

NDE 2015, Hyderabad
November 26 - 28, 2015

Radiation Protection & Personnel safety in Industrial Radiography

Alok Kumar Banerjee

Former Jt. General Manager & National Sales Manager, M/s SEIFERT & ATLAS Pvt. Ltd. (Subsidiary of Rich.Seifert & Co.-Germany)
Mob/Tel: 09321025683/ 09329427646 / 07582-298039 Email IDs: bsmitasagar@hotmail.com / akbanerjeev2@gmail.com

Abstract

Due to availability of a variety of radioisotopes from BRIT, a considerable number of industrial organizations may come up in India which employ radiation sources in one form or the other. More such organizations may come up in the near future due to the “**Make in India**” policy of the Government

All ionizing radiations, whether electromagnetic (**gamma- γ**) or corpuscular (particles of **alpha- α** , or **beta- β**), and **neutrons (n^1)** are harmful to the human body. The damage done by radiations is sinister as human senses are not capable of detecting even lethal doses of radiation. The dose of radiations absorbed by human body which take into account the biological effectiveness of different types of radiations as noted above. The overall outcome of exposure to radiation is initiated by damage to the cells of the organism. The effects of radiation may be deterministic or stochastic, early or late, of somatic or genetic type. The somatic effects (physical) can either be immediate or delayed when the whole body is acutely irradiated with radiation doses:

ICRP, a division of **IAEA**, is engaged in providing rules and Standards for the radiation protection. ICRP has established the values of permissible cumulative doses for a year for occupational and non-occupational radiation workers. These are indicated in the present paper.

All countries including **India** have brought their national laws / standards on ionizing radiation in line with the ICRP codes. The conditions for registration, transport, storage, protection and use of radiation sources have been laid down in regulations. The purpose of practical protection against radiation is to prevent any individual receiving a harmful dose.

Radiation measurement Instruments like dose meter, pocket dosimeter, NaI (TI) scintillation detector and recording instruments such as film/TLD badge have been briefly described.

Radiation hazards control includes

- **Distance:** Radiation exposure level which obeys the inverse square law $I_1 / I_2 = (d_2)^2 / (d_1)^2$
- **Time:** total dose received by the operator is directly proportional to the total time spent. $D \propto T$
- **Shielding:** whenever X-rays/Gamma-rays/Neutron pass through any medium their intensity will be attenuated exponentially $I = B I_0 e^{-\mu x}$

Enclosed as well as field/open radiography Installations have been explained for radiation protection and personnel safety.

Introduction

Radiation can be defined as the propagation of Energy through space or a material medium. It can be in the form of Electro-magnetic Radiation or Energetic particles. It can be classified as (1) **Ionization Radiation** which has enough energy to remove electron from an atom causing the atom become ionized. Examples of ionizing radiation include: • ${}^4_2\alpha$ -particles • ${}^0_{-1}\beta$ -particles • ${}^0_0n^1$ neutrons • ${}^0_0\gamma$ -rays • X-rays. In ionization radiation, the particles and Electro-magnetic radiation released by the decay of unstable atoms (2) **Non-Ionization Radiation** which does not have enough energy to ionize atoms in the matter to interact with but dissipates energy in the form of heat.. Examples are:• microwaves • visible light • laser • radio waves • Radar/TV waves • Power Transmission• Ultraviolet radiation (except for the very shortest wavelengths)

The Industrial applications of radiation and the radiation sources are one of the most significant benefits from positive uses of atomic energy. The Indian Atomic Energy Programme has provided adequate scope for the application of radiation sources in industries. Due to availability of a variety of radioisotopes from BRIT/DAE, a considerable number of industrial organizations have come up in India which employs radiation sources in one form or the other. More such organizations may come up in the near future due to the “**Make in India**” policy of the Govt. The radiation sources in such organizations are used in fields like industrial radiography, nuclear gauging, oil exploration, process control, radiation sterilization, ground water hydrology and so on. However, risks of potential hazards to environment as well as health do exist if appropriate precautions are not taken in such uses as mentioned above. Therefore, effective control measures are a must to control and regulate any activity involving use of radiation exposure. Such measures are necessary in production, sale, transfer/transport, import & export, acquisition, possession, uses, storage, and disposal of radioactive substances.

Human beings are exposed to naturally occurring radiation, that is, radiation from sun and outer space, radioactive materials present in the earth, food, water and even the body itself. However, levels of such radiation vary from location to location. In addition to radiation exposure existing from the natural sources, there is radiation hazard created by man himself e.g. x- γ rays. Such radiation are not always harmful, they have their beneficial effects also. All this depends on the control & protection measures applied during use of this type of radiation.

Basic Radiation Safety Measures

The objective of the radiation protection is to limit the radiation exposure so that the risk of harmful effects to the individuals and to the society is as small as possible compared to the benefits to be derived from the ionization of radiation. The principle of radiation protection are contained in the recommendations of the **International Commission on Radiological Protection (ICRP), a division of International Atomic Energy Authority (IAEA)**, concerning the limitation of doses from controllable sources upon which most International Standards and National Rules & Regulations are based. The recommendations and the guidance provided by the International agencies embody certain principles of particular importance to those planning to use radioactive materials in various fields These are: ^[1]

- (1) no practice shall be adapted unless their introduction produces positive net benefits.
- (2) all exposure shall be kept as low as reasonably achievable, economic and social factors being take into account
- (3) the dose equivalent to individuals shall not exceed the limits recommended by ICRP/IAEA.
- (4) the design of radiation source/assembly must meet the requirements of **ISO 2919**

Effect of Radiation on Organisms

All living organisms are made of tiny structures known as cells. A cell essentially consists of a cell wall (in plants), cell membrane surrounding cytoplasm which contains a nucleus. In general, the cytoplasm contains material for metabolism as proteins, enzymes etc and the nucleus contains the basic genetic material, the DNA contained in genes spread over thread like chromosomes. Obviously, any damage to cells by ionization radiation exposure would hamper with the normal functioning of the body.

The human body is constantly exposed to natural radiation (e.g. from space, the soil and buildings), also known as background radiation. All ionizing radiations, whether electromagnetic (**gamma** ${}^0_0\gamma$) or corpuscular (particles in the form of **alpha** ${}^4_2\alpha$, or **beta** ${}^0_{-1}\beta$), and neutrons (${}^0_0n^1$) are harmful to the human body. The unit “absorbed dose” (D) defines the effect of radiation on various substances. **D** is the absorbed dose in J/kg or Gray (Gy). The biological damage done by the various types of ionizing radiation, **α** , **β** , **γ** or fast neutrons, differs and depends on the quality factor (**Q**). The unit to which the damage quality factor is applied is the equivalent dose H. The equivalent dose is the product of absorbed dose (**D**) & quality factor (**Q**), calculated as **H = D x Q Sv**. The Q factors for various types of radiation are indicated in the table given below ^[2]

Type of radiation	Quality factor (Q)
X and gamma radiation γ	1
Beta radiation β	1
Alpha radiation α	20
Fast Neutron n	10

Table (I)

Somatic and Genetic Effects of Radiation

The cells in the body of an organism are of two types:

- 1) **Somatic Cells**, present in every organ of the body except reproductive organs. These are concerned with all body functions.
- 2) **Genetic cells**, present in gonads (reproductive organs) and concerned with reproduction.

Effect of radiation on Somatic cells is called ‘Somatic Effects. These are manifested as (1) effect of acute irradiation i.e. heavy exposure in a short period of time e.g. erythemia, skin burn, nausea, vomiting, fatigue, hemorrhage and even death; or (2) effects of chronic irradiation i.e. light (low) exposure over a long period of time e.g. leukemia (blood cancer), thyroid cancer, radiation cataract etc.

The somatic effects can either be immediate or delayed. Given below is a summary ^[3] of immediate effects when the whole body is acutely irradiated with a range of radiation doses

Doses Received	Somatic Effects
0 - 0.25 Sv	No manifested injuries and no clinical effects
0.5 - 1 Sv	Reduction in lymphocytes and neutrophils with delayed recovery. Delayed effects may shorten life. No clinical symptoms
1 - 2 Sv	Mild ARS (acute radiation syndrome): Nausea, fatigue, dizziness. Vomiting in 10-50% cases within 24 hours starting 2 hours after exposure or later. No disability
2 - 4 Sv	Moderate ARS: Nausea, fatigue, dizziness, loss of appetite. Vomiting within 2 hours in 70-90% of exposed persons. Latent period of 2 to 3 weeks where the victim seems relaxed and recovering. The critical period follows with epilation, loss of appetite and general weakness accompanied by fever, inflammation of the mouth and throat, diarrhoea, nose bleeding. Death due to infections could occur in 0-50% within 2 months without proper treatment.
4 - 6 Sv	Severe ARS: Nausea, weakness, loss of appetite, vomiting within one hour with 100% incidence. Mild diarrhea in less than 10% cases with an onset of 3-8 hours following the whole body exposure. Headache in 50% cases within 4-24 hours. Fever in 80-100% cases within 1 -2 hours. Drop of lymphocytes to about 500 on 2nd-3rd day. Latent period of 1-2 weeks followed by severe clinical picture, fever, infections (pneumonia). Death in 50-80% within 2 months.
8 Sv >	Lethal ARS: Severe nausea, fatigue and vomiting within 10 minutes followed by fever and diarrhoea and hemorrhage with no latent period. Rate of survival is very poor and death occurs within 2 weeks in 90-100% of exposed individuals. At whole body doses >15 Sv damage of the central nervous system characterized by cramps, involuntary movements of the muscles (ataxia) followed by coma. Death occurs within 2 days due to cerebral edema and probably heart failure

Effect on genetic cells is 'Genetic Effect' and relate to genetic injuries of reproductive organs. This type effect leads to impairment of hereditary mechanisms and manifest as sterility, physical deformation, hampered growth and even death of the offspring.

Genetic effects may be explained in the following way. It is a fact that children inherit characteristics such as appearance, strength, resistance to disease, temperament etc. from their parents. This happens because each of the parents contributes a characteristic gene to the reproduction process. The genes are contained in the sperm and egg cells of the parents producing them. Radiation can modify and damage the genes. However, genetic effects have never been manifested and proved in human population exposed to radiation (neither in A-bomb survivors) ^[3].

Annual Dose Equivalent Limit ^[1]

It is now generally regarded that any increase in the level of exposure above the background level is harmful to both the workers dealing with radiation and the general public. However, looking to the vast number of benefits by use of radiation survey, total rejection of such use is not possible. Therefore the best approach is a balance between risks and benefits. For this both National and International organizations such as **ICRP**, **IAEA**, and **WHO** etc. have suggested radiation protection standards. Their recommendations are followed world over including International Labour Organization (**ILO**)

The annual dose equivalent has been given by the ICRP for radiation workers as well as the general public. It is defined as the dose of radiation which a person may be exposed either over a long period of time or from a single exposure, without resulting in any unacceptable risk. Lower limits of dose equivalent value have been suggested for general public than that for the radiation worker who can accept a higher degree of risk as a part of his /her occupation.

Thus, two categories of individuals are recommended by ICRP for radiation exposure:

1. Adults exposed during the course of their work (occupational)
2. Members of the public including children

For planning purpose, it is considered appropriate to set the dose equivalent limits for the members of the public as a factor of ten below that for a radiation worker.

Recommended Dose Equivalent Limits (IAEA /ICRP)

There are two types of effect of radiation based on the severity of exposure:

1. **Non-Stochastic effects**, where severity varies with dose, hence a threshold may occur for it.
2. **Stochastic effects**, where the probability of an effect occurring rather than its severity is regarded as a function of the dose without any threshold

In case of protracted or low dose exposure, ionizing radiation may not produce immediate consequences but some delayed effects may appear a long time after the exposure. These types of effects may be late deterministic effects (life cataract) or stochastic effects (radiation induced cancer or genetic effects). ICRP ^[3] has recommended an annual dose equivalent limit of **0.5Sv (50 rem)**, for non-stochastic effects in a year to all tissues except eye lens for which the limit is **0.15Sv (15 rem)** in a year. These limits apply irrespective of whether the tissues are exposed as single or together with other tissues /organs.

For stochastic effects, the recommendation is **50mSv (5rem)** for uniform radiation of the whole body.

According to the latest **IAEA /ICRP** recommendation, dose equivalent or dose limits & safety regulations vide (Schedule II Safety series No. 115 of IAEA) ^[3] for occupational radiation workers & the members of public has been set, which are given below for ready reference.

1. Occupational workers ^[3]

(I) the occupational exposure of any worker shall be so controlled that the following limits be not exceeded:

- (a) an effective dose of **20 mSv** per year averaged over five consecutive years;
- (b) an effective dose of **50 mSv** in any single year;
- (c) an equivalent dose to the lens of the eye of **150 mSv** in a year; and
- (d) an equivalent dose to the extremities (hands and feet) or the skin of **500 mSv** in a year.

(II): For apprentices of 16 to 18 years of age who are training for employment involving exposure to radiation and for students of the same age group, who are required to use sources in the course of their studies, the occupational exposure shall be so controlled that the following limits be not exceeded:

- (a) an effective dose of **6 mSv** in a year;
- (b) an equivalent dose to the lens of the eye of **50 mSv** in a year and
- (c) an equivalent dose to the extremities or the skin of **150 mSv** in a year

(III): When, in special circumstances, a temporary change in the dose limitation requirements is approved: ^{3}

The occupational dose constraint for the whole body exposures in about forty years of working of an individual is **1 Sv**. The maximum accumulated dose to a radiation worker of age **N** years is given by **(N-18) x 20 mSv**. This means that no person less than 18 years of age can be employed for radiation work. Radiation workers such as radiographers are subjected to ionizing radiation while performing their work. The amount of radiation dose received depends on various parameters and conditions such as time, distance, shielding and working procedure. Thus, to ensure the safety of radiographers, it is important that supervisors or radiation protection officers continuously observe and record the amount of radiation received by each radiographer working under them. Such an activity is called personnel monitoring. In general, the main purpose of personnel monitoring is to ensure that the dose limit is not exceeded, to limit the exposure of the individual radiographer, to assist the medical authority in making analysis in the case of accidental over exposure and to provide information about work practices and personal dose history. The other type of monitoring is area monitoring in which the environment around the worker is monitored. This includes checking the equipment containing radioactive sources, and the correctness of the exposure procedures. Personnel monitoring devices include film badges, pocket dosimeters and thermo luminescence dosimeters (TLD), while the area monitoring is done with the help of radiation survey meters.

2. Non-occupational workers (Public) ^{3}

For all non-occupational workers and members of the public being exposed to external radiation, the above mentioned dose limits must be reduced appreciably to keep limited the spread of radiation effects, if any. The criteria and dose limits specified by Schedule II of IAEA Safety Series No. 15 ^{2} for this category of personnel are as given below:

(I): The estimated average dose to the relevant critical groups of members of the public that are attributable to practices shall not exceed the following limits:

- (a) an effective dose of **1 mSv** in a year;
- (b) in special circumstances, an effective dose of up to **5 mSv** in a single year provided that the average dose over five consecutive years does not exceed **1 mSv** per year;
- (c) an equivalent dose to the lens of the eye of **15 mSv** in a year; and
- (d) an equivalent dose to the skin of **50 mSv** in a year.

External Radiation Hazards Evaluation

By breathing contaminated air, drinking contaminated water, working with contaminated hands, radioactive materials can enter into the body and get deposited in specific organs of the body; they will continuously irradiate the organs of the body until eliminated. In order to control such internal radiation hazards, it is necessary to use safe handling device and limit the contamination levels in the working area, in air as well as water below the values recommended by ICRP/IAEA. However, in the case of industrial radiography, radiation sources used in either doubly encapsulated sealed isotopes or x-ray machines as such, pose only external hazards. In case any damage to the source capsule during accident, proper care should be taken against contamination and associated internal radiation hazards

^{1} The evaluation of external radiation hazards such as in the case of industrial radiography and other the used of sealed sources is usually done by (1) **Area Monitoring** (2) **Occupational Personnel Monitoring (Film / TLD Badges)**

Area Monitoring

Since the ionizing radiation can not be detected by senses, suitable detector and measuring equipment or survey meter are used for monitoring the radiation areas so as to confirm that the radiation levels prevailing around the location of use of radiation sources as well as within the maximum are under permissible levels. The radiation levels in those areas occupied by the occupational worker should not exceed 2.5mR/hr (25 µSv) e.g. in the control room. In areas occupied by the non-occupational worker the radiation level should not exceed 0.25 m R/hr (2.5 µSv) e.g. in the workshop, office room etc. These working limits are subject to the condition that the annual dose equivalent limits are not exceeded. It is also necessary to inspect the proper storage of all radiation sources and also the adequacy of storage facilities available. There are various survey meters available with which the radiographer can measure or register radiation. The common radiation survey meters are

1. Dose rate meters

2. Scintillation counters

Dose rate meters

A portable Geiger-Müller counter, (figure a) is the most commonly used Instrument for measuring dose rate, but the more accurate & more expensive ionization chamber is used as radiation monitor as well. Both instruments measure the electric current that is produced by ionization. The radiation level can be read instantly off a µ-ampere meter with a µSv/h or mSv/h calibrated scale. Some radiation monitors give an audible signal when a pre-set dose is exceeded.



Fig (a) ^{4}

The instruments are used by personnel working with radioactive material or X-ray equipment, to determine the safe distance and the dose rate for instance 7.5µSv/h at the safety barrier. GM-counter has a measuring range from 1.5µSv/h-20mSv/h in 5 auto-change ranges with warning threshold. The display is digital as well as bar indication.

Nal(Tl) Scintillation Counters

This instrument can accurately measure & analyze radiation. An ionizing radiation incident on a sodium-iodide thallium crystal NaI(Tl) is converted into a weak light flash signal which is amplified into electric pulses by an integrated photo-multiplier. By measuring the amplitude and number of these electric pulses, energy and intensity (dose rate) of the radiation can be determined. These instruments are predominantly used for scientific purposes.

Occupational Personnel Monitoring

It is very essential that the radiation dose received by all during their schedule be regularly monitored. A complete and up-to date record of the dose received by all the occupational personnel should be maintained by the by the employer.

(1) **Film badges** (2) **Thermo-luminescence dosimeters TLD** (3) **Pocket dosimeters. (Pen type)**

Every occupational personnel should always wear a personnel monitoring badge and in addition to a pocket dosimeter while handling radiation sources. The personnel monitoring film/TLD service information can be obtained from AERB/DRP, Mumbai 400 085.

Film badges (Film dose meters)

The film badge consists of two of X-ray films contained with filters in a holder. At the end of a specified period the films are developed and the density measured. The radiation dose received by the badge wearer can then be determined by consulting the density / exposure curves, and the type of radiation received can be established by checking the densities behind the filters. Film dose meter of size 25x25x5 mm are shown in figures (b) and (c). These are very cheap and convenient to wear. This is a reasonably accurate method of monitoring for the occupational personnel but processing of film badges are more complicated and time consuming



Fig (b) [4] Fig (c) [4]

Thermo luminescent dose meter (TLD badge) [5]

Thermoluminescent dosimeter, TLD, is a primary form of personnel radiation monitoring dosimeter. TLD makes use of the property of certain materials which absorb energy when exposed to α -, γ -, β and neutron radiations. On heating about 250°C, the absorbed energy is released in the form of visible light. A plot of light intensity emitted against temperature is known as "Glow Curve" and can be measured as the amount of energy initially absorbed through exposure to the energy source by a PMT device. The quantity of visible light emitted (TL output) is found to be proportional to the energy absorbed by TL materials. The estimation of radiation exposure may be based on either the height of the glow curve (differential method) or the area under the glow curve (integral method). TL materials includes calcium fluoride (CaF), lithium fluoride (LiF), calcium sulfate (CaSO₄), lithium borate (LiBr), calcium borate (CaBr), potassium bromide (Kbr) etc. A TLD personnel monitoring system consists of 2 major parts, (a) TLD Card and (b) TLD Card Reader.

TLD Card. Material & TLD Reader [5]

TLDs are often used instead of film badges. It is worn usually for 3 months or less and then it must be processed to determine radiation dose received, if any. TLD can measure intensity /dose as low as 50 μ Sv (5mRem), same as film badges. The advantage of a TLD over other monitor is the linearity of response to dose, its relative energy independence and sensitivity to low intensity/doses. It is also reusable & as it is read out digitally and can be linked to a database which is the advantages over film badges. But permanent record or re-readability and immediate readout is not possible. A TLD badge comprises of a plastic cassette containing 3 Teflon discs (13.3 mm & 0.8 mm thick) mechanically clipped on to a circular holes (12 mm) punched to an aluminum card (52.5x30x1 mm) Aluminum plate. 3 **CaSO₄:Dy** Teflon TLD discs are mechanically clipped on a Aluminum plate. An asymmetric "V" cut is provided in the card to ensure its loading in the plastic cassette. 1st disc consists of Al-Cu filter which cut off β -radiation and gives TL due to X- & γ -radiation. 2nd disc has of plastic window which cut off soft β & records X-, γ -rays & hard β Radiation. 3rd disc has no filter records all the radiations. The badge is affixed to the clothing of a person with the help of a crocodile clip attached to the badge. This has been designed by BARC and is regular in personnel monitoring since 1982, The TLD badge has shown satisfactory performance for monitoring α , β and γ doses of occupational radiation workers. At present about 40,000 radiation workers are covered with TLD monitoring service in nuclear industry, medical and industries as well as research institutions.

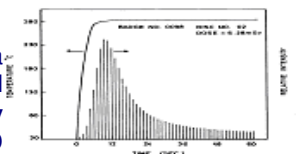


Fig. (d), (e) & (f) Glow Curve & Temperature Profile [6]

Pocket dosimeter

Direct reading calibrated pocket dosimeter for received x/gamma radiation 0-2 mSv, from 30 keV consists of a quartz fibre electrometer and a simple optic lens system housed in a fountain pen type holder, as shown in figure (g) & (h). A small charging unit is used to electrically charge the fibre which can then be viewed through the lens. The fibre is set on the zero mark of the calibrated scale as initial setting for the work period.



Pocket Dosimeter Fig. (g) [4]



Charger for dosimeter Fig. (h) [4]

Any radiation will cause the charge to leak away through its ionizing effect and the fibre will move across the scale. The amount of radiation received can be read off the calibrated scale. This type of instrument is excellent for personal protection as it is small, inexpensive and reasonably robust. It can be easily read and records the total amount of radiation received for the work period with an accuracy of ± 10 %.

Pocket Type Instrument for Personnel Monitoring

This (figure i) functions with accosting warning by increasing beep rate (approx. 1 beep/sec at 0.06 mSv/h). 3 selectable sound levels of energy range: 50 keV - 2 MV, γ - & X-radiation with energy compensation is present



Fig. (i) [4]

Dose registration ^[1]

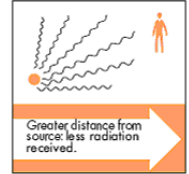
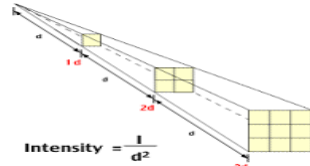
While performing the work the occupational personnel must wear TLD/Film badges (dose meters) over a specific time period for monitoring & registration of radiation dose received. This is due to the legal requirement as per AERB/DRP regulation. Radiation dose monitoring is carried out by AERB/DRP and is responsible for processing and viewing the reports generated. This contains the individual irradiation doses over a specified time period as well as the accumulated dose.

Radiation Hazards Control

After evaluating the radiation hazards, it is necessary to institute strict control measures so as to minimize the hazards well within the acceptable limits. The three fundamental factors by which external radiation hazards can be controlled are

- (1) Distance (2) Time (3) Shielding

Distance: **Source**

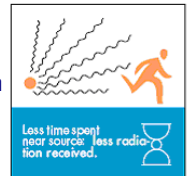


Radiation exposure level obeys the Newton's inverse square law according to which radiation intensity at a point is inversely proportional to the square of the distance. Thus, $I_1 / I_2 = (d_2)^2 / (d_1)^2$ or, $I_1 (d_1)^2 = I_2 (d_2)^2$ where I_1 is the initial intensity of radiation at a point distance ' d_1 ' from the source of radiation. I_2 is the final intensity and d_2 final distance. Therefore the most effective and economic means of reducing the external exposure from radioactive materials is to maintain a maximum possible distance between the source and the operator. This is particularly true in the case of open field industrial radiography, where it is common practice to cordon off a certain area around the source during radiography depending upon the nature and the strength of source used, total exposure time; and the nature of occupancies around the site. The use of remote handling device for the handling radiographic source and the long cable between the control panel and the x-ray unit emphasizes the usefulness of the distance factor. The operator should always try to make use of the maximum available length of the manipulating device or the operating cable so that the maximum possible distance is always maintained between the operator and the radiation source.

As a rule if the distance is double, the exposure is reduced by a factor 4 (25%) Greater distance = Less Exposure

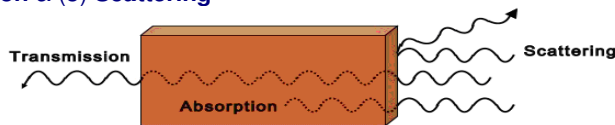
Time: The total dose received by the operator is directly proportional to the total time spent in handling the source. $D \propto T$ Where D = total dose received and T = total time. Hence, **Less time = less exposure**

In order to minimize the time of operation with the actual radiation sources, it is advisable to perform trial operations with a dummy source. All exposures should be well planned in advance & executed in the minimum possible time.



Shielding: x-,γ-, n-rays can travel forever until they can hit an object (shielding material). One of the 3 reactions occur :

- (1)Transmission, (2) Absorption & (3) Scattering



Absorption + Scattering = Attenuation

Scattering plays an important role for radiation protection and can be broadly defined as the redirection of radiation out of the original direction of propagation, usually due to interaction with molecules and particles. **Reflection; Refraction & Diffraction** are just the forms of scattering.

When maximum distance and maximum time do not ensure an acceptably low radiation, adequate shielding must be provided so that the radiation beam will be sufficiently attenuated. Whenever x-rays / gamma rays / neutron pass through any medium their intensity will be attenuated exponentially. The reduction in intensity depends upon the nature and thickness of the medium and the energy of the radiation. Usually high atomic number materials such as lead (Pb), depleted uranium etc are used as localized shielding materials for x-ray and gamma ray. Concrete and brick are used as constructional shielding materials. As gamma rays emit radiations all the time, they are always stored in well shielded containers made of high atomic number materials such as lead so that the leakage radiation levels from the shield are well within the allowable limits. Similarly x-ray tubes are also housed in lead shielding so as to limit the leakage radiation level other than in the direction of the primary radiation to well below the maximum permissible leakage levels. The attenuation of x-rays and gamma rays in the shielding materials is governed by the mathematical equation

$$I = I_0 e^{-\mu x} \quad (\text{narrow radiation beam})$$

In case of **broad radiation beam**, of x-ray/gamma ray with build up factor of shielding material, the equation can be written as

$$I = B I_0 e^{-\mu x} \quad (\text{Broad beam})$$

Where

I_0 = original intensity of radiation

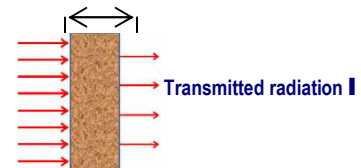
Incident radiation Intensity I_0

I = transmitted intensity through the medium of thickness 'x' in cm

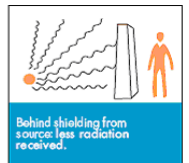
μ = linear absorption/attenuation co-efficient of the medium cm^{-1}

B = build up factor

Wall Thickness x



Enclosure Material



It depends upon the atomic number of the material, density, thickness and energy of radiation. The value of μ increases with the atomic number of medium and hence high atomic number materials are preferred to shielding against x-rays and gamma rays. A judicious selection and employment of the above three factors helps in controlling the radiation hazards to a great extent.

Concept of Half-Value-Layer: Attenuation Equation $I = I_0 e^{-\mu x}$ The value of μ can be determined by finding the thickness of the absorbing material which reduce the intensity of the radiation beam to **half** its value. Such thickness is known as Half-Value-Layer 'T' or HVL. Putting $I/I_0 = 1/2$ and $x = T$ we get $I/I_0 = e^{-\mu x} = 1/2$ or $e^{\mu T} = 2$ or $\mu T = \log 2 = 2.3 \log_{10} 2 = 0.693$ Therefore $\mu = 0.693 / T$ and the unit is cm^{-1} The attenuation equation can be written as $I/I_0 = 2^{-n}$ where 'n' is the HVL

Similarly **Ten-Value-Layer (TVL)**, From the definition $I/I_0 = 1/10$. Therefore the effect of radiation attenuation to the thickness shielding material $10 = e^{\mu \text{TVL}}$ where $x = \text{TVL}$ or $\log 10 = \mu \text{TVL}$ Hence $\mu = 2.3 / \text{TVL}$ and μ can be calculated if TVL is given Therefore HVL & TVL plays an important role for calculating shielding material thickness for exposure room.

ESTIMATE TVL AND HVL FOR VARIOUS TYPES OF SHIELDING MATERIAL [6]

Types of Materials	¹⁹² Ir		⁶⁰ Co	
	TVL	HVL	TVL	HVL
Concrete	15.74	4.82	22.86	6.85
Steel	2.90	0.87	7.36	2.20
Lead	1.62	0.48	4.11	1.24
Tungsten	1.09	0.33	2.62	0.79
Uranium	0.93	0.28	2.29	0.69

Table (II)

More Shielding = Less exposure. Finally the philosophy of "ALARA" (as low as receivable achievable) must always be practiced in every step of activity.

Design of Exposure Room: [6] Specially designed enclosed space with adequate shielding to protect people in the vicinity from radiation risk. The drawings of the installation and its surrounding including dimensions of each enclosed area and the shielding thickness, density and the type of material on all sides including the exposure area of top and bottom should be mentioned. Plan views of the door entries are given below showing (a) Incorrect and (b) & (c) correct method of fittings

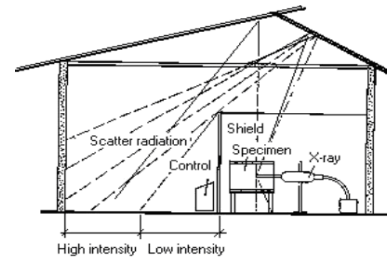
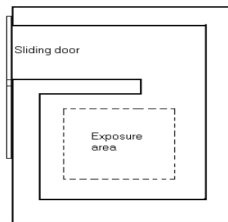
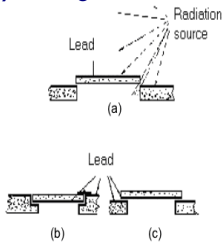
(a) Primary Leakage Radiation due to **incorrect fitting** of sliding door

(b) Hinged door

(c) Sliding door

EXPOSURE ROOM LAYOUT

SCATTERED RADIATION THROUGH ROOF



1. Exposure Room Design 2. This is effectively reduces the lead door thickness 3. Radiation is reduced approx. 0.2% on each scatter

OTHER REQUIREMENTS OF THE DESIGN

1. For shielding calculation the total radiation dose rate, both Primary and scatter radiations including usage and occupancy factor be taken into consideration.
2. The documentation & layout plan of the exposure room should be submitted to relevant authority—AERB /DAE- Mumbai and should include the results of calculation, radiation level & measurement and maximum expected radiation level inside the shielded enclosure and in all adjacent area

Safety in Radiography Installation [1]

There are two categories of Industrial Radiography Installations: (1) Enclosed Installations (2) Open Installations Enclosed installations are those areas specifically earmarked for radiography purpose with walls of adequate thickness all around so that the radiation levels outside the wall are well below the maximum permissible limit. Radiography work can be carried out safely inside the enclosure without causing interference to other work outside. These types of enclosure must be there in workshop areas where non occupational personnel are present all the time. A completely enclosed installation or an open –top cell or a pit type installation may be selected depending on the type of object to be radiograph. An open top or pit type enclosure may be used where the objects are large in size and also heavy, so that they may be lowered into the radiography room by means of overhead crane. In such enclosure the radiation dose to crane operator should be well within the permissible limits. In case of open type the sky shine radiation dose around the enclosure in the workshop should be kept below the permissible limits. The constructional material used for such installations may be bricks or concrete. The installations should be preferably located in least occupied areas. Expert opinion on the planning of such radiography installations may be obtained from the Radiation Protection Services Division, AERB, Mumbai-85.

Safety in Enclosed Radiography Installations

The following points are to be considered while planning radiography enclosures as well as during the use radiography sources inside such enclosed installations.

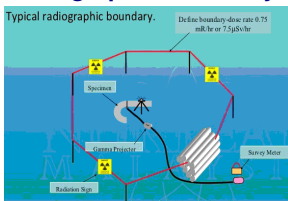
1. Approval for radiation safety of the proposed layout of radiography enclosure should be obtained from Radiological Protection, AERB prior to undertaking construction.
2. The radiography room should be kept locked when not in use. Entry of unauthorized persons should be prohibited.
3. The entrance door of the radiography room should be locked during exposure. A suitable interlocking unit for the door may be incorporated so that the radiation beam cannot be made 'ON' when the door is open.

4. A Red light should be provided at the entrance and it should be made 'ON' during the exposure. A radiation zone monitor should be installed at suitable location so as to indicate the radiation levels during exposures and also to positively indicate that the source/x-ray machine 'ON' or safe position
5. In case of open top enclosure, red lights should be provided on top of the walls and should be made 'ON' during exposure as warning to the crane operator.
6. All the equipment operations should be preferably done from the control room.
7. Ventilators and the exhausts should be situated at a height of not less than 2.4 m from the floor level. These ventilators or exhausts or any such openings in the walls should be provided with suitable baffles.
8. Wherever possible the radiation beam should be directed towards the areas of minimum occupancy. The beam should never be pointed towards the doors, windows and the control panel. Any restriction on beam directions which are assumed while planning the installation should be strictly adhered to. This information should be prominently displayed in a poster in the radiography area.
9. The setting up of the objects, films etc for radiographic inspection should be duly compiled before starting the exposure.
10. If more than one radiation machine is used in the same room it should be ensured that only one of them is operated at a time

Field Radiography Ins Field Radiography Installation ^[1].

In some cases, such as for radiography of huge objects, the same should be at the erection site. In such cases radiography work in field /plant area is permitted subject to the approval of the site by DRP/BARC. Radiation safety during field radiography is achieved mainly by distance factor and by instituting strict radiation surveillance procedure recommended by DRP/BARC. It is in general practice to cordon off a certain area around the source / x-ray machine with ropes and radiation warning symbols, red light etc such that the radiation level beyond the cordon is kept below the permissible limits. The area to be cordoned off will depend upon various factors such as nature and strength of the radiography source, type of exposures, the work load, the nature of occupancy around etc. Entry of unauthorized persons into these cordoned off areas during the exposures should be strictly prohibited. It is advisable to carry out field radiography during night time or on holidays i.e. when there are no other workmen in that part of the plant. The in-charge of the work should be thoroughly trained in radiation safety. The radiography cameras should be operated only by the certified radiographers. Radiation safety rules should be explained to all concerned workers and their co-operation should be sought in achieving safety. Radiation warning signs exhibited around the site should include legend bearing "DANGER" –"RADIATION" – "KEEP AWAY". Area monitoring of these field radiography must be regularly conducted by the in-charge to conform to safe radiation levels prevailing around the site. A log book should be maintained at the site to record the relevant details regarding day-to-day use of radiography sources. Radiation accidents such as damage to the source of cameras or loss of radiation sources should be immediately reported to DRP/BARC seeking their assistance. The area at which the accident has taken place should be immediately cordoned off and a strict vigil should be kept to prevent the entry of unauthorized persons until the expert arrival

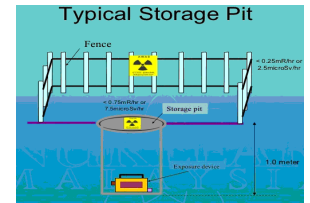
Radiographic Boundary ^[6]



WARNING! Radiography Work in Progress



Fully Open Field Sites



Storage of Radioactive Source ^[6]

Storage & Transportation of Radioactive Source & X-ray Equipment ^[6]

The radiographic work may involve the application of either radioactive source or x-ray equipment. Hence the storage of the devices at site should be done accordingly

- Sufficient warning notice should be displayed
- The ownership of the radioactive material should be displayed including name & address of the Company with Tel No. etc

The Storage facility of x-ray equipment is less complicated than radioactive source. It should be lockable store room.

The Storage pit of radioactive source picture is shown at the right side.

-The transportation of radioactive source at out side premise should be done according to the radiation protection regulation 1989.

-Should ensure that (a)the source is packed according to the regulation; (b) the vehicle to be used for transporting source is in good condition; (c) the radiation level does not exceed 0.02 mSv/h; (d) all emergency equipment such as radiation signage, rope, survey meter and necessary tools are available in the vehicle

-Any loss of gamma source during the transport or any accident shall be reported immediately AERB/Mumbai

-Source should not be moved freely from one place to another unless it is absolutely necessary to follow the regulation

-Transport of x-ray system may be undertaken under normal process..

Conclusion

This article has been written for awareness and better knowledge for the public in general and occupational workers in Industrial radiology in particular as well as the beneficiaries for their responsibilities for protection and against radiation. It has been observed that all are not fully aware of the importance of personnel safety against radiation. The beneficiaries are partially equipped with safety measurements and have a casual attitude. The names of the radiation workers especially from private beneficiaries may not have been registered for accumulated dose in a year. The number of beneficiaries has increased due to many Govt. projects and technological developments in industries. Consequentially the number of radiation workers would increase substantially due to "Make in India" policy. Therefore radiation protection and personnel safety is an important issue.

References

- [1] BARC/DRP, Subramanian V.G.R, 'ISNT' Workshop, Bombay, "NDT for Managers" Jan'93
- [2] Quality Factor & Equivalent dose data from Internet NDE/NDT
- [3] AEA, Vienna, 1999 Publication 'NDT Guide book' IAEA-TCS-9 Page 95
- [4] Rich. Seifert & Co. – Germany, Radiographic Accessories data sheets 04-'00
- [5] BARC/DRP Publication through internet – TLD Card, Materials & TLD Badge Reader development for personal monitoring
- [6] Nuklear – Malaysia Industriel Radiography présentation