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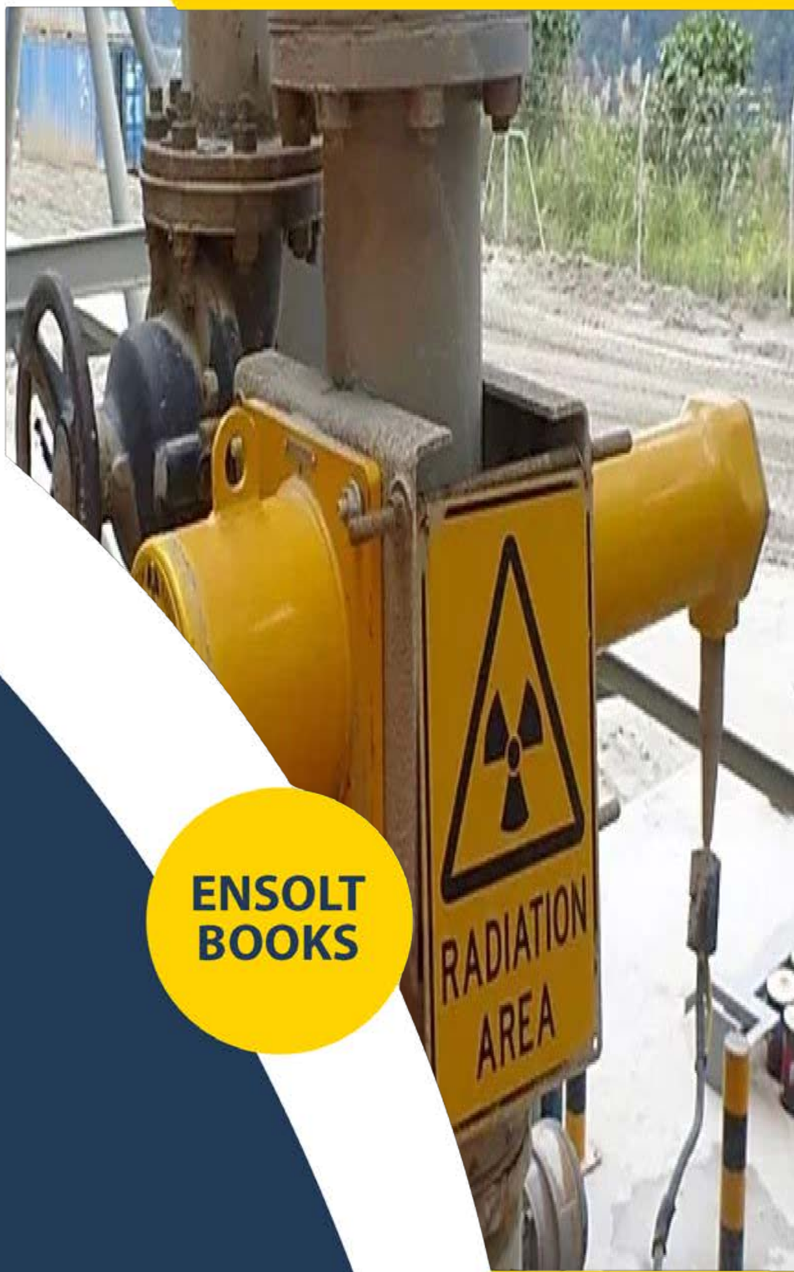

ENSOLT BOOKS

INSTRUMENTATION RADIATION SAFETY

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About the author

A.Gowthaman, is a recognized expert in the field of process instrumentation and controls system. A.Gowthaman is graduated from College of engineering, Guindy, Tamilnadu, India, in 1994 and had his master's degree in Electronics and control system engineering. He is presently working in Chennai Petroleum Corporation in southern India. He has a rich experience in various instrumentation engineering activities like tender preparation, project design, instrument specification design, material evaluation, testing and commissioning of projects and maintenance activities. His more than thirty years of instrumentation and controls experience covers a wide range of industries and applications. He has commissioned more than 15 refinery projects covering DCS, PLC and SCADA of various vendors.

INSTRUMENTATION

RADIATION SAFETY

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Volume 11	Supervisory Control and Data Acquisition System
Volume 12	Vibration Systems
Volume 13	Interview Questions
Volume 14	Instrumentation in Process Industry
Volume 15	Logic Distributed Control Systems (Anna University Syllabus)
Volume 16	Fire and Gas Detectors in Petrochemical Industries

1. INTRODUCTION

Radioisotopes are used by manufacturers as tracers to monitor fluid flow and filtration, detect leaks, and gauge engine wear and corrosion of process equipment. Small concentrations of short-lived isotopes can be detected whilst no residues remain in the environment. By adding small amounts of radioactive substances to materials used in various processes it is possible to study the mixing and flow rates of a wide range of materials, including liquids, powders, and gases and to locate leaks. Radiotracers are used widely in industry to investigate processes and highlight the causes of inefficiency. They are particularly useful where process optimization can bring material benefits, such as in the transport of sediments. Radiotracers are also used in the oil and gas industry to help determine the extent of oil fields.

Radioactive materials are used to inspect metal parts and the integrity of welds across a range of industries. Industrial gamma radiography exploits the ability of various types of radiation to penetrate materials to different extents. Gamma radiography works in much the same way as X-rays screen luggage at airports. Instead of the bulky machine needed to produce X-rays, all that is needed to produce effective gamma rays is a small pellet of radioactive material in a sealed titanium capsule. The capsule is placed on one side of the object being screened, and photographic film is placed on the other side. The gamma rays, like X-rays, pass through the object and create an image on the film. Just as X-rays show a break in a bone, gamma rays show flaws in metal castings or welded joints. The technique allows critical components to be inspected for internal defects without damage. X-ray sets can be used when electric power is available and the object to be scanned can be taken to the X-ray source and radiographed. Radioisotopes have the supreme advantage that they can be taken to the site when an examination is required – and no power is needed. However, they cannot be simply turned off, and so must be properly shielded both when in use and at other times.

The process of gamma radiography, a type of non-destructive testing (NDT), is used to validate the integrity of poured concrete and welds on fluid vessels, pipelines, or critical structural elements. The unique characteristics of gamma radiography have resulted in the technique becoming a crucial tool throughout many industries. For example, to inspect new oil or gas pipelines, special film is taped over the weld around the outside of the pipe. A machine called a 'pipe crawler' carries a shielded radioactive source down the inside of the pipe to the position of the weld. There, the radioactive source is remotely exposed and a radiographic image of the weld is produced on the film. This film is later developed and examined for signs of flaws in the weld. Gamma radiography has found use outside of core industrial applications, with the technique successfully employed following the devastating earthquake in Nepal in April 2015. NDT was used to test the integrity of critical buildings such as schools and hospitals, as well as historical attractions. Both Japan and Malaysia have since backed an IAEA initiative to use NDT for the inspection of civil structures more widely following natural disasters.

Gauges containing radioactive (usually gamma) sources are in wide use in all industries where levels of gases, liquids, and solids must be checked. The IAEA estimates that several hundred thousand such gauges are operating in industry worldwide. They measure the amount of radiation from a source which has been absorbed in materials. These gauges are most useful where heat, pressure, or corrosive substances, such as molten glass or molten metal, make it impossible or difficult to use direct contact gauges. The ability to use radioisotopes to accurately measure thickness is widely used in the production of sheet materials, including metal, textiles, paper, plastics, and others. Density gauges are used where automatic control of a liquid, powder, or solid is important, for example as in detergent manufacture.

Radioisotope instruments have three advantages:

Measurements can be made without physical contact to the material or product being examined, increasing the envelope of operating environments and decreasing inspection time.

Very little maintenance of the isotope source is necessary.

The cost/benefit ratio is excellent – many instruments pay for themselves within a few months through the time savings they facilitate.

There are two broad types of nucleonic gauges used in industry: fixed and portable. Fixed gauges are typically used in production facilities – mines, mills, oil and gas platforms – as a means of controlling and monitoring quality from a production process. For example, in the North Sea, fixed nucleonic gauges are sometimes deployed to determine conditions within separator vessels and to monitor residual oil content within separated gas streams.

Nucleonic gauges are also used in the coal industry. The height of the coal in a hopper can be determined by placing high energy gamma sources at various heights along one side with focusing collimators directing beams across the load. Detectors placed opposite the sources register the breaking of the beam and hence the level of coal in the hopper. Such level gauges are among the most common industrial uses of radioisotopes.

Some machines which manufacture plastic film use radioisotope gauging with beta particles to measure the thickness of the plastic film. The film runs at high speed between a radioactive source and a detector. The detector signal strength is used to control the plastic film thickness.

In paper manufacturing, beta gauges are used to monitor the thickness of the paper at speeds of up to 400 m/s. When the intensity of radiation from a radioisotope is being reduced by matter in the beam, some radiation is scattered back towards the radiation source.

The amount of 'backscattered' radiation is related to the amount of material in the beam, and this can be used to measure characteristics of the material. This principle is used to measure different types of coating thicknesses.

Portable gauges have applications in agriculture, construction, and civil engineering. For example, portable gauges may be used to determine the degree of soil compaction on agricultural land, or the density of asphalt in paving mix for a road surface. Neutron radiography is an NDT technique similar to that of X-ray and gamma ray. Neutrons from a research reactor can interact with atoms in a sample causing the emission of gamma rays which, when analyzed for characteristic energies and intensity, will identify the types and quantities of elements present.

The two main techniques are thermal neutron capture (TNC) and neutron inelastic scattering (NIS). TNC occurs immediately after a low-energy neutron is absorbed by a nucleus; NIS takes place instantly when a fast neutron collides with a nucleus. Most commercial analyzers use californium-252 neutron sources together with sodium iodide detectors, and are mainly sensitive to TNC reactions. Others use Am-Be-241 sources and bismuth germanate detectors, which register both TNC and NIS. NIS reactions are particularly useful for elements such as carbon, oxygen, aluminium and silicon, which have low neutron capture cross-sections. Such equipment is used for a variety of on-line and on-belt analysis in the cement, mineral, and coal industries.

Naturally-occurring radioisotopes

Carbon-14 (half-life: 5730 yr):

Used to measure the age of wood, other carbon-containing materials (up to 20,000 years), and subterranean water (up to 50,000 years).Chlorine-36 (301,000 yr):

Used to measure sources of chloride and the age of water (up to 2 million years).Lead-210 (22.3 yr):

Used to date layers of sand and soil up to 80 years.Tritium, H-3 (12.3 yr):

Used to measure 'young' groundwater (up to 30 years).

Artificially-produced radioisotopes

Americium-241 (half-life: 432 yr):

Used in backscatter gauges, smoke detectors, fill height detectors, and in measuring ash content of coal.Caesium-137 (30.17 yr):

Used for radiotracer technique for identification of sources of soil erosion and deposition, as well as in density and fill height level switches. Also for low-intensity gamma sterilisation.Chromium-51 (27.7 yr):

Used to label sand to study coastal erosion, also a tracer in study of blood.Cobalt-60 (5.27 yr), lanthanum-140 (1.68 d), scandium-46 (83.8 d), silver-110m (250 d), gold-198 (2.7 d):

Used together in blast furnaces to determine resident times and to quantify yields to measure the furnace performance.Cobalt-60 (5.27 yr):

Widely used for gamma sterilisation, industrial radiography, density, and fill height switches.Gold-198 (2.7 d) & technetium-99m (6 hr):

Used to study sewage and liquid waste movements, as well as tracing factory waste causing ocean pollution, and to trace sand movement in river beds and ocean floors.Gold-198 (2.7 d):

Used to label sand to study coastal erosion.

Hydrogen-3 (in tritiated water) (12.3 yr):

Used as a tracer to study sewage and liquid wastes.Iridium-192 (73.8 d):

Used in gamma radiography to locate flaws in metal components.Krypton-85 (10.756 yr):

Used for industrial gauging.Manganese-54 (312.5 d):

Used to predict the behaviour of heavy metal components in effluents from mining waste water.Nickel-63 (100 yr)

Used in light sensors in cameras and plasma display, also electronic discharge prevention and in electron capture detectors for thickness gauges. Also for long-life beta-voltaic batteries. Made from nickel-62 by neutron capture.Selenium-75 (120 d):

Used in gamma radiography and non-destructive testing.Strontium-90 (28.8.yr):

Used for industrial gauging.Thallium-204 (3.78 yr):

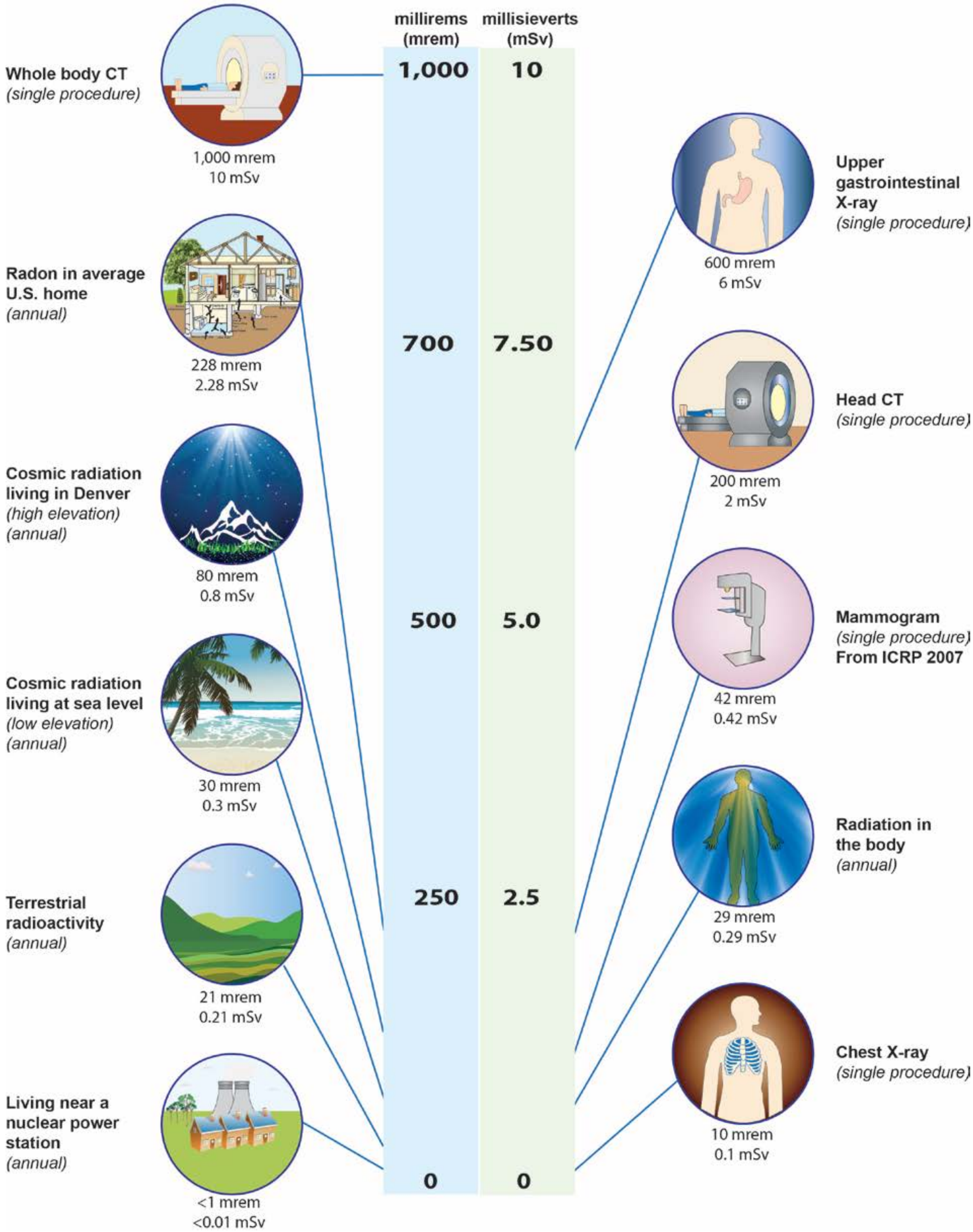
Used for industrial gauging.Ytterbium-169 (32 d):

Used in gamma radiography and non-destructive testing.Zinc-65 (244 d):

Used to predict the behaviour of heavy metal components in effluents from mining wastewater.

RELATIVE DOSES FROM RADIATION SOURCES

All doses from the National Council on Radiation Protection & Measurements, Report No. 160 (unless otherwise denoted)



2. BASIC ATOMIC AND NUCLEAR STRUCTURE

Radiation is energy. It can come from unstable atoms that undergo radioactive decay, or it can be produced by machines. Radiation travels from its source in the form of energy waves or energized particles. There are different forms of radiation and they have different properties and effects.

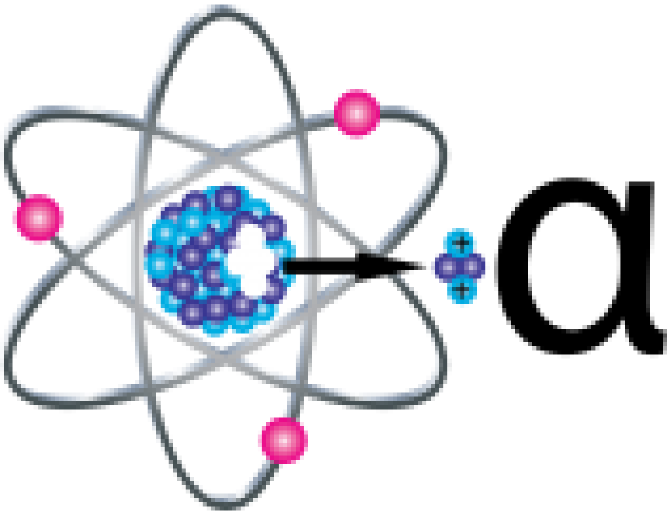
There are two kinds of radiation: non-ionizing radiation and ionizing radiation. Non-ionizing radiation has enough energy to move atoms in a molecule around or cause them to vibrate, but not enough to remove electrons from atoms. Examples of this kind of radiation are radio waves, visible light and microwaves.

Ionizing radiation has so much energy it can knock electrons out of atoms, a process known as ionization. Ionizing radiation can affect the atoms in living things, so it poses a health risk by damaging tissue and DNA in genes. Ionizing radiation comes from x-ray machines, cosmic particles from outer space and radioactive elements. Radioactive elements emit ionizing radiation as their atoms undergo radioactive decay.

The ionizing radiation that is emitted can include alpha particles, beta particles and/or gamma rays. Radioactive decay occurs in unstable atoms called radionuclides.

Alpha Particles

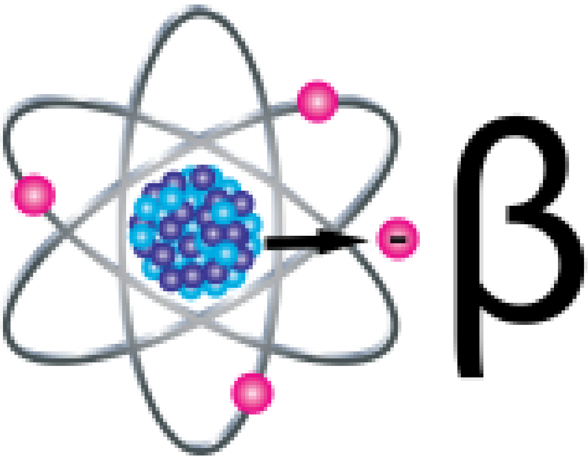
Alpha particles (α) are positively charged and made up of two protons and two neutrons from the atom's nucleus. Alpha particles come from the decay of the heaviest radioactive elements, such as uranium, radium and polonium. Even though alpha particles are very energetic, they are so heavy that they use up their energy over short distances and are unable to travel very far from the atom.



The health effect from exposure to alpha particles depends greatly on how a person is exposed. Alpha particles lack the energy to penetrate even the outer layer of skin, so exposure to the outside of the body is not a major concern. Inside the body, however, they can be very harmful. If alpha-emitters are inhaled, swallowed, or get into the body through a cut, the alpha particles can damage sensitive living tissue. The way these large, heavy particles cause damage makes them more dangerous than other types of radiation. The ionizations they cause are very close together - they can release all their energy in a few cells. This results in more severe damage to cells and DNA.

Beta Particles

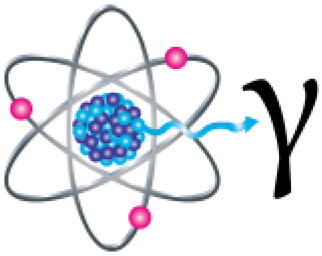
Beta particles (β) are small, fast-moving particles with a negative electrical charge that are emitted from an atom's nucleus during radioactive decay. These particles are emitted by certain unstable atoms such as hydrogen-3 (tritium), carbon-14 and strontium-90.



Beta particles are more penetrating than alpha particles, but are less damaging to living tissue and DNA because the ionizations they produce are more widely spaced. They travel farther in air than alpha particles, but can be stopped by a layer of clothing or by a thin layer of a substance such as aluminum. Some beta particles are capable of penetrating the skin and causing damage such as skin burns. However, as with alpha-emitters, beta-emitters are most hazardous when they are inhaled or swallowed.

Gamma Rays

Gamma rays (γ) are weightless packets of energy called photons. Unlike alpha and beta particles, which have both energy and mass, gamma rays are pure energy. Gamma rays are similar to visible light, but have much higher energy. Gamma rays are often emitted along with alpha or beta particles during radioactive decay.

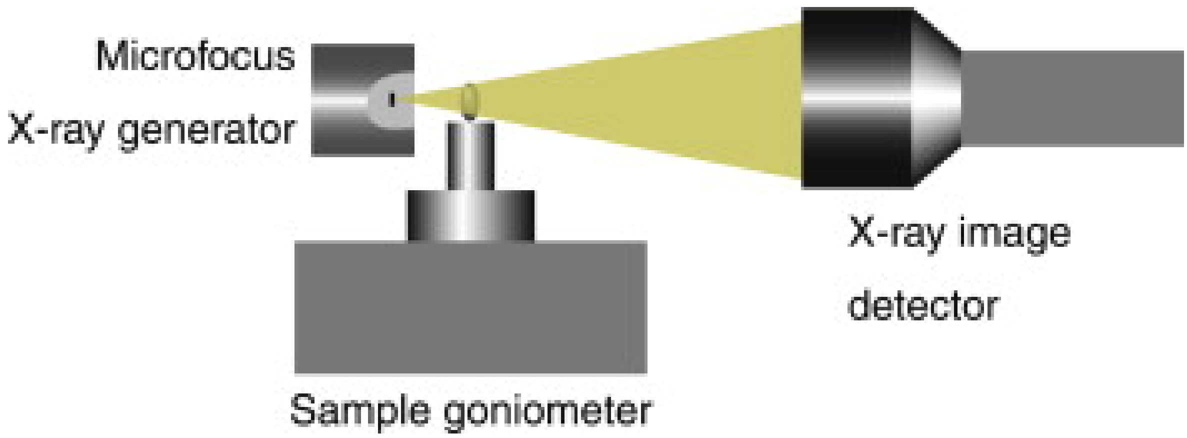


Gamma rays are a radiation hazard for the entire body. They can easily penetrate barriers that can stop alpha and beta particles, such as skin and clothing. Gamma rays have so much penetrating power that several inches of a dense material like lead, or even a few feet of concrete may be required to stop them. Gamma rays can pass completely through the human body; as they pass through, they can cause ionizations that damage tissue and DNA.

X-Rays

Because of their use in medicine, almost everyone has heard of x-rays. X-rays are similar to gamma rays in that they are photons of pure energy. X-rays and gamma rays have the same basic properties but come from different parts of the atom. X-rays are emitted from processes outside the nucleus, but gamma rays originate inside the nucleus. They also are generally lower in energy and, therefore less penetrating than gamma rays. X-rays can be produced naturally or by machines using electricity.

Literally thousands of x-ray machines are used daily in medicine. Computerized tomography, commonly known as a CT or CAT scan, uses special x-ray equipment to make detailed images of bones and soft tissue in the body. Medical x-rays are the single largest source of man-made radiation exposure. Learn more about radiation sources and doses. X-rays are also used in industry for inspections and process controls.



3. RADIATION TERMS AND UNITS

Scientists measure radiation in different ways. Sometimes, they measure the dose that a person receives from a radioactive source, and sometimes they measure the amount of radioactivity in water, or in soil, or in the air. Each measure describes a different aspect of radiation, and each has its own unit.

There are different but interrelated units for measuring radioactivity and its effects:

Radioactivity refers to the amount of ionizing radiation released by a material. Whether it emits alpha or beta particles, gamma rays, x-rays, or neutrons, a quantity of radioactive material is expressed in terms of its radioactivity (or simply its activity). This represents how many atoms in the material decay in a given time period. The units of measurement for radioactivity are the becquerel (Bq, international unit) and the curie (Ci, U.S. unit).

Exposure describes the amount of radiation traveling through the air. Many types of radiation monitors measure exposure. The units for exposure are the coulomb/kilogram (C/kg, international unit) and the roentgen (R, U.S. unit).

Absorbed dose describes the amount of radiation absorbed by an object or person. The unit for absorbed dose is the gray (Gy, international unit) or the rad (U.S. unit). One gray is equal to 100 rads.

Effective dose describes the amount of radiation absorbed by person, adjusted to account for the type of radiation received and the effect on particular organs. The unit used for effective dose is sievert (Sv, international unit) or rem (U.S. unit).

Dose Rate is a measure of how fast a radiation dose is being received. Dose rate is usually presented in terms of mR/hr, mrem/hr, rad/min, mGy/sec, etc. Knowing the dose rate, allows the dose to be calculated for a period of time.

The Constitution Order (1983) of AERB vide clause 2 (vii) entrusted the function of Prescribing acceptable limits of radiation exposure to occupational workers and members of The public and approve acceptable limits of environmental release of radioactive substances to AERB.

As per the AERB guide lines for an occupational worker, the annual dose limit is 30mSv, With the condition that it should not exceed 100mSv in a span of five years. Authorised Regulatory limits of radioactive effluents for the public are based on the apportionment of an effective dose limit of one mSv per year.

Activity of the source in measured in curie / bequrrel.

	Radioactivity	**Absorbed Dose**	**Dose Equivalent**	**Exposure**
Common Units	curie (Ci)	rad	rem	roentgen (R)
SI Units	becquerel (Bq)	gray (Gy)	sievert (Sv)	coulomb/kilogram (C/kg)

Conversion Equivalence

1 curie = 3.7 x 10^{10}		1 becquerel =
disintegrations per second		1 disintegration per second
1 millicurie (mCi)	=	37 megabecquerels (MBq)
1 rad	=	0.01 gray (Gy)
1 rem	=	0.01 sievert (Sv)
1 roentgen (R)	=	0.000258 coulomb/kilogram (C/kg)
1 megabecquerel (MBq)	=	0.027 millicuries (mCi)
1 gray (Gy)	=	100 rad
1 sievert (Sv)	=	100 rem
1 coulomb/kilogram (C/kg)	=	3,880 roentgens

Conversion Factors

To convert from	To	Multiply by
Curies (Ci)	becquerels (Bq)	3.7×10^{10}
millicuries (mCi)	megabecquerels (MBq)	37
microcuries (µCi)	megabecquerels (MBq)	0.037
millirads (mrad)	milligrays (mGy)	0.01
millirems (mrem)	microsieverts (µSv)	10
milliroentgens (mR)	microcoulombs/kilogram (µC/kg)	0.258
becquerels (Bq)	curies (Ci)	2.7×10^{-11}
megabecquerels (MBq)	millicuries (mCi)	0.027
megabecquerels (MBq)	microcuries (µCi)	27
milligrays (mGy)	millirads (mrad)	100
microsieverts (µSv)	millrems (mrem)	0.1
microcoulombs/kilogram (µC/kg)	milliroentgens (mR)	3.88

In order to illustrate the safety of working around nuclear gauges, let's examine the following scenario.

Assume that someone work at one meter from the source for one year. How much exposure would that person receive?

Source : Co – 60
Activity : 10 mCi
Dose rate : 7.1 micro Sieverts / at 1 meter
Annual dose : $7.1 \text{ X}10^{-6}$ X 8 hours X 30 days X 12 months = 20,448 micro Sieverts.

4. RADIATION HAZARD

The amount of risk depends on the amount of radiation dose received, the time over which the dose is received, and the body parts exposed. The fact that X-ray and gamma-ray radiation are not detectable by the human senses complicates matters further. However, the risks can be minimized and controlled when the radiation is handled and managed properly in accordance to the radiation safety rules. The active laws all over the world require that individuals working in the field of radiography receive training on the safe handling and use of radioactive materials and radiation producing devices.

Today, it can be said that radiation ranks among the most thoroughly investigated (and somehow understood) causes of disease. The primary risk from occupational radiation exposure is an increased risk of cancer. Although scientists assume low-level radiation exposure increases one's risk of cancer, medical studies have not demonstrated adverse health effects in individuals exposed to small chronic radiation doses.

The occurrence of particular health effects from exposure to ionizing radiation is a complicated function of numerous factors including:

Type of radiation involved. All kinds of ionizing radiation can produce health effects. The main difference in the ability of alpha and beta particles and gamma and X-rays to cause health effects is the amount of energy they have. Their energy determines how far they can penetrate into tissue and how much energy they are able to transmit directly or indirectly to tissues.

Size of dose received. The higher the dose of radiation received, the higher the likelihood of health effects.

Rate at which the dose is received. Tissue can receive larger dosages over a period of time. If the dosage occurs over a number of days or weeks, the results are often not as serious if a similar dose was received in a matter of minutes.

Part of the body exposed. Extremities such as the hands or feet are able to receive a greater amount of radiation with less resulting damage than blood forming organs housed in the upper body.

The age of the individual. As a person ages, cell division slows and the body is less sensitive to the effects of ionizing radiation. Once cell division has slowed, the effects of radiation are somewhat less damaging than when cells were rapidly dividing.

Biological differences. Some individuals are more sensitive to radiation than others. Studies have not been able to conclusively determine the cause of such differences.

External exposure

The risks associated with external exposure depend on the type of incident radiation:

Alpha radiation does not present any risk by external exposure

Beta radiation can be hazard at the site of exposure on the skin and deep derma

Neutrons entail the same risks as gamma radiation

Gamma radiation reaches the skin, the derma and all deep tissues

Internal contamination

When radioactive nuclides enter an organism it is still called internal exposure. Incorporation can occur via different pathways: respiratory, digestive, transcutaneous or through breaking and penetration of the skin. The most frequent points of entry are by inhalation and wounds.

In internal contamination the radio-elements are in contact with living cells. This position does not much alter the risk induced by beta or X radiation. By contrast, the risk associated with alpha radiation, which did not exist for the other modes of exposure, is major here.

The presence of radio-elements in an organism is not always pathological, a certain number of atoms, of which the organism is constructed, are radio-elements (example: K-40).

Biological Hazard

Alpha radiation is not an external hazard, because it can be stopped so easily.
If inhaled or swallowed, the alphas emitted from an alpha emitter, can deposit large amount of energy in a small area of body tissue.
If ingested or inhaled, a beta-emitter can be an internal hazard
Externally, beta particles are potentially hazardous to the eyes and skin

Exposure Limits

Over the years, numerous recommendations regarding occupational exposure limits have been developed by international radiation safety commissions. In general, the guidelines established for radiation exposure have had two principal objectives: 1) to prevent acute exposure; and 2) to limit chronic exposure to acceptable levels.

Current guidelines are based on the conservative assumption that there is no safe level of exposure. This assumption has led to the general philosophy of not only keeping exposures below recommended levels or regulation limits but also maintaining all exposure as low as reasonably achievable (ALARA). ALARA is a basic requirement of current radiation safety practices. It means that every reasonable effort must be made to keep the dose to workers and the public as far below the required limits as possible.

Dose limits for occupational worker & public

Occupational (Radiation worker, RSO) :

20 mSv per year averaged over a defined period or of 5 years, with no more than 50 mSv in any single year

For other employees :

1 mSv per year averaged over 5 years

The total effective dose equivalent to individual members of the public shall not exceed 100 mrem (1 mSv) in a year.

The dose in any unrestricted area shall not exceed 2 mrem (0.02 mSv / 20µSv) per hour.

Sl.No	Dose Range	Immediate Effect
1	<100mSV (<10rem)	None Detectable
2	0.1Sv to 0.25 Sv (10 rem to 25 rem)	Chromosome aberration. Recoverable.
3	0.25Sv to 1 Sv (25 rem to 100 rem)	Change in blood pressure. Recoverable
4	1 SV to 3 SV (100 rem to 300 rem)	Nausea, Vomiting, Diarrhea (NVD), Loss of appetite. Recovery probable.
5	3Sv to 5 Sv (300 rem to 500 rem)	NVD + Radiation fever. Recovery probable
6	>5 Sv (500 rem)	Death within few days to weeks
7	4 Sv to 6 Sv (400 to 600 rems)	X LD 50/30
8	10 SV (1000 rems)	NVD in all within two hours
9	50 Sv (5000 rems)	Incapacitation immediately. Death within few hours

Controlling Radiation Exposure

When working with radiation, there is a concern for two types of exposure: acute and chronic. An acute exposure is a single accidental exposure to a high dose of radiation during a short period of time. An acute exposure has the potential for producing both non-stochastic and stochastic effects. Chronic exposure, which is also sometimes called continuous exposure , is long-term, low level overexposure. Chronic exposure may result in stochastic health effects and is likely to be the result of improper or inadequate protective measures.

The three basic ways of controlling exposure to harmful radiation are: 1) limiting the time spent near a source of radiation, 2) increasing the distance away from the source, and using shielding to stop or reduce the level of radiation.

Time

The radiation dose is directly proportional to the time spent in the radiation. Therefore, a person should not stay near a source of radiation any longer than necessary. If a survey meter reads 4 mR/h at a particular location, a total dose of 4 mR will be received if a person remains at that location for one hour. The received dose can be simply calculated as: Dose = Dose Rate x Time

When using a gamma camera, it is important to get the source from the shielded camera to the collimator (a device that shields radiation in some directions but allow it pass in one or more other directions) as quickly as possible to limit the time of exposure to the unshielded source.

Distance

Increasing distance from the source of radiation will reduce the amount of radiation received. As radiation travels from the source, it spreads out becoming less intense. This phenomenon can be expressed by the Newton inverse square law, which states that as the radiation travels out from the source, the dosage decreases inversely with the square of the distance: I1 / I2 = D22/ D12

Shielding

The third way to reduce exposure to radiation is to place something between the radiographer and the source of radiation. In general, the more dense the material the more shielding it will provide. Lead and concrete are the most commonly used radiation shielding materials primarily because they are easy to work with and are readily available materials. Concrete is commonly used in the construction of radiation vaults. Some vaults will also be lined with lead sheeting to help reduce the radiation to acceptable levels on the outside.

5. MOBILE GAUGING EQUIPMENT AND ARTICLES

Numerous mobile gauging devices utilizing radiation, as well as other articles containing radioactive material, are used in the oil and gas industry, especially by service companies. These include small articles such as smoke detectors and self luminous signs (‘beta lights’ containing gaseous tritium), hand held testing instruments, and larger equipment intended primarily for use only at service companies’ own bases.

Fire protection equipment service companies commonly use hand held level gauges to determine the fluid level in fire extinguisher bottles or cylinders. Attached to the same long handle are two short probes, one containing a 137Cs source of several mega becquerels and the other a radiation detector. As the probes are moved up either side of an extinguisher bottle a signal from the detector provides a reading on a meter. The level of fluid is indicated when the detector indicates a change in the intensity of attenuated radiation. A similar hand held probe containing a source that consists of 241Am–Be is used primarily by NDT service companies to detect water trapped between lagging (insulation) and the insulated surface of a pipe or vessel. Fast (high energy) neutrons emitted by the source are ‘thermalized’ (reduced in energy) and scattered back to a detector in the probe if water is trapped behind the lagging. Water that is discovered using this procedure can then be released before it causes corrosion that would weaken the pipe.

FIG. Mobile gauge for detecting the level of liquids in closed fire extinguisher cylinders.

The ‘pipe wall profiler’ is an example of the larger equipment. It contains a 137Cs source of several giga becquerels and a detector mounted on an annulus and is used to check the wall thickness and uniformity of steel pipes intended for use in tubing strings. The annulus revolves at high speed around the axis of each pipe while the pipe is moved through the centre of the annulus. The service company issues certificates to indicate that the tubes are of an appropriate standard to be used in the high temperature and pressure environment of an oil or gas well.

Mobile level gauge systems incorporating appropriate sealed radiation sources are used commonly to determine the height of a fluid level or an interface between different fluids. One such investigation is carried out on offshore platforms to determine the level of potentially corrosive water ingress into subsea sections of ‘flooded members’. Divers manipulate the gauging system or it is attached to the remotely operated vehicle of a miniature submarine. Other examples include: the detection of liquid levels in storage containers, still bases, reactors and transport tankers; checking for blockages by solid deposits and accumulations on internal pipe walls; and determining the location of vessels’ internal structures such as packing levels in absorption towers and catalyst beds in reactors. For example, a reactor vessel at a petrochemical site could be investigated using a gamma transmission gauge showing that the catalyst had been spent and the packed beds had expanded, thereby narrowing the vertical separations between adjacent beds. The results may help the plant management to decide when to regenerate the catalyst. This ‘density profiling’ is most often used to investigate distillation columns. The vapour spaces are clearly differentiated from the relatively high radiation attenuation detected as the source or detector descends past the levels of the tray structures. ‘Reference scans’ (when the columns are operating normally) and ‘blank scans’ (when the columns are empty) permit the detection not only of flooding, foaming, missing or collapsed trays, but also of more subtle faults such as a high liquid level on the trays and high vapour density. It is also possible to quantify more accurately the foam densities forming in different parts of the column. Using a fast neutron (e.g. 241Am–Be) source to scan down the side of a vessel, it is possible to detect phase changes of hydrogenous substances, for example, to determine water, oil and vapour interfaces. Neutron sources have been used to monitor flare stack lines for ice deposits that start to form when condensates freeze in very cold weather and create a potential flare stack hazard.

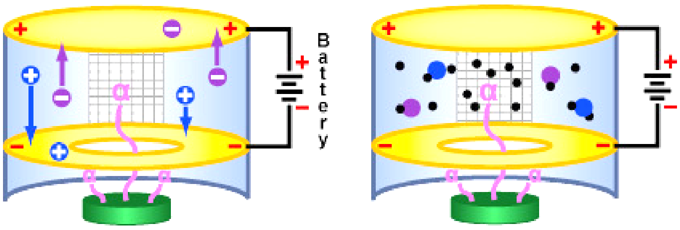
Radioactive sealed sources may be incorporated in a pipeline pig to track and possibly help locate it in the event that the pig is stopped by a stubborn blockage. Similarly, a pig labelled with a sealed source may be used to locate a leak in an umbilical pipeline; when the pig passes the leak in the hose, the driving force is lost and the location of the source (in the pig) indicates where the leak is occurring.

FIG. Radioactive sealed sources incorporated in a pipeline pig

6. IONISATION POINT SMOKE DETECTORS

An ionization smoke detector uses a radioisotope such as americium-241 to produce ionization in air; a difference due to smoke is detected and an alarm is generated. Ionization detectors are more sensitive to the flaming stage of fires than optical detectors, while optical detectors are more sensitive to fires in the early smouldering stage.

The radioactive isotope americium-241 in the smoke detector emits ionizing radiation in the form of alpha particles into an ionization chamber (which is open to the air) and a sealed reference chamber. The air molecules in the chamber become ionized and these ions allow the passage of a small electric current between charged electrodes placed in the chamber. If any smoke particles pass into the chamber the ions will attach to the particles and so will be less able to carry the current. An electronic circuit detects the current drop, and sounds the alarm. The reference chamber cancels effects due to air pressure, temperature, or the aging of the source. Other parts of the circuitry monitor the battery (where used) and sound an intermittent warning when the battery nears exhaustion. A self-test circuit simulates an imbalance in the ionization chamber and verifies the function of power supply, electronics, and alarm device. The standby power draw of an ionization smoke detector is so low that a small battery can provide power for months or years, making the unit independent of AC power supply or external wiring; however, batteries require regular test and replacement.



An ionization type smoke detector is generally cheaper to manufacture than an optical smoke detector; however, it is sometimes rejected because it is more prone to false (nuisance) alarms than photoelectric smoke detectors. It can detect particles of smoke that are too small to be visible.

Americium-241, an alpha emitter, has a half-life of 432 years. Alpha radiation, as opposed to beta and gamma, is used for two additional reasons: Alpha particles have high ionization, so sufficient air particles will be ionized for the current to exist, and they have low penetrative power, meaning they will be stopped by the plastic of the smoke detector or the air. About one percent of the emitted radioactive energy of 241Am is gamma radiation. The amount of elemental americium-241 is small enough to be exempt from the regulations applied to larger sources. It includes about 37 kBq or 1 µCi of radioactive element americium-241 (241Am), corresponding to about 0.3 µg of the isotope. This provides sufficient ion current to detect smoke, while producing a very low level of radiation outside the device.

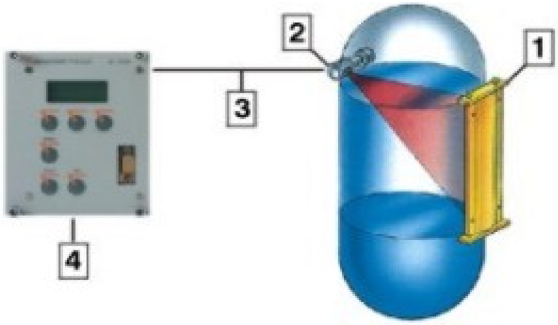
The americium-241 in ionizing smoke detectors poses a potential environmental hazard. Disposal regulations and recommendations for smoke detectors vary from region to region. Some European countries have banned the use of domestic ionic smoke alarms.

7. RADIATION LEVEL MEASUREMENT

Certain types of nuclear radiation easily penetrates the walls of industrial vessels, but is attenuated by traveling through the bulk of material stored within those vessels. By placing a radioactive source on one side of the vessel and measuring the radiation making it through to the other side of the vessel, an approximate indication of level within that vessel may be obtained.

The four most common forms of nuclear radiation are alpha particles (α), beta particles (β), gamma rays (γ), and neutrons (n). Alpha particles are helium nuclei (2 protons bound together with 2 neutrons) ejected at high velocity from the nuclei of certain decaying atoms. They are easy to detect, but have very little penetrating power and so are not used for industrial level measurement. Beta particles are electrons ejected at high velocity from the nuclei of certain decaying atoms. Like alpha particles, though, they have little penetrating power and so are not used for industrial level measurement. Gamma rays are electromagnetic in nature (like X-rays and light waves) and have great penetrating power. Neutron radiation also penetrates metal very effectively, but is strongly attenuated and scattered by any substance containing hydrogen (e.g. water, hydrocarbons, and many other industrial fluids), which makes it almost ideal for detecting the presence of a great many process fluids. These latter two forms of radiation (gamma rays and neutrons) are the most common in industrial measurement, with gamma rays used in through-vessel applications and neutrons typically used in backscatter applications.

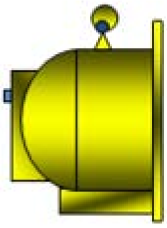
Figure shows a radiation level detector. It consists of gamma rays source holder in one side of the tank and a gamma detector on the other side of the tank. Radioactive source (cobalt-60) is used for this purpose to give out γ rays. The γ rays penetrate the vessel and strike a GM tube or scintillator kept diametrically opposite, on the other side of the vessel. The gamma rays from the source are directed towards the detector in a thin band of radiation. When the gamma rays penetrate the thick wall of the tank, its energy level afterwards is greatly reduced. The radiation received at the gamma detector is inversely proportional to the thickness of the tank walls and the medium between the radiation source and the detector. That is, the thicker the medium between source and detector, the less radiation received by the detector and vice versa.



1 Rod source
2 Point detector
3 Signal cable
4 Indicator

When the tank is empty, the gamma rays pass only through the two tank walls and the air or vapour in the empty tank. When liquid enters the tank and its level rises, the radiation beam passes through a path in the liquid, as well as the tank walls. The liquid in the tank reduces the radiation received by the detector. The amount of radiation received is inversely proportional to the amount of liquid between the radiation source and the detector. The difference in the amount of radiation received by the detector corresponds to the liquid level in the tank. Thus, when liquid level rises, the amount of radiation received is reduced and vice versa. The radiation loss received by the tank walls is constant whether the tank is full or empty.

SOURCE



The penetrating power of nuclear radiation is identified by its photon energy, expressed in electron volts (eV) and related to wavelength. The most common isotope used for level measurement is Cesium 137, which has a photon energy level of 0.56 MeV. Another isotope that is used is Cobalt 60, which has an energy level of 1.33 MeV. While the greater penetrating power of this higher energy radiation appears attractive at first, the penalty is that it also has a shorter half-life. As any isotope decays, it loses strength at the time it takes to lose half of its strength is called its half-life.

The half-life of Cobalt 60 is 5.3 years. This means that, in 5.3 years, the activity of a 100 millicurie (mCi) Cobalt 60 source will be reduced to 50 mCi. (One mCi is defined as the rate of activity of one milligram of Radium 226.) When used for level measurement, the continuous loss of source strength requires not only continuous compensation, but, eventually (in the case of Cobalt 60, in about 5 years), the source must be replaced. This means not only the expense of purchasing a new source, but also the cost of disposing of the old one. In contrast, the 33-year half-life of Cesium 137 is long enough that the source may well outlive the process. Another likelihood is that technological advances will increase the sensitivity of the detector faster than the rate at which the source is decaying. This provides users the option of replacing or upgrading the detector while keeping the source in place for the future.

Common source types for gamma-ray applications are Cesium-137 and Cobalt-60. The numbers represent the atomic mass of each isotope: the sum total of protons and neutrons in the nucleus of each atom. These isotopes' nuclei are unstable, decaying over time to become different elements (Barium-137 and Nickel-60, respectively). Cobalt-60 has a relatively short half-life of 5.3 years, whereas Cesium-137 has a much longer half-life of 30 years. This means radiation-based sensors using Cesium will be more stable over time (i.e. less calibration drift) than sensors using Cobalt.

The trade-off is that Cobalt emits more powerful gamma rays than Cesium, which makes it better suited to applications where the radiation must penetrate thick process vessels or travel long distances (across wide process vessels).

Source Sizing

Assume a point source of 10 mCi Cesium 137 (source constant for Cesium 137 is K=0.6) is installed on a high-pressure water tank having H-in steel walls. Usually, two criteria need to be satisfied: First, the radiation intensity at the detector must drop by at least 50% as the level rises from 0- 100%. The second and more important criterion is that the maximum radiation dose at the detector (when the tank is empty) must not exceed the safety limit (say, 2.4 mr/hr). It must exceed 1.0 mr/hr, however, in order to actuate the intended ion chamber detector. First the in air intensity (Da in mr/hr) is calculated at the detector, for the condition when there is no tank between the source and receiver. Assume distance (d) is 48 in:

Da = 1000 K(mCi)/d2 = 1000(0.6)(10)/482 = 2.6 mr/hr.

Because the source is shielded in all directions except towards the tank, the operator who is working near the detector will receive the maximum dosage when the tank is empty. The two H-in steel walls will reduce Da (% transmission of 1-in steel in Figure 1 is 49%) to 0.49 x 2.6 = 1.27 mr/hr. This is below the allowable maximum but above the minimum needed by the detector. When the tank is full, the presence of 30 in of water in the radiation path will reduce this maximum intensity to 0.045 mr/hr (0.035 x 1.9 = 0.045). This reduction in intensity well exceeds the required 50% drop needed for sensitive measurement.

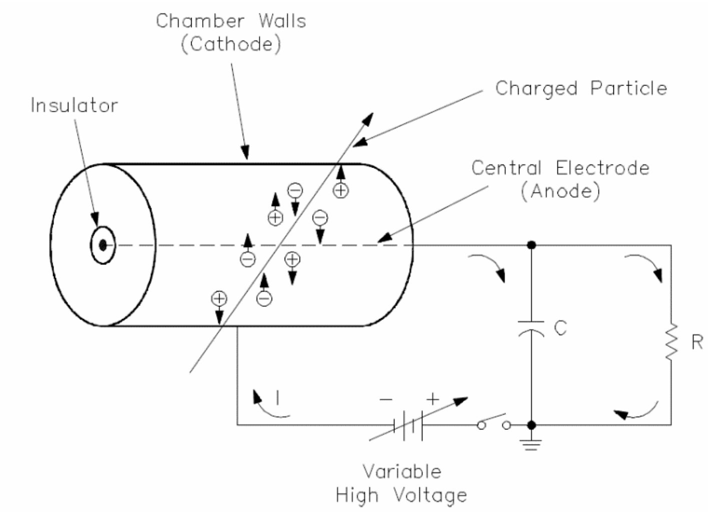
Note that the source size could have been cut in half if a Geiger- Mueller detector were used. A scintillation detector would reduce source size 5- to 10-fold. The source size can also be reduced by locating the source in the tip of a probe inside the tank and moving it relatively close to the wall. When large level ranges are to be measured, a strip source can be used instead of a point source.

The accuracy of most nuclear level gages is around 1% of range. If accounting accuracy is desired, the source and the detector can both be attached to motor driven tapes and positioned at the level (or at the interface level, if the tank contains two liquids). Fortunately, today as computers can easily crunch the numbers and formulas of any combination of geometry and design criteria. The biggest challenge is not the calculation, but the obtaining of accurate inputs for the calculations. Therefore, it is very important that your vessel's wall materials, thicknesses, other tank components such as baffles, agitator blades or jackets, and all distances be accurately determined. In short, the performance of a nuclear gage installation is very much a function of the accurate knowledge of the installation details.

DETECTORS BASICS

GAS-FILLED DETECTOR

The pulsed operation of the gas-filled detector illustrates the principles of basic radiation detection. Gases are used in radiation detectors since their ionized particles can travel more freely than those of a liquid or a solid. Typical gases used in detectors are argon and helium, although boron-triflouride is utilized when the detector is to be used to measure neutrons. Figure shows a schematic diagram of a gas-filled chamber with a central electrode.



The central electrode, or anode, collects negative charges. The anode is insulated from the chamber walls and the cathode, which collects positive charges. A voltage is applied to the anode and the chamber walls. The resistor in the circuit is shunted by a capacitor in parallel, so that the anode is at a positive voltage with respect to the detector wall. As a charged particle passes through the gas-filled chamber, it ionizes some of the gas (air) along its path of travel.

The positive anode attracts the electrons, or negative particles. The detector wall, or cathode, attracts the positive charges. The collection of these charges reduces the voltage across the capacitor, causing a pulse across the resistor that is recorded by an electronic circuit. The voltage applied to the anode and cathode determines the electric field and its strength.

As detector voltage is increased, the electric field has more influence upon electrons produced. Sufficient voltage causes a cascade effect that releases more electrons from the cathode. Forces on the electron are greater, and its mean-free path between collisions is reduced at this threshold. Calculating the change in the capacitor's charge yields the height of the resulting pulse. Initial capacitor charge (Q), with an applied voltage (V), and capacitance (C), is given by Equation.

$$Q = CV$$

A change of charge (ΔQ) is proportional to the change in voltage (ΔV) and equals the height of the pulse, as given by Equation

$$\Delta Q = CDV$$

$$\Delta V = \Delta Q / C$$

The total number of electrons collected by the anode determines the change in the charge of the capacitor (ΔQ). The change in charge is directly related to the total ionizing events which occur in the gas. The ion pairs (n) initially formed by the incident radiation attain a great enough velocity to cause secondary ionization of other atoms or molecules in the gas. The resultant electrons cause further ionizations. This multiplication of electrons is termed gas amplification. The gas amplification factor (A) designates the increase in ion pairs when the initial ion pairs create additional ion pairs. Therefore, the height of the pulse is given by Equation

$$\Delta V = Ane / C$$

Where ΔV = pulse height (volts)

A = gas amplification factor

n = initial ionizing events

e = charge of the electron (1.602 x 10-19 coulombs)

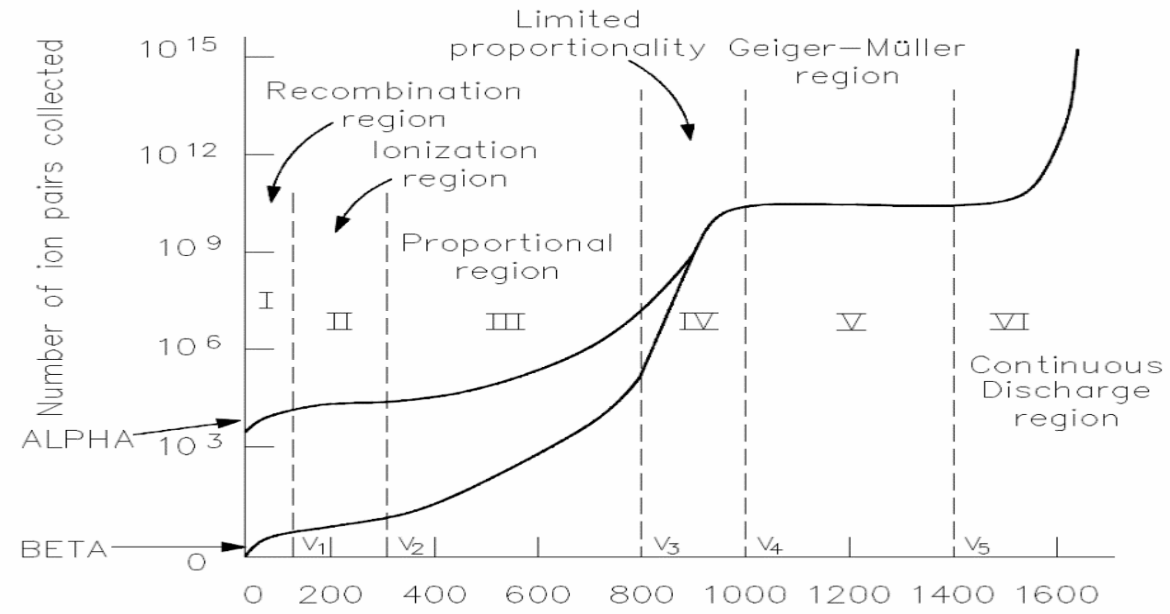
C = detector capacitance (farads)

The pulse height can be computed if the capacitance, detector characteristics, and radiation are known.

The capacitance is normally about 10-4 farads. The number of ionizing events may be calculated if the detector size and specific ionization, or range of the charged particle, are known. The only variable is the gas amplification factor that is dependent on applied voltage.

Applied Voltage

The relationship between the applied voltage and pulse height in a detector is very complex. Pulse height and the number of ion pairs collected are directly related. Figure illustrates ion pairs collected -vs- applied voltage. Two curves are shown: one curve for alpha particles and one curve for beta particles; each curve is divided into several voltage regions. The alpha curve is higher than the beta curve from Region I to part of Region IV due to the larger number of ion pairs produced by the initial reaction of the incident radiation. An alpha particle will create more ion pairs than a beta since the alpha has a much greater mass. The difference in mass is negated once the detector voltage is increased to Region IV since the detector completely discharges with each initiating event.



Recombination Region

In the recombination region (Region I), as voltage increases to V1, the pulse height increases until it reaches a saturation value. At V1, the field strength between the cathode and anode is sufficient for collection of all ions produced within the detector. At voltages less than V1, ions move slowly toward the electrodes, and the ions tend to recombine to form neutral atoms or molecules. In this case, the pulse height is less than it would have been if all the ions originally formed reached the electrodes. Gas ionization instruments are, therefore, not operated in this region of response.

Ionization Region

As voltage is increased in the ionization region (Region II), there is no appreciable increase in the pulse height. The field strength is more than adequate to ensure collection of all ions produced; however, it is insufficient to cause any increase in ion pairs due to gas amplification. This region is called the ionization chamber region.

Proportional Region

As voltage increases to the proportional region (Region III), the pulse height increases smoothly. The voltage is sufficient to produce a large potential gradient near the anode, and it imparts a very high velocity to the electrons produced through ionization of the gas by charged radiation particles. The velocity of these electrons is sufficient to cause ionization of other atoms or molecules in the gas. This multiplication of electrons is called gas amplification and is referred to as Townsend avalanche. The gas amplification factor (A) varies from 103 to 104. This region is called the proportional region since the gas amplification factor (A) is proportional to applied voltage.

Limited Proportional Region

In the limited proportional region (Region IV), as voltage increases, additional processes occur leading to increased ionization. The strong field causes increased electron velocity, which results in excited states of higher energies capable of releasing more electrons from the cathode. These events cause the Townsend avalanche to spread along the anode. The positive ions remain near where they were originated and reduce the electric field to a point where further avalanches are impossible. For this reason, Region IV is called the limited proportional region, and it is not used for detector operation.

Geiger-Müller Region

The pulse height in the Geiger-Müller region (Region V) is independent of the type of radiation causing the initial ionizations. The pulse height obtained is on the order of several volts. The field strength is so great that the discharge, once ignited, continues to spread until amplification cannot occur, due to a dense positive ion sheath surrounding the central wire (anode). V4 is termed the threshold voltage. This is where the number of ion pairs level off and remain relatively independent of the applied voltage. This leveling off is called the Geiger plateau which extends over a region of 200 to 300 volts. The threshold is normally about 1000 volts. In the G-M region, the gas amplification factor (A) depends on the specific ionization of the radiation to be detected.

Continuous Discharge Region

Here a steady discharge current flows. The applied voltage is so high that, once ionization takes place in the gas, there is a continuous discharge of electricity, so that the detector cannot be used for radiation detection.

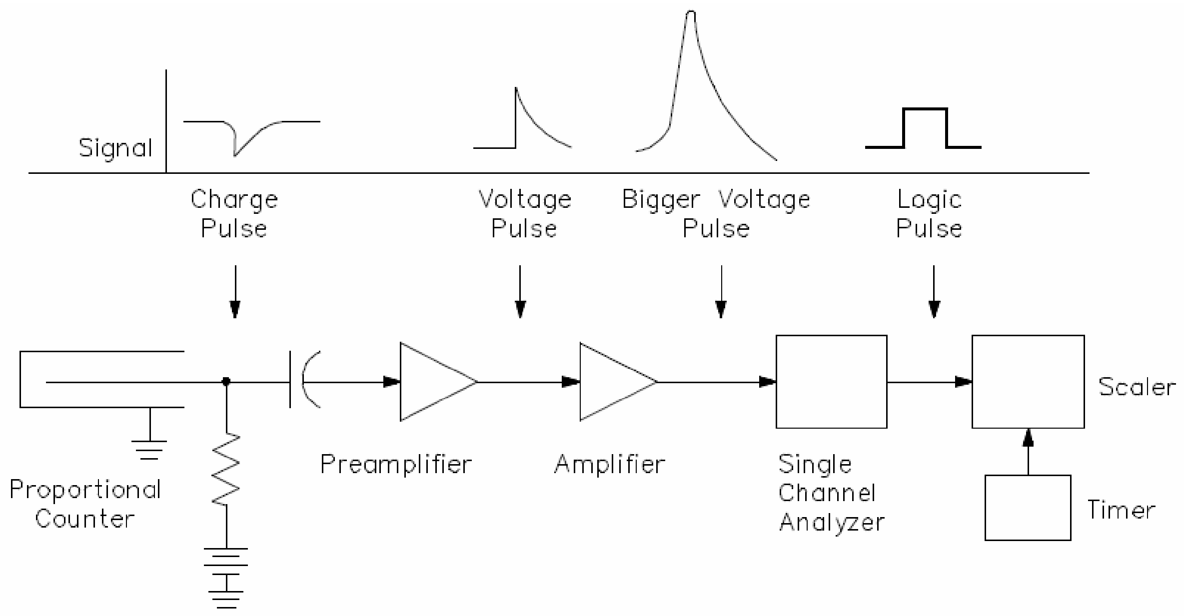
Radiation detectors are normally designed to respond to a certain type of radiation. Since the detector response can be sensitive to both energy and intensity of the radiation, each type of detector has defined operating limits based on the characteristics of the radiation to be measured. A large variety of detectors are in use to detect alpha and beta particles, gamma rays, or neutrons. Some types of detectors are capable of distinguishing between the types of radiation; others are not. Some detectors only count the number of particles that enter the detector, while others are used to determine both the number and energy of the incident particles.

Most detectors used have one thing in common: they respond only to electrons produced in the detector. In order to detect the different types of incident particles, the particle's energy must be converted to electrons in the detector. Gas-filled detectors are used, for the most part, to measure alpha and beta particles, neutrons, and gamma rays. The detectors operate in the ionization, proportional, and G-M regions with an arrangement most sensitive to the type of radiation being measured. Neutron detectors utilize ionization chambers or proportional counters of appropriate design. Compensated ion chambers, BF3 counters, fission counters, and proton recoil counters are examples of neutron detectors.

DETECTOR TYPES

PROPORTIONAL COUNTER

When radiation enters a proportional counter, the detector gas, at the point of incident radiation, becomes ionized. The detector voltage is set so that the electrons cause secondary ionizations as they accelerate toward the electrode. The electrons produced from the secondary ionizations cause additional ionizations. This multiplication of electrons is called gas amplification. Varying the detector voltage within the proportional region increases or decreases the gas amplification factor. A quenching gas is added to give up electrons to the chamber gas so that inaccuracies are NOT introduced due to ionizations caused by the positive ion.

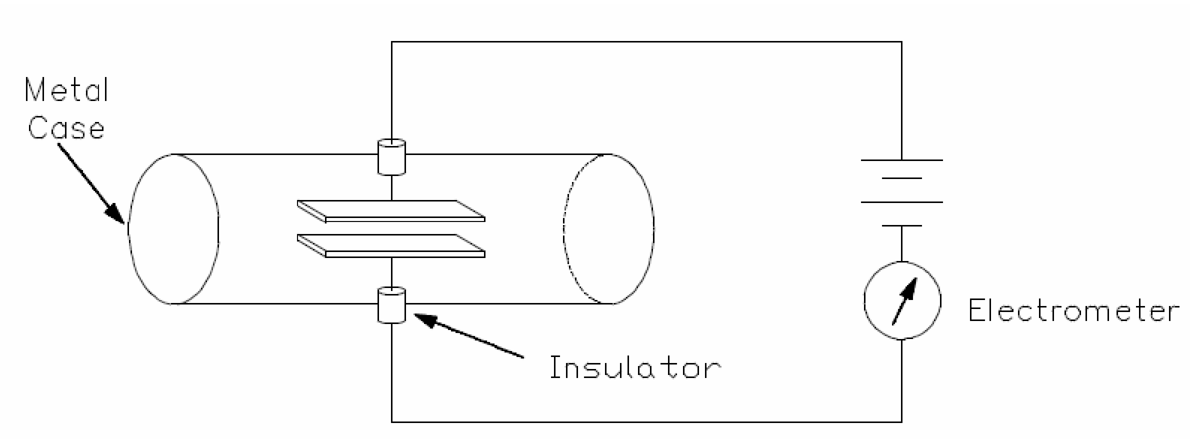


The proportional counter measures the charge produced by each particle of radiation. The preamplifier/amplifier amplifies the voltage pulse to a usable size. The single channel analyzer/discriminator produces an output only when the input is a certain pulse size. The scaler counts the number of pulses received during a predetermined length of time. The timer provides the gating signal to the scaler.

Ionization Chamber

Ionization chambers are electrical devices that detect radiation when the voltage is adjusted so that the conditions correspond to the ionization region. The charge obtained is the result of collecting the ions produced by radiation. This charge will depend on the type of radiation being detected. Ionization chambers have two distinct disadvantages when compared to proportional counters: they are less sensitive, and they have a slower response time. There are two types of ionization chambers to be discussed: the pulse counting ionization chamber and the integrating ionization chamber. In the pulse counting ionization chamber, the pulses are detected due to particles traversing the chamber. In the integrating chamber, the pulses add, and the integrated total of the ionizations produced in a predetermined period of time is measured. The same type of ionization chamber may be used for either function.

However, as a general rule, the integrating type ionization chamber is used. Flat plates or concentric cylinders may be utilized in the construction of an ionization chamber. The flat plate design is preferred because it has a well-defined active volume and ensures that ions will not collect on the insulators and cause a distortion of the electric field. The concentric cylinder design does not have a well-defined active volume because of the variation in the electric field as the insulator is approached. Ionization chamber construction differs from the proportional counter (flat plates or concentric cylinders vice a cylinder and central electrode) to allow for the integration of pulses produced by the incident radiation. The proportional counter would require such exact control of the electric field between the electrodes that it would not be practical.

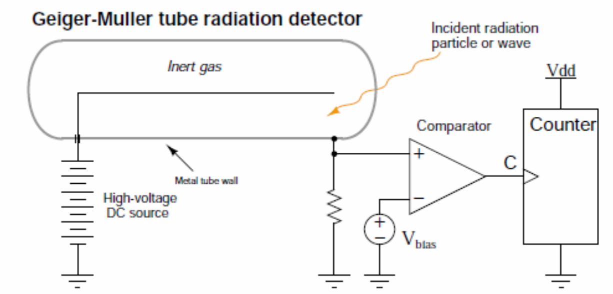


The ionization chamber is likewise filled with inert gas and sealed, but, rather than applying a breakdown voltage, a smaller voltage in the range of 60 to 100 V is applied across the chamber from end to end. The exact bias voltage varies among manufacturers and is related to optimal performance of that particular chamber design. When the chamber is exposed to gamma radiation, ionization occurs, and a continuous current in the microampere range is caused to flow. This current is proportional to field intensity.

When radiation enters an ionization chamber, the detector gas at the point of incident radiation becomes ionized. Some of the electrons have sufficient energy to cause additional ionizations. The electrons are attracted to the electrode by the voltage potential set up on the detector. If the voltage is set high enough, all of the electrons will reach the electrode before recombination takes place. Gamma sensitivity reduction is accomplished by either reducing the amount of chamber gas or increasing the boron coated surface area.

Geiger–Mueller Tube

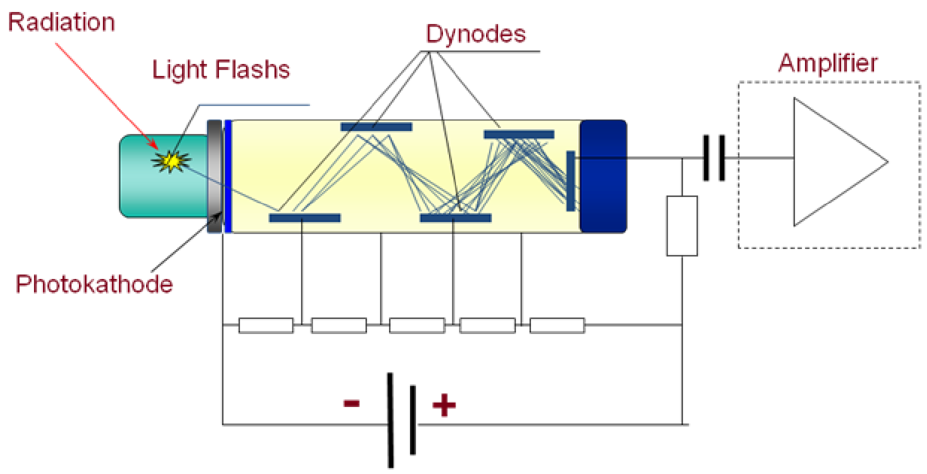
The G–M tube has a wire element anode in the center of a cylindrical cathode. The cathode tube is filled with inert gas and sealed. A bias voltage of up to 700 V is applied across the anode and the cathode. Incident gamma radiation ionizes the inert gas so that there is an electrical breakdown between the anode and cathode. The frequency of the breakdown is related to the intensity of the gamma radiation; therefore, field strength can be determined by counting the pulses produced over a given time interval.



The voltage of a Geiger-Müller (G-M) detector is set so that any incident radiation produces the same number of electrons. As long as voltage remains in the G-M region, electron production is independent of operating voltage and the initial number of electrons produced by the incident radiation. The operation voltage causes a large number of ionizations to occur near the central electrode as the electrons approach. The large number of positive ions form a positive ion sheath which prevents additional electrons from reaching the electrode. A quenching gas is used in order to prevent a secondary pulse due to ionization by the positive ions.

Scintillation

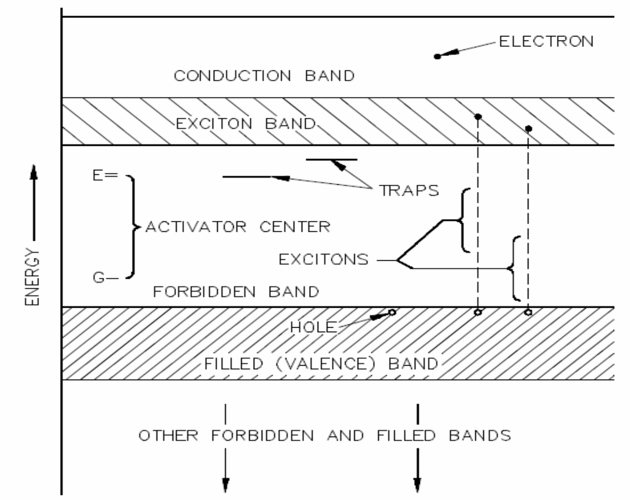
This technology is more sensitive to the same given field of radiation as compared to the G–M tube or the ion chamber. With this technology, a crystal, either specially treated plastic or sodium iodide, replaces the tube of inert gas. The crystal, when exposed to gamma radiation, will create photons of light within the crystal structure. The number of photons created will increase as the radiation field increases. A photomultiplier tube senses the photons of light from the crystal and converts the light to an electrical signal in proportion to the amount of light present.



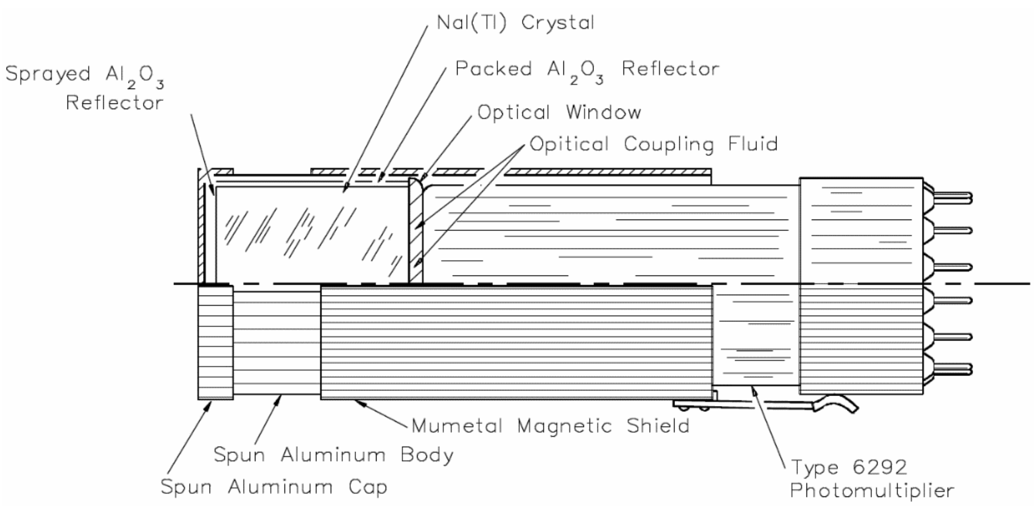
The scintillation counter is a solid state radiation detector which uses a scintillation crystal (phosphor) to detect radiation and produce light pulses. Figure is important in the explanation of scintillation counter operation. As radiation interacts in the Figure Electronic Energy Band of an Ionic Crystal scintillation crystal, energy is transferred to bound electrons of the crystal's atoms. If the energy that is transferred is greater than the ionization energy, the electron enters the conduction band and is free from the binding forces of the parent atom.

This leaves a vacancy in the valence band and is termed a hole. If the energy transferred is less than the binding energy, the electron remains attached, but exists in an excited energy state. Once again, a hole is created in the valence band.

By adding impurities during the growth of the scintillation crystal, the manufacturer is able to produce activator centers with energy levels located within the forbidden energy gap. The activator center can trap a mobile electron, which raises the activator center from its ground state, G, to an excited state, E. When the center de-excites, a photon is emitted. The activator centers in a scintillation crystal are referred to as luminescence centers. The emitted photons are in the visible region of the electromagnetic spectrum.



Scintillation counters are constructed by coupling a suitable scintillation phosphor to a light sensitive photomultiplier tube. Figure illustrates an example of a scintillation counter using a thallium-activated sodium iodide crystal.



Radiation interactions with a crystal center cause electrons to be raised to an excited state. When the center de-excites, the crystal emits a photon in the visible light range. Three classes of phosphors are used: inorganic crystals, organic crystals, and plastic phosphors.

The photon, emitted from the phosphor, interacts with the photocathode of a photomultiplier tube, releasing electrons. Using a voltage potential, the electrons are attracted and strike the nearest dynode with enough energy to release additional electrons. The second-generation electrons are attracted and strike a second dynode, releasing more electrons. This amplification continues through 10 to 12 stages. At the final dynode, sufficient electrons are available to produce a pulse of sufficient magnitude for further amplification.

8. WELL LOGGING

Logging tools and techniques

Well logging companies place rugged, highly technical 'logging tools' in the well to measure physical parameters in the well, the geological properties of the rocks around the well, and the presence of elements in the rocks. Among the many types of tools there are means to measure fluid temperature, pressure, density, and flow rates; detect casing corrosion and hardware; and measure rock density, porosity and isotopic content. Some of the tools contain one or more radiation detectors and radioactive sources or a machine that generates ionizing radiation. These are referred to as nuclear logging tools.

FIG. Well logging tool string suspended by a derrick above an oil well

In 'wireline logging' systems, the drill string is first removed from the well and the logging string (a series of logging tools connected together) is then lowered to the bottom of the well on a cable (the wireline).

The cable also carries the measurement data signals back to the surface where they are recorded on a log. As the wireline tool is slowly raised, the log plots the parameter being measured against the well depth. 'Logging-while-drilling' and 'measurement-while-drilling' systems avoid the need to first remove the drill string by incorporating the logging tools in the drill collar or coiled tubing. Signals are sent back to the surface by means of a positive mud-pulse telemetry system. Equipment at the wellhead interprets the mud pulses and logs the data.

There are four common nuclear logging techniques:

(i) The first, sometimes called the 'gamma measurement' technique (different logging companies may use brand names), simply measures and identifies the gamma rays emitted by naturally occurring radionuclides in rocks to help to distinguish the shale content of sedimentary rocks for lithological identification. The log records the uranium, thorium and potassium content of the rocks.

(ii) The second technique, which provides a neutron–neutron or compensated neutron log, demands a radioactive source of up to several hundred giga becquerels of 241Am–Be or Pu–Be in the tool to emit 4–5 MeV neutrons. An elongated skid hydraulically presses the tool against the wall of the well and two radiation detectors, located at different distances from the source in the tool, measure the neutrons backscattered from the rock formation. The relationship between the two readings provides a 'porosity index' for the rock. This indicates how porous the rock is and whether it is likely to contain hydrocarbons or water.

(iii) The third type of tool, called the gamma–gamma or density tool, also contains two detectors and a 137Cs source usually of up to 75 GBq. The amount of gamma backscatter from the formation provides the density log that, together with the porosity log, is a valuable indicator of the presence of gas. A brand name may refer to this technique.

(iv) The fourth technique, called neutron–gamma logging, involves a tool that houses a miniature linear accelerator. It contains up to several hundred gigabecquerels of tritium (3H, a very low energy beta particle emitter). When a high voltage (typically 80 kV) is applied to the device, it accelerates deuterium atoms (2H) that bombard the tritium target and generate a large number of very high energy (14–15 MeV) neutrons in pulses lasting a few microseconds.

Certain nuclides become radioactive when hit by this neutron flux, and their subsequent radioactive decay within the next few milliseconds can be monitored when the process is repeated a great number of times per second. Either the gamma radiation emitted as the activated atoms decay or the thermal neutron decay characteristics are measured to identify the activated species of atoms. The chlorine, or salt water, content of the rocks are of particular interest. A brand name may refer to this technique.

The gamma and neutron sources used in these tools are normally transported in separate heavy containers called shipping shields or carrying shields. They are Type A transport packages (or sometimes Type B for the neutron source) meeting the specifications for category III labelling as defined by the IAEA Regulations for the Safe Transport of Radioactive Material. They may be transported by road in the vehicles of the logging companies to the land well. When they are to be used offshore, the shields are usually contained in an overpack. This may be a large thick-walled box (external dimensions about 1.75 m × 1.75 m × 1.75 m) that also serves as a storage container at the well site. The shields do not provide adequate shielding for storing the sources without use of the large container. When the tools are hoisted into position above the well, the logging engineer transfers the sources from the shields to the tools using a handling rod of approximately 1.5 m long.

The dose rates of the 137Cs source are significant but not normally isotropic due to the construction of the source assembly. Dose rates may exceed 7.5 µSv/h for up to 30 m in the forward direction and about 4 m behind the engineer. The radiation from the source is directed away from any occupied areas. The dose rates of the neutron sources can exceed 7.5 µSv/h for distances up to about 4 m. In addition to a ‘set’ of sources used in the logging tools, the logging engineer will need a number of ‘field calibration
sources’ to carry out final checks on the tools before beginning the log. ‘Master calibrations’ are periodically performed on the tools at the logging company’s operations base. These tests will involve putting the sources into the tools or a section of the tool, and either placing the tool inside a calibration block or placing a block over the source position on the tool. The master calibration for the neutron–gamma logging tool involves generating neutrons while the tool is inside a tank filled with a suitable fluid (for example, clean water). The tank and its contents remain radioactive for a short time (up to 30 min) after the tool has been switched off.

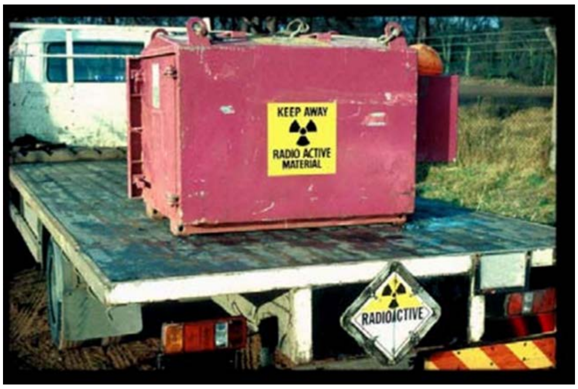


FIG. Radioactive source being transported by road

FIG. Transport container used as a temporary store for well logging sources

FIG. Wireline engineers transferring radioactive sources to logging tools on the drill deck

FIG. Wireline engineer using a handling tool to transfer a radioactive source during a calibration procedure

FIG. Controlled area in which low dose rate radiation test sources are used during tests in the workshop

The instrument technicians assigned to the service company's base will use a range of sources of relatively low activity to aid in adjusting the settings of the radiation detectors.

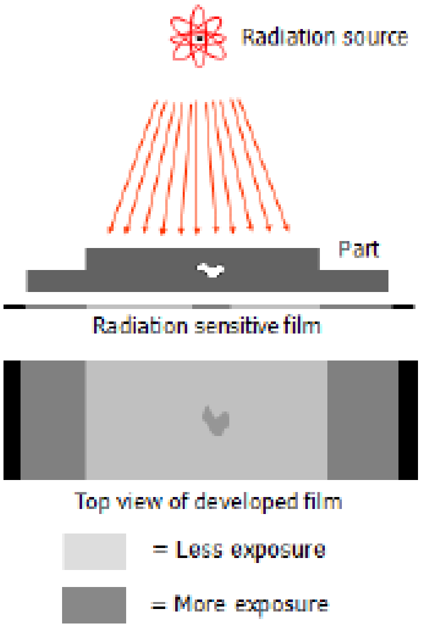
The logging tools and the sources they contain are subjected to very high temperatures and pressures downhole. The sources normally fall within the definition of 'special form radioactive material' as sealed sources satisfying the test criteria specified by the IAEA and ISO standards. Nevertheless the source(s) are normally given the further protection of a special container (a 'pressure vessel') whenever they are in the shield or logging tool. The sources also need frequent checks for leakage of radioactive material in accordance with test criteria specified by ISO standards.

9. RADIOGRAPHIC TESTING

Radiography is used in a very wide range of aplications including medicine, engineering, forensics, security, etc. In NDT, radiography is one of the most important and widely used methods. Radiographic testing (RT) offers a number of advantages over other NDT methods, however, one of its major disadvantages is the health risk associated with the radiation.

In general, RT is method of inspecting materials for hidden flaws by using the ability of short wavelength electromagnetic radiation (high energy photons) to penetrate various materials. The intensity of the radiation that penetrates and passes through the material is either captured by a radiation sensitive film (Film Radiography) or by a planer array of radiation sensitive sensors (Real-time Radiography). Film radiography is the oldest approach, yet it is still the most widely used in NDT.

n radiographic testing, the part to be inspected is placed between the radiation source and a piece of radiation sensitive film. The radiation source can either be an X-ray machine or a radioactive source (Ir-192, Co-60, or in rare cases Cs-137). The part will stop some of the radiation where thicker and more dense areas will stop more of the radiation. The radiation that passes through the part will expose the film and forms a shadowgraph of the part. The film darkness (density) will vary with the amount of radiation reaching the film through the test object where darker areas indicate more exposure (higher radiation intensity) and lighter areas indicate less exposure (lower radiation intensity).



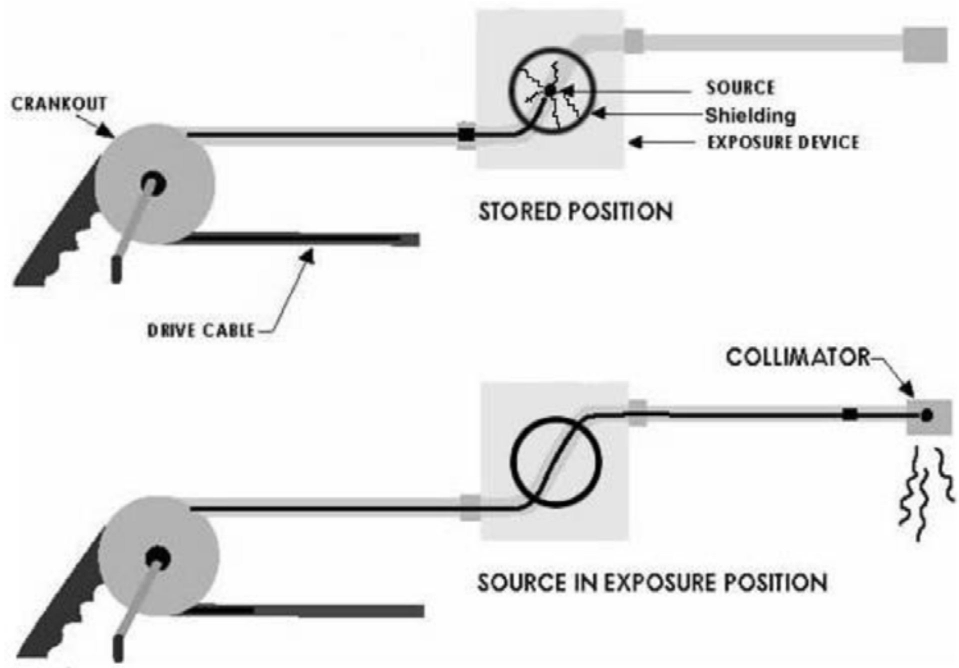
This variation in the image darkness can be used to determine thickness or composition of material and would also reveal the presence of any flaws or discontinuities inside the material.

Manmade radioactive sources are produced by introducing an extra neutron to atoms of the source material. As the material gets rid of the neutron, energy is released in the form of gamma rays. Two of the most common industrial gamma-ray sources for industrial radiography are Iridium-192 and Cobalt-60. In comparison to an X-ray generator, Cobalt-60 produces energies comparable to a 1.25 MV X-ray system and Iridium-192 to a 460 kV X-ray system. These high energies make it possible to penetrate thick materials with a relatively short exposure time. This and the fact that sources are very portable are the main reasons that gamma sources are widely used for field radiography. Of course, the disadvantage of a radioactive source is that it can never be turned off and safely managing the source is a constant responsibility.

Physical size of isotope materials varies between manufacturers, but generally an isotope material is a pellet that measures 1.5 mm x 1.5 mm. Depending on the level of activity desired, a pellet or pellets are loaded into a stainless steel capsule and sealed by welding. The capsule is attached to short flexible cable called a pigtail.

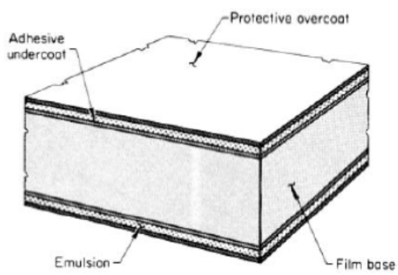
The source capsule and the pigtail are housed in a shielding device referred to as a exposure device or camera. Depleted uranium is often used as a shielding material for sources. The exposure device for Iridium-192 and Cobalt-60 sources will contain 22 kg and 225 kg of shielding materials, respectively. Cobalt cameras are often fixed to a trailer and transported to and from inspection sites. When the source is not being used to make an exposure, it is locked inside the exposure device.

To make a radiographic exposure, a crank-out mechanism and a guide tube are attached to opposite ends of the exposure device. The guide tube often has a collimator (usually made of tungsten) at the end to shield the radiation except in the direction necessary to make the exposure. The end of the guide tube is secured in the location where the radiation source needs to be to produce the radiograph. The crank-out cable is stretched as far as possible to put as much distance as possible between the exposure device and the radiographer. To make the exposure, the radiographer quickly cranks the source out of the exposure device and into position in the collimator at the end of the guide tube. At the end of the exposure time, the source is cranked back into the exposure device. There is a series of safety procedures, which include several radiation surveys, that must be accomplished when making an exposure with a gamma source.



Radiographic Film

X-ray films for general radiography basically consist of an emulsion-gelatin containing radiation-sensitive silver halide crystals (such as silver bromide or silver chloride). The emulsion is usually coated on both sides of a flexible, transparent, blue-tinted base in layers about 0.012 mm thick. An adhesive undercoat fastens the emulsion to the film base and a very thin but tough coating covers the emulsion to protect it against minor abrasion. The typical total thickness of the X-ray film is approximately 0.23 mm. Though films are made to be sensitive for X-ray or gamma-ray, yet they are also sensitive to visible light. When X-rays, gamma-rays, or light strike the film, some of the halogen atoms are liberated from the silver halide crystal and thus leaving the silver atoms alone. This change is of such a small nature that it cannot be detected by ordinary physical methods and is called a latent (hidden) image . When the film is exposed to a chemical solution (developer) the reaction results in the formation of black, metallic silver.



10. RADIATION MONITORING IN THE WORKPLACE

Note : 1 mSv per year is the limit of dose for the employees declared by International Atomic Energy Agency

MEASUREMENT PRINCIPLES AND INSTRUMENTS

A wide range of instruments is manufactured to carry out workplace monitoring for ionizing radiation and radioactive contamination. Instruments have not been developed specifically for use at oil and gas production and processing facilities and no single instrument is capable of detecting all types and energies of the radiation used in the industry. It is important to select and make available instruments that are appropriate and efficient for the different applications. Intrinsic safety for use in flammable atmospheres may be an important requirement for the instruments used.

FIG. Various instruments suitable for workplace monitoring

Radiation measuring instruments are usually designed to quantify only one of the two types of potential exposure:

External exposure to penetrating radiation emitted by sources outside the human body: Such exposures are associated with sealed sources, open sources such as radiotracers (whether they are contained or not), bulk quantities of NORM, and radiation generators or machines.

Internal exposure associated with radioactive materials that are in a form capable of being inhaled, ingested or otherwise entering and interacting with the human body: Open sources used as radiotracers, radioactive material that has leaked from a sealed source and NORM are potentially capable of causing internal exposure. Special attention is to be drawn to the radioactive noble gas radon which may accumulate near the exit points of sludges, water, mud and other drilling fluids.

Dose rate meters are used to measure the potential external exposure, and dosimeters to indicate the cumulative external exposure. Surface contamination meters indicate the potential internal exposure when the radioactive material is distributed over a surface; airborne contamination meters and gas monitors indicate the potential internal exposure when a radioactive material is distributed within the atmosphere.

Dose rate Meters

A suitable and efficient dose rate meter that is matched to the specific task is capable of measuring external exposure directly, indicating readings of the equivalent dose rate in microsieverts per hour. Dose rates of this magnitude are measured for safety purposes in most situations such as around source stores**,** installed level gauges or near accumulated NORM. For other purposes, such as making measurements at the external surfaces of a transport package, it is necessary to be able to measure up to several thousand microsieverts per hour and an instrument capable of measuring in millisieverts per hour is desirable. For some situations, such as implementing an emergency plan to recover an unshielded radiography source, a high dose rate range instrument capable of a continued response where there are tens of millisieverts per hour is needed. In such hazardous situations it is important that the instrument does not exceed the maximum of its range or, worse still, overload and give a zero reading. There are many wide-range or multi-range instruments (see for example Fig. 61) covering dose rates up to several millisieverts per hour and, particularly when working in remote locations, these may be supplemented by specialized high range instruments (indicating in sieverts per hour) assigned to the emergency kit.

FIG. Ion chamber dose rate meter

Instruments with sensitive probes capable of measuring low dose rate gamma radiation fields such as the background value at sea level (40–60 nSv/h) are useful. They can be used for monitoring mud returns when it is suspected that a sealed source might have ruptured downhole or when it is necessary to monitor over a wide area to find a lost source or equipment that contains a gamma source. This type of instrument may be used also to monitor the outside of equipment to detect the enhanced dose rates that would indicate the presence of accumulated sludge or scales containing radium.

As the shielding provided by the scale or sludge mass itself and that of the wall of the equipment can be substantial, it is usually not possible to convert reliably the measured dose rates either into areal inner surface contamination or the activity per unit mass of scale or sludge. Internal contamination by ^{210}Pb will not be detected by dose rate meters because all low energy gamma radiation, beta particles and alpha particles from this nuclide and its progeny are shielded by the intervening metal. Sensitive detectors are available that incorporate both a dose rate measuring capability and gamma spectrometry. Gamma spectrometry enables the radiation that produces the dose rate to be analysed in terms of the radiation energies present. This characterizes unequivocally the nature of the radioactive material (identifying it as ^{137}Cs, ^{226}Ra, etc.) emitting the gamma radiation.

FIG. Compensated and end window dose rate meters

FIG . Dose rate meters

The response of any dose rate meter is dependent on the characteristics of the detector it contains and in particular its detection efficiency at the energy (or energies) of the radiation to which it is exposed. An instrument may have a good detection efficiency over a range of radiation energies, reducing to zero (or nearly zero) efficiency at certain radiation energies perhaps at the range extremes. If the detection efficiency is poor the instrument will indicate zero readings whatever actual dose rate those radiations may be producing. For example, an instrument that provides an accurate indication of dose rates due to ^{137}Cs gamma radiation (of an energy of 662 keV) may measure less accurately the dose rates due to ^{241}Am gamma radiation (of an energy of approximately 60 keV). A specific detector may be able to detect radiation of only a certain type or of energy greater than some threshold value.

The neutron sources used in well logging, typically ^{241}Am–Be, emit both gamma and neutron radiation that cannot be measured using a single instrument. Well logging service companies therefore need both gamma and neutron dose rate meters and to sum the separate measurements to fully determine external exposure (see for example Figs 64–66). However, for the routine occasions when repetitive measurements are made, the gamma measuring instrument alone will normally suffice to provide adequate confirmation of the whereabouts of the source, the general condition of the shielded container, etc. The gamma measurement can be used with a gamma–neutron ratio to obtain the total dose rate under known exposure conditions. Dose rate measurements should be averaged over a suitable interval, for example 1 min or longer, depending on whether the prevailing dose rate is apparently constant or transient.

FIG. Intrinsically safe dose rate meter

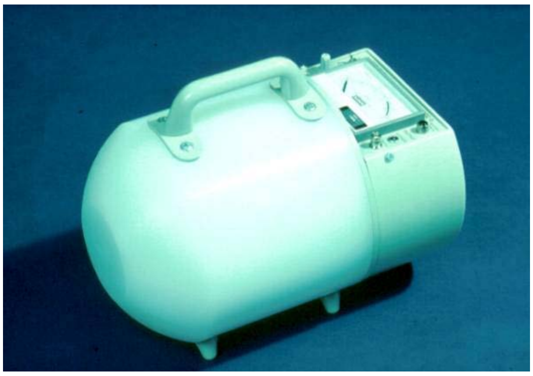


FIG. Neutron dose rate meter (17 MeV energy response)

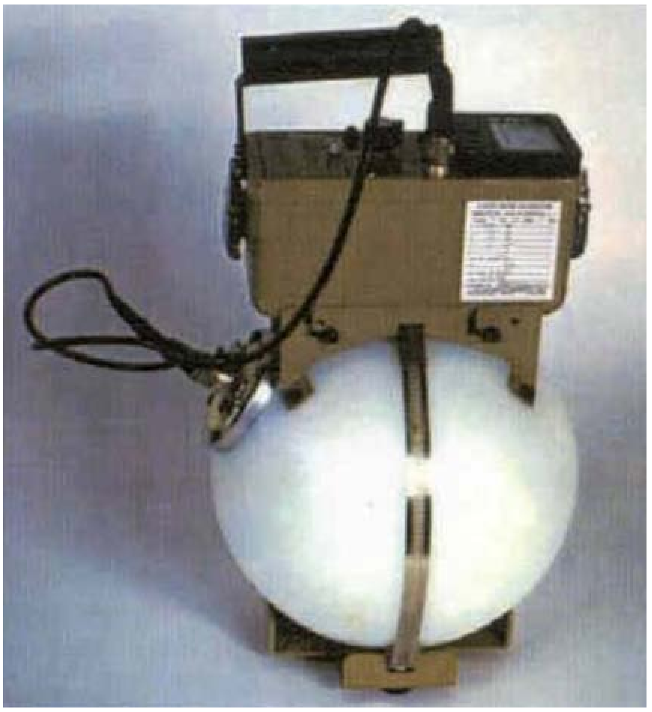


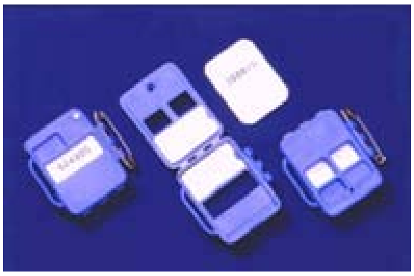
FIG. Neutron survey meter (10 MeV energy response)

Dosimeters

There are many situations in which workers are exposed to transient dose rates that change rapidly with time, for example when a logging source is being transferred from the shield to the tool, or when a radiography source is being projected from the exposure container along the projection sheath. It is not feasible to measure a single dose rate in such circumstances. In order to assess these situations and provide advice on optimizing radiation protection measures (applying the ALARA principle), a specialist in radiation protection may need to make 'time averaged' dose rate measurements. For these an 'integrating dose rate meter' is used to assess each exposure and average the dose over a longer period of time, for example a working day. There are different types of dosimeters for individual monitoring, generally designed to be pinned or clipped to clothing, that register the total dose accumulated over the period of exposure. Individuals involved in well logging or other tasks that involve the use of neutron sources need to wear dosimeters that will measure both gamma and neutron radiation so that the total cumulative exposure can be assessed.

Occupationally exposed workers must wear a suitable dosimeter and where high dose rates are possible, such as in radiography, a direct reading dosimeter in addition. Direct reading dosimeters provide an alarm to indicate a high dose or dose rate in the event of accidental exposure. The circumstances of the accident would necessitate further investigation and remedial actions.

Thermoluminescent



Film badge

Neutron badge

FIG. Personal dosimeters

FIG. Direct reading dosimeters: quartz fibre electrometer (left) and electronic dosimeters (right)

Surface contamination monitors

Surface contamination monitors usually are designed to measure a specific type of radiation and often have optimum detection efficiency over a limited range of radiation energies. For example the detector may respond only to alpha particles or gamma radiation or beta and gamma radiation. It may perform better in detecting high energy beta particles rather than those of low energy; or it may be designed to detect low energy gamma radiation but not high energy. It is important to select an instrument that has a detection efficiency optimized for the radiation (or isotope) of interest. Most surface contamination monitors indicate in counts/s (or s^{-1}) or counts/min and the instrument needs to be calibrated for the particular radiation being detected to enable the indicated reading to be converted into meaningful units such as becquerels per square centimetre. Some instruments are designed to allow either the calibration response factor to be programmed into the instrument or the isotope being used, perhaps as a radiotracer, to be selected from a list on the instrument so that response is automatically corrected and the reading is displayed directly in becquerels per square centimetre.

FIG. Two types of surface contamination monitor

One difficulty in quantifying the contamination due to NORM on a surface is that sludge and scales in which NORM is present contain a mixture of radioactive material that are seldom present in the same proportions. Assumptions need to be made about the NORM that is likely to be measured so that the likely response of the instrument may be determined in a laboratory. This may include examining how the monitor responds to an actual sample of the material.

Another difficulty is that the various substances emit radiation that differs widely in its ability to penetrate matter. NORM usually emits alpha particles but these are potentially stopped from reaching the detector depending on the condition of the surface being investigated. NORM incorporating radium generally emits beta particles and gamma radiation. The beta particles are significantly attenuated but even at their reduced energy are likely to be detected using an appropriate instrument. Gamma radiation has a much greater range in matter but an instrument used to measure it would always display a significant background gamma radiation component, particularly if the surface of interest is close to other accumulations of NORM.

Surface contamination monitors that incorporate either a beta detector or a combination of separate alpha and beta detectors offer the best options to monitor thin layers of NORM on surfaces. Care should be taken as most beta detectors are sensitive to gamma radiation the presence of ambient gamma radiation that might originate from inside a vessel could in such cases be misinterpreted as contamination. The use of a beta detector allows assumptions that are necessary to provide a calibration for the instrument, discriminating against any detectable alpha particles that may be present when the NORM contains radium and its progeny. While an instrument that has a combined response to alpha and beta particles may be calibrated for NORM constituents, interpreting the measurement may be problematic, depending on the condition of the surface being investigated.

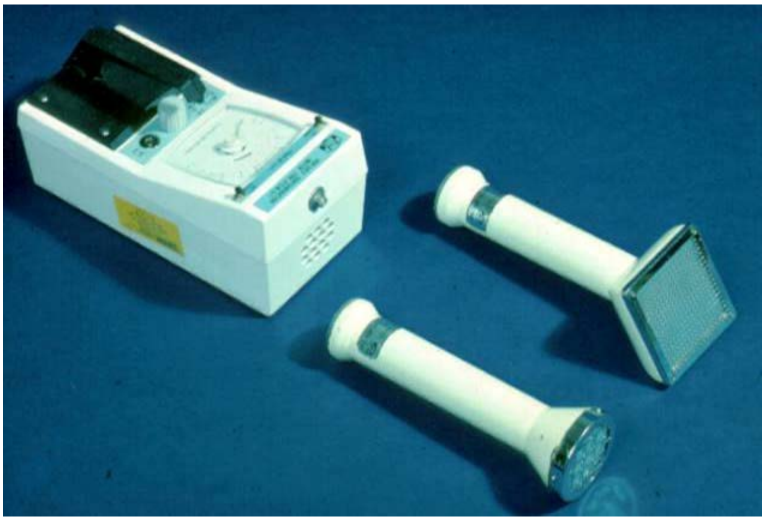


FIG. Portable contamination rate meter with beta probe and alpha–beta dual probe

Alpha contamination monitors are intrinsically sensitive to NORM because they do not respond to gamma radiation and consequently have no background count rate. However, they are vulnerable to mechanical damage and cannot be used reliably to measure surface contamination where the surface is irregular (for example, uneven or curved) or covered in a thick layer of NORM bearing material (which self-absorbs the radiation) or wet (with degrees of moisture producing variable self-absorption).

FIG. NORM contamination within a vessel being measured using a surface contamination measuring instrument

A beta contamination monitor will indicate whether NORM is present within a facility only after access is provided to internal surfaces because the particles do not penetrate structural materials such as the steel walls of tubulars and vessels. If beta contamination is detected outside a system, then the contaminant must be on the external surface of the object being investigated. It is unlikely that a beta contamination monitor will provide accurate quantitative measurements of the surface contamination (in becquerels per square centimetre) because assumptions made about the radioactive constituents of the contaminant may not be entirely correct and significant self-absorption of the beta radiation occurs in all but thin layers of contamination. At best, beta contamination measurements provide a reliable indication of the need for radiation protection measures and further investigation by sampling and radionuclide analysis. Specially designed instruments may be used in specific circumstances to monitor NORM surface contamination; for example, there are intrinsically safe instruments for use in potentially flammable atmospheres and a cylindrical form of beta detector may be drawn through the inside of whole tubulars to check for internal NORM contamination.

FIG. .Checking tubulars for NORM contamination

Gamma radiation detectors (either sensitive dose rate meters or contamination meters) may be used to detect accumulations of NORM within plant and equipment and, with appropriate calibration, to measure thick deposits of NORM surface contamination. Rugged gamma spectrometers may be used in the field, but it is more likely that samples of the contaminating material will need to be submitted to a laboratory for gamma spectrometry to identify and determine the NORM activity concentrations (in becquerels per gram).

Contamination monitors for airborne radioactivity

Instruments for measuring airborne contamination are used where there is the need to monitor a risk of radioactive material being either released into the atmosphere or resuspended from contaminated surfaces. The instruments normally draw potentially contaminated air at a constant rate through a filter mainly to monitor airborne alpha emitters, including radon progeny. 'Active detectors' are capable of detecting the accumulated radioactive material on the filter and initiating an alarm. Rugged, portable, lightweight personal instruments exist that measure radon levels and provide an acoustic warning with short reaction times. Samples of natural gas may be taken and measured at a laboratory to determine the radon content using the Lucas cell method. Personal air samplers based on the use of a filter may also serve as personal dosimeters, but like many of the installed versions, the filter needs to be assessed elsewhere. These so-called 'passive detectors' provide only retrospective assessments of the working conditions. The filter papers need to be handled carefully to ensure that they are kept flat, undamaged and not contaminated by contact. These factors, and the need for specialist assessment of the filters after sampling, limit the usefulness of these instruments in the oil and gas industry.

MONITORING STRATEGIES

A sufficient number of suitable and efficient radiation monitoring instruments need to be provided and used whenever work involves the production, processing, handling, use, holding, storage, moving, transport or disposal of radiation sources or radioactive material. They are to be used according to an overall monitoring strategy. Three levels of expertise generally may be recognized: task, routine and special monitoring.

Task monitoring

The worker who has day-to-day use of the radiation source or works with open sources or NORM performs task monitoring. It is important that the worker (possibly called a qualified operator) be adequately trained to use the instruments and interpret the measurements as part of a standard procedure, particularly when operations may involve an increased hazard. For example, a radiation-measuring instrument should be used by:

A radiographer to check that a radioactive source has safely returned to its shielded container after an exposure;
The user of a mobile gauge to check that a shutter has closed after using the gauge;
A well logging engineer to check the safe return of the sources after a logging tool returns from the well;
A radiotracer technician to check for contamination around high pressure joints and mixer vessels after the injection of the radiotracer;
A NORM worker to check for contamination on clothing before leaving an area where decontamination work is being carried out;
A technician to monitor the radon level at the exit points of fluids and gases.

Routine monitoring

In order to oversee, supervise, maintain and keep under review a programme for monitoring in the workplace, the radiation protection officer (RPO) will normally carry out routine monitoring. Surveys are conducted at appropriate regular intervals but not necessarily to a predictable timetable. The measurements are intended to confirm the extent of any designated supervised and controlled areas, to prove the adequacy of measures against external and internal hazards and to reveal any deterioration in the standard of radiation protection. A record of the measurements may be kept for an appropriate period, for example two years from the date on which the surveys are carried out, which will provide confirmation of a safe working environment and indicate any trends in the standard of safety provided. Examples of routine monitoring include the following:

(a) The RPOs of radiography and well logging service companies monitor their shielded containers and storage conditions;

(b) The RPOs of radiography and well logging service companies monitor to ensure the correct placement of barriers demarcating controlled areas;

(c) The RPO responsible for installed gauges monitors them to ensure that they are adequately shielded, that they show no physical damage and to confirm that the shutter of a gauge has closed prior to clearing it for vessel entry;

(d) The RPO of a radiotracer laboratory monitors bench surfaces, waste disposal routes, storage facilities, etc.;

(e) The RPO monitors any transport package for compliance with dose rate and surface contamination limits prior to labelling the package and providing relevant documentation;

(f) The RPO of an injection company monitors disused packaging prior to its disposal by the appropriate route;

(g) The RPO responsible for facilities in which NORM accumulates measures external dose rates where accumulations occur, monitors the plant when it is opened for operational reasons and designates the workplace prior to authorizing entry of workers; an area monitoring diagram and an on-site measurements record may be used in these situations (Fig. 73);

(h) The RPO responsible for NORM decontamination confirms the success of measures to contain surface and airborne contamination within the designated areas;

(i) The RPO responsible for NORM decontamination monitors to determine whether an item meets clearance criteria prior to its certification and release.

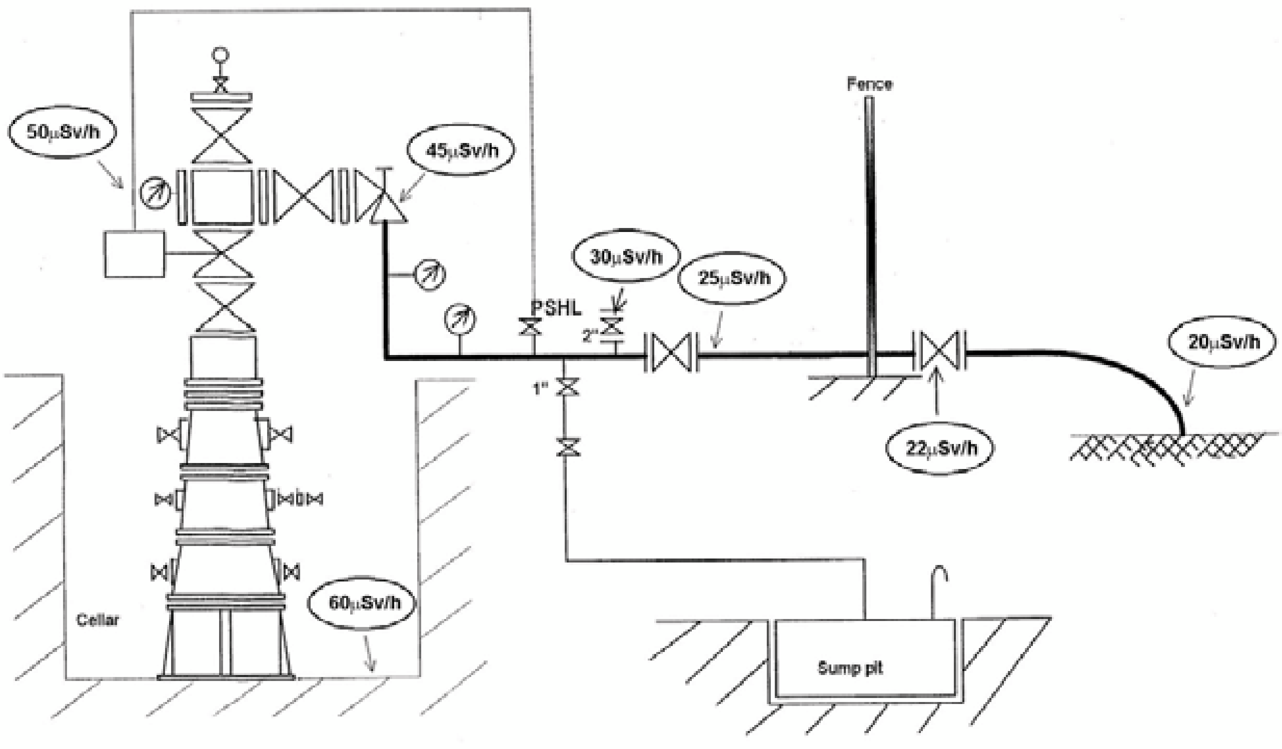


FIG. . Example of a completed area monitoring diagram

Special monitoring

Special monitoring will normally be carried out by qualified experts capable of using highly technical instrumentation, interpreting complex measurements or applying the results in computational methods in order to reach pertinent conclusions. A report has to be kept detailing the measurements, the conclusions and any recommendations that arise from them. Special monitoring might also refer to that carried out by a person such as a safety officer or inspector employed by the oil and gas operators or the regulatory bodies. The purpose of such monitoring would be to exercise a duty of care for the overall site or facility, to ensure that safe working practices are followed, and that there is compliance with regulatory requirements and relevant licence conditions. Examples of where special monitoring might be used include the following:

(a) The use of specialized monitoring instruments to assess external exposure and optimize protection against unusual radiation sources with low energy radiations, pulsed or transient emissions, narrow beams, etc.;

(b) Critical examinations, hazard evaluations and risk assessments of novel equipment and/or non-routine procedures;

(c) Reviews and measurements to determine shielding requirements and quality assurance assessments of equipment and facilities such as shielded containers, source storage facilities, transport packages, etc.;

(d) Audits and inspections of equipment, facilities, procedures and other arrangements for compliance with predefined company standards and regulatory requirements;

(e) Baseline surveys to assess whether NORM is present in an operating facility; where the survey is negative it may be repeated triennially or more frequently when changed operating conditions (e.g. changes in the salinity of produced water) or other factors

indicate the need; a flow diagram for the assessment of closed systems internally contaminated with NORM material is shown in Fig. 74;

(f) Baseline surveys to establish the conditions at a location prior to its development as a radioactive waste disposal facility;

(g) Where NORM is present in operational plant, sampling and analysing produced waters, scales, sludge, natural gas, gas condensates etc., as appropriate for radionuclide and activity concentrations;

(h) Decommissioning surveys of redundant facilities;

(i) The location and recovery of lost sources, damaged sources, etc., following an incident;

(j) Investigation of accident conditions and providing specialized dosimetric methods to determine effective doses and acute partial body doses;

(k) Obtaining samples and measurements and analysing samples for presentation as evidence in a legal action.

Other considerations

Some radiation measuring instruments, particularly contamination monitoring probes, are not robust and may be more suited to the laboratory environment rather than that of an oil and gas facility. However, there are also rugged instruments available for on-site contamination measurements and dosimetry, especially for gamma emitting radionuclides and radon. Superficial repairs are effected easily in the field provided the necessary spare parts, such as cables and foils covering the face of the detector, are readily available. The instruments are normally battery powered and a plentiful supply of batteries is needed especially where, for example, an instrument may be in almost constant use during a facility shutdown and the work is in a remote location. The battery needs to be tested each time an instrument is switched on and regularly while it is in use. Units operated with rechargeable batteries or accumulators will demand regular loading cycles and performance testing. It is important to have:

A test source of low activity available or a known location close to a shielded operational sealed source where the instrument may be placed prior to its use to confirm that it continues to provide a familiar response;

Every instrument tested at intervals defined by the regulatory body, usually at least annually, and where appropriate calibrated by a qualified expert. The results of such tests are given on a certificate, a copy of which is made available to the user.

Work with a radiation source should not proceed without suitable and efficient radiation measuring instruments available. It is normally the responsibility of the service company that owns the radiation source to provide the instrument(s). However, the field operator may ensure that an adequate range and number of appropriate radiation measuring instruments are available or are provided when mobilizing service companies to undertake such work.

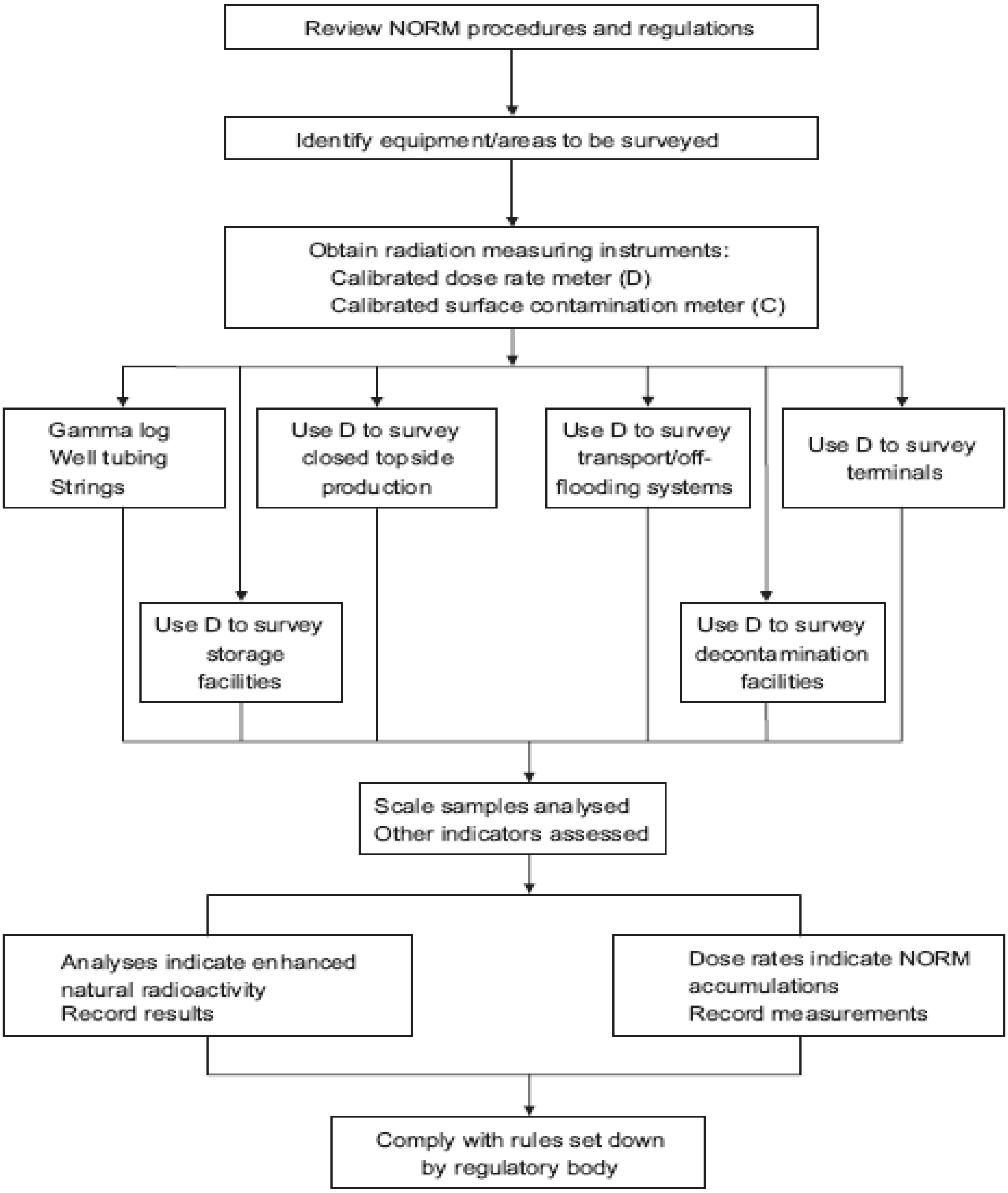


FIG. . Flow diagram for NORM assessments

It must be borne in mind that most radiation measuring instruments are electrical devices operating at high voltage. They may themselves constitute a risk in areas where there are flammable or explosive conditions. Some dose rate meters, but very few surface contamination meters, are intrinsically safe for use in these conditions and their use may need to be subject to prior authorization (a 'hot work' permit).

11. STANDARD OPERATING PROCEDURE FOR NUCLEONIC GAUGES

A. Procedure to work near (1 meter) Nucleonic gauges

1. Obtain cold / Hot / Height work permit.
2. Inform CPCL RSO about the duration, location and number of person working in the area.
3. Explain the radiation hazard of Cobalt 60 to the workmen.
4. Plan to execute the job in minimum possible time by proper planning of resources.
5. With the survey meter, take readings around the perimeter of the working area.
6. If the maximum meter reading value is more than 0.1 milli R/ hr (or) 1 micro Sieverts/hr, then stop the work and inform to concern performing authority.
7. To reduce the dose level, a steel plate shall be placed in between the source and the working area.
8. To reduce the dose level further, the corresponding Nucleonic gauge shall be closed till the job is completed.
9. If the maximum meter reading value is less than 0.1 milli R/hr (or) 1 micro Sieverts/hr,the job can be executed.
10. During job execution ensure that the source shielding is not damaged by means of mechanical shock or welding spark.
11. In case of any damage to the source by means of mechanical shock or welding spark, immediately inform RSO about the damage.
12. With the survey meter, take readings around the perimeter of the working area and compare with the previous value.
13. If the maximum meter reading value is more than 0.1 milli R/hr (or) 1 micro Sieverts/hr, then stop the work and inform to concern performing authority.

14. During execution of work, if the worker feels vomiting, he / she should be removed from the work site.
15. Any physical illness should be reported to OHS immediately.
16. On completion of work, ensure all the personals and tools are evacuated the area.
17. Inform CPCL RSO about the completion of the job.
18. Return the work permit to the concern manufacturing department.

B. PROCEDURE TO WORK WITH THE NUCLEONIC GAUGES

1. Obtain cold / Hot / Height work permit.
2. Inform CPCL RSO about the duration, location and number of person working in the area.
3. Explain the radiation hazard of Cobalt 60 to the workmen.
4. Plan to execute the job in minimum possible time by proper planning of resources.
5. Un lock the Nucleonic gauge source shielding and turn it to "CLOSED" position and lock it.
6. The shielding should be in "CLOSED" position till the job is completed.
7. With the survey meter, take readings around the perimeter of the working area.
8. If the maximum meter reading value is more than 0.1 milli R/hr (or) 1 micro Sieverts/hr, then stop the work and inform to concern performing authority.
9. To reduce the dose level, a steel plate shall be placed in between the nearby source and the working area.
10. To reduce the dose level further, the nearby Nucleonic gauge shall be closed till the job is completed.
11. If the maximum meter reading value is less 0.1 milli R/hr (or) 1 micro Sieverts/hr, the job can be executed.
12. During execution of work, if the worker feels vomiting, he / she should be removed from the work site.
13. Any physical ill ness should be reported to OHS immediately.
14. On completion of work, ensure all the personals and tools are evacuated the area.
15. Inform CPCL RSO about the completion of the job.
16. Return the work permit to the concern manufacturing department.

12. SPECIAL FOCUS TOPIC: NUCLONIC GAUGES

1. Follow authorized procedures when working with nuclear gauges.

2. Only trained and authorized workers should carry out the work. If appropriate, the workers should have had medical examinations and wear dosimeters.

3. Before proceeding with the work, read and ask questions about these safety guides.

4. Use only established methods, suitable equipment and a sealed source of an activity which is appropriate to the gauge's purpose. A portable gauge should be used only when all the necessary ancillary equipment which is associated with the particular gauge is also available. This might include source handling tools, barriers, warning notices and signals and a dose rate meter.

5. Keep safe and properly stored:

(i) Any source or housing which is waiting to be installed;

(ii) Any source housing which has been removed from its installation; or

(iii) Any portable gauge which is temporarily not in use.

6. Make regular, for example weekly, entries in a record to show that a check has been made on the stored items.

7. Keep a record to show where installed gauges are.

8. Keep the key for the source store in a safe place.

9. Before removing a gauge or interchangeable source from the store, remember to record who has them and where they are being moved to.

10. Check that the container is locked and use a dose rate meter to confirm that the source is shielded. This also serves as a check on the dose rate meter.

11. Attach two transport labels to the container and display warning placards on the vehicle. Keep the container segregated from the occupants.

12. Check installed gauges periodically, for example monthly, to confirm that they are safely installed. Measure accessible dose rates and ensure that a physical barrier marks the extent of any Controlled Areas.

13. Block any gaps in the shielding which might be inaccessible to the dose rate meter but not to fingers and hands. This is especially important if the gaps provide access to the primary beam.

14. Check that the shielding is firmly secured .

15. Check that warning signs are readable, especially on shielding and access doors or panels.

16. Maintenance workers should be reminded which person is to be contacted to ensure that the shutter is locked in the closed position before they enter these areas.

17. Before using a portable gauge, or working on an installed gauge, set up a barrier and warning signs either to mark the extent of the Controlled Area or as an indication to other persons in the vicinity to keep clear. Never leave a Controlled Area unattended.

18. Whilst working with a gauge, keep the dose rate meter with you and switched on. Use the dose rate meter to check that the shutter has closed after you have used a portable gauge. Likewise, check that the shutter is locked in the closed position before removing an installed gauge from its position.

19. Unless you are specifically trained and authorized to do so:

(i) Never attempt to remove a source from its housing; and

(ii) Never attempt to modify or repair the housing.

20. Appropriate handling tools and approved procedures must be used by persons who are responsible for manipulating sources. A source must not be allowed to be in contact with any part of a person's body.

21. Carry out the necessary routine maintenance. A portable gauge may require attention after each use but, before closely examining it, remember to use the dose rate meter to check that the shutter has closed or the source is otherwise safely shielded. Installed gauges will need less attention. Keep a record to show that the regular maintenance has included, for example:

(i) Cleaning the outside of the housing to remove grit and moisture.

(ii) Ensuring that external surfaces of the gauge are kept in good condition and that labels, warning signals and the tag displaying details of the source remain legible.

(iii) Using recommended lubricants to clean and maintain any moving parts. (iv) Examining any screws and nuts for tightness.

(v) Checking to see that the source is securely held within the housing and that uniform dose rates are measurable on all external surfaces of the housing.

(vi) Examining source handling tools for damage to springs, screw threads or the like. (vii) At the recommended intervals, and in the prescribed manner, carrying out leakage tests.

22. Report any faults to your supervisor.

23. If a gauge is involved in an accident or incident stay calm.

24. If the gauge is undamaged, do what is necessary to make it safe. For example, using a dose rate meter, confirm that the shutter is closed and place the gauge in its transport container.

25. If the housing appears to be damaged, move away from it and keep others away. Measure the dose rates and set up a barrier which marks the Controlled Area.

26. If it is suspected that the source has been very badly damaged, prevent access to those surfaces which might be contaminated by the radioactive substance. Detain anyone who may either have received a radiation dose or been in contact with a contaminated surface. Stay close but outside the marked area and send someone to inform your supervisor and obtain help. A leak test will indicate whether a source has been seriously damaged. A gauge which might be damaged should not be reused until it has been examined and, if necessary, repaired by a competent, authorized technician.

27. When work involving portable gauges or interchangeable sources is completed, a dose rate meter should be used to confirm that the sources are safely shielded.

28. Ensure that any container still displays two legible transport labels. If a vehicle is used, it should display warning placards to transport the container back to the source store.

29. A note of the return of sources should be made in the record book.

30. In the event of loss or theft of a source, inform your supervisor at once.

31. As soon as you have no further use for a gauge or a radioactive source, it should preferably be returned to the manufacturer or supplier. If any other method of disposal is used it must comply with your Government's laws. Radioactive substances being sent for disposal must be appropriately packaged and transported in accordance with the IAEA Regulations for the Safe Transport of Radioactive Material.

13. STANDARD OPERATING PROCEDURE FOR RADIOGRAPHY IN THE PLANT AREA

1. Whenever radiography test (RT) is planned in the plant area, the performing authority should inform the concerned section head well in advance with the following details viz., exact location, line size, line service,- camera number, source strength, source type, cordon off distance, name of agency including technician name and duration of time required and get concurrence.
2. The section head will give concurrence for issuing permit.
3. The radiation distance chart approved by Safety department for different source elements (Ir, Co and Se) for different strength to be made available along with permit.
4. The radiation distance charts for conventional method and Safe-rad method should be furnished separately.
5. One radiation survey meter should be issued to the section shift in-charge by the performing authority with valid calibration certificate.
6. Organisation's certified survey meters should be provided to the performing section & neighboring section
7. The RT permit should be prepared by the performing authority at site, by filling up all columns with the signature of Radiological Safety Officer (RSO) of the concerned - radiography agency. No columns should be left blank.
8. Manufacturing should complete the necessary prescribed checks in the cordon-off area before RT start-time.
9. Adequate distance as stipulated in the chart shall be cordon off around the radiation source& placards shall be displayed at the boundary.
10. Cordon off barricading should be done using special radiography alert tags with legend ·"RADIATION KEEP AWAY" with warning lights along the boundary.
11. The boundaries of adjacent radiography sites shall not overlap .
12. Field operator of concerned area along with Field supervisor should check the cordoning and note initial survey meter readings in all directions before signing the RT permit.

13.Shift in-charge will register the RT permit in F&S website.

14. F8,S in-charge will check the camera number (at site), source activity chart, cordon off area, RSO's AERB certificates and will issue registration number for the RT permit. The necessary documents should be readily available at work area for counter checking.

15. Shift in-charge will enter the F&S Registration number and issue the RT permit for execution. Permit will be issued field operator final check up and signature

16. The special instructions given in the RT permit to be followed strictly without any deviation.

17. If contractor violates the guide lines as prescribed in tile RT permit, the same will be viewed seriously and suitable penalty will be levied by performing authority accordingly.

18. Performing authority, should be available at the site till completion of RT(for maintenance, Performing authority/shift technician will be available).

19. Performing authority should ensure that the. radiographer has a walkie-talkie for communication.

20. All operating crew, maintenance crew, contract workers shall continue to perform their assigned works without entering inside the cordon-off area.

21. Unauthorized persons should not enter inside the cordon-off area.

22. No extension of time will be allowed for RT beyond the prescribed time.

23. The radiographer will confirm the completion of RT to the performing authority.

24. After completion of RT, the source should be evacuated from the site to the storage pit immediately. Barricading should be removed only after evacuation of source.

25. Performing authority will return the RT Permit to the Shift-in-charge (closure of permit) confirming the completion of RT.

26. The Shift in-charge will inform all concerned about the completion of RT.

27, During RT, if radiation dosage level is more than 100 μR/h (beyond the cordoned area). as indicated by the CPCL-issued radiation survey meter, the field operator should inform control room. Shift-in-charge shall direct the Performing authority to stop RT through walkie talkie.

28. When it is required to enter inside the cordoned area (for operational requirement), shift in-charge will ask the performing authority to stop RT. The performing authority will stop the RT immediately.
29. Information regarding RT area, timing, safe distance and source strength should be displayed at respective control room entrance.
30. Radiography should be stopped during shift relieving hours.
31. The radiation distance chart for conventional method or safe-rad method should be provided in all control rooms for reference.

14. SPECIAL FOCUS TOPIC: GAMMA RADIOGRAPHY

1. Follow authorized procedures when carrying out gamma radiography.

2. Only trained radiographers and authorized helpers who have had medical examinations and wear a dosimeter should carry out radiography. In normal circumstances, such workers should not have received greater than a dose limit (5 mSv to the whole body) in the current calendar year.

3. Before proceeding with the work, read and ask questions about these safety guides.

4. Rehearse the procedures and only use equipment that has been specifically manufactured for gamma radiography. The radiographer should be familiar with all of the equipment, its mode of operation and potential problems. An understanding of the source, its appearance and how it is to be exposed are particularly important.

5. Only carry out radiography when all the necessary equipment is available:
(i) A suitable source housed in an appropriate container;

(ii) Guide tubes, control cables or other source handling tools;

(iii) Collimators; barrier-making equipment;

(iv) Warning notices and signals; (v) Dose rate meter;

(vi) Emergency kit.

6. Record weekly maintenance carried out on the container, for example:

(i) Clean the container, removing grit and moisture.

(ii) Use only recommended lubricants to clean and maintain any moving parts.

(iii) Check screws and nuts for tightness and screw threads and springs for damage. (iv) Confirm that the source locking mechanism works.

(v) Remove the cover to examine the end of the pigtail for cleanliness, wear or damage. A wear gauge should be used.

(vi) Connect the control cable to the pigtail and check by gently pulling or twisting that it does not accidentally disconnect.

(vii) With the transit plug still in place, connect the cable housing to the locking ring and ensure a firm connection.

(viii) Disconnect the cable housing and cable, relock the pigtail and then remove the transit plug from the guide tube port.

(ix) Connect the guide tube, checking for crossed threads and a firm connection.
(x) Remove the guide tube and replace the transit plug.

(xi) Check that warning plates and source details are readable. (xii) Measure the dose rates close to the container's surface.

7. Report any faults to your supervisor.

8. Keep a record to show that weekly maintenance has been carried out on ancillary equipment, for example:

(i) Check the control cable crank and container connection ring or other source handling tool for loose fittings.

(ii) In a clean area, wind out a short length of cable to check for kinks and a smooth crank movement.

(iii) Use only recommended lubricants to clean and maintain moving parts.

(iv) Examine the cable end for damage or wear. A wear gauge should be used.

(v) Examine the control cable housing for tears, dents or other damage which might affect cable movement.

(vi) Examine guide tube and extension tubes for burred connector threads, dents or grit which might affect source movement.

9. Report any faults to your supervisor.

10. Prepare each radiographic shot in advance.

11. Consider moving the object to a place set aside for radiography where it will be either easier to prevent access or possible to do radiography without disrupting other construction work.

12. Calculate the current activity of the source and the exposure times needed.

13. If possible, choose shots which use a collimated beam and consider which beam directions are least likely to be occupied.

14. Examine whether it will be possible to use local shielding.

15. Calculate where the barriers will need to be to mark the Controlled Area and discuss with the site management when, and for how long, the area can be cleared of other workers.

16. Advise site management precisely when and where radiography will be carried out. Obtain any necessary permits and collect all documents.

17. Take all ancillary equipment to the location in advance. Deliver the barriers before the scheduled time, especially if only a short period (for example a meal break) has been set aside for the radiography to be carried out.

18. Collect the source store key and sign the source out.

19. Check that the container is locked and use a dose rate meter to confirm that the source is shielded. This also serves as a check on the dose rate meter by comparing the reading with those previously obtained.

20. Attach two transport labels to the container and display warning placards on the vehicle. Secure the container segregated from the occupants.

21. On site, at the arranged time, instruct helpers to first erect the barriers and warning notices and then to search the area to confirm that it is clear of other workers. Meanwhile, firmly fix the collimator in position and lay the guide tube out straight, checking that it was not damaged in transit.

22. Remove the container's transit plug (keep it clean and safe) and connect the guide tube.

23. Place the control crank near the container, uncoil the control cable and form it in a long loop, again checking for transit damage.

24. Unlock the container and remove the pigtail cover. Turn the control crank to reveal the cable and connect the cable to the pigtail. Confirm that this is a good connection before turning the crank to bring the control cable housing to the container to be secured.

25. Lay out the control cable as straight as possible and place the control crank preferably outside the marked area behind any available body shield.

26. Place a warning light or large notice near the collimator to mark the exposed source position.

27. The equipment is now ready to carry out a test exposure.

28. When the helpers have checked that the area is clear and have taken up their positions at the barrier in order to prevent unauthorized access, sound a

prearranged signal (for example, a loud whistle) to warn everyone near the Controlled Area that the source is about to be exposed.

29. Turn the crank quickly whilst counting the revolutions to ensure that the source is driven the full extent of the guide tube and into the collimator.

30. Leave the Controlled Area by the safest and, if practicable, the shortest route.

31. Dose rates in excess of 7.5 µSv/h will briefly occur at the barriers as the source travels along the guide tube but when the source is in the collimator the barrier should properly mark the extent of the Controlled Area.

32. Use the dose rate meter to check that the barrier is positioned in the correct place, especially along the beam direction. Move the barrier positions if necessary.

33. Return to the control quickly and turn the crank whilst counting the revolutions to ensure that the source is fully retracted into the container.

34. Use the dose rate meter to check the guide tube from the collimator to the container and finally check the dose rates at the container to confirm that the source is safely shielded.

35. The photographic films and film identification markers can now be attached.

36. Expose the source as previously described and time the exposure to produce the radiograph. For short exposure times it might not be possible to completely leave the Controlled Area. A convenient point should be taken up where the measured dose rate is as low as practicable and in any case is less than 2 mSv/h.

37. After each exposure use the dose rate meter to check the guide tube from the collimator to the container and finally check the dose rates at the container to confirm that the source has safely retracted.

38. The guide tube and collimator can now be safely handled and repositioned, together with the next film and identification markers.

39. Throughout each exposure stay alert and use the dose rate meter to confirm that the exposure is proceeding normally. If anything unexpected happens, such as someone entering the Controlled Area or a site emergency, quickly return to the control and retract the source.

40. If for any reason the source fails to retract, stay calm and move away to the barrier.

41. Measure the dose rates and, if necessary, reposition or set up new barriers. Stay close to the area to prevent people entering and send helpers to inform the site management and to bring the emergency kit.

42. The contingency plan should follow previously agreed stringent guidelines using time, distance and shielding to limit individual doses.

43. If the crank will not turn it may be necessary to dismantle the control to pull the control cable back by hand.

44. If the pigtail has detached from the cable or the source has stuck in the guide tube it will first be necessary to locate the source. Winding out the cable might push the source back into the collimator.

45. If shielding is placed on top of the guide tube close to the container and the control cable housing is then pulled, that part of the guide tube containing the source will eventually be pulled under the shielding.

46. The dose rate being measured at some distance away will then fall.

47. Placing more shielding on top of the source will allow closer access either to disconnect the guide tube from the container or to carefully cut the plastic sheath and unwind the wall of the guide tube.

48. Handling tongs can be used to lift an end of the guide tube so that the source pigtail slides out onto a solid surface.

49. Using the handling tongs the pigtail can be picked up and placed back in the container.

50. Under no circumstances should the source be allowed to come into contact with the hands or any other part of the body.

51. After the final exposure or when it needs to be moved to another area the radiography equipment must be disassembled.

52. Use the dose rate meter to check the guide tube from the collimator to the container and finally measure the dose rates at the container to confirm that the source is safely shielded.

53. Form the control cable in a long loop with the crank near the container.

54. Keep the dose rate meter working by your side and disconnect the cable housing from the container, if necessary turning the crank slightly to achieve this.

55. Lock the pigtail in the container and turn the crank to reveal the connection between the cable and the pigtail. Disconnect the cable and fit the pigtail cover.

56. Coil the control cable and set it aside. Disconnect the guide tube from the container and insert the transit plug in place.

57. Lock the source in the container.

58. Ensure that the container still displays two legible transport labels. Safely return the container to the source store. If a vehicle is used it should display warning placards and the container should be secured away from the occupants.

59. Wipe the container clean before placing it in the store and note its safe return in the record book.

60. Return the key to a safe place and maintain the security of the store at all times.

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Engineering Solutions and Training

About the Publication

ENSOLT is one of the leading design and engineering organizations in Chennai. Established in 1991, ENSOLT provides engineering consultancy and EPC services principally focused on the Oil & Gas, Power Plant and Petrochemical industries. The Company has also diversified into sectors like training and project guidance to engineering college students. ENSOLT is committed to quality knowledge transfer and training. The objective of this firm is to provide cost effective solutions to engineering glitches in the field of Electronics, Communication, Electrical and Instrumentation.

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