Course: Radiation Protection

Lesson: The Biological Effects of Ionizing Radiation

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INTRODUCTION

Radiation has been and will continue to be a part of your life. However, your role as a worker in a nuclear power plant and the associated training has, in all probability, increased your awareness of this environmental factor and raised some questions. The intent of this lesson is to answer your questions about radiation and its potential hazards and to acquaint you will certain protection guidelines and thumb rules.

OBJECTIVES

TERMINAL OBJECTIVE

The Contractor Health Physics Technician will explain the methods of internal exposure dose assessment.

ENABLING OBJECTIVES

Upon successful completion of this lesson the Contractor Health Physics Technician will be able to:

- List the pathways of internal contamination.
- List the elimination routes for internal contamination.
- List the monitoring methods for assessing internal exposure.

- Recognize the relationship between effective half-life, radiological half-life, and biological half-life.

1.0 RADIATION - MATTER INTERACTIONS

It took mankind approximately 25,000 years to reach a level of knowledge and understanding that led to the discovery of the existence of radiation. Thomson noticed the first clues in 1897 while he was conducting experiments with electrical discharges in vacuum tubes. These tubes were known as Crookes tubes. A high voltage was applied across electrodes in the tubes. The resultant noted Thomson attributed fluorescence to high-speed negatively charged particles, that he called electrons. In 1895 Conrad Roentgen and the Madam and Pierre Curie discovered X-rays and radioactivity. Following Chadwick's discovery of the neutron in 1932, the development of a radiation technology was very rapid.

Radiation safety became a necessity in 1942 during the building of the first atomic pile or reactor at the University of Chicago. It became apparent that the fissioning of even a small amount of uranium would produce more radiation than had ever before been concentrated in one place. Although injuries had occurred from the misuse of radioactive material, the potential now existed to cause injury in a very short period of time. This was possible because the quantity and intensity of the radiation was now much greater.

If science was to protect man and the environment form the harmful effects of ionizing radiation, it seemed only logical to have people knowledgeable in the health sciences and the physical sciences do the job. This resulted in the formation of a entirely new profession Health Physics or what today is more correctly known as Radiation Protection.

Radiation is energy that is transmitted in the form of waves or particles. Radiation encountered in a nuclear power generally come from the nuclei of radioactive atoms. This is different from radiation (X-rays) produced in machines only in its place of origin and sometimes its frequency. Atoms that emit radiation are called radionuclides. The chart of the nuclides is used to determine which nuclides are radionuclides. Any nuclide in the chart of the nuclides that is not represented by an all gray box is a radionuclide.

For example, Figure RP-1-1 shows us that the hydrogen has three forms, called isotopes, H-1, H-2, and H-3. The first two isotopes, H-1 and H-2, have all-gray boxes, so they are stable (non-radioactive) isotopes. The third isotope, H-3, does not have an all gray box, so it is a radionuclide. Thus, H-3, which is called tritium, is the only isotope of hydrogen that is a radionuclide.

Radiation is emitted from the nucleus and from the electron shells. Radiation emitted from the nucleus includes:

* Alpha particles
* Beta particles
* Neutron particles
* Gamma waves

Radiation emitted from the electron shells includes:

* X-ray waves
* Visible light waves

1.1. PURPOSES OF RADIATION PROTECTION

The radiation protection department in commercial nuclear power facilities has four responsibilities:

- Protecting in-plant personnel from radiation hazards.
- Protecting the general public by ensuring that releases of radioactive materials will have no significant adverse effects.
- Protecting the environment from the radiation and radioactive materials in the plant.
- Ensuring compliance with appropriate radiation protection regulations.

To meet these responsibilities, a separate radiation protection group is normally set up in the plant. This group makes sure that all appropriate radiation protection precautions are taken. The radiation protection group is equipped with the instruments required to measure and evaluate radiation levels both inside and outside the plant. However, the major responsibility for radiation protection rests with each individual in the plant. Each individual is responsible for acquiring a thorough understanding of radiation and the techniques available for protecting himself from unnecessary exposure to radiation.

1.2. ALPHA AND BETA INTERACTIONS

In this section, we will discuss alpha and beta interactions with matter. Alpha particles consist of two protons and two neutrons generally emitted from the nucleus of heavier atoms such as U - 238. When the alpha is emitted, it has a plus two charge (because of the two protons and no electrons) and possesses kinetic energy. As the alpha radiation interacts with matter, it will lose its kinetic energy (giving the kinetic energy to the material). After losing the kinetic energy, the alpha particle will pick up two electrons and become an He-4 atom (2 protons and 2 neutrons and 2 electrons).

A beta particle is a high energy electron emitted from the nucleus. The beta is formed in the nucleus by a neutron becoming a proton and an electron. The electron formed is ejected from the nucleus with a certain amount of kinetic energy. This energetic electron is called a beta particle. The beta radiation will interact with matter, giving its kinetic energy to the matter with which it interacts. After losing its kinetic energy, the beta (electron) will normally fill an outer electron shell of some atom.

Alpha and beta radiation have several properties in common; both are charged particles, and possess kinetic energy.

Both alpha and beta radiation lose kinetic energy by interacting with matter. As we will see, this is how all radiation losses its kinetic energy. Both the alpha particles and the beta particles are charged, and this influences how they interact with matter. All charged particles interact with matter by scattering (sometimes called indirect ionization) and by direct ionization interactions.

The scattering or indirect ionization interaction occurs when a charged particle passes close to an atom and is repelled by the nucleus or by the electrons around the nucleus. An alpha, having a plus 2 charge, is repelled by the positively charge nucleus. The negatively charged electrons around the nucleus repel a beta, having a minus 1 charge.

When a scattering or indirect ionization interaction occurs, the electrons in the electron shell may be moved to higher energy levels or may be moved completely out of the electron shells surrounding the nucleus. In the case of an alpha particle passing close to an atom, the electrons (having negative charges) are attracted by the alpha (having a positive charge of 2).

As Figure RP-1-2 shows, this attraction results in energy being transferred to the electrons, causing electrons to move to higher energy levels or causing electrons to be completely pulled away from the electron shells.

If a electron is moved to higher energy level, it will eventually emit energy in the form of X-rays or visible light and move back to its normal energy level.

If an electron is moved completely out of the electron shells, as Figure RP-1-2 shows, there are two ions produced an electron (a charged particle) and the atom (a charged particle with a +1 charge). These two ions are called an ion pair, and the process of producing ions is called ionization. In the scattering interaction, the alpha produces ionization indirectly. In other words, the ionization was not produced by a direct collision between the electron and the alpha particle.

A beta particle passing close to an atom can result in the same indirect effects produced by the alpha (Figure RP-1-2). however, a beta achieves this effect by repelling (pushing) the electrons to higher energy levels or completely out of the electron shells. Both the alpha and the beta can directly cause ionization by colliding with an electron, thus knocking the electron out of the electron shells. This will cause an ion pair to be formed. In both the indirect ionization (scattering) and direct ionization interactions, the alpha or beta loses energy. The material that the alpha or beta interacts with absorbs the energy and is, therefore, also affected.

An example of the effect of alpha or beta interactions is the effect on cells within the body. Cells contain molecules made up of atoms that share electrons. If an alpha or beta causes ionization by interacting with the shared electrons, the result may be the formation of ions or other agents that could destroy the cell. In addition, these ions can recombine, producing molecules entirely different from the original molecule. The different molecules can alter the proper functioning process of the cell.

1.3. PHOTON INTERACTIONS

A photon is radiation in the form of wave, such as a gamma, X-ray, or visible light. The methods of photon interaction with matter first explained by Einstein. He indicated that the type of interaction depended to a great extent on the energy of the photon. Based on Einstein's thoughts, it has been determined that there are three basic methods of photon interaction with matter:

- Pair production predominant with high energy photons.
- Compton scattering predominant with mid energy range photons.
- Photoelectric effect predominant with low energy range photons.

Pair production is the predominant method of interaction for high energy photons. As Figure RP-1-3 indicates, if the energy of a gamma photon is high enough (it must be at least 1.02 Mev), the photon can interact in the strong electromagnetic field near the nucleus.

In this interaction, the gamma disappears, and the energy s actually converted into mass. Two particles are formed an electron and a positron. (A positron is a particle with the same mass as an electron, but with a single positive charge.) The incoming gamma must have at least 1.02 Mev energy, because the mass of an electron and positron is equivalent to 1.02 Mev.

If the gamma has energy greater than 1.02 Mev, the extra energy will be given to the electron and the positron in the form of kinetic energy. Because both of these particles have kinetic energy (if the original gamma photon was greater than 1.02 Mev), they interact with atoms (much as beta and alpha particles do) to produce ionization. Eventually the positron interacts with an electron, the positron - electron pair disappears, and two 0.51 Mev photons are known as annihilation radiation. If the electron and the positron have excess kinetic energy when the annihilation reaction occurs, more energetic photos will be given off in the reaction. Therefore, the eventual result of the pair production reaction is that a high energy photon is broken down into lower energy photons that can undergo other types of reactions.

Compton scattering is the predominant method of interaction for mid-energy range photons. As Figure RP-1-4 indicates, in Compton scattering a medium energy gamma interacts with an orbiting electron near the nucleus imparting some of its energy to the electron. When this occurs, the electron that absorbs the energy leaves the atom to form an ion pair, and, because it has a significant amount of kinetic energy, produces ionization the same as a beta particle does. In addition, because the energy of the original gamma photon was not all absorbed the lower energy photon continues on to cause other interactions. Therefore, the eventual result of a Compton scattering reaction is that a mid energy range photon results in the production of an ion pair, and the photon continues at a reduced energy to undergo another interaction.

The photoelectric effect is the predominant method of interaction for low energy range photons. As Figure RP-1-4 indicates, the photoelectric effect, a low energy photon strikes an electron. If the photon has the same energy as the binding energy of the electron (the energy that holds the electron in its orbit), the photon will give all its energy to the electron and disappear. The electron is knocked out of the electron shells, forming an ion pair. Therefore, in the photoelectric effect reaction, the photon disappears and an ion pair is formed. (The photoelectric effect is applied in light meters used in photography.)

Not all types of photons can undergo all three types of photon interactions. For example, visible light is a photon, but it does not have enough energy to cause a pair production interaction. Table 1 lists the three types of photon interaction and the types of photons that can undergo each reaction.

Table 1 - Photon Interactions

Type	Energy	Photon
Pair Production	High-Energy	Gamma
Compton Scattering	Mid- Energy	Gamma X-ray
Photoelectric Effect	Low Energy	Gamma X-ray

		Visible light

It should be noted that a photon can cause ionization in the Compton scattering and photoelectric effect interactions. However, because a photon is not a charged particle, it cannot cause ionization by attracting or repelling electrons out of the atom. For this reason, photons do not cause as large an amount of ionization as an alpha or beta particle.

1.4. NEUTRON INTERACTIONS

Neutrons, like photons, possess no charge. For this reason, neutrons cannot produce ions by attracting or repelling electrons out of the electron shells. Therefore, neutrons, like photons, do not cause as much ionization as charged particles such as alpha particles, beta particles or free protons. However, as we will see, neutrons can cause ionization in other ways.

There are four basic neutron interactions:

* Elastic scattering
* Inelastic scattering
* Fission
* Capture

These four basic interactions can be categorized into scattering interactions and absorption interactions.

The two types of scattering interactions are elastic and inelastic scattering. In the elastic scattering interaction (Figure RP-1-5), a neutron collides with the nucleus of an atom, and the neutron and the atom rebound. In the elastic scattering interaction, the kinetic energy and the momentum of the incoming neutron are equal to the sum of the kinetic energy and the momentum of the rebounding neutron and the atom. In other words, kinetic energy and momentum are conserved, and the rebounding atom is not in an excited state. The elastic scattering interaction is often called a billiard ball reaction. In a collision between billiard balls, the kinetic energy and the momentum of the incoming ball equal to the kinetic energy and the momentum of the two balls after the collision.

Elastic scattering is the primary interaction that causes high energy neutrons to slow down so that they may more readily cause fissions. If a neutron collides with a light atom, such as an H-1 atom, the neutron, at times, may lose all of its energy, causing the H-1 atom to rebound with an energy equal to the energy possessed by the incoming neutron (Figure RP-1-6 part a). This collision may result in the H-1 nucleus (free proton) producing ions in the surrounding material. If, however, a neutron collides with the nucleus of a large atom in an elastic scattering reaction, the neutron can rebound with almost the same amount of energy it previously had (Figure RP-1-6). This is similar to a ping-pong ball colliding with a bowling ball. The bowling ball will not move, and the ping-pong ball will bounce off with the same amount of energy it had before the collision.

Therefore, to slow neutrons down effectively, a light material, such as hydrogen, must be used. This is one of the reasons that water is used in the reactor.

In the inelastic scattering interaction (Figure RP-1-6), a neutron collides with a nucleus of an atom (Figure RP-1-7) and is momentarily absorbed. Some of the energy of the neutron is given to the nucleus causing it to be excited. A reduced energy neutron is emitted and the excited nucleus gives off energy, such as a gamma ray, and returns to its ground (unexcited) state. Unlike the elastic scattering interaction, kinetic energy is not conserved. Some kinetic energy is converted to excitation energy.

The two absorption interactions are fission and capture. The fission interaction is the absorption of a neutron in the splitting or fissioning of the nucleus and a release of energy.

Capture, as the name implies, is the absorption of a neutron by the nucleus. This absorption can, at times, result in the production of a radioactive nuclide that will emit radiation. This process is called activation. As an example, the stable nuclide Co - 59 can absorb a neutron and become Co - 60, which is a radioactive nuclide.

We have seen that there are two ways in which alpha radiation interacts, two ways in which beta radiation interacts, three ways in which gamma radiation interacts and four ways in which neutron radiation interacts with matter.

2.0 IONIZING RADIATION'S BIOLOGICAL EFFECTS

On November 6, 1895, Conrad Roentgen discovered an invisible radiation that he names the X-ray. He made this discovery while performing experiments concerning the conduction of electricity through gases in vacuum tubes. The development of a radiation technology was to follow in rapid succession. In January of 1896, the first X-ray picture was taken of the hand of a colleague of Roentgen. In February of 1896, a Professor Pupin of Columbia University used X-rays for the first medical diagnosis. Naturally Becquerel and Pierre and Madame Curie discovered occurring radioactivity shortly thereafter. These three shared the 1903 Nobel prize in Physics for their discovery.

Much popular and scientific excitement was aroused by these early discoveries, but it soon became apparent that radiation was hazardous. An early experiment to ascertain just how hazardous the radiation exposure could be was conducted at the Vanderbilt physics department in March of 1896 by Professor John Daniel on Professor Dudley, a volunteer.

The problem was that the professors wanted to X-ray the brain of a 5-year-old child, but they did not know what the effect of such an exposure would be. Dudley volunteered to be exposed first so a determination of effect could be made. Daniel used a Ruhmkorff coil and an old Crookes tube, with a metal diaphragm containing a 1-in. hole. Dudley had a metal coin and a photographic plate tied to one side of his head; the Crookes tube, with its 1-in. hole, placed 0.5 in. from the other side of his head, was operated for 1 hour! Once developed, the plate showed no image of the coin, indicating the radiation has not penetrated through Dudley's skull, but 21 days after the exposure, Dudley's hair all fell out in a 2-in. circle where the skin had been exposed to the radiation. No untoward effects on Dudley had been noted earlier, and it is not clear that there were further physiological effects. Fortunately for Dudley, the radiation was evidently weak, because there was no effect on the photographic plate. There is apparently no succeeding publication on this matter, although Dudley's bibliography lists the physiological effects of X-rays as one of his scientific activities.

One of the suggested results of this experiment was the possibility that X-ray radiation could be used as a substitute for shaving!

Some other early noted effects included epilation or hair loss, erythema or reddening of the skin and in 1907, death. Seven deaths were reported in 1907 due to the improper use of X-rays. These circumstances led to the first organized efforts to limit radiation dose in 1920, and from 1929 to 1946 the National Council on Radiation Protection and Measurement (NCRP) and the International Commission of Radiation Protection (ICRP) started publishing dose limits based on tolerance level. Radiation injuries soon started to decrease.

In 1942 the Atomic Energy Program was started and the possibility of radiation injury increased due to increased intensity of new radioactive sources. By 1950, the ICRP had recommended a dose limit of 0.3 R per week.

There were many problems involving the improper use of radioactive materials in the early years of radiation technology. Included in these were the 1924 radium dial painter scandal and from 1928 to 1932 the radium poisoning scandal involving a Mr. Byers of Pittsburg. He was a prominent and wealthy industrialist who drank radium tonic called Radithor. A study at Massachusetts Institute of Technology (MIT) 33 years later showed that he retained 6 µCi of 226Ra. It was estimated that his total intake of radioactive material amounted to 500 µCi of 226Ra. and 500 µCi of 228Ra. As late as 1936 products such as face cream and contraceptive jelly still contained 226Ra!

The previous discussion has shown that radiation can originate from a variety of sources and occurs in a number of forms. Heat, as an example, is a form of radiation that can be felt and light is a form that can be seen. Radiation can come from the food we eat, the soil around us, or the building materials used to build our homes. It is very difficult to say if we suffer any biological damage from the naturally occurring radiation that has surrounded us since we arrived on the earth. If there is any damage, it does appear to be very slight, so slight as to be almost undetectable. The cells in your body are constantly being replaced, slight damage would not be noticed.

If we expose ourselves to the sun in an attempt to develop a nice suntan, we do so over a period of time and the skin is not permanently harmed. But, if we attempt to get the same suntan in a very short period of time, the result may be a very severe sunburn and possible lasting damage to the skin. This is similar to what happens to a person who is overexposed to nuclear radiation. The damage is so rapid that the body just doesn't have time to "catch up" and repair itself. If the damage is severe enough, the result could be fatal.

In radiation protection we are most concerned with the radiation emitted from radioactive atoms when they undergo a nuclear decay. Neutron radiation, a radiation primarily concerned with the fission reaction, is a special concern, although not one frequently encountered. We have seen that the radiation we are concerned with are either a particle or wave type of radiation. We also know that radiation interacts with matter through which it passes primarily by giving up kinetic energy. These interactions can result in biological damage if enough take place in a single cell.

We have learned how radiation interacts with the material through which it passes. These interactions are very important in radiation protection for two reasons; these interactions can cause biological damage and they allow us to measure the amount of radiation present.

Alpha and beta reactions are the same, direct and indirect ionization. The gamma photon interactions are photoelectric effect, Compton scattering and pair production. Elastic and inelastic scattering, fission and capture are the four neutron interactions.

Radiation does interact with the matter through which it passes and if the material happens to be human cells, the radiation could damage those cells. This section will explore the ways in which radiation causes damage to cells. There are two ways in which cells can be damaged by radiation, directly and indirectly.

2.1 DIRECT CELL DAMAGE

The cells of the human body generally consist of an outer cell membrane, an intercellular fluid, a nuclear membrane surrounding the nucleus and small bodies within the nucleus called genes. The genes are made up of a material called DNA (deoxyribonucleic acid). Every cell in the body has this central core. It is responsible of control of the cell and replication. These responsibilities make the DNA extremely important to cell life and life of the whole organism. If radiation interacts with the DNA molecules it can cause the molecules to separate. In this case the radiation has directly affected the cell. If the cell can repair the damage, it may survive. If it can't it will die. Since the damage was directly caused, the affect is called Direct Cellular Damage.

2.2 INDIRECT CELL DAMAGE

A second type of cell damage in indirect cellular damage which occurs when radiation strikes the cytoplasm surrounding the nucleus rather then the nucleus itself. The cytoplasm is compose primarily of water and is the intercellular fluid described in the previous section. When radiation interacts with a water molecule, certain free radicals can be formed. The free radicals are chemically reactive, and they can cause the cell to become chemically imbalanced; the result is cell damage. The effect is caused indirectly, the chemical changes brought about by the formation of the free radicals are what ultimately cause the cell damage. If the damage is so great that the cell cannot repair itself, the result is the same as in direct cell damage, the cell dies.

2.3 RADIOSENSITIVITY OF CELLS

Look at your hand. The skin is made up of a certain type of cell, the finger nails another type and the muscles in your hand still another type. In fact, the human body is made up of many different types of cells including muscle, nerve, blood, and bone cells. Each of these cells responds to radiation in a different manner. This relative response to radiation exposure is called radiosensitivity. It follows that cells that are highly radiosensitive are easily damaged by radiation and cells that are less radiosensitive are more difficult to damage with radiation.

What makes a cell more or less radiosensitive? One factor is the function of the cell. If a cell has only one function, it is very specialized and is less radiosensitive. Nerve cells, as an example, are among the least radiosensitive cells in the body because of their singular function. The reproduction capacity of the cell also affects it's radiosensitivity. If a cell is multiplying rapidly, it is more radiosensitive than a cell that is not multiplying. The important factor affecting cell radiosensitivity is it rate of replication.

In the late eighteen hundreds and early nineteen hundreds, two French scientists, Bergionne and Tribondeau conducted experiments exploring the radiosensitivity of cells.

They found that cell radiosensitivity varied indirectly as the degree of differentiation and directly as the rate of multiplication. This has become known as the Law of Bergionne and Tribondeau.

Table 2 lists some common adult body cells and/or tissues in decreasing order of radiosensitivity. Cells in the lymphoid tissue are the most radiosensitive, so they are at the top of the list. Cells that make up bones, muscles, and nerves are the least radiosensitive, so they are at the bottom.

Table 2 - Radiosensitivity of Adult Body Cells and Tissues

Lymphoid tissue, particularly lymphocytes (most radiosensitive)
Immature blood cells found in bone marrow
Cells lining gastro-intestinal canal
Cells of the gonads-testes more sensitive than ovaries
Skin, particularly the portion around hair follicles
Lining of blood vessels
Lining of liver and adrenal glands
Other tissues - including bone, muscle and nerves, in that order (least radiosensitive)

Note: This table applies to adult body cells only and specifically does not apply a cells of the developing fetus (unborn child). Immature nerve cells of the developing fetus are in fact among the most radiosensitive cells. Established exposure limits for pregnant females take this into account.

2.4 ACUTE WHOLE-BODY EXPOSURE

When discussing biological effects of radiation exposure, there are two symptom complex responses to the exposure. The first is an "acute" exposure effect and the second is a "chronic" exposure effect.

Acute exposure effects appear when a person is exposed to large amount of radiation in a short period of time. It is possible for the acute effects to be limited to a certain areas of the body. Exposure to hand results in effects to the hand only, the whole body is not necessarily affected.

When radiation dose is discussed some units of measure are required. In this case the unit is the Rem or in most cases the unit is the millirem (m/R) or 1/1000th. of a Rem. (Units of exposure and dose will be discussed in further detail in a later lesson). The dose ranges we are concerned with and the effects that occur are shown in Table 3. When studying this table you should remember that the magnitude of the dose required to cause any of the listed effects is many times more than what is routinely allowed by the Nuclear Regulatory Commission.

Looking at the table, you see two key words, injury and disability. Injuries are temporary effects and disabilities are permanent effects.

Table 3 - Biological Effects of Radiation from Acute Doses

Dose(Rem)	Probable Effects

0 - 100	No injury
	No disability
100 - 200	Injury - nausea, vomiting, diarrhea, hair loss, skin reddening
	No disability
200 - 300	Injury - same as above, plus internal bleeding
	Disability - blood disorders and some deaths
Above 300	Severe injury - same as above, except more severe
	Disability - severe blood disorders and more deaths.

We see that in the 0 - 100 Rem exposure range there is no injury and no disability. In the 100 - 200 Rem range, we see that there is some injury including nausea, vomiting, diarrhea, hair loss, and at the higher end of the exposure range, reddening of the skin. Because there may be some long-lasting blood effects there is the possibility of a disability. The likelihood of death resulting from an exposure in this range is extremely unlikely, but you should know that as the dose gets larger the effects get more severe. The symptoms that we discuss will appear more rapidly as the dose gets larger.

Looking at the table again, we see that a dose in the range of 200 - 300 Rem will likely result in injury and disability. The injuries will include all those explained for the 100 - 200 Rem range but they will be more severe and appear more rapidly. As the dose increases, the probability of death increases.

Above an exposure of approximately 300 Rem, severe injury and severe disability re very likely. The short term effects are again the same as those for an exposure in the 100 - 200 Rem range, but they appear sooner.

There are two exposure values that are important. The first is 400 Rem and the second is 600 Rem. A lethal dose (LD) is an amount of radiation exposure that will be fatal. 400 Rem would be a lethal dose to 50% of those exposed within 30 days and 600 Rem would be a lethal dose to 100% of the population exposed within 30 days. Both of these values assume no medical attention. These values are specified as LD 50/30 and LD 100/30.

All of the values we have discussed are general in nature. This means that a particular response may occur for some of the individuals exposed. It does not hold true that all of the people exposed to 600 Rem will die. The individual's state of health has a great deal to do with what the response to the exposure will be. If you are in better overall health than I, you may survive the 600 Rem exposure and I may not. Generally these values were determined with animal experiments. Very few humans have ever been exposed to the very large doses required to show an acute exposure effect.

2.5 RADIATION SYNDROME

There is a pattern of physiological response through which the human body passes after exposure to an acute whole body dose. This response is called the Radiation Syndrome. There are four stages to the Radiation Syndrome, they are:

* Initial illness
* Apparent recovery

* True illness

* Death or recovery

As was discussed earlier, the larger the dose the sooner the onset of the physiological response and the shorter the duration in any particular stage.

Table 4 is a summary of the expected response to various amounts of radiation exposure. If, for instance, a person were to receive an exposure to 200 Rem, the first stage lasts several days. The victim will likely suffer nausea, vomiting ad diarrhea. The second stage lasts about a week and a half. At this time the patient appears to recover and may in fact be symptom fee. This is the latent stage. The third stage will show effects starting between week two and three, a loss of appetite and a general feeling of lethargy will occur. There may be minor hemorrhage, purpura (purple patches under the skin, caused by hemorrhage), pallor, diarrhea, and moderate emaciation. The victim is truly ill at this stage. The fourth stage is the death or recovery stage. With an exposure of 200 Rem, recovery would be expected within approximately 3 months. Exposure of this magnitude is potentially disabling, in this case the disability could be manifested as long term blood effects, such as leukemia.

Table 4	**Symptoms of Radiation Syndrome [3]**		
Time After Exposure	**Survival Improbable (700 Rem or More)**	**[3] Survival Possible (550 rem-300 Rem)**	**Survival Probable (250 rem-100 Rem)**
	Nausea, vomiting and diarrhea in first few hours	Nausea, vomiting and diarrhea in first few hours	Possibly nausea, and vomiting diarrhea on first day
1st Week	No definite symptoms in some cases (latent period)		
	Diarrhea Hemorrhage Purpura Inflammation of mouth and throat	No definite symptoms (latent period)	No definite symptoms (latent period)
2nd Week	Fever Rapid emaciation	Epilation, loss of appetite and general malice	
	Death (mortality probably 100%	Fever	
		Hemorrhage Purpura Petechiae Nosebleeds	Epilation Loss of appetite and malaise Sore throat

3rd Week		Pallor Inflammation of the mouth and throat Diarrhea Emaciation	Hemorrhage Purpura Petechiae Pallor Diarrhea Moderate emaciation
4th Week		Death in most Serious cases (mortality 50% for 400 Rem)	Recovery likely in about 3 months unless complicated by poor health or infection, etc.

Let's suppose, for a second example, that a person is exposed to a whole body dose of 1000 Rem. We already know that the response to the exposure will be more rapid and the effects will be more severe. Remember, these effects assume no medical intervention. As a matter of fact, a whole body dose of 1000 Rem is used in leukemia therapy to kill the bone marrow (that is producing cancerous cells) so that the patient may be given a bone marrow transplant. But, with this type of therapy, the patient is under full medical attention so recovery could be expected. With a 1000 Rem exposure the initial illness stage will be extremely short, response will start within 1 hour and last up to several days. Because of the magnitude of the exposure, we would expect this individual to die within 30 days (without medical intervention). The symptoms are the same for as the first stage response for the 200 Rem exposure, but more severe. The second stage, the apparent recovery stage, will be very short and the patient will progress to the third stage, true illness, very rapidly. This stage includes hair loss, reddening of the skin (both symptoms are noted during radiotherapy for leukemia), and internal bleeding. The person will be subject to infection due to the massive loss of white blood cells (the cells in the body that fight infection) and will probably die within 30 days, if not sooner.

Both of these examples are extreme and exposures in between these values will show responses that are in between the ones discussed.

2.6 CHRONIC WHOLE BODY DOSE

Unlike an acute dose, a chronic whole body dose is caused by exposure being received in relatively small amounts over a long period of time. An excellent example of chronic exposure is the exposure received by a radiation worker in a nuclear power station. This individual would be expected to receive exposure in the range of 10 - 40 millirem per month for possibly many years. This is a chronic exposure and the effects of this exposure are markedly different from that experienced by the acutely exposed individual. We may conveniently relate the different effects to that you experience when you sun bathe. If you stay out in the sun for many hours the first sunny day of the summer, you very well may experience an acute effect-sunburn. However, if you space out your exposure to the sun over a few weeks or longer, you will experience a chronic effect - a very nice suntan.

An acute exposure is much more damaging than a chronic exposure. In fact, radiation exposure limits are set by the federal government to assure that the chronic exposure received will in fact show no effects within the worker's lifetime.

This is not to say that there are no harmful effects from a chronic exposure. Chronic radiation exposure effects are long term effects. The most serious long term effects are a possibly of increased risk of cancer, possible genetic mutations, and possibly shortened life span.

The amount of radiation exposure required to elicit long term effects is much higher than the dose you would receive while working in a nuclear power station, but there is disagreement as to how much higher. There are two theories as to the dose response effect. These theories are called the linear dose effect theory and the threshold dose effect theory.

2.7 LINEAR/THRESHOLD DOSE EFFECT THEORY

As the title indicates, the linear dose effect theory states that there is a linear relationship between the exposure received and the effects of that exposure. This theory also proposes that for even very small amounts of radiation exposure, there is some effect. If we consider that we have been exposed to radiation since man was on this earth, this theory may or may not be valid. We do know that the upper end of the curve shown in Figure RP-1-8 is probably correct. This is because we have seen in animal experiments that the response to very high levels of radiation does have a linear

or near linear effect. The graph shows Biological Effects on one axis and Cumulative Dose on the other axis. Scientists who believe in the linear dose effect theory use both the human data and the animal data to support their contention that for any dose, there is some effect. The straight line of the graph illustrates this.

The second theory, the threshold theory says that below a certain dose there is essentially no effect. Hence, this is called a threshold. If we again consider the exposure we have received since we arrived on this earth, it is questionable whether it has had an effect on us or not. This exposure comes from cosmic radiation, naturally occurring radioactive materials in the earth and naturally occurring radioactive material in the food we eat and the air we breathe.

3.0 EFFECTS OF CONTAMINATION

In the last chapter, we discussed radiation and its effects on the body. You know that radiation is emitted from radioactive material and you are aware that there is radioactive material in your plant in the reactor, in pipes, and in tanks. This radioactive material is located where we want it to be, and, as long as we keep it where it should be, we can make sure that it doesn't cause any significant damage.

When radioactive material is someplace where we do not want it, we give it a special name “contamination”. Contamination is radioactive material where we do not want it. For example, if some radioactive material leaked from a valve onto the floor of the plant, it would be called contamination. We do not want radioactive material on the floor where it could be tracked all over the plant. Similarly, we do not want radioactive dust in the air where we might breathe it into our lungs.

Contamination enters the body, it is that much closer to the vital organs. The ingested contamination continues to emit radiation and, because the radiation is being emitted inside the body, skin or muscles do not shield the vital organs. Contamination that has gotten inside the body may be very difficult to remove. This means that radiation could be emitted inside the body for an extended period of time. The body does not take special steps to rid itself of contamination, because it does not know the difference between radioactive nuclides and non-radioactive nuclides. For example, when iodine is taken into the body, some of it is sent to the thyroid. If the iodine is radioactive iodine - 131, the body still sends it to the thyroid. In the thyroid, the radioactive iodine would continue to emit radiation, which, as we know, can damage cells.

The most obvious way for contamination to enter the body is through the mouth. That is why there are signs in the plant that warn you not to eat, drink, or smoke in contaminated areas. Your nose may be another entrance into the body for contamination. Contamination in the air may be breathed in through the nose to the lungs. A cut in your skin is another way that contamination can enter the body. Some contamination can get into your body right through the pores of your skin. One radionuclide that does this is tritium, the radioactive isotope of hydrogen. This is why we have to were air-supplied suits when we are in areas where high levels of tritium are present.

As we have said, once contamination gets inside the body, it continues to emit radiation. But this process does not last forever; radionuclides decay and, as each atom decays, it changes into another nuclide. Eventually, the decay process will cause the radioactive material to disappear. You can use the Chart of the Nuclides to get an idea of how fast any radionuclide will decay by looking up the radiological half-life of the radionuclide on the chart. The radiological half-life (TR), of course, is the time required for half of the radioactive atoms to decay.

The body also rids itself of contaminated material through normal body functions. We can get idea of how long this would take by looking at the biological half-life of the radionuclide involved. The biological half-life (TB) is defined, as the time required for the body to eliminate half of the atoms through normal bodily functions. Every nuclide has a radiological half-life and a biological half-life. These values can be found in references in the plant.

Methods used to assess the internal exposure of the individuals include the collection of the forementioned bodily functions for counting purposed. The collection and counting of these specimens are called bioassays. Another method of determining the amount of a radionuclide deposited in an individual or group of individuals is in

vivo or whole body counting. In this method, liquid or solid crystal scintillation detectors count an individual’s whole body. Also, if a particular organ or part of the body was of concern, a partial body in

vivo counter may be utilized to determine the organ or body burden.

Because the processes of radioactive decay and biological elimination are going on at the same time, neither the radiological half-life nor the biological half-life will be a true measure of the actual half-life of a radionuclide inside the body. The actual half-life would be a combination of the radiological half-life and the biological half-life. This combined half-life is called the effective half-life. The effective half-life (TEFF) is defined as the time required for half of the radioactive atoms to be removed from the body by a combination of decay and body elimination.

The effective half-life can be calculated by means of the following equation:

$$\mathrm{TEFF} = \frac{\mathrm{TB\ x\ TR}}{\mathrm{TB} + \mathrm{TR}}$$

NOTE: All of the half lives in the equation must be in the same units of time, or the equation is not valid.

EXAMPLE: The biological half-life of iodine - 131 is 138 days, and the radiological half-life is 8 days. What is the effective half-life?

In this example, all of the half-lives are in units of days, so we can use the equation:

$$T_{eff} = \frac{T_B \ x \ T_R}{T_B + T_R}$$

Substituting the values given, we have:

$$T_{eff} = \frac{T_B \ x \ T_R}{T_B + T_R}$$

When we perform the calculations, we see that:

T_{eff} = 7.56 days

In the example, notice that the effective half-life is less than either the biological half-life or the radiological half-life. This is always the case.

This example tells us that if iodine - 131 enters a person's body, it will take 7.56 days for half of that iodine to be removed from the person's body by both decay and bodily elimination. After a second 7.56 days, half of the iodine that was left will be gone. This will continue until the iodine has virtually disappeared.

3.1 LONG TERM EFFECTS

Another harmful effect is the increased risk of cancer in man due to radiation exposure. During the early years of radiation technology there were skin cancers at the site of repeated X-ray exposures among early X-ray workers. X-ray technologists of the ear usually held the X-ray films while taking X-rays of their patients. This resulted in extreme exposure to their hands and in some cases skin cancer. Other incidents of radiation exposure resulting in cancer have been found in the early radium watch dial painters, the increased incidence of leukemia among physicians using X-rays and the Japanese survivors at Hiroshima. There is also an increased incidence of thyroid cancers and leukemia in certain patients treated with therapeutic X-rays. It is not certain whether there is a threshold for this radiation exposure effect.

3.1.1 Genetic Effects

There is a possibility of another harmful effect to radiation exposure; this is genetic mutation. Experiments with fruit flies conducted in 1927, showed that radiation exposure increased the rate of genetic mutations. This effect has been confirmed with experiments with other species.

Genetic mutations are normally occurring phenomena. They have been occurring for many thousands of years. Most genetic mutations are self limiting; that is, undesirable mutations tend to die out and only desirable mutations survive. Because of our technological development, natural selection and the self limiting effect of genetic mutations is no longer taking place. For example because of advances in medicine, humans can expect to survive for a much longer time than they would have only a few hundred years ago. This means that the undesirable genetic mutations carried by any one individual have a greater chance of being transmitted to a future generation. Therefore, natural selection is restrained.

There does not appear to be a threshold for the genetic effects of radiation exposure. Any dose is accompanied by the production of mutations, and the number of mutations produced is proportional to the exposure. This may mean that there is no tolerance dose or safe dose to radiation.

3.1.2 Somatic Effects

Somatic effects are those effects that are manifest in the individual exposed to the radiation. These may include such effects as life shortening and the development of cancer. Federal exposure limits are set to minimize the chances of any long term effects. There is no evidence to show that people exposed to federal limits have had any detectable biological effects from the radiation.

4.0 SUMMARY

To be able to protect ourselves from any hazardous substance, a basic understanding of the biological interactions possible is essential. This section has provided us with that understanding. There are two types of cellular interaction; direct and indirect. Cellular radiosensitivity varies directly by the cells rate of multiplication and indirectly by cells differentiation. The symptoms of the radiation syndrome were discussed. Linear and threshold dose/effect theories were also presented. The basic effects of contamination were presented. Entry and exit paths for the human body were discussed as well as methods for assessing internal exposure. The important methods for determining effective half-life from radiological half-life and biological half-life were explained