Quality Assurance of Radiation Protection Monitoring Instruments in India

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Abstract. Bhabha Atomic Research Centre (BARC) is the National Metrology Institute (NMI) for developing, maintaining and disseminating standards for ionizing radiation in India. Radiation Safety Systems Division (RSSD) of BARC has the requisite infrastructure in the form of experts, trained manpower, laboratories, equipments and facilities for providing calibration services to users and ascertaining traceability to international standards. It periodically participates in various international inter-comparisons. RSSD maintains reference radiation fields that are required for calibrating Radiation Protection Monitoring Instruments that form the backbone of the radiation monitoring programme for harnessing the benefits of nuclear energy and ionizing radiations. These instruments are type-tested and periodically calibrated at standard reference radiation fields to ensure their healthy working condition and fitness for their intended use. This paper describes the details of the standardization procedures adopted for reference radiation fields and infrastructure established and maintained at RSSD, BARC in accordance with the recommendations of ISO-4037. The paper describes the various tests that are carried out for radiation protection monitoring instrument to study the variation of the calibration factor with influencing quantities like linearity of response, energy response, angular dependence and overload characteristics. The results of these tests for typical instruments are also discussed. The present work also describes various types of indigenously developed radiation protection monitoring instruments and their performance characteristics. Adaptability of these instruments for the implementation of operational quantities are discussed briefly. It also dwells on the IAEA Quality Audit for radiation protection level calibrations, which RSSD has been participating since 2001. Our results of the quality audit are well within the acceptance limit (±7%) set by IAEA for the participating laboratories.

KEYWORDS: Metrology, traceability, quality assurance, quality audit, radiation monitors, type testing

1. Introduction

The quality of a radiation protection program depends on the quality of the radiation measurements made by the radiation protection monitoring instruments. Mostly the quality is unknown and is merely evaluated on the basis of the calibration. If these instruments are not calibrated then the decisions based on these instruments will be misleading. Quality assurance involves the methods used to ensure that the dosimetric measurements are correct and traceable to national standards. Radiation Standards Section of Radiation Safety Systems Division, Bhabha Atomic Research Centre, Mumbai maintains the national standards for ionising radiation in India. It is the apex laboratory to develop, maintain and disseminate standards for ionising radiation measurements. This paper describes the methods adopted for quality assurance of radiation protection monitoring instruments in India based on the recommendations of ISO-4037.

2. Reference standard for protection level calibration

A 100.9 cc cylindrical graphite walled ion chamber is maintained as a reference standard for the calibration of protection level radiation monitoring instruments [1]. The sensitivity of this ion chamber was calculated and experimentally established according to the procedures for the dosimetry of X and gamma reference radiation specified in ISO 4037-2 [2]. Various parameters like saturation characteristics, linearity of response, energy response, polarity effect, short-term stability and long-term stability were studied to establish it as a reference standard. The output current of the ion chamber is measured using a sensitive digital picoammeter (UNIDOS, PTW make). The reference radiation fields maintained at BARC have been standardized using the 100.9 cc reference standard ion chamber. The overall uncertainty in the standardization of the radiation field with reference standard has been evaluated to be within ± 5% using the GUM method, recommended by ISO [3]. Recently

three ion chambers (0.3 cc, 30cc and 1lit) have been procured from PTW, Germany for establishing them as standard ion chambers to cover a wider range of air kerma rates.

3. Calibration facilities at Radiation Standards Section

Radiation Standards Section has requisite infrastructure comprising of laboratories and equipment for the calibration of protection level radiation monitoring instruments. A wide range of reference radiation fields is maintained for the calibration of radiation monitoring instruments from 100 μR/h to 10^4 R/h. Three different laboratories are equipped with radioactive sources of different strengths. The dimensions of the laboratories conform to the requirements of ISO-4037-1 for less than 5% scattering contribution [4]. The laboratories are well equipped with Radiation Instrument Positioning System (RIPS) for accurately positioning the instruments at the desired distance in the reference radiation field. Laser beams are used for the alignment of the instrument in the collimated radiation beam. Qualified and experienced staff carries out the calibration. The details of facilities for the calibration for radiation protection monitoring instruments are given in Table 1. Protection Level Calibration Laboratory has been shown in Fig. 1.

Table 1: Details of the facilities at Radiation Standards Section

Name of the Facility	Source Exposure Device	Source	Nominal Activity
Protection Level Calibration Laboratory	Multi Source Exposure Device	^{137}Cs	37 MBq
		^{137}Cs	370 MBq
		^{137}Cs	3.7 GBq
		^{137}Cs	37 GBq
		^{137}Cs	370 GBq
		^{137}Cs	3.7 TBq
		^{60}Co	1.85 GBq
		^{241}Am	37 GBq
	Cs - Camera with three attenuators	^{137}Cs	9.25 GBq
	Cs - Camera	^{137}Cs	74 GBq
	Am - Camera	^{241}Am	185 GBq
Low Energy Calibration Laboratory	XYLON Dosimetry Grade X-ray Machine	--	--
High Range Calibration Laboratory	Co-Radiography Camera	^{60}Co	370 GBq
Cobalt Teletherapy Laboratory	Cobalt Teletherapy Machine	^{60}Co	100 TBq

Figure 1: Protection Level Calibration Laboratory

4. IAEA TLD postal quality audit of ^{137}Cs reference radiation field:

Radiation Standards Section, RSSD, BARC is a member of the IAEA/WHO Network of SSDLs. It periodically participates in the TLD postal dose quality audits conducted by IAEA as a part of the quality assurance program. TLD samples are dispatched to the participants by IAEA, for irradiating it to a known dose. These samples are then evaluated at the IAEA Dosimetry Laboratory and the results are conveyed to the participating laboratories. The reference radiation field from a collimated beam of ^{137}Cs source exposure device is routinely used for the calibration of radiation protection monitoring instruments. This reference radiation field was standardised using a graphite walled reference standard ion chamber in conjunction with a digital picoammeter. Temperature and pressure corrections were applied to the measured current to evaluate the air kerma rate. The ion chamber was substituted by the TLD samples of IAEA by mounting it on a jig made up of low Z material to provide scatter free environment. These samples were irradiated to K_{air} = 5mGy at the calibration position free-in-air. The overall uncertainty in measurements was estimated by using the ISO recommended GUM method (refer Table 2). Since 2001 Radiation Standards Section, RSSD has been participating in the IAEA quality audit for radiation protection calibrations [5]. The results of all the previous quality audits were within the acceptance limit of ±7% as shown in Table 3.

Table 2: Uncertainty budget for the standardization of reference radiation fields

Quantity	**Type**	**(%)**
Current	A	0.09
,,	B	0.02
Sensitivity	B	0.20
Distance	B	0.07
Temperature	B	1.15
Pressure	B	0.33
Relative Combined Uncertainty (%)		**1.22**
Coverage factor		2
Overall Expanded Uncertainty (%)		**2.44**

Table 3: Results of quality audit conducted by IAEA

Year	**Participant stated / IAEA measured**
2001	0.99
2003	0.98
2005	0.99
2007	1.01

5. Protection Level Radiation Monitoring Instruments

Various types of protection level radiation monitoring instruments are manufactured in India. The instruments available are based on GM Tube, ion chamber, scintillation detector, and semiconductor detectors. Radiation Survey Meters based on GM tube with analog display, having multiple ranges up to 5R/h, are widely used for workplace area monitoring. The instruments are marked in terms of "mR/h" with a symbol of GM tube affixed to indicate the detector location. Radiation Survey Meters based on GM tube with digital display, measuring range up to 2000 mR/h, equipped with auto ranging facility, also are used widely for low level radiation monitoring. There are few instruments available

with readout in terms of "Sv/h". These instruments use a relation of 1 Sv = 100 R for changing the display to indicate in terms of Sv/h. Table 4 shows different types of radiation protection monitoring instruments manufactured in India and Fig. 2 shows typical radiation protection monitoring instruments manufactured in India.

Experiments conducted to assess the suitability of these survey meters for adapting them to indicate in terms of new operational quantities i.e. ambient dose equivalent, H*(10), revealed that those with flat energy response for exposure were not suitable at energies less than 100 keV for new operational quantities [6]. Type tests conducted on indigenously developed high range radiation survey meters having telescopic extendable probes indicated an acceptable response within ±20%. BARC has indigenously developed direct reading dosimeters for personnel radiation monitoring i.e. quartz fibre pocket dosimeters and semiconductor detector based digital pocket dosimeters. Calibration of these personnel dosimeters is carried out on phantom as recommended by ISO 4037-3 [7]. Experiments were conducted to study the linearity of response from 1 mR/h to 2.5 R/h using a ^{137}Cs source [8].

Table 4: Radiation Monitoring instruments calibrated at RSS, RSSD, BARC, Mumbai, India

Name of the instrument	Model No	Manufacturer	Ranges	Detector	Detector location	Display
Beta Gamma Exposure Ratemeter	SM 4502	ECIL, Hyderabad, India	0-50 mR/h, 0-500 mR/h, 0-5 R/h	Ion chamber (400 cc)	Not marked	Analog
Contamination monitor	CM 710E	Nucleonix, Hyderabad, India	0-20 mR/h	GM Tube	Not marked	Digital
Digicon		Nucleonix, Hyderabad, India	0-20 mR/h	GM Tube	Not marked	Digital
Gamma Radiography Survey meter	MR 4500A	ECIL, Hyderabad, India	0-5 mR/h, 0-50 mR/h, 0-500mR/h, 0-5 R/h, 0-50R/h	GM Tube	2 cm inside	Analog
Gamma Area Monitor	PAM - 365	PLA, Mumbai, India	0-100 mR/h	GM Tube	detachable probe	Digital
Gamma Area Monitor	PAM - 351 - L	PLA, Mumbai, India	0-9999 mR/h	GM Tube	detachable probe	Digital
Gamma Radiation Area Monitor	GA720	ECIL, Hyderabad, India	0-100 mR/h	GM Tube	detachable probe	Digital
Gamma Zone Monitor	AM 4551 B	ECIL, Hyderabad, India	0-100 mR/h	GM Tube	1 cm inside	Analog
Gamma Zone Monitor	Zone Monitor	Pulsecho Systems Ltd., Mumbai, India	0-100 mR/h	GM Tube	1 cm inside	Analog
Low Level Gamma Area Monitor	LR727	Nucleonix, Hyderabad, India	0-1000 mR/hr, 0.1-100 mR/hr	GM Tube	not marked	Digital
Radiation Survey meter	Minirad (Lo range)	Pulsecho Systems Ltd., Mumbai, India	0-5 mR/h, 0-50 mR/h, 0-500 mR/h	GM Tube	1 cm inside	Analog
Radiation Survey meter	Minirad	Pulsecho Systems Ltd., Mumbai, India	0-5 mR/h, 0-50 mR/h, 0-500 mR/h, 0-5 R/h	GM Tube	1 cm inside	Analog
Radiation Survey meter	Digirad (Lo range)	Pulsecho Systems Ltd., Mumbai, India	0-2 mR/h, 0-20 mR/h, 0-200 mR/h	GM Tube	1 cm inside	Digital

Radiation Survey meter	Digirad	Pulsecho Systems Ltd., Mumbai, India	0-20 mR/h, 0-200 mR/h, 0-2000 mR/h (auto ranging)	GM Tube	1 cm inside	Digital
Radiation Survey meter	MR-121-C	ECIL, Hyderabad, India	0-0.2 mR/h, 0-2 mR/h, 0-20 mR/h	GM Tube	Detachable probe	Analog
Radiation Survey Meter	PRM 125L	PLA, Mumbai, India	0-5 mR/h, 0-50 mR/h, 0-500 mR/h, 0-5000 mR/h	GM Tube	1 cm inside	Digital
Radmon	RM 701	Nucleonix, Hyderabad, India	0-2 mR/h, 0-20 mR/h,0-200mR/h, 0-2000mR/h, 0-20 R/h	GM Tube	1 cm inside	Analog
Radmon	RM 703	Nucleonix, Hyderabad, India	0-999.9 mSv/h, 0-9999 mSv/h, 0-99.99 mSv/h, 0-199.9 mSv/h	GM Tube	1.5 cm inside from symbol	Digital
Roentgenometer	RM 102	PLA, Mumbai, India	0-1 R/h, 0-10 R/h, 0-100 R/h, 0-1000 R/h	GM Tube	Marked	Analog
Teleminirad-II		Pulsecho Systems Pvt. Ltd., Mumbai	0-2.5 mR/h 0-50 mR/h 0-2.5 R/h 0-50 R/h 0-1000 R/h	GM Tube	Marked	Analog
Telescopic Survey Meter	TL-103	PLA, Mumbai, India	0-999 R/h	GM Tube	Marked	Digital

Figure 2: Photograph of typical radiation protection monitoring instruments in India

Gamma Area Monitors based on GM tube, having range 0-100 mR/h, are installed at the workplace for continuously monitoring the radiation level. They are equipped with audio and visual alarm signals for responding to radiation level above the set point. Nuclear power reactors in India are equipped with special type of gamma area monitors based on ion chambers designed to sustain the accidental scenario in the reactor. Performance evaluation of these ion chambers, designed and fabricated by Electronics Corporation of India Ltd. (ECIL), Hyderabad was carried out by studying its saturation characteristics, linearity of response, energy response, sustainability under LOCA conditions and high radiation exposure. Table 5 shows the linearity of response over a wide range of exposure rates.

Table 5: Linearity of response of ECIL make gamma ion chambers for power reactors

Type	Sensitivity (A/R/h) at					
	10 R/h	30 R/h	500 R/h	1000 R/h	3.47×10^4 R/h	2.16×10^5 R/h
G12	4.5×10^{-9}	4.5×10^{-9}	4.4×10^{-9}	4.35×10^{-9}	--	--
G12A	1.1×10^{-10}	--	1.12×10^{-10}	1.08×10^{-10}	1.13×10^{-10}	1.29×10^{-10}

Indian Real-time Online Decision suppOrt System (IRODOS) has been installed at Narora Atomic Power Station, Narora. It serves as an early warning system in near surroundings of the Nuclear Power Plant. The measurement data from these detectors will be used to take decisions in the event of a nuclear accident resulting in release of radioactivity in the environment. The system consists of 28 nos. of GM tube based detectors for radiation monitoring around the nuclear power plant. These are installed in two rings of 800m and 1600m radius around the nuclear power plant. The detectors are solar powered having GSM based mobile communication system. Performance evaluation of these detectors was carried out on-site to assess its integrity under field conditions by using standard radiation fields of 1 mR/h and 10 mR/h from ^{60}Co source, which is traceable to national standards [9]. The results of the measurements are shown in Fig. 3-4. Three inner ring IRODOS detectors showed an under-response at 10 mR/h whereas the remaining detectors had acceptable response within ± 30%.

Figure 3: Performance of the outer ring IRODOS detectors at 1 mR/h

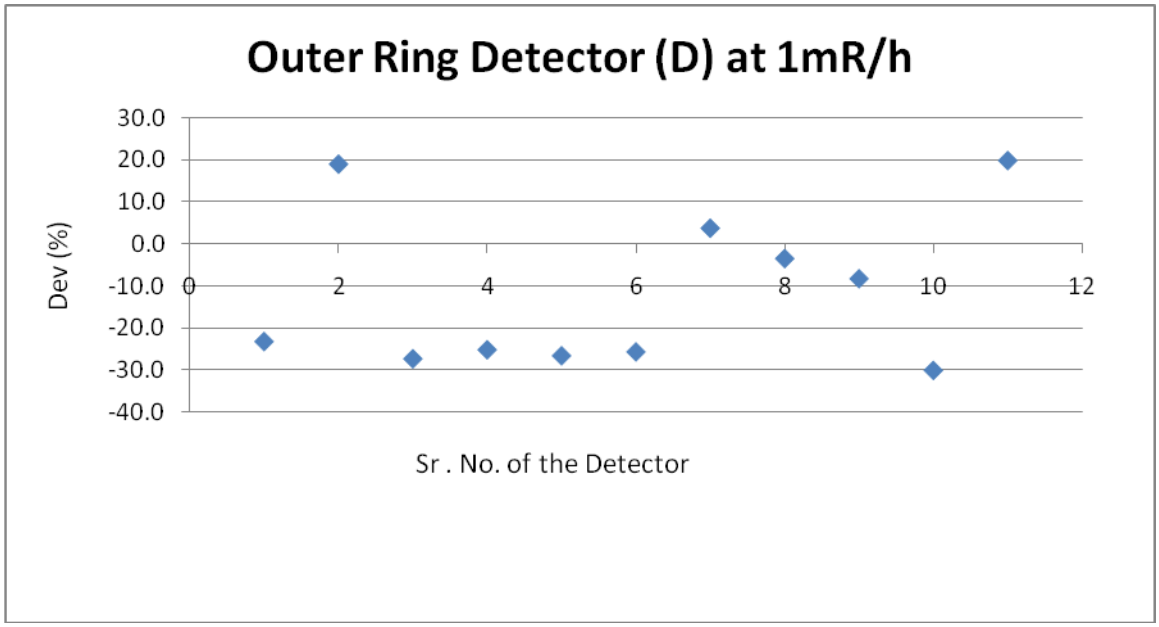
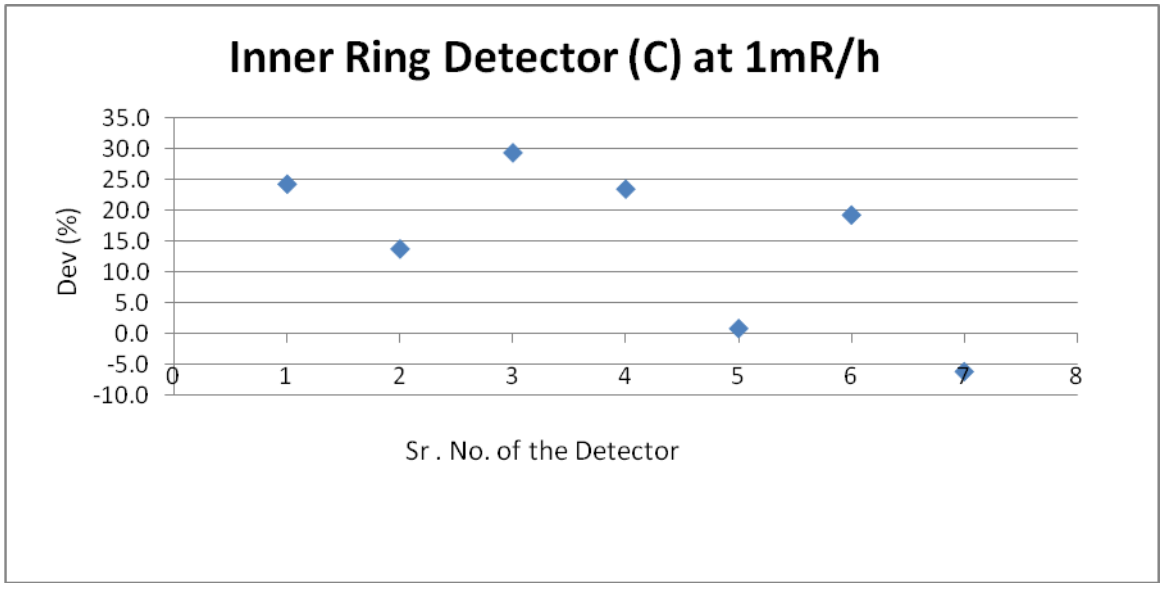


Figure 4: Performance of the inner ring IRODOS detectors at 1 mR/h



6. Traceability through on-site measurements

Presently there is only one accredited laboratory (Defence Laboratory, Jodhpur) for calibration of radiation protection monitoring instruments. TLD units and Health Physics Unit at the power reactor sites are maintaining reference sources for calibration of their instruments viz. TLD badge readers and radiation survey meters. Manufacturers of radiation monitoring instruments namely M/s PLA Electroappliances, Mumbai, M/s Pulsecho Systems Pvt. Ltd., Mumbai have reference sources for the in-house calibration of their instruments. On-site standardization of the radiation fields from the reference sources maintained at these laboratories have been carried out with the 100.9 cc reference standard ion chamber thus providing traceability to national standards for their measurements.

7. Statistical analysis of the results of calibration

More than 200 radiation protection monitoring instruments are calibrated annually. Fig. 5 shows the total number of instruments calibrated annually at Radiation Standards Section. These instruments belong to different organisations from various sectors like defence, research institute, government organisation, industry, hospitals and organisations belonging to Department of Atomic Energy (DAE), India. From the graph shown in Fig. 6 it is clear that 50% of the instruments calibrated annually, belong to DAE organisations. Fig. 7 states that on an average 70% of the instruments, submitted annually for calibration, are found to be in the "Acceptable category" i.e. observed reading is within ±30% of the true value. Whereas 25% of the instruments fall in the "Not acceptable category" i.e. observed reading is beyond ±30% of the true value. Also 5% of the instruments submitted for calibration were found to be non-functional.

Figure 5: Number of instruments calibrated annually for Department of Atomic Energy (DAE) and other institutions (NON-DAE)

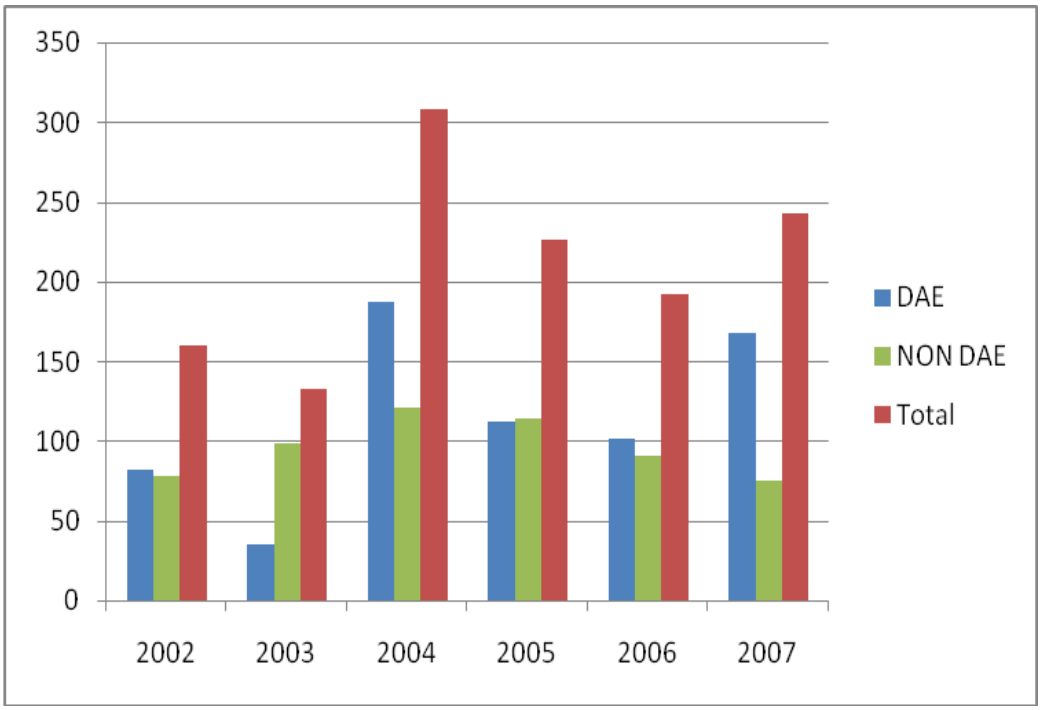


Figure 6: Institution-wise distribution of calibrated instruments (Defence, Research Institute, Government Institute, Industry, Hospital and Department of Atomic Energy)

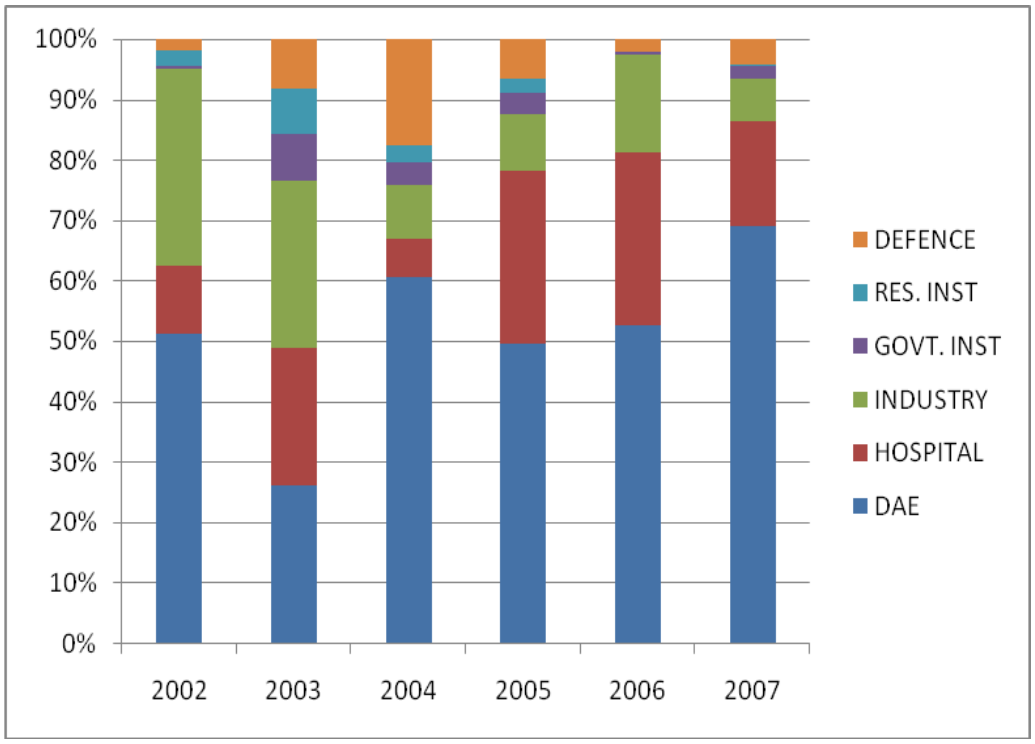
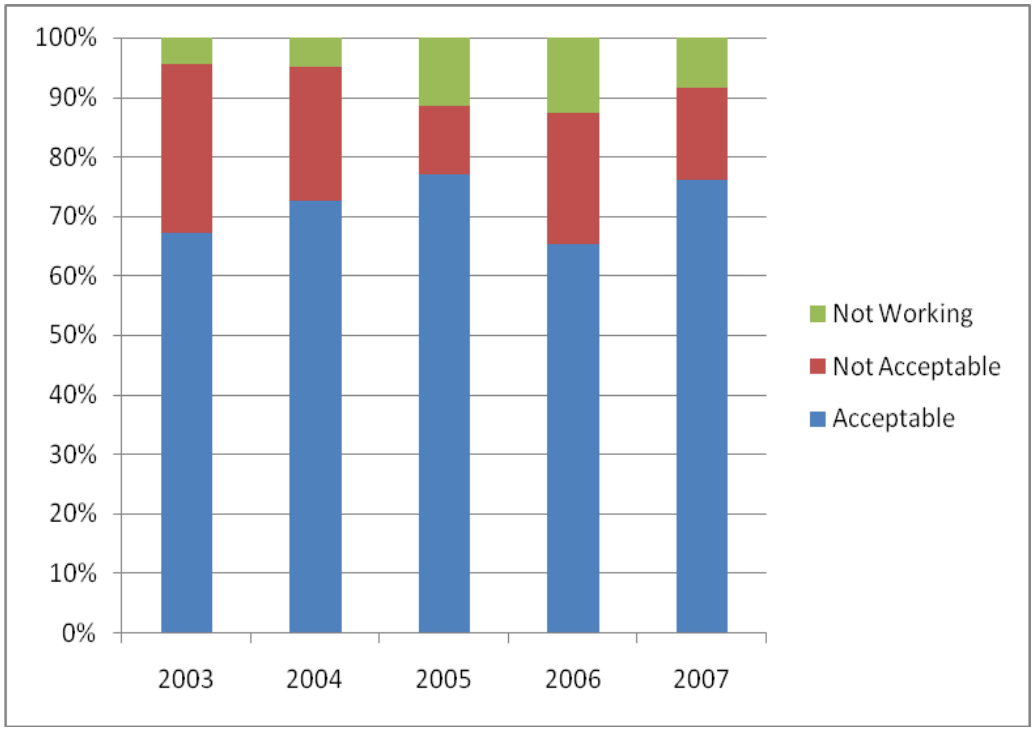


Figure 7: Status of instruments after calibration



7. Conclusion

Radiation Standards Section of Radiation Safety Systems Division, BARC is well equipped with the facilities for the calibration of radiation protection monitoring instruments. In India these instruments are type tested and calibrated according to the procedures recommended by ISO/IEC standards. The results of quality audit conducted by IAEA provide the confidence in dosimetric procedures adopted and standards maintained at Radiation Safety Systems Division, BARC. It is planned to accreditate few other laboratories for providing calibration services to the increasing number of radiation protection monitoring instruments.

8. Acknowledgement

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7. References

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