An introduction to gamma radiation training using simulators

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Introduction

Any accident or incident that involves a known or suspected radiological hazard has the potential to place response personnel, the wider public and the environment at significant risk.

Radiological emergencies can occur in a wide variety of settings and for a multitude of reasons - be it in the context of defence and security, the nuclear industry, radiological medicine, irradiators, the transportation of radioactive materials or as the result of the illicit release of a radiological dispersal device (RDD).

For anyone who is tasked to work with, alongside, or in response to a radiological source, the accuracy with which they are able to measure and monitor levels of ionising radiation is vital. The impact of radiological events can be significantly reduced through comprehensive emergency response planning, the conducting of structured radiation safety training programmes and experience in using radiological surveying instrumentation.

In this eBook we explore the wide variety of environments in which ionising radiation can commonly be encountered, and we examine the importance of radiological surveys in maintaining safety. We also provide an overview of the instrumentation that facilitates these safety-critical activities.

In particular, we will focus on the characteristics and the risks of gamma radiation - including the properties of gamma rays, the technology most commonly used for gamma surveying and the evolution in the development of gamma radiation training simulator detectors.

When and why do we survey?

The key goals in performing a radiological survey are to determine the nature and source of an ionising radiation hazard and to establish appropriate protective control boundaries. The data that is collected will also provide the basis for recommendations to relevant stakeholders and will determine any further actions that may be appropriate.

Radiological surveying is an integral task in ensuring routine radiation safety wherever quantities of ionising radiation are in use. This may be in the context of a commercial, industrial or medical environment where safe radioactive sources are utilised in a controlled manner - or it may be for the purposes of emergency response, military operations, defence or border / national security.

The effectiveness of a radiological survey will rely on the following actions:

- The selection, testing and calibration of appropriate survey equipment
- Acquisition of materials with which to record survey results
- Establishment of clear communication links between the survey team and survey command

Routine radiological monitoring

Ionising radiation has a wide range of applications in modern society - from its use in medical treatment and diagnostics to its role in industrial radiography, irradiation for sterilisation, non-destructive testing (NDT), energy production, defence, education and research.

The UK Ionising Radiations Regulations 2017 (IRR17) form the main legal requirements for the use and control of ionising radiation in the workplace, and require that all organisations working with radioactive substances employ the services of a qualified Radiation Protection Advisor (RPA) to ensure legal compliance.

In North America, congress and the president assign radiation protection responsibilities to the Environmental Protection Agency (EPA). These include regulations for specific radiation sources such as nuclear power operations, uranium mill wastes and protection standards for the management and disposal of spent nuclear fuel.

In the European Union (EU), the Council Directive of 5 December 2013 (2013.58/EURATOM) lays down basic safety standards for protection against the dangers that can arise from exposure to ionising radiation.

Routine radiological surveys are an integral part of maintaining a safe environment and to ensure regulatory compliance in any setting where radiological sources are handled, stored or transported.

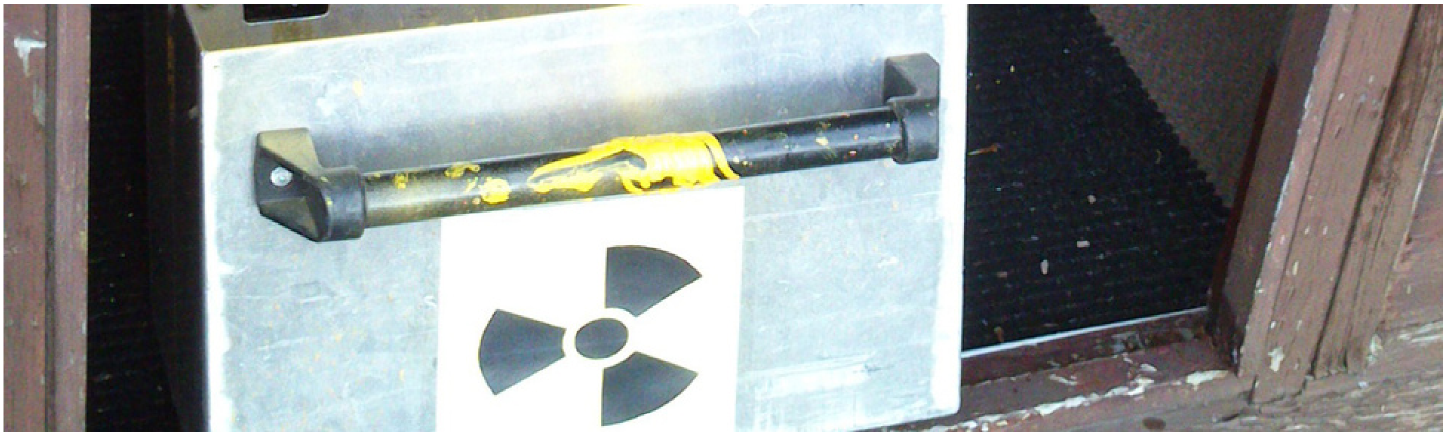
Exactly how often a radiological survey may need to be conducted will depend on the specific circumstances of the radiological source and the environment in which it is being used.
Key considerations may include: whether the radioactive sources are sealed or unsealed, whether there are activities taking place that might cause contamination, whether there are radiation generating machines in use that might result in radiation leakage or scattered radiation, and whether the existing shielding methods intact and fit for purpose.

Emergency Response

Incidents that lead to the release of radioactive materials into the environment can occur for a variety of reasons.

It may be as the result of an accidental radiological release from a medical or industrial device, an accident that occurs during the storage, handling or transportation of a radioactive source. It may be in the case of an industrial fire where ionising radiation presents a secondary hazard; or may be the outcome of a malicious act involving radioactive material, including theft.
First Responders, HazMat teams or CBRNe personnel may be tasked with responding to an incident where there is a known radiation hazard. In other cases however, they may not be aware of the extent of the hazard until arriving on the scene.

The successful management of a radiation incident will rely on informing the appropriate authorities of the nature of the radiological event; controlling the incident perimeter; establishing Incident Command; accurately identifying radiation types and isotopes; and continuously monitoring radiation levels.



An overview of ionising radiation

A radioactive source is defined as any known quantity of a radionuclide that emits ionising radiation and that is typically made up of one or more of the following radiation types - gamma rays, alpha particles and beta particles.

Ionising radiation can originate from radioactive elements, x-ray machines or cosmic particles. The process of ionisation refers to the way in which a neutral molecule or atom either gains or loses electrons, causing it to acquire either a positive or a negative electrical charge.

When ions pass through living things they can cause serious physical damage to the atoms - affecting human tissue, organs and DNA.

Alpha radiation

Alpha radiation particles are positively charged particles comprised of two protons and two neutrons that come about as the result of the decay of heavy radioactive elements such as radium, polonium or uranium.

The heaviness of alpha particles means they are only able to travel very short distances, often just one to two inches. They do not tend to penetrate very deeply into the skin and can be stopped by paper or clothing.

Alpha radiation particles are the least dangerous form of ionizing radiation in terms of external exposure, however, they can present a serious hazard if they are inhaled or ingested.
Alpha particles don‘t typically cause radiation sickness, however, they are known to be directly linked to incidents of cancer.

Beta radiation

Beta radiation particles are high-energy, fast-moving particles that are emitted by a group of unstable atoms such as strontium-90, carbon-14 and hydrogen-3.

Beta particles are about 8,000 times smaller than alpha particles and are able to travel significantly further in air, covering distances of up to 10 feet.
Their small size means they are able to penetrate clothing or skin, however, because the ionizations that beta particles produce are less dense, they cause less damage to human tissue or DNA.

Like alpha particles, beta particles are most hazardous if they are swallowed or inhaled.

Gamma rays

Gamma (x-ray) radiation waves are a form of pure energy, similar to visible light, with the ability to travel distances in excess of 200 feet.

Gamma rays pose a particular threat because of the highly energetic nature of their electromagnetic waves which operate at a frequency of 10 to the power of 20 (or 10 quadrillions) cycles per second.

Gamma radiation has the power to penetrate virtually anything - passing easily through human bones and teeth, destroying human cells, producing mutations in DNA and being directly linked to cancer.

Despite their inherent dangers, however, gamma rays also have a significant lifesaving role to play in clinical medicine, most commonly within the fields of radiotherapy and radio-oncology for the purpose of shrinking tumours and killing cancer cells. Gamma rays also have an important role to play in the sterilisation of equipment and food.

> **“Despite their inherent dangers, however, gamma rays also have a significant lifesaving role to play in clinical medicine”**

The origins of radiation detection

Our understanding of ionising radiation owes much to the groundbreaking scientific achievements of the late 19th and early 20th centuries which spurred further research into the nature of matter and gave birth to the field of nuclear physics.

The powerful applications of radiation were first realised in 1896, with Wilheim Roentgen's invention of x-ray photography. Later that same year, French physicist Henri Bequerel would go on to publish his findings on the evidence of radioactivity.

Other notable scientific landmarks include:

- British physicist Joseph Thomson's discovery of the electron in 1897, and his extensive research on the operational characteristics of ionisation chambers.
- Marie and Pierre Curie's discovery of the radioactive elements polonium and radium in 1899.
- Ernest Rutherford's research into the nature and characteristics of alpha, beta and gamma rays, published in 1903.
- German physicist Hans Wilheim Geiger's invention of the first successful detector of individual alpha particles in 1908, with later versions being used to count beta particles and other forms of ionising radiation.
- Scottish physicist Charles Thomas Rees Wilson's creation of the world's first cloud chamber in 1911.

These early discoveries captivated the world's scientific and medical communities, as physicists and medical experts explored ways to capitalise on the penetrating properties of radiation.

What would also soon became apparent was the substantial risk that ionising radiation posed to human health.
Within months of Roentgen's release of his research into x-rays, scientists were reporting their "poisonous effects" - with incidents of hair loss, skin burns and cancerous tumours.
Over the next few decades, many investigators and physicians developed symptoms of radiation poisoning, with more than a hundred dying as a result of their exposure.
It was also thanks to these regrettable early experiences however that awareness of the importance of radiation safety was realised - and that the science of what we now know as 'radiobiology' was born.

These early radiological discoveries would also provide the foundation for the research, development and production of the radiation detection tools in use today.

Key advances in electronics in the early to mid-twentieth century had an especially significant part to play in the design of modern-day radiation survey instrumentation:

- 1937 - the invention of the count rate meter
- 1938 - the development of miniature electrometer tubes
- 1945 - the invention of photomultiplier tubes
- 1947 - the commercial release of the transistor

Pre-1945, only a handful of companies were actively involved in the production of commercial available radiological instrumentation - perhaps most notably Victoreen and its production of the ion chamber.

However, key events such as Operation Peppermint, the atomic tests in the Pacific in 1946 and 1947, the development of the US weapons programme in the 1950s, and the growth of the nuclear power industry would all prove pivotal in spurring the design and manufacture of electronic radiological instrumentation.

Radiological survey tools

Portable hand-held radiological survey instruments provide first responders and radiation safety personnel with the means to accurately and consistently measure external or ambient ionising radiation fields and to detect and monitor personnel, equipment and the environment for radioactive contamination.

In much the same way as a radio receiver converts radio waves to sound, a radiological survey instrument converts radiation energy into a meter reading.

Different types of instruments will be used depending on the nature of the radiation hazard.

The characteristics of some of the more commonly used detectors can be summarised as follows:

Ionisation chambers - which measure dose and dose rate from gamma and x-ray radiation - typified by the handheld ion chamber survey meter.

Geiger-Mueller Counters - used for the detection of gamma photons or beta particles and usually equipped with audible detection of radiation in the form of “clicks”

Proportional Counters - used to detect one type of radiation in the presence of other forms of radiation - most widely used for the detection of alpha particles, neutrons and protons

Scintillation Counters - combining a photomultiplier tube with a scintillating material to produce “pulses” of current that can be counted - most commonly employed as alpha counters or gamma detectors and for the more efficient detection of low-level gamma backgrounds

Chemical Dosimeters - systems which measure the visible chemical changes produced by ionising radiation

Photographic Emulsions - film badges which use photographic film to record dose by measuring the optical density of the emulsion

Thermoluminescent Dosimeters (TLDs) - passive radiation detection devices used for monitoring personal dose

Portable, battery-powered, electronic survey meters can be used wherever gamma radiation is suspected to be present, both to detect the activity and to measure the dose rate from the radioactive material.

The addition of gamma sensitive probes (whether internal or external) are essential tools in locating sources of radiation, establishing control zone boundaries, ensuring safe demarcation and controlling personal exposure.

Although there are variations in design, a radiation survey meter will typically be comprised of three main components:

- A sensor (either in a probe or within the meter itself) which converts the ionizing radiation into an electric signal
- An electronic scaler that converts the electrical signal into a visual/numerical indication of intensity
- A speaker which provides an audible indication of the ionizing radiation count or dose rate

Some survey meters are constructed as fully integrated units where the probe and electronic processor are encased in the one housing. Others may be designed for use in conjunction with one or more external detector probes.

United States Air Force Radiation survey exercise

UK Fire and Rescue Service radiation source location exercise

Measurements - their meaning and relevance

Disintegrating atoms can emit an alpha particle, beta particle, gamma-ray or x-ray (or any combination of these.)

When measuring ionising radiation, there are two properties that need to be classified:

- the activity (or strength) of the source (measured in becquerel or curie)
- the dose (or amount) of ionising energy that is absorbed by a person - expressed in sieverts/ Gray (Europe) or Rem/Rad (US).

In order to keep radiation doses at a level that is low as reasonably achievable (ALARA), it is vital that operatives both minimise the time that they spend in affected areas and that they maximise the distance between themselves and the radiation source.

It is also important to consider not just the type of radiation that is being emitted, but also the route by which that radiation enters the body.

A commonly held image of radiation is that it emanates from a source device and strikes the outside of the body - in what's known as external exposure.

However, the radioactive material from radiation also has the ability to deposit its energy in our internal organs through the process of ingestion, injection, absorption or inhalation - or what is termed internal exposure.

Key Terms

Dose - A measurement of how many molecules are disrupted, depending on the energy (or dose) deposited. As radiation moves through the body it dislodges electrons from atoms and disrupts molecules, gradually losing energy until it escapes from the body or disappears.

Dose Limits - Regulatory limits that are designed to protect radiation workers, and members of the public, from the serious effects of ionising radiation. Operational guidelines, published by the UK's Chief Fire and Rescue Advisor in 2011, advise that the maximum allowable dose for all radiation workers (including firefighters/first responders) not exceed 20 mSv (2 Rem) per year, with a recommended dose constraint of 5 mSv (0.5 Rem) per each operational incident.

Absorbed dose - A measurement of the intensity or concentration of energy deposited in a unit mass of body tissue in order to assess the potential for biochemical changes in that tissue. The unit of measurement for absorbed dose is the milligray (mGy) which measures the amount of energy absorbed in a material.

Cumulative Dose - Referring to the total energy (or absorbed dose) deposited in the body as the result of prolonged, continuous or repeated exposure to ionising radiation

Dose Rate - The radiation dose delivered per unit of time, for example per hour.

Equivalent Dose - A quantity (measured in sieverts or rem) that places all radiation on a common scale in order to account for the impact that each type of radiation has on human tissue. The dose equivalent is calculated by multiplying the absorbed dose by the quality factor (ie the difference in the effect of different types of ionising radiation.)

Effective Dose - A calculated quantity (measured in Sv, mSv, rems or millirems) that takes into account the absorbed dose to all organs of the body, the relative harm level of the radiation and the sensitivities of specific organs to different types of radiation.

Collective Dose - A calculation of the potential health effects that ionising radiation has on an area, a region or a large number of people.

Dosimetry - The assessment of personal radiation dose.

Dosimeter - A small portable instrument for measuring and recording the total accumulated ionising radiation dose that an individual receives

Exposure - A measure of ionisation in the air caused by gamma rays or x-rays.

Exposure Rate - A measure of the ionisation in air produced by gamma rays or x-rays per unit of time.

The importance of radiation safety training

The often unpredictable locations of radiological incidents can make advance response planning a significant challenge.

Under emergency conditions, there may be limited information, and little time, with which to assess options.

Each incident will pose a unique threat to public and environmental health depending on the radionuclides involved, the size and magnitude of the release and the speed with which notification, response and protective action is initiated.

With advance emergency response planning and regular training, however, it is possible to reduce the complexity of the decision-making process by identifying the viability of specific responses to a range of potential incidents.

Effective radiation safety training should ensure that personnel are confident in the following skills:

- The ability to select and use appropriate radiological survey equipment to locate, identify and monitor radiation levels within a controlled area
- Maintaining their personal safety through the use of electronic personal dosimeters and suitable personal protective equipment (PPE)
- Keeping any exposure to radiation as low as reasonably achievable (ALARA)
- Communicating findings and making appropriate safety recommendationsRealistic

Which specific instrument will be best suited to which task depends upon the type of radiation that is suspected to be present, as well as the required outcome - be it for the purposes of measurement, personal protection or search.

If the goal is measurement, then there is either a known, (or a highly likely) source of radiation that needs to be monitored in order to establish the strength of the radioactive field, its boundaries and fluctuations.

The types of detectors that will be used to take these measurements are likely to have higher measurement ranges or will be adapted to detect a specific type of radiation.

If the aim is radiation protection then, just as with radiation measurement, there is a known or highly likely radiation source in the location.

The goal however, becomes one of monitoring personal radiation exposure (or dose) through the use of hand-held or person-worn radiation dosimetry tools.

If the purpose of the activity is radiation search, then the task becomes one of identifying and detecting smaller and possibly concealed sources of radiation where they may not be expected or desired - such as when responding to a suspected radiological release, in the context of customs or border security or to support anti-terrorism operations.

In such scenarios, it may be desirable to be able to identify one or more of a small group of radioactive isotopes that are of particular concern - as well as being able to filter any legitimate or naturally occurring radioactive materials.

The role of simulators in radiological survey training

Most radiation detection instruments are fairly straightforward to use.

What can be more difficult however, is for trainees to make sense of the readings they obtain, and to correctly interpret changes in measurement - and doing so whilst operating in a potentially complex, unfamiliar or highly charged emergency environment.

While hands-on CBRNe and HazMat training is widely regarded as offering significant benefits in enhancing learning outcomes, radiation training presents its own unique challenges due to the regulatory, administrative and health and safety implications of working with live sources.

Electronic simulators can help to address these issues by providing a means to conduct safe and effective training scenarios that truly reflect the operational challenges of live incidents. By substituting actual radiation detectors with their simulator equivalents, radiation safety instructors have the freedom to create a safe and compelling training environment in which students can experience all the responses, physicality and functionality of a real device.

The use of simulators also ensures students understand the real-time effects of time, distance and shielding and that they build an understanding of the relationship between the measurements on their survey meters and their own personal dose readings.

Selecting a simulator training device

When assessing the qualities of different radiation training simulator options, there are certain criteria that will be key:

- The look and feel of the simulator - Does it replicate the appearance, weight and functionality of the actual device? How closely does the simulator's user interface match the original?
- Consistency and repeatability - Is the device's signal processing powerful enough to ensure that simulated readings are repeatable each time a student revisits a scenario location? Are the readings that are observed within the accepted tolerances of the actual detector?
- Responsiveness - When you approach and withdraw from the simulation source, does the simulator respond as realistically and as quickly as the actual detector does?
- Cost-effectiveness - What is the whole life cost of ownership of the device? Is there a requirement for preventative maintenance, regular calibration or replacement of consumables?
- Compatibility - Is the simulator compatible with other live field or tabletop exercise systems and simulators that may already be in use?

A final crucial factor to consider is the technology that underpins the device.

Some of the common techniques used in gamma simulation are known to lead to unrealistic reading fluctuations and a lack of consistency in the readings obtained.

When using radio waves, for example, multipath reflections can impact adversely on the indication that the student sees.

Similarly, while certain forms of ultrasound simulation work well in open spaces, they become less reliable when a human body is positioned between the simulated source and the simulator detector.

Training systems that rely upon the instructor to directly inject and vary the simulated readings can prove to be burdensome, requiring excessive instructor attention.

There are however newer simulator technologies that respond to electromagnetic sources, have managed to overcome these challenges enabling a much more realistic simulation of the effects of shielding.

Sample scenarios for gamma survey training

The use of simulator detectors provides the opportunity for trainees to experience the characteristics and the behaviour of different types of ionising radiation in a safe and immersive learning environment.

Useful training scenarios could include:

Establishing a hazard perimeter

Knowing how to create and control a hazard perimeter, for example, is a vital task which requires trainees to take into account a variety of factors:

- Physical considerations - the nature and severity of the radiation incident, the presence of any co-existing or subsequent threats in the location, protection of critical infrastructure.
- Health and Safety considerations - maintaining the safety of the public and emergency responders
- Security considerations - using existing roads, structures or topography to enforce the perimeter and facilitate the protection and gathering of forensic evidence

Understanding Time, Distance and Shielding

Once it has been established that the only radiation at an incident is from a sealed source (ie that there is no contamination risk) personnel safety will depend upon the practical application of three key factors - time, distance and shielding.

Time

An individual's potential external radiation exposure (or dose) is directly connected to the duration of that exposure or the amount of time that they are exposed. By limiting the time in the radiation field the amount of radiation absorbed will correspondingly reduce.

Distance

The amount of radiation an individual receives is dependent on how close they are to the source. By knowing the intensity at one distance it is, therefore, possible to determine the intensity at any other distance relative to the source.

The inverse square law states that radiation exposure and distance are inversely related - meaning that the strength of ionising radiation from a point source will decrease with the square of the distance it travels.

The greater the distance from the source of radiation, the less the intensity of the dose will be - so if the distance between an object and a radiation source is doubled, then there will be one fourth as much exposure. Conversely, if the distance between the object and the source is multiplied by 10 times, then the exposure will reduce by 100 times.

Shielding

Radiation shielding is based on the principle of attenuation, which is the degree to which a radio wave or ray can be blocked or shielded through the use of a barrier.

The selection of radioactive shielding materials and the amount of shielding that will be required will depend on the penetration of the dose.
Metals, for example, are strong and highly resistant to radiation damage, with lead being especially effective in lessening the effects of gamma and x-rays due to its higher atomic number.
In most cases, higher-density materials will be more effective at blocking gamma and x-ray radiation than lower-density ones, however, some lower-density materials are able to compensate for their disparity through increased thickness.

Search and monitoring of containers, visitor screening and checkpoints

The ability to hide a simulation source within a package, wooden crate or even a vehicle storage compartment enables students to be trained in the important art of search. Containers may be presented within an open environment or inside a building where the structure of the building will present additional shielding.

Simulations sources hidden within vehicles or personal backpacks provide an excellent means by which vehicle checkpoints and visitor screening exercises can be implemented with personal dose simulators activating to draw initial attention followed by more detailed survey monitoring.

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Conclusion

Radiological emergencies that involve gamma radiation can pose a significant risk both to human safety and to the environment.

For those tasked with responding to such incidents, the efficiency and the confidence with which they are able to assess a situation, collate the relevant information, make suitable recommendations and take appropriate action, will be vital.

Comprehensive emergency response planning, together with the creation of realistic radiation safety training programmes, will be key factors in facilitating a successful outcome.
In addition, there can be significant benefits to be gained by providing personnel with the opportunity to train with highly responsive simulated versions of the very radiological surveying instrumentation that they will be required to use in real-life events.

Request Argon's online product demonstration

Retired Army Sergent Major Bryan Sommers

If you're interested in Argon's simulators consider signing up for a free, online product demonstration with one of the members of our team.

We will walk you through the details of any simulators you're interested in, including chemical and radiological detectors simulators, as well as exercise training solutions. This will be your opportunity to ask our experts any questions about our simulators.

Discover how Real Experience Training can enhance your HazMat and CBRNe training today!

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