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Draft Indian Standard

Radiometry of Metallic Components and Structures using Sealed Radioactive Sources — Code of Practice

ICS 13.280

Nuclear Energy for Peaceful Application Sectional Committee, CHD 30	**Last date of comments: 29 July 2024**

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 1000 mm of concrete or equivalent thickness
d) Obtaining regulatory clearance for use of radioisotope sources

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.

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*).

Draft Indian Standard

RADIOMETRY OF METALLIC COMPONENTS AND STRUCTURES USING SEALED RADIOACTIVE SOURCES — CODE OF PRACTICE

1 SCOPE

1.1 This code of practice standard covers radiometry practices used for metallic components and structures by using sealed radioactive sources.

1.2 The practice outlined in this document is intended to provide the basis for good working practices for producing desired radiometric results.

2 TERMINOLOGY

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

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

2.2 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

2.3 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

2.4 Qualified Person — An individual who, by virtue of certification by appropriate authorities and through experience, is duly recognised as having expertise in a relevant field of specialisation like quality assurance, radiation protection, plant operation, fire safety or any relevant engineering or safety specialty.

2.5 Radiation Work — Radiation work means work involving exposure to ionizing radiation

2.6 Worker — worker means radiation worker

2.7 Controlled Areas— A controlled area is a defined area to which access is controlled and in which specific protection measures and safety provisions are or could be required for: (a) controlling normal exposures or preventing the spread of contamination during normal working conditions; and (b) preventing potential exposures or limiting their extent should they occur.

3 EQUIPMENT FOR RADIOMETRIC TESTING USING SEALED GAMMARADIOISOTOPE SOURCES

3.1 Typical radiometric measurement system consists of two components:

a) a sealed radioactive source that emits gamma radiation for example, Cesium-137 (^{137}CS) and Cobalt-60 (^{60}Co) nuclides;
b) a nucleonic detector and data acquisition system.

3.2 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.

3.3 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.

3.3.1 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

$$A = A_o e^{-\frac{0.693}{\text{Half-life}} \times t} \quad \text{or} \quad A = \frac{A_o}{2^n} \tag{1}$$

Where,

A_o is an initial activity at the time of source loading t=0;

A is activity after time t and;

n=t/half-life is the number of half lives.

3.4 Cesium-137 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 50 mm to 200 mm steel equivalent. The heart of radiometry equipment is source assembly with its housing. Exposure mechanism is either built in the source housing or separately attachable. Method of exposure is selected depending upon inspection requirements such as type of source and source holder to be used, amount of activity to be loaded, availability of raw material and flexibility. Two commonly used exposure devices (source driving type and shutter type) for radiometry work are shown in Fig. 1. The exposure device using source driving type mechanism is called Industrial Gamma Radiography Exposure Device (IGRED) or gamma camera. In this device, 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) shows ^{60}Co gamma camera with cranking unit and guide tube. The IGRED is utilized to store, transport and make radiation exposure. For remote operation, it 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. In India, many types of manual and remote operated exposure devices are in use. The commonly used device for ^{60}Co source is COCAM-120. In India, Board of Radiation and Isotope Technology (BRIT) supply the device incorporating ^{60}Co source. It is designed as per various national and international standards and is approved by Atomic Energy Regulatory Board (AERB) for use in India and abroad. COCAM-120 is a Type B (U) and is designed for a maximum capacity of 4.44 TBq (120 Ci) ^{60}Co. Shielding material for this camera is lead and heavy alloy. Fig. 1(b) shows a typical shutter type exposure device with beam collimator and locking mechanism. The main body of the device serves as is a shielded container for the gamma source during its storage. In this unit, source holder (source pencil) remains fixed in the housing and the shutter is displaced to expose the source.

(a)

Exposure device

Cranking unit

Guide tube

FIG. 1 (a) PHOTOGRAPH OF A CO-60 GAMMA CAMERA WITH CRANKING UNIT AND GUIDE TUBE

(b)

Sealed radioisotope source pencil

Exposure device with beam collimator and locking mechanism

FIG. 1(b) PHOTOGRAPH OF SOURCE PENCIL AND TYPICAL EXPOSURE DEVICE WITH BEAM COLLIMATOR AND LOCKING MECHANISM FOR RADIOMETRY WORK

3.5 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 1000 R/hr (10 Sv/hr) in five different scales starting from 0.5 mR/hr upto 0 to 1000 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

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

4.1 Fundamental Principles of Radiometric Testing

4.1.1 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.

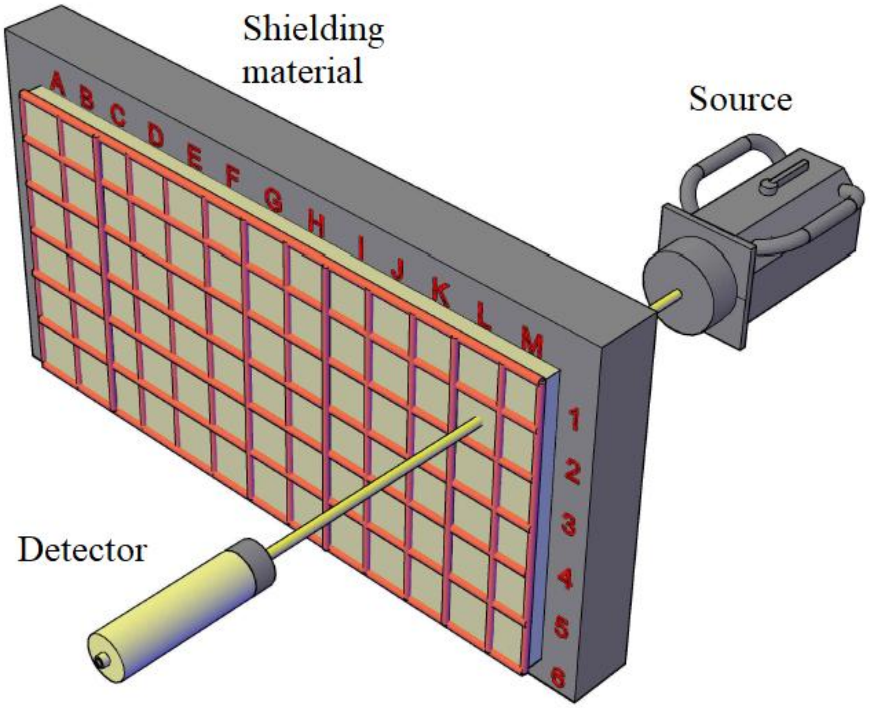

FIG. 3 SCHEMATIC DIAGRAM OF A TYPICAL RADIOMETRY SETUP

4.1.2 As shown in the Fig. 3, in good geometric condition (narrow-beam geometry) i.e. when the thickness of the shield is low and the beam is parallel, contribution of scattered components is eliminated (buildup factor, B = 1). In broad-beam geometry in which photons are diverging and the shield is relatively thick, scattered component has to be taken into account (buildup factor, B > 1). The scattered radiation adds to the output intensity. For broad-beam geometry, transmitted intensity can be given by the following exponential relationship:

$$I = I_o B e^{-\mu x} \qquad (2)$$

Where,

Io 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. To determine buildup factor for variety of elements and mixtures, there are many methodologies exists. Most widely used are Berger’s and Taylor’s approximations. The Taylor’s approximation has been broadly customized through numerous studies for single-layer shields and has been found sufficiently precise to provide buildup information in the compounds and the elements tested for. Another approach is to use a transmission curve that accounts for buildup. Transmission curves are plots of transmission (I/Io) verses shield thickness for various radioisotope sources. Buildup factors for some materials and example transmission curves can be found in the Radiological Health Hand book. As a rough guide, the buildup factor for thick slabs is about equal to the thickness of the absorber, measured in units of mean free paths (mfp) of the incident gamma-rays. It is approximately given by $B=1+\mu x$.

4.1.3 For practical purposes, Half Value Thickness ($HVT=\ln 2/\mu=0.693/\mu$) and Tenth Value Thickness ($TVT= \ln 10/\mu=2.303/\mu$) would be great advantage for shielding calculations. Attenuation and absorption coefficients can be found online at Institute of Standards and Technology (NIST) Photon and Charged-particle Data Center. Table 1 gives an approximate HVT and TVT values for several shielding materials for different radioisotope sources.

Table 1 Approximate 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	4.5	14.95	1.27	4.22	0.48	1.60	0.28	0.93
ii)	Co – 60	6.2	20.6	2.0	6.0	1.2	4.0	0.7	2.2
iii)	Cs-137	4.8	15.7	1.6	5.3	0.65	2.16	--	--

4.2 Industrial Radiometry Procedure (Including Safety Precautions)

4.2.1 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, following regulations and guidelines on the work at heights/handling lead/usage of radioisotope sources etc. The sequence of steps involved in radiometry is given below.

4.2.2 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 calculating cordoning off distance, consider the members of public at the cordon fence and not the radiation worker. Cordon off required area with fencing rope and radiation symbol. During the period of radiometry, Cordon off the working areas and display radiation sign caution board with expected radiation level at cordon off/entrance with the message “KEEP AWAY, RADIOMETRY IN PROGRESS” 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: $$d = \sqrt{\frac{A \times RHM \times W \times T}{P}} \qquad (3)$$

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* 4.2.2)

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* 4.2.2)

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
iii)	Cs-137	33 years	0.34

Exercise: Cesium-137 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 Cs-137 is 0.34 R/hr/Ci at 1m.

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: $d=\sqrt{(AX\ RHMX\ WXT\ /P)}$

$= \sqrt{(20X\ 0.34X\ 5X(1/16)/0.002)}$

$= 32.6$ 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

(*Clause* 4.2.2)

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

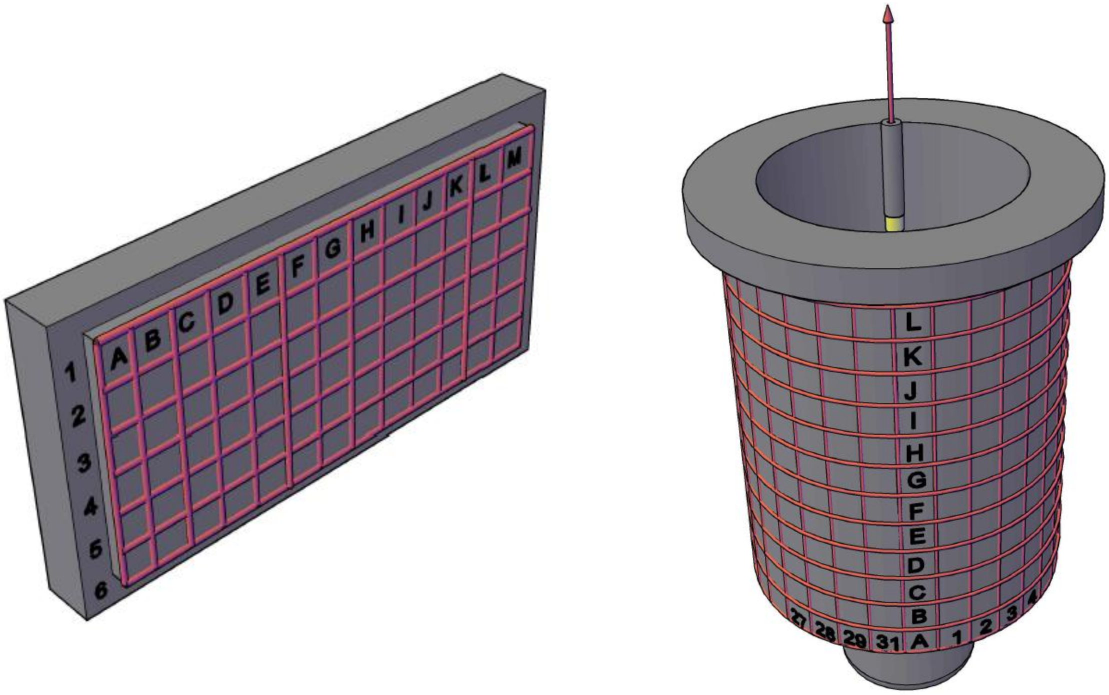

FIG. 4 SCHEMATIC REPRESENTATION OF GRID MARKING AND LABELING ON HIGH THICKNESS SPECIMENS (FOR EXAMPLE, LEAD BLOCK AND CASK) FOR CARRYING OUT RADIOMETRY TESTING.

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

5 RADIATION PROTECTION IN RADIOMETRIC TESTING

Before undertaking any radiometry work, the regulatory requirements as established by the relevant regulatory bodies should be ensured. The appropriate standard operating procedure shall be established for handling radiatioactive source in accordance with the guidelines provided by the regulatory body. Some of the important factors for preparation of standard operating procedure are as follows as follows:

a) The radioactive source should be handled in the presence or supervision of Radiological Safety Officer (RSO).
b) Wear personal monitoring TLD (Thermoluminescent Dosimeter)/film badge, Pocket dosimeter (charged)
c) 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.
d) Check the radiation levels on the source shielded 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.
e) Carry the source along with its accessories such as remote handling tongs, lead pot, lead shots, fencing ropes, warning symbols etc. to the site.
f) Ensure protection requirements during exposure of source i.e connection of guide tube, cranking unit etc.
g) Following safety precautions for working at heights shall be considered.
    - assess the risks by considering the height of the work site, duration and frequency and condition of the surface being working
    - make sure work is properly planned, supervised and carried out by competent personnel
    - ensure right type of equipment is used
    - provide protection from falling objects
    - consider emergency evacuation and rescue procedures
    - ensure working personnel wearing personal protection equipment like helmet, gloves, aprons, eye protection glass and work shoes

h) Lead is a widely used and highly effective means of shielding radiation. It is cheaper, easily available and can be cast in any shape. However, it is a toxic metal that can cause health effects if ingested or inhaled. For safe usage of lead materials,
  - always wear gloves when handling lead blocks
  - wash hands thoroughly after handling lead and before leaving the site
  - avoid putting labels or stickers on lead as they can make future reuse or recycling difficult.
  - While lifting heavy lead blocks only lift one brick at a time, and avoid reaching or twisting.

In addition to the above recommendations, regulations and guidelines on the work at heights/handling lead/usage of radioisotope sources shall be followed.

6 PERSONAL QUALIFICATIONS

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 under the supervision and presence of designated Radiological Safety Officer (RSO) approved by competent authority.

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