Philippine Journal of Science
149 (S1): 151-157, Special Issue on Nuclear S&T
ISSN 0031 - 7683
Date Received: 19 Jul 2019

Capacity Building in Nuclear Science and Technology in the Philippines through the Use and Operation of Small Neutron Sources for Education, Training, and Research

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For the past three decades, the Philippines' expertise in nuclear science and technology (S&T) has diminished resulting from the shutdown of the Philippine Research Reactor-1 (PRR-1) in the 1980s. In addition, the mothballed Bataan Nuclear Power Plant (BNPP) and the low confidence in nuclear technologies led to the non-prioritization of nuclear science in the country. Consequently, new nuclear facilities were never re-introduced, and the transfer of knowledge declined and nuclear applications were limited to radiation and isotopic studies. If the current initiatives of the Philippines in the use of nuclear energy will push through, the country will need competent human resources who will be responsible for building the nuclear facilities and their safe operation. To augment the declined nuclear expertise in the country, the DOST-PNRI implemented capacity building activities to reestablish and sustain knowledge and expertise in nuclear S&T in the country. Activities that were implemented include the development of training materials for undergraduate students and the development of research facility using isotopic neutron sources. This paper discusses the capacity building strategies implemented and their significant outputs, as well as plans for sustainability and continual development.

Keywords: capacity building, isotopic neutron source, neutron laboratory, Philippines

INTRODUCTION

Nuclear science research was very active in the Philippines in the 1970s because two major nuclear facilities were built in the country. First was the PRR-1, a facility donated by the United States to the Philippines as part of its "Atoms for Peace" program; the second was the 612 MW BNPP, a facility built as a solution to the 1973 oil crisis (IISS 2009). These facilities led to a very active nuclear research in the country. However, they were shut down during the 1980s and have been non-operational for decades, which resulted in the eventual decline of expertise in nuclear S&T in the country.

Meanwhile, in South East Asia, nuclear research is moving and very active. While none of the eleven countries

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have a concrete decision on the use of nuclear energy, countries such as Vietnam, Indonesia, and Malaysia appeared to have made the most progress in their nuclear infrastructure. Vietnam came nearest to constructing its first nuclear power plant (Putra 2017). As far as nuclear research is concerned, Thailand is the most active with the use of its nuclear research reactor that offers a broad range of nuclear applications such as the production of radioisotopes, neutron scattering, neutron radiography, neutron activation analysis (NAA), and training and education (T&E) in the nuclear field (Tiyapun *et al.* 2016). In the Philippines, a portion of these applications was accessible when the PRR-1 was still operating but is now unavailable.

In 2018, an International Atomic Energy Agency (IAEA) expert mission reviewed the progress of the Philippines' infrastructure on the development of a nuclear power program. The Secretary of Energy affirmed the Government's commitment to implement the IAEA's recommendations when it takes its next steps in considering the development of nuclear power program (IAEA 2018). With these current developments, the government must equip its people with knowledge and skills on the safe use of nuclear technology. However, nuclear science has not been a priority in the country for a very long time and no new nuclear facilities were built; therefore, the propagation of nuclear S&T was minimal. Moreover, if the initiatives on the use of nuclear energy will push through, the country will need competent human resources who will be responsible for building the nuclear facilities and their safe operation. However, the country's expertise in nuclear S&T had diminished over the years. Therefore, there is a need to build capacity for an anticipated nuclear power program and advancement in non-power applications of nuclear energy.

The DOST-PNRI is the sole government agency that has the mandate of promoting and regulating the application of nuclear S&T in the country (DOST-PNRI 2015). It was originally a large organization under the Office of the President and was known as the Philippine Atomic Energy Commission (PAEC). The downsizing of the organization, from the PAEC to the DOST-PNRI, led to the migration of Filipino nuclear scientists and engineers abroad where they can practice their profession. This resulted in brain drain, with very few Filipinos who were trained in nuclear science and engineering remaining in the country.

For the past decade, nuclear-based and radiation technique research and development (R&D) in the DOST-PNRI have continued with its two major radiation facilities – the Cobalt-60 gamma irradiation facility and electron beam accelerator facility. These facilities were able to produce research results in the areas of mutation breeding of crops and ornamental plants, sterile insect technique, radiation processing, and use of nuclear-related techniques in product authentication (DOST-PNRI 2018a). The DOST-PNRI has received several awards and recognitions in these fields (DAP 2019, Nazario 2019, Dantes 2017). Capacity building in the areas of cytogenetic biological dosimetry (CBD), receptor binding assay (RBA) in the detection of harmful algal bloom, isotopic techniques in waste management, and nuclear material recovery were also successful. The CBD laboratory has become fully operational and the RBA technology was transferred to DOST-PNRI stakeholders (DOST-PNRI 2017). However, in the field of neutron and nuclear research, the outputs were minimal as compared to the above-mentioned nuclear-related applications because a working nuclear facility is non-existent.

To augment the declined nuclear expertise in the country, capacity building in nuclear S&T was initiated in 2009 that utilized small isotopic neutron sources. The small neutron sources were utilized in this initiative for two reasons. First, they were the only available neutron source in the Institute; and second, they offer portability, which makes them suitable for teaching and education as well as basic research. Without a neutron source, the establishment and retention of essential knowledge in nuclear S&T in the county will always be a challenge. The rationale of the project was to develop simple neutron experiments and related facilities that can be used by young DOST-PNRI researchers and stakeholders. The goal is to help them understand the basic nuclear S&T with the use of small neutron sources and use this knowledge when they handle more complex neutron applications (*i.e.*, neutron imaging, neutron diffraction, and nuclear research reactor technology) when they are sent abroad for training or as an exchange researcher. Moreover, this capacity building will provide human resources not only in nuclear reactor technology but also in the non-power applications of nuclear energy that are equally important to the society (*i.e.*, agriculture, healthcare, water management, materials modifications, environmental remediation).

This paper presents the results of capacity building activities in nuclear S&T in the Philippines since 2009. Three sections were devoted to discussing the activities on the capacity building on T&E, R&D, and future activities on capacity building.

STRATEGY OF CAPACITY BUILDING

Capacity building has been defined by the IAEA as a systematic and integrated approach to develop and continuously improve the governmental, organizational, and individual competencies and capabilities necessary for achieving a safe, secure, and sustainable nuclear power program (IAEA 2015). The Philippines, a country that considers nuclear energy to be part of its energy mix in the future, has to ensure that necessary resources are available when it embarks on using nuclear power.

In the DOST-PNRI, there was a small influx of young people specializing in nuclear science because it was not a priority of the DOST in the past decade. This results in an aging nuclear workforce and a significant age gap of nuclear scientists. The solution to this problem is to build a program or strategy that is focused on T&E, human resource development, knowledge management, and knowledge networking in order to retain the knowledge and remaining expertise in the country.

To solve the problem of diminishing expertise on nuclear science in the country, a capacity-building strategy to reestablish, develop, and sustain knowledge in nuclear science in the country is proposed as shown in Figure 1.

The strategy is composed of two phases with four main objectives. Phase 1 is the development stage of the capacity building, and Phase 2 is designed for the expansion and sustainability of the initiative to rebuild the country's expertise in nuclear science. The four main objectives are: (1) to set up a facility for T&E and R&D in basic neutron techniques, (2) to set up a training program for basic neutron and nuclear techniques, (3) to initiate and perform R&D, and (4) to present a proposal to build or acquire one or more major nuclear facilities in the Institute.

Phase 1 of the strategy for capacity building involves human resources development and the establishment of small neutron facilities. Small radioisotope neutron sources that were stored and disused were recovered from the Radioactive Waste Management Facility (RWMF) and used as radiation sources in small experimental setups. To ensure safe and reliable operation of neutron sources, radiation safety assessments and neutron characterization experiments were performed. The characterized sources were placed in a renovated laboratory for research and T&E activities.

Phase 2 of the capacity building strategy was designed to expand the reach of the developed learning materials and to sustain the interest of nuclear science to young scientists and other DOST-PNRI stakeholders. A training program was developed and the syllabus was implemented for young science and engineering students in the academe, particularly junior and senior college students in engineering and physical sciences.

TRAINING AND EDUCATION ACTIVITIES

T&E is an essential component of any capacity-building strategy because it provides a means to develop the capacity of an individual to perform simple and complicated activities in nuclear S&T. T&E also provides the basis for human resource development and other strategies of capacity building such as knowledge management and knowledge networking. Nuclear research organizations such as the DOST-PNRI have the responsibility to ensure that all radiation and nuclear-related activities that may affect safety are performed by suitably qualified personnel. This requirement can be met by training and learning programs through skills development, training, and exercises (IAEA 2015).

In the Philippines, T&E in nuclear science is obtained from higher education institutions and through courses offered by the DOST-PNRI (Bernido 2003). However, the courses given by the DOST-PNRI are mostly radiation-safety related to users of radioactive materials and radiation technologies. The DOST-PNRI has on-the-job training

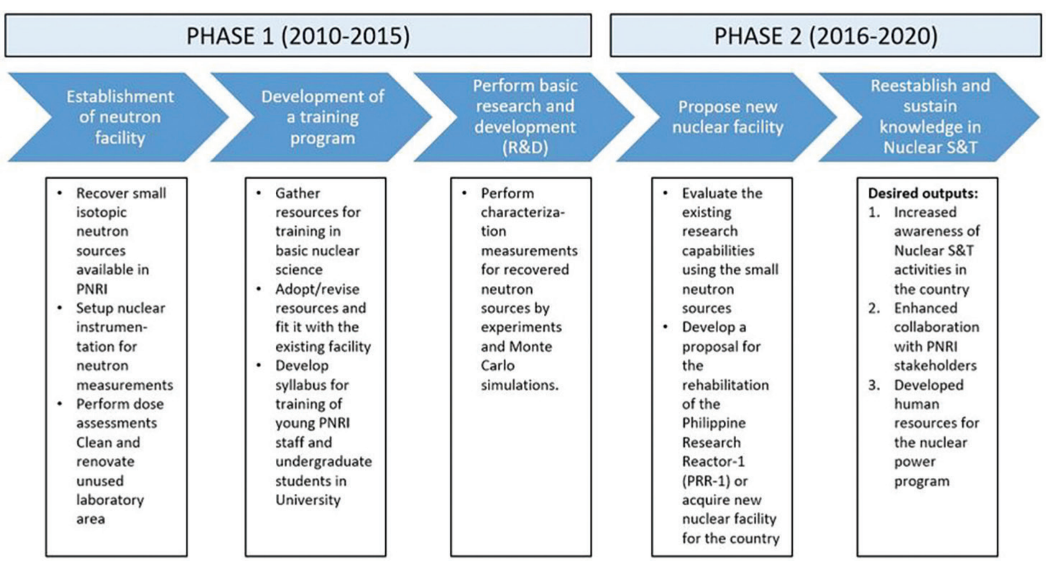

Figure 1. Strategy for capacity building in nuclear S&T in the Philippines through the use and operation of small neutron sources.

(OJT) and thesis/research advisorship opportunities for undergraduate students who wish to study radiation-related techniques and applications. These programs are well-appreciated by the students and even generated several thesis manuscripts and technical papers. However, there are little to no resources for teaching basic nuclear science to undergraduate students.

A training program in basic nuclear S&T was started to meet the need for T&E. The program has two main components. The first one was the establishment of a small neutron facility that houses the recovered radioisotope sources in the Institute. The second was the development of a course syllabus and a training program for young students and professionals.

Establishment of the Small Neutron Laboratory

The last operation of the PRR-1 was in 1984 and, after that, most if not all neutron applications were stopped in the DOST-PNRI (ISSS 2019). To start a program on capacity building, the available small neutron sources in the Institute were recovered and characterized for research and experiment demonstration purposes. The recovered neutron sources were Americium-Beryllium (Am-Be), Californium-252 (Cf-252), and Plutonium-Beryllium (Pu-Be).

The neutron sources used to be located in different research sections of the Institute. The Am-Be neutron source was with the Isotope Techniques Section and was being studied for Prompt Gamma Neutron Activation Analysis (PGNAA). This source is a Neutron Calibrator donated by the IAEA for use in the calibration of neutron detectors for the BNPP. The Cf-252, on the other hand, was recovered from the RWMF of the DOST-PNRI. It was previously used by a cement company for PGNAA applications. The last neutron source, the Pu-Be, was also a neutron source donated by the IAEA and was previously used by the DOST-PNRI Nuclear Training Center for demonstrating half-life experiments. Table 1 presents a summary of information on these neutron sources.

To be familiarized with these sources, several activities were performed. These include the following: neutron dosimetry and characterization experiments such as NAA, measurement of neutron flux and neutron leakage using boron trifluoride (BF_3) detector, and active neutron survey meters. These activities helped in understanding the nature and behavior of different neutron sources and became the topic of OJTs and thesis students of the DOST-PNRI.

After performing such activities, the Applied Physics Research Section (APRS) recovered the Cf-252 from the RWMF of the DOST-PNRI and transferred it to a renovated laboratory located at the basement of the Atomic Research Center (ARC) building. This laboratory was designed and dedicated to the demonstration of neutron interaction with matter, particularly neutron moderation and absorption using various materials and available neutron detectors. In 2018, the Pu-Be and Am-Be were transferred to the upgraded neutron laboratory in West Wing of the ARC building (see Figure 2) for neutron dosimetry and calibration measurements, and sample irradiation experiments.

Development of Training Program and Training Materials

The first formal training on nuclear science and engineering was offered in the 1980s at the University of the Philippines Diliman Campus, offered as the Master in Nuclear Engineering program. However, after the BNPP was mothballed, the graduate program in nuclear engineering was also stopped (DOST-PNRI 2018b). After this event, there have been no formal education programs on nuclear science in the country.

To solve this problem and introduce nuclear S&T to young people, a training program called the Annual Neutron School (ANS) was developed. The ANS provides training and teaching environments for future nuclear scientists. It

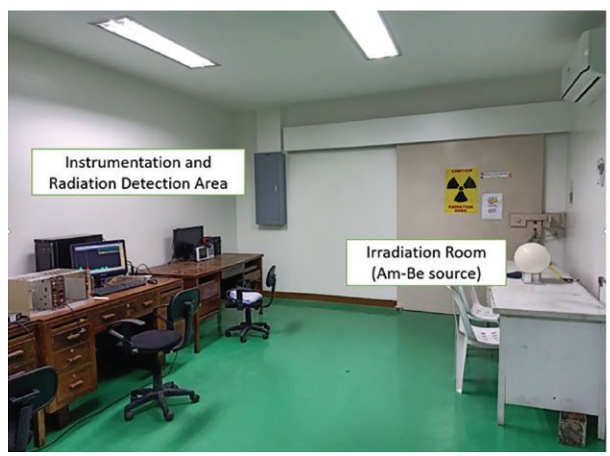

Figure 2. Nuclear Services Division Neutron Laboratory.

Table 1. Recovered radioisotope neutron sources, performed activities, and neutron detectors.

Neutron source	Original activity (GBq)	Reference date	Neutron emission rate (n/s)	Activities/ measurements performed	Neutron detectors used
Am-Be	185	16 Aug 1990	1.1×10^7	dosimetry, NAA, neutron leakage, neutron flux, *etc.*	Boron trifluoride (BF_3), helium-3 (He-3), proton scintillator, and REM ball
Cf-252	0.4	19 Sep 1996	4.3×10^7		
Pu-Be	37	unknown	1.8×10^6		

was composed of experimental and theoretical experience roughly at the level of advanced undergraduate nuclear science courses. The ANS is a two-week course composed of lecture sessions in the morning and laboratory exercises in the afternoon. This training program has the main objective of building competence in students and expertise in lecturers in the areas of nuclear instrumentation, neutron moderation and shielding, neutron flux measurements, dosimetry in the mixed neutron and gamma field, neutron calculations, and modeling. The contents of the developed course syllabus are shown in Appendices I and II.

The syllabus contains 15 lectures and six laboratory experiment demonstrations. The topics covered were basic radiation interaction, radiation detection and instrumentation, and radiation applications. The syllabus had the initial testing in 2011 but the formal implementation commenced in 2014. The actual number of students and trained instructors are shown in Table 2. As of 2019, several students, DOST-PNRI research staff, and university faculties and researchers have been part of the training program. It is hoped that these developed human resources will pursue a career in nuclear S&T to contribute to the country's anticipated nuclear power program.

Table 2. Record of trained students from 2011–2017.

Year	No. of trained students	No. of trained instructors
2011	6	1
2012	1	4
2013	11	5
2014	10	5
2015	11	6
2016	25	7
2017	19	7

R&D ACTIVITIES

The only research reactor in the Philippines, the PRR-1, has not been operational for almost three decades and this caused a significant decline in the knowledge and experience of nuclear researchers and DOST-PNRI stakeholders in the country. R&D activities were started to identify the gaps in the scientific and technical capability in the Institute that included knowledge, expertise, research and education, and training (IAEA 2015). R&D started with the use of small neutron sources that are either disposed of or stored in the Institute. These sources were recovered, studied, and characterized.

The recovered neutron sources served as the training materials for gaining hands-on experience in different aspects of neutron detection and measurement. The sources were used to study neutron detection, measure neutron flux, neutron leakage, and neutron dose; and to perform Monte Carlo simulations alongside experimental measurements. The results of these R&D activities were presented in various local and international conferences held from 2013 to 2018 (Pantua *et al.* 2013; Asuncion *et al.* 2014; Itliong *et al.* 2014; Dingle *et al.* 2016, 2017; Gatchalian *et al.* 2016; Hila *et al.* 2017, 2018). The summary of the names of undergraduate thesis, technical papers, country presentations, technical reports, and conference proceedings is summarized in Table 3. Moreover, the newly trained DOST-PNRI researchers have already performed criticality calculations for the subcritical assembly for safety analysis and updated the radioactive material inventory of the PRR-1 (Gatchalian *et al.* 2018, 2019; Asuncion-Astronomo *et al.* 2019; Jecong *et al.* 2019). It is worth noting that, before this capacity building initiative, there was virtually no disseminated knowledge on neutron and reactor physics activities from the DOST-PNRI since the late-1980s.

CONCLUSION

As discussed in the previous chapters, the capacity building in nuclear S&T in the Philippines has been very productive and successful – Phase 1 and some parts of Phase 2 of the proposed strategy were implemented well. The goal to reestablish the expertise in nuclear science was achieved by setting up a learning system that consists of basic neutron laboratory, training syllabus, and R&D topics on the utilization of small neutron sources. Moreover, the capacity building initiatives have led to the creation of newly trained DOST-PNRI researchers that are now in charge of reusing the PRR-1 for subcritical reactor applications, the establishment of the first neutron dosimetry laboratory in the country, and implementation of other neutron-related applications. These accomplishments of the Institute will be beneficial in sustaining the knowledge of nuclear S&T in the country.

FUTURE PERSPECTIVES

The use of small neutron sources for T&E and for R&D is beneficial. For T&E, the accreditation of the developed training program in basic nuclear S&T by the Commission on Higher Education is highly considered. The goal is to offer the program to the academe to promote nuclear S&T.

The use of small neutron sources for R&D is very helpful in understanding the behavior and detection of neutrons. However, the measured values of neutron flux with these sources were minimal; thus, other neutron applications such as NAA and neutron imaging were limited. In the future, the purchasing of new neutron sources such as a neutron generator with moderate to high neutron flux shall be highly considered.

Table 3. R&D outputs of capacity building from 2013–2018.

Year	Name or title of research	Type*
2013	Neutron and Gamma Flux Measurement in a Cf-252 Source Storage Drum using BF_3 Detector and Sodium Iodide Scintillation Detector	UT, CP
2013–2014	Neutron Flux Measurement Inside the Am-Be Neutron Calibrator Source	UT, CP
2014–2015	Neutron Flux and Dose Leakage Measurement Outside the Neutron Howitzer Tank with Pu-Be Neutron Source	UT, TP
	Recent Status of Nuclear Development and Youth Organization/Outreach Program	CP (country report)
2015	Conduct of ANS for Capacity Building in the Use and Operation of Small Neutron Sources	TR, TP
	Optimization of Gamma Rejection and Sensitivity of a Proton Recoil Scintillator Neutron Dosimeter	TP
	Neutron Science and its Applications	TP
	Neutron Moderation and Absorption Using Borated Paraffin Wax and Cf-252	CP (poster)
	The ANS – Program and Facility for Nuclear S&T	CP (poster)
	Determination of Limit of Detection for Gold using NAA with Pu-Be Neutron Howitzer	UT
2016	MCNP5 Simulation of an Am-Be based Neutron Calibrator	CP (oral)
2017	Characterization of Cf-252 Neutron Energy Spectrum Leaking in the Neutron Storage Drum using MCNP5	CP (oral)
	Potential of Unused Pu-Be Isotopic Neutron Source for Detection of Gold by NAA	CP(oral)
2018	Design of Semi-portable Shielding for Cf-252 Neutron Source using MCNP5	CP (poster)
	Neutron Flux Mapping of a Pu-Be Neutron Irradiator using PHITS Monte Carlo Transport Code	CP (poster)
	Study on the use of Plexiglass and High-density Polyethylene Neutron Moderators for Spent Cf-252 Irradiator System	CP (poster)
	Technical Report on the Characterization of Proto-type Cf-252 Neutron Irradiator using Gas Proportional Counter (BF3) and Gold Foil Activation Method	TR
	Effect of Low-dose Neutron Irradiation by a Cf-252 Neutron Source on *Escherichia coli* (*E. coli*) Survival	UT

*Notes: UT – undergraduate thesis, TP – technical paper, CP – conference proceedings (oral, poster, country presentation), TR – technical report

ACKNOWLEDGMENTS

The authors wish to thank the IAEA. A large portion of this work was supported by the IAEA through the Technical Cooperation Project, TC Project PHI 0015. The authors would also like to express their sincerest gratitude to the different sections of the DOST-PNRI who have contributed to the success of the capacity building – namely the Office of the Director, Radiation Protection Services Section, Nuclear Training Center, and Isotope Techniques Section.

NOTES ON APPENDICES

The complete appendices section of the study is accessible at http://philjournalsci.dost.gov.ph/

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Appendix I. ANS lectures.

Topic	Contents
Introduction to Radiation Dosimetry	Radiation Quantities: Exposure (R); Absorbed Dose (Gy); Equivalent Dose (Sv); Radiation Dosimetry: Dose Limits; Lethal Dose; Time, Distance, Shielding; ALARA Principle
Interaction Cross Section	Interaction Probability; Attenuation Equation; Interaction Probability Density; Mean Free Path; Linear Attenuation Coefficient (charged particles and photons); Macroscopic Cross-section (neutrons); Atomic Density; Linear Energy Transfer (charged particles)
Overview of Prerequisites Basic Physics Knowledge	Momentum, Impulse and Collisions; Thermal Properties of Matter; Relativity; Wave-Particle Duality; Properties of Photons; Quantum Mechanics; Atomic Structure; Molecules and Condensed Matter; Nuclear Physics
Basic Radiation Detection and Instrumentation	Types of Radiation; Types of Radiation Detectors; Types of Electronic Detectors: Gas-filled, Semiconductor, Scintillator; Voltage Response Curve for Gas-filled Detectors; Radiation Instrumentation: Pre-amp, Oscilloscope, Amplifier, SCA, MCA
Basic Neutron Physics I	Basic Properties of Neutrons; Nuclear Reactions and Compound Nucleus; Conservation Laws; Q-value; Production of Neutrons (photonuclear, fusion, fission, spallation); Neutron Energy Distribution; Neutron Sources in DOST-PNRI (optional); Interaction of Neutron with Matter
Gamma Spectrometry Using NaI and HPGe Detectors	Interaction of Photons With Matter; Basic Concepts of Photon Radiation Detection and Measurement Using NaI Scintillation Detector and HPGe Semiconductor Detector; Components of a Gamma Spectrum; Understand Calibration Types – Energy, Resolution, and Efficiency
Basic Neutron Physics II	Interaction Cross-Section (macroscopic, mfp, resonance); Elastic Collision; Center of Mass *vs.* Laboratory Frame; Neutron Scattering and Absorption; Lethargy; Neutron Slowing Down; Maxwell-Boltzmann Distribution; Neutron Density; Neutron Flux; Reaction Rate
Neutron Detection I	Simple Active Gas-filled Neutron Detectors – BF3, He3, and Li; Neutron Detection Instrumentation; Energy Spectrum and Wall Effect; Fast Neutron Detection; Neutron Moderation
Neutron Detection II	Passive Neutron Detection by Activation; Activation Rate and Decay Rate; Decay Correction; Neutron Flux Estimation; Atom Density; Nuclear Reaction of Interest; Properties of Activation Detector Materials
Neutron Flux and Dose Measurement	Neutron Energy Distribution; Flux-to-Dose Conversion; Detector + Moderator – REM Ball, Bonner's Sphere; Proton Recoil Scintillation Detector
Intro to Laboratory Safety Practices	Laboratory Rules; Laboratory User's Logbook; User's Manual; Controlled Area; Handling of Radioactive Sources; Personnel Monitoring Devices; Radiation Monitors; Time-Distance-Shielding Principle; Data Logging
Introduction to Nuclear Instrumentation	Types of Cables; Oscilloscope; Detectors; NIM Bin; Module Functions – High Voltage Supply, Pre-amplifier, Amplifier, Single-channel Analyzer, Counter/Scaler/Timer; Multi-channel Analyzer; Description of Output Pulses from Pre-amp, Amp, and SCA; Single-channel Pulse Height Analysis
Gamma Spectrometry Using Sodium Iodide Detector	Parts of an MCA Gamma Spectrum – Photopeak, Compton Peaks and Other Spectrum Artefacts; $1/r^2$ Fall-off and Attenuation Effect; Energy, Resolution and Efficiency Calibration; Identification of Background Spectrum
Neutron Detection Using Gas-filled Detectors	Measurement of Bare and Shielding Source; Neutron Moderation; Gamma Discrimination; Wall Effect; Neutron Absorption
NAA (optional)	Description of Activation Foils *i.e.*, Au or In; Irradiation of Foils; Gamma Spectrometry; Computation of Flux

Appendix II. ANS Laboratory demonstrations.

Laboratory demonstration	Contents
Intro to Laboratory Safety Practices	Laboratory Rules; Laboratory User's Logbook; User's Manual; Controlled Area; Handling of Radioactive Sources; Personnel Monitoring Devices; Radiation Monitors; Time-Distance-Shielding Principle; Data Logging
Introduction to Nuclear Instrumentation	Types of Cables; Oscilloscope; Detectors; NIM Bin; Module Functions – High Voltage Supply, Pre-amplifier, Amplifier, Single-channel Analyzer, Counter/Scaler/Timer; Multi-channel Analyzer; Description of Output Pulses from Pre-amp, Amp, and SCA; Single-channel Pulse Height Analysis
Gamma Spectrometry Using Sodium Iodide Detector	Parts of an MCA Gamma Spectrum – Photopeak, Compton Peaks and Other Spectrum Artefacts; $1/r^2$ Fall-off and Attenuation Effect; Energy, Resolution and Efficiency Calibration; Identification of Background Spectrum
Neutron Detection Using Gas-filled Detectors	Measurement of Bare and Shielding Source; Neutron Moderation; Gamma Discrimination; Wall Effect; Neutron Absorption
NAA (optional)	Description of Activation Foils *i.e.*, Au or In; Irradiation of Foils; Gamma Spectrometry; Computation of Flux