Radiation Basics Made Simple

Segment 1: Sources of Radiation

Hello, and welcome to the Radiation Basics training. My name is Armin Ansari, I'm a Health Physicist at the Centers for Disease Control and Prevention. Now, if you're participating in this training, you may be a public health professional, a clinician, a law enforcement official, a first responder, or someone who wants to know more about radiation and radioactivity. And you are in the right place.

Now, the word "radiation" carries a negative connotation for many of us. It's not something we want in our lives generally. But the truth is that radiation is all around us, every day. We're exposed to radiation constantly, from radiation that comes to us from outer space, elements in the ground, the food we eat, and the air we breathe. And these everyday exposures don't do us any harm because our cells in our bodies have evolved and adapted to living in these conditions just like any other life form on earth.

So, it's important to keep this context in mind as we explore and evaluate additional exposures to radiation. Now, this training gives you a basic understanding of radiation and radioactivity and prepares you for more advanced training. Radiation Basics is divided into eight segments. In these segments we will discuss sources of radiation, radioactive decay, measuring radiation, biological effects of radiation, radiation protection, decontamination, environmental impact of radioactivity, responding to radiation emergencies.

After you complete this training, I invite you to visit our website, where you will find additional resources and training products. And if you have any comments on this particular training or other products you see on our website, please email us your comments. Now thank you again for your interest in this topic, and lets' get started.

Now, in this training whenever we talk about radiation, we're really talking about ionizing radiation. So let me first describe to you what radiation is, and then tell you what's different about ionizing radiation. Radiation is energy that originates from a source and then travels through space at the speed of light. And this energy has an electric field and a magnetic field associated with it, and it has wave-like properties.

So, a more technical term for it would be electromagnetic wave, but we just call it radiation. The most familiar form of radiation is actually visible light. Visible light is electromagnetic waves. It's energy that originates from a source and travels through space at the speed of light. It has wavelengths and frequencies that defines its energy.

And if we're blessed with good vision, we can actually see this radiation. We can detect it with our eyes and see this radiation.

And the difference between colors of light – red, green, blue, and so forth – is in their energy wavelength. That's what sets them apart, and that's how we can detect them. So different colors of light are actually radiation of different energies that we can see. Now the spectrum of visible light that we see, the range of visible light, the different colors, is only a tiny fraction of the entire spectrum of electromagnetic radiation in nature. The nature has radiation with energies that are far less than and far higher than visible light.

So, if we start in the range that we can see, let's start with red, which has the lowest energy. Red light has lower energy than blue light. So, let's say we start with red and go down in energy. We go to infrared, microwaves, radiation from cell phones, radio waves – these are all forms of radiation that have less energy than visible light. And of course they're invisible to us.

If we go higher energy, to start again, come back to the visible spectrum, and go to blue light, which has a higher energy, then purple. Then we go to ultraviolet, and X-rays, and gamma rays. And these types of radiation have much, much higher energies than visible light, and of course we can't see them. But we have detectors, instruments that can detect these types of radiation, and in other segments I'm going to show you how we do that, but we have instruments that can detect these types of radiation.

Just like we have instruments that we can measure the intensity of visible light, we have light meters that do that. We can detect it with our eyes of course, and then radios. Radios that can tune into frequencies on the radio frequency and do that. So, we have instruments to detect all types of radiation. In fact, it's interesting, because at any moment all the radiation signals that carry information for our favorite radio stations and television stations are all here, in this room. Just a matter of having the right instrument to tune into it.

I want to talk about ionizing radiation, which is X-rays and gamma rays. So, what happens at the higher energy side of the electromagnetic spectrum, these forms of radiation interact with matter. They have enough energy to remove an electron from an atom. And when they do that, the atom becomes charged, or ionized. So that's why we call these ionizing radiation, because they have the capability to ionize atoms when they interact with them.

This is a unique property that these other forms of radiation, including what we get out of a cell phone, don't do that. So, in this training we're going to focus exclusively on ionizing radiation; even though we might just say radiation for simplicity, what we really mean is ionizing radiation.

So where does ionizing radiation come from? Well, in nature ionizing radiation comes from radioactive atoms. And radioactive atoms, just like any other atom, as you know, are building blocks of matter. So, they could come in solid form, they could come in the form of gas, like this, or liquid. So just like any other matter, radioactive material or radioactive atoms are part of matter. It could come in gas, liquid, or solid.

But what makes an atom radioactive? As you know, atoms are composed of a nucleus, and have a cloud of electrons that surround them. In the nucleus we have protons and neutrons. And it needs to be a good balance between protons and neutrons for the atoms to feel stable.

Let's take carbon, for example. Now carbon has six protons and six neutrons. And that's a pretty happy carbon atom because it's pretty stable. The proton determines what the identity of the atom is, so, if you take the carbon atom and you add an additional proton 7, it's no longer carbon; it becomes nitrogen. Nitrogen has seven protons, and nitrogen likes to have seven neutrons to be happy and stable.

Often you see in this training we will follow the name of the element with a number – say, Nitrogen 14, or Carbon 12. That number is the atomic mass number; it is a summation of protons and neutrons, the sum of protons and neutrons. So that number, that's what it refers to. So, nitrogen, with 7 protons and 7 neutrons is a stable nitrogen, Nitrogen 14 is happy.

For carbon, 6 and 6, is a stable carbon atom. But Carbon 14, which we see in nature, and we'll talk about later, has six protons, which makes it carbon, but eight neutrons. So, it has two additional neutrons, and that's an unstable nucleus. And it's radioactive, because unstable nucleus doesn't like to remain unstable. It likes to reach a more stable state. And what it does is eject some of that extra energy, ejects it out to reach a more stable state.

And this process I just described is radioactivity. So, let's discuss some key terms. Radioactivity, then, is the spontaneous release of energy from an unstable atom. Radioactive material could be a solid, liquid, or gas that contains radioactive atoms. And radiation is the energy that comes out of the radioactive atom. Radioactive isotopes, sometimes we call that radionuclides, are radioactive atoms of the same element that have different numbers of neutrons.

An example would be iodine. Iodine 131 or Iodine 125. Now, these are both iodine, the element is iodine. But they have a different number of neutrons and they're both radioactive. So, we call these radionuclides, or radioactive isotopes. And radioactive decay is that process, the change, going from an unstable atom to a more stable atom by emitting radiation. So, the Carbon 14 that I mentioned earlier, the Carbon 14 atom would go through a radioactive decay process, expel some of that extra energy and change back to Nitrogen 14. So, Carbon 14 will go to Nitrogen 14, which is a more stable atom.

Uranium also we find in nature. Uranium would go through a radioactive decay process and transform into an atom of thorium, which is a more stable atom. But sometimes even the atom that it transforms into still needs to go through more processes. The thorium is still radioactive, has less energy than uranium, but it still needs to go through a few steps of radioactive decay.

So, I'm talking about now a lot of different types of radionuclides – uranium, thorium, carbon, nitrogen. We actually have quite a lot of radioactive material in our environment that occur naturally, actually most of them occur naturally. One group of radioactive atoms, we call them primordial. These atoms were around when the solar system and the planets were formed. These include uranium, thorium, and potassium. So, they were around, well, we find today they were around when the planet was formed.

I want to talk about potassium a little bit because all of us know about potassium. Potassium 40 is radioactive, but Potassium 39 is the stable one. Stable potassium has 19 protons and 20 neutrons. That's the balance of proton-neutron that makes it happy. So, potassium with the number 39, that's the stable. And out of every 10,000 potassium atoms we find in nature, 9,999 are Potassium 39. But 1 in 10,000 has an extra neutron, which makes it Potassium 40. And that is a radioactive potassium, because it's a little bit unstable. So, it needs to get rid of that extra energy to become more stable.

Now, Potassium 40 happens to be a patient atom, because it takes it about a billion years to do that, on average. The half-life of potassium, we'll talk about half-life later, but it takes it more than a billion years to go through that transition and become a more stable atom.

Now, some of our foods, I'm sure many of you like bananas. As you know, banana is rich in potassium. Anything that has potassium, it also has Potassium 40, because out of 10,000 atoms, one of them is Potassium 40. So, we have actually plenty of Potassium 40 atoms right here in these bananas that we eat. Our bodies? The potassium in our bodies, and we have Potassium 40 in our bodies, and we can actually measure the radiation that we emit because of that.

The other group of radionuclides we have in our nature, we call them cosmogenic. And that means that when we have cosmic rays coming to us from outer space, these cosmic rays interact with atoms we have in our environment, particularly in that atmosphere. And they create new species of radioactive material. A good example, we have plenty of nitrogen in our atmosphere. And cosmic rays interact with nitrogen and make Carbon 14. Remember, Carbon 14 is the radioactive carbon. Carbon 12 is stable.

So, Carbon 14 is generated in our atmosphere when cosmic rays from outer space interact with nitrogen in our atmosphere. And this Carbon 14, over time, becomes part of our nature, incorporated in our environment, and becomes part of every organic life on earth. We all are carbon-based. That means we have carbon. In fact, one out of every trillion carbon atoms is a radioactive carbon. So, we have Carbon 14 in our bodies, and anything else that's organic.

Now, you're familiar with carbon dating, that's based on this principle. The reason we can do carbon dating is because anything that has carbon in it, we know has Carbon 14 in it, and we know the half-life, and we can estimate the approximate age of whatever it is that has carbon as part of it.

The last group of radionuclides I wanted to talk about, they're called man-made. They call them man-made, because as the name implies, man made them. They're through human activities that we have them in nature. One example of that would be Cesium 137. Cesium 137 does not occur naturally in our environment. It's actually a by-product of nuclear fission.

And the Cesium 137 that we find in our environment are remnants of atmospheric testing of nuclear weapons in the 1950s and 1960s. Cesium 137 was part of that nuclear fallout, and now it has become part of our environment. Small amounts have become part of our environment.

We use this knowledge of how to produce new species of radioactive material actually to our benefit, too. Because many of the man-made radionuclides we produce today are intentional, because they have either applications in medicine, industry, or research.

Another man-made source of radiation I should mention is those that are machine-generated. They don't come from radioactive materials, they're machine-generated, and you all know about them: X-ray machines and CT scanners. In those machines, there's no radioactivity, but they use electricity to generate ionizing radiation. But once they generate it, those ionizing radiations have the same properties as the ionizing radiation that we get naturally from radioactive material. But the generation is through a different mechanism, and there's no radioactivity involved in there.

So now we're talking about lots of stuff, lots of radioactive material, lots of radiation coming from everywhere. So, the question is how much are we getting from all of these sources? What we call the amount of radiation is the dose. And we measure it in units of millisieverts. In the United States, an average person receives 3 millisieverts of radiation from natural sources, from the cosmic rays, the ground, the food and everything, 3 millisieverts.

Of that 3 millisieverts, two-thirds of it, on average, comes from radon. Radon is a radioactive gas that occurs naturally and has its origin actually to the uranium in the soil, the breakdown of uranium in soil. So, it's a naturally occurring radioactive material that is in the form of gas.

So, when I showed you earlier the balloon, this technically has radioactive materials in it, because I exhaled in it. When I blew the balloon, I exhaled, every time we breathe, we breathe in some radon. And then I exhaled, and some of those got trapped in the balloon. So technically we do have radioactive atoms here in the air that we breathe.

And of course, region to region, place to place, sometimes with radon home to home, there's variation, so we always have variation in the amount of radiation we get from natural environment. But on average we get 3 millisieverts of radiation from the environment, that's living on earth. On average we get another 3 millisieverts from medical procedures.

And a lot of us are getting X-ray exam or CT scans so forth. On average that contributes another 3 millisieverts. Thirty years ago, that was less than 1 millisievert, but now it's close to 3 millisieverts because the technology has advanced so we're using that technology more. So total, on average, 3 millisieverts from the environment and 3 millisieverts from medical exposures, that gives us 6 millisieverts average annual dose to a person in the United States. Individual doses can vary.

So many factors can influence your individual dose. If you smoke, the dose to your lung is actually quite significant, radiation dose, because of the radioactive material that's in tobacco. So, smoking increases your radiation dose to your lungs. If you live at high elevation, say Denver, Colorado, you get a higher dose from cosmic radiation than if you live near the coastline; so where you live makes a difference.

If you share a bed with someone, with your spouse or a partner, remember our bodies contain radioactive material, and we actually measure radiation coming out of our bodies. We irradiate all the time, so when you're sitting next to someone, also you're irradiating each other. So obviously those who share a bed, they get a little extra radiation dose just because they don't sleep alone.

So, these factors – now that's a small factor, but there are these other factors- smoking, high elevation, and also other activities that would increase your individual dose. In this chart you see some of the typical doses associated with some common activities, like air travel, chest X-rays, CT scans, in units of millisieverts, compared to what we get from our natural background. Now the frequency of these activities, like air travel, or medical procedure, would impact your total dose as an individual. So even though our average is about 6 millisieverts as individuals, your individual dose could vary and could be actually much higher in any given year.

Now, we talked about medical procedures and in the chart, I showed you doses from medical procedures. Now, this does not mean that we should avoid medical procedures, like CT scans, because they have a clear benefit for us. Doctors – the imaging studies provide valuable information to our doctors to make diagnoses, so that's a clear benefit to us. So, it's important to consider the risks and benefits of any procedure or activity that exposes us to ionizing radiation.