General Nuclear Worker Radiation Training

Gary W. Castleberry, PE

Course Description

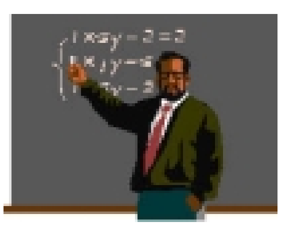
This course will prepare the student with an understanding of the basic radiological knowledge requirements for nuclear plant workers who must work in areas where they may be exposed to radiation. The sources and types of radiation along with the potential biological effects of radiation exposure are discussed. Understanding of radiological postings and radiation measurement devices will help the future nuclear worker be prepared for an exciting new career.

Performance Objectives

Upon completion of this course the student should be able to:

1. Understand the sources and types of radiation;
2. Be knowledgeable about the biological effects of radiation;
3. Know the limits and guidelines for exposure set by the government;
4. Understand radiological postings;
5. Understand and use personal dosimetry;
6. Practice the concept of ALARA; and
7. Use a Radiation Work Permit.

Introduction



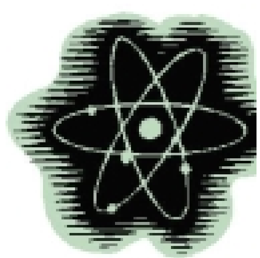
Prior to being granted unescorted access to a commercial nuclear facility, a new employee or contractor must pass a written examination. This exam tests the workers general knowledge of the various facility organizations. Upon successful completion of orientation training and the written exam, the employee will be granted unescorted access to the Protected Area but not to any Radiation Controlled Areas (RCA). In order to perform unescorted work in a RCA, the worker must take additional training and pass a written examination on radiation work practices. The training is referred to as General Nuclear Worker Training (GNWT). This is the subject matter for this course.

Although each commercial nuclear facility has developed their training modules for GNWT, a large amount of the information is standard for the industry. This has become necessary over the years due to the number of contract workers who move from plant to plant. This course will provide the basic generic information which is applicable to any plant. Therefore, a new employee who has successfully completed this course will only have to address the minimal site specific topics in order to obtain unescorted access.

Each plant also tends to place emphasis on certain areas where they have experienced problems. Therefore, when you take radiation training at a plant some of the requirements or rules may be more severe than presented here.

Course Content

Part 1 Understand the sources and types of radiation



Matter is composed of atoms. They are the building blocks of our known universe. A great deal has been learned about the structure of the atom over the last fifty years. A great deal more is still not understood. This is not a course in theoretical atomic physics, and as such, there is no need to present information beyond the basic structure of the atom.

For the purposes of this course, each atom is primarily composed of three particles. These are:

- Neutrons – These particles are found in the nucleus (center) of the atom and are electrically neutral (they carry no charge).

- Protons – These particles are also found in the nucleus of the atom and carry a positive electrical charge. The number of protons determines the type of material (element).

- Electrons – These particles are found in orbits around the nucleus of the atom and carry a negative charge. The mass of the electron is very small in relation to the protons and neutrons. When compared to the diameter of the nucleus, the orbits of the electrons are far away. Thus the atom is mostly composed of empty space.

Most atoms are in what can best be described as a stable state. The appropriate number of protons, neutrons, and electrons for that particular element exist in harmony and are in a normal, unexcited state; however, an atom can become unstable (an excited state) due to several different causes such as impact by a particle. When the atom becomes unstable it will emit small increments of energy in an attempt to become stable. These small amounts or increments of energy are known as radiation. One of the ways an atom becomes unstable is when it captures an extra component such as a neutron. This produces an unstable atom that will emit radiation. This is what occurs in the nuclear reactor.

If radiation reacts with the electron cloud of an atom it can cause one or more of the electrons to be removed. This is called ionization of the atom and the type of radiation that can cause this effect is called ionizing radiation.

When an atom with a large nucleus (large number of protons and neutrons) is unstable, it may split into two smaller atoms and in turn release amounts of radiation. This process is called fission and occurs within the nuclear fuel in the reactor. The energy released is used to heat large amounts of water into steam that eventually spins a turbine/electrical generator producing electricity. This is what we are all about in commercial nuclear power industry.

A commercial nuclear power plant contains numerous potential sources of radiation. It is important to understand where radiation is found in the different parts of the plant.

- The water used to take heat away from the reactor, known as reactor coolant.
- The reactor fuel itself which also may be found in underwater storage pools or in above ground storage containers.
- Corrosion and fission products that have been in the reactor water cycle but have become deposited on plant equipment.
- Various plant components such as piping, drains, valves and filters.
- Operation of the reactor which emits neutron radiation and nitrogen-16 isotopes [formed from radiation disassociating (breaking down) water molecules in the reactor coolant].

In a commercial nuclear power plant, four types of ionizing radiation can be found. These are known as Alpha, Beta, Neutron, and Gamma.

- Alpha (α)
    - This is the least penetrating of the four radioactive particles
    - A piece of paper will stop/shield an Alpha particle
    - The sources of alpha particles are reactor fuel and radon gas
    - The primary source of concern for Alpha particles is internal contamination. If ingested the particle can be in close contact with human cells and give a large dose of radiation.
    - The Alpha particle is composed of two protons and two neutrons and thus is very similar to a helium atom. The lack of electrons to counter the effect of the two protons gives the alpha particle a plus 2 electrical charge.

  - The Alpha particle eventually will attract two electrons and form a helium atom.

- Beta (β)
  - The Beta particle carries an electrical charge of minus one (-1).
  - It originates in the nucleus of the atom
  - Beta particles can only travel a few feet in air
  - Beta particles originate from activated corrosion (rust) particles and fission in the primary system and as such are present when systems are opened to perform work.
  - Shielding is accomplished by plastic such as safety glasses.
  - Beta radiation is a hazard to the skin and the lens of the eye. Your safety glasses effectively shield your eye lens from Beta radiation.

- Gamma (γ)
  - Gamma radiation is a pure energy wave and does not have any mass or electrical charge.
  - Gamma radiation is very penetrating and can give whole body doses.
  - The sources of Gamma radiation are the fluids within the primary systems (reactor coolant) on Pressurized Water Reactors (PWRs) and in the steam going to the turbine/generator on Boiling Water Reactors (BWRs).
  - Gamma accounts for most of the dose received by workers at a commercial nuclear plant.
  - It takes a very dense material to shield from Gamma radiation. Materials such as lead, water, concrete and steel are commonly used.

- Neutron (η)
  - Neutrons are part of the nucleus of an atom that have been released due to decay or fission.
  - Neutrons have no electrical charge.
  - Neutron radiation is one of the most penetrating forms of radiation. It requires water or concrete to shield personnel.
  - The source of neutron radiation is the reactor core at power.
  - Due to its highly penetrating ability, neutron radiation is a personal hazard for anyone who must enter the reactor building while the reactor is at power or for those personnel who handle spent fuel. Neutron radiation produces whole body doses.

Dose, Dose Rate and TEDE

Dose is the amount of radiation absorbed by the human body or by an organ in the human body. The unit of measure used in USA plants is the rem. The rem is a measure of the amount of radiation energy received adjusted for the type of radiation.

Dose rate is the rate that radiation is being absorbed by the human body or by an organ of the human body. It is usually expressed in mrem/hour (pronounced milli rem per hour).

Dose is determined by the dose rate times the amount of time exposed to the dose.

> Example: If you spend 30 minutes in a 30 mrem/hour area of the plant you would receive a dose of 30/60 hour X 30 mrem/hour = 15 mrem.

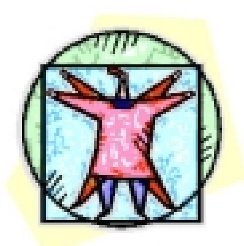
The Total Effective Dose Equivalent (TEDE) is the total of internal plus external dose. TEDE is also express in rem or mrem where 1 rem equals 1000 mrem.

To convert mrem to rem divide the rem by 1000. Likewise, to convert rem to mrem multiply the rem by 1000.

> Example: If the administrative limit for exposure is 2500 mrem what is the value expressed in rem?
> 2500 mrem /1000 rem/mrem = 2.5 rem

<u>Part 2 Be knowledgeable about the biological effects of radiation</u>

The human body is composed of living cells. When these cells are exposed to ionizing radiation one of four things can happen to that cell.



1. Nothing – no damage
2. Some damage
3. Destruction or death of the cell
4. Mutation

The effects of the radiation on human cells is dependent upon many factors such as the type of cell, type of radiation, and how much dose and how much time the radiation is received. In general, most human body cells will repair themselves.

How the radiation is received further quantifies radiation exposure.

Chronic radiation exposure is a small amount of radiation received over a long period of time. It is believed by scientists that the human can withstand chronic radiation exposures over many years and not have any harmful effects.

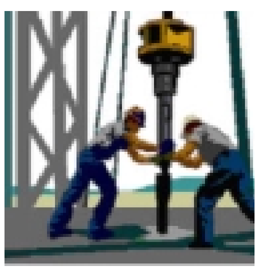
Acute radiation exposure is a large amount of radiation received over a short period of time, usually measured as a day or less.

The effects of radiation exposure are classified as somatic and genetic. Somatic effects occur in the individual who received the exposure and may occur promptly or may be delayed in manifesting. Genetic effects are effects that materialize in future generations.

Human cells that reproduce rapidly are the most vulnerable of human cells to radiation effects. For this reason, special limitations for dose are made for female workers who become pregnant in order to protect the unborn fetus.

Your occupational dose records will be maintained by your employer. Nuclear Regulatory Commission (NRC) Form-4 is used to document your occupational dose record. If you move to a different company and plant the Form – 4 is your record and will be sent to you by your former employer.

Part 3 Know the limits and guidelines for exposure set by the government



The NRC has set limits on the amount of radiation a worker may receive in any given year. The dose limits are based upon what a career nuclear worker may receive if that individual worked for fifty years in the nuclear industry and received the limit dose each of those years. The total dose that individual received should not have caused any prompt effects, it should have minimized the risk of the chronic dose received, and in general kept the overall risk to health comparable to other industrial jobs.

The following table summarized the federal limits which can be found in Title 10 of the CFR Part 20.

Exposure Conditions	10 CFR Part 20 Limits
Adult Total Effective Dose (TEDE)	5.0 rem/year
Adult Lens Dose Equivalent (LDE)	15.0 rem/year
Adult Shallow-Dose Equivalent (SDE) 1. Skin 2. Extremities	50 rem/year

Any Internal Organ (CDE)	50 rem/year
Minors (less than 18 years old)	10% of Adult
Declared pregnant worker	500 mrem/pregnancy
Planned Special Dose (PSE)	5 times the normal limits

Limit definitions (from 10CFR Part 20.1003):

- Planned Special Dose (PSE) – A dose received in a rare set of circumstances such as life saving rescue or very serious accident mitigation.

- Committed – a term used in regards to internal exposure, being the dose which would be received if a radioisotope were inside the body and remained there for 50 years.

- Deep Dose Equivalent (DDE) – This is the external whole body exposure measured at a depth of 1 cm. This is the sum of the gamma and neutron dose (beta and alpha can not reach that depth of tissue}. The whole body includes the trunk of the body, head, arms above the elbow, legs above the knee and the male gonads.

- Lens Dose Equivalent (LDE) – This is the external dose to the lens of the eye at a tissue depth of 0.3cm.

- Shallow Dose Equivalent (SDE) – This is the external dose received by the skin or an extremity at a tissue depth of 0.007 cm averaged over a 1 cm^2. An extremity is the arms below the elbow and the legs below the knee.

- Committed Dose Equivalent (CDE) – This is the internal dose of the body organs or tissues. It is calculated based upon an intake of a radioactive isotope that stays in the body and continues to add dose for the next fifty years. The isotope may be ingested, inhaled or otherwise entered the body.

- Committed Effective Dose Equivalent (CEDE) – This is the sum of the doses to organs or tissues received over a fifty year period after a radioisotope has been ingested, inhaled or otherwise entered the body, weighted for it's effect on the whole body.

- Total Effective Dose Equivalent (TEDE) – This is the total internal and external dose to the body and is the sum of the deep dose equivalent and the committed dose equivalent (DDE + CEDE = TEDE).

Most utilities establish Administrative Limits below the federal limits to reduce exposure and to assure no violations of federal law occur due to overexposure.

Part 4 Understand radiological postings

Radiological postings are signs which are placed around the RCA to provide the worker with information and warnings. Failure to adhere to the warnings on a radiological posting can be grounds for dismissal and result in federal violations to the station. In addition, moving or altering a radiological posting is not allowed and can also result in federal violations. The following are the common postings and their meanings:

- Radiation Control Area (RCA) – area within the protected area where radiation sources may be encountered. Personal dosimetry is required to enter the RCA.

- Radiation Area – An area with a dose rate in excess of 5 mrem/hour but less than 100 mrem/hour as measured 30 cm from the source.

- High Radiation Area – An area with a dose rate in excess of 100 mrem/hour but less than 1000 mrem/hour as measured 30 cm from the source.

- Very High Radiation Area – An area with a dose rate greater than 500 rem/hour (**Note this is rem.** The industry standard is to use rem once a value reaches 1000 mrem). This sign will have the words **GRAVE DANGER** on it. Fortunately, there are only a few areas in the plant (normally not accessible) that are Very High Radiation Areas.

- Contaminated Area – An area which contains loose surface contamination greater than 1000 dpm/100cm^2 (disintegrations per 100 square centimeters).

Part 5 Understand and use of personal dosimetry

Dosimetry devices are used to measure the radiation dose received by workers in a commercial nuclear facility. Three primary types are used:

Thermoluminescent Dosimeters (TLDs) - These devices are small plastic boxes which contain a mineral chip of special material. When this material is heated in a special laboratory oven, the chip will emit light proportional to the amount of radiation to which it has been exposed. The TLDs are used to document the workers permanent dose records. They are usually gathered every quarter and a new TLD is provided.

TLDs are usually attached to your security badge and thus are properly worn between the head and waist. TLDs have a distinct front and back and have to be facing outward properly in order for the TLD to measure Beta radiation.

Self-Reading Dosimeters (SRDs) – SRDs are dosimetry devices that are read by the worker. The most common type are the pocket ion-detector and the Personal Alarming Dosimeter (see below). The pocket ion-detector only measures gamma radiation. They resemble a telescope the size of a thick ink pen. When held up to the eye a small scale and gradient can be seen showing the dose received. High range versions of these devices are often given to workers who are entering areas where the doses are high (greater then 100 mrem/hour) and are backups to their normal dosimetry.

Pocket dosimeters are fragile. If dropped they will lose their reading. If you drop your pocket dosimeter you must report back to the Radiological Control point and report what has happened.

Personal Alarming Dosimeters (PADs)

Most of the industry has migrated to the use of Personal Alarming Dosimetry or PADs. The reason is these devices have information programmed into them about the dose rates and maximum exposure you are allowed on a particular job. If the PAD detects you are in a dose field higher than allowed it will alarm. Also, if you exceed your dose limit the device will alarm (actual alarm values are set below the limit so you do not exceed your allowed dose).

It should be clear why the industry has adopted the use of these devices. They allow the worker to better manage his exposure, provide more accurate readings, and are more robust than pocket dosimeters.

Part 6 Practice the concept of ALARA

The Nuclear industry makes wide use of acronyms which are the grouping of the first letters of a phrase. ALARA stands for As Low As Reasonably Achievable. Although the federal government has established lifetime limits of exposure for nuclear workers in order to keep the health risks of nuclear work comparable to other industries, there is still some small amount of risk with occupational radiation exposure. Therefore, federal regulations further mandate that programs shall be in place to limit the exposure workers receive to the lowest possible amount.

ALARA is another of the individual nuclear worker responsibilities. **You** are responsible for keeping your exposure as low as reasonably achievable.

The ALARA program has many facets some of which are:

- Job planning using lessons learned from similar work performed in the past
- Minimizing the number of workers to perform a task
- Working the job right the first time so no one has to go back again and receive more dose
- Use of shielding
- Practice training in a non-radiological area

Three important methods of ALARA, which all radiation workers are required to practice are the concepts of time, distance and shielding.

- **Time**

Of the two components that contribute to dose (recall that dose = radiation rate x time exposed), time is the component we can usually control. Sometimes little can be done about the dose rates in a work area; however, we can control the amount of time that is spent in the area. If a worker can reduce the time spent performing a task by 20% then the dose received will also be reduce by 20%.

Dose time can be reduced by moving to a low dose waiting area when an unexpected pause in the work occurs. These low dose waiting areas are well marked in the plant with signs and are the place where you will receive the lowest dose in that area while waiting for a task to resume or start.

-
- **Distance**

The strength of most radiation fields reduces as you put distance between yourself and the source of radiation. For this reason, strong sources of radiation are marked in the plant so the worker knows to not loiter in that area.

- **Shielding**

Dense materials can absorb radiation and act as a shield to the worker. Temporary shielding is often used for local shielding in high radiation areas. This shielding may be in the form of lead blankets (flat bags full of lead shot), steel plates, or water filled metal tanks.

Radiation Protection departments will have a designated ALARA person who can determine if shielding is beneficial. Sometimes the dose received by the workers installing the shielding exceeds what savings will be made to the overall task and shielding will not be used.

Part 7 Use a Radiation Work Permit

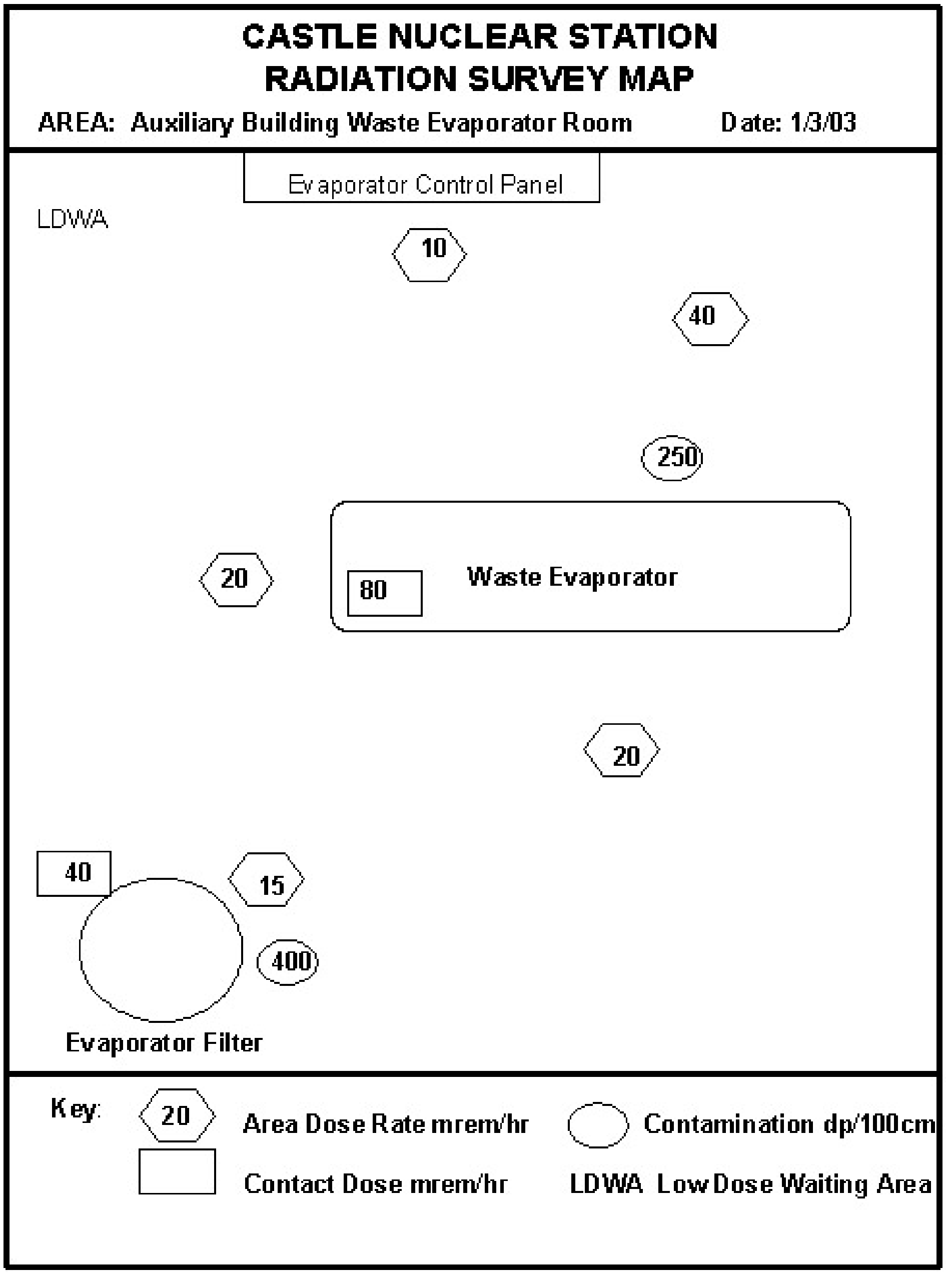
Work performed in a nuclear plant is performed under a system of work permits. Work permits provide a variety of information to tell the worker what the assignment involves and what steps to follow to perform the work. A Radiation Work Permit is a special form of work permit that addresses the radiological issues associated with performing tasks in a specific area. Although the industry has not standardized on the forms used for radiation work permits, the content is pretty much the same at all plants.

A simplified facsimile of a Radiation Work Permit is presented at the end of this section. Here are the pertinent facts the permit is communicating:

- RWP number. This number usually is formed with a combination of the year and a sequential number. Workers are expected to be able to recite the RWP number they are working under when in the field.
- Job Description. This describes in general the type of work the RWP has been created to support. In this example it is for Engineering Inspections in part of the facility known as the Auxiliary Building.
- Dose alarm. This is the value, that when reached, will cause your PAD to alarm. Again, you are expected to know this number while in the work area. In addition, you are expected to check your PAD every 15 minutes to see how much dose you are receiving and to ensure that the dose makes sense based upon what you read on the RWP. If it does not you should leave the area and return to the RP Control Point.
- Dose Rate Alarm. This is the dose rate which will cause your PAD to alarm. This is the third thing you always need to remember when you are working under a RWP.
- Dress requirements. The RWP matches the type of work you are going to perform to the correct protective clothing you will be required to wear. Example: You are going to be performing a generator test. That is covered by Task C and it tells you to use the dress requirements in part iv which is gloves, lab coat, and booties.

CASTLE NUCLEAR STATION **FIELD COPY**	
RWP 2003-01	**Revision: 2**
JOB DESCRIPTION: **ENGINEERING INPECTIONS** **AUXILIARY BUILDING**	
DOSE ALARM: 15mrem	**Dose Rate Alarm: 50 mrem**
TASKS **A. Visual inspections only With no loitering** **B. Visual inspections with Loitering** **C. Performing test and Measurements**	**DRESS REQUIREMENTS:** **i** **iii** **iv**
PROTECTIVE CLOTHING REQUIRED: **i. None** **ii Surgical Gloves** **iii Gloves and lab coat** **iv Gloves, lab coat, and booties** **v Overalls, glove liner, rubber gloves, booties, rubber covers, hood**	
SPECIAL INSTRUCTIONS **1. This RWP does not cover work in wet areas**	
Approved by:	**Effective Date:**

In addition to the RWP there is another tool the worker uses to understand the radiological issues associated with performing work in the RCA. That is the survey map. The survey maps are plan drawings of the various areas in the RCA that show dose rates and contamination levels. These maps are updated on a regular basis based upon changing conditions in the plant. It is necessary to review the survey map to identify areas of high contamination, high dose areas and hot spots (which are localized sources of radiation several times higher than any other sources in the area).



In this example you can see that the highest area of contamination is near the Evaporator Filter with a value of 400 dpi/100cm^2. The highest dose area is the contact reading on the evaporator which reads 80 mrem/hour. Actual surveys contain information about hot spots, fixed contamination and any other information necessary to support safe radiological work. This example has been simplified for the purposed of this course.

Glossary of Terms

- Acute radiation exposure - a large amount of radiation received over a short period of time usually measured as a day or less.
- ALARA - As Low As Reasonably Achievable.
- Biometric – the electronic measurement of human body attributes to establish identity
- BWR – Boiling Water Reactor
- CFR – Code of Federal Regulations
- Chronic radiation exposure - a small amount of radiation received over a long period of time.
- Committed – a term used in regards to internal exposure, being the dose which would be received if a radioisotope were inside the body and remained there for 50 years
- Committed Dose Equivalent (CDE) – This is the internal dose of the body organs or tissues
- Committed Effective Dose Equivalent (CEDE) – This is the sum of the doses to organs or tissues received over a fifty year period after a radioisotope has been ingested, inhaled or otherwise entered the body, weighted for its effect on the whole body
- Contamination – the presence of radioactive material where it is not desired
- Contaminated Area – An area which contains loose surface contamination greater than 1000 dpm/100cm^2 (disintegrations per 100 square centimeters)
- Decay – the process of the unstable atom emitting radiation as it seeks a stable state
- Deep Dose Equivalent (DDE) – This is the external whole body exposure measured at a depth of 1 cm.
- Dose – is the measure of, or amount of, radiation absorbed by the human body or an organ of the human body
- EPA – Environmental Protection Agency
- Extremity - the arms below the elbow and the legs below the knee
- High Radiation Area – An area with a dose rate in excess of 100 mrem/hour but less than 1000 mrem/hour as measured 30 cm from the source
- Hot Spots - localized sources of radiation several times **higher than any other sources** in the area
- INPO – Institute of Nuclear Power Operators
- Lens Dose Equivalent (LDE) – This is the external dose to the lens of the eye at a tissue depth of 0.3cm
- PAD – Personal Alarming Dosimeter – an electronic device for measuring and alarming dose and dose rates

- PAG – Protective Action Guides – a manual developed by the EPA defining the appropriate responses for radiological and nuclear incidents.
- Planned Special Dose (PSE) – A dose received in a rare set of circumstances such as life saving rescue or very serious accident mitigation.
- Program – a set of procedures which implement a required set of tasks such as welding
- Program Owner – the department responsible for administrating a program
- Protected Area – the area within the double fences which surround the power plant
- PWR – Pressurized Water Reactor
- NRC – the Nuclear Regulatory Commission
- Radiation – the energy that is emitted from an unstable atom
- Radiation Area – An area with a dose rate in excess of 5 mrem/hour but less than 100 mrem/hour as measured 30 cm from the source
- Radioactive Material – substance, matter, material that emits radiation due to the natural decay process
- RCA – Radiation Controlled Area
- Rem – standard measure of dose in USA plants
- Shallow Dose Equivalent (SDE) – This is the external dose received by the skin or an extremity at a tissue depth of 0.007 cm averaged over a 1 cm^2
- SRD – Self-Reading Dosimeter – any dosimeter which is read by the worker
- STAR – Stop, Think, Act, Review
- Total Effective Dose Equivalent (TEDE) – This is the total internal and external dose to the body and is the sum of the deep dose equivalent and the committed dose equivalent (DDE + CEDE = TEDE
- TLD – (Thermoluminescent Dosimeter)- a device for recording radiation exposure
- Very High Radiation Area – An area with a dose rate greater than 500 **rem**/hour (500,000 mrem/hour)
- Whole Body - the trunk of the body, head, arms above the elbow, legs above the knee and the male gonads

Conclusions

As noted in the companion course for General Nuclear Worker Training, the nuclear industry has its own jargon and ways of doing things; however, due to the consequences of not doing things right the first time, adherence to the rules and standards of behavior are mandatory. This is especially true when it comes to radiation protection. Each plant has several professional radiation protection professionals who are well trained and tested in good radiation work practices. Always follow their advice.

The amount of information that must be learned in a short amount of time can be intimidating to a new employee. This course has provided a good introduction to the radiological expectations to which you will be held accountable at a commercial nuclear facility and should make your first few days there a little less stressful. Again, one final nugget to take away from this course is to remember that the nuclear industry respects people who say “I don’t understand this, would you help me.” Never be afraid or embarrassed to ask for help or direction, because the person you asked for help has been there and done that.