Introduction

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Hi and welcome to our this year‘s Radiation Protection Instruction
This course introduces radiation and radiation safety to people who work in environments where radiation is used.

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This courses is based on „Understanding Radiation Safety“, an English free Radiation Safety online course from the Radiation Safety Institute of Canada.
(Reference: https://radiationsafety.ca/online-courses/free-radiation-safety-online-course/)

Concerning figures and data specified in legal texts this course is adapted to our German conditions.

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It will be described what radiation is and how the types of radiation differ. Various ways of quantifying radiation will be discussed, equally how radiation affects the body, and we will see how that leads to setting radiation dose limits. Finally, we’ll talk about common radiation exposures.

Overview

- Use of Radiation in Germany

- Radiation and Energy
- Non-Ionizing (Low Energy) Radiation
- Ionizing Radiation
- Sources of Radiation
- Types of Ionizing Radiation
- How are X-Rays produced?
- Gamma Rays and X-Rays
- Radiation Penetration

- Acitivity
- Half-Life
- Radiation Dose
- Absorbed Dose
- Equivalent Dose
- Effective Dose

- Interaction with the Body
- Potentioal Risks
- Cancer Risk from Radiation
- Limit Values and Dose Values in Comparison
- Chronic Exposure
- Acute Exposure
- Acute Dose Effects

- Common Radiation Exposure

- Summary

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1 - Use of radiation in Germany

Between 1997 (beginning of the central collection of occupational doses in Germany) and 2020, the amount of monitored employees per year has grown by about 28 %.

About 420.000 Germans are monitored annually for workplace radiation exposure in 2020. From these workers 99.000 have been measurable exposed in Germany 2020.

This continues the trend of slightly increasing monitoring numbers observed over many years.

So let‘s see what radiation is.

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2- Radiation and Energy

Radiation is simply a form of energy. All matter, whether at rest or in motion, has energy.

With radiation, the energy can take the form of moving particles or bundles of pure energy. Either way, the important thing is that this energy can then be transferred to another material.

The type of radiation and its energy will affect how it interacts with matter.

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2 - Non-Ionizing (Low Energy) Radiation

Before going any further, note that in this course, we will only be discussing high energy radiation. Low energy radiation, also known as non-ionizing radiation, is radiation that is not energetic enough to knock electrons out of atoms. Examples of this type of radiation are radiowaves, microwaves, infrared light, and visible light. These types of radiation are all around us constantly.

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2 - Ionizing Radiation

To understand how radiation interacts with matter, let’s begin with what matter is actually made of. All matter is made up of atoms. Atoms in turn are made up of protons, neutrons and electrons. Protons and neutrons make up the nucleus of the atom, and the electrons orbit the nucleus. Most atoms around us have as many protons, which are positively charged, and electrons, which are negatively charged. The positive and negative charges balance each other out, so atoms are electrically neutral.

When radiation with high enough energy interacts with one of the orbiting electrons, it can transfer some or all of its energy to the electron, knocking it out of orbit. This leaves the atom with more positive charges than negative charges, resulting in a positively charged atom. The electron is now free and travels away from the atom. This process of knocking an electron out of orbit is called ionization. In other words, ionizing radiation is radiation which is energetic enough to break atoms apart.

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2 - Sources of Radiation

There are two sources of ionizing radiation: radioactive atoms and man-made devices (or sources). Most atoms in nature have a stable nucleus, in other words, a nucleus which will stay intact forever.

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Some atoms, though, have an unstable nucleus, one that will emit radiation, or energy, to try to become stable. Examples of naturally occurring radioactive atoms include uranium, radium, and radon. We can also create radioactive atoms for medical purposes such as Technetium-99m.

When a radioactive atom emits energy, it either becomes stable, or changes into another element that may also be radioactive.

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We can also build machines which produce ionizing radiation without the use of radioactive atoms. In this case, we are talking about X-ray units, these days we know computer tomographs or CT scanners.

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2 - Types of Ionizing Radiation

There are several types of ionizing radiation. Alpha particles, beta particles, and gamma-rays are all emitted from the nuclei of radioactive atoms.
Neutrons are liberated during the fission of large atoms like uranium, and X-rays are created by man-made devices.

All of these types of radiation have enough energy to knock electrons out of their orbit around the nucleus of the atom.

Let’s take a closer look at these different forms of radiation.

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Alpha radiation is a large particle made up of two protons and two neutrons. This means that it has a positive two charge. Because negative electrons are attracted to the two positive protons, alpha particles interact a lot with the matter around them, specifically with the electrons orbiting nearby atoms. During each one of these interactions, the alpha particle gives up some of its energy, ionizing the matter around it. Alpha particles, therefore, do not travel far, because they lose their kinetic energy quickly through the large amount of ionization they cause. A sheet of paper, or even the dead layer of skin on our body, have enough electrons in them to quickly absorb all of the alpha energy, effectively stopping alpha radiation from traveling any farther.

Beta particles are about 8000 times less massive than alpha particles and have an identical mass to electrons orbiting the nucleus. They also originate from the nucleus of a radioactive atom and can either have a positive charge or a negative one. Because they only possess half of the charge that alpha particles have, they will interact less than alpha particles with the matter around them.
Still, because they possess charge, they do interact with nearby electrons, ionizing matter and losing energy with every interaction.
Although beta radiation travels farther than alpha, it still doesn’t travel very far. It can penetrate our dead layer of skin and deposit energy in our “live” skin, but generally can’t penetrate further into the body. A shield made of plastic, glass, or aluminum contains enough electrons to absorb all beta radiation energy and stop it from traveling farther.

X-rays and gamma rays are examples of electromagnetic radiation, just like radiowaves, microwaves, infrared, visible, and UV light. They are all what we call photons or bundles of energy which travel through space at the speed of light. They are pure energy and do not have charge or mass.

The difference between X-rays and gamma rays is their origin—gamma rays are emitted from the nucleus of a radioactive atom, following alpha or beta radiation. X-rays are created when electrons hit a target.

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2 - How are X-rays Produced?

The first step in X-ray production is to accelerate electrons, by sending them through a voltage in an electrical circuit. The electrons gain a lot of energy, and then they are sent crashing into a target, typically often a piece of tungsten.

As the electrons quickly stop, their kinetic energy is lost and has to be dissipated. If the electrons are energetic enough when they crash into the material, the kinetic energy will be released as X-rays, which are emitted in all directions and are passing out of the tube through an exit window.

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2 - Gamma Rays and Xtab3-Rays

Like alpha and beta radiation, gamma rays and X-rays are forms of ionizing radiation. However, because gamma-rays and X-rays don’t have mass or charge, they don’t interact as easily with matter. They need to crash directly into an electron to knock it out of orbit.

Gamma-rays and X-rays can, therefore, theoretically travel forever in matter, until they directly interact with an electron. No amount of shielding will stop all gamma or X-ray radiation, but the more material that shields a photon beam, and the denser that shield is, the more the intensity of the beam will be reduced (the attenuation will increase), as more and more of the gamma rays or X-rays do directly crash into electrons.

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2 - Radiation Penetration

To summarize, shielding alpha radiation is very easy. A single piece of paper will stop all of the alpha particles.

Most beta particles will get past a piece of paper, but a thin sheet of aluminum for example will stop all of that radiation.

X-rays and gamma rays penetrate materials a lot easier, because they have no charge or mass. They might lose a bit of energy in aluminum, but thicker, denser materials, like lead, are needed to appreciably decrease the beam’s intensity.

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3 - Activity

The activity of a radioactive substance is the number of radioactive decays which occur per second.

The unit of activity is the becquerel (Bq), named after the person who discovered radioactivity, Henri Becquerel. A becquerel is simply one radioactive decay per second.

$$\mathbf{1\ Bq = 1\ s^{-1}}$$

(The old unit, still used in the United States, is the curie. 1 curie is equal to 37 billion becquerels.)

3 - Half-Life **SLIDE 17**

Another important property of a radioactive material is the half-life. The half-life is an indication of how long a substance remains radioactive. Specifically, it is the time required for half of the radioactive atoms in a material to have decayed or emitted radiation. After one half-life, the activity will have decreased by 50%. After two half-lives, it will be down to half of a half of the original activity, or 25%. This will continue until the material is basically no longer radioactive.

The half-life of the different radioactive substances can range from fractions of a second to billions of years.

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For example, the most common type of uranium has a half-life of 4.5 billion years. On the other hand, Technitium-99m for example, commonly used in hospitals, has a half-life of only 6 hours.

3 - Radiation Dose **SLIDE 19**

When we discuss radiation dose, we are looking to measure the amount of energy that is transferred from radiation to your body. Remember that when radiation interacts with electrons, it gives up all or some of its energy to the electrons and knocks them from their orbits. This is the transfer of energy that we are talking about when discussing radiation dose.

It's important to note that this transfer of energy is done immediately, as the radiation reaches your body, the tissue. Just like a physical punch, the energy is transferred only when there is contact between the more energetic object (the radiation) and the tissue. Once the radiation is gone, there is no more transfer of energy.

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3 - Absorbed Dose D

One measure of radiation dose is to simply measure the amount of energy transferred per unit mass of tissue.

This is called

Absorbed Dose D,

and is measured in gray, where 1 gray = 1 joule per kilogram.

One gray is a very large dose, so often we refer to milli-gray (1/1000th of a gray), or even micro-gray (1/1 millionth of a gray) when we measure radiation dose.

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3 - Equivalent Dose H

Different types of radiation produce different amounts of biological damage, however, for the same absorbed dose.

We therefore needed a different unit to take this into account.

The equivalent dose H is the Absorbed Dose D, in Gray, multiplied by a radiation weighting factor w_R, which indicates how biologically damaging that type of radiation is.

$$H = D \times w_R$$

The unit of Equivalent Dose H is the Sievert, or more commonly, in Radiation Protection practice, the millisievert, equal to one one-thousandth of a Sievert or the microsievert, equal to one-millionth of a Sievert.

$$1 \text{ Sievert} = 1\text{Sv} = 1\text{J/kg}$$

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Gamma, X-ray, and beta radiation all produce about the same amount of biological damage as they interact with tissues. Their radiation weighting factor is therefore set to 1. One unit of absorbed dose of internal alpha radiation, on the other hand, produces approximately 20 times more damage than the same amount of absorbed dose from gamma, x-ray, and beta radiation. In other words, 1 mGy of internal alpha radiation is as damaging as 20 mGy of gamma, beta, or X-ray radiation. The radiation weighting factor for alpha radiation is therefore 20.

Equivalent Dose H takes the biological damage into consideration, making 1 mSv of one type of radiation equivalent to 1 mSv of any of the other types of radiation.

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3 - Effective Dose E

Different body parts have different sensitivities to radiation.

Therefore, we need to add the Equivalent Doses H to all organs, each adjusted to account for the sensitivity of the organ to radiation. The Effective Dose E considers the different sensitivity of organs and tissues for stochastic radiation effects.

The Effective Dose E is the Equivalent Dose H multiplied by a tissue weighting factor w_T.

$$E = H \times w_T$$

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The weighting factors represent the relative contributions of the single organs and tissues to the total health detriment resulting from uniform irradiation of the whole body.

The Effective Dose E is sum of the the tissue-weighted Equivalent Doses in all specified organs and tissues of the body. It is weighted such that the sum of the tissue weighting factors is unity.

The unit of Effective Dose E is the Sievert, too, or more commonly, in Radiation Protection practice, the millisievert, equal to one one-thousandth of a Sievert or the microsievert, equal to one-millionth of a Sievert.

1 Sievert = 1Sv = 1J/kg

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Summary Effective Dose E:

So, Effective Dose E is a calculated value, measured in mSv, that takes 3 factors into account:

- **the Absorbed Dose D [Gy] to all organs of the body,**
- **the relative harm level of the radiation (radiation weighting factor $w_{R,}$), and**
- **the sensitivities of each organ to radiation (tissue weighting factor w_T).**

Effective Dose E represents the stochastic health risk to the whole body, which is the probability of cancer induction and genetic effects, of low levels of ionizing radiation. It takes into account the type of radiation and the nature of each organ or tissue being irradiated, and enables summation of organ doses due to varying levels and types of radiation, both internal and external, to produce an overall calculated effective dose.

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4 - Interaction with the Body

Radiation interacts with atoms in the human body in the same way as with any other atom by transferring its energy and ionizing the atom.

When radiation strikes living tissue, there are a number of possible outcomes. For one thing, there can be no effect at all. The radiation can, for example, ionize an atom which serves no crucial purpose in the body. Because we are made of more than a trillion trillion atoms, these types of events are very common.

On the other hand, radiation can also interact with more important atoms in our body, damaging certain cells. Our body has several layers of defence against this type of event. Primarily, the cells in our bodies have enzymes and proteins whose purpose it is to locate damage and repair it. Cell damage is therefore often not problematic at all. Our cells' secondary defence mechanism is to kill itself if it does not have the capacity to repair. We have trillions and trillions of cells in our body, so if a few die because of radiation, it is not a problem. Cells are dying naturally in our body continuously. This only becomes problematic when you are exposed to a very large amount of radiation over a short period of time, at which point a large number of cells will die at once, potentially leading to serious consequences such as illness, or, in very extreme cases, death.

Finally, there could be damage within the cell, specifically to the chromosomes, which hold genetic information—the instructions for the cell to function correctly. It is possible for the damage to the chromosome to be improperly repaired. This low probability event is called a mutation, which has in turn a certain chance of leading to cancer, several years in the future.

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4 - Potential Risks

The production of a radiation-induced mutation in a cell which leads to cancer is a probabilistic event. Radiation exposure increases the likelihood of developing cancer: the more you are exposed, the greater your chance of getting cancer.

But for any one individual, there is no way of saying if cancer will occur or not, no matter how much radiation to which that person is exposed. Probabilistic events are meaningless on an individual basis, but rather apply to a large number of people.

The most common risk factors for cancer include aging, tobacco, sun exposure, radiation exposure.

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4 - Cancer Risk from Radiation

Let’s look at what the increased risk of cancer from radiation exposure is. The International Commission on Radiological Protection (ICRP), an independent body which reviews all scientific literature on radiation and publishes standards and guidelines, estimates that the risk of developing a fatal cancer increases by 4% for every 1000 mSv of radiation exposure.

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4 - Limit Values and Dose Values in Comparison

These numbers are actually the ones used to set limits on the amount of occupational radiation exposure.

Taking the previous numbers into consideration, along with what might be considered an acceptable risk, limits are set for the amount of occupational exposure a worker is allowed to receive each year.

There are different limits for example for pregnant nuclear energy workers and for people who are under age.

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4 - Acute vs. Chronic Exposure

The types of effects we just discussed mostly come from chronic exposure to radiation, in other words, receiving small amounts of radiation over months or years. The main concern with these types of exposures is cancer.

Acute exposures, on the other hand, are exposures to high amounts of radiation within a short period of time. Though they are extremely uncommon, they can still occur in the event of an accident or if radiation safety procedures are not followed. The more immediate effects from acute exposure are deterministic, which again means that they will certainly happen above a radiation dose. Along with deterministic effect, acute exposures also increase a person’s risk of developing cancer.

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4 - Acute Dose Effects

Deterministic effects are not generally observed below an acute dose of 250 mGy.
Changes in the blood counts will be noticeable at a dose of 250 mGy. Higher doses will lead to more severe effects
At a dose of about 3000 mGy, or 3 Gy, half of the people will die if left untreated, and higher doses still will increase the odds of death and the speed at which the effects occur.

Doses to specific organs will also lead to acute effects. Damage to the skin and hair loss can occur at 3-5 Gy. Acute doses of 3.5-5 Gy specifically to the reproductive regions can result in sterility.

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5 - Radiation Exposure

An important thing to realize is that every one is exposed to radiation constantly. We live in a radioactive world! We are exposed to radiation from the Sun and from radioactive particles in soil, foods, and air. We call these sources of radiation the natural background radiation. This background radiation exposure gives Germans 2.1 mSv of radiation dose per year. Cosmic radiation, terrestrial radiation, and the radiation exposure we get from foods is unavoidable.

In addition to natural radioactivity, humans are also affected by radiation from medical and technical applications, especially from X-Ray diagnostics. The resulting average radiation exposure in Germany is about 1.9 mSv per year.

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Summary

Now, we are at the end of our Radiation Protection Course.

We learned:

- What radiation is
- How types of radiation differ
- How to quantify radiation
- How radiation affects the body
- How to determine radiation limits
- What are common radiation exposures

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I hope you have enjoyed this course.

And I would like to ask you to sign the attendance list, please!