Advanced Nuclear Science and Technology Techniques (ANSTT2) Workshop

Monday 18 March 2019 - Wednesday 20 March 2019

J Block

Book of Abstracts

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The Ionising Radiation related activities at NMISA

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NMISA supports the South African industry with measurement traceability and measurement solutions. The ionising radiation division has dosimetry and radioactivity laboratories and recently has introduced capabilities for performing measurement audits at radiotherapy centres. The presentation will look at different programmes and projects currently running at these laboratories.

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Primary Activity Standards and Nuclear Data for Targeted Alpha Therapy

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Targeted alpha therapy is a rapidly evolving discipline, referring to an emerging class of revolutionary cancer agents delivering alpha-particle-emitting radiopharmaceuticals selectively to cancerous lesions via attachment to appropriate ligands and carriers.

Clinically effective alpha particle–emitting radionuclides for cancer therapy exhibit short half-lives, (limiting long-term radiation exposure to patients) and exhibit a high level of radiobiological effectiveness (due to the high-energy and short-range of the alpha radiation) thus limiting damage to non-cancerous surrounding tissue.

The calculation of the absorbed dose delivered to malignant and surrounding normal tissue is a key parameter in optimising the effectiveness of these treatment modalities, requiring accurate assessment of the activity administered to patients (via demonstrable traceability of clinical Dose Calibrator assay to primary activity standards) as well improvements in the knowledge of radioactive decay scheme parameters/nuclear data for the radionuclides employed.

This report reviews the current status of measurement and standardisation needs for Targeted Alpha Therapy, and details recent work performed at the United Kingdom's National Physical Laboratory (and worldwide), to address these key measurement issues for the Targeted Alpha Therapy radiopharmaceuticals 223Ra, 227Th and 224Ra each of which may be considered as the parent of a radioactive decay-chain. The nuances of radioactive decay (and associated progeny ingrowth) for each radionuclide on activity measurements (for primary and secondary standardisations, as well as clinical use) are detailed.

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Commissioning the DT neutron facility at the University of Cape Town

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A new fast neutron facility has been established within the Metrological Applied Sciences University Research Unit (MeASURe) located in the Department of Physics at the University of Cape Town. The facility features a D-T sealed tube neutron generator within a bunker which can produce a well-collimated beam of 14 MeV neutrons suitable for a wide variety of applications, including cross section measurements, elemental analyses of materials in bulk, and neutron detector characterization and calibrations.

We introduce the facility, and how it is situated within the field of neutron metrology. We detail the existing infrastructure, both physical and computational, and present experimental characterisations of neutron yields, energy spectra and beam profiles. Current and future applications will be discussed.

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Producing a standard thoron source.

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Thoron (Rn-220) is the radon isotope with a shorter half-life (55 s) than the better known Rn-222. Thoron has been identified as a possible health concern in specific places such as monazite processing plants and (rare-earth) mines. The short half-life of thoron (55.8 s) makes thoron calibration sources and thoron chambers less common than the corresponding radon ones. We have developed a an inexpensive and straight forward but accurate standard thoron source that can be set up easily in typical nuclear environmental laboratories. The source of thoron is a solution of Th(NO3)4 in water. Thoron is extracted by bubbling air through the solution using an aerator. The gamma rays from the solution are measured at the same time. The thoron activity concentration in the exit stream follows from the reduction in the intensity of the gamma rays from the progeny of thoron over time.

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Positron Emission Particle Tracking: towards Principled Education, Physics and Technology

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We use advanced nuclear measurement techniques to study the fundamental physics of material flows and the dynamics of physical systems. At the previous ANSTT meeting we presented a research strategy broadly aligned to the scientific programme. We now present developments over the past year, including new high speed data acquisition systems, machine learning explorations, and novel radioisotope techniques specific to iThemba LABS. We will provide an update on our laboratory's role in personnel development and training, and offer thoughts towards the use of our facility for metrology applications.

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Measure it! Nuclear science and the science of measurement

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I will explore the growing relationship between measurement in nuclear science and the science of measurement. In recent times metrology is relying more on fundamental science and in November 2018 the SI units were redefined with direct traceability to the fundamental constants of nature. I will illustrate how metrology in playing a more central role in nuclear physics, including at iThemba LABS, and discuss the research domains of the Metrological and Applied Sciences Research Unit (MeASURe) within the Department of Physics at UCT.

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Excited State Lifetime Nuclear Metrology: Precision Half-life Measurements in 164Dy and 166Dy and Reaction Channel Selection Techniques using the NuBALL Spectrometer

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Results are presented from the first in-beam experiment using the NuBALL hybrid HPGe-LaBr3 gamma-ray spectrometer at IPN, Orsay, performed in November 2017, with the physics aim of determining the electromagnetic transition rates to the ground state of the N=100 nucleus 166Dy. In this first configuration, the NuBALL spectrometer comprised 24 Compton suppressed HPGe Clover detectors, 10 coaxial HPGe Compton suppressed spectrometers, and 20 single-element LaBr3 detectors supplied by the FATIMA and UK Nuclear Data Network collaborations. These detectors were read out using a fully-digital data acquisition system. Excited states in 166Dy were populated via the 164Dy(18O,16O)166Dy two-neutron transfer reaction using a 6.3 mg/cm2 164Dy gold-backed target of 95% purity and a pulsed 18O beam with energies of 71, 76 and 80 MeV provided by the tandem Van de Graaff accelerator at IPN Orsay. The ultimate physics goals of this work are to determine excited state lifetimes in the vicinity of the valence maximum nucleus 170Dy104 [1], using the HPGe-gated, LaBr3-LaBr3 fast-timing time-difference technique. The states identified as populated in 166Dy are compared with results from previous spectroscopic studies of this quadrupole deformed nucleus, using deep-inelastic reactions to populate high-spin cascades [2,3], and (t,p) transfer reactions on 164Dy [4] and β-decay from 166Tb [5] which are more selective for lower-spin states. A value for the previously unknown half-life of the first excited 2+ state in 166Dy is presented. Values for the half-lives of the first excited 2+ and 4+ states in 164Dy are also presented, obtained from direct gamma-gamma time differences for the first time [6]. Methods of channel selection used to enhance the peak-to-total ratio for the 166Dy and to discriminate these from the 178W populated via the competing fusion-evaporation channel [7,8] will be demonstrated. In particular, the effects of total energy-total gamma multiplicity and prompt-delayed coincidence timing will be discussed.

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This work is partially supported by grants from the UK Science and Technology Facilities Council (STFC); the UK Government Department for Business, Energy and Industrial Strategy (BEIS) via the National Measurement System (NMS); and the Marion Redfearn Trust.

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A study to investigate the use of natural radionuclides as radiotracers in sedimentation processes

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The natural occurring radionuclides of thorium, uranium and potassium is present in varying concentrations in all rocks and sand. Natural radionuclides can therefore be a good tool when studying sediment characteristics. The uranium nuclide usually has the lowest activity concentrations, and potassium by far the highest concentrations. Natural radionuclide concentrations were consequently acquired and mapped by means of in situ measurements at various locations. These locations included beaches, pans and rivers in South Africa, Mozambique, Botswana and Namibia. The distribution of the naturally radionuclides demonstrated good agreement with the geophysical characteristics of the areas which includes underlying sedimentation processes. These studies also showed that radionuclide mapping provides valuable information on beach formation and erosion.

Black sand that contain high levels of heavy minerals were also gathered from some of the sites and analysed. Uranium and thorium concentrations in excess of 550 Bq/kg and 950 Bq/kg, respectively, were measured. Very low concentrations of potassium were however detected in the black sand. These exceptionally high levels of radionuclides gave rise to the idea that black sand can be used as a natural radiotracer when studying sediment transport. This article will explore the possible utilization of natural thorium and uranium in black sand as radiotracers.

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Environmental Radioactivity Laboratory of iThemba LABS

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The Environmental Radioactivity Laboratory of iThemba LABS, in the Department of Subatomic Physics has been using radiation detectors for measurements of anthropogenic (man-made) and natural radionuclides present in our environment. The radiation detectors consist of a laboratory-based HPGe detector, field-based MEDUSA detector systems and a flexible radon monitor, RAD7. To assist in the testing and calibrations of the detectors, various Monte Carlo (MC) codes are also being used to optimise the experimental data with the calculations. To date, various users have used the facilities to count and analyze their samples. For this contribution, current activities and future plans of the facility will be discussed.

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Characterisation, Performance Assessment and Improvement of a Small Anode Germanium (SAGe) Well Detector for Environmental Applications.

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In environmental gamma-ray spectroscopy, it is essential that the detectors employed have high efficiency and excellent energy resolution in order to give accurate assessment, identification and quantification of radionuclides present in the sample being measured.

As part of a joint project with the Environmental Radioactivity Research Centre at the University of Liverpool a Mirion Techonologies (formerly Canberra) Small Anode Germanium (SAGe) well detector was used to measure a number of small volume environmental samples.

The SAGe well detector is a high purity germanium detector which offers excellent resolution and high efficiency as samples are placed within the well for data collection.

The high resolution at low energy gamma-ray energies are achieved by using point-contact electrodes. As these detectors are relatively new there is a requirement to fully understand their performance with the intention to improve its measuring capabilities.

Data will be presented for this detector.

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Measurement of activity concentration of ^{238}U and ^{232}Th series radionuclides in beach sand with a multidetector ($LaBr_3$:Ce) gamma-ray spectrometer

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The activity concentrations of ^{238}U and ^{232}Th series radionuclides in beach sand were measured using a gamma-ray spectrometer comprising four $LaBr_3$:Ce (2" x 2") detectors without background shielding. The sample was placed 10 cm equidistant from the detectors and counted for 48 hours. This spectrometer allowed for measurement in singles and coincidence (gamma-gamma) modes. Time-stamped data were acquired and time correlation used to remove the background offline.
In coincidence mode, the minimum detectable activity (MDAs) were two orders of magnitude lower than in singles mode. The weighted activity concentration of ^{238}U series radionuclides in singles and coincidence modes are 908 $\pm$ 70 Bqkg^{-1} and 972 $\pm$ 99 Bqkg^{-1} respectively. The weighted activity concentration of ^{232}Th series radionuclides in singles and coincidence modes are 1599 $\pm$ 70 Bqkg^{-1} and 1754 $\pm$ 185 Bqkg^{-1} respectively. Therefore we conclude that the results are consistent to within measurement uncertainty.

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Natural Radioactivity in soils of Ijero, Nigeria: measurements and risk assessment

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Soil samples were obtained from Ijero, Nigeria where the chemical and radiotoxicity of soil is under question due to ongoing and unprofessional mining activities. The soil samples were crushed, sieved, dried and sealed in identical cylindrical containers. The activity concentration of primordial radionuclides 238U, 232Th and 40K was measured using a High-Purity Germanium (HPGe) detector coupled with the Palmtop MCA. Subsequently, radiological risk factors were calculated to assess the

risk, on average, to an individual living in Ijero.
The measured activity concentration for 238U ranged from 11.87±1.06 to 94.02±6.81 Bq/kg with a mean value of 40.76 Bq/kg. For 232Th the activity concentration ranged from 18.29±6.71 to 111.2±1.89 Bq/kg with a mean value of 43.59 Bq/kg. Finally, 40K ranged from 66.56±26.2 to 1195±35.8 Bq/kg with a mean value of 568.1 Bq/kg. Thus the mean values for the activity concentration of primordial radionuclides 238U, 232Th and 40K were higher than the global averages of 30 Bq/kg, 39 Bq/kg and 400Bq/kg respectively.
In total, 30 soil samples were evaluated. Of these samples, only 1 had hazard indices outside of the permissible limit of 1 mSv/yr. Exactly 10 samples were above the permissible limit for the Annual Effective Dose rate, where indoor and outdoor dose rates must sum to 1 mSv/yr. The Annual Gonadal Equivalent Dose limit of 300 μSv/yr was surpassed by 25 samples. For the Excess Lifetime Cancer Risk and Percentage Risk, 7 samples were outside of the 5% limit, with the highest risk at 61%. The average risk across all the soil samples was well below the limit. Therefore there are certain high risk locations where the activity concentration of primordial radionuclides is significant in Ijero, Nigeria.

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Overview of environmental radioactivity studies in South Africa and neighboring countries

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High concentrations of radionuclides and toxic elements in abandoned gold mine facilities present a potential health hazard to the people living around these former mining areas and lead to a degradation of the environment. Environmental measurements were performed around the areas designated as gold mines, coal mines, coal power stations, mine dumps and abandoned mines. Soil and water samples were collected and analysed to determine the activity concentrations of 238U, 226Ra, 232Th and 40K. The presentation will cover an overview of the results obtained using a high purity germanium (HPGe) well detector and high purity germanium broad energy (BEGE) detector as well as an inductively coupled plasma mass spectrometer (ICP-MS). A general overview of the activities obtained and the radiological and toxicological risks associated with the pollution will be discussed.

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Design of a national indoor radon survey for South African Homes: review of existing indoor radon concentration data and associated measurement techniques

Authors: Abbey Matimba Maheso[1]; Richard Newman[2]; Peane Maleka[3]; Ryno Botha[4]; Jacques Bezuidenhout[None]; Lebogang Phefo[5]; Astile Ocwelwang[None]

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Radon 222Rn is a natural radioactive gas directly produced from the decay of Radium, 226Ra found in rocks and soil. Since radon is a gas, it can move freely through the soil allowing it to escape into the atmosphere or flow into buildings. Elevated radon-in-air levels are associated with an increased risk of developing lung cancer. Over the years comprehensive surveys of indoor radon levels were performed in a number of countries (e.g. Ireland, France). In 2018 the Centre for Nuclear Safety and Security (CNSS) in South Africa, initiated a project call to design a national indoor radon survey in South Africa. Stellenbosch University was successful in getting funding to execute this collaborative project. Here we report on results from our desktop-based survey of existing indoor radon data for South Africa. We present an initial statistical analysis of the data and discuss radon measurement techniques used to date.

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Assessment of radium and radon activity concentrations in water sources near selected former uranium mines in the West-Rand area of Johannesburg.

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Abstract:
Radioactivity has existed since the beginning of time and is part of our planet Earth. Several studies have been well documented to monitor natural radioactivity as a source of radiation exposure to the environment and to human beings. In order to determine the effects of natural radioactivity in around areas of former uranium mines in the West-Rand area, an investigation of radiation exposure through ingestion of contaminated water will be carried out. In the present work, focus will be on Uranium daughter radionuclides; Ra-226 and Rn-222. Measurements will include the use of Alpha and Gamma spectroscopy to identify radionuclides concentrations, as well as Inductively Coupled Plasma Mass Spectrometer (ICP-MS) and Radiochemical Neutron Activation Analysis (RNAA) to analyze the isotopes of interest.

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Measuring Radon emanation from soil in South Africa to inform a survey of radon in houses.

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The National Nuclear Regulator is funding a project to plan a residential radon survey in South Africa. This is a very large project and we are looking at ways to decide if different areas are likely to be radon prone. Two of the important parameters to predict the radon levels in houses is the radium concentration in the soil and the emanation coefficient. This project aims to measure the latter for soils from different areas in South Africa where the radium (uranium) content is large.

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Improvement of Methods for Establishing Baseline Data for Uranium Mines in Tanzania

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In order to monitor future environmental pollution and to enforce uranium mining regulations during and after mining, several efforts have been made to establish pre-mining baseline data at proposed uranium mines in Tanzania1-6. However, these attempts did not produce the desired baseline data because there was no clearly defined sampling area. The basis of the methods used for selection and reduction of sampling points used back then could not be justified, knowing that the boundaries of the study area were not demarcated to include potential areas that would be appreciably polluted by mining activities. In this regard, clearly defined methods for production of reliable baseline data are urgently needed for subsequent enforcement of uranium mining regulations in Tanzania. My study therefore, aims at improving the methods used for establishing baseline data in the proposed uranium mining areas and their vicinity in Tanzania.

Once these methods are improved and the areas to be sampled are clearly defined, radiological baseline data will be established at these areas in two ways. In the first way, gamma dose rates in air will be measured 1 m above ground using a radiation survey meter after calibration. In the second way, activity concentration of natural occurring radionuclides in soil will be determined and converted to absorbed dose rates in air. The soil samples will be collected and prepared using standard environmental sampling procedures recommended by the IAEA7. The samples analyses needed to obtain the activity concentration will be based on gamma-ray spectroscopy.

The information developed from my study will provide an improved method for establishing effective baseline data for uranium mines which are being established in various countries in Africa. It will also provide the public and the scientific community with the baseline data that will subsequently be used to evaluate the impact of uranium mining in terms of increased radiological risks during operation and after closure of the proposed mine.

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Prompt Gamma Imaging: Verifying Proton Therapy Treatment Dose

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Prompt Gamma Imaging (PGI) focuses on the detection of secondary (prompt) gammas during a proton therapy treatment. With the use of a Compton camera, PGI is working to create an in-vivo image of the dose deposited within the patient as a dose verification system. I will present the UCT PGI detection system and the current work being performed. I will also discuss the next steps towards the development of PGI and our role in the larger project to develop a complete clinical system.

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Monitoring of targets for radionuclide production

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Direct monitoring of targets for isotope production implies harsh conditions with large neutron and gamma fields. These have implications on the type of instrument to use and how to extract information. Micro fission pocket detectors for nuclear power generation applications, for example, can sustain neutron fluxes in the order of 1014n/cm2/s or more. This makes them suitable to quantify neutron/gamma fluxes in real time but spectroscopic information is not accessible. An alternative was implemented at iThemba LABS to monitor leakage of radionuclide within the water cooling system. Water is sampled after the bombardment target and circulated in front of a germanium detector. Even though the conditioning and transport of water imply delays, the specific transition lines identified in the gamma spectrum allow for fine diagnostics of the bombardment targets. This can be used to deduce the type of target being bombarded, monitor its condition and identify anomalous leakage. Ultimately, this can also be used to measure the integrated number of projectiles complementary to indirect beam current measurement using non destructive probes.

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Pathways of radiotracer development for PEPT

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PEPT Cape Town is a dedicated research centre focused on measuring the underlying physics of opaque multiphase flow systems. The basis of this nuclear

measurement technique hinges on how accurate and representative the tracer particle is of the media of interest in these dynamic applications. This presentation will report the current state of tracer particle techniques and the areas of active radiochemical tracer development for future applications in PEPT.

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Sub-Millimetre Particle Tracking Using PEPT with the PolarisJ Semiconductor Array

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The Positron Emission Particle Tracking (PEPT) technique has been in development in Cape Town since 2009, and allows one to track a 1mm positron-emitting point source travelling at 1m/s to within 1mm, 1000 times a second. Typically, this utilises a large, high efficiency scintillation detector like BGO. However, recent experiments have shown that high resolution, relatively high efficiency semiconductor (CdZnTe) detectors, which are usually used in prompt gamma-ray detection during proton radiotherapy, are able to track particles down to sub-millimetre precision. We have been using the PolarisJ detectors to develop the PEPT technique, and hope to use them to track particles in micro-scale fluid dynamics applications. Initial measurements have been able to locate a ^{22}Na button source in three-dimensional space with an uncertainty of 0.11mm and a signal-to-noise ratio of 85%. This is a promising first step towards tracking micrometre-sized particles with sub-millimetre accuracy.

Special Lecture / 45

The role of Radionuclide Metrology in Nuclear Physics

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National Metrology Institutes (NMIs) involved in Radionuclide Metrology play an important role in enabling societal benefits from nuclear physics research (1). NMIs are responsible for the development and maintenance of primary measurement standards, distributed to end users to calibrate their own instruments in an uninterrupted 'traceability chain' of calibrations. NMIs compare their primary standards (with associated uncertainty budgets) with other NMIs through international comparison exercises co-ordinated by the Bureau International des Poids et Mesures (BIPM). The 'Mutual Recognition Arrangement' (CIPM MRA) is an arrangement among NMIs to allow for the mutual recognition of national measurement standards (and for measurement and calibration certificates issued by NMIs), thus meeting the increasing need to provide reliable and quantitative information on the comparability of national measurement services to a variety of users (governments, academic institutions, manufacturers, industry, etc).

A primary standard of radioactivity allows the decay rate from a source to be determined using a technique which does not itself need calibration, and underpins developments in characterising nuclear decay scheme parameters (such as photon emission intensities utilised in gamma-ray spectrometry). Since the activity of each radionuclide species depends on unique decay properties, different

experimental techniques are required for the primary standardisations of individual radioisotopes. The particular technique depends on the radioactive decay mode(s), half-life, decay scheme of the daughter nucleus and branching ratios for competing decay modes. The main methodologies used for primary radionuclide standardization are discussed in this presentation.

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Spitbraai / **16**

Fast neutron studies on concrete used in the nuclear industry

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Concrete is extensively within just about all nuclear facilities for its structural and shielding properties. In a re used actor facility, for example, the concrete will be subjected to high neutron and gamma-ray fluxes for the lifetime of the reactor (60+ years), and must retain is mechanical integrity and shielding properties at an acceptable level until decommissioning. Beyond the typical structural properties, there are three key properties that are required of any shielding material used in reactor conditions: attenuation of neutron flux; attenuation of gamma-ray flux; and well-known activation properties post irradiation. South Africa does not have a standard procedure for quantifying these properties for concrete, and other materials for the nuclear industry. The aim of this project is to develop and demonstrate proof-of-principle of a standardized measurement technique for quantifying radiation shielding properties of nuclear grade concrete.
We are establishing the first fast neutron beam reference facility in South Africa for the non-destructive testing of concrete (and in principle other materials used in the nuclear industry). We will initially focus on developing methods to measure overall shielding properties to fast neutrons, and the consequences of aging, where effects of radiation damage on both the structural integrity and shielding capability of concrete is of significant interest. The measurements are also being used to benchmark results from simulations using radiation transport codes. An additional area of interest is the development of methods for the independent verification of the alignment to regulatory codes of the constituent materials used in concrete mixes for nuclear facilities, both existing and planned. We present our methods and examples of illustrative analyses from typical measurements.

Spitbraai / **34**

Development of a digital data acquisition system for neutron metrology

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Neutron fields are found in a variety of industries such as high energy accelerators, and in medical radiation facilities. These fields vary widely with respect to energy, type of radiation and fluence.

Neutron energy spectra are typically measured using Bonner sphere detector systems. Systems based on scintillator detectors provide better energy resolution and a number of other advantages. A disadvantage of using scintillator detectors is their sensitivity to all types of radiation, requiring complex analysis of pulses to select for a particular type of radiation. The advent of digital pulse processing electronics has made it more possible to move from being heavily reliant on analogue electronics coupled to a Bonner sphere detector system, to scintillator based systems coupled to compact digital electronics as a standard.

Most neutron metrology groups around the world are thus developing systems of digital pulse processing to replace their aging analogue systems, which are suitable for use in a wide range of contexts and a wide range of detector types. We present progress on the development of a new digital data acquisition system for fast neutron spectroscopy and metrology using advanced scintillator technology, for use in contexts with or without the availability of time of flight.

Spitbraai / 6

Inverse-Oslo studies at iThemba LABS

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Reactions induced by beams of light ions such as protons, deuterons, ^{3}He and particles have been the main tool for investigating nuclear properties for almost a century. In recent years such reactions have been used to measure the nuclear level density (NLD) and the -ray strength function (SF) [1]. These quantities have been identified as one of the key quantities in proper description of

reaction rates that play an important role in the nucleosynthesis of heavy elements [2] and are vital to understand the enhancements found in the tail of the giant dipole resonance [3].

Unfortunately, the application of the traditional light ion experiments is limited, as it requires targets that are reasonably stable, both in terms of chemistry and radioactivity. This limitation makes it challenging or even impossible to probe the SF and NLD with traditional light ion beam experiments in certain parts of the nuclear chart such as the noble gases, neutron rich nuclei, etc. A possible resolution of this problem is to use inverse kinematics where the beam and target have been interchanged. This was first tested at iThemba LABS in 2015 with a ^{86}Kr beam and a deuterated-polyethylene target, with the goal of probing the NLD and SF of ^{87}Kr. This experiment has been followed up by additional explorations of the noble gases in 2017 with experiments with both ^{84}Kr and ^{132}Xe beams at iThemba LABS.

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Spitbraai / **22**

.Lifetime measurements in 44Sc excited states using LaBr3 :(Ce) detectors coupled with the AFRODITE Array

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The progressive development of the scintillator detectors has made it possible to do direct electronic lifetime determination. The 2” x 2” LaBr₃:Ce detectors provide a combination of excellent time resolution and good energy resolution. With these detectors it is possible to perform direct lifetime measurements of excited nuclear states up to a few hundred picoseconds. Six 2” x 2” LaBr3 :Ce detectors were coupled to the AFRODITE array as their first in-beam experiment. AFRODITE consisted of eight HPGe clover detectors as well two 3.5” x 8” LaBr₃:(Ce) detectors. A dE-E particle telescope was used to select the desired reaction channel. All detectors were used conjunction with the 16 channel all-digital waveform acquisition card, PIXIE16.
The reaction of interest ⁴⁵Sc(p,d)⁴⁴Sc was carried out at a beam energy of 27MeV. Through this reaction, excited states that have lifetimes which are apt for the characterization of the 2” x 2” LaBr₃ :Ce detectors were populated. One of the nuclei of interest in this work, ⁴⁴ Sc, has states with a wide range of lifetimes at low to moderate energies. Various techniques such as the slope method and the centroid shift method have been employed to extract the lifetimes of excited states. All these endeavours will seek to unveil the quadrupole moment of nuclei and their intrinsic behaviour.

Spitbraai / **47**

Development of new in-house detector facility at the University of the Western Cape

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The Physics academic community in South Africa is historically small with an increasing number of postgraduate students taking Masters and PhD. The University of the Western Cape (UWC) consist diverse student bodies, mainly supporting students from historically disadvantaged backgrounds in South Africa [1]. The nuclear physics group at UWC has research interests in nuclear physics which carries out research centered on the iThemba LABS facility in the Western Cape. The laboratory is well-resourced but the experimental apparatus at the laboratory is largely bought in commercially and comprises expensive items such as high-purity germanium detectors. The upcoming in-house detector facility aims at developing a strand of nuclear applications work at UWC and UniZulu in partnership with University of York (UoY), UK. UoK group lead by Prof. David Jenkins has its history in designing and building detectors with supporting instrumentation for the industry as well as leading research institutes. Transferring the knowledge from UoY on detector development will help to up-skill the young people. A team at UWC is working on developing a laboratory-based facility to facilitate detector development in their home institutions. The specific detector development activities have been devised in close consultation and are based on the existing strengths at UoY as well as interests of the SA team and the industrial connections in SA.

So far so, detectors such as NaI(Tl), have been tested using the conventional analog signal processing methodology. However in order to process the signals using the digital signal processing is underway to get the good timing information. Standardization of the digital parameter will help to get insight into the analog and digital pulse shape analysis. XIA's PIXIE-16 module has been employed for digital signal processing. Data acquisition (DAQ) has been developed to record the signal information. These detectors with the supporting electronics will be employed for the Coulomb excitation experiments at national and international laboratories. We also intend to develop an array of CsI(Tl) as well as gas detectors for such studies.

In future we plan to fabricate PET scanners using the plastic scintillator material interfaced to the fiber optical cables. To obtain the best timing resolution for tumor detection the DAQ modification is in process where we intend to detect the coincidence gamma-rays.

[1] http://nuclear.uwc.ac.za/

Nuclear Structure Studies / **33**

Plans for the new K600 focal plane detector

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A new position sensitive detector system for the focal plane of the K600 magnetic spectrometer is currently being developed. The existing focal plane detectors (FPDs) were designed to detect Z≤2

ions with kinetic energies 30 MeV/u or higher. A new low-pressure gas-filled tracker combined with a stopping scintillator detector is required to allow for the efficient detection of heavier particles (Z>2) over a range of kinetic energies, as well as light particles (Z≤2) at lower kinetic energies (<30 MeV/u). The different physics cases currently envisaged that require the low- pressure gas-filled detector will be reviewed, and an overview of the design of the new FPD will be presented.

Nuclear Structure Studies / **11**

Overview on the African LaBr Array at iThemba LABS

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The African LaBr Array (ALBA) consists of 23 large volume LaBr3:Ce. The characteristics of these crystals, such as the good energy resolution and the high efficiency, make this array very useful for the detection of high-energy gamma rays. The ALBA project foresees the use of the gamma spectrometer in stand-alone mode and coupled to the K600 spectrometer or to silicon-detector arrays for the particle identification. A Digital acquisition system based on XIA PIXIE 16 cards (12 bit 500Mz digitization) is currently under test.

The first six detectors of ALBA arrived in 2018 and they were successfully used in an experiment to investigate the pygmy dipole resonance in deformed nuclei. An overview of the project will be given underling the physics program that is envisaged for the upcoming future.

Nuclear Structure Studies / **20**

Neutron-rich nuclei in the vicinity of 208Pb

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Information gained on neutron-rich N~126 nuclei is essential for the understanding of nuclear structure in heavy nuclei. Studies around doubly magic systems allow direct tests of the purity of shell model wave functions. In the case of the beta decay of N~126 nuclei there is strong competition between allowed and first-forbidden transitions. This is the mass region where first-forbidden transitions can be dominant. The prediction of the FF component of the beta decay also requires good understanding of the wave-functions of individual states. From a longer-term perspective, experiments in this region pave the way toward the proposed nuclear-astrophysical r-process waiting point nuclei along the N = 126 shell closure.
Recently several experiments were performed at ISOLDE with the aim to study neutron-rich nuclei around 208Pb. Both beta decay and Coulomb excitation were used. In addition, the coupling of the iThemba LABS K600 spectrometer with a Ge array will allow the study of nuclei in this mass region in particle transfer experiments.

The presentation will report on recent results and their relevance on the structure of neutron-rich nuclei around 208Pb, and it will explore future opportunities.

Nuclear Structure Studies / **26**

Electric Monopole Transitions (E0) in the study of 70Ge

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Monopole transition studies has been of theoretical and experimental interest for over 50 years now. Since gamma decay is forbidden between two 0+ states, the study of nuclear structure through the usual technique of gamma measurement cannot be useful in such a case. Hence, the decay mode of spin zero state is most probable by electron emission. Depending on the probable transition energies, this can be achieved through either internal conversion or by internal pair formation. Therefore, measurement of electrons is crucial for E0 studies.
In order to implement E0 studies at iThemba labs, an electron spectrometer has been refurbished and characterised using calibration sources of internal conversion electrons (ICE): 133Ba and 207Bi. The results of the spectrometer characteristics are described. The spectrometer coupled with an array of fast timing detectors and Low energy photon spectrometer (LEPS) was successfully implemented for in-beam experiment.
Preliminary result will be presented for the measured conversion coefficient and monopole strength parameter in 72Ge and 72Se determined from electron-gamma coincident experiments from 70Ge(α,α') reaction.

Nuclear Structure Studies / **36**

Development of a spectrometry system for measurement of internal-pair studies

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Excited nuclei eventually de-excites mainly through electromagnetic transitions, e.g. gamma-ray transitions or electric monopole (E0) transition in an event that the former is forbidden. E0 transitions proceed via conversion electrons and electron-positron pairs (for transition energies > 1022 keV). Compared to gamma-ray transitions that are predominantly studied across the chart of nuclides, a great deal of E0 transitions and their associated excited 0+ states are still not firmly characterized.

Apart from being the only alternative means of unambiguously assigning spin and parity to states, E0 transitions also offer a reliable thumbprint for shape coexistence in nuclei, as the E0 transition strength can be used in the calculation of the mixing parameters for shapes suspected to be coexisting. Measurements of E0 transitions also helps elucidate phenomena relating to nuclear compressibility and isotope and isomer shift as well as provide sensitive tests on various models of nuclear structure [1][2][3][4].

A new facility, namely the electron spectrometer, for measuring E0 transitions was recently commissioned at iThemba Laboratory for Accelerator Based Sciences (LABS). The current work is aimed at giving the equipment new capability by adapting a segmented germanium (LEPS) detector into the spectrometer in order for it to be used to measure e-/e+ pairs of higher (> 3 MeV) energies as well. The LEPS detector is opted for owing to the scarcity (or exorbitant prices if found) of thick segmented Si(Li) detectors around the globe. The refurbishment is being aided by Geant4 simulations with magnetic field mapped out of the solenoid magnetic lens using OPERA-3D software [5]. The Transmission, efficiency, momentum resolution and other parameters of the spectrometer, obtained using Geant4 simulations, will be presented. On-going investigation on the feasibility of using a LEPS detector to measure internal pairs will also be discussed.

Once the facility is fully operational, the physics case will involve measuring E0 transitions in 50Ti, which will provide information that will subsequently be used to investigate the previously suspected existence of admixtures of 0+ excited states with 2+, 3+ and 4+ states [6][7][8].

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Nuclear Structure Studies / 12

Uncertainties in Measuring the Lifetime of a Nuclear Excited State via γ−γ Coincidences using NaI(Tl) Scintillators

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Metrological difficulties in measurement of lifetimes of nuclear excited states have posed controversies in the quest to answer the fundamental question of whether lifetimes of nuclear states are

in variable or not. Although several studies have suggested the possibility of slight variations of lifetimes depending on conditions of the nucleus [1, 2, 3], it is important to note that any claims of non-constancy of lifetimes as a consequence of deviation from the exponential decay curve can only be considered upon verification and accountability of stability and uncertainty of the devices used during the experiment [4]. Consequently, studying the uncertainties in lifetime measurement is a crucial step towards studying the possibility of variation of the lifetimes of nuclear-excited states when the nucleus is subjected to resonance conditions via multiple emission and reabsorption of gamma rays. We have, therefore, designed a system to precisely measure the lifetime of the state via gamma-gamma coincidences using multiple fast scintillators. Measurement uncertainties were thoroughly studied using a pair of NaI(Tl) detectors on a simple bench-top setup. All possible sources of lifetime measurement uncertainties with their magnitudes are presented in the uncertainty budget. A measurement uncertainty of 0.661% was observed indicating the suitability of the system for observing the variations of the lifetime that range from 1% of the known value.

Nuclear Structure Studies / **24**

Wavelet signatures of K-splitting of the Isoscalar Giant Quadrupole Resonance in deformed nuclei from high energy-resolution (p,p′) scattering off ^{146,148,150}Nd

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The phenomenon of fine structure of the Isoscalar Giant Quadrupole Resonance (ISGQR) has been studied with high energy-resolution proton inelastic scattering at iThemba LABS, in the chain of stable even-mass Nd isotopes covering the transition from spherical to deformed ground states. A wavelet analysis of the background-subtracted spectra in the deformed ^{146,148,150}Nd isotopes reveals characteristic scales in correspondence with scales obtained from a Skyrme RPA calculation using the SVmas10 parameterization. A semblance analysis shows that these scales arise from the energy shift between the main fragments of the K = 0, K = 1 and K = 2 components.

Nuclear Structure Studies / **17**

Continuing Influence of Shell Effects in the Nuclear Quasi-Continuum

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The nuclear dipole polarizability - a second order effect – governed by dynamics of giant dipole resonances was investigated. Along with the resulting effects of recently observed enhancement of photon strength functions at low energies for nuclide in A ≈ 50, 90 mass region. Empirical drops observed in ground-state nuclear polarizabilities indicate deviations from the effect of giant dipole resonances and reveal the presence of shell effects in semi-magic nuclei with neutron magic numbers N = 50, 82 and 126. Similar drops of polarizability in the quasi-continuum of nuclei with, or close to, magic numbers N = 28, 50 and 82, reflect the continuing influence of shell closures up to the nucleon separation energy. These findings strongly support recent large-scale shell-model calculations in the quasi-continuum region describing the origin of the low-energy enhancement of the radiative or photon strength function as induced paramagnetism, and assert the Brink-Axel hypothesis as more universal than originally expected.

Nuclear Structure Studies / **39**

Investigation of the beginnings of star formation and the synthesis of chemical elements in the early Universe

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Metal-poor stars provide a unique testing ground to investigate the beginnings of star formation and the synthesis of chemical elements in the early Universe. In particular, the abundance patterns seen in these metal-poor stars provide constraints on the nature of first generation of super-massive stars in the universe. These stars are also characterized by unusual abundance patterns of carbon, nitrogen and oxygen, which could probably assign them as a Population II stars that formed from material chemically enriched by a first-generation supernova. A parametrical search for best fits suggest a scenario involving low-energy supernova explosions with a relatively narrow range of masses (10 – 25 solar masses) and little mixing. Although this supernova scenario might elucidate the formation of the light elements up to aluminium, the experimental upper limits currently observed for the abundances of heavier elements such as Cr, Mn, Co, Ni and Zn do not allow stronger constraints of the original supernova properties.

More puzzling, however, is the large abundance of Sr (Z=38) with [Sr/Fe] +1. Strontium is the only element heavier than the iron group currently observed in HE1327-2326. Supposedly, there are two nuclear-reaction scenarios that could produce Sr:

• The slow-neutron capture, the s-process, occurring in asymptotic giant branch (AGB) stars; however, this process is inefficient in low metallicity.
• The main rapid-neutron capture, the r-process, could also produce strontium in a type-II supernova; although the production of Sr is not included in some of the supernova models.

A measurement of the Ba abundance is fundamental to distinguish between the s-process, with an expected relative abundance of [Sr/Ba] −1, and the r-process, with a different ratio of [Sr/Ba] = −0.5 to −0.4. Here we present the first astronomical data for EC20291-3603, a metal-poor star observed with the SALT telescope.

Nuclear Structure Studies / **40**

High-Resolution β- - γ Study of the 110Tc – 110Ru – 110Rh – 110Pd Isobaric Decay Chain

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Neutron-rich nuclei close to mass A=100 display a variety of intriguing shape phenomena such as exotic triaxial shapes, shape changes and shape coexistence. Recent investigations exploiting Coulomb excitation have helped to shed light on these phenomena [1]. However, as more intense radioactive beams of these refractory isotopes become available it has become evident that some of the key nuclear structure information required to fully analyse this data is lacking.

Consequently, in conjunction with new Coulomb-excitation investigations, dedicated decay studies were performed in this mass region. For these studies a cocktail beam of radioactive A=110 ions from ANL's CARIBU source were implanted onto a gold foil and gamma decays were registered with the Gamma-Ray Energy Tracking In-Beam Nuclear Array (GRETINA) [2]. The analysis of this data will yield new information, refining the level scheme and determining angular correlation and mixing ratios in these exotic isotopes for the first time. This new information is vital for the extraction of nuclear matrix elements and deformation parameters in the Coulomb-excitation analysis. In this talk preliminary results will be presented on the discrete-line gamma-ray coincidence analysis associated with the β-decay feeding of states in 110Ru from 110Tc and subsequent decays along the isobaric chain and these compared with the existing literature on this sequence [3,4].
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Nuclear Structure Studies / **2**

Coulomb-excitation studies @ iThemba LABS

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A new pipeline for Coulomb-excitation studies has been developed at iThemba LABS with the first particle-gamma coincidence measurements carried out during a two-month campaign in April-May 2016 using an XIA-based digital DAQ. We used the reorientation effect to determine the spectroscopic quadrupole moment of the first high-lying excitation in Tz=0 self-conjugate nuclei (20Ne, 32S, 36Ar) - typically associated with clustering formation - and 40Ar. These measurements present higher accuracy than previous work and, surprisingly, for 20Ne, 36Ar and 40Ar they represent the first measurements done at safe bombarding energies, well below the Coulomb barrier, onto a heavy target. Our new results show a zig-zag pattern of nuclear shapes at the end of the sd shell and will be compared with state-of-the-art mean-field calculations. Five MSc degrees have been awarded from these data sets.

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Source Head Fluence Modulation in Cobalt-60 Teletherapy: A dosimetric and Monte Carlo study

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Background and Purpose: Innovations in external beam radiotherapy have been limited to linear accelerators, yet radiotherapy began with cobalt-60 teletherapy. One such technology is called intensity modulated radiotherapy (IMRT), which can be executed with cobalt-60 teletherapy units to yield dosimetric characteristics that are comparable with linear accelerator beams. The lower energy and weaker penetration may be negligible in the delivery of efficient IMRT in cobalt-60 teletherapy especially for head and neck cancers with superficial extent. The aim of this study was to investigate the implementation of step and shoot technology in cobalt-60 teletherapy.

Materials and Methods: A clinical MDS Nordion Equinox 80 unit was used at dose rates of 67.7 ± 7.4 cGy/min and 61.4 ± 3.1 cGy/min. Three intensity maps were prescribed with Oncentra 4.3, and they were verified with GafChromic EBT2 film measurements in a PTW universal IMRT verification phantom. Two other measurements were made with GafChromic RTQA2-1010 film whilst a physical compensator was constructed and placed in the accessory holder. A 0.125 cc PTW 31010 Semiflex thimble chamber was used for dose rate constancy checks, and a calibrated Lufft OPUS 20 was used to monitor temperature and pressure. Images of post-irradiation films were acquired prior to net optical density readouts and normalised lateral beam profile plots. Two-dimensional gamma index evaluations of the results were made against Monte Carlo simulations of three source diameters.

Results and Discussion: Film calibration curves showed that GafChromic RTQA2-10101 film had a low dose response than GafChromic EBT2 film. Normalised lateral beam profiles generated from film measurements and Monte Carlo simulations output data revealed that step and shoot technology can be executed in cobalt-60 teletherapy by symmetric and asymmetric segmented secondary collimator jaw motion or by using a three-dimensional physical compensator. Gamma passing rates were highest between physical measurements and Monte Carlo simulations of a 1.5 cm diameter source when using 3 mm, 3 % and 5 mm, 5 % criteria. Furthermore, radiochromic film can be a viable tool for dose verification and quality assurance measurements in resultant beam fluence maps.

Conclusions and Future Recommendations: Sharply defined beam intensities can be achieved in cobalt-60 teletherapy by a shift to small source diameters, as revealed by the results of Monte Carlo simulations for the smallest source diameter. Effort is needed to extend this study to the use of multileaf collimation for more complex beam intensity.

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Hybrid potential analysis of alpha cluster structure above doubly-closed shell

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Phenomenological interactions have been successful in the description of the alpha cluster structure of light nuclei. The interactions however lack the required fundamental Nucleon-Nucleon character. This shortcoming is addressed by exploiting the known surface localization of the cluster that is well described by microscopic interactions. The ground-state band properties of 94Mo and 136Te

were investigated using a Saxon-Woods type local interaction with parameters obtained from the microscopic double-folding potential. The hybrid interaction is supplemented with a short range interaction to correct the observed underbinding of the ground state resulting from possibly the core-cluster overlap. The energy spectra, reduced intra band transition rates, decay width and the root- mean-square charge radii were satisfactorily reproduced

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To Be Confirmed

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Acceleratore Centre for Exotic Isotopes

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The iThemba Laboratory for Accelerator Based Sciences is based around a K=200 Separated Sector Cyclotron (SSC) which is used for radionuclide production and for research in nuclear physics and radiobiology. It plans to build the "South African Isotope Facility", comprising two phases; the first is the Accelerator Centre for Exotic Isotopes (ACE Isotopes) and the second is the Accelerator Centre for Exotic Beams (ACE Beams). Here we focus an ACE Isotopes, for which initial funding has been approved.
Radionuclides are currently produced with the SSC for local and export markets, with only longer lived isotopes available for export. iThemba LABS presently supplies 20% of the worlds 82Sr, 40% of the worlds 68Ge/68Ga generator and all of its 22Na. Ace Isotopes will see the acquisition of a new cyclotron dedicated to the production of radionuclides for medicine. The accelerator will be a negative-ion machine, capable of accelerating protons to 70 MeV and delivering currents of up to 700μA. Isotope production will increase by more than a factor of two with the commissioning of the new cyclotron.
The high-current cyclotron will take radionuclide production away from the SSC, freeing it up for an increased tempo of research. iThemba LABS plans to build a "Low Energy Radioactive-Ion Beam" (LERIB) facility based on the Isotope Separation OnLIne (ISOL) method. The SSC will be used as the driver accelerator to deliver a proton beam to various carbide production targets. Because the "flat-topping" implemented on the SSC is optimized to supply currents of up 350μA of 66 MeV protons, this energy will be used on production targets – a uranium-carbide target has been designed to produce up to 2×10^{13} fission/s using a 66 MeV proton beam of 150 μA intensity. The "front-end", housing the target/ion-source will be a copy of the front-end developed for the SPES project, which is itself derived from the ISOLDE front-end. LERIB will supply low-energy (60 keV) RIBs for research, which includes the study of the □-decay of exotic isotopes, the use of radioactive ions as probes to study the properties of materials and as a way extract radionuclides of interest for therapy and diagnostics.
The next phase, ACE Beams, will see the RIBs post-accelerated to energies of at least 5 MeV/A.

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ANNUAL EFFECTIVE DOSE AND EXCESS LIFE CANCER RISKS FROM COMMONLY CONSUMED VEGETABLES CULTIVATED THROUGH SURFACE WATER IRRIGATION IN LAGOS METROPOLIS

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The specific activities of 226Ra, 232Th and 40K in some commonly consumed leafy vegetables cultivated through surface water irrigation in Lagos metropolis were determined using High Purity Germanium (HPGe) detector. To assess the radiation hazards associated with the consumption of these vegetables, annual effective dose (AED) and excess lifetime cancer risk (ELCR) were also determined. The specific activities of 226Ra, 232Th and 40K in the investigated samples ranged from 0.49±044 to 6.00±1.19 Bq/kg, with an average value of 2.08±0.59 Bq/ for 226Ra, from 0.10±0.07 to 0.61±0.12 Bq/kg with an average value of 0.85±0.08 Bq/kg for 232Th and from 28.69±3.09 to 126.71±5.86 Bq/kg with an average value of 72.56±5.36 Bq/kg for 40K. The mean activities of 226Ra and 232Th were 40 and 56 times higher than the (World Health Organisation (WHO) reference values for 226Ra and 232Th in leafy vegetables respectively. The AED estimated from the consumption of vegetables was 0.048 mSv/y, which is about 16 % of the reference AED value for radionuclides of natural origin in the total diet while leafy vegetable represents about 8 % of the total diet of an adult in Lagos. The ELCR obtained from this study was 0.17 ×⊠10⊠^(-3) this is lower than the world's average value. This study has found elevated concentrations of 226Ra and 232Th in leafy vegetables, and noticeable increase in AED associated with 226Ra exposure in the consumption of leafy vegetables cultivated in Lagos. There are therefore potential radiological health risks to the health of the public from long-term consumption of leafy vegetables cultivated through surface water irrigation in Lagos, Nigeria.

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ESTIMATION OF RADIATION DOSE PARAMETERS AND RADIOLOGICAL HAZARD INDICES DUE TO A LIMESTONE MINING COMPANY AROUND IN SAGAMU, OGUN STATE, NIGERIA

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This work investigated the radioactivity due to some selected radionuclides in the vegetation, soils and waters in an urban settlement around a cement producing factory. Samples of the vegetation, soils and waters of were collected from different locations close the factory and there treated for HPGe gamma spectroscopy to detect and measured the activity concentration of the radionuclides present in the different samples. The gamma absorbed dose rate and annual effective dose equivalent were calculated so as to estimate the hazard index of the primordial radionuclides. The mean absorbed dose and effective dose is 51.61 nGyh^(-1) and 0.237 mSv respectively. The excess lifetime cancer risk was calculated as 0.772. The mean annual effective dose estimated for infants, children and adult citizens that ingest river water sampled were 0.23,0.63×⊠10⊠^(-3) and 0.90×⊠10⊠^(-3) mSv y^(-1) respectively. The values of annual effective dose for infants, children and adults were within the reference levels of 0.26,0.20 and 0.10 mSv y^(-1) respectively. The estimated fatal cancer risk to adult citizens and the lifetime hereditary effects was estimated for an adult. The radiological hazard indices such as absorbed dose rate, hazard indices (H_(ex) and H_in), gamma index, alpha index, annual gonads dose were calculated and found to be below the internationally recommended values. But the annual outdoor and indoor effective dose equivalent (AEDE) which are 2.44 and 9.79 mSvy^(-1) respectively were above the recommended limit of 1mSvy^(-1). The excess lifetime Cancer Risk (⊠ELCR⊠_out) was above the world average value of 0.29 × ⊠10⊠^(-3) as recommended by UNSCEAR.