

## Lesson 5: EPA PAGs – Dose, Exposure, and Effects

### Lesson Overview

The purpose of this lesson is to introduce EPA Protective Action Guides (PAGs). This lesson also describes units of dose, exposure pathways, and health effects from exposure.

Upon completion of this lesson, you will be able to:

- Explain the purpose of the Environmental Protection Agency (EPA) Manual of Protective Action Guides and Protective Actions for Nuclear Incidents.
- Differentiate between total effective dose equivalent (TEDE), committed dose equivalent (CDE), committed effective dose equivalent (CEDE), and effective dose equivalent (EDE) in describing projected dose.
- Describe the radiation exposure pathways.
- Identify the health effects associated with each type of exposure.

Remember you can access the glossary in one of two ways throughout this course. You can select the glossary button in the top right hand corner of each main content screen. In addition, on content screens you can select underlined words to access their definitions in the online glossary.

This lesson should take approximately **1 hour** to complete.

### Protective Actions and Protective Action Guides (PAGs)

As you learned in Lesson 1, the Environmental Protection Agency (EPA) has established protective action guides (PAGs) for the principal phases of a nuclear incident. The public usually can be protected in the case of a nuclear incident by some form of intervention that will disrupt normal living. Such intervention is called a protective action.

PAGs help public officials make protective decisions during a nuclear incident. Specifically, they outline the projected dose to a standard man (e.g., reference man) or other defined individual from an unplanned release of radioactive material, and the level at which a specific protective action to reduce or avoid that dose is warranted. They are primarily based on the avoidance of acute health effects.

### EPA Protective Action Guides

The Environmental Protection Agency announced a revised manual titled Protective Action Guides And Planning Guidance For Nuclear Incidents (FR Vol. 78, No. 72, page 22258). This revised guidance is noticed for Interim Use and Public Comment and replaces the 1991 document when implemented. There is no ruling on when this new guidance must be implemented in State and local government plans and procedures. In the remainder of this course, the new guidance will be the basis for the lessons.

This lesson includes information concerning early phase (sometimes called the emergency or plume phase) and intermediate phase (also known as the post-plume phase) EPA protective action guides.

The PAG Manual is designed for the use of those in Federal, state, and local government with responsibility for emergency response planning and provides guidance for implementation of the protective actions.

## Units of Dose

This lesson includes three major topics:

- Units of dose
- Exposure Pathways
- Health Effects

Let's begin by learning about units of dose.

**Exposure (Roentgen)** - Even though it is not a measure of dose, exposure needs to be discussed here as a related term in common use. Exposure measures the ability of photons (gamma and X-ray) to produce ionization in air. Most commonly available instruments give exposure rate in Roentgen per hour (R/hr) or milliRoentgen per hour (mR/hr). This quantity is useful in estimating the external hazard from radioactive material.

**Absorbed Dose (rad and Gray)** - Absorbed dose (rad) is a measure of energy imparted per unit mass. One rad is the dose delivered to any material that receives 100 ergs of energy per gram of that material.

The International System (SI) unit for absorbed dose is the Gray (Gy), which is the delivery of one joule per kilogram of material (100 rad = 1 Gray).

The rad (or Gy) is used to measure all ionizing radiation at any energy level. It does not, however, take into account the differing relative biological effectiveness (RBE) of different types of radiation. (The same dose of different types of radiation—alpha, beta, gamma—causes varying amounts of damage.) Therefore, to arrive at a calculated dose equivalent that represents biological damage, it is necessary to modify the absorbed dose by a modifying quality factor.

The modifying quality factors for varying radiations are as follows:

- X-ray, gamma, beta: 1
- Alpha, multicharged particles, fission fragments, heavy unknowns: 20
- Neutrons of unknown energy, high-energy protons: 10
- Neutrons based on energy (low to high): 2-11

**Dose Equivalent (rem and Sievert)** - The dose equivalent is a measure of biological damage that is calculated by multiplying absorbed dose by quality factor for the type of radiation involved.

The unit of dose equivalent is the rem. The SI unit is the Sievert (Sv). 100 rem = 1 Sv.

Dose equivalent quantities are calculated in dose projections; that is, they represent future dose calculated for a specified time period, in the absence of protective actions. They are then compared to PAGs for decisions on protective actions. Protective actions are taken to avoid projected dose.

## Quantities of Projected Dose

Projected dose may be expressed in quantities of:

- Dose equivalent (DE)
- Effective dose equivalent (EDE)
- Committed dose equivalent (CDE)
- Committed effective dose equivalent (CEDE)
- Total effective dose equivalent (TEDE)

In the next section of this lesson, you'll learn more about each of these quantities.

## Dose Equivalent (DE)

Dose equivalent (DE) is the product of the absorbed dose in organs/tissue (in rad or Gy) and modifying factors related to the relative biological effectiveness (RBE) of the radiation.

These factors are expressed in rem (or Sv). DE is usually used to express a dose to a particular organ.

For example:

1 rad of alpha delivered to lung tissue equals 20 rem  $DE_{lung}$ : 1 rad  $\times$  quality factor 20 (alpha) = 20 rem  $DE_{lung}$ .

## Effective Dose Equivalent (EDE)

Effective dose equivalent (EDE) is the sum of the products of the DE to each organ and a weighting factor that is related to the risk of fatal cancer in the organs that have been exposed to the radiation.

EDE is expressed in rem (or Sv). The weighting factors are as follows:

- Gonads – 0.25
- Breast – 0.15
- Red bone marrow – 0.12
- Thyroid – 0.03
- Bone surface 0.03
- Other organs – 0.30
- Whole body – 1.00

Suppose you wanted to determine the whole body risk of cancer caused by a 0.4 rem DE to the gonads. As the table on this screen demonstrates, the weighting factor for gonads is 0.25. A 0.4 rem gonadal dose  $\times$  0.25 = 0.1 rem EDE. The risk of a fatal cancer from a gonadal dose of 0.4 rem is about the same as that from a whole body dose of 0.1 rem.

The early-phase skin PAG for evacuation is 50 rem DE. The intermediate-phase beta skin PAG for relocation is 100 rem DE.

### **Committed Dose Equivalent (CDE)**

Committed dose equivalent (CDE) measures the effect, over time, of radiation output from contaminants that have been internalized. It is the dose equivalent an organ or tissue will receive from intake during the 50-year period following the intake. The 50-year dose is dependent on:

- The physical characteristics of the isotope
- The chemical characteristics of the isotope
- Breathing rates
- Deposition velocities of the contaminant
- Pathways of internalization
- Biological removal mechanisms

For example, tritium (oxide) has a radiological half-life of  $4.5 \times 10^3$  days (12.3 years). However, tritium has only a 12-day biological half-life, yielding also an effective half-life (combination of the two) of 12 days. Thus, most of the radiation dose resulting from tritium ingestion will be delivered in the first 12 days of the 50-year calculated period.

The early-phase thyroid PAG for evacuation is 5 rem CDE.

### **Committed Effective Dose Equivalent (CEDE)**

Committed effective dose equivalent (CEDE) is the total internal dose the body receives in the 50 years after the inhalation or ingestion of radioactive materials with respect to the risk of fatal cancer in the affected organs. It is calculated by:

- Multiplying, for each tissue or organ irradiated, the weighting factor applicable to that tissue or organ by the CDE to that organ, then
- Adding together the results obtained for each individual organ.

For example, suppose the thyroid received a CDE of 25 rem from an I-131 uptake. Suppose further that the thyroid also received a CDE of 5 rem from an I-132 uptake. The weighting factor for the thyroid is 0.03; therefore, the CEDE is 0.90 rem.

$[(25 \times 0.03) + (5 \times 0.03) = 0.90]$ .

### **Total Effective Dose Equivalent (TEDE)**

Total effective dose equivalent (TEDE) is a Nuclear Regulatory Commission (NRC) term that combines the effects of both the internal and external exposures. It is the sum of the deep dose equivalent (DDE), dose to the skin to a depth of 1 cm, from external gamma radiation and the CEDE from internal exposure. The term TEDE is not used in the current PAG Manual but will be used in any revisions of the manual that may be issued. For our purposes, DDE and EDE are synonymous.

For example, suppose exposure to a concentration of  $1 \times 10^{-6}$   $\mu\text{Ci}/\text{cc}$  of I-131 for 1 hour yielded a 1.3 rem CDEthyroid dose.  $1.3 \text{ rem CDEthyroid} \times 0.03 \text{ weighting factor (for thyroid)} = 0.039 \text{ rem CEDE}$ . That same concentration yielded an external dose of 0.014 rem EDE. Therefore, the TEDE dose received was 0.053 rem (TEDE = EDE + CEDE).

The early-phase TEDE evacuation PAG is 1 rem.

The intermediate-phase TEDE relocation PAG is 2 rem (1st year).

## Exposure Pathways

Now that you have learned about units of dose, you will learn about the pathways through which people can be exposed to radiation.

### Radiation Exposure Pathways (1 of 2)

During and after a release of radioactive material, individuals may be exposed to radiation through a variety of pathways. Pathways that contribute less than 10% of the total dose need not be considered in determining the potential dose for purposes of comparing it to the PAG.

Major and minor exposure pathways considered in developing the EPA and FDA PAGs include:

- Plume shine
- Immersion in the plume
- Deposited materials
- Resuspended materials
- External contamination
- Ingestion of contaminated food and water

### Radiation Exposure Pathways (2 of 2)

Some of these pathways apply only to the early phase, others only to the intermediate phase, and some to both phases.

For example, the following are included in dose projections for early-phase evacuation PAGs:

- Plume shine
- Immersion in the plume
- Deposited materials

Included in calculations for intermediate-phase relocation PAGs are:

- Resuspended materials
- External contamination

Planning must take into account dealing with members of the public and emergency responders who become externally contaminated with radioactive material. Ingestion of contaminated food and water is considered in FDA ingestion PAGs, and will be covered in Lesson 9.

You will learn more about each of these pathways in the next section of this lesson.

## **Plume Shine**

An airborne plume may contain:

- The noble gases (xenon and krypton, which emit both beta and gamma radiation).
- Radioiodines (also beta and gamma emitters).
- Various radioactive particulates.

For those in the path of a plume, exposure to gamma radiation from the airborne radioactive materials overhead called plume shine (sometimes called cloudshine or sky shine) is the leading exposure pathway and contributes to external dose. Since the plume may be a considerable distance away from or above the population affected, the gamma components are the only contributors of exposure (the beta components present a negligible threat). This exposure ends when the plume is gone.

## **Immersion in the Plume (1 of 3)**

Immersion is the state of being completely surrounded by a radioactive plume. It leads to:

- External exposure to both beta and gamma radiation.
- External contamination from radionuclides in the plume.
- Internal exposure and contamination due to inhalation.

Because of the nearness of the radioactive material, those immersed in a plume are externally exposed to both beta and gamma radiation.

## **Immersion in the Plume (2 of 3)**

Inhalation of radioiodines has the potential to result in large doses to the thyroid in certain nuclear power plant accidents.

Radioiodines:

- Are present in large numbers because a large inventory is created during fission and is available for release.
- Are absorbed through lung tissue and circulate through the body via the bloodstream.
- Will concentrate in the thyroid gland, producing a specific organ dose (CDE).

Those leaving the plume must be monitored and decontaminated to end their external exposure. Medical evaluation and treatment may be necessary to reduce their internal exposure.

## **Immersion in the Plume (3 of 3)**

Protecting the thyroid from radioiodine can be accomplished by:

- Evacuation prior to arrival of the plume containing radioiodine.
- Respiratory protection, though usually limited to on-site emergency workers during specific situations.
- Administration (ingestion) of potassium iodide (KI), though it may not be available to the public.

Exposure to particulates, such as cesium and strontium, can lead to a major internal dose if such particulates are released from containment. The dose due to inhalation of Cs-137 while being exposed to a concentration of 1  $\mu\text{Ci/cc}$  for 1 hour is  $3.8 \times 10^4$  rem committed effective dose equivalent.

Inhalation of noble gases is not considered an inhalation hazard because:

- Noble gases are inhaled and then exhaled.
- They are chemically inert (group VIII of the Periodic Table). They are, however, still radioactive and yield an external dose.

### **Deposited Materials (1 of 2)**

External exposure to beta and gamma radiation from materials deposited on the ground is sometimes called groundshine. However, the beta component is not expected to be a controlling factor in determining whether an evacuation is required during a nuclear reactor accident.

Soon after a release, there may be doses to the public from both airborne and deposited radioactive materials. Since the deposition dose to persons not evacuated will continue until they are relocated, evacuation PAG dose calculations assume four days of exposure. The four-day exposure assumption is based on the duration of the primary release being less than four days, and the exposure to deposited materials after four days being addressed through protective actions such as relocation, if warranted. Four days of gamma exposure from the deposited radionuclides could be a significant contributor to total dose received during the early phase, especially if the release contains large quantities of radioiodines or particulates.

### **Deposited Materials (2 of 2)**

Intermediate-phase relocation PAGs involve calculations of gamma exposure from deposition for the first year after termination of a release. Long-term goals include two-year and fifty-year exposure calculations.

The PAG Manual states on page 45, "For situations where it is impractical to meet these objectives through decontamination, consideration should be given to relocation at a lower projected first year dose than that specified by the relocation PAG."

### **Resuspended Materials**

Calculations show that in reactor accidents, the dose from inhalation of resuspended materials is usually not an exposure pathway controlling the decision to relocate during the early or intermediate phases. Resuspension factors will vary between site locations. Verification of resuspension factors for a given site is therefore necessary. This is accomplished by air sampling.

A resuspension factor of  $1 \times 10^{-6}$  has been demonstrated, for example, for non-arid locations. Thus, if one curie of a material has been deposited per square meter in a non-arid location, typically only one microCurie ( $1 \times 10^{-6}$  Ci) per cubic meter will be in the air above the ground.

## **External Contamination (1 of 2)**

If an area has been contaminated by the passing plume, the potential exists for people to be contaminated and/or receive dose from passing through it. Beta and gamma exposure will continue for the contaminated individuals after they leave the area until they are decontaminated.

## **External Contamination (2 of 2)**

External beta exposure pathways include:

- Direct exposure from immersion in the plume
- Exposure from materials deposited on skin and clothing
- Exposure from materials deposited on nearby surfaces

Beta exposure is not expected to be the controlling factor in determining protective actions required for reactor accidents. Evacuation is not the preferred protective action for external beta exposure. Showering and changing clothes will reduce or eliminate external contamination on individuals. Evacuation, however, is warranted for protection from an associated high inhalation dose.

External beta PAGs are 50 times higher than gamma PAGs.

## **Health Effects of Radiation**

Now that you have learned about units of dose and the pathways through which individuals can be exposed, you will learn about the health effects of radiation.

### **Radiation Health Effects**

The dose from exposure to radioactive material may be delivered only during the period of environmental exposure (e.g., external gamma radiation), or over a longer period (e.g., inhaled radionuclides that are deposited in organs). In the latter case, the dose not only is delivered at the time of intake from the environment but also continues until all of the radioactive material has decayed or been eliminated from the body.

The health effects of radiation include:

- Acute health effects
- Brain damage to the unborn
- Delayed health effects Radiogenic cancers
- Thyroid disorders and cancers
- Genetic disorders

The risk of acute health effects is the primary basis for setting EPA PAG values. Avoidance of health effects from accidents that involve the release of radioactive materials is the primary justification for all radiological emergency planning.

On the following screens, you will learn about these types of health effects.

### **Acute Health Effects (1 of 2)**

Three factors define acute health effects:

- Prompt radiation effects (observable within a short time period, two to three months after exposure)
- Varying severity of effect, depending on dose
- Existence of a practical threshold

PAG values and emergency worker dose limits are set low enough to avoid these effects.

## **Acute Health Effects (2 of 2)**

EPA's PAG Manual further describes acute effects as either severe or non-severe.

Severe effects (including death) occur at high doses and have clinically observable symptoms. Prodromal effects (first indicators of damage) are not severe in themselves but are a forewarning of more severe effects.

Prodromal effects include:

- Anorexia (loss of appetite)
- Nausea
- Vomiting
- Diarrhea
- Epilation (hair loss)
- Erythema (skin reddening)
- Fatigue
- Nonmalignant skin damage

Non-severe effects include hematological deficiencies, temporary infertility, and chromosomal changes. These may not be considered severe, but are detrimental to the individual's health in varying degrees.

## **Brain Damage to the Unborn**

Brain damage to the unborn is a class of injury reported in atomic bomb survivors that does not fall into either an acute or delayed effect category, but exhibits elements of both.

Radiation doses received in the eighth to fifteenth weeks of gestation pose the greatest risk to the fetus.

Potential health effects include:

- Small head (microcephaly)
- Small brain (microencephaly)
- Mental retardation

The risk per unit dose during this period in a pregnancy is taken to be about  $4 \times 10^{-3}$  per rad of dose. Because of this relatively high risk, special consideration should be given to the protection of the fetus during this period. The National Council on Radiation Protection (NCRP) has recommended an exposure limit of 0.5 rem for pregnant women.

## **Delayed Health Effects**

Now that you've learned about acute health effects and brain damage to the unborn, you will now learn about delayed health effects considered in establishing PAGs.

The risk of delayed health effects in exposed individuals is the second principle involved in establishing PAGs.

According to the PAGs, the risk of delayed effects (primarily cancer and genetic effects, which are assumed to have linear non-threshold relationships to dose) should not exceed upper bounds that are judged to be adequately protective of public health under emergency conditions, and are reasonably achievable.

### **Delayed Health Effects: Cancer**

Radiogenic cancers are stochastic effects. That is, the chance of getting cancer is proportional to the dose received, but the severity is not proportional to the dose received (e.g., you either get or don't get cancer).

There may be no threshold dose. There is a latent period associated with the onset of radiation-induced cancers, so the increased risk due to exposure to radiation is not immediately apparent.

The increased risk is assumed to commence two to ten years after the time of exposure and continue the remainder of the exposed individual's lifespan. Risk data are based on studies of Japanese A-bomb survivors, but risk estimates continue to change.

### **Delayed Health Effects: Thyroid Cancer**

Thyroid exposure to very high levels of radiation may cause degeneration of the thyroid. At moderate levels of exposure some loss of thyroid function will occur. At lower levels, there are delayed health effects, which take the form of both thyroid nodules and thyroid malignancies. Doses as low as 14 rad to the thyroid have been associated with thyroid malignancy.

In adults, the increased risk of radiation-induced cancer is assumed to commence about 10 years after initial exposure and continue for the remaining lifespan of the exposed individual. The early-phase evacuation PAG is 5 rem CDE to the thyroid.

### **Delayed Health Effects: Skin Cancer**

The risk of fatal skin cancer is estimated to be on the order of 1% of the total risk of fatal cancer for uniform irradiation of the entire body.

The ratio of nonfatal to fatal skin cancers from irradiation of the skin is high (100 to 1).

The early-phase evacuation PAG is 50 rem EDE to the skin.

### **Delayed Health Effects: Fetal Cancers**

A fetus is estimated to be five to ten times as sensitive to radiogenic cancer as an adult.

There are reports of increased relative incidence of childhood cancers following prenatal X-ray doses as low as 0.20–0.25 rem and of doubling of childhood cancers following prenatal X-ray doses between 1 and 4 rem.

### **Delayed Health Effects: Genetic Disorders**

An average parental dose of 1 rem before a baby's conception has been estimated to produce between 5 and 75 significant genetically related disorders per million liveborn offspring. Taking into account all genetically related disorders, the estimated risk of genetically related disorders in all generations is 1 x 10<sup>-4</sup> per person-rem (collective dose of all those exposed) to a typical population.

Estimates of all radiation-induced genetic effects include:

- 50%: Minor to moderate medical problems
- 25%: Severe medical problems
- 23%: Require extended hospitalization
- 2%: Die before age 20

### **Lesson Summary**

- Let's summarize what you have learned in this lesson:
  - Projected dose may be expressed in quantities of:
  - Dose equivalent (DE) Effective dose equivalent (EDE)
  - Committed dose equivalent (CDE)
  - Committed effective dose equivalent (CEDE)
  - Total effective dose equivalent (TEDE)
- Pathways considered in developing the EPA and FDA PAGs include: Plume shine
  - Immersion in the plume
  - Deposited materials
  - Resuspended materials
  - External contamination
  - Ingestion of contaminated food and water
- The health effects of radiation include:
  - Acute health effects
  - Brain damage to the unborn
  - Delayed health effects

The next lesson will cover the implementation guidance in the EPA PAG Manual.

