validations against available analytical cases, isotopes wise validations against another widely used code FISPACT-2007, following the Second International Activation calculation benchmark comparison developed by International Atomic Energy Agency (IAEA) and FENDL benchmark studies (see ref 1,2,3,4,5 and 6 for details). Recently ACTYS has been qualified and approved by the Nuclear Integration Unit of ITER for all ITER-related nuclear activation calculations, which includes calculations that lead to nuclear safety-related reports. These codes can be made available to users of BARC Research Reactors for their needs. In this presentation physics, models, databases, and various uses of ACTYS will be discussed along with a detailed comparison of the code with its counterparts.

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Dosimetric Characterization of HS-3018 Neutron Imaging Beam line at Dhruva Reactor using various neutron detectors

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Neutron dosimetry has wide application in measurement of dose and fluence rates in reactors and various nuclear facilities. For thermal, epithermal and fast neutron measurements various detectors suchas, bubble detectors, albedo dosimeters (TLD 600 and 700), electronic pocket dosimeters, Solid State Nuclear Track Detectors (SSNTD) are used. Most of them are passive and require processing to evaluate the dose. Dhruva is a research reactor with rated power of 100 MW (thermal). One of the main utilization of the reactor is for production of radioisotopes of high specific activity for application in medical and industrial fields and provide beamlines for material research. A state-of-art thermal neutron imaging beamline has been developed at HS-3018 port of Dhruva reactor for advanced imaging applications such as neutron radiography, tomography and phase contrast imaging in material studies. The beam-line consists of a collimator, shielded experimental hutch, enclosed within shielded walls, roof and a movable shielded hutch door acting as beam dump [1].

Sets of $CaSO_4$:Dy+Teflon and $CaSO_4$:Dy+^{6}LiF+Teflon discs were used for gamma and neutron (thermal+epithermal) dose equivalent measurement whereas CR-39 detectors for fast neutron measurements (above 100 keV) [2] and were exposed for 25 min at sample position inside the beamline hutch. For comparison purpose of neutron and gamma dose measurements, an electronic pocket dosimeter (model: DMC 200GN M/s Mirion Technologies) was also used, which was exposed for 3 min. These detectors were calibrated with standard sources as per the ISO recommendations. The cumulative neutron (thermal+epithermal+fast) dose equivalent measured using passive TLD and CR-39 and active detectors were found to correlate well. Gamma dose measurment using active and passive detectors was also found to be in agreement. The fluence rate was derived from dose equivalent rates using dose conversion co-effecients. Measurement outside the beam line hutch was also carried out with the above mentioned passive and active detectors and observed that neutron and gamma dose equivalent (Neutron + Gamma =3 µSv/h) are within acceptable limit (<10µSv/h) for occupational workers.

Table 1. Results on gamma and neutron dose equivalent measurements inside thermal neutron imaging beam line hutch using passive and active detectors.

Type of detectors	**Sensitive to Neutron Energy range**	**Dose Equivalent rate (mSv/h)**	**Derived neutron fluence rate measurements (n cm^{-2} s^{-1})**
CR-39	Fast neutron (<100KeV)	326 ± 39	~ 7.13E+05
TLDs	Thermal + epithermal	2588 ± 181	~ 6.78E+07
Electronic Pocket dosimeters (DMC200GN)	Thermal to Fast	2800	-
DMC 200GN	Gamma	61	-
TLD	Gamma	57 ± 3.2	-

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Decay Heat Measurements from Manganese using Whole Energy Absorption Spectrometer

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For nuclear reactor applications, the decay power is theoretically estimated using codes such as ORIGEN2. To gain confidence on the predictions of reactor physics codes or nuclear database used for calculations, the results must be validated against experimental/theoretical benchmarks. But no such benchmarks are available for validating the decay power predictions. An uncertainty of about 20% is usually taken over the predicted values to accommodate approximations involved in the numerical methods, the uncertainty in fission product yield, nuclear reaction and decay data and neutron flux. With an intention to reduce the uncertainty margin and to validate the decay power predictions, an experimental set up for decay heat measurements using Whole Energy Absorption Spectrometer (WEAS) has been installed near KAMINI reactor. WEAS consists of a pair of large BGO scintillators mounted on a movable assembly for 4π geometry and associated electronics facilitating high efficiency measurement [1].

As a first step, sample of Mn was irradiated in KAMINI reactor and decay power is measured using WEAS. The predicted decay power was 40% lower than the measured. To find the reasoning, a sample of Mn foil (99.9% pure) having mass of 510 mg is irradiated for 47h in Thermal Neutron Flux Standard Facility (TNFSF). Gold foil of mass 192 mg is also irradiated for 400h in TNFSF. The neutron flux, estimated using the measured Au activity, is 1.20E+04 n/cm^2/s. The measured average capture cross section of Mn, found by ratio method (with Au as standard) is 8.04b. With this value, the decay power from Mn55 sample is estimated using ORIGEN2 code [2]. Table 1 gives the comparison of measured and predicted decay powers. The predicted decay powers are about 4% higher than the measured values and lies within measurement errors. Based on the results, it was found that the lower C/E decay powers of Mn sample, which is irradiated in KAMINI PFTS, is due to average capture cross section of manganese used in theoretical decay power prediction.

Table 1: Measured and predicted decay powers for Mn55

Decay time (h)	Measured	Error	Predicted	C/E
1.80	65.16	4.87	65.80	1.01
2.12	59.36	4.26	60.41	1.02
3.25	43.04	3.35	44.58	1.04
3.73	37.83	3.18	39.18	1.04

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Research reactor utilization for determination of Thermal Scattering Law

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Silicon Carbide is the most promising structural and cladding material for next generation fusion and fission reactors. Its superior mechanical and thermal properties, high radiation resistance and low activation under neutron radiation is key to improve the TRISO fuel particles [1,2,3]. The quest for high temperature reactors, and small modular reactors has reignited research interest into BeO as nuclear moderator material owing to its higher density and better neutron cross section [4]. The double differential scattering cross section for thermal neutron inelastic scattering is dependent on the thermal scattering law (TSL). Generation of experimentally validated TSL at relevant neutron energies is paramount for nuclear reactor design, criticality safety analysis, neutron beam spectral shaping, etc. This is achieved through a combination of lattice dynamics computations and inelastic neutron scattering measurements at research reactors.

The thermal neutron scattering measurement data available in EXFOR database needs revisions and timely updates with data from state of the art neutron scattering facilities. In the current research, the computation of phonon density of states for silicon carbide and BeO is performed using the Quantum Espresso software [5]. The model results are validated through inelastic thermal neutron scattering cross section experiments performed at DHRUVA reactor in BARC. The computed thermal scattering law is shown in Fig. 1.

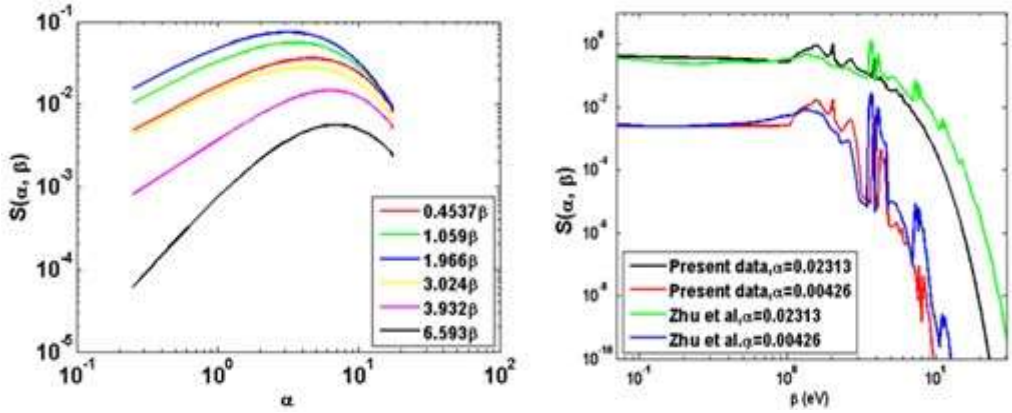

Fig. 1. Thermal scattering law for BeO, and SiC.

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Estimation of self-shielding factors in the resonance region for the neutron capture of U^{238} and Th^{232}

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Neutron activation analysis has been established as a reference method for quantitative and qualitative multi-element analysis of samples. This is due to its high accuracy, reliability and superior sensitivity that enable detection of even trace elements in the sample. Accurate estimation of self-shielding factors (SSF) helps in minimizing the uncertainty of neutron flux inside the sample for neutron activation analysis(NAA). The nuclear database (NuDAT) of IAEA provides the nuclear data essential for NAA. However, the existing database has to be revised based on the availability of updated nuclear data, as well as improved processing methods. A recent paradigm shift has been the release of NJOY 2016, the open source code for processing nuclear data, which has undergone revisions to handle the latest available evaluated nuclear data (ENDF/B-VIII.0). In this work the SSF are estimated from nuclear cross section data stored in ENDF/B-VIII.0 files [1] processed using NJOY 2016 [2]. The flux calculator method of NJOY 2016 allows the calculation of the flux perturbation due to the presence of a strong absorber nuclide. In Fig. 1, the resonance SSF for U^{238} in [1,35keV] are compared with experiment[3]. In Fig. 2, the resonance SSF in [1,35keV] for Th^{232} are compared with experiment[3]. It is seen that SSF estimated from ENDF/B-VIII.0 agree more closely with the experiment than SSF estimated from JENDL-3. The self shielding factors calculated will be further validated and the feasibilty of its use in practical problems for isotopes of interest form the basis of this work.

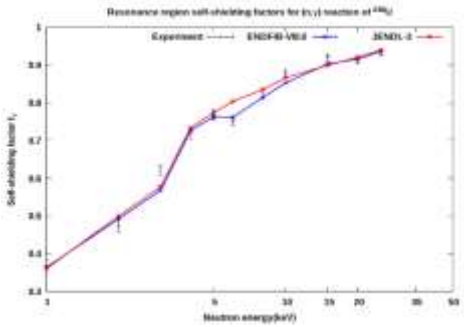

Fig.1 Resonance SSF for U^{238} (n,γ)

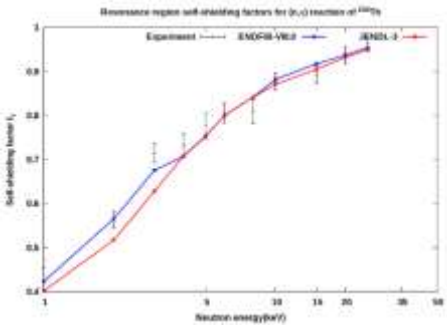

Fig.2 Resonance SSF for Th^{232} (n,γ)

Comparison of SSF at several dilutions in the resonance region of U^{238} (n,γ) and Th^{232} (n,γ)								
σ_0 (b)	**Energy (keV)**	**Experiment**	**ENDF/B-VIII.0**	**JENDL-3**	**Energy**	**Experiment**	**ENDF/B-VIII.0**	**JENDL-3**
1	**1 - 2**	.291±2.9%	.2925	.288	1 - 2	.344±3.4%	.3487	.325
	5 - 6	.703±2.0%	.6857	.703	5 - 6	.665±7.0%	.6310	.685
	20 - 25	.899±1.5%	.8675	.873	20 - 25	.917±4.9%	.8990	.893
10	**1 - 2**	.366±1.7%	.3645	.361	1 - 2	.453±1.9%	.4234	.402
	5 - 6	.769±1.3%	.7634	.774	5 - 6	.775±2.8%	.7534	.754
	20 - 25	.914±0.8%	.9161	.921	20 - 25	.937±2.0%	.9371	.932
100	**1 - 2**	.649±1.6%	.6145	.612	1 - 2	.750±1.5%	.6834	.707
	5 - 6	.928±1.5%	.9209	.922	5 - 6	.975±2.3%	.9123	.910
	20 - 25	.959±1.0%	.9806	.982	20 - 25	.974±1.7%	.9862	.984

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Neutron Shielding Experiments with High density Concrete (density 3.6 g/cc) and Comparison with other shielding materials

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Concretes of different densities are commonly used for shielding of both neutrons & gammas in nuclear reactors and in radiation facilities. In the present work, neutron and gamma attenuating properties of high density (HD) concrete slabs (density 3.6 g/cc) are studied [1] and compared with normal concrete, paraffin, polyethylene and Borated Polyethylene (BPE). The irradiation experiment is done by stacking the HD concrete slabs of total thickness 39 cm at the south beam end of KAMINI reactor. Neutron flux at the south beam end of KAMINI is of the order of 10^8 n/cm^2-sec.Various activation foils [2] and thermo luminescent dosimeter (TLD) cards are placed in between the HD slabs at different locations. The foils are selected so that their activation characteristics covered the neutron energy spectrum from epithermal to fast region. Foils become activated when subjected to neutron flux and gamma dose is accumulated in TLD cards. Using HPGE detector, the activities of irradiated foils are measured. The ratios of reaction rates of foils of different locations with respect to the first location provided the attenuation behavior of neutrons with respect to HD blocks.

The fast neutron flux attenuation of HD concrete is compared with other shielding materials and is shown in Figure 1. With 26 cm thickness of BPE, 100 times reduction is observed in fast neutron flux and which is equivalent to 26 cm in the case paraffin, 30 cm for HD concrete, 34 cm in case of polyethylene and 40 cm in case of normal concrete. It is found that HD concrete is more effective than normal concrete and polyethylene. The measured epithermal neutron flux attenuation is compared with 10 keV neutron attenuation of MCNP study [3] and is shown in Figure 2. They are almost matching up to an areal density of 60 gm/cm^2. Beyond that, theoretical study shows better attenuation. The reason for deviation in experimental attenuation may be due to reflection effect in the KAMINI south beam tube pit. In case of gamma dose attenuation, 65 times reduction is observed in 33cm of HD concrete. This is equivalent to 15 times reduction in normal concrete blocks. The measured data will be used as a basic reference for future measurements with other prospective concrete based shield materials and for validation studies.

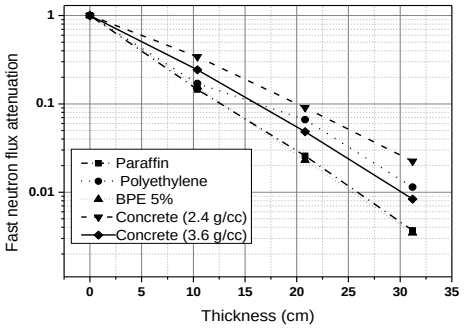

Fig.1: Comparison of fast neutron flux attenuation of HD concrete with other materials

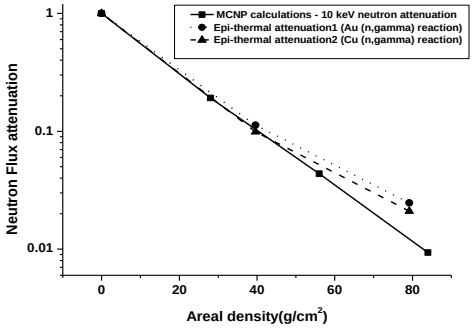

Fig.2: Comparison of measured epithermal neutron flux attenuation with 10 keV neutron attenuation of MCNP

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Development of point depletion code and integration to ORPAC-2

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In research reactors, reactor physics calculations are required for activities related to not only reactor operation but also for in-pile irradiations of the samples for production of radioisotopes**.** In this regard, a software named "ORPAC-Operational Reactor Physics Code**"** which is a system of many computer codes on a single platform, has been developed to address the issues related to operational reactor physics aspects of research reactors like Dhruva, 2MW Apsara-U, etc. The code is aimed at providing a handy tool for radioactivity estimation, safety analysis related with isotope irradiations and post irradiation handling, xenon transients etc. The code ORPAC is upgraded to solve generalized Bateman equation for neutron transmutation reactions e.g. (n, γ), (n,p) , (n,α), (n,2n) etc. Radioactive decay such as isomeric decay, β^- , β^+, electron capture and alpha decay etc are also considered in the newly developed module. For this, a point depletion code module is developed and integerated with ORPAC. Considering the differences in neutron spectra of heavy water moderated reactor Dhruva and swimming pool type light water reactor Apsara-U, it was imperative to use reactor specific spectrum-average cross-section library. The code is designed to provide users to select cross-section data library from drop down list for appropriate spectrum of irradiation position in the concerned reactor. Spectrum averaged cross section library which has been generated using PREPRO-19 and ENDF/B-VIII library for Apsara-U and Dhruva reactors. 69- group structure from WIMSD is used to generate effective one-group cross section of isotopes using neutron spectrum of given irradiation position. In addition to above, spectrum-averaged cross-section libraries for PWR and PHWR as well as decay data library, photon data library and fission yield data library as used in ORIGEN-2 code, have been incorporated in the upgraded version of ORPAC. For benchmarking purpose results obtained using ORPAC-2 for different targets including fissile as well as non-fissile for different irradiation history has been compared with the corresponding results from ORIGEN-2.

Reactor Physics studies for Fission moly production in HFRR

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Tc-99 is a radioisotope which is vastly used in medical field. It is produced from the decay of Mo-99 by irradiating the natural molybdenum in the reactor or by nuclear fission. As the specific activity of Mo-99 produced from nuclear fission route is comparatively higher than the natural molybdenum irradiation route, fission route is preferred for Mo-99 production. Two irradiation positions in the reflector vessel have been allocated in the proposed High Flux Research Reactor (HFRR) at Visakhapatnam for the production of fission moly. The maximum unperturbed thermal flux at this irradiation positions will be about $1.2x10^{14}$ n/cm^2/s. In each irradiation position, there are two fission moly assembly targets loaded one above the other. The targets consist of fuel plates which are arranged parallel to each other in an Aluminium holder. In this paper studies on heat generation aspects have been described for three different targets considering (i) 6 plates, (ii) 7 plates and (iii) 8 plates configuration of fission moly target assembly. The plate contains LEU-Al based fuel which is 1.4 mm thick with 0.3 mm thick Aluminum clad. LEU with U^{235}enrichment of 19.75±0.25 % is considered in the design. The simulations have been performed by Monte-carlo method based computer code to calculate the fission heat generation distribution in axial and radial direction. The results indicate that the 7-plate and 8-plate target assembly produce 13% and 24% more heat in comparison to 6-plate configuration. The maximum specific activity of Mo-99 will be about 12 kCi/g considering 14 days irradiation time and subsequent 5 days cooling period.

Understanding Irradiation Damage in Materials at Atomic Scale: An Atom Probe Tomography Perspective

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Atom Probe Tomography (APT) is a microscopy and microanalysis technique that provides sub-nanometer resolution three-dimensional mapping of elements within a small volume of material [1]. Owing to its unparalleled capabilities, APT is being extensively utilized in various scientific fields, nano-electronics, materials science, semiconductor device metrology, geology, to name a few. Since its inception, APT is also widely applied to the nuclear materials, especially the structural materials used in nuclear power reactors [2]. Very recently, APT is also employed to determine the local burn-up in irradiated fuels and it has successfully displayed the distribution of fission products at nano-scale [3]. In another report, nanoscale mapping of U isotopic enrichment and impurity elements in U-Mo fuels with high sensitivity has been carried out using APT [4]. In nutshell, APT provides vital information about materials that no other technique can offer at this scale and spatial resolution.

The study of irradiation damage of materials is a quest to understand the displacement of atoms from their respective lattice sites in the solid after irradiation. It is well known that the microstructure of the material can change drastically in response to the radiation, thereby degrading the bulk material properties, jeopardizing the safety. Owing to this, understanding the structural change/damage in materials at near atomic scale is a subject of paramount importance. Processes like radiation induced precipitation, clustering, segregation at grain boundaries/dislocations and initial stages of phase separation need special attention at the highest possible spatial resolution. APT is uniquely capable to study these phenomena and provide information at near atomic resolution. Materials Science Division of BARC is equipped with the state-of-the-art APT instrument that has all the capabilities mentioned above.

In this context, this presentation will shed light on the basic principle of APT technique along with the sample preparation for the same. Examples from the existing literature where APT is utilized to study the irradiation damage as well as the examples from author's present work [5,6] will be presented to demonstrate the unique abilities of this technique.

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Hydrogen Diffusion Studies in Zr-2.5%Nb alloy Pressure Tube Material

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Zirconium alloys are used as core structural materials for reactors due to their low neutron absorption cross section, irradiation stability and excellent corrosion resistance. Though the initial hydrogen content in core components is kept as low as possible, it can pick up hydrogen during reactor operation resulting in a steady increase of hydrogen during service. This hydrogen has deleterious influence on the integrity of the core components manifested as gross and local embrittlement. Hydrogen estimation in Zirconium alloys is being routinely carried out using several techniques like hot vacuum extraction, inert gas fusion, metallography, differential scanning calorimetry etc. However most of these techniques are either destructive or provide only surface information. Neutron radiography offers the advantage of being a nondestructive technique which provides bulk hydrogen information in a short span.

For zirconium alloys local embrittlement can be caused by migration of hydrogen up the tensile gradient and down the thermal gradient leading to delayed hydride cracking and blisters respectively. Hydrogen diffusion studies under concentration, stress and temperature gradient thus have become important to predict the behavior of hydrogen migration in reactor conditions. Several studies have been conducted worldwide to evaluate hydrogen diffusion parameters for different zirconium alloys of interest. A thermal neutron radiography beamline has been set-up at Dhruva reactor, India [1]. Neutron radiography experiments have been carried out for hydrogen estimation and determination of diffusion parameters in zirconium alloys. This work focuses on measurement of diffusivity parameters for hydrogen in Zr-2.5%Nb alloy under concentration gradient in the temperature range 523K-723K [2]. Samples for the study were prepared by electrolytic charging on one end and subsequent annealing at desired temperatures to generate a hydrogen v/s depth profile. This profile was mapped using neutron radiography and diffusivity was calculated by fitting the data with solution of diffusion equation. The effect of microstructure and dependence of diffusion on various pressure tube directions has also been studied.

Acknowledgements: The author would like to thank Mr. R. Baribaddala (TPD) for supporting with beam line instrumentation and Mrs. A Samanta (PIED) for hydrogen analysis of calibration samples.

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Utilization of Fission Reactors for Fusion Reactor Material Development

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Lack of data and predictability of materials behaviour under 14 MeV neutron irradiation is a grand-challenge problem of fusion. Not only do we need extensive testing and characterization but also the development of radiation tolerant alloys and compounds. A typical neutron spectrum is shown in Fig. 1; transmutation reactions at lower energy cause long-term decline of material properties and the high energy part creates intense displacement damage and helium production. For example, the maximum primary knock-on atom (PKA) energy produced by a 14 MeV neutron in tungsten is about 300 keV and that in iron is about 1 MeV. There exists no test facility that can simulate the fusion-reactor relevant conditions, therefore, accurate predictive modelling with a set of experimentally validated and benchmarked models is the only option. Surrogate particle-irradiation using ions, electrons, γ-rays and fission neutrons can not only validate such models but also provide insights about different mechanisms of multi-scale processes leading to their failure. In this context, we present the ongoing activities in tungsten plasma-facing material which is one of the most promising candidates for both first-wall and divertor of the fusion power reactors.

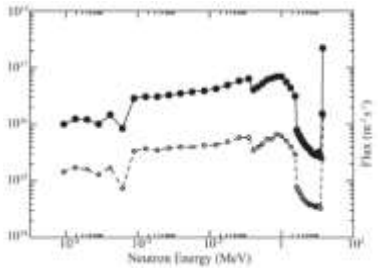

Fig. 1: Typical neutron spectrum at the front (solid) and rear (open) side of the tungsten plasma-facing materials [1]

Extensive ion-irradiation experiments, carried out across India, under the IAEA-CRP project (No. 18180/R0) and supported by modelling, have revealed that contrary to belief, the choice of ion-mass and energy plays a critical role in the creation and character of defects in tungsten (Fig. 2) [2,3,4]. Novel features like atomistic strain-driven gas-diffusion in metals are seen, which might explain the fundamentals of blister-formation, gas-permeation in advanced metal-membranes and gas-target formation [5,6]. We discuss how the fission reactors can be utilized for the ongoing studies with gamma and neutron-irradiation. The scope of activities to create statistical-models for failure of the reactor-materials by compiling experimental and modelling data, their visualization and the methods of deduction using statistical and AI-based techniques will be presented.

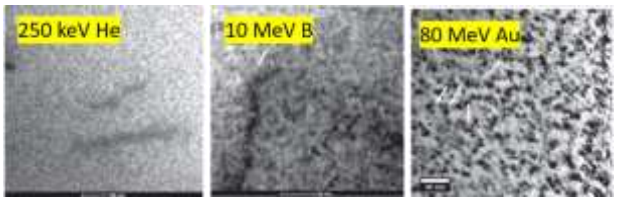

Fig. 2: TEM of defects created by different ions [3]

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Investigation of the mechanical properties of reactor pressure vessel steel after neutron irradiation

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Irradiation embrittlement is one of the life limiting factors of the reactor pressure vessel (RPV) steel of pressurized water reactors. Thus, it is important and essential to investigate the degradation of the mechanical properties of the RPV steel after neutron irradiation. A class of RPV steel (Mn-Ni-Mo type low alloy steel) is being developed for the proposed Indian Pressurized Water Reactor (IPWR). A part of the shell forging of thickness 390 mm was received in the form of a ring. Testing on the unirradiated RPV steel have shown that the mid thickness section of the forging has the lowest marging for strength and impact toughness. Thus it was decided that irradiation studies will be carried out on specimens taken from the mid-thickness region of the forged ring.

Two types of specimens are being irradiated to determine the change in the mechanical properties due to irradiation (i) miniature Charpy specimen (for impact energy) and (ii) tensile specimen (for yield strength). Schematic drawings of the specimens is shown in Fig. 1.

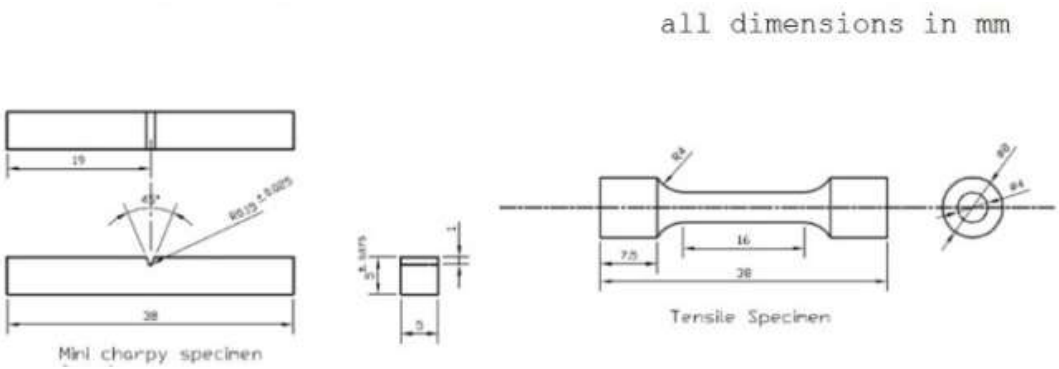

Fig. 1: Drawings of miniature Charpy and tensile specimens being subjected for neutron irradiation.

The RPV receives a total end of life fast neutron (E > 1MeV) fluence of ~ 4×10^{19} n/cm^2 which corresponds to about 0.05 dpa. Neutron irradiation of the RPV steel results in an increase in the yield stress (YS) and upward shift in the Ductile to Brittle Transition Temperature (DBTT). The increase in the DBTT is generally determined from the shift of the Charpy impact curve at a specific energy level, typically 41J. Tensile testing is carried to determine the effect of irradiation on the YS and ductility of the steel. Fracture toughness tests using pre cracked Charpy specimens is used to generate the master curve for the irradiated steel. The standard practice of initial screening of the RPV steel is performed on the basis of the impact energy value at -12 ˚C. The aim of this comprehensive irradiation campaign is to evaluate the irradiation embrittlement of the RPV steel using extensive mechanical testing.

Determination of variability in irradiation growth behavior of different generation of Zr-2.5%Nb pressure tube material used in Indian PHWR

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The Zr-2.5%Nb alloy pressure tubes (PT) used in Indian Pressureize Heavy Water Reactors (PHWR) are the most critical component. Alloy chemistry and fabrication route play importnat role in govering the pereformance of the PTs. With time, several modfications have been implemented in the alloy chemistry and manufacturing processes of the pressure tube. In intial period, tube were fabricated from double melted ingots using hot extrusion and double step cold pilgering. Later, it was relaized that the PTs manufactured from double melted ingots exhibit poor fracture toughness due to presence of Cl, P and C. Quadruple melted ignots are now being used for fabrication of PT. In recent time, hot radial forging has been implemented in the processing route for breaking the cast structure. The PTs for PHWR 700 and EMCCR of KAPS have been fabricated following hot radial forging, hot extrusion and single step cold pilgering. The 6 meter long Zr-2.5%Nb PTs used in IPHWRs exhibit axial elongation of several milimeters during service. Irradiation growth, a process of change of macroscpic shape of a specimen due to irradiation in absence of stress, is partially responsible for the axial elongation displayed by the PTs. The irradition growth behavior is governed by the alloy chemistry, microstructure (grain size, shape, dislocation density) and texture of Zr-2.5Nb alloy. Thus it is impornat to invesitgate the effect of change in processing route on the irradiation growth behavior of the Zr-2.55Nb PT.

Samples of dimension 40 mm length and 4 mm width cut precisely from different generation PTs will be subjected to neutron irradiation at the high flux location of the APSARA-U reactor. The axial strain per fluence exhibited by the PTs are ~ $0.7x10^{-24}$ to $2x10^{-24}$ per $n.cm^{-2}$. Thus at a fast neutron flux of ~ $1.3x10^{13}$ $n/cm^2/s$ at 40 mm long specimen might display a change in length ~ 50 to 100 μm in a time frame of 2 to 4 years. Samples will be taken out of the reactor after one year interval and length will be meaured using a specially desgned fixture for remote dimension measurement inside the hot cell. The outcome of the study will provide information on variablity of the irradiation growth behavior of different generation of Zr-2.5%Nb PTs used in Indian PHWRs.

Spin Lattice and Magnetoelectric Coupling in $Pb(Fe_{1/2}Nb_{1/2})O_3$ and $Pb(Fe_{2/3}W_{1/3})O_3$

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Crystal structure, spin-lattice and magneto-electric coupling were studied $Pb(Fe_{1/2}Nb_{1/2})O_3$ (PFN), $Pb(Fe_{2/3}W_{1/3})O_3$ (PFW) and their solid solutions. Low temperature neutron diffraction (ND) studies were carried out on polycrystalline samples in the temperature range of 2K to 300K to understand the structural and magnetic properties. The Néel (T_N) temperatures for PFN and PFW are 155K and 350K, respectively. The crystallographic structure for PFN at room temperature was found to be *monoclinic*, space group *Cm* and for PFW it was *cubic* space group *Pm*-3*m*. For both the compounds, no structural transition was observed down to 2 K. In case of PFN at temperatures below T_N an additional peak appears at scattering vector, Q = 1.35Å^{-1}, indicating the onset of antiferromagnetic ordering. PFW is magnetic at room temperature (RT) and is easily characterized by the magnetic Bragg peak in the room temperature ND pattern at Q = 1.35Å^{-1}. Magnetization (*M-T*) and dielectric measurements (ε-*T*) of PFN and PFW reveal a strong anomaly at their respective magnetic/ferroelectric ordering temperature (T_N/T_C) indicating the magneto-electric coupling. We studied the crystal structure, electric and magnetic properties of (1-x) $Pb(Fe_{1/2}Nb_{1/2})O_3$ – x $Pb(Fe_{2/3}W_{1/3})O_3$ (PFN_{1-x} – PFW_x) (x = 0.0, 0.2, 0.4, 0.6, 0.8 and 1.0) solid solutions. Raman spectroscopy corroborates the changes in structural symmetry from *monoclinic* (*Cm*) to *cubic* (*Pm*-3*m*) on varying from x = 0.0 to x = 1.0. The coexistence of both *monoclinic* and *cubic* phases was observed for compounds with x = 0.2 to 0.8. Magnetic measurements shows that, the magnetic phase transition from paramagnetic to antiferromagnetic (AFM) was observed at or above RT for x = 0.6 and above. The temperature dependent magnetization (*M-T*) confirms the augmentation of Néel temperature (T_N) from 155 K to 350 K on increasing x. From the neutron diffraction, magnetic and dielectric measurements corroborates spin lattice and magnetoelectric coupling.

Irradiation damage behavior of Ni based alloy studied using positron annihilation spectroscopy

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The present study is mainly focused on understanding the effect of Helium ion irradiation on the microstructure of a Ni-41.5%Cr-1.5%Mo alloy. For this purpose, a set of three samples were prepared by standard metallographic techniques and irradiated at fluence values of 3×10^{16}, 2×10^{17}, and 7×10^{17} ions/cm^2 respectively using He ion beam having energy of 65 keV. All the irradiation experiments were carried out at room temperature and in vacuum of approximate 10^{-6} mbar. The irradiation damage depth profile was simulated using SRIM software. After irradiation the samples were subjected to depth dependent Doppler broadening measurements using slow positron beam. The variable energy positron fit analysis of depth dependent momentum distribution suggested formation of two different layers within the damaged region having different characteristic S-parameter values. Irradiation induced hardness was ascertained using nanoindentation technique. A linear correlation between hardness and the characteristic S-parameter of the damaged region is established and rationalized.

An Advanced Investigation on Neutron Irradiation Induced UGs of $Al_{0.27}Ga_{0.73}N/GaN$ for Disinfection Applications under Nanotechnology

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This primordial research work's dominant aim has been to analyze an advanced investigation on neutron irradiation induced UGs (Ultraviolet Gain-characteristics) of $Al_{0.27}Ga_{0.73}N/GaN$ heterogeneous nanostructure for disinfection applications under emerging nanotechnology. At first in this research work taking into account pertinent fluence effects of neutron irradiations on $Al_{0.27}Ga_{0.73}N/GaN$ an advanced S&M sub-bands effective mass theory has been utilized in enumerating the various UV gain parameters. Further, in this work the intensity performance of UV gain spectra with UV-photon's wavelength of $Al_{0.27}Ga_{0.73}N/GaN$ has been investigated and analyzed at neutron irradiation fluence of ($5.6\times10^{11}cm^{-2}$). Owing to the fluence effect of neutron irradiation of (5.6×10^{11} cm-2) the potential height of barrier nanoscale layers is enhanced, hence leakage of electrons occurs diminished as a consequence intensity of UV gain is obtained in enhanced order. Thus this enhancement of intensities of spectra of UV gain (in cm^{-1}) has been obtained in the wavelength range 180 nm to 380 nm. However, in the analytical results, the crest value of UV gain intensity (~ 2750 cm^{-1}) has been achieved at the UV-photn's wavelength ~ 254 nm. This UV light of wavelength ~ 254 nm has not only played a substantial role for disinfection applications in today's life but this UV light of wavelength ~ 254 nm has also been used in the high purification to disinfect the surfaces, air and water by eliminating the various types of viruses, bacteria and harmful contaminants. Moreover, in today's research UV light of wavelength ~ 254 nm can also be used for BT (Biochemical Testing), MDs (Mercury Detectors) and Process of DNA Analysis etc.

Table 1. Structural Data of $Al_{0.27}Ga_{0.73}N/GaN$ heterogeneous nanostructure

Specified Nanoscale Layers	**Compositions of $Al_xGa_{1-x}N$**	**Thickness of Nanoscale Layer**
Quantum Nanoscale Layer	0.27	7nm
Barrier Nanoscale Layer	0.36	9nm
Cladding Nanoscale Layer	0.45	11nm

Acknowledgements: Author has been very grateful to Banasthali Vidyapith-304022, Rajasthan (INDIA) for providing appropriate research facilities in the Department of Physics.

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Diffusion of Xenon through irradiated nano-crystalline U-10 wt% Zr alloy

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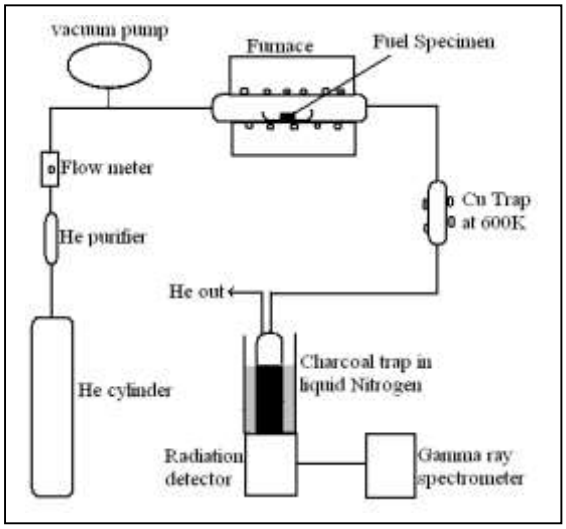
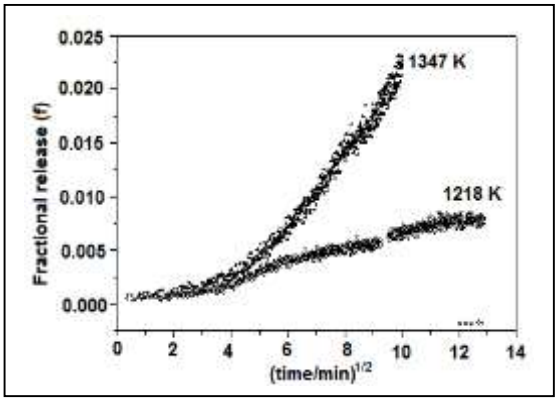
In this study, carried out at Chemistry Division, BARC, the kinetic data for the transport and release of xenon in the base alloy, U-10wt%Zr, were obtained using the post-irradiation annealing technique (PIA) of trace-irradiated samples at different temperatures.

Objective: To obtain the transport characteristics of the fission gases in the alloy matrix for the analysis of high burnup performance.

Experimental: For post-irradiation annealing experiments (using the set-up shown below) about 100mg of arc melted U-10wt% alloy was irradiated using the pneumatic carrier facility in Dhruva, BARC for 1 min at a neutron flux of ~ 10^{13} neutrons/cm^2.sec. After required cooling the irradiated alloy was annealed at different temperatures and the released xenon at each temperature was swept out by passing He as a carrier gas and monitored gamma spectrometrically using 81 keV gamma of Xe-133.



Schematic diagram for PIA study



Xe release kinetics in U-10wt%Zr cast at two temperatures using helium as carrier gas

Result: The released fraction of xenon was found to have parabolic dependence on √ (time) as shown in the above plot. The value of diffusion coefficient (D) was derived from the linear part of slope of the fractional release versus √(time) plot for each different temperature. Using these 'D' values the temperature dependence of diffusion coefficient was obtained using Arrhenius equation and was found to be ln D(m^{2}s^{-1}) = (-13697 ± 2380)/T – (6.2 ±1.8), ($1285 \leq (T / K) \leq 1393$), with the activation energy and frequency factor as 114 kJ.mol^{-1} and 2.03 x10^{-3} s^{-1} respectively.

Effect of irradiation temperature in RPV steel

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The present study focusses on bringing out the effect of heavy ion irradiation on the microstructural evolution of indigenously developed RPV steel for Indian PWR. He ion irradiation experiments were performed at 77 K, 300 K and 573 K. The energies of irradiation ions during experiments were varied in such a way that nearly uniform irradiation damage of 0.05, 0.2 and 3 dpa in a ~300 nm wide region could be achieved. All the samples were characterized using GIXRD, PAS, TEM and nanoindentation. PAS study showed a predominant presence of a combination of di- and tri-vacancy type of defects in unirradiated samples. Unirradiated sample showed presence of mostly screw type of dislocation which is expected in RPV steels being a bcc structure. XRD analysis clearly showed change of nature of dislocation from screw to edge type upon irradiation irrespective of the irradiation temperature. TEM study confirmed formation of dislocation loops and defect clusters on irradiation. PAS could have confirmed the formation of distinct defect types at different irradiation temperatures. Higher irradiation temperature resulted in an increase of diffusion of irradiation induced defects causing the extension of the width of the damage region. The present study, by virtue of irradiation at both 77 K and 573 K, could bring out the effect of the irradiation induced defects on microstructural and mechanical property changes at different stages of their existence starting from the state of cascade damage till the point of their free migration.

Ageing Studies on Irradiation Induced Degradation of In-Core Components of Research Reactor Cirus

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Cirus, a 40 MW (Thermal), tank type research reactor was shut down permanently on 31st December, 2010 after about 50 years of operation. Subsequently the core was unloaded of all spent fuel assemblies, isotope production assemblies, experimental assemblies and shut off rods. With implementation of suitable steps, the reactor has been brought to a 'Safe Storage' state of deferred decommissioning.

The permanently shut down Cirus research reactor provides an opportunity to carry out studies and generate data on material property degradation due to irradiation, environmental and operational conditions / stresses. The data can be utilized for life prediction and ageing management of operating reactors. The samples collected on Cirus SSCs, can also be used for assessing radio-inventory of core which is a prime requirement for future decommissioning of the reactor.

Studies were carried out on Aluminium tubes of reactor vessel for assessment of change in mechanical properties and on Graphite reflector for stored energy due to irradiation. The average values of YS, UTS and BHN are 55 MPa, 82 MPa and 22 for unirradiated Aluminium material and 102 MPa, 163 MPa and 41 for irradiated Aluminium material which shows an increase of approximately 100% in strength and hardness values on irradiation. The estimated fast neutron fluence (energy >1 Mev) of Aluminium material was 1.54 $x10^{22}$ n/cm^2. Analysis of various Graphite samples indicates that stored energy (Wigner energy) is low in nature and in line with the neutron fluence exposure. There is no concern of uncontrolled release of energy.

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Microstructural Effect on the Enhancement of Electronic and Field Electron Emission Properties of Nanocrystalline Diamond Thin Films by Ion Implantation and Annealing Processes

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Chemical vapor deposition grown nanocrystalline diamond thin films are investigated systematically for their application as field electron emitters owing to their negative electron affinity and low effective work function. While the physical properties of these films depend on the intrinsic structure of the materials, their electrical and optical properties are more closely related to the microstructure of the films. Therefore, the ability to control the microstructure and surface morphology of NCD film could tailor this material for variety of applications such as hard coatings, optical windows, micro-electro-mechanical systems and electron emitters. The decrease in diamond grain size increases the proportion of grain boundaries, which contain non-diamond carbon phases such as amorphous carbon (a-C) or trans-polyacetylene phases. These non-diamond carbon phases act as conducting channels, facilitating easy tunneling of electrons through a 'grain boundary conduction emission' mechanism and thus improve the field electron emission (FEE) characteristics of NCD films [1].

Ion implantation is a possible way to alter the electrical properties of materials via controlled doping with a wide variety of dopant species. By proper selection of the implantation energy and dose, the sp^2/sp^3 ratio of diamond and related carbon materials can be tailored. The sp^2-bonded carbon induced during ion implantation and post-annealing treatments of NCD films is the conductivity promoter, which enables the electrons to move freely inside the films [2]. In this work proposal, the effect of ion implantation by suitable ions and post-annealing processes on the electrical conductivity and FEE properties of NCD films will be investigated. Post-annealing could heal the defects and eliminate the electron trap centers in the implanted NCD films. Hall effect, four-point probe and FEE measurements will be carried out to analyze the electrical and electron emission characteristics of ion implanted NCD films. Scanning electron microscopic, Raman spectroscopic, X-ray photoelectron spectroscopic and transmission electron microscopic examinations will be carried out to understand the microstructural changes in the ion-implanted/post-annealed NCD films, which will assist to derive the mechanism for the enhancement of electronic and field electron emission characteristics of NCD films.

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SANS studies on Conventional and Gemini surfactants with and without additives: past, present and future

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Solution behaviour of surfactants can be changed by the addition of different additives or by changing experimental conditions. Alkyl amine, quaternary ammonium salts and counter charged amphiphiles have been used to modify micellar morphologies and SANS data were analysed to get micellar parameters and structural information. During above studies, few surfactant systems gave closed bi-layer morphologies at certain composition (mole fraction x=0.4 or 0.6). Compositional variation may modify micellar environment as studied by fluorescence measurements. Length of hydrocarbon chain or nature of spacer (in a typical gemini surfactant) shown contribution towards vesicle formation. Among all surfactant assemblies, vesicles are of utmost importance because they are widely used as model bio membranes, nano-container for drug delivery and for nanotechnology. Deep Eutectic solvents (DESs) are greener liquid systems which can be used as association medium for surfactants. Water based DES are finding importance as they can be used with variety of conventional and gemini surfactants. However, morphological information are missing with surfactant + DES systems, therefore, can be studied in future with the SANS spectrometer.

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Characterization of proton irradiated microstructure of deformed pure Nb

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Niobium (Nb) and its alloys have been considered as one of the potential candidate structural materials for high-temperature nuclear reactors due to their excellent high-temperature properties [1]. It is important to understand the effect of irradiation on the microstructure and the related changes in various properties of these materials before any application to nuclear reactors. The characterization of irradiated microstructure of deformed (rolled) pure Nb is carried out to understand the effect of pre-existing defects on the evolution of irradiated microstructure. Pure Nb samples were subjected to 10 and 20 percent rolling before irradiation. The initial characterization of deformed samples were carried out by synchrotron XRD (SXRD) and EBSD measurements. These samples were then irradiated using 7 MeV proton beam from Variable Energy Cyclotron, Kolkata. The XRD pattern of all the samples were collected at BL-12, INDUS-2, RRCAT, Indore. Different methods of XRD line profile analyses (XRDLPA) were adopted to extract the microstructural parameters from the SXRD data. It is observed that domain size decreases slightly in the 10 percent rolled sample whereas it remains almost similar in case of 20 percent rolled sample after irradiation. The dislocation density initially decreases and then increases with dose for both the cases. The correlation among the dislocations are lost at the initial dose of irradiation in both the cases. The microhardness value is found to decreases in the initial dose and then again increases with dose in both the cases. These observations suggests that the annihilation of dislocations by irradiation induced defects take place in the initial dose for both 10 and 20 percent rolled samples with more prominent effect in 20 percent rolled irradiated samples.

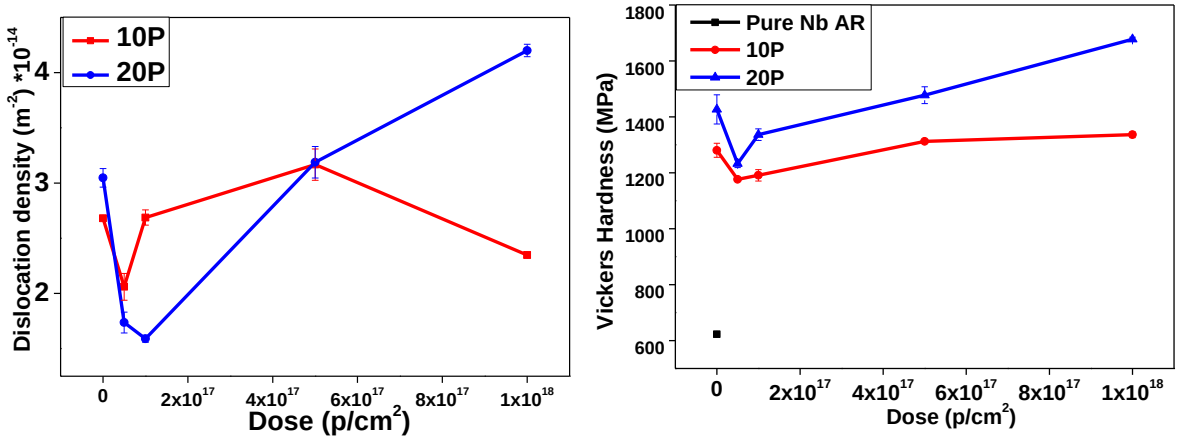

Fig. 1: Variation in a) dislocation density and b) microhardness as a function of dose

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Cotton Fabric Conjugation with Nanoparticles – *In-Situ* formed Metal Nanoparticles by Bio-reduction Method for Multifunctional Applications

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The main objective of the proposal on Cotton Fabric Functionalization with Metal Nanoparticles (MNPs) in general and Gold Nanoparticles (AuNPs) in particular, is to understand and enhance effectiveness of Antibacterial and UV- Shielding properties. Generally, use of NPs is multidisciplinary approach to provide Antibacterial, UV-shielding, flame retardant, water repellent and self-cleaning properties to cotton fabrics [1,3]. Antibacterial textiles with improved functionalities find several applications namely, health and hygiene products and infection control and barrier material. The novel route of green synthesis of bio-reduction method through plant extracts as a reducing agents for *in-situ* formed MNPs in cotton fabric is environment friendly in nature [2].

We had synthesized Nanocomposite Cotton Fabrics (NCCF) with in-situ formed AuNPs using citrus lemon leaf extract as a reducing agent. The studies of Antibacterial activity, XRD, FTIR, SEM and TGA had been carried on fabricated NCCF. The Antibacterial test against both bacteria, Gram-negative and Gram-positive, shows inhibition zones with diameters ranging from 24mm to 37mm indicating effective antibacterial activity. XRD analysis revealed that peaks at $2\theta=15^0$, 16.6^0 and 22^0 resulting from reflections of (1-10), (110), (200) planes of Cellulose-I structure of matrix. The low intensity peaks at $2\theta=38^0$, 44.2^0, 64.5^0 and 77.5^0 resulting from reflections of (111), (200), (220) and (311) planes respectively of FCC AuNPs. The SEM and EDAX studies revealed the average diameter of AuNPs in NCCF is 84nm. FTIR studies revealed that AuNPs are held in the NCCF by electrostatic interactions. TGA analysis revealed that the inflection peaks of the NCCF are marginally lower than for matrix due to catalytic effect of formed AuNPs.

The Cotton fibers conjugation with metal Nanoparticles and subsequent functionalzation of NCCF depends on size of MNPs. The final characteristics of MNPs depends on *size of nanoparticles, plant extracts as reducing agent, stirring rate, reaction temperature, the ratio of source solution to reducing agent*. The SANS studies are vital in realizing morphology and size of MNPs in NCCF, which enable us to functionalization of cotton fabrics.

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Preparation and Charecterization of Some Polymer Matrix Based Nanocomposites for UV Shielding

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Polymer matrix based Nanocomposites with suitable Nanoparticle reinforcement can offer better Electrical, Optical, Mechaical Properties and enhanced UV-shielding ability. Such material systems are being prepared for many commercial applications including window shields and automobiles [1]. We Prepared Multiwall Carbon Nanotubes (MWCNT) incorporated Polyvinyle Butyral (PVB) Polymer Nanocomposites by Solution Costing method. The XRD and SEM results showed that MWCNTs are dispersed excellently in the PVB polymer matrix. It is observed that incorporation of MWCNT in PVB matrices results in an increase in glass transition temperature (Tg) to 84.8 ^{o}C (for pure PVB 63.3 ^{o}C), melting point from 90.5 ^{o}C to 121.6 ^{o}C and thermal decomposition temperature from 225.3^{o}C to 232.2 ^{o}C. The electrical conductivity of 2.0 wt.% MWCNTs reinforced PVB nanocomposites observed $2.16x10^{-12}$ S/m at room temperature (for pure PVB $7.20x10^{-13}$ S/m). The activation energies changed from 0.346 eV to 0.183 eV before Tg and after Tg 0.201 eV to 0.104 eV. A significant improvement in Glass transition temperature, melting point and electrical conductivity of these nanocomposites can be utilized in molecular electronics, automotive, aerospace, EMI shielding and multilayer printed circuit applications.

The UV-Visible Spectroscopic studies were performed in the wavelength range of 190–1100 nm and the absorption edge, direct band gap, indirect band gap and Urbach energy values were evaluated. The loading with 2.0 wt. % of MWCNTs in PVB resulted in significant changes in direct band gap from 4.62 eV to 1.72eV, indirect band gap from 4.90 eV to 2.49 eV and Urbach energy from 0.77 eV to 1.80 eV. The results showed that the spectroscopic properties of PVB nanocomposite films are modified considerably with small loadings of MWCNT and these Nanocomposite are can be used as better UV Shelding materials for different commericial applications.

We are also Interested to do Small Angle Neutron Scattering (SANS) Experimental studies on some polymer matrix based nanocomposites, because SANS is a powerful sophesticated experiemntal technique which directly gives different structural parameters of polymers and thier nanocomposites [2] . We are interested to find size, shape, specific surface area and surface fractal dimenions of the some polymer based nanocompoistes which are very useful paramters to understand the interaction between nanoparticles and polymers for preparation of better UV sheilding materials.

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Ion (O^{6+}) induced micro-structural changes on pre-deformed V-4Cr-4Ti by XRD and EBSD

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Vanadium-based alloys are potential candidate structural materials (first-wall and blanket) for application in fusion reactor because of their good mechanical properties, good resistance to irradiation-induced swelling and damage, high thermal conductivity, good compatibility with lithium and inherently low irradiation-induced activity [1]. Among these alloys, V-4Cr-4Ti is identified as the most promising alloy for these purposes [1]. In this contest we have carried out the study related to the irradiation resistance properties of the initially pre-deformed V-4Cr-4Ti samples followed by O^{6+} irradiation with different doses. The unirradiated and 160 MeV O^{6+} irradiated (with 1E14, 3E14, 3E15 and 1.3E16 O^{6+}/cm^2dose, corresponding to an average dpa of 0.0003, 0.001, 0.01 and 0.05 respectively) V-4Cr-4Ti samples (pre-deformed) were characterized using X-ray diffraction line profile analysis (XRDLPA) and EBSD measurements for understanding the changes in the microstructure with irradiation dose. Dislocation density as calculated from the XRDLPA is shown in the Fig. 1(a). It decreases at the first dose and more or less saturates with further irradiation. IPF map of the unirradiated and one of the irradiated sample is shown in Fig 1(b). Band contrast and local mis-orientation (Fig. 1(c) and 1(d)) have been obtained from the analysis of EBSD measurement. Detoriation of the band contrast was observed at the first dose which then improves with further irradiation. The formation of higher local mis-orientation boundaries is seen at the first dose and these are partially annihilated with further irradiation. The variation of the the parameters reavels the microstructural stability of the pre-deformed V-4Cr-4Ti alloy with irradiation.

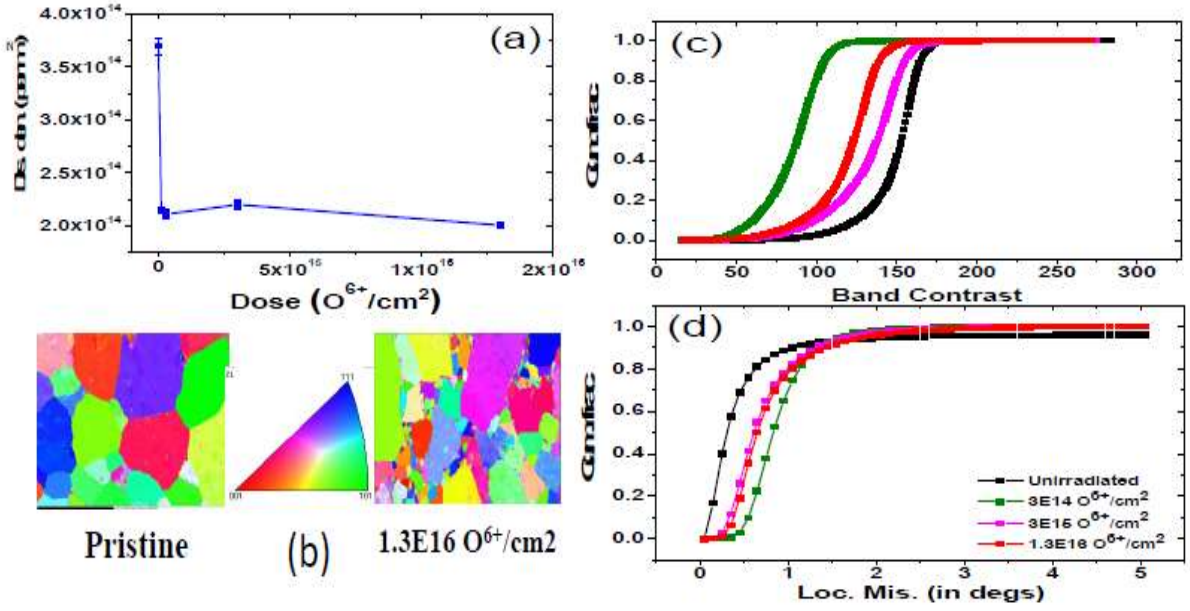

Fig. 1: The variation of (a) Dislocation density (b) EBSP (c) Band contrast and (d) Local mis-orientation with different irradiation doses

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Development of supermirror guide tube element for DHRUVA neutron guide upgradation

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In research reactors neutrons are generally guided away from the reactor to an experimental hall using neutron guide tubes to accommodate several end stations for various neutron scattering based experiments and also to avoid high gamma background during experiments. If the conventional single layer Ni coated guide tube is replaced by multilayer supermirror coated guide tube the neutron flux at the experimental stations can be increased several times. A typical neutron supermirror is a non-periodic multilayer of hundreds of layers of Ni and Ti where continuous high reflectivity of neutrons can be achieved up to higher grazing incidence angle. A supermirror is designated by its 'm-value' which signifies how much the critical angle of high reflection is increased compared to natural Ni. Using the in-house developed 9 m long magnetron sputtering system at A&MPD, BARC [1], 98-layer m=2.0 Ni/Ti neutron supermirrors have been developed. The structure of the supermirror has been designed using an in-house developed computer code and subsequently, the process parameters were optimized by depositing several test samples and by measuring their neutron reflectivities at the PNR facility of DHRUVA (Fig.1(a)). From Fig 1(a) it can be observed that when the Ni layers of the supermirror are deposited in the mixed ambiance of Ar+ N_2 the neutron reflectivity increases significantly to 95% from that deposited under pure Ar ambience which shows only 71% reflectivity [1]. At the optimized condition eight supermirror of sizes 120 mm X 500 mm, 25 mm X 500 mm, 120 mm X 1000 mm and 25 mm X 1000 mm (two number each) have been deposited. Using these supermirrors two prototype neutron guide tube elements of 500 mm and 1000 mm length have been fabricated as shown in Fig 1(b). The two guide tube elements have been tested at DHRUVA and maximum 96% and 94% neutron transmission have been observed for the 500 mm and 1000 mm long guide tube elements respectively as shown in Fig 1(c) which imply an increase in neutron transmission by 20% and 35%. With this success, development of 300 such supermirrors have been started in our laboratory for the upgradation of the neutron guide tube of DHRUVA, 100 supermirrors being already successfully fabricated. This upgradation will increase the neutron flux of DHRUVA guide tube several times.

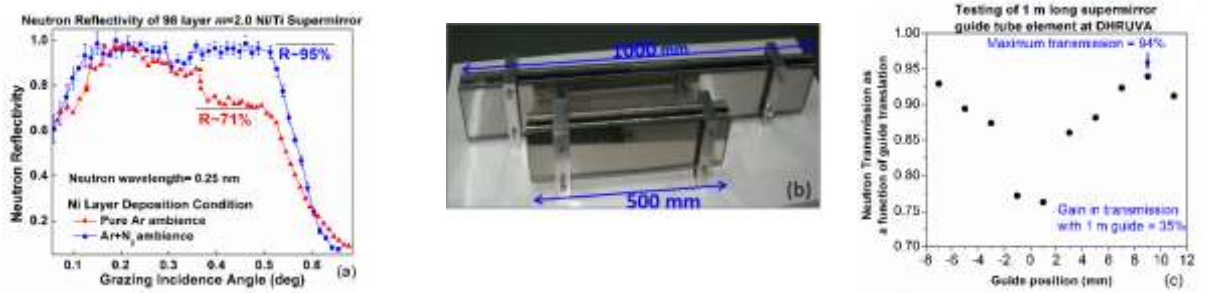

Fig 1: (a) Neutron reflectivity of Ni/Ti supermirror measured at DHRUVA (b) Photograph of 1000 mm and 500 mm long supermirror guide tube element (c) Neutron transmission of 1 m long guide tube measured at DHRUVA

Acknowledgements: The authors acknowledge Dr. S. M. Yusuf, Director, Physics Group, BARC for his keen interest in the above work.

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Synthesis, Characterization and Magnetic Properties of Refractory and Non-magnetic Transition Metal Substituted Cobalt Ferrites

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The nanostructured materials of vanadium substituted cobalt ferrite ($CoFe_{2-x}V_xO_4$; where x=0.0 to 0.9) were synthesized by citric acid assisted sol-gel autocombustion method [1, 2]. The samples were prepared at lower temperature of 400ºC in phase-pure and nanocrystalline state. Substitution of V^{5+} in the cubic spinel lattice is evident from the fact that there is an alteration in the values of lattice parameters with the progressive incorporation of V^{5+} in the lattice as observed in XRD studies. The average crystallite sizes and SEM particle sizes were found to be in the range of 10nm – 40 nm and 20nm - 80 nm for various $CoFe_{2-x}V_xO_4$ materials, respectively. IR and Raman spectroscopy studies were performed in order to confirm the existence of M-O bonds in tetrahedral and octahedral coordinations in the crystal lattice. The values of the saturation magnetization were found to decrease from 77.6 emu/g to 37.8 emu/g with progressive increase in V^{+5} substitution, i.e. from x=0.0 to 0.9 in $CoFe_{2-x}V_xO_4$, respectively. The coercivity values of various $CoFe_{2-x}V_xO_4$ materials were moderately high and were ranging from 1264 Oe for pure cobalt ferrite to 991 Oe for x = 0.9. In summary, we have observed significant nanostructured size and surface effects in structural and magnetic properties of vanadium substituted cobalt ferrite.

From the above mentioned result, it is clear that shape and size determination plays an important role in describing magnetic characteristics of the materials [3]. Conventional techniques are inadequate in predicting dimension and narrow size distribution of nanomaterials. In addition, elucidating interparticle interactions and surface structures of the vanadium substituted cobalt ferrite nano-materials could be of great importance not only for investigating the properties but also for technological applications. Therefore, we would like to propose small angle neutron scattering experiment for determination of shape, size and interparticle interactions of a series of selected vanadium substituted cobalt ferrite nanomaterials using reactor facility in BARC.

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Understanding of Thermodynamic Behaviour of Neutron-Irradiation Graphite From CIRUS Reflector

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Graphite is used as a moderator and reflector material in nuclear fission reactors. Graphite also serves as a non-replaceable structural component in reactor cores, which must remain stable over the lifetime of the reactor while operating at elevated temperatures. The irradiation of graphite in a nuclear reactor results in a complex population of defects. Heating of the irradiated graphite at high temperatures results in annihilation of the defects with release of an unusually large energy, called the Wigner energy.

We have performed neutron diffraction experiments on highly irradiated graphite samples by neutrons over 50 years in the CIRUS research reactor at Trombay and ab-initio simulations [1, 2]. We have identified various 2-, 3- and 4-coordinated topological structures in defected graphite, and provided microscopic mechanism of defect annihilation on heating and release of the Wigner energy. The annihilation process involves cascading cooperative movement of atoms in multiple steps involving an intermediate structure.

Neutron diffraction experiments performed on irradiated graphite samples upto 750 K show that the static disorder along the *c*-axis of the graphite hexagonal structure persists at high temperatures much above the temperature of release of the Wigner energy (653 K). The persistence of the defects at high temperatures has important consequences for the application of graphitic materials in high radiation environments.

The magnetization experiments reveal weak ferromagnetism at 300 K that persists up to 850 K, and also a large paramagnetic contribution. The Electron spin resonance experiments have been performed to show that irradiation may have broken many chemical bonds resulting in significant number of unpaired spins. Ab-initio spin-polarized density-functional calculations are performed to understand the origin of magnetism in irradiated graphite, which show that the magnetism arises on one of the 2-coordinated carbon atoms in the region around a vacancy.

Our experimental observation of magnetism in defected graphitic materials is of fundamental importance as these materials find wide applications. Our work provides new insights in understanding of the defect topologies, observation of magnetism and defect annihilation in graphite, which is of considerable importance to wider areas of graphitic materials including graphene and carbon nanotubes.

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Study of atomic dynamics and diffusion mechanism in phenecite compound: $LiAlGeO_4$

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Their is surge in design and discovery of new materials for energy storage to fulfill the future demands of electrification of vehicles and search for renewable energy resources[1,2]. Hence, to meet the future energy demand, we need to accelerate the design and discovery of new materials. It requires a detailed understanding of the structure and dynamics of materials on their ionic transport properties. We have investigated the atomic dynamics in $LiAlGeO_4$ using inelastic (INS) and quasielastic neutron scattering (QENS) experiments and supplemented with extensive ab-initio molecular dynamics (AIMD) simulations. The $LiAlGeO_4$ crystallizes in a hexagonal phenecite-structure with R3 space group and lattice parameter a= 13.77 Å and c=9.19 Å , where AlO_4 and GeO_4 polyhedral units form the framework structure, and Li-ions lie between AlO_4 and GeO_4 layers[3] (Fig 1(a)). The measured INS spectra at 300 K shows good agreement with the AIMD estimated neutron weighted phonon density of states (PDOS). AIMD simulation allows us to resolve the elemental contribution to total PDOS (Fig 1(b)). We found that Li, Al, and Ge dynamics are limited to 80 meV, while O dynamics extended in the entire spectral regime up to 150 meV. At elevated temperature, our simulation shows that the Li spectral weight shifted to lower energy, becoming more anharmonic. Our measured QENS shows significant broadening at elevated temperature over entire Q-range of measurements indicates the Li is mostly exhibits loclaized diffusion in crystalline LAGO (Fig 1(c)). We also performed simulations in the different possible configurations of $LiAlGeO_4$, namely, in amorphous configuration and with Li-Excess and Li-deficient $LiAlGeO_4$. At high temperatures (>1400 K), the Li-Excess compound exhibits Li diffusion dominated along the c- axis, while the amorphous $LiAlGeO_4$ shows isotropic behavior. The most significant Li conductivity is observed in the amorphous phase, followed by Li-excess and Li-deficient. Observing the phonon spectra in these cases shows that the host dynamics play an important role in Li migration in these compounds.

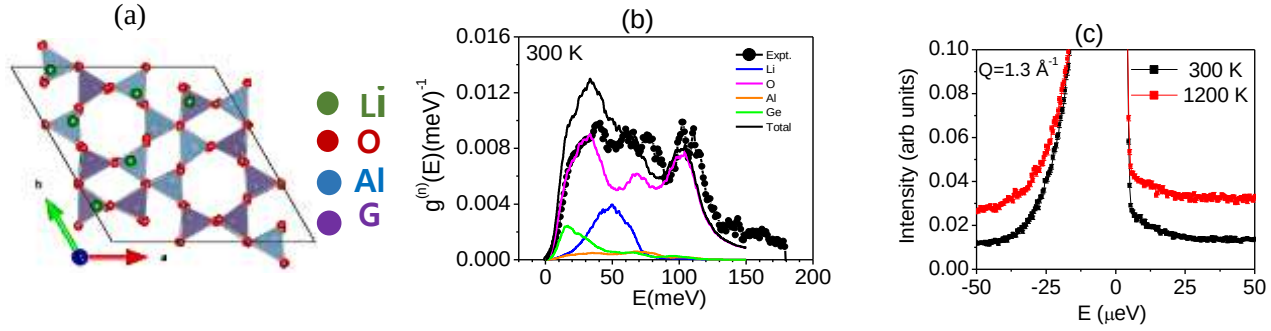

Fig.1: Crystal structure of ordered hexagonal phenecite structure. (b) the measured and simulated phonon density of states at 300 K. (c) The temperature dependence of measured QENS spectra at Q=1.3 Å.

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Effect of high and low gamma irradiation on spectroscopic properties of different glass modifier

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The shielding materials are necessary safeguards against the ionizing radiations. The research on radiation shielding materials has increased extensively due to concerns relating to safety. The main quest in developing shielding materials is that it should have high density, should be non-toxic and transparent. In this regard, glasses are considered as promising materials because they can be made in different shapes and sizes. In addition, glasses are economical, transparent and can be made in different compositions. The present studies report on effect of irradiation on aluminium modified alkali and heavy metal oxide borate glasses. The various spectroscopic studies on these glasses have been done at high (50kGy) and low (2.5kGy) gamma-irradiation. The effect of irradiation on glass composition shows that changes in glass matrix due to irradiation depend on the structure of glass. The studied glasses maintained their amorphous character even after irradiation. The prepared glasses showed a decrease in transmission and induction of new structural units after irradiation.

The effect of rare earth on spectroscopic properties of gamma irradiated tellurite and borate glasses

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Several optical applications demands for enhanced optical response of irradiated glasses. The introduction of rare earth (RE) ions into different matrices is considered as vital aspect in the advancement of optical devices. An extensive spectroscopic studies on irradiated RE-doped (Er^{3+}, Dy^{3+}) glasses samples had been done. The aim of study was to highlight the role of RE ions on the gamma irradiated glasses having different glass formers (borates, tellurites). Glass samples with different base compositions were prepared and characterized using X-Ray diffraction (XRD), differential thermal analysis (DTA), UV-Vis-NIR spectroscopy, photoluminescence (PL) and decay time measurements. The results suggested that changes in glass matrix due to irradiation depend on structure of glass and vacancies formation. The studied glasses maintained their amorphous character after irradiation also. Transmission decreased after irradiation due to various defects like hole centres generation and increase in non-bridging oxygen atoms. The glasses also showed formation of new structural units after irradiation. The results suggested that the shielding properties of the glasses improved with the addition of RE. The half value layer and mean free path decreased with increase in RE concentration, whereas, the effective atomic number increased with increasing RE – concentration. The spectroscopic properties such as stimulated emission cross-section, lifetime etc. of tellurite and borate glasses were marginally modified due to gamma irradiation. Our studies revealed that the glasses with rare earth doping showed less changes in their characteristic properties after gamma irradiation, which indicates that these glasses are more resistant to gamma radiation as compared to the base glass.

Atomistic Modeling and Experimental Study of Defect Microstructure and Tensile Behaviour in Pure Molybdenum Irradiated with 7 MeV Protons

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Molybdenum, due to its favourable high temperature characteristics, is an important constituent of candidate alloys for applications as structural materials in nuclear reactors. In this study, we report the microstructure and tensile deformation behaviour of pure Mo samples irradiated with 7 MeV protons at the VEC, Kolkata. Tensile tests of pristine and irradiated samples have shown an increase in the yield stress and plasticity and FESEM study of fractured surfaces have ascertained the increase in ductile fracture with irradiation. The X-ray diffraction line profile analyses (XRDLPA) of the samples have revealed a high density of dislocations and average microstrain in the pristine sample and a subsequent decrease and eventual saturation in the quantities with irradiation. High doses of irradiation of both perfect and pre-defected (initially introduced with dislocations) Mo and dose-dependence of tensile deformation of the samples are modeled using molecular dynamics to get a detailed understanding. The irradiation mainly leads to formation of small defect clusters and interstitial loops of irregular shapes of 1/2<111> dislocations in Mo. There is an enhancement in plasticity of the pre-defected samples with irradiation. This is observed to be due to the irradiation-induced formation of glissile dislocations in moderate concentrations and in less entangled configurations compared to that in the pristine sample which facilitate the slip process. The slip process is sustained efficiently by the 1/2<111> dislocations and dislocations with edge character enhance plasticity. Formation of large defect clusters, stable immobile junctions of <100> dislocations and screw components of dislocations lead to hardening and fracture of the material during tensile deformation.

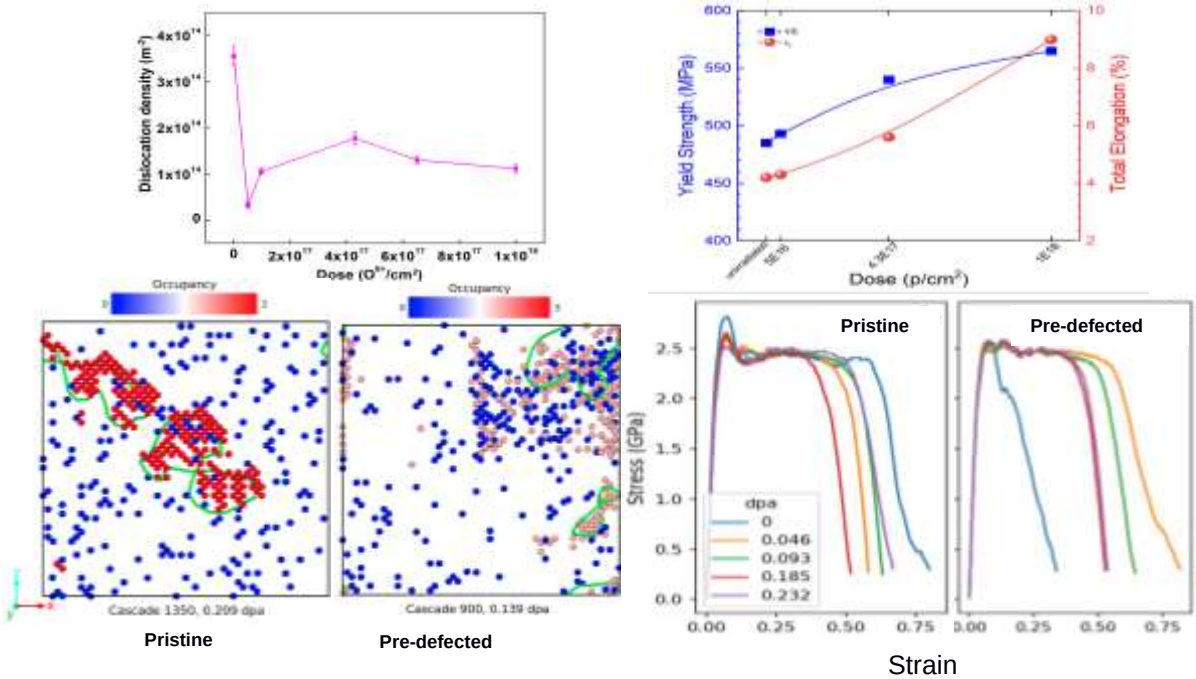

Fig. 1: (Clockwise from top left) Variations of dislocation density, YS and elongation with dose; stress-strain curves due to tensile deformation and interstitial dislocation loops during irradiation.

Development of a radiation resistant ceramic for nuclear reactor application

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The nuclear reactor is one of the great scientific inventions of the last century which has radically changes the human life but production of high level radioactive wastes (HLWs) and its safe disposal is the main concern for the nuclear industry. The ceramic, as well as glass materials, are studied over the last 50 years to get rid of HWL. Among various oxides, pyrochlore oxide and stabilized zirconia have drawn considerable interest for their applications as an "*inert matrix material (IMM"* for the development of an advanced nuclear fuel [1].Our group has been developed advanced ceramic and simulated their radiation tolerance as a function of temperature [2,3], grain size [4,5], compositions [6], and stoichiometry.We have designed and engineered ternary oxide (pyrochlore structured ceramic) *i.e.*,$Nd_2Zr_2O_7$. The swift heavy ion induced radiation resistance has been analyzed through advanced techniques, like *in-situ* X-ray diffraction, micro-Raman spectroscopy, Scanning electron microscopy, and Transmission electron microscopy. The pyrochlore compound $Nd_2Zr_2O_7$ exhibits interestingly high radiation resistance at elevated temperature. Grain size dependent studies on $Nd_2Zr_2O_7$ shwoed that the nano grain sized pyrochlore exhibits extensively high radiation stability again SHI-induced amorphization. A study on pyrochlore structured compounds $Nd_{1.8}Zr_{2.2}O_{7.1}$ has revealed the less prevalence of irradiation induced amorphization in non-stoichiometric structure. A series of $Gd_2Ti_{2-y}Zr_yO_7$ $(0.0 \leq y \leq 2.0)$ solid solutions has been synthesized to examine effect of composition on radiation resistance. The results provide information about the higher efficacy of Zr-rich compositions towards SHI-induced disordered transformation with very little amorphization.Furthermore, we have stabilized the cubic phase of zirconia by 80 mol % doping of Ceria (CeO_2) and irradiated with 100 MeV iodine beam to imitate the actual in-service nuclear reactor environment.The obtained results manifest Ce doped ZrO_2 as superior radiation tolerant material which does not show any irradiation induced phase transformation or amorphization on irradiation with swift heavy ions.Therefore, these results give the evidence of their potential application as IMM.

Acknowledgements:
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Effect Of Swift Heavy Ion (SHI) Irradiation On Structural, Electrical And Magnetic Properties LaMn1−xCoxO3 (0 ≤ x ≤ 0.5) Thin Film

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Perovskites are the materials having ABO_3 type of structure, where A and B are cations having different sizes. Perovskites are known to exhibit interesting electronic and magnetic properties, and rich phase diagram because of interplay between various degrees of freedom. Because of these number of distinct properties perovskites find potential applications in sensors, magnetic memory devices , spintronic devices and Colossal magneto-resistance effect based applications. Keeping in view the rich properties exhibited by perovskite materials we wish to study the effect of irradiation on the structural, electrical and magnetic properties of $LaMn_{1-x}Co_xO_3$ (LMCO) thin films. To implement this idea, we will choose LaMnO3 (LMO) which is an A-type antiferromagnetic (AFM) transition metal oxide. In LMO, Co will be doped at Mn site which is known to induce ferromagnetism in LMCO and its thin films will be prepared by Pulsed Laser Deposition (PLD) technique. The use of Swift Heavy Ion Irradiation will be made to tune the properties of LMCO thin films and its effect on structural, electrical and magnetic properties of the mentioned samples will be studied. SHI are accelerated high energy heavy ions and are utilized for modification of materials. The SHI have different impact on various materials depending on the energy of ion, fluence, and ion species. Especially, the interaction of ions with materials is the crucial aspect in material alteration mediated by the ion beam. SHI produces novel effects in a range of materials not achieved by any other means, making it particularly helpful for modifying the properties of thin films. The irradiated thin films will be looked into for the properties of colossal magneto-resistance (CMR) effect, exchange bias effect, ferromagnetic and spin glass properties.

Irradiation of Ceramic Breeder and RAFMS Fusion Reactor Materials

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In the fusion reactor the ceramic breeder serves as the tritium breeding materials. The lithium-containing ceramics (Li_2TiO_3, Li_4SiO_4 etc.) are considered to have excellent potential as tritium breeders because of the ease of tritium recovery, excellent thermal performance, and good irradiation behaviour. In the fusion reactor, these ceramic materials will be operated under harsh conditions. They will, in particular, be exposed to considerable levels of neutron irradiation. Ceramic breeder materials have been tested under various conditions to determine their irradiation response in terms of tritium production and release and their microstructural, thermal, chemical, and mechanical stability. The nuclear loading of ceramic breeder affects their performance in various ways. Therefore, their optimum properties must be tested under relevant neutron irradiation conditions.

The Rediced Activation Ferritic Martensitic Steel (RAFMS) is considered as the structural steel in the breeding blanket components. This martensitic steel belonging to the family of 9Cr-1Mo steel. A reduction in the long-term radioactive inventory could be reached substituting elements like molybdenum, niobium and nickel with other ones like tantalum and tungsten (Ni, Nb, Mo are replaced by W, Ta, W) which have the same functions as alloying elements and, if irradiated, do not produce long lived radioisotopes. The high levels of gaseous (H, He) transmutation products associated with deuterium–tritium (D–T) fusion neutron transmutation reactions, along with displacement damage dose requirements few displ ()acements per atom (dpa) for ITER and up to 50–100 dpa for a fusion demonstration (DEMO) reactor pose an extraordinary challenge. Since the intense deuterium–tritium fusion neutron source is not yet available, material stability under irradiation is typically examined using fission test reactors.

The details effect opf irradiation on Lithium ceramics and RASFMS materiuals and the proposal of utilization research reactor for their irradiation and the post-irradiation characterization requirement will be discussed in this paper.

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Preparation of flexible ceramic-rubber composite for hybrid gamma and neutron radiation shielding

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Fabrication of flexible and light materials that successfully protect radiation workers and the environment from high-energy gamma and X-rays has already been accomplished in various practical applications. Conformability, cost-effectiveness, weight factor, toxicity, durability, and other factors must all be considered when selecting an appropriate shielding material [1]. X-ray and gamma radiation, which may be protected by high density materials like cement, lead, and bismuth, is the most frequent ionising radiation type employed in many applications. Shielding materials for neutrons, on the other hand, are mostly depending on the kind of neutron source, its power, and the application type. Many investigations have been conducted on the neutron radiation shielding properties of materials generated primarily by the integration of hydrogen-rich elements [2]–[4]. The present emphasis of industry and academic organisations is on producing neutron shielding materials.

Because of tuneable elasticity, natural rubber (NR) can be considered as a promising candidate for neutron and gamma shielding material. Some research suggests that combining metal ores and aggregates with rubber may improve the flexibility, gamma absorption, and neutron shielding capabilities of the material[5]. When constructing bio filled polymer composites, good filler-matrix adhesion, high modulus, low stress, low moisture absorption, high durability, and longer life length are all factors to consider. Ceramics and coconut shell may be used as a filler in biodegradable polymer composites because of their greater mechanical strength and thermal stability when compared to other agricultural wastes [4], [6]. The current proposal focuses on the development and testing of a series of rubber basted ceramic composites (heavier than wax) that would efficiently decrease shielding thickness and improve the shielding ability. The characteristics of the shielding material must be investigated in the thermal, epithermal, and fast neutron regions, as well as the prompt gamma yields.

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A comprehensive study on the effect of saccharides on an EO-PO based star block copolymer

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Here we report, the effect of saccharides viz. glucose, maltose, sucrose and lactose on the polymeric micelles of an ethylene oxide-propylene oxide star block co-polymer T1304® using plethora of techniques such as cloud point (CP), dynamic light scattering (DLS) and small angle neutron scattering (SANS). The presence of saccharides in the polymeric system significantly decreased its CP while the micellar size as determined by SANS and DLS notably improved. The solubilizing behavior of poorly water soluble anticancer drug, Quercetin (QN) was also checked and a prominent increase in the solubility of drug was recorded. The results of the present work are anticipated to be highly commodious in understanding the behavior of the commonly used pharmaceutical excipients, saccharides on the copolymeric micelles which serve as a common ingredient in several therapeutic applications.

Acknowledgements: The authors thank Dr. V. K Aswal, Solid State Physics Division, Bhabha Atomic research Centre for his kind support in the measurements and analysis of SANS.

Multivalent Ion-induced Reversal of Interactions in Nanoparticle-Surfactant Systems

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The nanoparticle-surfactant conjugates, result of synergistic or antagonistic interactions between nanoparticles and surfactant micelles, are of quite significance for their potential applications in colloidal stability, design of functional interfacial nanostructures, detergency among others [1]. Most of these applications require understanding of the interaction of nanoparticles with surfactants and even strongly depend on their individual characteristics. Surfactants self-assemble to form micelles in aqueous solution. However, in the presence of nanoparticles they can still form micelles or adsorb on nanoparticles or deplete the nanoparticles itself. The resultant structure depends on these competing interactions.

The interaction of electrostatically-stabilized anionic silica nanoparticles (HS40) with nonionic (C12E10) and ionic surfactants (anionic SDS/cationic DTAB) in presence of multivalent electrolyte $ZrCl_4$ has been studied using small-angle neutron scattering (SANS). There is no direct interaction between the similarly-charged nanoparticles and surfactant and they coexist individually in the mixed system. On the other hand, the presence of oppositely charged surfactant leads to the aggregation of silica nanoparticles even with very low surfactant concentration. In the case of nonionic surfactant, interaction of micelles with the individual silica nanoparticles results in the decoration of nanoparticle surface by the micelles [2-4]. However, in presence of $ZrCl_4$ in these systems, their respective phase behaviors suggest drastic change in interactions, and that too depending on the concentration of the salt. The contrast-variation SANS studies have shown that the charge inversion of nanoparticles in presence of $ZrCl_4$ changes the phases of nanoparticle-micelle interactions. This multivalent ion-induced tuning of the nanoparticle-surfactant interaction gives a control over the phases and the understanding of phase behavior-structure relationships provide better tunability.

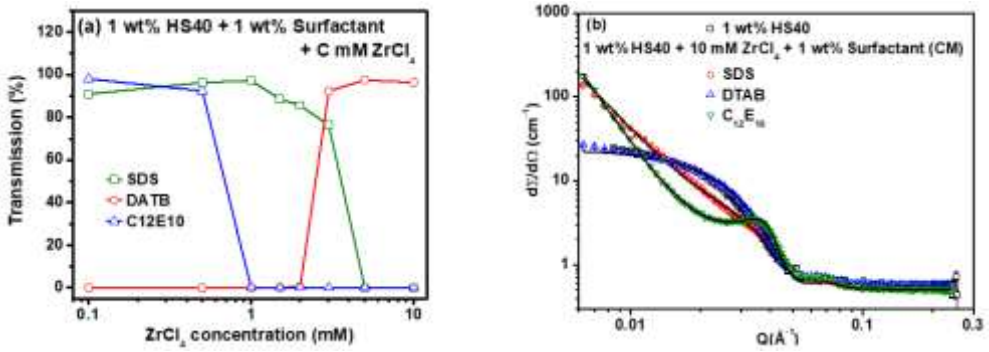

Fig.1: (a) Phase behavior and (b) SANS data of the 1 wt% HS40+1 wt% surfactants systems with $ZrCl_4$.

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Investigation of Neutron Exposure Impact on Alumina

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Insulators are widely used in reactors for high voltage insulations, diagnostic windows, RF feedthrough etc. Nuclear reactors are meant to operate for several years with minimal maintainence requirements under harsh nuclear conditions. It is therefore necessary that the, operational performance of insulators in presence of harsh environment degrades minmally with time in terms of its mechanical and electrical properties. Several reports demonstrate the degradation of the insulators in presence of radiation exposure for various insulator materials. It is therefore becomes important to establish a methdology to test the material against such radiation exposure and its impact on its properties.

Al_2O_3 (Kyocera A479) is one such ceramic insulator which is widely used in high voltage systems of fusion reactors but lacks the desired database about its performance in harsh environment. Its operational performance in presence of radiative environment is a matter of detail assessment and therefore, subject of this presentation.

We had carried out priliminary assessment of neturon exposure on Alumina. Samples required for the irradiation and analysis were prepared from production proof material with the required size followed by ultrasonic cleaning and irradiated using two available neutron sources at Institute for Plasma Research (IPR) viz (i) Am-Be source (max. flux at ~0.5 MeV) & (ii) 14.1 MeV neutrons. Effect on electrical and structural properties were studied post irradiation and compared with the pre-irradiated characterizations. Also, effect on surface morphology is studied. Abrupt reduction of IR at the time of irradiation was observed which was due to radiation induced conductivity. This study was performed using 2 probe method. XRD peak intensity of irradiated sample was observed to reduce ~25-30% which indicate reduction in crystalline behavior after irradiation. Surface morphology of pristine and irradiated samples was studied by Scanning Electron Microscopy (SEM) and Atomic Force Microscopy (AFM). SEM of low energy neutron irradiated sample showed blister structure formation on the sample surface which might be induced by the defects created by radiation. It is observed that surface morphology is getting affected mainly due to low energy neutrons for long time exposure.

This are priliminary observations with low flux neutron exposure. However, considering harsh environment of future reactors, we prospect to extend this study with high dose of thermal and fast neutrons to create damage up 1 DPA.

Effect of gamma irradiation on spectroscopic properties of Er^{3+}-doped vitreous zinc borotellurite

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In the present report, erbium doped zinc borotellurite glasses were irradiated with 50 kGy gamma radiation using a ^{60}Co radioisotope source. The effect of gamma irradiation on the spectroscopic properties of erbium doped zinc borotellurite glasses was studied. The gamma irradiation caused some structural changes as indicated by FTIR spectra which may be due to the formation of the new structural units. Its influence on the optical properties like band gap (direct and indirect band gap), Urbach energy and refractive index were analyzed with the help of UV-Vis-NIR spectrometer. The UV-Vis-NIR absorption spectra showed increase in absorption after the gamma irradiation. The optical band gap value decreased for the irradiated samples. The spectroscopic properties such as stimulated emission cross-section, bandwidth, lifetime etc. got marginally modified due to gamma irradiation. The glasses with rare earth doping showed less changes in their properties after gamma irradiation which indicates that these glasses are more resistant to gamma radiation as compared to the base glass.

Neutron Beam Irradiated Isotropic and Anisotropic Nanomaterials as SERS Substrate for Chemical and Biological Sensing

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The surface-enhanced Raman scattering (SERS) phenomenon deals with the increase of the weak Raman scattering intensity of molecules in the presence of a nanostructured metallic surface especially gold and silver [1]. Over the last forty years, it has developed into a versatile spectroscopic and analytical technique due to the rapid progress of nanoscience and nanotechnology. SERS is known as one of the most sensitive spectroscopic tools for highly sensitive and selective detection of chemical and biological systems. The advent of SERS has opened up a promising way to overcome the low sensitivity of traditional Raman spectroscopy. The versatility of the SERS technique can be utilized as a versatile tool to determine the molecular structure and also provides ultrasensitive detection limits, including single molecule sensitivity [2]. However, most of the SERS-based assays face a disadvantageous challenge due to too much fluctuation of captured SERS signals. These large fluctuations occur mainly from the non-homogeneity of SERS-active substrates and due to inconsistent binding between the bacterial cell surface and the SERS substrate. Metal colloids and nanostructures, which can be used as SERS active substrates, have poor biocompatibility. Therefore, it is necessary to develop new novel biocompatible and homogeneous substrates for Raman enhancement in the case of biological and chemical molecules especially for rapid pathogen detection and chemical sensing. We have reported SERS study of bacteria using biosynthesized silver nanoparticles as the SERS substrate [3] and biological synthesis of triangular gold nanoprisms [4], these isotropic silver nanoparticles and anisotropic gold nanoparticles can be utilized for chemical and biological sensing after irradiation with neutron beam as SERS substrate. Isotropic and anisotropic nanoparticles can also be used for neutron imaging and their effect on enhancement of SERS signals.

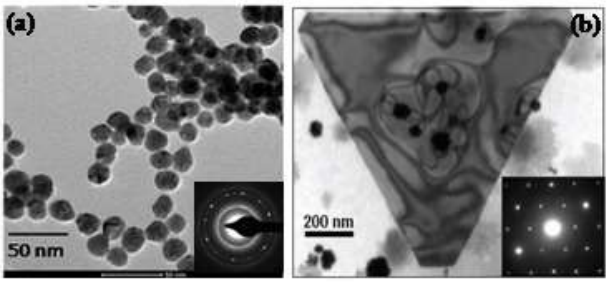

Fig. 1: (a) TEM images along with their SAED patterns of the as-synthesized Ag nanoparticles [Ref. 3] and (b) triangular gold nanoprisms [Ref. 4].

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Utilisation of research reactors for fuel design & development

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New fuel concepts which includes various advances carried out periodically in fuel design to improve safety or performance, require extensive testing before being adopted in power reactors. Research reactors have an important role in this and it usually involves fuel irradiation testing in dedicated test loops. The test loop has independent coolant system isolated from that of the main research reactor coolant to provide simulated power reactor coolant conditions. The test loop cooling system consists of pumps, heat exchanges, ion exchangers, heaters to control experiment temperature, and chemistry control systems. The test loop is also provided with instrumentation to continuously monitor and record the loop operating parameters and also an on-line failed fuel detection system to detect fuel failure if any at the earliest.

The experimental cluster of fuel pins is installed in the test-section of the loop for carrying out the irradiation testing for desired time duration or fuel burnup. The experimental fuel pins can be either short-length or full-length pins depending on the testing requirements and test-section size. There are closure plugs at the top of the test-section to facilitate easy insertion and removal of the experimental fuel cluster in the core. After the irradiation testing, pool-side examinations of the experimental fuel pins are carried out under water in storage pool of the reactor. This is followed up with both destructive and non-destructive examinations in hot-cells which help in validation of the reactor physics and fuel performance analysis computer codes. The results of PIE which include fuel burnup, temperatures, fission gas generation and release, fuel swelling, irradiation effects on fuel materials, etc. are compared with that of the analysis codes.

As part of our power reactor fuel development programme, fuel irradiation tests in research reactors CIRUS and Dhruva have generated a large data-base on various design and manufacturing aspects. Fuel irradiation tests have been carried out on BWR, PHWR and AHWR types of fuel pin design and with different fuel materials and MOX compositions - UO_2, (U-Pu) MOX, ThO_2 and (Th–Pu) MOX.

This paper brings out the experience of RED, BARC in the use of research reactors for design and development of different types of power reactor fuels and in validation of our fuel performance analysis codes.

Polymer composites for shielding of neutron and γ-radiations

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The advancement in nuclear science and technology have fostered the use of ionizing radiations in diverse sectors, making radiation exposure indispensable for the mankind. Consequently, different shielding materials must be used to protect personnel or equipment from detrimental effects. As the structure of shielding material varies with type of radiation exposure and its application area (e.g., nuclear reactors, nuclear waste disposal, medical diagnostics and therapy, aerospace, food and agriculture, etc.), high performance materials are mostly desirable. Attenuation of neutrons is especially an important aspect of shielding and for this reason polymer matrix composites (PMCs) are considered to be materials of prime importance, owing to their light-weight and cost-effectiveness. Besides neutrons, PMCs must also provide adequate shielding against highly energetic accompanying γ-rays, produced as a result of neutron-matter interactions. Along with this, it is crucial for PMCs to effectively absorb or shield X-rays, as they have great medical and industrial relevance. Nonetheless, these PMCs should be diversified in accordance with design requirements related to thermal resistance, mechanical strength and radiation damage. To meet all these requirements, there is an immediate need to develop advanced and multi-functional PMCs, that are robust and non-toxic. Some of the studies reported on simultaneous neutron and γ-ray shielding include PMCs containing high-Z/low-Z mixed additives such as boron carbide/lead oxide (PbO)/benzophenone, carbon fibre/samarium oxide (Sm_2O_3), boron nitride/gadolinium oxide (Gd_2O_3), etc [1-3]. As very little work is carried out in this area, further research will open new avenue to next-generation dual-purpose shielding materials. Our team is actively involved in studying the X-ray and γ-rays shielding properties of novel PMCs. With the help of *Neutron-Gamma detector facility* available at BARC, Mumbai, we will be able to extend our studies to simultaneous neutron and photon shielding.

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AA5052 Tube to SS304L Tube Sheet/End Plug Joining by Magnetic Pulse Welding

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The components/assemblies used in the reactor should have low thermal neutron absorption cross section. For this purpose, Zr and Al based material are preferable as their thermal neutron absorption cross-section is lower than other available structural material. These materials also have sufficient strength and low induced activity. The out of core components/assemblies and piping etc. are made up of steel material as it has lesser cost, easy availability and fabrication. The joining of AA-SS material is beneficial because it will allow to use aluminium material for in core components and steel material for out of core components.

Fig.1.AA5052 tube OD 70mm x 2mm thick to SS304 end sheet in expansion mode. Joint after 500 thermal cycles (300K and 373K)

Fig.2.AA5052 tube (OD 22mm x 2mm thick) to SS304 end plug in compression mode, HL rate < 1.5 x 10^{-10} mbar.l/sec

In APPD two different type of joints between AA5052 tube to SS304 end sheet/end plug have been developed by Magnetic Pulse Welding (MPW) technique that have high potential of application in research reactor. MPW [1] is a well-established technology under the branch of solid-state joining processes. Joining dissimilar metals like AA and SS by fusion welding faces a lot of hardship due to its wide variation in physical properties. In MPW, there is no application of heat to melt the base metal and jet formed during the process clean the two mating surfaces. Special tool coils, fixtures have been designed for this application. Experiments were conducted on available MPW machine at APPD. These both type of joints are at various stages of destructive and NDT qualifications.

Acknowledgements:
Authors acknowledges the constant encouragement received from Dr.Archana Sharma, Director BTDG in this developmental activity.

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Utilization of Research Reactor at BARC for Studies on Reactor Materials

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Radioanalytical Chemistry Division of BARC has a mandate on supporting the chemical characterisation and quality control requirements of various reactor materials. For this F, Cl and B are analysed in several matrices using pyrohydrolysis and ion chromatography. Separation of halides and boron by pryrohydrolysis requires different pyrohydrolysis conditions depending on the nature of the matrix and therefore, a development of new methodology is inevitable whenever new matrix to be analysed. It is important to mention here that certified reference materials are not available for most of the reactor and nuclear materials. Therefore, in order to validate the newly developed analytical methods, alternate analytical techniques are required and for this purpose, Neutron activation analysis (NAA) is one of the reliable techniques as it has an advantage of multi-elemental determination.

We are also working on the development of a pyrohydrolysis based method for fission molly separation. In this, pyrohydrolysis of solid U matrix is carried out to separate molybdenum under at high temperature and moist oxygen environment [1]. In this line further investigations are planned to understand the behaviour of different target materials during pyrohydrolysis and recovery of molybdenum. To facilitate these studies time to time irradiations of several target materials will be required.

To support the above requirements of (i) use of NAA technique to validate newly developed analytical methods and (ii) irradiation of different target materials for separation of fission molly, we will require support and services of PCF facility, Self-Serve facility at Dhruva and Apsara-U reactors in future.

Acknowledgements:
Authors thank Dr R. Acharya, RCD, BARC, for his support and collaboration in chemical characterisation of nuclear materials using NAA.

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Commissioning & Utilisation of Dhruva Simulator

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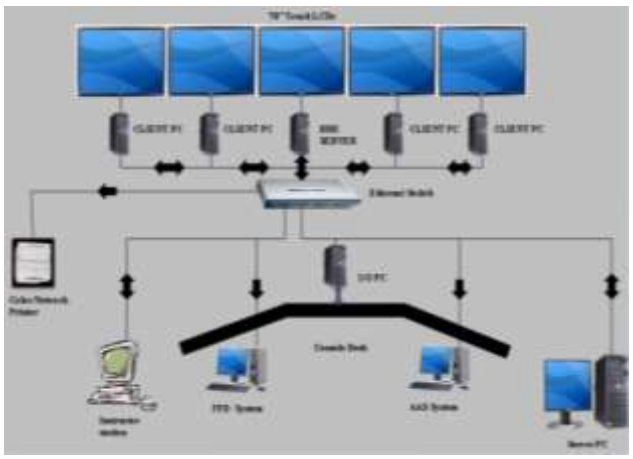
One of the key elements that determines the operational safety of a Nuclear Reactor is the training and technical knowledge of its operators about the behaviour of their plant under normal, transient and accidental conditions.
The operation of a complex system like a nuclear reactor requires thoroughly trained and licensed manpower. Simulators greatly support in the training and transfer of knowledge to the plant operators by making use of the latest available technologies. Simulator based training facilitate the trainees to learn the particular module and repeat till he gets mastery. It enhances the training quality and performance of the trainee. Full scope, non-replica Simulator for 100 MW Dhruva research reactor is indigenously designed, commissioned and made operational in BARC in co-ordination with ECIL. Apart from normal training, important Postulated Initiating Events (PIEs) like Loss of Offsite Power, Loss of Coolant Accident, Loss of Regulation Incident, etc. have been modelled. This information will provide an insight to verify and validate the plant Emergency Operating Procedures (EOPs). The simulator will also be used for development of human factor models as well as the design of future VDU based control rooms. This will also enable the operators to align themselves from the traditional panel based human-machine interface (HMI) to personal computers.
Hard wired graphic panels were reproduced in the form of soft touch screens. The development activities were completed in a time bound manner. The development contract was awarded to a vendor (ECIL) with whom the requisite expertise and indigenously developed simulation software was available. The relevant data on design and operation parameters, details of interlocks, alarm and trip settings, Process & Instrumentation (P&I) diagrams, etc. pertaining to each system was provided by reactor group for model development.



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Radiological Safety During Handling of Radioisotopes at Dhruva

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Dhruva is a 100 MWth research reactor uses natural Uranium as fuel, heavy water as moderator and primary coolant and has maximum thermal neutron flux is of the order of 2.1 x 10^{14} n/cm^2/sec.The reactor provides various irradiation facilities like Pneumatic carrier facility, self-serve, tray rods, and adjuster rod. Radio-isotope handling involves safety evaluation of samples considering irradiation period,reactivity change and nuclear heating in samples. Post irradiation handling involves assessment of cooling and shielding requirements and loading of samples into shielded flask for safe transport.All operation on irradiated samples capsules should be carried out in hot cells to avoid radiation exposure and spread of contamination. Radiological safety surveillance is provided during the loading of radioisotopes in the suitable shielding flask on the basis of gross radioactivity.The following radiological safety criteria /regulatory limits are ensured based on the measurements such as

- Surface dose rate should be less than 2mSv/h for normal transport of package.
- If Maximum surface dose rate on any point of the flask is more than 2mSv, transport should be under exclusive use (Health physicist required to accompany the flask.)
- Transferrable Contamination Should be less than 3.7Bq/cm^2 for averaged over 300cm^2 for beta and gamma and 0.37Bq/cm^2 for averaged over 300cm^2 for alpha.
- Radioactive Material transit tag should be issued to each flask.

The samples are loaded in shielded flask in presence of the health physicist and after measurement of surface dose rate on the flask and transferable contamination , it is cleared for dispatch. The Area Gamma Radiation monitor is installed near to flask receiving area to measure any accidental increase in radiation dose rate in the area. Following typical samples are irradiated, loaded and dispatched to the user on regular basis.

Sr. No	Sample	Radioisotope	Flask Thickness (Inch)	Flask Surface Dose Rate ($mSvh^{-1}$)
1	MoO_3	**Tc^{99}**	5"	0.3-0.4
2	TeO_2	**I^{131}**	7"	0.07-0.1
3	Sm_2O_3	**Sm^{153}**	4"	1-2
4	$LuCl_3$	**Lu^{177}**	4"	1-2
5	Ir	**Ir^{192}**	5"	0.05-0.07
6	Cobalt	**Co^{60}**	9"	2-5

Personnel monitoring of radiation workers involved in isotope handling is carried out with Thermoluminescence Dosimeter (TLD) and Direct Reading Dosimeter (DRD).No case of overexposure has been reported during the handling of radioisotopes.Strict adherence to safety norms and standard procedures are necessary to minimise radiation exposure and avoid any spread of contamination.

Refrence:

1. Technical Specifications for Dhruva Operations Revision-III
2. Radiation Protection Manual for BARC Facilities; BSC/SM/2020/3 Rev.-0

Status of Neutron & Ion Irradiation facility at Institute for Plasma Research

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The accelerator-based D-T neutron source has been developed at Institute for Plasma Research, Gandhinagar for fusion neutronics studies as well several other applications like Radioisotopes for Medical applications, neutron radiography, deuterium ion beam irradiation, etc. The main subsystems of the D-T neutron generator are ECRIS, High voltage deck, Low Energy Beam Transport (LEBT) system, Acceleration column, Medium Energy Beam Transport (MEBT) system, 300kV HVPS, Tritium handling & recovery system, and Rotating tritium target. The LEBT transports the extracted deuterium ion beam (20 mA) from ECRIS to the acceleration system. The MEBT transports the accelerated deuterium beam (300 keV) and bombards the Tritiated target (~140 Ci), which produces the 14-MeV neutron. The 14-MeV neutrons were produced via 3He(D, n)4He nuclear reaction. This paper presents the status of an intense 14 MeV neutron generator facility at IPR and the latest result of neutron yield measurement.

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Performance of ion exchange resin in various process systems of Nuclear Reactor

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Polystyrene-Divinylbenzene based ion exchange resins are widely used in purification processes in the nuclear industry. Generally, performance of ion exchange resin in purification system depends on the properties of ion exchange resin (viz. salt splitting capacities, cross linking, uniformity coefficient etc.) along with the different process parameters such as purification flow, temperature and differential pressure across the resin bed. However, in a nuclear reactor, presence of ionising radiation plays a very crucial role on the performance of ion exchange resin. Resin in such systems is subjected to an intense radiation exposure which significantly reduces its operational life and leads to generation of excessive radioactive waste. To assess the governing factors, a radiation stability study on ion exchange resin was carried out using a γ radiation source and by analysing a comprehensive set of samples from exhausted ion exchange resins from process systems of reactor.

Based on the conclusions drawn from these studies, factors affecting the performance of ion exchange resin in various process systems of nuclear reactors have been discussed and possible remedial measures have been suggested to improve quality and the service life of the ion exchange resins.

Investigation of ionic and non-ionic radio gamma emitting radio-nuclides in primary cooling water system of Dhruva reactor

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Build-up of radiation field due to the deposition of activation and fission products, generally present in primary coolant water, on out-of-core surfaces of system piping, pumps and heat exchangers, etc. is a well-known phenomenon in nuclear reactors. In the nuclear industry, it is therefore, essential to minimize the deposition of activity on out-of-core surfaces to achieve the ALARA limit set by IAEA of radiation exposure to the personnel working in it. However, it is a well-known fact that with a given design, structural materials, and water chemistry activity build up is proportional to operating power of a nuclear reactor. A highly optimized online purification system is essential to control the build-up of radio nuclides in primary coolant. Optimization of purification system heavily depends on radio nuclide wise estimation of cationic and anionic activity load. The PCW has been passed through the different columns separately filled with cation and anion exchange resin and also with activated charcoal for categorizing the radio nuclides in the PCW in terms of their ionic and non-ionic nature to understand the radio nuclide wise load to every components of the purification system. Gamma activity in inlet and outlet water samples taken from these columns were then estimated using HPGe detector-based gamma spectrometer. Mainly isotopes of Xe, Ar, Kr etc. were found to be non-ionic and gaseous while major cationic activity load consisted of Na^{24} , Cs^{138} , $Sr^{91,92}$ etc. Radio Iodines, $I^{131-135}$, mainly, contributed to the anionic load. The radio nuclides such as Mo^{99}-Tc^{99m} also contributed to anioic load. Neptunium-239, which also contributes significantly to the radiation field in PCW system, has been found to be removed by both cation and anion exchange resin as well as activated charcoal suggesting it to be somewhat in colloidal form. The study has been proven to be very useful in deciding the proportions of ion exchange resins in moderator/PCW purification units.

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Se-75 isotope preparation and its usage to investigate solid-liquid interface reaction of selenate and selenite ions

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Special concern regarding selenium (Se) is attributable to its two contrasting characteristics: at low concentrations, it is an essential nutrient while a toxic contaminant at higher quantities [1]. Within natural waters at environmental pH values, selenium exists primarily as oxyanions in the redox state (IV) as selenite (SeO_3^{2-}) or in (VI) as selenate (SeO_4^{2-}). It (Se-79; half life: 4.9×10^5 yrs), as a U-235 fission product, may contribute to the selenium distribution to the biosphere from high-level nuclear waste (HLW) repository. In aquatic environment mobility of selenium oxyanions, solid-liquid interface reaction of Se is therefore of vital importance.

Se-75 radiotracer (gamma energy: 136, 264 and 400 keV) was produced by neutron irradiation of H_2SeO_4 solution and H_2SeO_3 solid (~10 mg of Se amount; neutron flux ~ 1×10^{13} n cm^{-2} s^{-1}; 7 days irradiation; Cirus research reactor, Mumbai). An aliquot (60 µL) of ^{75}Se-oxyanion solutions (pH 1 0.01 M NaCl medium) in sorption samples gave 1×10^{-7} M. For these samples, Goethite particles were first equilibrated with 10 mL of 0.01 M NaCl over 48 hours and subsequently Se oxyanions were added, pH was adjusted and the suspensions were equilibrated for next 72 hours. Percentage retention of Se(VI) and Se(IV) on goethite particles were analyzed using the radioactivity of Se-75 isotope left over in supernatant. NaI(Tl) detector was used to assay the Se radioactivity.

Small but significant difference in retention behaviour of Se with varying oxidation state and specific surface area of the goethite particles indicates the need to distinguish between inner sphere complexation binding and hydrogen bonded outer sphere binding of selanate onto goethite surface.

Acknowledgements: Authors acknowledge the support and encouragement of Head, RACD and Head, CCS, RACD during this work.

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Environment friendly extraction of rare earth elements using bio-nano-conjugated material from red mud waste of aluminum plants in Odisha

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It is broadly established that the rare-earth elements are critical components in modern materials for numerous present and future energy applications [1]. Due to the increasing demand and limited primary resources, their recovery from secondary resources has been in limelight nowadays. Red mud, a potential source of rare earths,is a reddish-brown waste resulted from bauxite residue after the Bayer process extracts Aluminium from bauxite[2].Leaching, a widely used hydro metallurgical technique used for the separation of useful constituents from the resources. Leaching using environmental friendly organic acids and biogenic method is highly required to address the need for rare earth separation and recovery. Bioleaching is one of the most well-established and industrially implemented technique involving the use of acidophilic microorganisms with Fe/S oxidizing metabolism to increase metal solubilization from solid matrices. Due to the high abundance of ionized phosphate groups together with carboxylic, and hydroxyl groups on its cell wall, these facilitate binding of the rare-earth elements. The induction of polysaccharides and lipids boosts the bio sorption efficiency of the microorganism. Furthermore, the secretion of bio generated metabolite products such as oxalic acid and citric acid, will be stimulated. Process culture parameters such as pH, temperature, dissolved oxygen, substrate concentration, etc., will be optimized. Application of conjugated bio-nanomaterial especially green-synthesized zero-valent Sulphur/iron and reduced graphene/functionalized 3D graphene/carbon quantum dot with microorganisms will be carried out for the enhancement of rare-earth extraction. Further research will concentrate on kinetics and thermodynamic analyses, in which metal speciation and leaching agent bio-production can be used to predict eventual metal solubility equilibrium. Aluminium plant like NALCO in Odisha is producing huge red mud as bauxite residue, hence the proposed research aims at extraction of valued rare earth metals from these waste materials. The rare earth metal contents in the process will be analyzed using neutron activation analysis technique.

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Empirical Study On The Application Of Dermatoglyphics For The Profiling Of Population Groups: Establishing Prospective Geomarkers And Occupational Markers Through Neutron Activation Analysis Of Fingerprint Residues

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Forensic science is one of the most integral parts of criminal justice delivery system. Of late the field has been encompassing a larger discipline for the effective criminal justice system with the technology and science-oriented investigations and examinations. One of the most vital areas of this field is the criminal and personal identification. This has become the cornerstone of the Forensic Sciences with the reliable databases. Though the databases have always been yielding good results with reference to the identification of individuals, probable limitation among the few is the time consumption. It is quite obvious that the database analysis requires exclusive time and skill. There is always a scope for the reduction of time through the application of the associated chemical and morphological profiling. In various forensic disciplines like toxicology in which arsenic has been detected from the hard and soft tissues. In case of ballistics, mercury has been detected in the gun shot residues. In case of wild life forensics, hair of the wild animals is the indicator of geographical origin of the respective species. In the same way, in this study, fingerprints residues/ dermatoglyphics of two different population groups namely the Jammu and Gujarat regions have been subjected for the analysis of the microscopic examinations and chemical profiling. This was done through scanning electron microscopy, inductively coupled plasma -mass spectrometry and the neutron activation analysis. The results in all this analytical work were similar and significant. The same results have been compared with the chemical profiling (Tungsten, Thorium, Rubidium, Ytterbium etc..,) of the nail and hair and were found to be substantiated. This has given rise to more reliable results as far as the identification of individuals is concerned leading to the probable identification. The results were found to be highly significant giving rise to the contemplation of fingerprints as the geographical and occupational markers

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Cross-section measurement of nuclear reactions induced by reactor neutrons in elements of Actinides and Rare Earth elements

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Actinides and Rare Earth elements form an important and useful group of elements having key applications in various industries and energy generation. Most of these elements are useful in reactor design and fuel technology. And as such study of the various nuclear parameters including the cross-section of nuclear reactions induced by reactor neutrons in these elements form a useful database. Using the neutron activation analysis with a suitable flux monitor the cross-section values can be estimated in the reactor neutron energy range. The cross-section value for nuclear reactions induced by thermal, epithermal and fast neutrons in the reactor neutrons can be calculated separately using a cadmium cover over the experimental target samples and also choosing a suitable flux monitor alongwith the sample. If the irradiation of the sample is carried out using the APSARA-U reactor which has thermal neutron column then the cross-section value can be taken to be for thermal neutron energy. The following elemental isotopes(most abundant isotope for each element) are proposed to be studied with their corresponding suitable sample material:
i) Actinides(89Actinium227, 90Thorium232, 91 Protactiniumr 231, 92Uranium238, 93Neptunium237, 94Plutonium244, 95Amerecium243, 96Curium247, 97Berkelium247, 98Californium251, 99 Einstenium252),ii) REE-Rare earth elements(21Scandium45, 39Yttrium89, 57Lanthanum139, 58Cerium140, 59Praseodymium141, 60Neodymium142, 61Promethium145, 62Samarium152, 63Europium153, 64Gadolinium158,65Terbium159, 66Dysprosium164,67Holnium165, 68Erbium166, 69Thulium169, 70Ytterbium174,71lutetium175,

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Utilization of PCF and Self Serve Facilities of Dhruva and Tra-rod facilities of Apsara-U for R&D work using NAA and radiotracers

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Radiochemistry Division (RCD), BARC has been benefitted from extensive utilization of research reactors since their inception at BARC. The R&D and Applied works include Neutron Activation Analysis (NAA), Nuclear Fission and Reaction, Radiotracer applications and detection of low level U and Pu through solid state (fission / alpha) nuclear track detector (SSNTD). In this respect all types of irradiation facilities at research reactors at Trombay starting from swimming type 1MW Apsara reactor (1956) to upgraded 2 MW Apsara (Apsara-U) reactor (2018).

RCD has a long term plan to utilize various facilities as given below.

1. Pneumatic Carrier Facility (PCF) at Dhruva for short-lived nuclides using NAA and quantification of low level U and B by SSNTD
2. Utilization of Self-serve facility at Dhruva for medium and long-lived nuclides
3. Utilization Core and outside core irradiation facilities at Apsara-U for NAA (conventional and epithermal) using conventional and k_0-NAA methods
4. Utilization of thermal column at Apsara-U for large and non-standard geometry samples using low neutron flux
5. Utilization of thermal neutron beams at Dhruva and in future at Apsara-U for Promat Gamma-ray NAA (PGNAA) work for non-destructive assay of materials.

All the works are focused first in R&D mode and then applications to various fields including areas having enormous societal applications like forensics, archeology, geology, biology, food and agriculture, uranium explorations and REEs, QA/QC of finished products including precious materials as well as colouration studies of topaz and other gemstones via neutron irradiation.

Utilization of Dhruva and Apsara (U) for the production of medical grade High Specific Activity (HSA) Mo-99 from irradiated LEU targets

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Introduction: Technetium-99m (Tc-99m) is one of the most important diagnostic radioisotopes due to its suitable characteristics. ~ 30 million nuclear diagnostic procedures are performed annually using Tc-99m radiopharmaceuticals world-over. Tc-99m is obtained from its parent Mo-99 ($T_{1/2}$= 66 h) and used after tagging to suitable carrier molecule. Alumina-based $^{99}Mo/^{99m}$ Tc column chromatographic generator which utilizes HSA ^{99}Mo is the gold standard for availing Tc-99m [1]. Mo-99 is produced by fission of U-235 in nuclear reactors. In India, DAE is working towards production of medical grade HSA Mo-99 by irradiation of low enriched uranium targets (LEU). A 300 Ci capacity (6 day calibration) radiochemical processing facility, BRIT-Fission Moly Plant (BRIT-FMP) for production of HSA Mo-99 has been set up at South site, BARC, by BRIT.

Materials and Methods: Design and construction of civil structure was done by DCSEM. LEU target plates were designed by Reactor group, BARC and fabrication of target plates would be carried out by NFG, BARC. Radiochemical processing facility has been set up by M/s. INVAP, Argentina. Fabrication support, regulatory approvals, and commercial production are the scope of BRIT. Provision for target irradiation is made at Dhruva, and is in progress at Apsara (U). Processing technology is based on alkaline dissolution, followed by filtration, and subsequent purification of Mo-99 containing filtrate via series of three ion-exchange resins.

Results and Discussion: All major systems and sub-systems have been installed. Cold trials were performed with Aluminum plates establishing the smooth working of all systems. Hot runs with irradiated LEU targets shall be performed after regulatory approvals. Once commissioned, BRIT-FMP will make our country self-reliant in HSA Mo-99. Present domestic requirement of HSA Mo-99 is ~80 Ci (6 day Ci per week). Hence, the facility will ensure the current and the future requirement of this medically important isotope in our country.

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Selenium and Seleniferous Crops of Punjab, India: A need for NATs to establish concentration, localization and speciation of Se in environmental and dietary matrices

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The presentation is focused on a comprehensive research account of the studies carried out on quantification, speciation and bioactivity of selenium (Se) sourced from Se rich cereal grain cultivated in seleniferous agricultural belt of Punjab during the period of 2008-2021. Samples of cereal grains viz., wheat, rice and maize, were collected at sites near the villages of Jainpur and Barwa geographically located at 32'46^{o}N, 74'32^{o}E, in the Nawanshahr-Hoshiarpur Region, Punjab, India. Quantification of Se was carried out using neutron activation analysis (NAA) [1,2] as well as other quantification tools such as florescence spectrometry and ICP-MS [3-6]. The Se levels (ug g^{-1}) in wheat and maize were 96.9 ± 0.2 and 37.2 ± 0.2, respectively were higher than those reported in the Se-impacted region of Enshi, China or other Se-impacted areas. The speciation studies on wheat and maize using HPLC-ICP-MS indicated the dominant presence of selenomethionine, followed by selenite and methylselenocysteine. So as to establish the quantification and speciation, myriad of analytical techniques were used based on validity and access. However, looking at the potential use and therefore distribution of these Se rich dietary matrices to population that is Se deficient and Se compromised it is important to have a set of standard and robust analytical tools that can be cross-validated across the globe. Nuclear analytical techniques (NATs), in this regard, can be considered for the above context, as they are widely accepted and used by all research groups in such endeavours.

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Dr. P.K. Pujari, Distinguished Scientist, is the former Director, Radiochemistry and Isotope Group at Bhabha Atomic Research Centre. He has developed a state of the art positron laboratory including positron accelerator at BARC, and has overseen R&D in the area of nuclear chemistry, radioanalytical sciences, specialized radiation measurements, actinide chemistry and quality control of nuclear materials as well as radiation and radioisotope applications in the area of healthcare and industry. He is a recipient of Homi Bhabha Medal (1985), IANCAS Dr. Tarun Datta Memorial Award (1997), Japan Society for the promotion of Sciences (JSPS) Fellowship (1998-2000), DAE-SRC Outstanding Research Investigator Award (2008) and Homi Bhabha Science and Technology Award (2008). Dr. Pujari is a member of the International Committee of Positron Annihilation (ICPA) and was elected as Chair of the International Committee of Positron and Positronium Chemistry during 2014-17. Presently, he is President of IANCAS and SPAN, c/o RCD, BARC.

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