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## **Measuring & Monitoring Ionizing Radiation**

By Lawrence A. Mauerman, MAS, PE, CSP

Two years ago, *The Monitor* published a small article I wrote on ionizing radiation.<sup>1</sup> In that article, I mentioned that it was the first of a two-part series and that the second installment would be forthcoming. It never happened. Recently, several of my colleagues have contacted me to ask what happened. Also, several personal experiences here at the university have reminded me to write the second article. Here is Part Two of the article series.

### **The Goiânia Incident**

Some years ago, I had the opportunity to live in Brazil. Part of that time was spent in a city called Goiânia. The city is one of Brazil's 20<sup>th</sup>-century experiments in moving its state capitals from their often inaccessible colonial locations to places that were easier to get to and that would serve better as the focal points of regional growth and development. At the time I lived there, Goiânia was already 28 years old and was showing real promise of fulfilling its mandate. Not only was it stimulating the development of the State of Goiás, but it had also become the jumping-off point for the nation's new capital, Brasília, then under construction. It was a lovely city with winding, tree-lined avenues and parks. The nine months I lived there are one of my most cherished memories.

Imagine my surprise several years later when Goiânia became the unlikely site of one of the world's major nuclear incidents and a symbol, along with Chernobyl and Three-Mile Island, of all that can go wrong, both real and imagined, in the nuclear world. The story of how the incident came about is both interesting and informative. It did not involve the "meltdown" of an enormous nuclear power plant nor did it involve an explosion in an industrial facility, a natural disaster or anything of the like. In fact, the circumstances leading to the event are so unremarkable that, if it were not for the immediate effects it had upon those it involved directly and the lasting mark it has left on the community, it would not have been noticed at all. As it has turned out, it is still considered second only to Chernobyl as the most important nuclear incident of all time.

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<sup>1</sup> Lawrence A. Mauerman, P.E., CSP. "Ionizing Radiation," *The Monitor*. American Society of Safety Engineers, Spring, 2005; Vol. 4. No. 3, pp1, 7-9, 16.

In 1971, a cancer treatment clinic had been built near a charity hospital in downtown Goiânia. A cesium-137 radiation therapy device was installed in the clinic but was replaced by a more modern cobalt device in 1978.

In 1985, the clinic with the cobalt device was moved to a newer location, but the cesium device was left in the old clinic building, which, due to some legal entanglements, remained unoccupied for years. Later, it was said that it was the legal troubles that prevented the clinic personnel from returning and removing the cesium device.

By 1987, part of the old building had been torn down and what was left had large holes in the walls. Access to the structure was unguarded and unimpeded. It had even become a place where homeless people routinely slept to get out of the rain.

On September 13, 1987, two men who made a living by scavenging entered the building and removed the large lead cylinder from the cesium device and took it to one of their houses. They tried to hammer the device open but with no success. Finally, on September 16, using sharp tools, they managed to break through the iridium “window” by which action they received high doses of gamma radiation as they observed the deep blue light that emanated from the cylinder. In addition to the gamma emissions, cesium chloride dust could now escape and be carried unknowingly around the city.

The next day, the two scavengers took the lead cylinder to a junk dealer who bought it. He wanted to make a ring for his wife from the blue metal inside the lead cylinder. The cylinder was stored in his wife’s closet. A few days later, two employees managed to hammer the cylinder apart and released the cesium chloride cylinder inside. Other people who had contact with the cylinder traveled to other cities in the region, spreading the contamination with them. The brother of the junk dealer gouged out some of the cesium chloride dust and took it home where he let his six-year-old daughter play with it. As she ate with her contaminated hands, she ingested some of the material. Another brother of the junk dealer took some of the cesium chloride home in his pocket on the bus and still another brother used the cesium chloride to make a cross on his abdomen.

On September 28, the wife of the junk dealer had one of the workers take the cylinder to a state agency because she suspected the material was making her family members sick. A physician examined the woman and suspected radiation sickness. The physician called in two physicists who, using a scintillation counter, verified that the material was highly radioactive. Her action saved many lives.

The woman died on October 23 in a hospital in Rio de Janeiro. Her six-year-old niece died the same day in Goiânia and was buried in a lead-lined coffin surrounded by concrete. On October 29, two of the junkyard workers died at the hospital in Rio.

As the result of this incident, it was thought that as many as 2,000 people had potential exposure to radiation and at least 244 persons had measurable contamination of cesium chloride on their bodies with 20 of them seriously radiated. Ten of the 20 underwent extensive procedures for decontamination, but four died. At least 14 different contaminated areas have been identified in Goiânia, most of them at low levels. Some cesium chloride dust was eventually tracked as far as São Paulo, some 850 km away. It was discovered in a bundle of newspapers that had been in the building where the original scavengers had succeeded in

opening the cylinder. The immediate area of the junkyard, about 2,000 sq m, was vacated of all its inhabitants and isolated. It contained some 25 small houses and two junkyards. The incident is still by far the most serious event ever recorded involving a medical radiation source and ranks along with Chernobyl as one of the deadliest non-wartime radiation incidents ever.

### **Lessons Learned**

In 1997, I had the opportunity to return to Goiânia. By then it had become a much larger city of nearly two million people. Goiânia had become a modern capital, its skyline punctuated by the steel and glass towers of modern business. The scars of 1987 were still there, however, both visible and invisible. Some of the original incident sites were still barricaded as remediation and restoration efforts continued. Friends with whom I visited still spoke of the agony when their town had been thrust into chaos because of the unknown and poorly understood threat of radiation contamination.

As I have worked as an industrial hygienist and worked in concert with health physicists, the need to understand and be able to quantify the hazards posed by ionizing radiation has become very apparent. Those who work with it regularly have come to recognize its potential threats and have developed the techniques and methods of which I write. But those who work primarily with the hazards of the chemical world still only partially understand. Ionizing radiation still mystifies and confounds.

Although many opinions are to the contrary, the applications of ionizing radiation will increase, not decrease, in the immediate future. Thus, now more than ever, SH&E professionals must become familiar with these materials and methods to evaluate and control them. Like the chemicals, which can add immeasurably to the quality of our lives, ionizing radiation can also be a useful tool if safely and properly handled.

### **Sources of Ionizing Radiation in the Industrial Setting**

#### **Background Radiation**

Ionizing radiation is with us; always has been and always will be. It is one of those unseen, ignored and misunderstood facts of life. The world we live in and the endless space it floats in are both sources of ionizing radiation. As mentioned in the previous article, almost all of the elements we know of have at least one radioactive isotope.

Perhaps, this morning you ate a banana because you know that it is an excellent source of the element potassium, which is necessary for a healthful body. Potassium is one of the elements that make nerve impulse transmission along the axon work so well. It has other important uses in our body. What you probably did not know is that it is very likely that a small portion of the potassium in your banana was its isotope. So at least in theory, you may have ingested a little ionizing radiation this morning for breakfast. Do not quit eating, however, because exposure to small amounts of ionizing radiation from multiple sources is an almost constant process.

Radiation is generated by the minerals of the earth as they decay beneath our feet, and it reaches us from the cosmic activities of the farthest stars. It is called background radiation, and our bodies have learned to deal with it quite successfully. In fact, it damages our bodies' cells with its high energy, but the insults are small enough and infrequent enough that our bodies heal themselves, and we never notice the effect. As Paracelsus, paraphrased by Dr.

Alice Ottoboni, said, “the dose makes the poison.”<sup>2</sup> When ionizing radiation insult becomes so large that the body cannot reconstruct and restore the damaged tissue, its effects become a serious concern.

Background radiation is significant enough that good radiation measurement practice dictates that before taking a reading on a radioactive source, the technician should take a reading on the background levels and then take them into account when doing the source reading.

Some of the more common categories of locations where ionizing radiation may be found in industry are briefly discussed below. The list is by no means complete but shows just how common, and yet unexpected, this potential hazard can be.

### **Instrumentation in Industrial Facilities**

Most people are aware that very small radioactive sources are used in smoke and fire detection equipment, even those found in residential applications. This usually only becomes a problem when someone wants to dispose of a smoke detector, and they do not want to put a piece of potentially harmful material in the household trash.

Far more serious sources of ionizing radiation are commonly found in industrial settings. These appear in the form of specialized instrumentation, many used to measure and gauge flow of materials in systems that cannot otherwise be monitored.

Several years ago, I performed periodic radiation surveys for a large plant involved in the manufacture of various polymers. After the plastic had been manufactured, it was formed into tiny pellets, which were then stored until it was time to load them into railroad cars to be shipped to customers. At several phases during their manufacture, the pellets needed to be moved from one place to another. Pellets do not flow through the pipes like a liquid, so they needed to be blown by powerful streams of air. The characteristics of such flow could not be gauged by the same means used to measure liquid flow, so special instrumentation was used.

A typical instrument consisted of a small but powerful radioactive source in a shielded container, mounted on one side of the pipe. The side of the shield mounted on the pipe had a small window, which allowed a measured amount of the radiation to escape and pass through the pipe with the pelletized flow inside. Directly across the pipe, 180° from the source, was a radiation-sensitive receiver, which detected the amount of radiation that had made it through the pipe and the pellet flow. The density of the material flow in the pipe absorbs some of the electromagnetic energy of the source, so the amount of radiation detected is inversely proportional to the flow in the pipe. In the plant I surveyed, there were more than 50 such sources.

### **Radiographing Operations**

Another source of ionizing radiation in industrial settings is that used for radiographing pipes and other objects that have been welded to test for the integrity of the weld. This practice is often inaccurately referred to as x-raying the pipes.<sup>3</sup> The passage of the electromagnetic beam

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<sup>2</sup> M. Alice Ottoboni, PhD. *The Dose Makes the Poison: A Plain Language Guide to Toxicology*. Berkeley, California: Vincente Books, 1984.

<sup>3</sup> The practice of referring to the technique as x-raying comes from the early use of actual industrial-grade x-ray equipment to do the job. Early x-ray machines were very large and unwieldy and required enormous sources of

through the object and onto a piece of energy-sensitive film on the other side will reveal weak spots and thin places in the weld, which can then be repaired or replaced. This practice eliminates potential hazards of another sort, which could result in disastrous consequences. This technique is used wherever piping and other systems will carry materials under great pressure and the integrity of those systems is essential. In fact, it is the extensive use of radiographing that makes nuclear power electrical generating facilities in this country so reliable. It is ironic that the use of ionizing radiation makes the use of ionizing radiation safer.

### **Ionizing Radiation in Mining & Oilfield Exploration Operations**

In mining and oil field explorations operations, applications for ionizing radiation sources are somewhat similar to those in the industrial setting. In the "oil patch" in particular, instruments containing radioactive sources are lowered several thousand feet into drill holes where they can be used to measure several parameters of the operation remotely. These sources are not always safety "down-hole" and require extensive precautions for storage, handling and use when at the surface.

Another type of ionizing radiation found in mining and oilfield operations is naturally occurring radioactive material (NORM). Particularly in old oilfields, as the crude oil comes to the surface, it is accompanied by substantial quantities of brine. Dissolved in this brine are quantities of water-soluble minerals such as calcium. These minerals have their isotopic components, but usually the concentration at any one time is not enough to cause concern. The brine is separated from the oil, and the brine is injected through deep wells back into the earth where it came from. Before it is reinjected, however, it passes through many pipes, pumps and other equipment at the surface. The minerals in the brine tend to separate and plate out on the inside of the pipes, in elbows, transitions, reducers and other locations, much like how minerals in hard water are deposited in pipes in residential plumbing. The radioactive components, while at low concentrations in the flowing brine, are now concentrated in the plated material in the production equipment and are of sufficient strength to be a problem if personnel are exposed. The potential for this exposure occurs during routine maintenance operations. One of the continuing activities in oilfield maintenance operations, therefore, is the conduct of NORM surveys.

### **Medical Applications**

We have come to expect that some radioactive sources will be found in hospitals, clinics and other medical facilities. They are part of the instrumentation, machinery and other equipment. They are also an integral part of the treatment for some serious diseases. They perform both diagnostic and therapeutic functions. Great care is given in the training of technicians who operate the equipment and in the use and maintenance of the equipment. However, much depends on the dedication and attention of the human element.

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electrical power to operate. Since the practice involves the exposure of a piece of film on one side of the pipe by the emission of powerful electromagnetic energy passing through the pipe, it was soon discovered that a smaller ionizing radiation source could be used to accomplish the same purpose. The main obstacle was that an x-ray machine was more easily focused in a single direction, while a radioactive source radiated in all directions. This problem was solved by locating the source in a portable "camera" with an opening, or lens, on one side that could be controlled by using a shutter.

## **Nuclear Power**

Large nuclear power plants are probably the most visible evidence of ionizing radiation. Once seen as the future of cheap, environmentally clean power in this country, they fell on bad times due to problems associated with the radioactive waste they produce and the potential for incidents affecting the populations in the immediate areas surrounding the plants. No new nuclear facilities have been built in the U.S. for more than 20 years. Still, many built prior to that time are in full operation and provide continuous daily protection for personnel who work there.

The U.S. Nuclear Regulatory Commission (NRC) regulates the nuclear power plant environment. Each and every aspect of the work has been analyzed, and measures have been implemented to eliminate exposures to unsafe amounts of ionizing radiation. The equipment mentioned in this article and many others are employed in this work.

## **Instruments for Measuring & Monitoring Ionizing Radiation**

Several types of instruments are used for analyzing radiation hazard potential. Although they function on varying principles and perform several functions, they can generally be sorted into two large, broad categories. The first category is generally referred to as survey instruments, also called counters. This category includes those instruments whose primary purposes are to measure the amount of radiation present and, insofar as is possible, to identify its type, i.e., alpha, beta, gamma, etc. In certain circumstances, they may be used to pinpoint the source of the radiation. They may also be used to scan a worker who has worked in the presence of radioactive materials and will undergo decontamination. To ensure that the worker is not carrying any of the radioactive material out of the contaminated area, s/he will be “frisked” with a specially adapted instrument.

The second category is monitoring instruments, which track the actual levels of radiation encountered over a specific time period or, in other words, measure exposure and dose. Wearable forms of these instruments are commonly called radiation dosimeters.

## **General Principles of Survey Meters (Counters)**

All survey meters have three basic components in common. The first component is the detector (or transducer). Its purpose is to change radiation energy into another form of energy, usually electricity. The second component is a combined power supply/amplifier that amplifies and otherwise modifies the electrical pulse to improve its qualities. Finally, the third component is a metering circuit, which counts or measures the electrical pulse, its rate and translates it into useful units such as counts per minute (CPM), milliRoentgens per hour (mR/hr) or microRoentgens/hour ( $\mu$ R/hr).

Radiation-counting instruments produce signals in one of two modes depending on the make and design. In the first, the detected energy serves as a signal to produce an electrical output, which is then detected and interpreted by electronic circuitry. The output electrical pulse is constant regardless of the amount of energy sensed in the detector or the nature of the particle. This is the mode of operation for the Geiger-Müller counter.

Scintillation counters, gas proportional counters and semiconductor detectors all operate in the second mode. In this mode, the magnitude of the output pulse is proportional to the amount of energy sensed by the detector. The greater the energy, the larger the pulse out.

## Geiger-Müller (G-M) Counters

The most familiar survey meter is the Geiger-Müller Counter.<sup>4</sup> Its principles are simple, it is easy to operate, it is relatively inexpensive and it is durable. It is also sensitive, reliable and versatile. The sensing portion of a G-M counter is essentially an ionization chamber. Shapiro provides the following description of a simple G-M counter:

Put a gas whose molecules have a very low affinity for electrons (for example helium, neon or argon) into a conducting shell, mount at the center a fine wire that is insulated from the shell, connect a positive high-voltage source between the wire and the shell, and you will have a Geiger counter.<sup>5</sup>

The walls of the detection tube are negatively charged (the cathode), and the wire or rod in the center is positively charged (the anode). If a radioactive particle ionizes even just one of the gas molecules, it will institute a succession of ionizations and discharges within the counter that will cause the center wire to build up an excess of electrons. This results in a large multiplication of charge, which may amount to as many as  $10^9$  electrons. A typical G-M circuit will generate a signal of about 1 volt. This potential then activates the counting circuit. The current that flows through the detector, the amplifier and the metering circuit is called the pulse.

The most common G-M detector is the end-window variety. Think of it as a cylindrical or tubular shell covered at one end with a very thin window. The window must be of such thinness as to allow low-power beta particles, and in some cases, even less-penetrating alpha particles, to pass through. Yet at the same time, it must be impermeable to the gas to prevent it from escaping. A 30-micron window thickness will allow about 65% of the beta particles emitted by carbon-14 to pass. If the window tube is to measure alpha particles, the window can be no thicker than 15 microns. Gamma rays, of course do not require a special window and will penetrate the counter from any direction.

G-M counters are most effective in detecting charged beta particles. Almost every beta particle that reaches the counter gas will induce a charge and thereby register on the counting equipment. On the other hand, gamma radiation is composed of photons (rays) that have no charge. When they encounter the detector, a small portion interacts with the walls and an even smaller portion will interact with the gas inside to produce electrons that will generate discharge. Most gamma photons will pass completely through the chamber without any interaction with the gas molecules and go unrecognized and unrecorded.

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<sup>4</sup> It is commonly called a Geiger counter. Its inventor, Hans Geiger (1882-1945) was a German physicist who, after receiving his doctorate, accepted a fellowship in 1907 to work in England with Ernest Rutherford, a noted British physicist. There he conducted research on the detection of alpha particles, ionization and radioactivity. His work contributed significantly to the development of the science of nuclear physics. In 1908, he built his first device to detect radioactive particles, known as the Geiger counter. During his career, he constantly improved the instrument, and in 1925 while at the University of Kiel, he worked with another German physicist, Walther Müller, to improve the sensitivity and durability of the Geiger counter, which subsequently became known as the Geiger-Müller counter. Improvements included detection and measurement of beta particles and ionizing electromagnetic photons. His illustrious career continued until 1940 when a debilitating illness overtook him, resulting in his death in 1945.

<sup>5</sup> Shapiro, p. 251.

Regardless of the kinds of particles or photons detected or their energies, the signals from a G-M counter are all of constant size. For this reason, a G-M counter is purely a particle/pulse counter. Its output provides no information on the particles that triggered its response.

### **Scintillation Detectors**

Scintillation detectors operate on the principle that light is emitted when energy from radiation interacts with certain materials. The amount of light is proportional to the amount of energy. This light can be measured and the results used to calculate the amount of radiated energy. These instruments are more useful than G-M counters in analytical measurements when both the type and magnitude of the radiation are important. Scintillation counters are energy-sensitive devices.

Scintillators are made of many materials. They can be gaseous, liquid and solid. Many are crystalline in form and come in various shapes and sizes. Some of the materials commonly used for scintillators are zinc sulfide, anthracene crystal and a sodium iodide-thallium-activated (NaI-T1) crystal. Except for the end attached to the photomultiplier, they are completely encased because external light must be prevented from entering the device. Some scintillators may be made of plastic, but those intended to detect gamma photons must be made of larger and heavier materials. The higher mass gives them greater detection efficiency.

When a charged particle, such as a beta particle, enters a scintillator, it slows down, and as it does so, part of its energy is imparted to atoms in the scintillator and is converted to light photons. The light generated is proportional to the energy imparted by the beta particle, i.e., the greater the energy imparted, the greater the number of light photons produced and the more intense the light signal in the scintillator.

Scintillation detectors are much better at detecting gamma photons than G-M detectors. When gamma photons pass through a scintillator, they impart energy to electrons, which causes the atoms in the crystal to emit light. The more energetic the gamma photons, the more energetic the electrons they liberate and the more intense the pulses of light they produce.

This light energy is still very minute. The scintillator must still employ a device that detects and multiplies the light energy to a level where it is useful. This device is a photomultiplier. The scintillator is attached to the photomultiplier by an optical coupling. Through several features in the photomultiplier, the tiny electric impulses are multiplied to a factor of  $10^6$ . The electrons are collected at the anode in the photomultiplier and saved for subsequent processing and analysis by the electronic circuits.

A sample taken with a G-M counter is analogous to a grab sample of an airborne contaminant taken by an industrial hygienist. It is a reading of the conditions at a specific moment in time. It can only imply what conditions were like a few moments or minutes prior to the sample or what they will be like a few hours later. Although emissions from radioactive sources are more constant than the airborne emissions from chemical sources and are not affected by air current, temperature and such, many other variables can affect radioactive emissions over time. For total exposure, dosage measurements must be taken.

### **Monitoring Instruments**

Monitoring instruments are used to measure amounts of radiation exposure over longer periods of time and thus provide a dose measurement instead of a single sample. They are

commonly referred to as dosimeters. In many cases, the dosimeters are small enough to be worn by personnel and are able to provide information about individual exposure.

### **Film Badges**

The first and perhaps best known of these devices is the common film badge. It is primarily a beta/gamma measuring instrument, which consists of a small plastic holder with a clip for attaching it to the wearer's clothing. The badge is worn in a consistent location on the worker's body, usually on the upper-front torso.

Mounted in the device are two small pieces of film similar to the type used for dental x-rays. One piece of film is for low-radiation exposure levels and the other is sensitive to high-radiation exposure levels. The film is wrapped to protect it from exposure to light. Various inserts are added to the badge to differentiate between how much and to what types of radiation the film has been exposed. Ionizing radiation exposes the film by producing ions that react with the silver molecules in the film gelatin, in much the same manner that light exposes photographic film. After a possible exposure, the film is developed and then read with an instrument called a densitometer. The density of portions of the film that have been exposed indicate how much radiation was absorbed during the exposure period. From this information, the dose can be calculated.

The film badge provides an accurate record of exposure. It is small, lightweight, easy to use and does not require calibration. Its disadvantage is that it does not provide rapid information but must be developed and read by a trained technician before the results can be known. Also, reading with the densitometer is subject to interpretation, and its accuracy and consistency depend on the technician's training and skill. Although still in use in many places, the film badge is not as common as it once was.

### **Thermoluminescent Detectors (TLDs)**

The thermoluminescent detector (TLD) is often used in place of the film badge. Like the film badge, it is small and easily worn by an individual. It is not subject to densitometer interpretation but is designed to be read automatically and objectively and to provide a basic for accurate record keeping.

The TLD badge contains a small chip composed of thermoluminescent material. Thermoluminescent material, as the name implies, gives off light when heated. In this case, the amount of light given off is directly proportional to the amount of ionizing radiation to which it has been exposed. To read the film badge, it is placed in a reader device, which consists of the heater and a photomultiplier tube. The photomultiplier increases the signal emanating from the TLD, registers it and counts its magnitude. It then records the information.

TLDs have the advantage in that they are more sensitive than film badges and are reusable. Reading the badge discharges it, and it can be used over and over again. However, they are considerably more expensive than film badges.

TLDs must be read in a special device. They cannot be interpreted by the wearer. This means that the dose cannot be determined until the device has been taken to a location where the reading can be performed. This brings us to a brief discussion of the last instrument to be examined—the pocket dosimeter, sometimes referred to as the pencil dosimeter.

## **Pocket Dosimeters**

The advantage of the pocket dosimeter is immediately apparent. It can be read by the user, and the results are immediately obtainable. It is a direct-reading instrument. The pocket dosimeter is a small ion chamber mounted as a slender cylinder with a pocket clip much like a mechanical pencil, hence its nickname. The chamber contains a small capacitor that is charged prior to its use. The capacitor is connected to a small, glass-fiber electroscope, which is two pieces of glass laminate that will deform with electrical charge. If the detector is exposed to ionizing radiation, a loss of electrical potential occurs in the chamber and the electroscope deforms or changes shape. The amount of deformation is proportional to the loss of charge, which is directly related to the amount of ionizing radiation. This is observed by pointing the dosimeter toward the light and looking through a small magnifying lens mounted in one end of the dosimeter.

The advantage of the pocket dosimeter is that it provides an immediate estimate of radiation dose received by the wearer. However, it must be charged anew every day, but this is not particularly difficult. The wearer must just remember to do it. More common and difficult problems are its sensitivity to being struck or dropped. Also, it is sensitive to heat and humidity. For these reasons, it is generally not considered to be accurate enough by itself. It is usually worn as a backup to either a film badge or a TLD. If a radiation worker suspects an exposure, s/he will consult the pocket dosimeter. If it shows the possibility of a dose received, then the worker will exit the area and take the film badge or TLD for a more certain reading.

## **Conclusion**

The major types of equipment used to measure and monitor ionizing radiation have been discussed. We have looked at both counters and dosimeters and the methods of operation of each type.

Other topics still need examination. These include the interpretation of results gained from the instruments and what to do with that information, namely the control methods that can be established along with their relative effectiveness and practicality.

## **Definitions**

**Controlled Area**—A specified area in which exposure of personnel to radiation or radioactive material is controlled.

**Counter**—A device for counting nuclear disintegrations.

**Dosimeter**—An instrument used to determine the radiation dose a person has received.

**Film Badge**—A piece of masked photographic film worn as a badge for personal monitoring of radiation exposure.

**Ionization Chamber**—A basic counting device to measure radioactivity. In this article, it is called a “detection tube.”

**Photon**—A discrete bundle of photon energy. Photon energy is the energy possessed by electromagnetic energy when characterized in quantum theory. The unit of photon energy is the Joule (J) or the electron volt.

**Scintillation Detector (Counter)**—A radiation-counting device that registers tiny flashes of light (scintillations), which particles produce when they strike certain crystal or liquids.

## References

DiNardi, Salvatore R. (ed.). *The Occupational Environment - its Evaluation and Control*. Fairfax, Virginia: American Industrial Hygiene Association, 1997.

Plog, Barbara A., Niland, Jill and Quinlan, Patricia J. *Fundamental of Industrial Hygiene* (4th Ed.). Itasca, Illinois: National Safety Council, 1996.

Magill, Joseph, and Galy, Jean.. *Radioactivity Radionuclides Radiation*. Berlin, Heidelberg, New York: Springer, 2004.

Mauerman, Lawrence A. *TEXACO NORM Surveyor Training*. Hammond, Louisiana: Industrial Hygiene, Environment & Loss Prevention, Inc. (I HELP), 1990.

Roper, L. David, and Leite, Marco Antonio Sperb. *The Goiania Radiation Incident: A Failure of Science and Society*, 1988. Recovered from:  
[http://veneermagazine.com/01-18/01/the\\_group/goiania.html](http://veneermagazine.com/01-18/01/the_group/goiania.html). (10/31/07).

Radiation Technical Services, Inc. *NORM: Survey & Control Certification* (Training Manual). Baton Rouge: Radiation Technical Services, 1994.

Shapiro, Jacob. *Radiation Protection: A Guide for Scientists, Regulators, and Physicians*. (4th Ed.). Cambridge, Massachusetts, Harvard University Press, 2002.

Health Physics Society. Website located at: <http://www.hps.org/>

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