Radiation Metrology

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Ionizing Radiation Metrology: Role of BARC as a "Designated Institute"

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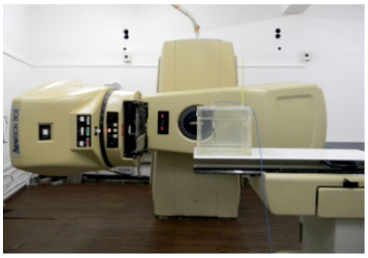

Tele-cobalt calibration facility

ABSTRACT

BARC is the DI for ionizing radiation and represents India in the consultative committee of CIPM, IAEA and APMP. It realizes, establishes, maintains, and upgrades the national measurement standards & calibration facilities for ionizing radiation measurements which has applications in medical, environmental, radiation protection, industrial and scientific research. The activities carried out at BARC are related to dosimetry for radiotherapy, brachytherapy, nuclear medicine, radiation processing, radiation protection, calibration of radiology instruments etc. BARC is in the process of implementing Quality Management System as per ISO/IEC:17025 and progressing for an international peer review.

KEYWORDS: *Dosimetry, Radiotherapy, Radiation protection, Radiopharmaceutical, Nuclear medicine, Radiation metrology*

Introduction

Metrology is the science of measurement which ensures that measurements are consistent, comparable, accurate and have stated level of uncertainty, in any field of science and technology. Metrology assures the measurement results, required in the important areas like national/international trade, health, safety, environmental monitoring, food safety, regulatory and law enforcement. These measurement results are linked to a national standard (primary/reference measurement standards) through a documented unbroken chain of calibrations, each contributing to the measurement uncertainty. The responsibility of maintaining measurement standards and its dissemination lies with the National Metrology Institute (NMI) or Designated Institute (DI) of that country. In India, CSIR-NPL is the NMI whereas Bhabha Atomic Research Centre (BARC) is the DI for Ionizing Radiation (IR). Similarly, responsibility of maintaining international measurement standards and its dissemination lies with International Bureau of Weights and Measures (BIPM) which is an international organization established by the Metre Convention, through which Member States act together on matters related to measurement science and measurement standards. The activities of BIPM are supervised by International Committee for Weights and Measures (CIPM).

As the "Designated Institute" (DI) for ionizing radiation, BARC represents India in the consultative committee of CIPM, International Atomic Energy Agency (IAEA) and regional metrology organization i.e., Asia Pacific Metrology Programme (APMP). Additionally, BARC is also recognized as Secondary Standards Dosimetry Laboratory (SSDL) for India by IAEA, in collaboration with World Health Organization (WHO). Therefore, as the DI, the statutory obligation of BARC is to realize, establish, maintain, and augment the national measurement standards & calibration facilities for ionizing radiation measurements which has applications in medical, environmental, radiation protection, industrial and scientific research. Accordingly, BARC has developed, established, and is maintaining various standards (primary, secondary, working and field standards) for ionizing radiation, covering the measurements of alpha, beta, gamma, X rays and neutrons. The degree of equivalence of these measurement standards are established through participation in international intercomparisons conducted by Consultative Committee for Ionizing Radiation (CCRI), BIPM, Asia Pacific Metrology Program (APMP) and IAEA. Participating in these comparisons (i) demonstrates the international equivalence of national measurement standards, (ii) enables exchange of knowledge, information, and experience at the international level and (iii) contributes to global decision-making concerning metrological developments. BARC also participates in the postal quality audit, conducted by IAEA, for assessment of the quality of service provided by it.

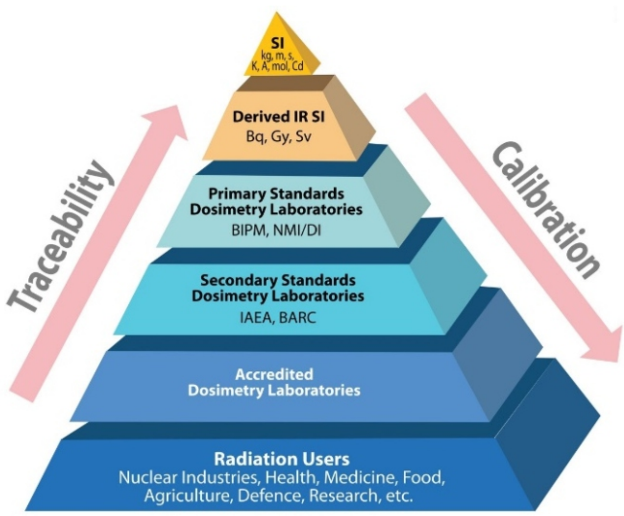

Fig.1: Hierarchy of traceability chain (present status of radiation dosimetry in India).

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Fig.2: a) Tele-cobalt calibration facility, b) Typical cylindrical ionization chamber, c) Parallel plate ionization chamber.

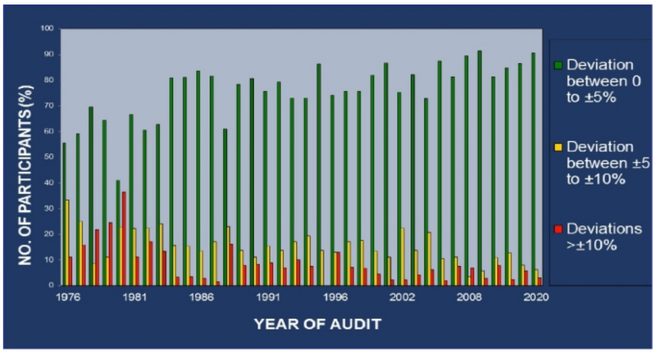

Fig.3: Dosimetric Quality Audit Programme conducted by SSDL-BARC.

BARC disseminates the ionizing radiation measurements to the end users in the country by means of providing traceable calibration services. The traceability chain of radiation measurement is a vertical concept (as shown in Fig.1: present status of radiation dosimetry in India, as per IAEA terminology). In the hierarchy, the SI units of a measurement have highest accuracy and are realized by international measurement standards. National measurement standards, maintained in a National Metrology Institute (NMI) or the DI is compared with these international standards. The result of such comparisons, together with the degree of equivalence and uncertainty of the national standard are stated and available in the BIPM key comparison database at www.bipm.org/kcdb. The national standards serve as a reference for calibration of users standards with lower precision or higher uncertainty. At each stage in the traceability chain, a certain degree of precision is lost.

The activities carried out at BARC are synonymous to the activities of CCRI which is distributed in three sections of CCRI namely CCRI Section I (Dosimetry): X- and gamma rays, charged particles; CCRI Section II (Radioactivity Measurement): Measurement of radionuclides and CCRI Section III (Neutron): Neutron measurements. In BARC, the responsibility of looking after the activities of the DI lies with Radiation Standards Section (RSS), Radiation Safety Systems Division (RSSD), Health Safety & Environment Group (HS&EG). Some of the important activities of BARC as the DI, are discussed here.

Activities related to ionizing radiation dosimetry

Dosimetry of ionizing radiation deals with application related to medicine (treatment of cancer and diagnostic radiology), radiation protection and radiation processing. In medicine (radiotherapy and brachytherapy), accurate dosimetry is very important for optimization of cancer treatment. It is also important for radiation protection of occupational workers (working in various radiological and nuclear facilities) and patients undergoing diagnostics examinations (radiology). Similarly, dosimetry is also important for radiation processing like blood irradiation, sterilization of health care products, processing of food & agriculture products, etc.

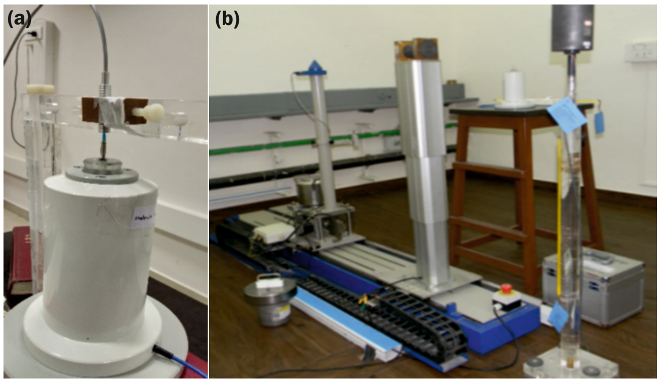

Fig.4: a) Well type ionization chamber, b) BARC brachytherapy calibration facility.

Dosimetry for radiotherapy

Radiotherapy, an important tool for cancer cure, requires the highest level of accuracy (within ±5%) to optimize the absorbed doses delivered to the tumour, sparing surrounding normal tissues. In India, currently, there are over 500 radiotherapy institutes having more than 230 telecobalt and 350 accelerator units. To ascertain the stated level of accuracy of dose delivery in India, SSDL-BARC has established a telecobalt facility (Fig.2a), that maintains measurement standards (ionization chamber, Fig.2b), calibrates dosimeters of hospitals and conducts TLD postal dose quality audit for radiotherapy centres. Cylindrical ionization chambers (Fig.2b) and parallel plate ionization chambers (Fig.2c) of nominal volume about 0.6 cc are generally used in dosimetry of external beam therapy. SSDL-BARC maintains a reference standards ionization chamber for absorbed dose to water which is calibrated at BIPM with a relative standard uncertainty of 0.2%. The user (hospitals) chambers are calibrated against this standard, in terms of absorbed dose to water as per the IAEA TRS 398 [1] protocol. This calibrated chamber is used by hospitals/radiotherapy centres to perform dosimetry of their beam qualities, used for radiotherapy. Annually, ~300 such chambers (Secondary Standard Dosimeters) are calibrated at SSDL-BARC. SSDL-BARC also maintains reference standard ionization chamber for air Kerma at ^{60}CO energy and provides calibration against this standard.

An independent verification of the quality of the dosimetry practices in hospitals / radiotherapy centres is also carried out by RSS, RSSD, BARC through postal dose quality audits. Since 1976, SSDL-BARC has been conducting TLD postal dose quality audits leading to improvement in the accuracy of the dose delivery capability at radiotherapy centers over a period of 5 decades (Fig.3).

Dosimetry for Brachytherapy

Brachytherapy dosimetry generally involves use of Well type ionization chambers (Fig. 4a) of nominal volume of around 200 cc to determine the brachytherapy source strength. Calibrations of these dosimeters are carried out in terms of

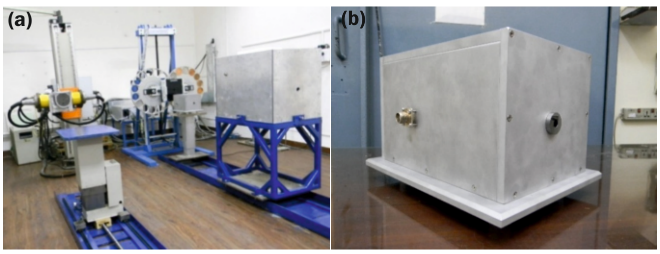

Fig.5: a) X-ray calibration facility, b) Free air ionization chamber for 20-150 kV X-rays.

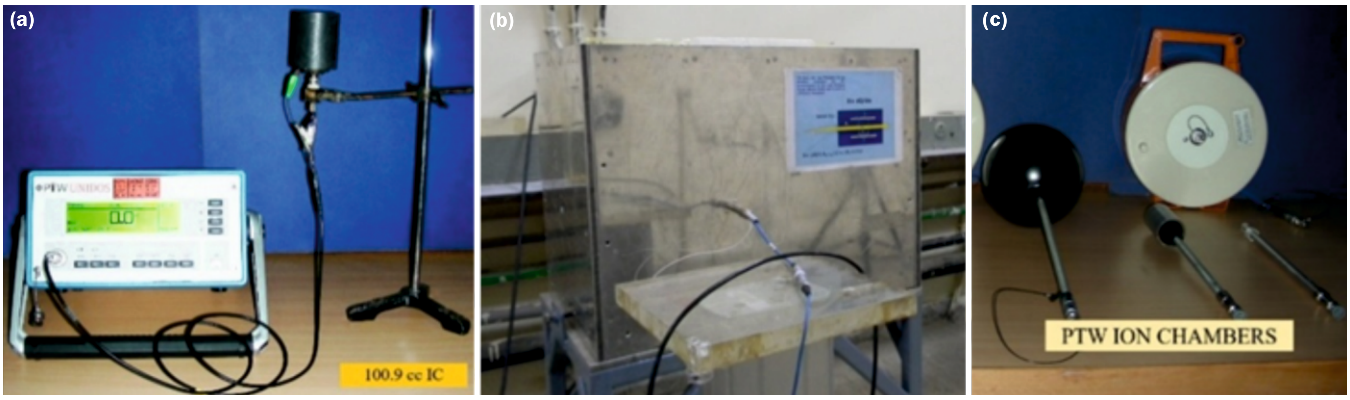

Fig.6: a) 100.9cc graphite ion chamber, b) Free air ionization chamber (upto 300 kV), c) Working standards for radiation protection.

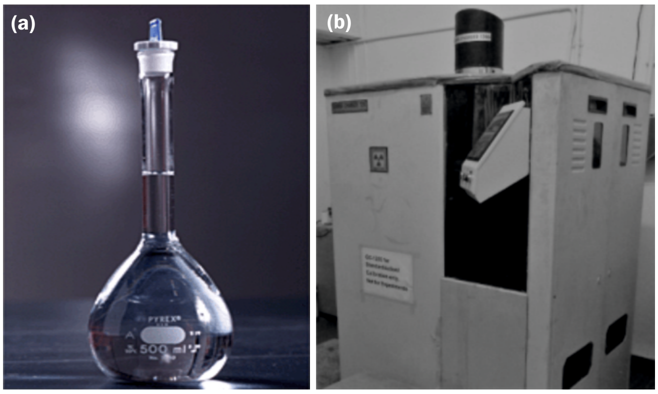

Fig.7: a) Fricke solution in a standard volumetric flask; b) Gamma Chamber 1200.

reference air Kerma rate (RAKR) for ^{192}Ir and ^{60}Co energy as per IAEA TECDOC 1274 recommended procedure [2]. BARC has developed a reference standard (graphite walled ionization chamber having a nominal volume of 1000 cc, Fig.4b) for RAKR measurement and calibration of well type ionization chambers. Annually around 100 well type ion chambers are calibrated at ^{192}Ir based brachytherapy calibration facility (Fig.4b) of BARC. In addition, onsite well type chamber calibration is also carried out for ^{60}Co HDR brachytherapy sources based on the request from institutions.

Dosimetry for calibration of radiology instruments (20-150 kV X-ray diagnostic beam qualities)

SSDL-BARC has established nineteen diagnostic beam qualities at its X-ray calibration facility (Fig.5a), as per recommendations of IEC 61267 [3] and the IAEA protocol TRS-457 [4]. These beam qualities are established using the free air ionization chamber (Fig.5b), a primary standard. Traceable calibration is provided at these beam qualities for users.

Dosimetry for Radiation Protection

Radiation monitors (radiation survey meters, area gamma monitors, environmental monitors, and pocket dosimeters) are backbone for all the radiological and nuclear installations, for the safety of radiation workers. Periodic calibration of these radiation monitors is required to ensure that they are working properly and are suitable for their intended use/purpose. BARC has developed and is maintaining a cavity ionization chamber (Fig.6a) and a Free air ionization chamber (Fig.6b) as national standard for gamma and X-ray dosimetry, respectively. Commercially available PTW ion chambers (Fig.6c) are calibrated against reference standards and are used routinely for calibration of users radiation monitors and radiation fields. Radiation monitors, installed in almost all the radiological facilities of BARC, are calibrated for dose rate range 1 μGy/h (~1 μSv/h) to 100 Gy/h (~ 100 Sv/h). Annually, more than 300 radiation monitors are calibrated at RSS, BARC.

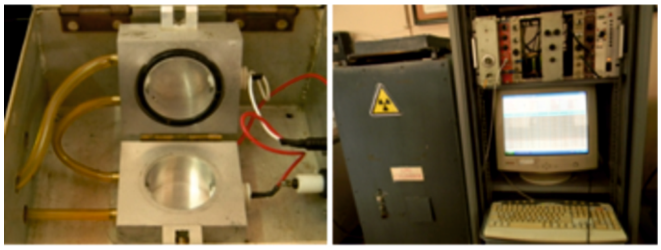

Fig.8: Photograph of 4πβ (PC) - γ coincidence counting system.

Role of BARC in establishment of calibration laboratories and their traceability

BARC provides measurement traceability, technical support, and guidance for establishment of radiation monitors calibration laboratories by government bodies and private agencies. Currently, more than 10 NABL accredited/AERB recognized calibration laboratories are established with the help from BARC which are spread across the country. Three of them are within DAE (IGCAR, Kalpakkam, ECIL, Hyderabad and BRIT, Vashi), one in defence (Defence Laboratory, Jodhpur) and the remaining from the private sectors.

Dosimetry for Radiation Processing

Now a days, radiation processing technologies are very widely used in medical (blood irradiation) and industrial applications like sterilization of health care products, processing of food & agriculture products (for disinfestation, shelf-life extension, sprout inhibition, pest control, sterilization, etc.) and materials modification (such as polymer cross linking, chain scission and gemstone colorization, etc). Proper dosimetry is the backbone of success of these high dose applications (few Gy to kGy range). BARC maintains Fricke dosimeter (Fig.7a) as a primary reference standard, according to ISO/ASTM 51026 [5], in this field.

Gamma chamber (Fig.7b), used for irradiation and other R&D applications in this field, are calibrated using the Fricke dosimetry system; as per ISO/ASTM 52116 standard [6]. BARC also maintains and uses other dosimeters like Alanine ESR, glutamine (indigenously developed), etc. for dosimetry in the field of radiation processing. These standards provide results with uncertainty better than 3-4% at coverage factor k =1.

Activities related to Radionuclide measurements (CCRI Section II):

Metrology in Nuclear Medicine

There has been a tremendous surge of usage of radioisotopes in medical applications especially in the field of

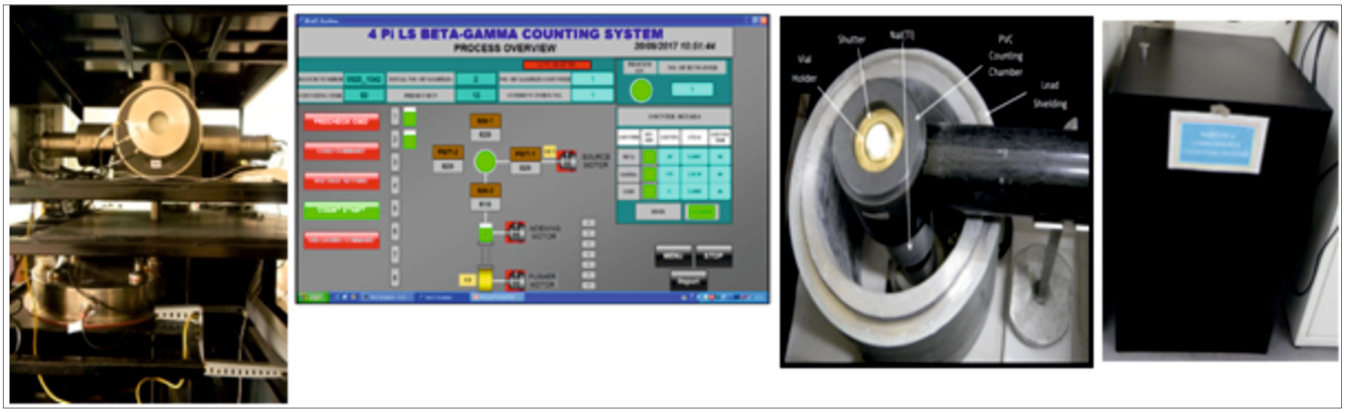

Fig.9: Photograph of 4πβ (LS) - γ coincidence counting system.

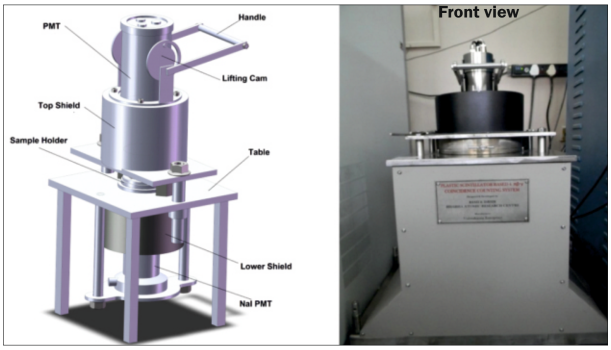

Fig.10: 4πβ (PS) - γ coincidence counting system.

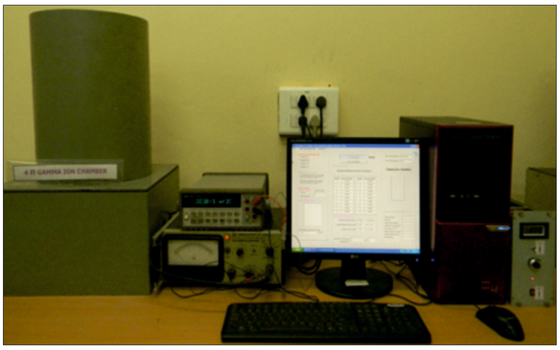

Fig.11: Photograph of 4π re-entrant pressurized gamma ionization chamber.

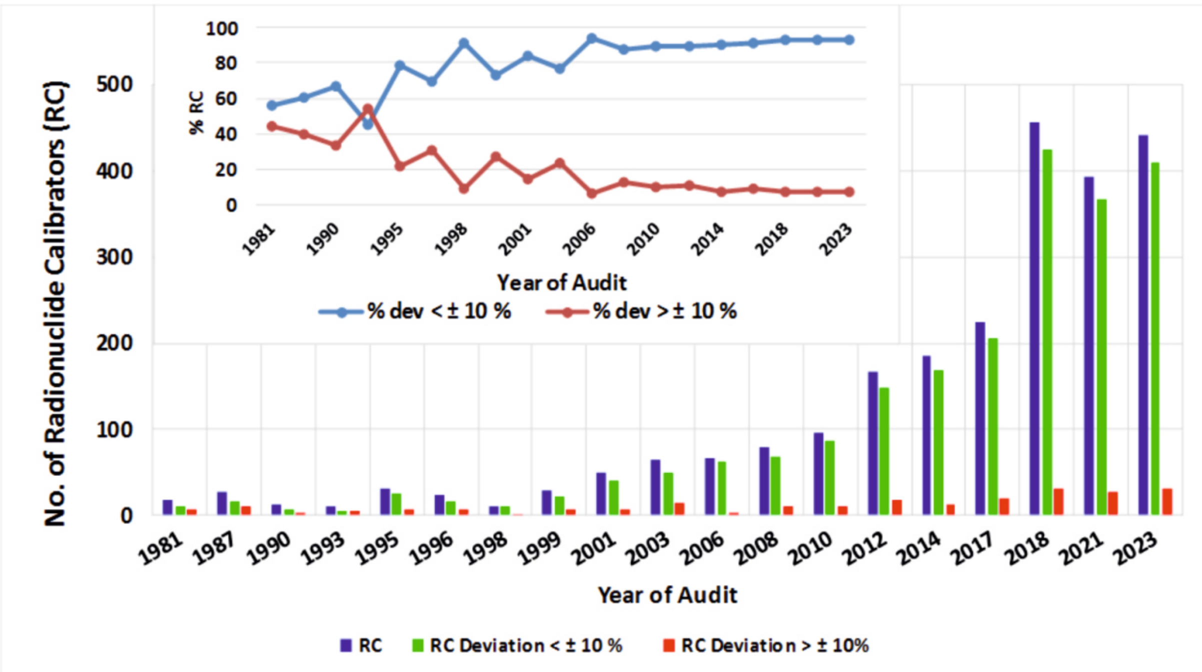

Fig.12: Summary of ^{131}I National Audit results conducted from 1981 to 2023.

nuclear medicine. One such application is targeted therapy where the liquid form of radioisotope is administered orally or intravenously to the patients to specifically target the diseased tissue while sparing the surrounding healthy tissue. Therefore, it becomes very important to measure the activity of radioisotope, to be administered, accurately so that the patient receives optimum dose with minimal risk.

The safety and efficacy of the radiopharmaceutical (RP) depends on various factors and on the ability of the clinic to accurately determine the amount of radioactivity which determines the dose to the patient. Prior to administering the RP to the patient, the activity of the RP is measured at the nuclear medicine centres using the radionuclide calibrators (RC). BARC has been conducting national audit programme biannually for activity measurements with RC over four decades (since 1979), Quality audit programmes (QAPs) help to ensure that the RCs are working satisfactorily so that the activity of the radiopharmaceutical measured before administering to patients is within the acceptable limits of 10% from the prescribed dose. The results of all the audits conducted over four decades, since 1979 to 2021 for Dose calibrators for ^{131}I are shown in Fig.12 which shows an encouraging result, as the number of RCs whose deviation greater than ± 10% has declined tremendously over the years.

Fig.13: a) Manganese sulphate bath system, b) Thermal stag, c) Portable Thermal neutron water jig.

BARC ensures accurate activity measurements by means of various primary and secondary standards developed and maintained for radioactivity measurements.

The primary standards based on coincidence technique for activity measurements are a) Proportional counter based 4πβ (PC)-γ coincidence counting system (Fig.8) and b) Liquid scintillation based 4πβ (LS)-γ coincidence counting system (Fig.9) and c) Plastic scintillation based 4πβ -(PS)-γ coincidence counting system (Fig.10).

The secondary standard for activity measurements for gamma emitting radionuclides is the re-entrant pressurized gamma ionization chamber (GIC) that has an excellent stability (Fig.11). The typical uncertainty of activity measurements with GIC is about ± 3% at k =2. The GIC measurements are traceable to national and international standards.

Activities related to Neutron measurements (CCRI Section III)

Neutron measurements in the country are traceable to the national standards developed, established, and maintained at RSS, BARC. The primary standard for the neutron source yield measurement is the manganese sulphate bath system (Fig.13a) while that for thermal neutron fluence rate is the thermal stag (Fig.13b) whose fluence rate is traceable to international laboratories in terms of gold and manganese cross section. A water jig with a 5Ci ^{241}Am-Be neutron source is regularly used for the onsite testing and calibration of start-up counters, DNM detectors and ion chambers used in power reactors to ensure the traceability to the national standards.

Quality management system

Currently, BARC is in the process of implementing Quality Management System as per ISO/IEC:17025 [7] and progressing for an international peer review, as required by CIPM-Mutual Recognition Arrangement (CIPM-MRA), for getting our Calibration Measurement Capabilities (CMC) published in the Key Comparison Database of BIPM (KCDB) so that calibration certificates issued by BARC would have global acceptability for international trade/commerce.

Conclusion

An overview of the metrological activities of ionizing radiation and the standards maintained per se at BARC are summarized briefly in the present paper. The international equivalence of the radiological standards maintained at BARC has been well-established with the other national metrology institutes around the world as well as demonstrated traceability of measurements to international system (SI) through regular participation in the intercomparison programmes organized by BIPM, IAEA and APMP. In addition, metrological traceability of measurements in the country at the end user level too is very well established by providing calibration services and through conducting regular audit programmes for various radiation units. Summing up it can be ascertained that BARC is able to meet satisfactorily the demands in the field of nuclear measurements and corroborated measurement traceability in India. In the recent years as a DI, BARC is endeavouring and expanding the field of ionizing radiation metrology, to address the requirements of stakeholder such as radiotherapy centres, nuclear medicine centres, nuclear reactors and research, accelerators and radiation processing industries etc. The measurement traceability ascertains confidence in the crucial results needed for drug, device development and marketing, therapy planning and efficacy, disease screening, patient safety, and industry support for now and into the future.

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