# Prospective appraisal of a formative nuclear and radiation physics at Nairobi

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**Abstract**. We provide a prospective appraisal of the evolution of the graduate nuclear and radiation physics program at the University of Nairobi underscoring its unique growth in the framework of relevant knowledge networks and a nascent nuclear power program. Due to the distinctive characteristics of the nuclear fuel cycle, there arose in Kenya especially nuclear security educational requirements for a proliferation-free nuclear power program as well as the need for provision of a broad spectrum of technical capacities to plan, regulate, and safely handle a nuclear power infrastructure. We detail how the graduate program centres on our newly established research line in nuclear forensics. Learning from this experience we propose, as a result, moving into nuclear photonics enabled by accelerators so as to play more key roles in accelerating capacity building embracing both nuclear and laser physics.

## 1. Introduction

University of Nairobi is the largest of the 47 universities in Kenya comprising of 31 Faculties, Schools and Institutes; and 60,000 undergraduate and 15,000 graduate students. Department of Physics is constituted in the Faculty of Science and Technology as is comprised of 6 thematic areas: (i) Theoretical Physics (ii) Nuclear and Radiation Physics (iii) Condensed Matter Physics (iv) Earth, Environment and Applied Geophysics (v) Laser Physics and Spectroscopy and (vi) Electronics and Instrumentation. Nuclear and Radiation Physics was started in 2002 building on basic undergraduate atomic and nuclear physics [1]. Since 1982 only Institute of Nuclear Science was graduating about 5 graduate students yearly in the multidisciplinary applications of nuclear science. This scope, not only in the University of Nairobi but in the whole country was too narrow considering the diverse and interdisciplinary as well as industrial nature of nuclear (physics, radiation) technology. The Institute's 1979 national mandate to train human resources in the applications of nuclear science techniques was thus limited.


**Fig 1.** The interplay and mediation of nuclear forensics in nuclear safety, security and safeguards.

By 2006 Kenya had already become party to the International Convention for the Suppression of Acts of Nuclear Terrorism [4], Convention on Nuclear Safety [5], Convention on Early Notification of a Nuclear Accident [6] and Joint Convention on the Safety of Spent Fuel Management, and the Safety of Radioactive Waste Management [7], demonstrating commitment to pursue peaceful uses of atomic energy. It should be noted that lack of educational capacity in nuclear security was the key impediment to the countries that failed to develop nuclear power [8].

In order to ensure success, educational capacity in broad-based nuclear and radiation physics must be an essential part of a new NPP [9]. Due to the distinctive characteristics of the nuclear fuel cycle, there are special educational requirements for a proliferation-free nuclear power program. Lack of educational capacity in nuclear security especially was the key impediment to the countries that failed to develop nuclear power. No Kenyan University had a nuclear security educational program before the advent of the country's nuclear power program. Only Kenyatta University and the University of Nairobi had graduate programs in Applied Nuclear and Radiation Physics [10]. These graduate programs build on the normal, basic undergraduate Atomic and Nuclear Physics courses. Considering the characteristics of nuclear security, this narrowness portrays dismally Kenya's NPP educational capacity building effort.

**Table 1.** Evolution of Graduate Nuclear and Radiation Physics at University of Nairobi

| Old Curriculum [2002-2018] | Revised Curriculum [2022-] |
|---|---|
| <u>Year I (Semester I)</u><br>3 basic physics courses<br>+ Advanced Nuclear Physics<br><br><u>Year I (Semester II)</u><br>Radiation Physics<br>Radiation Measurement and Spectroscopy<br>Radiation Protection<br>Advanced Laboratory Techniques<br>Applications of Radiation<br><br><u>Year II</u><br>Thesis | <u>Year I (Semester I)</u><br>4 basic physics courses<br>+ Advanced Nuclear Physics (Revised)<br><br><u>Year I (Semester II)</u><br>Radiation Physics (Revised)<br>Radiation Measurement and Spectroscopy (Revised)<br>Dosimetry and Radioprotection (New)<br>Advanced Laboratory Techniques (Revised)<br><br>Reactor Physics (New)<br>Radioecology (New)<br>Nuclear Radiometrics Instrumentation (New)<br>Particle Physics (New)<br>Nuclear Structure and Reactions (New)<br>Experimental Methods in Nuclear and Particle Physics (New)<br><br>Fundamentals of Nuclear Security (IAEA-NSS 1)<br>Nuclear Forensics and Attribution (IAEA-NSS 19)<br>Nuclear Energy and Fuel Circle (IAEA-NSS 3)<br>Nuclear & Radioactive Material Accountancy (IAEA-NSS 13)<br><br><u>Year II</u><br>Thesis |

The old graduate curriculum at our department was comprised of 4 common basic physics courses in Year I (semester I), then in semester II students chose any 3 of the specialist courses (see Table 1) plus the compulsory Advanced Laboratory Techniques. There were no district tracks of specialization. It will be noted from Table 1 the new curriculum recognizes the interdisciplinary dimensions of nuclear and radiation physics and adapts to the needs of an NPP. We have no accreditation requirements at our University for non-professional courses; instead we have a policy guide on how this is done which includes invitation of stakeholder inputs and meetings as well as external refereeing, followed by cascaded review from the departmental level upwards till Senate approval.

The new program takes 2 years and is also by coursework and thesis. Students will take 5 basic physics courses in Year I (semester I) plus another five (5) elective courses in semester II appropriately guided to realize following specializations: (i) Health Physics and Radioprotection (ii) Nuclear Radiometrics Instrumentation (ii) Nuclear Science Techniques (iv) Nuclear and Radiation Physics (v) Nuclear Security and Safeguards. The courses with IAEA-NSS have been adopted from the IAEA nuclear security series guides prepared by International Nuclear Security Education Network (INSEN) to which the Department belongs.

In Year II of study students will pursue thesis research (equivalent to: 10 x 45 hour courses), focusing on our current research strengths:

(i) Nuclear and radiation physics applied to:

- Rpectroanalysis and modelling of nuclear traces and impact dynamics in complex ecosystems;
- Radiometric and dosimetric quality assurance in nuclear based imaging and radiation medicine.

(ii) Nuclear forensics and attribution development methodologies in support of nuclear security/safety

- Novel signatures and measurement techniques;
- Integrated deep learning driven strategies.

(iii) Method development (based on laboratory and synchrotron instrumentation) in nuclear and laser spectroscopy for trace (atomic, molecular, radiogenic) analysis and imaging utilizing deep learning.

## 2. Role of Knowledge Networks

Forging international links has been key. This achievement testifies that networks are a proven modern way of organizing knowledge production and play an important role in building and sustaining education innovations. Scientific networks have helped to unite us geographically with distant researchers thus providing mentors and closing gaps between us and colleagues. We emphasize a few networks as curriculum reform drivers (i) International Nuclear Security Education Network (INSEN), (ii) African Spectral Imaging Network (AFSIN) and (iii) World Academy of Sciences for the Advancement of Science in Developing Countries (TWAS).

### *2.1. International Nuclear Security Education Network (INSEN)*

To address future requests for assistance in nuclear security education, the International Atomic Energy Agency (IAEA) in 2010 started to support the development of academic courses in nuclear security and to build on the framework outlined in the IAEA's Nuclear Security Series No. 12: 'Educational Programme in Nuclear Security'. INSEN was formed as a collaboration among universities, research institutes, and other stakeholders to promote the implementation of this guidance [11]. INSEN's mission is to enhance global nuclear security by developing, sharing, and promoting excellence in nuclear security education by (i) supporting, sustaining, and promoting nuclear security education, achieved through development and review of teaching materials and tools, academic programmers and curricula consistent with IAEA-defined terminology and guidance; (ii) assisting in the different areas of nuclear security education through faculty professional development and exchanges, infrastructure, good practices, expertise, and information sharing; and (iii) promoting nuclear security education among INSEN members as well as other interested institutions and stakeholders. In line with its mission, INSEN assisted us in the development of the new graduate courses via production of teaching materials, professional development opportunities for faculty, and global networking of staff.

### *2.2. African Spectral Imaging Network (AFSIN)*

AFSIN is a gender-sensitive research collaboration between physicists in Burkina Faso, Cameroon, Côte d'Ivoire, Ghana, Kenya, Mali, Senegal and Togo in the fields of spectroscopy and spectral imaging (mostly biophotonics). Besides research, the network builds instruments for realistic diagnostic tools related to tropical diseases, to monitor pollution affecting agriculture and environment, and for quality control and improved crop yield. At AFSIN we organize workshops every two years in different countries for exchanging research results as well as training students and young scientists. Every year guest lectures travel to Cot de Voir for six weeks to give lectures to PhD students drawn from the network. The network is supported by the International Scientific Program (ISP) of Sweden. By 2006 we had developed 4 new courses in laser physics and spectroscopy that established applied photonics in the department. ISP also funded the purchase of our key research equipment through the grant "Advancing Integrated Machine Learning Enabled Microphotonic Approaches to Nuclear Forensic Analysis (2017-19)." A synergy has been achieved at Nairobi by combining machine learning with the microphotonics for nuclear forensics. ISP assists lower-income countries in building and strengthening their domestic research capacity and postgraduate education in the basic sciences.

*2.3. World Academy of Sciences for the Advancement of Science in Developing Countries (TWAS)*

Our efforts in the nuclear forensics research group have also been supported by The World Academy of Sciences (TWAS) for the Advancement of Science in Developing Countries, which supports sustainable prosperity through research, education, policy, and diplomacy. TWAS helped three MSc and one PhD students pursue research in nuclear forensics at our research group under the grant "Development of Machine Learning Enabled Laser Based Spectrometry and Imaging Approaches for Direct Rapid Nuclear Forensics Analysis and Attribution (2014-16)".

These collaborative efforts align with Kenya's commitment to pursue its nuclear power program through international involvement. Since 2012 Kenya has signed several memorandums of understanding (MoU) with Slovakia, China, Republic of Korea, and Russia. These MoUs aim at enhancing collaboration in the development of Kenya's nuclear power program.

## 3. Developments towards Nuclear Photonics

It became apparent embracing nuclear photonics enabled by accelerators will be key in accelerating capacity building in both nuclear and laser physics. This is envisioned in the African Union's Agenda 2063 of the strategic framework for sustainable development and economic growth based on nuclear science and technology. Today more than 20,000 particle accelerators are operating world-wide. A review of their landscape and future took place recently at the first IAEA International Conference on Accelerators for Research and Sustainable Development [12]. Nuclear photonics portends a renaissance in nuclear physics wrought by new high-power, short-pulse lasers and novel sources of highly brilliant, intense $\gamma$-ray beams that will open up unprecedented perspectives for photonuclear physics [13].

Founded in 2010 nuclear photonics uses the unique capabilities of two disciplines namely heavy ion physics and physics of super-strong laser fields to fashion out a new cross-disciplinary field of physics and engineering applying controlled photo-nuclear reactions with artificial $\gamma$-ray beams. With the new low-energy, pulsed, polarized neutron beams of high intensity and brilliance [14] as well as new positron sources with significantly increased fully polarized brilliance [15], radically new clinical applications are expected in the use of radioisotopes [16], non-invasive tomography and microscopy, management of nuclear materials, nuclear forensics, and materials science.

Most of these developments are however taking place out of Africa - at the Extreme Light Infrastructure – Nuclear Physics (ELI-NP) in Bucharest (Romania), MEGaRay in Livermore (USA), NICA (Nuclotron based Ion Collider fAcility) in Dubna (Russia) and the I$\gamma$S facility at Duke University (USA). At Nuclear Research (Dubna) the NICA (Nuclotron based Ion Collider fAcility) will soon be used to study the properties of dense baryonic matter [17].

## 4. Conclusion

We have reported progress in the establishment of a prospective graduate nuclear and radiation physics program at Nairobi in line with the renaissance in nuclear power in Africa. Being policy-informed, stakeholder-driven and student-centered the program addresses the distinctive characteristics of nuclear fuel cycle. Besides, it is supported by a strong research line in nuclear forensics. The program has resulted in the reshaping of our undergraduate-level nuclear, radiation and health physics track with tailored experiments focusing on microscopy with applications in nuclear sciences, detector electronics

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and digital signal and image processing. We have underscored the key role of knowledge networks in circumnavigating challenges to realise the new program curriculum review and development. Although challenges still exist in designing the optimal curriculum that promotes student learning, it is hereby envisaged embracing nuclear photonics will play a key role in shaping the evolution of the program.

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