Lecture 1. Introduction to Radiation

Given the general fear regarding radiation levels around Japan, this seems the perfect time to give a short introduction to this important topic. There is a lot of confusion regarding radiation and radiation poisoning and this article will try and break it down.

Radioactive decay

To start off with, here is a little recap of the physics that is important. Atoms can be thought of as made up of protons, electrons and neutrons. The type of element is determined by the number of protons. The number of protons in any element is fixed, but the number of neutrons is variable (within limits). When you get 2 atoms of an element, with a different number of neutrons, they are known as isotopes of that element. The number of neutrons affects the stability of the atom and for every naturally occurring atom, there is a optimal number (or range of numbers) of neutrons needed to keep the atom stable.

During fission reactions (the type of reactions in all commercial nuclear power stations), unstable isotopes of an element are created from the splitting of an atom. These unstable isotopes will eventually decay via one of various decay processes. Three of these processes are important for our discussion: alpha, beta and gamma decay.

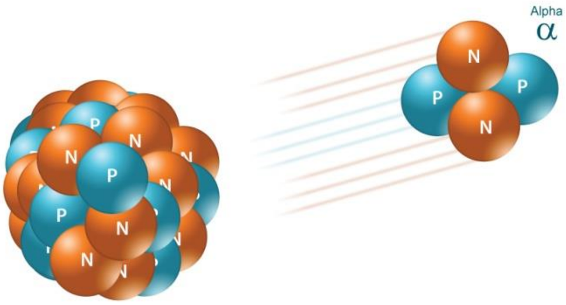
Lecture 2. Ionizing radiation: Ultraviolet radiation

Non-ionizing (or non-ionising) radiation refers to any type of electromagnetic radiation that does not carry enough energy per quantum (photon energy) to ionize atoms or molecules—that is, to completely remove an electron from an atom or molecule.[1] Instead of producing charged ions when passing through matter, the electromagnetic radiation has sufficient energy only for excitation, the movement of an electron to a higher energy state. Ionizing radiation which has a higher frequency and shorter wavelength than nonionizing radiation, has many uses but can be a health hazard; exposure to it can cause burns, radiation sickness, cancer and genetic damage. Using ionizing radiation requires elaborate radiological protection measures which in general are not required with nonionizing radiation.

The region at which radiation becomes considered as "ionizing" is not well defined, since different molecules and atoms ionize at different energies. The usual definitions have suggested that radiation with particle or photon energies less than 10 electronvolts (eV) be considered non-ionizing. Another suggested threshold is 33 electronvolts, which is the energy needed to ionize water molecules. The light from the Sun that reaches the earth is largely composed of non-ionizing radiation, since the ionizing far-ultraviolet rays have been filtered out by the gases in the atmosphere, particularly oxygen. The remaining ultraviolet radiation from the Sun is in the non-ionizing band, and causes molecular damage (for example, sunburn) by photochemical and free-radical-producing means that do not ionize.

Lecture 3. Gamma, alpha, beta and radiation

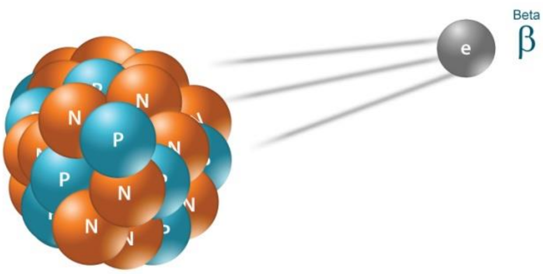
Alpha Radiation



Alpha radiation: The emission of an alpha particle from the nucleus of an atom

Alpha radiation occurs when an atom undergoes radioactive decay, giving off a particle (called an alpha particle) consisting of two protons and two neutrons (essentially the nucleus of a helium-4 atom), changing the originating atom to one of an element with an atomic number 2 less and atomic weight 4 less than it started with. Due to their charge and mass, alpha particles interact strongly with matter, and only travel a few centimeters in air. Alpha particles are unable to penetrate the outer layer of dead skin cells, but are capable, if an alpha emitting substance is ingested in food or air, of causing serious cell damage. Alexander Litvinenko is a famous example. He was poisoned by polonium-210, an alpha emitter, in his tea.

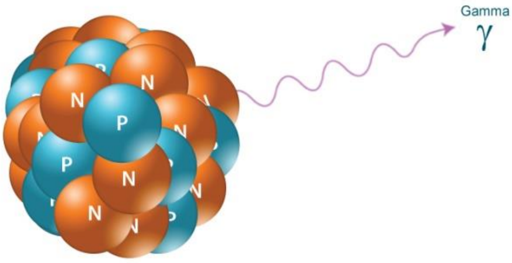
Beta Radiation



Beta radiation: The emission of a beta particle from the nucleus of an atom

Beta radiation takes the form of either an electron or a positron (a particle with the size and mass of an electron, but with a positive charge) being emitted from an atom. Due to the smaller mass, it is able to travel further in air, up to a few meters, and can be stopped by a thick piece of plastic, or even a stack of paper. It can penetrate skin a few centimeters, posing somewhat of an external health risk. However, the main threat is still primarily from internal emission from ingested material.

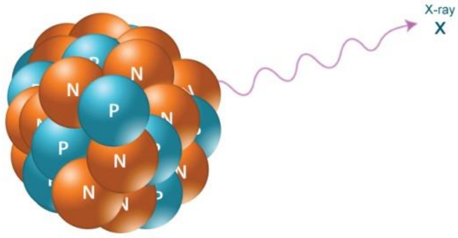
Gamma Radiation



Gamma radiation: The emission of an high-energy wave from the nucleus of an atom

Gamma radiation, unlike alpha or beta, does not consist of any particles, instead consisting of a photon of energy being emitted from an unstable nucleus. Having no mass or charge, gamma radiation can travel much farther through air than alpha or beta, losing (on average) half its energy for every 500 feet. Gamma waves can be stopped by a thick or dense enough layer material, with high atomic number materials such as lead or depleted uranium being the most effective form of shielding.

X-Rays



X-Rays: The emission of a high energy wave from the electron cloud of an atom

X-rays are similar to gamma radiation, with the primary difference being that they originate from the electron cloud. This is generally caused by energy changes in an electron, such as moving from a higher energy level to a lower one, causing the excess energy to be released. X-Rays are longer-wavelength and (usually) lower energy than gamma radiation, as well.

Lecture 4. Radioactivity in material

Naturally Occurring Radioactive Materials (NORM) and Technologically Enhanced Naturally Occurring Radioactive Materials (TENORM) consist of materials, usually industrial wastes or by-products enriched with radioactive elements found in the environment, such as uranium, thorium and potassium and any of their decay products, such as radium and radon.[1]

Natural radioactive elements are present in very low concentrations in earth's crust, and are brought to the surface through human activities such as oil and gas exploration or mining, and through natural processes like leakage of radon gas to the atmosphere or through dissolution in ground water. Another example of TENORM is coal ash produced from coal burning in power plants. If radioactivity is much higher than background level, handling TENORM may cause problems in many industries and transportation.

Lecture 5. Working with radiation

Anyone working with a radiation source should:

- Learn about and follow the rules and regulations for the use of radiation sources.
- Be aware of the responsibilities line leaders and academic supervisors have in terms of radiation protection. You should also familiarize yourself with the responsibilities of the central and local radiation protection coordinators.
- Inform the academic supervisor or the local radiation protection coordinator about alterations in the use of radiation sources (for instance new sources, damaged sources, new projects).
- Learn about the radiation source you are using.
- Go through specific information on the radiation source before you start using it
- Learn emergency procedures.
- Work so as to minimize the radiation activity and avoid risking yourself and others' health, safety and environment.
- Log your use of the source as per the requirements. For example, the use of non-ionizing sources should be noted in the log book kept next to the source.
- Test your workplace for contamination and, when the regulations specify it, yourself (for example after working with open or unshielded radioactive sources).

NTNU uses several types of radiation sources in non-medical research and teaching. All radiation sources and their uses have been approved by the Norwegian Radiation Protection Agency. Nevertheless, many of these radiation sources can potentially be harmful to people and equipment. The use and handling of radiation is regulated by laws, national and international standards, and NTNU's own radiation source regulations and guidelines.

Lecture 6. Risk control when we work

Health concerns #

Medical examinations #

You should have a medical examination if:

- You may have been exposed to an effective dose of more than 6 mSv/year.
- If the radiation you have received may correspond to an equivalent dose of more than 3/10 of the limit designated in § 31 in the regulation on radiation protection and the use of radiation.
- You have been exposed to artificial optical radiation exceeding the limit given in § 4-2 in the Regulations concerning Action and Limit values (also see § 16-7 in the regulations concerning the Performance of Work).
- You have an illness that stems from exposure to artificial optical radiation.
- The exposure to electromagnetic fields exceed the limit values given in § 4-3 in the Regulations concerning Action and Limit values.
- A risk assessment determines that your health is at risk.

The medical examination will determine if there are medical reasons hindering you from working with ionizing or non-ionizing radiation, or if special precautions should to be taken.

Pregnant employees #

If you are pregnant or are planning to become pregnant, you should inform your academic supervisor and your local radiation protection coordinator as soon as possible, so that the necessary precautions can be taken.

In some cases, pregnant employees will be given work without exposure to ionizing radiation. This means work that doesn't expose the foetus to a total dose of more than 1 mSv for the rest of the pregnancy.

After you find out you are pregnant, the dose to be received by the foetus for the rest of the pregnancy needs to be evaluated. The Norwegian radiation protection agency gives the following advice:

- If the dose is certain to be less than 1 mSv: the pregnant employee can continue her work without special precautions.
- If the dose is most probably less than 1 mSv: the pregnant employee can continue her work, but the amount of radiation could be reduced.
- If the dose is likely larger than 1 mSv: the pregnant employee should be given other work with smaller radiation doses, or without exposure to ionizing radiation at all.
- The dose to the foetus as measured with an RIA kit should be less than 1 mSv.

For a more detailed description of dose limits, see chapter 4.2: Dose limits in Guidelines on the use of radioactive sources in the laboratory (PDF in Norwegian) by the Norwegian radiation protection agency.

Lecture 7. Physical Forms of Radiation

As previously indicated, matter gives off energy (radiation) in two basic physical forms. One form of radiation is pure energy with no weight. This form of radiation — known as electromagnetic radiation — is like vibrating or pulsating rays or "waves" of electrical and magnetic energy. Familiar types of electromagnetic radiation include sunlight (cosmic radiation), x-rays, radar, and radio waves.

The other form of radiation — known as particle radiation — is tiny fast-moving particles that have both energy and mass (weight). This less-familiar form of radiation includes alpha particles, beta particles, and neutrons, as explained below.

Lecture 8. Nuclear Fission

In some elements, the nucleus can split as a result of absorbing an additional neutron, through a process called nuclear fission. Such elements are called fissile materials. One particularly notable fissile material is uranium-235. This is the isotope that is used as fuel in commercial nuclear power plants.
When a nucleus fissions, it causes three important events that result in the release of energy. Specifically, these events are the release of radiation, release of neutrons (usually two or three), and formation of two new nuclei

Lecture 9. Units of radiation intensity

In radiometry, radiant intensity is the radiant flux emitted, reflected, transmitted or received, per unit solid angle, and spectral intensity is the radiant intensity per unit frequency or wavelength, depending on whether the spectrum is taken as a function of frequency or of wavelength. These are directional quantities. The SI unit of radiant intensity is the watt per steradian (W/sr), while that of spectral intensity in frequency is the watt per steradian per hertz ($W \cdot sr^{-1} \cdot Hz^{-1}$) and that of spectral intensity in wavelength is the watt per steradian per metre ($W \cdot sr^{-1} \cdot m^{-1}$)—commonly the watt per steradian per nanometre ($W \cdot sr^{-1} \cdot nm^{-1}$). Radiant intensity is distinct from irradiance and radiant exitance, which are often called intensityin branches of physics other than radiometry. In radio-frequency engineering, radiant intensity is sometimes called radiation intensity.

Lecture 10. Radiation protectionRadiation protection, sometimes known as radiological protection, is defined by the International Atomic Energy Agency (IAEA) as "The protection of people from harmful effects of exposure to ionizing radiation, and the means for achieving this". The IAEA also states "The accepted understanding of the term radiation protection is restricted to protection of people. Suggestions to extend the definition to include the protection of non-human species or the protection of the environment are controversial".[1] Exposure can be from a radiation source external to the human body or due to an intake of radioactive material into the body.

Ionizing radiation is widely used in industry and medicine, and can present a significant health hazard by causing microscopic damage to living tissue. This can result in skin burns and radiation sickness at high exposures, known as "tissue" or "deterministic" effects (conventionally indicated by the gray), and statistically elevated risks of cancer at low exposures, known as "stochastic effects" (conventionally measured by the sievert).

Fundamental to radiation protection is the reduction of expected dose and the measurement of human dose uptake. For radiation protection and dosimetry assessment the International Committee on Radiation Protection (ICRP) and International Commission on Radiation Units and Measurements (ICRU) have published recommendations and data which is used to calculate the biological effects on the human body, and thereby advise dose uptake limits. Supporting this is a necessary range of radiation protection instruments to indicate radiation hazards, and dosimeters to measure dose; assisted by preventative techniques such as radiation shielding.

Lecture 11. Radiation Survey meters

Survey meters are portable radiation detection and measurement instruments used to check personnel, equipment and facilities for radioactive contamination, or to measure external or ambient ionizing radiation fields (to evaluate the direct exposure hazard). The hand-held survey meter is probably the most familiar radiation measuring device to society owing to its wide and highly visible use.

Lecture 12. Laboratory rules

These rules are designed to limit unnecessary radiation exposures and contamination of the facilities and equipment and to minimize the consequences of a radiation accident if it should occur. Copies of these rules will be posted in the appropriate laboratories.

Eating, drinking, & smoking	Eating, drinking and smoking are not permitted in laboratory areas where radionuclides in liquid form are being used or stored.
Wash hands	Wash hands after handling any radioactive material and before going about any other work. Always wash hands before leaving laboratory.
Pipetting	Never pipette anything by mouth.
Protective Clothing	Always use gloves when handling radioactive material. Lab coats should be worn in the laboratory and left in the laboratory.
Confine the activity	The spread of radioactive contamination may be minimized by working on the tray lined with absorbent material. Radioactive materials that are being transported should be transported in a closed lid secondary container which should resistant to impact and breakage.
Spills	Notify the DMPRS of all spills except those of a very minor nature (note: contamination surveys are required to be performed and documented after a minor spill).
Labeling	Label radioactive material with your name, date, radionuclide, and quantity of radionuclide.
Before leaving	Before leaving the laboratory, clean up and monitor your work area and yourself using appropriate radiation detection instrument. Remove lab coat and wash hands.
Disposal of Liquid Radiological Waste	Liquid radioactive waste should be stored in plastic bottles if possible. The radionuclide, quantity, and date of disposal must be recorded on the waste container. Small amounts of nontoxic wastes may be disposed of in the sanitary sewer as directed by the RSO.

Disposal of Solid Radiological Waste	Solid radioactive waste must be placed in plastic-lined containers. The radionuclide, quantity, and date of disposal must be recorded on the waste container.
Hoods	Hoods or glove boxes must be used when handling stock solutions of radioactive materials specified by the Radiation Safety Committee as being a potential internal safety (ingested, inhaled or absorbed) hazard.

Lecture 13. Emergency procedures

Emergency Procedures

Minor Spills

Less than 100 mL of liquid or less than 100 μCi.

1. Alert co-workers.
2. Wipe up spill placing items in the radioactive waste container.
3. Apply decontamination cleaner. Rub area clean.
4. Survey area for contamination with portable instrument and contamination swipes.
5. Continue steps 3 and 4 until the survey results are below contamination limits.
6. Document results on Daily Lab Survey Form.
7. If assistance is needed, contact Radiation Safety at 974-5580, or the UT Police Department at 974-3111.

Major Spills

Greater than 100 mL of liquid or greater than 100 μCi

1. Alert co-workers.
2. Contact the Radiation Safety Department at 974-5580 to clean the area.

Other Contamination

Radiation contamination on skin, clothing, or shoes

1. Do not leave the area.
2. Immediately contact the Radiation Safety Department at 974-5580 for assistance.
3. If unavailable, contact the UT Police Department

Lecture 14. Radioactive waste

Radioactive waste is waste that contains radioactive material. Radioactive waste is usually a by-product of nuclear power generation and other applications of nuclear fission or nuclear technology, such as research and medicine. Radioactive waste is hazardous to all forms of life and the environment, and is regulated by government agencies in order to protect human health and the environment.

Radioactivity naturally decays over time, so radioactive waste has to be isolated and confined in appropriate disposal facilities for a sufficient period until it no longer poses a threat. The time radioactive waste must be stored for depends on the type of waste and radioactive isotopes. Current approaches to managing radioactive waste have been segregation and storage for short-lived waste, near-surface disposal for low and some intermediate level waste, and deep burial or partitioning / transmutation for the high-level waste.

A summary of the amounts of radioactive waste and management approaches for most developed countries are presented and reviewed periodically as part of the International Atomic Energy Agency (IAEA) Joint Convention on the Safety of Spent Fuel Management and on the Safety of Radioactive Waste Management

Lecture 15. Sum of the Radiation

In physics, radiation is the emission or transmission of energy in the form of waves or particles through space or through a material medium.[1][2] This includes:

- electromagnetic radiation, such as radio waves, microwaves, visible light, x-rays, and gamma radiation (γ)
- particle radiation, such as alpha radiation (α), beta radiation (β), and neutron radiation (particles of non-zero rest energy)
- acoustic radiation, such as ultrasound, sound, and seismic waves (dependent on a physical transmission medium)
- gravitational radiation, radiation that takes the form of gravitational waves, or ripples in the curvature of spacetime.

Radiation is often categorized as either ionizing or non-ionizing depending on the energy of the radiated particles. Ionizing radiation carries more than 10 eV, which is enough to ionize atoms and molecules, and break chemical bonds. This is an important distinction due to the large difference in harmfulness to living organisms. A common source of ionizing radiation is radioactive materials that emit α, β, or γ radiation, consisting of helium nuclei, electrons or positrons, and photons, respectively. Other sources include X-rays from medical radiography examinations and muons, mesons, positrons, neutronsand other particles that constitute the secondary cosmic rays that are produced after primary cosmic rays interact with Earth's atmosphere.

Gamma rays, X-rays and the higher energy range of ultraviolet light constitute the ionizing part of the electromagnetic spectrum. The lower-energy, longer-wavelength part of the spectrum including visible light, infrared light, microwaves, and radio waves is non-ionizing; its main effect when interacting with tissue is heating. This type of radiation only damages cells if the intensity is high enough to cause excessive heating. Ultraviolet radiation has some features of both ionizing and non-ionizing radiation. While the part of the ultraviolet spectrum that penetrates the Earth's atmosphere is non-ionizing, this radiation does far more damage to many molecules in biological systems than can be accounted for by heating effects, sunburn being a well-known example. These properties derive from ultraviolet's power to alter chemical bonds, even without having quite enough energy to ionize atoms.

The word radiation arises from the phenomenon of waves radiating (i.e., traveling outward in all directions) from a source. This aspect leads to a system of measurements and physical units that are applicable to all types of radiation. Because such radiation expands as it passes through space, and as its energy is conserved (in vacuum). The intensity of all types of radiation from a point source follows an inverse-square law in relation to the distance from its source. Like any ideal law, the inverse-square law approximates a measured radiation intensity to the extent that the source approximates a geometric point.