

# **Advanced Nuclear Science and Technology Techniques Workshop (ANSTT 6)**

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NRF-iThemba LABS, Old Faure Road, Cape Town

## **Book of Abstracts**



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## Nuclear Structure Studies / 3

### Electric monopole (E0) studies at iThemba LABS

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Electric monopole (E0) transition studies focus on nuclear transitions between states of the same spin and parity (typically  $0^+ \rightarrow 0^+$ ), which are critical for probing nuclear structure, shape coexistence, and deformation. The E0 strengths ( $\rho^2(E0)$ ) are key parameters to understanding nuclear shape mixing and isomerism in various nuclei, including light, odd-A, and shape-coexistence in nuclei.

Because single-photon emission is forbidden, these transitions are measured via internal conversion electrons (ICE) or electron-positron pair formation (IPF), serving as a sensitive indicator of changes in the mean-squared charge radius.

As such, high-precision electron spectrometers (e.g., Si(Li) detectors) and detector arrays consisting of HPGe and LaBr3:Ce detectors are used to measure internal conversion coefficients (ICC) to identify E0 components.

iThemba LABS has, in the last 5 to 10 years, been developing spectrometers suited for E0 transition studies. This talk will focus on the in-house refurbishment of the existing solenoid magnetic lens into an electron and internal-pairs spectrometer, the in-beam experiment involving 30 MeV proton beam on a  $^{50}\text{Ti}$  target aimed at investigating the excited  $0_2^+$  state in  $^{50}\text{Ti}$ , as well as future experimental possibilities, for example when this facility will be used in conjunction with other existing spectrometers like the K600.

## Environmental Physics & Applications / 4

### Radiological Health Risk Assessment of Agricultural Soils Around Selected Quarry Sites in Selected States, Nigeria

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Soil samples in the agricultural farmland surrounding selected quarry sites in Ondo and Ekiti states was assessed to measure the concentration of 238U, 232Th, 40K using NaI (TI) detector and estimating radiological parameters in order to determine the possible radiation effects to the farmers and member of the public consuming the farm products. Analysis of the result revealed that the average contents of the measured radioelements were 15.19, 31.92 and 1354.15, 16.55, 38.60 and 1185.44, 24.66, 34.25, 1385.89 and 18.10, 37.66, 1242.67 Bq/kg for Iyin, Ita ogbolu, Aaye and Ikere quarry sites, accordingly. The absorbed dose rate in the soil samples ranges from 64.91 nGy/h in Iyin quarry site to 146.88 nGy/h in Aaye quarry site with the mean value of 86.06 nGy/h for the four study locations. The concentration of 40K, the absorbed dose rate, the indoor and outdoor annual effective dose and the excess lifetime cancer risk were higher than the world limit in the study area, predisposing the member of the public in these locations to hazard of radiation exposure. There is the need for constant monitoring of the quarry sites, provision of radiation protective shield for workers mining at the sites, awareness of radiation risks to the farmers and members of the public around the quarry sites.

## Radiation and Health Physics / 9

## Organ-Specific Dosimetric Assessment of Radon Exposure via Drinking Water in a Selected Population

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This study evaluated organ-specific annual effective doses and excess lifetime cancer risk (ELCR) from radon exposure through 20 groundwater samples in a selected population. The experiment was analysed using Liquid Scintillation Counter (LSC). Radon concentrations ranged from 10.6 to 43.1 Bq/L, with over 90% of samples exceeding the U.S. EPA limit of 11.1 Bq/L, though remaining below the WHO limit of 100 Bq/L. Total annual effective doses ranged from 34.4 to 140.1  $\mu\text{Sv}/\text{year}$ , with the lungs receiving the highest organ-specific dose (up to 13.0  $\mu\text{Sv}/\text{year}$ ), followed by the stomach. Estimated ELCR values ( $1.21 \times 10^{-4}$  to  $4.90 \times 10^{-4}$ ) exceeded the EPA's acceptable threshold of  $1.00 \times 10^{-4}$  in most samples, suggesting a notable radiological health risk. Inhalation was the dominant exposure pathway. These findings underscore the need for regular monitoring, public awareness, and mitigation measures in areas with elevated groundwater radon levels.

Flash Posters / 10

## Computer-Aided Diagnosis of Breast Cancer via Mammography

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**Advanced Nuclear Science and Technology Techniques (ANSTT6) Workshop**

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### Computer-Aided Diagnosis of Breast Cancer via Mammography

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### Abstract

Zambia faces a critical shortage of radiologists and limited mammography infrastructure. This has resulted in significant diagnostic delays and in turn to high mortality rates due to late-stage breast cancer presentation [1]. This study aimed to develop and validate a computer-aided diagnosis (CAD) system utilizing the YOLOv11 deep learning architecture to automate the detection and classification of breast cancer lesions in mammograms [2]. A quantitative research design was employed, using a dataset of 4,060 anonymized mammograms collected from Maina Soko Hospital in Lusaka, Zambia. The model was developed using a progressive training strategy, incorporating curriculum

learning [3] and utilized both manual and model-assisted annotation to identify masses, calcifications, and architectural distortions. The CAD system achieved robust performance results, reaching an accuracy of **71.4%**, precision of **72.2%**, recall of **70.8%**, and an F1-score of **71.1%**. While the progressive training strategy successfully improved detection of underrepresented lesions like architectural distortions, the model faced challenges with small lesions and false positive results. These findings demonstrate that deep learning-based CAD systems can enhance radiological workflows in resource-limited environments through fast, automated screening.

**Keywords:** Breast Cancer, YOLOv11, Computer-Aided Diagnosis (CAD), Mammography, Zambia.

**Category:** Radiation and Health Physics

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3. Y. Bengio, J. Louradour, R. Collobert, and J. Weston, "Curriculum learning," in *Proc. of the 26th Annual Int. Conf. on Machine Learning*, pp. 41–48, 2009.

## Radiation and Health Physics / 11

### Estimation of Annual Effective Dose and Excess Lifetime Cancer Risk from Background Ionizing Radiation at Udege Mbeki Abandoned Excavated Mining Site, Nasarawa State, Nigeria

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This study evaluates the radiological health implications of human exposure to background ionising radiation (BIR) at the mining site, with particular emphasis on the Annual Effective Dose Equivalent (AEDE) and Excess Lifetime Cancer Risk (ELCR). Soil samples were collected from four distinct zones; dumps, farmland, surface soil and the processing site, and analyzed using a gamma-ray spectrometer to determine the activity concentrations of naturally occurring radionuclides <sup>40</sup>K, <sup>226</sup>Ra, and <sup>232</sup>Th. Radiological hazard indices, including absorbed dose rate, AEDE, and ELCR were subsequently computed. At the processing site, mean activity concentrations of <sup>40</sup>K, <sup>226</sup>Ra, and <sup>232</sup>Th were 218.58 Bq kg<sup>-1</sup>, 114.35 Bq kg<sup>-1</sup>, and 420.06 Bq kg<sup>-1</sup>, respectively. These elevated radionuclide levels resulted in a mean absorbed dose rate of 315.66 ± 9.72 nGy h<sup>-1</sup>, corresponding to a mean AEDE of 161.30 ± 4.97 mSv y<sup>-1</sup> and a mean ELCR of 564.56 × 10<sup>-3</sup>. The highest values were recorded at sample point P7, with AEDE and ELCR reaching 387.03 mSv y<sup>-1</sup> and 1354.59 × 10<sup>-3</sup>, respectively. In the dumps, mean AEDE and ELCR were 148.81 ± 4.49 mSv y<sup>-1</sup> and 520.83 × 10<sup>-3</sup>, respectively, while farmland soils showed comparatively lower values with mean AEDE of 67.12 ± 2.67 mSv y<sup>-1</sup> and ELCR of 234.92 × 10<sup>-3</sup>. Surface soils exhibited intermediate radiological characteristics, with mean AEDE and ELCR of 121.49 ± 3.48 mSv y<sup>-1</sup> and 425.22 × 10<sup>-3</sup>, respectively. Overall, the estimated AEDE and ELCR values across the studied locations exceeded internationally recommended safety limits for public exposure, indicating significant radiological risk, particularly within the processing and dump sites. The elevated ELCR values suggest an increased probability of cancer development over a lifetime of exposure. These findings underscore the need for continuous environmental monitoring, restriction of prolonged human activities within high-exposure zones of the mined area to mitigate long-term

health risks and enforcement of land reclamation agreement to restore excavated mining sites into usable land for agriculture or residential purposes.

#### Radiation and Health Physics / 14

### Estimation of radiation exposure to family members of patients treated with I-131 in Tanzania

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#### Abstract

Radiation therapy using Iodine-131 (I-131) is a widely employed treatment for thyroid disorders; however, it poses potential radiation exposure risks to patient caregivers due to gamma emissions from treated patients. This study estimates the radiation doses received by family members of patients undergoing I-131 therapy in Tanzania, where cultural practices and living conditions complicate adherence to international safety guidelines. Using the Particle and Heavy Ions Transport-code System (PHITS), exposure scenarios during hospitalization and post-discharge phases were modelled, accounting for proximity, activity levels, and caregiver-patient interactions. These models were utilized to estimate the radiation exposure to family members of patients treated with I-131 in Tanzania. Results indicate that family members assisting dependent patients during hospitalization received doses of 1.53, 2.33, and 2.99 mSv for 3700, 5550, and 7400 MBq, respectively. These doses are below the 5 mSv/episode limit but exceed the 1 mSv/year public dose limit. Post-hospitalization, the doses decreased significantly, with the highest exposure caused by close-contact activities. Meanwhile, transportation scenarios showed the exposure to be less than 1 mSv/year for short durations. Nevertheless, strict adherence to maintaining a one-meter distance and minimizing the duration of close contact is emphasized. These findings provide critical insights for maintaining public health while ensuring effective thyroid cancer treatment.

**Keywords:** Caregiver safety, family members, Iodine-131 therapy, PHITS simulation, radiation exposure, Tanzania, thyroid cancer.

#### Nuclear Energy, Safety, and Security / 15

### Quantitative Determination of Uranium in a Certified Uranium Ore Concentrate Reference Material Using ICP-MS

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Accurate determination of uranium concentration in uranium ore concentrates is essential for nuclear safeguards, material accountability, and nuclear forensic investigations. Reliable analytical techniques supported by certified reference materials are therefore required to ensure measurement accuracy and traceability. Inductively Coupled Plasma Mass Spectrometry (ICP-MS) is widely used for quantitative determination of uranium due to its high sensitivity, low detection limits, and capability for multi-element analysis. In this study, the uranium content of a Canadian Certified Reference Material (CRM) uranium ore concentrate was quantitatively determined using ICP-MS following acid digestion and dilution procedures. The solid CRM sample was digested using nitric acids

under controlled laboratory conditions to ensure complete dissolution of the sample matrix. The resulting solution was analysed using a NexION 2000 ICP-MS, and the measured uranium concentration was converted into weight percent uranium through appropriate dilution and mass balance calculations.

The analytical results indicated a uranium concentration of approximately 76.55 wt.% U, corresponding to 90.27 wt.%  $U_3O_8$  equivalent, which is consistent with the expected composition range for high-grade uranium ore concentrates. The use of a certified reference material provided confidence in the accuracy and reliability of the analytical methodology. These findings demonstrate the effectiveness of ICP-MS for quantitative uranium analysis in uranium ore concentrates and highlight the importance of validated analytical techniques for nuclear safeguards, nuclear forensics, and material verification. The development and application of such analytical capabilities contribute to strengthening nuclear security frameworks and support ongoing efforts to establish nuclear forensic databases and analytical capacity within Africa.

## Environmental Measurements / 18

### Investigating radiological risk due to solid-phase 'black powder' from the Secunda Gas Pipeline

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The extraction and transport of natural gas leads to the accumulation of black powder, a hazardous byproduct composed of corrosion species, microorganisms and Naturally Occurring Radioactive Materials (NORM) within gas pipelines. These NORM contaminants tend to concentrate within dust filters and during periodic 'pigging' operations, posing a potential radiological threat to workers and the environment. The study evaluated the radiological assessment of black powder collected at the Secunda gas pipeline by determining the activity concentrations of naturally occurring radionuclides  $^{226}\text{Ra}$ ,  $^{232}\text{Th}$  and  $^{40}\text{K}$  using gamma spectrometry. Results show that the average activity concentrations for black powder obtained from pigging operations were  $2.53 \pm 0.18$  (range: 1.87 - 2.94),  $4.23 \pm 0.32$  (range: 2.78 - 5.00) and  $27.17 \pm 1.75$  (range: 23.59 - 29.76) Bq/kg for  $^{226}\text{Ra}$ ,  $^{232}\text{Th}$  and  $^{40}\text{K}$  respectively. Similarly, the average activity concentrations for black powder obtained from dust filters during normal operations resulted in  $1.82 \pm 0.21$  (range: 1.34 - 2.24),  $1.67 \pm 0.26$  (range: 1.27 - 2.21),  $25.98 \pm 1.73$  (range: 18.36 - 2.71) Bq/kg for  $^{226}\text{Ra}$ ,  $^{232}\text{Th}$  and  $^{40}\text{K}$  respectively. Radiological hazard indices were also determined by calculating the Raeq, D, Hex, Hin, AEDE and ELCR. Average values for these indices for black powder samples from pigging operations were 10.68 Bq/kg, 4.86 nGy/h,  $0.03, 0.04, 5.96 \times 10^{-3}$  mSv/yr and  $2.0 \times 10^{-5}$  respectively. For black powder samples from dust filters, the corresponding average values were 5.13 Bq/kg, 2.47 nGy/h, 0.01, 0.02,  $3.03 \times 10^{-3}$  mSv/yr and  $1.06 \times 10^{-5}$ , respectively. All calculated radiological hazard indices were significantly below the recommended regulatory safety limits, indicating negligible radiological risks to maintenance workers during pigging and filter replacement operations.

## Cosmic Ray and Muon Physics and Applications / 20

### Estimation of the composition of the primary cosmic ray particles by measurements of the cosmic ray muon component

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The primary cosmic ray particles constitute 85% protons, 12% helium, 3% iron, and heavier elements. They interact with the Earth's atmosphere, producing secondary particles known as Extensive Air Showers (EAS). Among the particles produced in EAS are pions and kaons, which subsequently decay into muons. Cosmic ray muons form the main part of cosmic ray particles that reach on the earth's surface. The lateral distribution of cosmic ray muon coincidences is often used to model and understand the development of the EAS in the earth's atmosphere. In this work, the lateral distribution of cosmic ray muons was investigated using two-fold coincidences. Four detectors were positioned at two-fold coincidence separated at regular intervals. The coincidence rate was between these detector stations was measured. The measured data was compared with Monte Carlo (MC) simulations of EAS. The EPOS and GHEISHA models were used for high and low-energy particle interactions respectively. The analyses indicate the following composition of primary cosmic ray: protons (81±0.01) %, helium (10±0.04) %, and iron and heavier elements (9±5.88) %. The knowledge gained from the lateral distribution of cosmic ray muons is essential for the understanding of the interaction of cosmic ray particles and the development of extensive air showers. Furthermore, this information enhances our understanding of the chemical composition of primary cosmic ray particles.

**Flash Posters / 21**

## **Comparison of tangential-intensity modulated radiotherapy (t-IMRT) and volumetric modulated arc therapy (VMAT) for different sizes of left breast cancer**

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**Background:** Radiotherapy is an essential part of the management of left-sided breast cancer, and this requires an optimal balance in target volume coverage and organs at risk, such as the ipsilateral lung and the heart. Advanced techniques such as tangential-intensity modulated radiotherapy (t-IMRT) and volumetric modulated arc therapy (VMAT) are commonly used. However, the dosimetric performance of t-IMRT and VMAT for varying breast sizes has been poorly characterized.

**Aim:** To compare the effectiveness of tangential-IMRT and VMAT for hypo-fractionated left-sided breast cancers across small, medium, and large breast sizes.

**Materials & Methods:** A total of 30 CT datasets from female patients with left-sided breast cancer, acquired between 2020 and 2025, were analyzed. Patients were divided into groups based on breast volume, with a mean volume of 781.00 cc. For each patient, two treatment plans were designed using the Monaco treatment planning system, which uses the Monte Carlo method. A dose of 26 Gy in 5 fractions was prescribed according to the FAST-Forward hypo-fractionated protocol. Evaluation of the dosimetric parameters included the Planning Target Volume (PTV) coverage indices D2%, D5%, D95%, Homogeneity Index (HI), Conformity Index (CI), and doses to the heart (V7 and V1.5 Gy), as well as the ipsilateral lung volume receiving V8 Gy. A two-way ANOVA was performed, with a significance ( $p < 0.05$ ).

**Results:** VMAT showed superior target coverage, conformity, and dose homogeneity compared to t-IMRT across all breast sizes ( $p < 0.05$ ). PTV D95% coverage with the VMAT plans was 99.8%, 98.3%, and 97.0% for small, medium, and large breasts, respectively, whereas the t-IMRT plans failed to achieve the required coverage of  $\geq 95\%$  and resulted in 89.2-90.0% coverage across all the breast sizes. Also, the homogeneity and conformity indices were improved with the VMAT plan. Both plans satisfied the PTV hotspot constraints of  $D2\% < 107\%$  and  $D5\% < 105\%$ . Although the t-IMRT plans resulted in lower hotspot doses for small and medium breasts, the VMAT plans resulted in slightly better hotspot dose control for large breasts. However, the differences were not clinically significant, as they were within 1%. However, the t-IMRT plans resulted in superior OAR sparing, with lower ipsilateral lung V8 Gy and lower high-dose cardiac exposure (Heart V1.5 Gy: 0.9 - 1.1 Gy), compared to the VMAT plans, which resulted in higher high-dose cardiac exposure (2.9 - 3.3 Gy), exceeding

the tolerance limit, though the VMAT plans resulted in lower low-dose cardiac exposure (Heart V7 Gy).

Conclusion: VMAT provided superior target coverage, conformity, and homogeneity across all breasts compared to t-IMRT, achieving the required PTV D95%  $\geq$  95% in all cases. Both techniques were able to meet the PTV hotspot requirements, with slightly improved control for larger breasts with VMAT, while this may not have a clinically significant impact. However, t-IMRT showed superior sparing of OARs, particularly the ipsilateral lung and high-dose cardiac areas. In contrast, VMAT showed increased dose to high-dose cardiac areas and decreased dose to low-dose cardiac areas.

Keywords: VMAT, Tangential-IMRT, Left-sided Breast radiotherapy, Breast sizes, UK FSAT-Forward protocol.

## Cosmic Ray and Muon Physics and Applications / 22

### Cosmic rays – origin, composition, interactions and applications

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This presentation highlights the origin of cosmic radiation, their interactions in the earth's atmosphere, their measurements and their applications. The work by Theodore Wulf and Victor Hess showed increased rates ionization with height above the ground. This observation led to the conclusion that the source of ionization is not from the earth but from space. That marked the discovery of cosmic radiation. Over the years, there has been extensive research work carried out in order to understand cosmic radiation. It is now known that the primary cosmic ray particles comprise of about 85% protons, 12% helium, 3% iron and other heavier elements. These primary cosmic ray particles interact with nuclei in the earth's atmosphere to produce secondary particles such as kaons, pions, neutrons. The kaons and pions decay into muons which further decay into electrons. Neutrinos are produced in these decay processes. Experimental data shows that the all-particle cosmic ray energy spectrum follows a simple power law with a spectral index of about 2.7. However, the value of the spectral index changes at cosmic ray energies of about  $10^6$  GeV – known as the “knee” region and  $10^9$  GeV known as the “ankle” region. The bending of the spectrum at the knee region is attributed to the varied energy losses due to the difference in masses of the cosmic ray particles at those energies. Cosmic ray particles with energies beyond  $10^9$  GeV have been observed by several experiments. These are known as Ultra-High-Energy-Cosmic-Ray (UHECR) particles. The UHECR particles are thought to be of extra-galactic origin. These particles lose a large fraction of their energies when they interact with photons from the Cosmic Microwave Background Radiation (CMBR). This leads to a drastic cut-off on the cosmic ray energy spectrum – known as the Greisen-Zatsepin-Kuzmin (GZK) cut-off. The earth's magnetic field acts as a shield for charged cosmic ray particles. Exposure to cosmic radiation is therefore not only dependent on the altitude but also on the latitude on the earth surface. The dose due to cosmic radiation is minimum around the equator and increases as one moves away from the equator. On the earth surface, cosmic radiation comprises mostly of cosmic ray muons. These cosmic ray muons are useful in imaging large structures like volcanos and pyramids on the earth. They are also useful in security applications and in the nuclear industry. In the field of agricultural science, the flux of cosmic ray neutrons on the earth surface provides a reliable and efficient means of monitoring the moisture content of the soil. The knowledge of cosmic radiation in our earth's atmosphere and on the earth has applications in diverse fields of science and technology in support of our development goals at the national, regional and global levels.

## Flash Posters / 23

### Categorization and characterization of uranium-bearing materi-

## als for nuclear forensic attribution using ICP-MS

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The increasing risk of illicit trafficking and misuse of nuclear and radioactive materials has highlighted the importance of nuclear forensics in supporting radiological crime scene investigations and nuclear security. This study focuses on the categorization and characterization of uranium-bearing materials to support nuclear forensic attribution and investigative processes. Uranium materials originating from different stages of the nuclear fuel cycle were analyzed using advanced analytical techniques to determine their physical, chemical and isotopic signatures. Samples including Uranium ore and triuranium octoxide were prepared through crushing, pulverization and microwave digestion prior to analysis. Elemental and isotopic measurements were performed using Inductively Coupled Plasma Mass Spectrometry. These techniques enabled the determination of trace elements concentrations, rare-earth elements (REE) patterns, uranium isotopic ratios and lead isotopic ratios that serve as distinctive nuclear forensic signatures.

The results demonstrate that uranium-bearing materials possess measurable elemental and isotopic characteristics that can be used to distinguish materials originating from different geological sources and processing stages. Rare-earth element distributions, uranium and lead isotopic compositions provided valuable geochemical fingerprints that support source attribution. Overall, the study highlights the importance of combining elemental and isotopic analysis for reliable categorization and characterization of uranium-bearing materials. These signatures provide critical information for nuclear forensic investigations and may contribute to the development of a national nuclear forensic library to assist law enforcement and regulatory authorities in identifying the origin and history of intercepted nuclear materials.

**Environmental Measurements / 24**

## Why the Need for Environmental Measurement?

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Environmental measurement is essential for evaluating environmental quality, detecting contamination, and protecting human health. Increasing industrial, agricultural, and urban activities have led to the release of chemical and radiological pollutants into environmental systems. Accurate measurement of these parameters is therefore critical for monitoring environmental media such as air, water, and soil. This lecture highlights the importance of environmental measurement in pollution detection, environmental risk assessment, and regulatory compliance. Particular emphasis is placed on environmental radioactivity monitoring and the application of radiation detection techniques in assessing naturally occurring and anthropogenic radionuclides. Strengthening environmental monitoring capacity remains vital for effective environmental management and sustainable development.

**Radiation and Health Physics / 25**

## Monte Carlo-Based Optimization of Occupational Radiation Protection in a Diagnostic Radiology Facility at Kitui County Level

## V Hospital, Kenya

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Accurate occupational dose estimation is essential for optimizing radiation safety and ensuring compliance with regulatory guidelines. The spatial distribution of scatter radiation in the radiography room was characterized using Monte Carlo simulations based on Geant4. A diagnostic X-ray system was accurately modeled and validated using experimental measurements to evaluate the magnitude and distribution of scattered radiation. Simulated and measured dose rates showed good agreement within  $\pm 10\%$ , with a root mean square error of  $0.08 \mu\text{Sv h}^{-1}$ , indicating strong model reliability. Scatter dose exhibited a general decrease with distance from the source, approximately following the Inverse Square Law, although deviations were observed due to distributed scatter sources and attenuation in air. The scatter dose decreased from  $1.51 \mu\text{Sv h}^{-1}$  at 0.25 m to  $0.36 \mu\text{Sv h}^{-1}$  at 2.0 m from the source, representing approximately a 76% reduction. Increasing the field size from  $10 \times 10 \text{ cm}^2$  to  $20 \times 20 \text{ cm}^2$  and  $30 \times 30 \text{ cm}^2$  significantly increased scatter dose even at far-field positions. The combined use of lead protective clothing and 0.5 mm mobile lead shielding reduced scatter dose by approximately 90–96%. Overall, the estimated occupational dose levels were within internationally recommended limits. The observed distribution and variability of scatter radiation highlight the importance of continuous radiation protection optimization. The study therefore recommends routine indoor radiation monitoring, particularly for staff working in radiology departments. Strict implementation of the ALARA principle through appropriate positioning and effective shielding using lead aprons is strongly recommended.

**Keywords:** Occupational dose, Monte Carlo simulation, X-ray dosimetry, Scatter Dose, radiation safety.

### Nuclear Experimental Techniques & Data Analysis / 26

## Measurement of angular correlations in gamma-gamma cascades using coincidence detection and Monte Carlo simulation

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Coincidence counting techniques are widely used to determine correlated  $\gamma$ -ray emissions from nuclear decays. Measured singles and coincidence rates share common factors - i.e. absolute efficiency - that can be divided out in analysis. However, standard formulations often assume perfect isotropic correlation between emitted quanta, neglecting possible decay chain losses, and ignore angular correlations. In this work, we use coincidence-based absolute activity measurements to show that the angular correlation function,  $W(\theta)$ , modulates the detection probability of cascade pairs. Using  $^{60}\text{Co}$  and  $^{22}\text{Na}$  as benchmark sources with differing cascade and correlation properties, we demonstrate that the true coincidence rate reflects detector efficiencies and angular correlations, which can be extracted from the observed measurands.

A custom FLUKA Monte Carlo source routine was developed to implement angular distributions in  $\gamma$  -  $\gamma$  correlations to support these observations. A Python proof-of-concept generated the normalised cumulative distribution functions of  $W(\theta)$ , which were incorporated into FLUKA for multi-detector simulations. The Monte Carlo results successfully reproduce the experimentally observed angular modulation, confirming that coincidence counting combined with a tailored simulation framework can probe angular correlations.

Our approach forms the groundwork for future studies of more complex decay schemes with non-trivial cascade probabilities and for developing multi-detector techniques for angular-correlation metrology.

**Environmental Physics & Applications / 27****Portable African Neutron-Gamma Laboratory for Innovative Nuclear Science****Authors:** Pete Jones<sup>1</sup>; Shanyn Hart<sup>1</sup>; Glen Taylor<sup>2</sup>; Christo van Tubbergh<sup>3</sup>; Ahmen Vanker<sup>2</sup><sup>1</sup> *iThemba LABS*<sup>2</sup> *SARAO*<sup>3</sup> *iThemba Labs***Corresponding Author:** pete@tlabs.ac.za

The Portable African Neutron-Gamma Laboratory for Innovative Nuclear Science (PANGoLINS) [1] project aims to investigate measurements of both gamma rays and neutrons which forms an important component part on site or in transit and the detection of both fissile material for the use in decarbonised energy sources or disposal thereof. A core component of the project is to miniaturize the weight of the gamma ray detection device and associated infrastructure so that it can be loaded on an unmanned aerial vehicle to enable access to and enhance performance of radiation monitoring measurements at remote sites leading to autonomous operations.

PANGoLINS incorporates commercial detector assemblies of LaBr<sub>3</sub>(Ce), SrI<sub>2</sub>(Eu) and/or CLYC(Ce) for spectroscopy. In addition, the project encompasses the instrumentation of other scintillation detectors with silicon photomultiplier technologies. The coupling of these to readout devices such as high-density ADC readout are planned for applications for nuclear science, medical imaging [2] or astronomy.

An overview of the project, its progress and potential outcomes will be presented.

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**Cosmic Ray and Muon Physics and Applications / 28****Compact scintillator-based neutron spectrometers for use in aviation and space applications****Authors:** Miles Kidson<sup>1</sup>; Andy Buffler<sup>2</sup>; Tanya Hutton<sup>1</sup>; Francois Trompier<sup>3</sup><sup>1</sup> *University of Cape Town*<sup>2</sup> *UCT*<sup>3</sup> *ASNR***Corresponding Author:** kdsmil001@myuct.ac.za

Cosmic radiation, composed of Galactic Cosmic Rays (GCRs), Solar Energetic Particles (SEPs), and their associated secondary particles, represents a recognized radiation risk to space missions, satellites, and air travel. To improve risk assessment models in these contexts, it is essential to measure the various components of the radiation environment at the specific location of interest, particularly during unexpected high-energy space weather events. Secondary neutrons, with characteristic spectral features around 1 MeV and 100 MeV, are produced by cosmic ray interactions with matter and contribute substantially to overall radiation exposure at flight altitudes and in space. Neutrons pose a particular hazard to biological tissue because they interact directly with atomic nuclei, producing

energetic, densely ionizing recoil particles that induce DNA damage. Continuous monitoring of radiation environments aboard aircraft and spacecraft using active radiation detectors would provide key data for improved risk assessment.

Current neutron spectrometry technologies, such as Bonner sphere systems or liquid organic scintillators coupled to photomultiplier tubes, are not well suited for use outside the laboratory. This work aims to develop a compact detector system based on plastic scintillators and silicon photomultipliers that is robust, portable, and suitable for non-expert use. A prototype spectrometer has been constructed for operation in high-energy neutron fields. Accurate spectrometry using unfolding techniques relies on well-characterized detector response functions covering the full energy range of interest. The high-energy neutron facility at iThemba LABS in Cape Town, South Africa, provides a unique opportunity to directly measure detector response functions up to 200 MeV.

We present progress toward the development of a novel detector system for high-energy neutron spectrometry in aviation and space environments, as well as in accelerator facilities such as proton therapy centres. Detector design, calibration methodology, and planned field testing are discussed.

## Environmental Measurements / 29

### Measurement of Azimuthal Bremsstrahlung Photon Emission from a 28-GHz ECR Ion Source Using NaI(Tl) Detectors

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The emission of high-energy bremsstrahlung photons beyond the expected critical energy during electron cyclotron resonance (ECR) heating has attracted significant attention, and its underlying mechanism remains not fully understood. In this study, we measured the azimuthal angular distribution of bremsstrahlung photons produced in a 28 GHz ECR ion source at the Busan Center of the Korea Basic Science Institute (KBSI). Three round-type NaI(Tl) scintillation detectors were used to simultaneously measure bremsstrahlung photons emitted radially from the plasma chamber. An additional NaI(Tl) detector was positioned downstream of the ECR ion source to monitor the overall photon intensity. The ion source was operated at an RF power of 1 kW to extract an 16O ion beam, with dominant charge states of O<sup>3+</sup> and O<sup>4+</sup>. Bremsstrahlung photon energy spectra were recorded at nine azimuthal angles on the extraction side of the ion source. To evaluate possible systematic uncertainties arising from differences among the three detectors, measurements were repeated by alternating the detector positions. Geant4 Monte Carlo simulations were performed to account for geometrical acceptance and energy-dependent detection efficiency caused by non-uniformities in the material budget. The true bremsstrahlung spectra were then reconstructed using an inverse-matrix unfolding method. The extracted end-point energies of the bremsstrahlung spectra were  $(2.040 \pm 0.045)$  MeV at 150°,  $(1.650 \pm 0.040)$  MeV at 330°, and  $(1.610 \pm 0.040)$  MeV at 330° for detectors D1, D2, and D3, respectively. These values exceed the maximum electron kinetic energy of approximately 1.330 MeV expected from standard ECRIS operating parameters. The higher end-point energy observed near 150° appears to correlate with the structural configuration of the ion source and the the shape of the ECR plasma. However, the secondary maximum near 330°, located roughly 180° opposite to 150° which is among the maximum angles, cannot be explained solely by the shape of the ECR plasma. We interpret these observations as evidence of unconfined high-energy electrons reaching the chamber wall and producing bremsstrahlung radiation. These escaping electrons likely arise from imperfect magnetic confinement within the ECR plasma. The results provide new insight into the mechanisms of high-energy bremsstrahlung production in ECR ion sources and suggest that improved magnetic confinement design could reduce electron losses and associated high-energy photon emission.

## Activation of p53 pathway in combination with photon irradiation for treatment of cancer

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Medulloblastoma (MB) and glioblastoma (GB) are highly aggressive brain tumours that exhibit substantial resistance to radiotherapy, largely due to impaired DNA damage repair mechanisms. The cellular response to radiation-induced DNA double-strand breaks (DSBs) is a critical determinant of radiosensitivity. This study investigated the effects of the MDM2 inhibitor AMG232 in combination with photon irradiation on DNA damage signalling in MB and GB cell lines using  $\gamma$ H2AX foci analysis. Photon irradiation induced a clear dose-dependent increase in  $\gamma$ H2AX foci across all cell lines, confirming effective DSB formation. Treatment with AMG232 resulted in prolonged persistence of  $\gamma$ H2AX foci, particularly in MB cell lines, indicating delayed or compromised DNA repair. Residual foci detected at later time points suggest increased reliance on error-prone repair pathways, notably non-homologous end joining (NHEJ), especially in G0/G1-arrested cells. In contrast, GB cell lines exhibited sustained  $\gamma$ H2AX foci levels irrespective of AMG232 treatment, consistent with intrinsic radioresistance. These findings demonstrate that AMG232 enhances radiosensitivity primarily by extending DNA damage signalling rather than increasing initial DNA damage, highlighting impaired repair kinetics as a key mechanism influencing treatment response in aggressive brain tumours.

**Environmental Physics & Applications / 32**

## Development and Optimisation of a Two-Stage SiPM-Based Compton Camera

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This work investigates the development of a two-stage Compton camera for environmental radiation monitoring, with a focus on energy resolution, detection efficiency, fast timing, and optimal geometrical configuration. While significant advances have been made in radiation imaging technologies, challenges remain in achieving high sensitivity and accurate source localisation in complex environments.

A prototype Compton camera is studied using compact, low-voltage  $14 \times 14 \times 25.4$  mm LaBr<sub>3</sub>:Ce scintillation detectors coupled to SiPM readout, with the aim of leveraging the advantages of modern SiPM technology. These detectors, manufactured by CapeScint (MA, USA), demonstrate excellent energy resolution (3.4% at 662 keV) and fast timing performance. Scatter event tracking is modelled using the TOPAS Monte Carlo toolkit to determine optimal detector geometry and timing characteristics, complemented by experimental measurements with standard gamma-ray sources.

In addition, two Cs<sub>2</sub>LiYCl<sub>6</sub> (CLYC-6) SiPM-readout detectors of the same geometry have been commissioned to exploit their neutron sensitivity. Pulse shape discrimination is used to distinguish neutron and gamma-ray interactions, enabling simultaneous gamma–neutron detection for comprehensive environmental radiation assessment.

The development of this system has the potential to improve radiation source localisation, contamination mapping, and situational awareness in environmental and nuclear safety applications. Its compact design and fast-timing capabilities make it well suited for field deployment in scenarios such as nuclear facility monitoring, waste management, and emergency response. Preliminary results from simulation and experimental studies will be presented.

## Nuclear Structure Studies / 34

### New High-spin states in W-182

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This work presents a detailed investigation of high-spin states in <sup>182</sup>W, populated through a deep-inelastic reaction using an 840 MeV <sup>136</sup>Xe beam on a thick <sup>186</sup>W target and studied using coincidence  $\gamma$ -ray spectroscopy. Out-of-beam data were used to extend the known level scheme, confirming the  $K^\pi = 16^+$  rotational band up to the  $19^+$  state and identifying new levels feeding this structure. The study is motivated by the need to understand how nuclear structure evolves at high angular momentum. Several new intrinsic states have been observed up to 6549 keV, including an isomeric state with a lifetime of 148(9) ns. Spin and parity assignments were derived from transition multipolarities using internal conversion coefficients, angular correlation and mixing ratios, with most states firmly characterized, including the 6549 keV state assigned  $K^\pi = 24^-$ .

No new rotational bands were observed, indicating a dominance of intrinsic configurations at high spin. Configuration assignments, supported by multi-quasiparticle calculations, led to the identification of several six-quasiparticle states with transition strengths consistent with neighboring nuclei in the  $A \approx 180$  region. At high  $K$ -values, weak transition intensities limited the full characterization of some states, however, the long lifetime of the  $K^\pi = 24^-$  isomer is suggested to arise from configuration changes rather than  $K$ -forbidden decay, while  $K^\pi = 20^+$  isomer shows behavior consistent with  $K$ -isomerism. Overall, this work provides insight into the increasing dominance of intrinsic structure over collective motion at high-spin in <sup>182</sup>W.

## Environmental Measurements / 35

### Use of Environmental Measurements as a Tool to Understand Factors Influencing Radionuclides Concentrations

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Radon (Rn-222) is a radioactive gas that originates from uranium (U-238) and is ranked as a major source of natural ionising radiation and identified among the leading causes of lung cancer. It is therefore essential for its occurrence and concentration levels present in the environment to be well

understood, quantified and assessed. This study characterised indoor radon levels regionally in the gold mining sites of Gauteng Province and coal mining sites in the Mpumalanga Province using the solid-state nuclear track detectors, which were deployed predominantly during summer and winter months. Moreover, radon parent nuclides were determined in mine tailing residues, soils, rocks and water to help in the understanding of the primary sources and controls of radon.

The study aimed to evaluate the extent to which the local conditions such as the underlying lithology, content of the parent radioisotopes in primary sources, mining activities, seasonal variations and building characteristics affect indoor radon. It was found that the gold tailings residues and coal related operations have no drastic effect on indoor radon concentrations measured in the dwellings studied, other than at a localized location where contamination resulting from tailings materials was observed. The major contributing factors were the uranium content in geological formations and soil, which depicted a positive correlation with indoor radon concentrations at  $R^2 = 0.7827$  for rocks and  $R^2 = 0.5302$  for soil. The uranium content in the ground surface was proven to be a good first indicator of indoor radon. Contributions from water to indoor radon were found to be negligible. Variations in meteorological conditions with seasons, ventilation rate of the house and the rooms where measurements are conducted, the age of the dwelling and type of building materials were found as additional contributors and controls to indoor radon concentrations.

## Nuclear Experimental Techniques & Data Analysis / 36

### K600 magnetic spectrometer and the NUMEN project

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The NUMEN (NUclear Matrix Elements for Neutrinoless double-beta decay) project aims to obtain the nuclear matrix elements (NME) to be used as inputs in models to determine the lifetime of neutrinoless double-beta ( $0\nu\beta\beta$ ) decay, which is related to the absolute mass of the neutrino [1]. This will be achieved by conducting heavy-ion double charge-exchange (DCE) reactions and measuring the cross sections of these reactions for all isotopes that have been identified to undergo  $0\nu\beta\beta$  decay [1]. The occurrence of the  $0\nu\beta\beta$  decay will imply that the lepton number is violated [2]. It is, therefore, very important to determine the NMEs as they will assist in elucidating Physics beyond the Standard Model [2]. The transition operators of the  $0\nu\beta\beta$  decay and DCE reactions have a similar mathematical structure with a combination of short  $0\nu\beta\beta$  decay range Fermi, Gamow-Teller, and rank-2 tensor components [3]. The weights of such components are different, being controlled by the axial and vector coupling constants in the weak sector and by the energy-dependent isospin, spin-isospin, and tensor coupling strengths for the strong interaction [3]. Therefore, more experimental data are required from a range of incident beam energies for DCE measurements. Additionally, to explore the candidate nuclei of  $0\nu\beta\beta$  decay in a systematic way, more experimental data are required. Previous experiments for the NUMEN project at Istituto Nazionale di Fisica Nucleare - Laboratori Nazionali del Sud (INFN-LNS) have suffered from high signal rate due to the interaction of the target and projectile, which greatly outnumber any potential DCE events. Additionally, the limited energy resolution of the MAGNEX spectrometer for DCE measurements makes it a cumbersome task to decouple transitions of interest relevant to the NUMEN project. Particle- $\gamma$  coincidence measurements are a plausible attempt at a solution for this problem. Thus, a high-resolution magnetic spectrometer like the K600 at the iThemba Laboratory for Accelerator Based Sciences (iThemba LABS), which is already used for coincidence measurements, is a perfect candidate for baseline measurements especially given that the LNS facility is still under upgrade. However, in its current design, the existing K600 detection system is limited in the detection of heavy ions (e.g.  ${}^6\text{Li}$ ,  ${}^{12}\text{C}$ ,  ${}^{18}\text{O}$ ,  ${}^{18}\text{Ne}$ ) at moderate kinetic energies ( $\approx 10\text{-MeV}/u$ ) and light ions at low energies ( $\approx 5\text{-MeV}/u$ ) [4]. The development of a new low-pressure detection system for the K600 is currently underway to expand the

spectrometer research program [4]. Thus, an already existing detection system from the MAGNEX large-acceptance spectrometer at INFN-LNS has been coupled to the K600 to provide a baseline as to how the K600 will operate with a low-pressure detection system. The coupling of the MAGNEX focal-plane detection system with the K600 is also beneficial for other nuclear-structure studies to be conducted with the K600 spectrometer.

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## Environmental Measurements / 37

# An Integrated Baseline Environmental Radioactivity Assessment Across Various Exposure Pathways

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Monitoring natural radionuclides in the environment is important for establishing baseline radioactivity levels that support the evaluation of public exposure. The study presents baseline environmental radioactivity levels measured in collected soil, external gamma, water and indoor radon samples to assess resultant public doses through external, inhalation and ingestion exposure pathways.

The soil media comprised six (6) beach sand samples, seven (7) sediments, and twenty-two (22) surface soils. Water samples included twelve (12) surface water, five (5) seawater, and sixteen (16) groundwater samples, which were analysed for natural radionuclides originating from the Uranium-238, Uranium-235 and Thorium-232 decay series. External gamma radiation measurements were conducted at fifty-three (53) locations, and indoor radon concentrations were measured in fifteen (15) dwellings. The water and soil samples were analysed using calibrated gamma spectrometry and alpha spectrometry. External gamma radiation was measured in situ using a calibrated portable gamma survey meter (RS-230) to determine ambient dose rates. Passive solid-state nuclear track detectors were deployed in dwellings for a period of three (3) months to measure indoor radon (Radon-222) concentrations.

The radioactivity levels measured in soil samples were found to be significantly lower than the reported worldwide average values of 420 Bq/kg for Potassium-40, 32 Bq/kg for Radium-226, and 45 Bq/kg for Thorium-232. The calculated radiological hazard indices, including radium equivalent activity and external hazard index, were also below internationally recommended safety limits. Similarly, radioactivity levels in water samples were below the World Health Organisation’s (WHO) recommended drinking water reference levels, corresponding to an annual committed effective dose of less than 0.1 mSv/year. The measured external gamma dose in the study area due to natural background radiation was below the reference level of 1 mSv/year, which is the public dose limit for planned exposure situations. Indoor radon concentrations were generally below the 100 Bq/m<sup>3</sup> reference level recommended by the World Health Organisation, except for one measurement (117 Bq/m<sup>3</sup>), which was nonetheless below the 300 Bq/m<sup>3</sup> action level recommended by the International

Atomic Energy Agency (IAEA). Further investigations indicated that the elevated level was unlikely to be attributed to underlying geology but may instead be attributed to factors such as building characteristics or ventilation.

The results of this study provide integrated baseline data of environmental radioactivity levels, which are relevant for environmental monitoring and assessment of public exposure. These findings support radiation protection and safety initiatives.

## Nuclear Structure Studies / 38

### Shape coexistence in neutron deficient nuclei

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Across the nuclear chart, many interesting and diverse phenomena arise through the interplay of single-particle motion, nucleon pairing and collectivity. One such phenomenon, known as shape coexistence, is defined as the presence of distinct nuclear shapes within the same nucleus and at similar energy [1]. Significant theoretical and experimental effort is taking place to explore this phenomenon in different mass regions, while it is suggested that it could manifest in most, if not all nuclei [2].

One of the more prominent regions where shape coexistence has been observed, is in neutron-deficient nuclei close to the neutron mid-shell at  $N=104$  and the  $Z=82$  magic number. A broad range of experimental approaches including laser spectroscopy,  $\alpha$ -decay fine structure measurements, in-beam  $\gamma$ -ray and conversion electron spectroscopy, lifetime measurements and Coulomb excitation experiments have been employed to study this phenomenon in detail.

In this presentation, we will explore some of these techniques, focusing primarily on simultaneous in-beam  $\gamma$ -ray and conversion electron spectroscopy [3], that has been instrumental in recent years in the study of shape coexistence in lead nuclei [4-8]. To demonstrate its effectiveness we will discuss some of the latest findings in particular in even-even lead isotopes.

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## Radiation and Health Physics / 39

### Establishment of Local Diagnostic Reference Levels for Adult and Pediatric Patients in Intraoral Radiography at South African Oral Health Care Center

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This work contributes to the Radiation and Health Physics theme through the application of dose quantification and optimization methodologies in intraoral radiography. By establishing locally relevant Diagnostic Reference Levels (DRLs) for both adult and pediatric populations, the study addresses a key gap in South African radiological protection practice. The findings support standardization efforts and provide a framework for future national DRL development and optimization strategies in medical imaging.

## Cosmic Ray and Muon Physics and Applications / 40

### **Extreme Energy Events Project: A National Network of MRPC Muon Telescopes for Cosmic-Ray Physics and Science in Schools**

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The Extreme Energy Events (EEE) Project is an innovative cosmic-ray experiment that combines frontier astroparticle physics with a large-scale educational mission. EEE is built around a network of muon telescopes based on Multigap Resistive Plate Chambers, distributed across Italy and hosted primarily in high schools. One of the defining features of the experiment is the direct involvement of students and teachers in many stages of the scientific process, from detector construction and commissioning to monitoring, data taking, and analysis.

EEE addresses several key topics in cosmic-ray physics, including measurements of the secondary muon flux at ground level, the observation of extensive air showers, and the study of correlations between distant events through synchronized observations over a wide geographical area. The distributed nature of the array, together with centralized reconstruction and analysis, makes EEE an effective observatory for investigating both local and large-scale features of cosmic radiation.

In 2018, the EEE scientific program was further extended through the PolarquEEEst initiative, which introduced compact scintillator-based detectors to perform cosmic-ray measurements at very high geomagnetic latitudes. The first campaign explored the latitude dependence of the secondary cosmic-ray flux up to the Svalbard archipelago, and in 2019 three detectors were installed at Ny-Ålesund (Svabard) enabling long-term monitoring of muons in an extreme environment. This extension broadened the scientific reach of EEE toward high-latitude studies, with potential connections to atmospheric and environmental phenomena, while preserving the project's emphasis on compact instrumentation and distributed measurements.

The talk will provide an overview of the EEE scientific program, the detector and network architecture, and selected physics results, while also discussing the broader impact of the project as a model of research-driven education. EEE demonstrates that a school-based infrastructure can produce meaningful scientific results while at the same time fostering scientific culture, hands-on training, and long-term collaborative communities in experimental physics.

## Environmental Physics & Applications / 41

### **Gamma and radon measurements in the Huguenot tunnel for the PAUL project**

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The PAUL project has made significant progress toward planning and designing an underground laboratory to be constructed during the upgrade of the Huguenot Road Tunnel near Paarl in the Western Cape, South Africa. Measurements of muon-flux suppression in the tunnel—critical to demonstrating reduced cosmic-ray backgrounds—will be presented in a separate contribution to this conference. Here, we report on measurements of the gamma-ray background and radon concentrations, which are also crucial for assessing the site's suitability for low-background experiments.

This presentation summarizes radon monitoring results, gamma-ray spectra measured in the tunnel, and the concentrations of naturally occurring radionuclides in the surrounding rock. Measurement methods and results will be described, with emphasis on implications for background mitigation and for the design of the planned underground laboratory.

## Nuclear Structure Studies / 43

### Bridging Reaction Physics and Nuclear Structure: $\gamma$ -Ray Spectroscopy and Cross-Section Systematics for Nucleon-Induced Reactions

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We present here a comprehensive and systematic study of nuclear  $\gamma$ -ray production cross-sections induced by proton reactions on a series of key nuclei, specifically  $^{24,25,26}\text{Mg}$ ,  $^{28,29,30}\text{Si}$ ,  $^{40}\text{Ca}$ , and  $^{56}\text{Fe}$  [1,2]. These investigations are conducted within the framework of an Algeria-France-South Africa collaboration at the iThemba LABS facility, utilizing the high-resolution AFRODITE gamma-ray spectrometer. The primary objective is to provide high-precision experimental data in a proton energy range of 30-200 MeV [1,3] where existing data are often scarce or inconsistent, yet crucial for multiple scientific domains.

The measured cross-sections serve as a cornerstone for several applications. In medical physics, they are essential for optimizing radioisotope production and improving dose calculations in proton therapy. In nuclear astrophysics, these data are employed to simulate  $\gamma$ -ray line emissions resulting from the interaction of galactic cosmic rays (GCRs) with abundant elements in the interstellar medium (ISM) and solar flares. By comparing laboratory measurements with satellite observations (such as those from INTEGRAL or COMPTEL), we can better determine the chemical composition and understand the energetic processes of the cosmos.

A central technical aspect of this work involves the adjustment of optical model potential (OMP) parameters for nucleon-nucleus interactions. Beyond the primary gamma-ray line analyses following inelastic scattering on target nuclei, our analysis allows for the measurement of production cross-sections for a wide range of residual nuclei. Indeed, the complex interaction mechanisms lead to the

observation of various isotopes resulting from nucleon or alpha emission, such as  $^{21,22}\text{Ne}$ ,  $^{22,23}\text{Na}$ , and  $^{24,25,26}\text{Al}$  from magnesium and silicon targets, as well as  $^{38,39}\text{K}$ ,  $^{36,38}\text{Ar}$ ,  $^{54,55}\text{Fe}$ , and  $^{52}\text{Cr}$  for heavier targets. To ensure the highest accuracy, the analysis of the  $\gamma$ -ray spectra is complemented, whenever necessary and possible, by a lineshape calculation to account for Doppler effects and peak broadening.

This process is a fundamental approach to better understand the physics of reactions and the complex interactions between the candidates (incident particles and target nuclei). By systematically adjusting the OMP parameters, we can adjust the nuclear level coupling and determine the nuclear deformation parameters ( $\beta_2$  and  $\beta_4$ ). While the analysis of the  $^{40}\text{Ca}$  data is currently in progress - focusing on the optimization of nucleon-induced reactions and their implications for residual Argon nuclei - future objectives aim to extend this methodology to  $\alpha$ -particle induced reactions as they are rather scarce. Ultimately, this hierarchical approach - moving from fundamental interaction physics to the adjustment of theoretical models - is needed for improving the predictive accuracy of global nuclear reaction codes such as TALYS.

The experimental and theoretical results obtained and compiled will be presented and discussed.

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## Environmental Measurements / 44

### Revisiting Radiocesium Retention in Japanese Cedar: Implications for Post-Accident Forest Recovery

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The long-term management of contaminated forest landscapes depends not only on declining environmental inventories of radiocesium ( $^{137}\text{Cs}$ ), but also on how this radionuclide is retained within commercially important tree species. Japanese cedar (*Cryptomeria japonica*), which underpins much of Japan's plantation forestry, exhibits an unusual internal distribution of  $^{137}\text{Cs}$  within wood (stem), marked by preferential accumulation in heartwood rather than sapwood. This pattern challenges conventional assumptions about radionuclide behavior in woody tissues and raises questions about the processes controlling internal redistribution and retention. This study synthesizes current knowledge and ongoing works on radial radiocesium dynamics in Japanese cedar, focusing on anatomical, physiological, and environmental factors that may drive these observations. Key uncertainties are identified, and directions for future research are outlined to improve predictive capability and inform risk-based decisions on the utilization of forest timber in post-accident environments.

**Keywords:** Japanese cedar, Radiocesium, Forest ecosystems, Fukushima.

## Nuclear Experimental Techniques & Data Analysis / 45

## Nuclear structure studies relevant for $^{136}\text{Xe}$ neutrinoless double beta decay

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The search for neutrinoless double beta ( $0\nu\beta\beta$ ) decay provides a unique probe of the Majorana nature of neutrinos, i.e whether neutrinos are their own antiparticles. The observation of this process would imply the violation of lepton number conservation and signal new physics, beyond the Standard Model. However, the interpretation of  $0\nu\beta\beta$  experimental searches relies critically on nuclear matrix element (NME) calculations, which are sensitive to nuclear structure inputs and remain a significant source of uncertainty. In this talk, I will discuss nuclear structure properties relevant to the  $^{136}\text{Xe}$   $0\nu\beta\beta$  decay, investigated via the  $^{137}\text{Ba}(d,^3\text{He})^{136}\text{Cs}$  single-nucleon transfer reaction. The results provide experimental constraints on single-proton occupancies and contribute to reducing uncertainties in NME calculations.

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### Nuclear Experimental Techniques & Data Analysis / 46

## Extraction of Giant Monopole Resonance strength with Multipole Decomposition Analysis

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It has been established that inelastic alpha scattering at a few hundreds MeV, particularly at very forward scattering angles including  $0^\circ$ , is effective for probing the Isoscalar Giant Monopole Resonance (ISGMR) strength distribution ( $E0$ ) in atomic nuclei. Two previous studies on the evolution of the ISGMR in the even-even  $^{40,42,44,48}\text{Ca}$  isotopes were conducted at two different facilities: the Research Center for Nuclear Physics (RCNP) and the Texas A&M University Cyclotron Institute (TAMU). These studies produced conflicting results regarding the systematic trend of nuclear incompressibility across the calcium isotopic chain under investigation.

In response, the iThemba LABS group conducted an independent study of the same isotopes to investigate the potential origins of these discrepancies. Measurements

were carried out at  $0^\circ$  and  $4^\circ$  scattering angles, and an energy-dependent version of the difference-of-spectra (DoS) method was initially employed. While this method offers high energy resolution, it relies on the strength contributions of all  $L \geq 0$  multipolarity components published in the literature, thereby compromising the independence of our results. To address this, Multipole Decomposition Analysis (MDA) was applied to extract the E0 strength distributions. Although the limited angular range may reduce the precision for higher multipolarity strengths, it does allow for the accurate extraction of the E0 component independently of other studies.

Two MDA methods were used in the analysis: the emcee Python code, which employs the sophisticated Markov Chain Monte Carlo (MCMC) sampling algorithm, and a second MDA method is based on the MINUIT algorithm, implemented within the ROOT data analysis framework. Selected results obtained using both methods will be presented at the workshop.

This research work is supported by the National Research Foundation (ref no: PMDS22062727817).

#### Environmental Physics & Applications / 48

### Applications of Accelerator Mass Spectrometry in southern Africa

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The AMS facility at iThemba LABS is the only one of its kind on the African continent. It operates with NRF support to achieve a threefold mandate: to provide a technology platform for users, to train future science leaders, and to do research. In meeting this mandate the AMS facility operates in a partnership with the user base in the provision of know-how to run analyses on science agendas set by the users, and in leading in-house research that accommodates academic partners and post-graduate student training. While the AMS facility is framed securely in the particle physics domain, the greatest impact is found in applied disciplines. The greatest demand is from the traditional heritage market, and the “recent archaeology” of southern Africa is almost entirely dependent on AMS radiocarbon dating to provide a chronological framework. Other important applications include testing climate change forecasts, dating groundwater recharge, assessing global phenomenon such as magnetic field fluctuations over the last 50 000 years, and assessing the mechanisms of coastal erosion. The essence of the AMS program is to use particle physics for the benefit of the people of South Africa, and Africa, and this depends on attracting innovative young scientists into the field.

#### Environmental Physics & Applications / 49

### Review of Environmental Radioactivity in Mkuju, Manyoni, and Bahi Uranium Deposits in Tanzania

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Uranium deposits in Tanzania, particularly at Mkuju, Bahi, and Manyoni, have attracted increasing attention due to their economic potential and environmental implications. Over the past two decades, numerous studies have investigated activity concentrations of naturally occurring radionuclides, including uranium-238, thorium-232, and potassium-40, as well as associated radiological hazards. However, these studies remain scattered, limiting a spatial pattern, methodological consistency, potential environmental and public health implications. This paper aims to systematically

review and synthesize published studies on natural radioactivity in the Mkuju, Bahi, and Manyoni uranium deposits. The findings reveal that activity concentrations in soil for  $^{238}\text{U}$  (21 to 846 Bq/kg),  $^{232}\text{Th}$  (12 to 107 Bq/kg) and  $^{40}\text{K}$  (38 to 791 Bq/kg) in Manyoni indicating moderate to high variability depending on sampling location. In contrast, Mkuju exhibits the highest radioactivity levels, particularly within concession areas where  $^{226}\text{Ra}$  reaches extremely elevated values of 2430 – 4200 Bq/kg, accompanied by increased  $^{232}\text{Th}$  (130 – 220 Bq/kg) and  $^{40}\text{K}$  (up to ~1466 Bq/kg). Bahi deposit shows comparatively lower to moderate  $^{226}\text{Ra}$  concentrations (9.19 – 69.38 Bq/kg), but relatively high  $^{40}\text{K}$  levels, reaching up to 1384.75 Bq/kg. Despite these observations, inconsistencies in sampling strategies and limited longitudinal studies hinder reliable comparisons and comprehensive trend analysis. This review emphasizes the need for standardized methodologies, long-term environmental monitoring, GIS-based mapping, geochemical fingerprinting and expanded studies on radionuclide transfer through environmental pathways. This review provides a comprehensive perspective on radioactivity measurements in Tanzanian uranium deposits and serves as a benchmark for future investigations in radiation safety and sustainable uranium exploitation in Tanzania.

## Environmental Physics & Applications / 50

### The Rhisotope Project - A novel use of radiation to deter poaching

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The rate of poaching of rhinos in South Africa shows little sign of slowing. The numbers are down but there are less animals to be poached. South Africa is custodian of the majority of the world's black and white rhino populations. The conventional methods of anti poaching are proving barely adequate whilst at the same time risking the lives of antipoaching patrols. The Rhisotope Project utilises nuclear science in a novel manner to protect these megaherbivores and give them the chance to survive and thrive once again.

## Radiation and Health Physics / 51

### Collimator-Free Non-Collinear Cascade Gamma Coincidence Imaging: A GATE-Based Study Achieving Sub-Millimeter Resolution and High Sensitivity

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This study presents the GATE-based Monte Carlo model and performance evaluation of a non-time-of-flight, collimator-free tomographic medical imaging system based on non-collinear cascade gamma-ray Coincidence (CGC) imaging. A CGC imaging model was developed to reconstruct three-dimensional decay vertices from valid coincidence events. A custom geometric back-projection reconstruction algorithm was implemented to generate tomographic images in transverse, coronal, and sagittal views, enabling quantitative assessment of spatial resolution, sensitivity, and coincidence detection efficiency (CDE). The results show, with  $^{111}\text{In}$ -ion point source at the center of field

of view (FoV), the modeled imaging system achieved sub-millimeter isotropic spatial resolution of approximately 0.477 mm (FWHM) along all axes and demonstrated resolving capability between 1.5-2.0 mm for closely spaced point sources. The CGC imager achieved a coincidence efficiency of  $1.50588 \times 10^{-2}$  and sensitivity of 15,058.8 cps/MBq for a  $^{111}\text{In}$  source at the center of the FoV in air, their corresponding values for source in PMMA phantom were  $1.25279 \times 10^{-2}$  and 12,527.9 cps/MBq, respectively. These values were significantly higher than those reported for conventional parallel-hole, focused, and hybrid collimator-based systems, representing improvements of several orders of magnitude. For positional reconstruction, the analysis confirmed the reconstructed source position within  $\pm 16$  mm transaxially and  $\pm 17$  mm axially resembles to simulated position. To evaluate the impact of radionuclide decay characteristics on imaging performance, four cascade gamma emitters ( $^{43}\text{K}$ ,  $^{73}\text{Se}$ ,  $^{111}\text{In}$  and  $^{177}\text{Lu}$ ) were simulated under identical conditions.  $^{111}\text{In}$  and  $^{73}\text{Se}$  exhibit the highest CDEs, followed by  $^{177}\text{Lu}$ , while  $^{43}\text{K}$  shows the lowest due to its extremely short intermediate-state half-life of 46 ps, which is below the detector timing resolution ( $\sim 0.549$  ns), leading to missed valid coincidence events. The higher CDE for  $^{111}\text{In}$  is partly from random coincidences caused by its longer half-life and wider timing window. These results emphasize that detector timing resolution, isotope selection, and coincidence window design are critical for optimizing cascade gamma imaging performance. On the other hand, spatial resolution remained the same ( $\sim 0.477$  mm FWHM) across radionuclides. This finding confirms that system resolution is governed by detector geometry and reconstruction parameters rather than decay properties. The findings demonstrate that non-collinear CGC imaging enables the simultaneous achievement of both high sensitivity and sub-millimeter spatial resolution. However, experimental testing of the system should be conducted to assess its practical performance.

## Flash Posters / 52

### Characterization of an I-125 seed using the AAPM TG-43 dosimetry protocol

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#### Introduction:

I-125 seeds are often used in temporary or permanent radiotherapy implants. The American Association of Physicists in Medicine (AAPM) formed Task Group (TG) 43 to propose a dosimetry protocol for such cylindrically symmetric seeds. The protocol calculates the dose rate at a particular point by taking into account the air kerma strength, dose rate constant, geometry function, radial dose function, and anisotropy function.

#### Methods and Materials:

OncoSeed 6711 I-125 seed dimensions of 20 seeds were confirmed with a Vernier caliper. These dimensions were then used to obtain the geometry function, which provides an inverse square correction based on the activity distribution in the source. Air kerma strength was confirmed using a calibrated PTW Sourcecheck  $4\pi$  chamber. The anisotropy and radial dose functions were measured in specially designed solid water phantoms using thermoluminescent dosimeters (TLDs). Gafchromic film was also used for these measurements. The dose rate constant was determined using the ratio of the measured dose rate at 1 cm and the air kerma strength. Spectral measurements were made with a Silicon Drift Detector. These results were used to determine the average seed energy, as well as the dose rate constant by taking into account each peak's individual contribution.

#### Results:

The active length of the seeds was measured to be  $2.85 \text{ mm} \pm 0.99 \%$ , while the nominal seed length was given as 3.0 mm. The difference in the geometry function was less than 1 % at 0.5 cm, and less than 0.06 % at distances of 2 cm and larger. The average ratio of stated and measured air kerma strengths was  $0.999 \pm 0.031$  for 175 seeds measured from 7 different batches of seeds. The anisotropy and radial dose function matched published data to within one standard deviation. The measured dose rate constant using TLDs was  $\Lambda = 0.96 \pm 0.2 \text{ cGy h}^{-1} \text{ U}^{-1}$ , while the calculated one using the spectrum was  $\Lambda = 0.978 \text{ cGy h}^{-1} \text{ U}^{-1}$ . The average energy of the I-125 seed excluding the

titanium characteristic X-rays of the seed housing was 27.44 keV, in good agreement with published data.

Conclusion:

All seed parameters matched published data very well, allowing accurate and precise dose calculations for radiotherapy treatment planning.

## Nuclear Energy, Safety, and Security / 53

### From neutrons to knowledge

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Research reactors play a pivotal role in transforming fundamental nuclear particles into powerful tools for scientific discovery and societal advancement. Unlike power reactors, these facilities are specifically designed to produce high fluxes of neutrons that can be harnessed for a wide range of applications. This paper explores the journey “from neutrons to knowledge,” highlighting how research reactors enable breakthroughs in fields such as materials science, medicine, energy, and environmental studies. Through techniques like neutron scattering and neutron activation analysis, researchers can probe the structure and behavior of matter at the atomic level, providing insights that are often unattainable by other methods. Additionally, research reactors contribute to the production of medical isotopes essential for diagnostics and cancer treatment, as well as to the training of skilled scientists and engineers. By examining both the scientific capabilities and the broader impacts of these facilities, this work underscores the enduring importance of research reactors as engines of innovation and the development of next-generation systems, including small modular and advanced reactors. At the same time, they support applications in environmental monitoring, isotope production, radiation protection, and nuclear security, demonstrating their broad societal relevance and knowledge generation in the modern world.

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### Radiative capture reaction studies at iThemba LABS

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The low-energy nuclear astrophysics beamline at the iThemba LABS 3-MV Tandatron facility enables the study of radiative capture reactions using proton and alpha beams. The setup can presently be instrumented with either up to twelve 3”×3” LaBr<sub>3</sub>:Ce detectors or six HPGe detectors (with associated BGO Compton-suppression shields), or with a combination of both detector types. To date, proton beams have primarily been employed for studies of the photon strength function (PSF), which is important not only for calculating nucleosynthesis reaction rates but also for probing the underlying nuclear structure. Experiments using alpha beams have focused on reactions relevant to helium burning in stars.

As is typical for measurements at such low energies, the sensitivity of the experiment is strongly affected by background produced when Rutherford-scattered beam particles interact with nuclei in surrounding hardware rather than in the intended target.

Preliminary results from selected experiments will be presented, together with a discussion of background-mitigation strategies and investigations into the origin of the observed background due to the  $^{19}\text{F}(p,\alpha)^{16}\text{O}$  reaction.

**Nuclear Energy, Safety, and Security / 55**

## **A new 30 MeV cyclotron facility for radioisotopes and research**

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The UCT Proton Therapy Initiative has as its primary goal the re-establishment of a proton therapy facility in Cape Town. In addition, the project aims to establish a complementary facility featuring a 30 MeV cyclotron capable of proton, deuteron and alpha-particle beams. This new facility will manufacture a range of short and longer-lived radioisotopes and related products that complement those already available from the NRF's iThemba LABS, and other cyclotron facilities in the region. In particular the production of radioisotopes suitable for Targeted Alpha Therapy for cancer is of particular interest. Beyond radioisotope production for medical use, the new 30 MeV facility will also provide a unique platform for fundamental and applied nuclear physics research in the mid-energy range, complementing higher-energy research at iThemba LABS. A dedicated research vault will include dual beamlines: one for charged-particles, and one for neutron production, optimised for time-of-flight (TOF) measurements. Together, these beamlines will support, for example, activation and radiation damage studies, radiobiology, and instrumentation development with applications across fundamental science, metrology, engineering, medicine, and industry.

I provide a status report on this project and seed an audience discussion on the design of the facility and how it might best serve the broadest user base in South Africa.

**Nuclear Experimental Techniques & Data Analysis / 56**

## **From Nuclear Giant Resonances to Environmental Radiation Monitoring: Recent Research Activities and Perspectives for Collaboration.**

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The Isoscalar Giant Monopole Resonance (ISGMR), often referred to as the nuclear “breathing mode,” provides essential constraints on the incompressibility of nuclear matter and therefore on the nuclear equation of state. In this contribution, recent investigations of the ISGMR strength distribution and its fine structure obtained through high-resolution inelastic scattering measurements will be presented. Particular emphasis will be placed on the extraction and interpretation of fine-structure features and their relation to underlying nuclear dynamics and decay mechanisms.

These studies were carried out within the framework of nuclear structure research activities at iThemba LABS and contributed to a better understanding of collective excitations in nuclei.

In addition, a brief overview will be given of ongoing research directions at Laboratoire de Physique Corpusculaire de Caen related to environmental radiation measurements and the development of innovative portable low-cost detector systems for environmental monitoring applications. Possible avenues for future collaboration between the South African and French teams in this field will also be discussed.

**Environmental Measurements / 57**

## **Recent Research Activities and Perspectives for Collaboration**

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A brief overview will be given of ongoing research directions at Laboratoire de Physique Corpusculaire de Caen related to environmental radiation measurements and the development of innovative portable low-cost detector systems for environmental monitoring applications. Possible avenues for future collaboration between the South African and French teams in this field will also be discussed.