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Draft Indian Standard

RECOMMENDED PRACTICE FOR RADIOMETRY OF METALLIC COMPONENTS AND STRUCTURES USING SEALED RADIOACTIVE SOURCES

ICS 13.280

Nuclear Energy for Peaceful Application Sectional Committee, CHD 30 **Last date of comments:**

Nuclear Energy for Peaceful Application Sectional Committee, CHD 30

FOREWORD

(*Formal clause shall be added later*)

Radiometric testing is an indirect measurement technique used for troubleshooting and flaw detection in industrial structures and processes. Sealed source based gamma radiometry is often employed in many fields such as nuclear and its allied industries for detection of flaws present in the large and thick shielding components and assemblies. The flaws can be in the form of voids, cracks, foreign material or even design faults. Flaw detection in such manufactured components and assemblies is necessary for the purpose of reducing transmitted dose rate to an acceptable limit as permitted by the regulatory body.

Challenges in industrial radiometry include:

a) Development of a better manipulation system for source and detector positioning for efficient use of manpower and resources

b) Challenges with the time consumed to complete the job as in industry time is money

c) Finding faults in material with thickness higher than 1000mm of concrete or equivalent thickness

d) Obtaining regulatory clearance for use of radioisotope sources

In reporting the result of a test or analysis made in accordance with this standard, if the final value, observed or calculated, is to be rounded off, it shall be done in accordance with IS 2 : 2022 ‘Rules for rounding off numerical values (*second revision*).

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RECOMMENDED PRACTICE FOR RADIOMETRY OF METALLIC COMPONENTS AND STRUCTURES USING SEALED RADIOACTIVE SOURCES

1 Scope

This standard covers the recommended practice for sealed source based radiometry of metallic components and assemblies. The practice outlined in this document is intended to provide the basis for good working practices for producing desired radiometric results. This standard deals with equipment for radiometric testing, radiometry measuring technique, specimen preparation for radiometric measurements, data recording method and radiation protection in radiometry while using sealed radioactive sources.

2 REFERENCES

The standards listed below contain provisions which, through reference in this text, constitute provisions of this standard. At the time of publication, the editions indicated were valid. All standards are subject to revisions, and parties to agreements based on this standard are encouraged to investigate the possibility of applying the most recent editions of the standards listed below:

IS No.	*Title*

3 TERMINOLOGY

For the purpose of this standard, the definitions given below shall apply.

3.1 Source — That which causes radiation exposure either by emitting ionizing radiation or by releasing radioactive substances or materials.

3.2 Sealed Source — Sealed source means radioactive material that is –

a) permanently sealed in a capsule; or in a solid form which is closely bounded and
b) Is designed to meet the safety standards prescribed by the competent authority

3.3 Radiometric Source — A source sealed in one or more capsules or an X-ray tube, or an accelerator, or a neutron source which is used for radiometry work

3.4 Qualified Person — A person who, having complied with specific requirements and having met certain conditions, has been approved by the Regulatory body, where necessary, to discharge specified duties and responsibilities

3.5 Radiation Work — Radiation work means work involving exposure

3.6 Worker — worker means radiation worker

3.7 Controlled Areas — Areas which are occupied only by radiation workers and are under direct supervision of Radiological Safety Officer (RSO) are called controlled areas and the radiation levels in these areas shall not exceed the specified whole body dose limits for radiation workers.

4 EQUIPMENT FOR RADIOMETRIC TESTING USING SEALED GAMMA RADIOISOTOPE SOURCES

4.1 Typical radiometric measurement system consists of two components:

a) a sealed radioactive source that emits gamma radiation e.g., ^{60}Co or ^{192}Ir nuclide;
b) a nucleonic detector and data acquisition system.

4.2 In most cases, these two components are placed on the opposite side of an industrial component or assembly under investigation. The detector converts incident radiation into an electrical signal. The signal can be processed further to derive required information with the use of appropriate calibration. In industrial scenario, a wide variety of measurement geometries and requirements are encountered. Thus customized solution for each measurement task is designed through a combination of different sources and detectors.

Depending upon application,

a) Source and its activity,
b) Type of exposure – collimated or panoramic,
c) Detector type and
d) Data communication interfaces are selected.

4.3 A radioisotope to be useful in industrial radiometry should have;

a) suitable radiation energies to penetrate through component or assembly under examination,
b) higher radiation output,
c) reasonably long-half life and
d) possibility of economic production at higher specific activity.

4.3.1 To estimate radiation levels, activity of the source need to be determined on the day of testing by using supplier’s data and applying decay correction. Present activity of a sealed source is calculated by

$$A = \frac{A_o}{2^{\left(\frac{T}{\text{Half-life}}\right)}}$$

Where,

A_o is an initial activity at time;

T= 0 and;

A is activity after time T.

4.4 Iridium-192 and Cobalt-60 are two commonly employed gamma-emitting sealed radioisotope sources in industrial radiometry. The two sources together can cover an inspection range of thickness 10 mm to 200 mm steel equivalent. They are used by housing in a shielded container or device such as Industrial Gamma Radiography Exposure Device (IGRED) or gamma camera or radiography device. IGREDs are used to store, transport and make radiation exposure. For remote operation, radiography device is connected to cranking unit and guide tube to facilitate the movement of the source to the required position. This ensures minimum exposure to the operator and others. Fig. 1(a) depicts a typical gamma exposure device with cranking unit and guide tube. Fig. 1(b) shows source in metallic and disc form, source capsules well as pigtail. In India, many types of manual and remote operated radiography device are in use. The commonly used radiography devices are: ROLI models (ROLI-2/ROLI-3) and COCAM-120. In India, Board of Radiation and Isotope Technology (BRIT) supplies these devices incorporating Ir-192 and Co-60. They are designed as per various national and international standards and are approved by Atomic Energy Regulatory Board (AERB) for use in India and abroad. ROLI-2 is designed for Ir-192 source with a maximum capacity of 2.4 TBq (65 Ci). It is approved as a Type B (U) transportation package. ROLI-3 is a portable one. It is designed to carry 0.74T Bq (20 Ci) of Ir-192 source and approved as a Type A transportation package. COCAM-120 is a Type B (U) and is designed for a maximum capacity of 4.44 TBq (120 Ci) Co-60. Shielding material for there radiography devices is lead and heavy alloy. In these devices, source is housed in a small metal capsule at one end of a short flexible cable called a "pig tail". At the other end of the pig tail is a connector that is used to attach the source to a long "crank-out" cable. The crank-out cable allows the operator to operate the source from a safe distance.

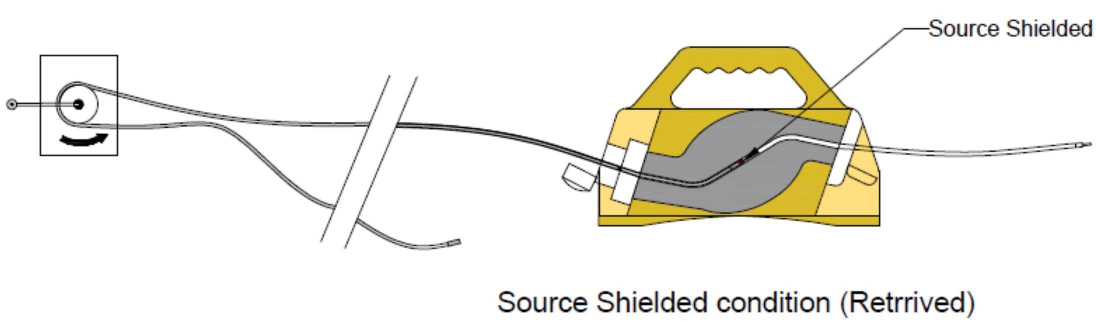

FIG. 1 (a) SCHEMATIC DIAGRAM OF A TYPICAL RADIATION EXPOSURE DEVICE WITH CRANKING UNIT AND GUIDE TUBE

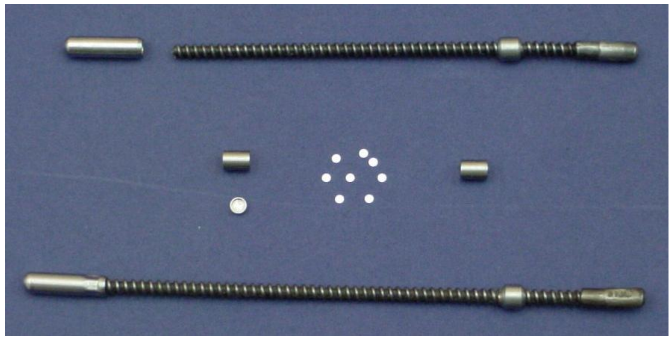

FIG. 1 (b) SOURCE IN METALLIC AND DISC FORM, SOURCE CAPSULE AND PIGTAIL.

4.5 The most commonly used detectors for industrial radiometric work are teletector with GM (Geiger-Muller) tubes and scintillation detectors. Teletector (*see* Fig. 2) is a portable detector very similar to radiation survey meter. But it employs two GM tubes to cover wide range from background upto 1 000 R/hr (10 Sv/hr) in five different scales starting from 0.5 mR/hr upto 0 to 1 000 R/hr (10 Sv/hr). As the name indicates, the detector can be moved telescopically away from the unit for measurement at a distance upto about 5 meters and the detector can be retrieved manually by telescopic arrangement. Another detector commonly employed for a wide range of detection applications is a scintillation detector (e.g., NaI(Tl)). By suitable choice of scintillator diameter (or shape) and thickness, from low background to high counting rates can be achieved. Detector should be calibrated before put in use.

FIG. 2 **C**OMMONLY USED DETECTOR (TELETECTOR) IN INDUSTRIAL RADIOMETRY

5 GENERAL PROCEDURE FOR INDUSTRIAL RADIOMETRIC TESTING OF METALLIC COMPONENTS AND STRUCTURES

5.1 Fundamental Principles of Radiometric Testing

5.1.1 Gamma radiometric investigation relies on the principal of nucleonic measurement based on a simple yet sophisticated concept – the principle of attenuation. Type of exposure can be collimated narrow-beam or panoramic depending upon application. Fig. 3 represents a schematic diagram of a typical radiometry setup with parallel geometry. A beam of radiation emanating from the source container and directed towards the test specimen undergoes preferential absorption as it travels through the object. The extent of attenuation depends on composition and geometry of the test object as well as energy and type of radiation. The transmitted intensity undergoes little or no attenuation if there is very less attenuation in the beam path either due to very low density or very less thickness of the material in between the detector probe and the source. The amount of radiation detected by the detector is converted into an electrical signal which is processed further to derive relevant value such as dose rate by measuring system. It can be used to detect faults and to estimate loss of equivalent material thickness in relation to expected degree of attenuation through a standard configuration of the test specimen.

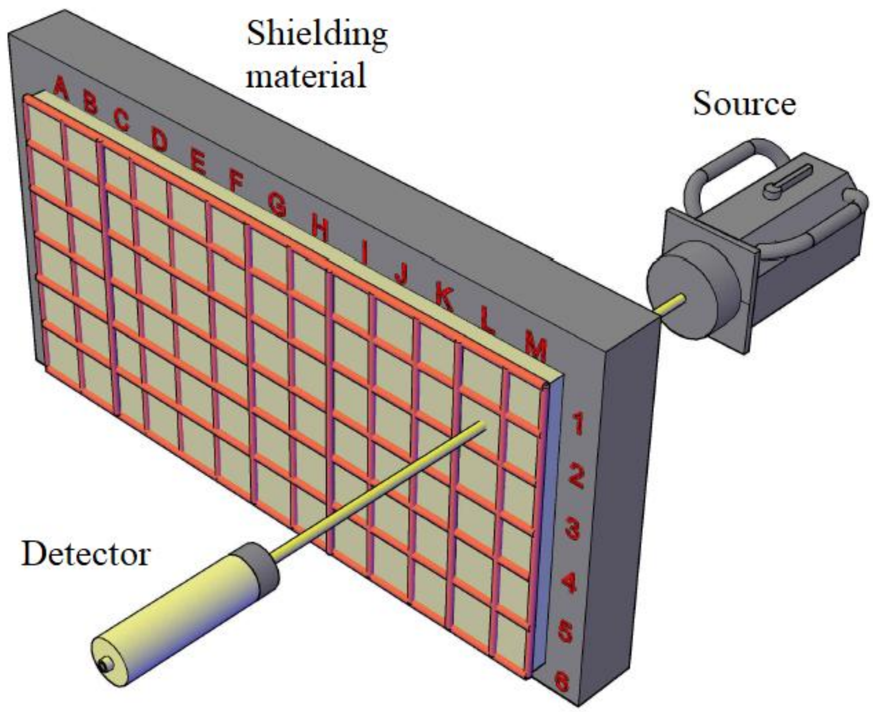

FIG. 3 SCHEMATIC BLOCK DIAGRAM OF A TYPICAL RADIOMETRY SETUP.

5.1.2 In narrow-beam geometry as shown in the Fig. 3, contribution of scattered components is eliminated (build up factor, B = 1). In many industrial field radiometry applications, panoramic exposure is employed. In such situations, scattered component has to be taken into account (build up factor, B > 1). The scattered radiation adds to the output intensity. This condition is known as ‘broad-beam geometry’. For broad-beam geometry, transmitted intensity can be given by the following exponential relationship:

$$I = I_o B e^{-\mu X}$$

Where,

lo and I are radiation intensities at a point before and after introduction of a shield of thickness x, μ is the linear attenuation coefficient, and B is called ‘build up factor’. It is the ratio of (Primary component + Scattered component) /primary component i.e, (P + S)/P. It depends on the thickness of shield, material (atomic number and density) of the shield and its attenuation characteristics μ.

5.1.3 For practical purposes, Half Value Thickness (HVT=0.693/μ) and Tenth Value Thickness (TVT=2.303/μ) would be great advantage for calculations to determine the quantity of transmitted radiations. Table 1 gives the different HVT and TVT values in various materials for different radioisotope sources.

Table 1 HVT and TVT Values in Various Materials for Different Radioisotope Sources

(*Clause* 4.1.3)

Sl. No.	**Isotope Source**	**Concrete cm**		**Steel cm**		**Lead cm**		**Uranium cm**	
		HVT	**TVT**	**HVT**	**TVT**	**HVT**	**TVT**	**HVT**	**TVT**
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
i)	Ir – 192	4.1	13.5	1.25	4.2	0.5	1.65	0.31	1.0
ii)	Co – 60	6.1	20.25	2.0	6.6	1.2	4.0	0.7	2.2

5.2 Industrial Radiometry Procedure (Including Safety Precautions)

5.2.1 Before commencing radiometry operations at a site, preparatory work need to be carried out which includes cordoning and shielding, grid marking and labelling on the test object, etc. The sequence of steps involved in radiometry is given below.

5.2.2 In order to keep dose levels within limit for the radiation workers as well as public, cordoning is required for the area where radiometry is being done. If adequate distances are not available one may need additional shielding and use of collimator. The prescribed radiation limit along the cordon off may change according to the local/international rules and regulations. Please ensure the cordon-off distance calculation process by consulting with the regulatory body where the radiometry testing is to take place. While cordoning it will be always considered that the members of public will be at the cordon fence and not the radiation worker. Cordon off required area with fencing rope and warning symbols. Placards shall be displayed at the boundary to warn against unauthorized presence inside or near the radiometry site. Make reflective signs during night time operation. The actual dose rates at the boundary shall be measured during trial exposure using a calibrated survey meter and the location of the boundary shall be rectified as necessary before subsequent exposures. The cordon off distance shall be determined on the basis of source activity, RHM of that source, weekly workload (no of exposures x duration of each exposure), occupancy factor outside the boundary and limitation of annual dose specified for public by the Competent Authority. The equation to evaluate cordon off distance is derived from the following equation.

Cordon-Off distance in the direction of primary beam: $d = \sqrt{\dfrac{A \times RHM \times W \times T}{P}}$

Where

d = Cordon off distance in meters
W = Working hours in a week
A = Source present activity
T = Occupancy factor around the site (*see* Table 2)
RHM = Roentgen per hour per curie at 1 meter from given radioisotope source (*see* Table 3)
P = Public dose limit or prescribed radiation level along the cordon off

Table 2 Values for T May be Used as a Guide for Planning Radiometric Work
(*Clause* 5.2.2)

Sl. No.	**Values for occupancy factor (T)**	
	Nature of human occupancy	**Occupancy Factor (T)**
(1)	(2)	(3)
i)	Full	1
ii)	Partial	1/4
iii)	Occasional	1/16

Table 3 Radiation Output for Commonly Used Radiometry Sealed Radioactive Isotopes
(*Clause* 5.2.2)

Sl. No.	**Source**	**Half life**	**Radiation Output (RHM) R/hr/Ci at 1 meter**
(1)	(2)	(3)	(4)
i)	Ir-192	74.4 days	0.48
ii)	Co-60	5.27 Years	1.30

Exercise: Iridium-192 of 20 Curie is used in radiometry of Occasional Occupancy for a period of 5 hours per week. Calculate the cardon off distance. Assume prescribed radiation level along the cordon-off area is 2 mR/week(20 µSv/Week) and RHM of Ir-192 is 0.5 R/hr (5 mSv/hr).
Solution:

Prescribed radiation level along the cordon-off area, P = 2 mR/week = 0.002R/week (20 μSv/week)

Cordon-Off distance in the direction of primary beam: d = √(AX RHMX WXT /P)

= √(20X 0.5X 5X(1/16)/0.002)

= 39.5 meter

a) Prepare the specimen for radiometry testing by making different segments on the surface and label the grid points for taking measurements. Each measurement is averaged over a typical area of 10 square cm. Fig. 4 shows schematic representation of grid marking and labeling on high thickness specimen. Fig. 5 shows preparatory work for carrying out radiometry testing of high thickness specimens (Lead block and cask) in actual field setup.

b) Position the source and detector in the required exposure geometry for carrying out radiometry. Ensure proper connection of guide tube and cranking unit of the source.

c) By scanning the surface of the test specimen, measure radiation level (exposure rate typically in mR/hr or μSv/hr) at each of the grid points and note down the readings. Record all readings in a tabular form. Table 4 indicates a data recording format.

d) Construct a line profile by plotting exposure rate v/s detector position on the circumference for flaw analysis. Results (that is, observation and acceptance/rejection decision) obtained from data analysis can be recorded. Based on the results correction action can be taken if faults such as misalignment of parts or welding defects are observed.

e) If hot spot is found, the grid point area can be further subdivided to identify more accurate location depending on application requirements.

Table 4 A Data Recording Form for Radiometry Work

Segment/ grid point	1	2	3	4	5	6	7	8	9	…
A										
B										
C										
D										
E										
F										
…										

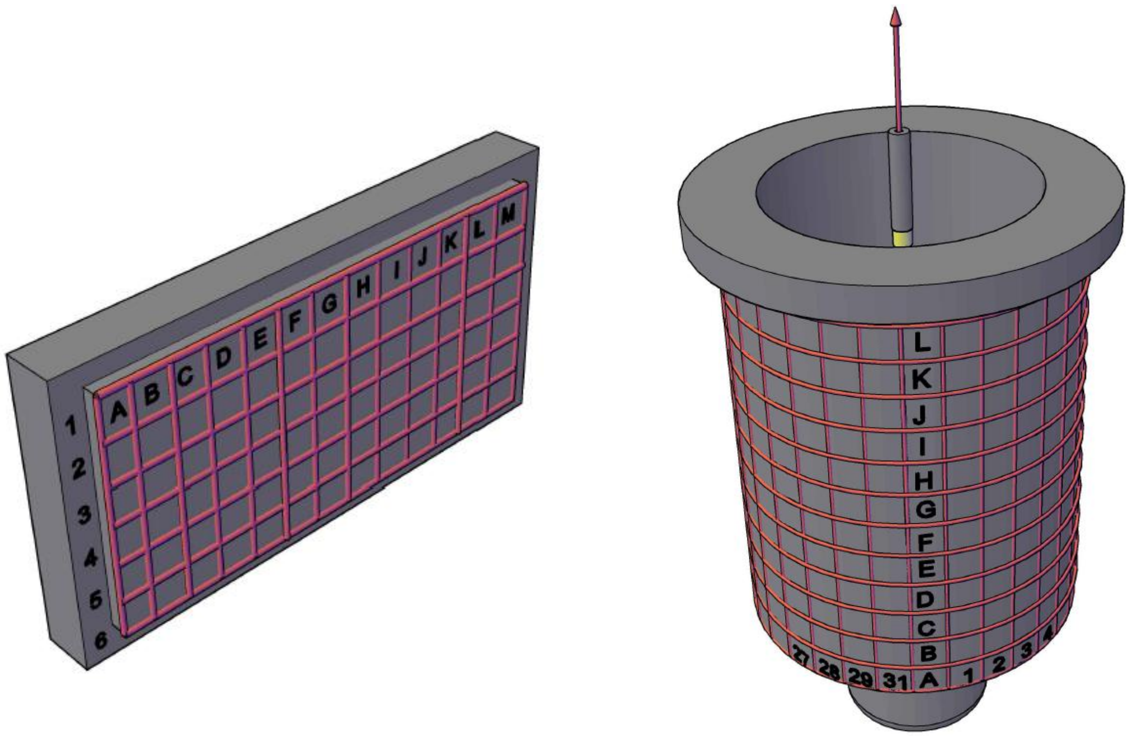

FIG. 4 SCHEMATIC REPRESENTATION OF GRID MARKING AND LABELING ON HIGH THICKNESS SPECIMENS (FOR EXAMPLE, LEAD BLOCK AND CASK) FOR CARRYING OUT RADIOMETRY TESTING.

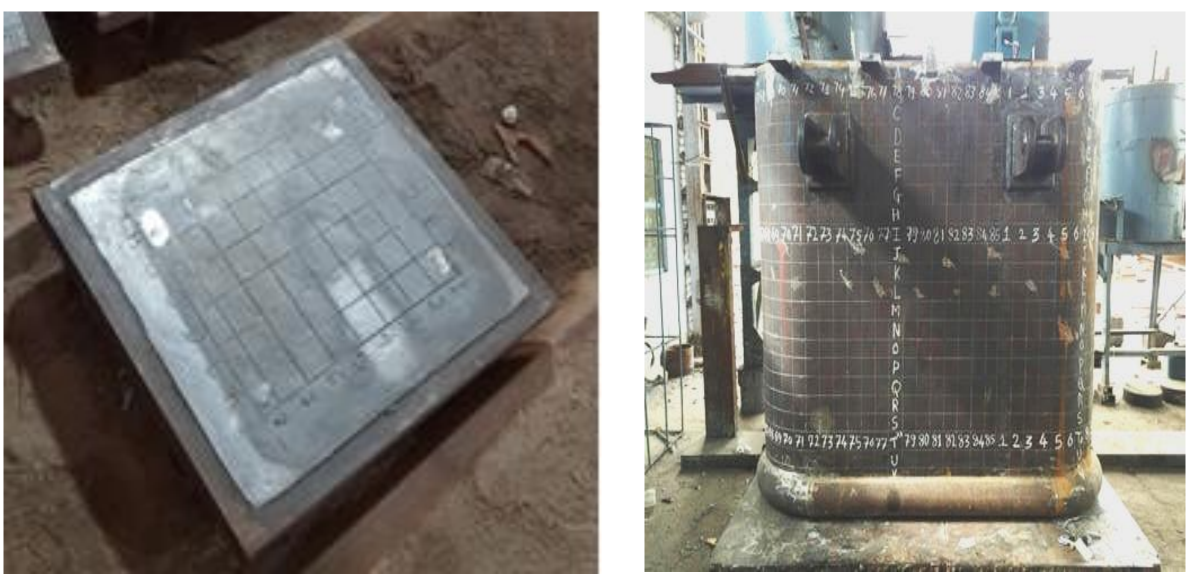

FIG. 5 FIGURE ILLUSTRATING PREPARATORY WORK FOR CARRYING OUT RADIOMETRY TESTING OF A LEAD BLOCK (LEFT) AND A CASK (RIGHT) IN ACTUAL FIELD SETUP.

6 RADIATION PROTECTION IN RADIOMETRIC TESTING

Before undertaking any radiometry work, appropriate standard operating procedure shall be established by the licensee (designated Radiological Safety Officer) as follows:

a) Wear personal monitoring TLD/film badge, Pocket dosimeter (charged)
b) Take a survey meter and check for its proper working condition such as battery check, calibration etc. and put it on before going near the source.
c) Check the radiation levels on the source container/exposure device and ensure safe position of the source in the device. Conduct visual inspection of exposure device locks, drive cable condition, coupling, guide tube etc.
d) Carry the source along with its accessories such as remote handling tongs, lead pot, lead shots, fencing ropes, warning symbols etc. to the site.
e) Ensure protection requirements during exposure of source i.e connection of guide tube, cranking unit etc.

7 PERSONAL QUALIFICATION

Personnel designated to carry out radiometry shall be trained, qualified and/or certified on the sealed radioisotope equipment. They should work safely in compliance with all relevant regulations and safety standards. They shall be familiar with operation of the equipment and shall have a good working knowledge of the equipment. Radiometry inspection shall be carried out by designated Radiological Safety Officer (RSO) approved by competent authority.

Relevant References

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