THE FUNDAMENTALS OF …

Radiation

Robert M. Dondelinger

Since the dawn of time, this planet and everything on it has been bombarded by all types of radiation. Fortunately, through the evolutionary process, our bodies have learned to deal with radiation and even thrive—sometimes because of it and sometimes in spite of it. Is radiation bad, good, or simply harmless? The answer is yes—to all three. To better understand this phenomenon, this edition of "The Fundamentals of …" will depart from the norm of spotlighting medical device technology and instead provide an overview of the types of radiation, and how biomeds can protect themselves from their harmful effects.

Radiation is electromagnetic energy, or sometimes energy with particle-like characteristics, that emanates from a source into space. Radiation may be classified by any of its many characteristics. The most common classification method makes a distinction between non-ionizing and ionizing radiation. Non-ionizing radiation is less powerful than ionizing radiation and therefore only contains sufficient energy to move or vibrate atoms within a molecule.

Ionizing radiation, on the other hand, contains more than enough energy to not only vibrate atoms within a molecule, but to move them with such force that electrons actually leave the outer ring of the atom and fly into space. When this occurs, two new charged particles or "ions" are created. One ion is formed from the nucleus of the once-stable molecule with a positive charge, and other ion is the free electron with its inherent negative charge.

Another common classification method is frequency (Figure 1). Very low frequency radiation—less than 100 hertz or Hz, such as that from an electrical power line—induces miniscule currents in coils of wire and objects near the source. Although 100Hz—10 kHz is well within the range of human hearing and is perceived as audible sound when it radiates from a speaker, this article does not address audio frequency radiation. As the frequency increases, so do the effects. For example, at high frequencies, such as those used for radio and television transmission, between 1 and 100 MHz, small currents are induced in coils of wire much farther from the source. This is the basic principle upon which radio and television operate. Above the radio and television frequencies are the microwave frequencies. Frequencies above 100 MHz and up to about 2,500 MHz or 2.5 GHz are capable of exciting the electrons in the atoms of objects. As the name implies, these frequencies are particularly useful for heating things, such as food in a microwave oven, and are also used in the diathermy units found in physical therapy departments. At yet higher frequencies, radiation may be felt and seen, particularly at infrared and visible light frequencies.

These are the frequencies at which laser light is found. (The word "laser" is an acronym formed from the words describing how the light is generated: light amplification by

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stimulated emission of radiation.) The light from conventional sources, such as sunlight, incandescent bulbs, and general purpose light-emitting diodes appears as random waves of energy over a relatively wide bandwidth. Laser light differs in these respects from conventional light because its light waves are in phase with each other and are produced over a narrow bandwidth, hence the characteristic laser light colors. The power derived from laser light comes from the ability to focus, through lens and mirrors, in-phase light into small concentrated beam. These visible light frequencies are also generally considered to be non-ionizing radiation. At even higher frequencies, above those of visible light, are the ultraviolet or UV light, X-ray, and gamma ray regions around 100 terahertz or THz, which can damage both human and animal DNA.

A third way of classifying radiation is by energy level. Low-energy radiation is considered non-thermal since it produces no apparent effects to either the surroundings or objects within it. Medium-energy level radiation produces noticeable and measurable thermal changes in the surroundings, the objects within it, or both. High-energy radiation produces visible optical effects, such as infrared, visible, and UV light. Above these energy levels, there is sufficient energy to break molecular bonds and be classified as ionizing radiation.

The final classification for radiation is form, and there are two. The first and the most common form is pure energy, without mass or weight. Non-ionizing radiation such as sunshine, radio frequencies, microwaves, and visible light occurs as pure energy. Although light exhibits properties of both energy and matter, actual matter has never been found.

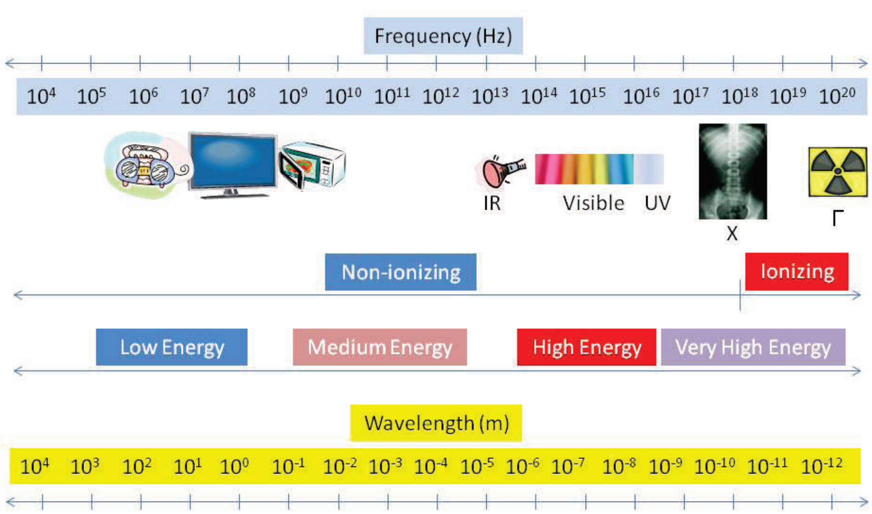

Figure 1. Radiation Spectrum

Only ionizing radiation, by virtue of its definition and molecular action, occurs as both energy and particles. Once the ionization process occurs—that is, once the molecular bonds are broken—what remains are incomplete and unstable molecules. Since nature abhors an imbalance, the molecule will endeavor to become stable again. It does so by emitting radiation to divest itself of excess energy and restore balance to the molecule. The unstable molecule, now called a radioisotope, will never totally lose its radioactivity. The loss of radioactivity is called decay and is measured in half-lives. A half-life is the amount of time it takes for one half of the atoms of the radioisotope to decay, and become stable again, by emitting radiation. Another half-life later, one half of the remaining atoms of the radioisotope will decay. This decay process continues indefinitely, and the radioisotope remains hazardous during the decay process, emitting radiation below the background level. After 10 to 20 half-lives have elapsed, the amount of radiation emitted cannot be differentiated from background radiation, but the decay never stops.

The decaying radioisotope releases two forms of radiation—pure energy and particles. The pure energy, depending on the frequency and energy level, is either X-rays or gamma rays. The small, extremely fast-moving particles produced by ionizing radiation are of three types—alpha, beta, or neutrons—and have both mass and energy. Both X-rays and gamma radiation are high-energy waves that travel at the speed of light over long distances and can usually penetrate other materials. Although they penetrate objects, they do not contain sufficient energy to break molecular bonds and make the object radioactive.

Alpha particles carry a positive charge and are produced by naturally occurring elements such as thorium, radium, and uranium as well as by man-made elements such as plutonium and americium. It is very hard for them to penetrate objects such as a sheet of paper, human skin, or just a few inches of air. When breathed in or ingested they are potentially dangerous, but externally they pose minimal danger. They can

The energy level of X-rays used in hospitals is insufficient to break molecular bonds, but repeated exposure can pose a health risk.

be removed from skin by soap and water. Beta particles are negatively charged, lighter than alpha particles, and produced by naturally occurring elements such as strontium-90. Unlike alpha particles, they have a greater ability to penetrate objects including human skin, but can be blocked by thin sheet metal, plastic, or a block of wood. Like alpha particles, they should not be inhaled or ingested and can be removed from outside the human body by vigorous scrubbing. The neutron has the highest speed and is also the most dangerous of the three due to its exceptional ability to penetrate most other materials—stopped only by thick hydrogen-laden materials, such as water or concrete. Neutrons are the only particles with sufficient energy to make other objects radioactive and, fortunately, are usually only produced inside a nuclear reactor or during a nuclear explosion.

Current Technology

As they carry out their duties, biomeds can expect to encounter, in ascending order of likelihood of contact, X-ray and gamma ionizing radiation, light, and RF radiation. X-ray and gamma radiation are typically found in radiology and nuclear medicine, respectively, and both are areas frequented by biomeds on a regular basis. Every X-ray unit, even digital units, produce energy levels high enough to generate low levels of ionizing radiation. It is this radiation that penetrates the body and is seen as the image on the film or digital image or capture device. The energy level of both X-rays and gamma rays used in healthcare is insufficient to break molecular bonds and make objects radioactive, but it is high enough to be problematic in two main ways. The first is through repeated exposure to X-ray and gamma radiation, which can cause genetic and chromosomal instabilities and is thought to explain many illnesses and tumors. The second is by a process called bioaccumulation, where small amounts of radioactive substances collect in muscle and fat tissues, and build up to unsafe levels. Fortunately, the body will normally cleanse itself once it is no longer exposed to the radioactive substance. This cleansing process is both a function of the radioactive material's physical half-life and the body's biological half-life of that substance.

Materials that release gamma radiation are particularly useful for medical applications in a number of ways since they can be bound to another substance or suspended in sterile saline and injected into the human body. For example, radioactive iodine is used to outline and assess the thyroid because of this gland's natural affinity for iodine. In some cases, a period of time elapses before the patient is scanned with a gamma camera. In the case of radioactive iodine, the elapsed time allows iodine to concentrate in the thyroid. When scanned with the gamma camera, the resulting image indicates both size and the level of function of the thyroid. In radionuclide imaging, the mixture is injected into a vein while the gamma camera is used to track and photograph the movement of the injectate through the body. This outlines the venous system without the use of dyes and allows the physician to see blockages, often exposing the patient to less radiation than an X-ray.

Light, both UV and laser, is another source of radiation likely to be encountered by biomeds.

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Hand-held UV lights, also known as Wood's lamps, are used by preventive medicine personnel during onsite inspections of food service areas. Similar lights are used in dermatology clinic to assist in diagnosing a variety of bacterial and fungal infections on skin. Much larger UV therapy units, resembling stand-up, walk-in tanning booths, are found in some large dermatology clinics to treat extensive or whole-body psoriasis and other conditions. Lasers can be found in operating rooms, ophthalmology clinics, eye, ear, nose, and throat clinics. Each has a specific purpose. Although not ionizing radiation, laser light must be respected for its ability to easily burn tissue and damage both the retina and cornea, depending on the frequency of the laser light.

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Many sources of RF exist within the walls of the healthcare facility. Most of them are low power and relatively harmless sources such as cellular telephones, walkie-talkies, microwave ovens, and radio frequency identification (RFID) locator systems. However, biomeds may also be exposed to the moderately higher energies used in radio frequency (RF) heat sealers found in the laboratory and central or sterile supply packaging areas and even the much higher RF energy of medical diathermy units.

How to Manage Radiation-Producing Devices

Sources of potentially harmful radiation should be managed uniquely. That is, maintenance should be uniquely scheduled by device serial number or other identification number. The preventive maintenance frequency and procedures should be in accordance with the manufacturer's instructions. Accurate historical records become critical evidence if a device-related mishap occurs. These service and maintenance records, including device updates, modification, and upgrade documentation, will be instrumental in defending any lawsuit which may be brought against the institution.

Regulations

Across the entire energy spectrum, only a few sources of radiation fall under federal regulation, but fortunately most forms of radiation found within healthcare facilities are regulated. For example, the U.S. Food and Drug Administration (FDA) regulates X-ray and gamma radiation, while some other forms of radiation fall under the purview of two or more federal agencies. While the FDA has primary authority over laser light in healthcare facilities, both the FDA and the Occupational Safety and Health Administration have regulating authority for UV light, the former from a medical device perspective and the latter as a potential workplace hazard. Likewise, the FDA and the Federal Communications Commission (FCC) have rules regulating RF-producing medical devices such as diathermy units, which are the most common high-energy RF producers in a healthcare facility. Other devices or technology, such as medical telemetry units, wireless networks, etc., produce negligible amounts of radiation and are subject to both FDA and FCC regulations, with the FDA focusing on patient parameter accuracy and the FCC concerned with transmitter frequency, power, and modulation.

Risk Management Issues

Medical diagnosis and treatment invariably involves some element of risk for both staff and patient. Mitigating this risk is important to provide successful outcomes. To accomplish this, healthcare facilities employ several mitigation methods. First and foremost are engineering measures, such as proper design, equipment interlocks, and lock-out design defaults which prevent inadvertent operation, unauthorized parameter changes, and overexposures. These engineering measures will not completely mitigate risk because, for example, a therapeutic radiation dosage for an adult may be an overdose for an adolescent or infant. They mitigate human error to some extent, but they do not completely eliminate inadvertent user errors.

Second, and equally important, is the use of personal protective equipment (PPE) unique to the type of radiation to which one is exposed. For those exposed to ionizing radiation, PPE includes radiation-monitoring devices and lead-lined apparel for workers, and lead-lined drapes and shields for patients. For patients and workers exposed to laser and ultraviolet light, PPE includes special goggles, some of which are designed to be worn over conventional eyeglasses, appropriate warning signs, and treatment area access controls are most commonly used. There must be signs posted for devices producing sufficiently high levels of radiation to be problematic, no matter the form. A sufficient variety of commercially produced signage is available and should be used to warn others in areas where X-ray and gamma ionizing, laser light, and RF radiation is present, and for marking entrances to areas where this equipment and these hazards exist. Sometimes the access controls are part of an engineering measure, such as the door interlocks commonly found on radiographic and fluoroscopic X-ray rooms that prevent or stop the unit from producing X-rays when the room's door is open or opened.

Training and Equipment

Although brand/model-specific training is certainly helpful, there will be times when biomeds performing on-call services will be required to service radiation-producing equipment with little or no specific training. This can be dangerous since this equipment can contain hidden hazards. For example, blood irradiators and gamma-beam therapy units using radionuclides as their radiation source do not hum or glow as often depicted in the movies and television. The source just sits there quietly and emits its radiation 24 hours per day, 365 days per year, just like the magnetic field around a magnetic resonance imaging (MRI) machine. Although there is an off switch for the device's electronics, there is no off switch for the actual source. Safety depends on the lead shielding around the source; removing or compromising its integrity can cause debilitating illness or an excruciating death. Therefore, at a minimum, radiation safety training is recommended for all biomedical equipment technicians, whether they work with radiation-producing devices or not. This training should not only cover nuclear and X-ray radiation, but laser and ultraviolet light as well high-energy RF radiation. It may be provided by the institution's health physicist, if one exists, or from one of the many online training courses available on the Internet.

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Future Development

Many companies are experimenting with various forms of radiation to determine both the effects on the human body and to develop new uses for radiation in the future. As recently as fifty years ago, no one could have reasonably foreseen the importance of RF energy in a MRI machine, but without it, such a machine would be nothing more than a superconducting electromagnet. Similarly, researchers are experimenting with new drug delivery methods for radiopharmaceuticals, and their combination with nanotechnology is one area showing great promise. Future applications of radiation are truly limitless. ■

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