U.S.NRC
United States Nuclear Regulatory Commission
Protecting People and the Environment

HRTD
Human Resources
Training & Development

Chapter 4:

Control of Radiation Exposure

Objectives

- Discuss the need to keep total radiation exposure As Low As Reasonably Achievable (ALARA).
- Describe typical sources of radiation and contamination originating in a nuclear power station, fuel cycle facility, or medical/industrial application.
- Describe three methods for reducing exposure from external sources.
- Explain the importance and methods for contamination control.
- Describe the use of Radiation Work Permits (RWPs).
- Describe general radiation and contamination surveys.

LWRs

There are two light water reactor (LWR) designs – the boiling water reactor (BWR), and the pressurized water reactor (PWR). Although the design varies somewhat, they have the same function – the production of electricity by using steam.

There are different vendors that made these reactors, such as General Electric (GE), Westinghouse, Babcock & Wilcox (B&W) and Combustion Engineering (CE). GE was the supplier for BWRs. The other vendors provided PWRs.

BWRs

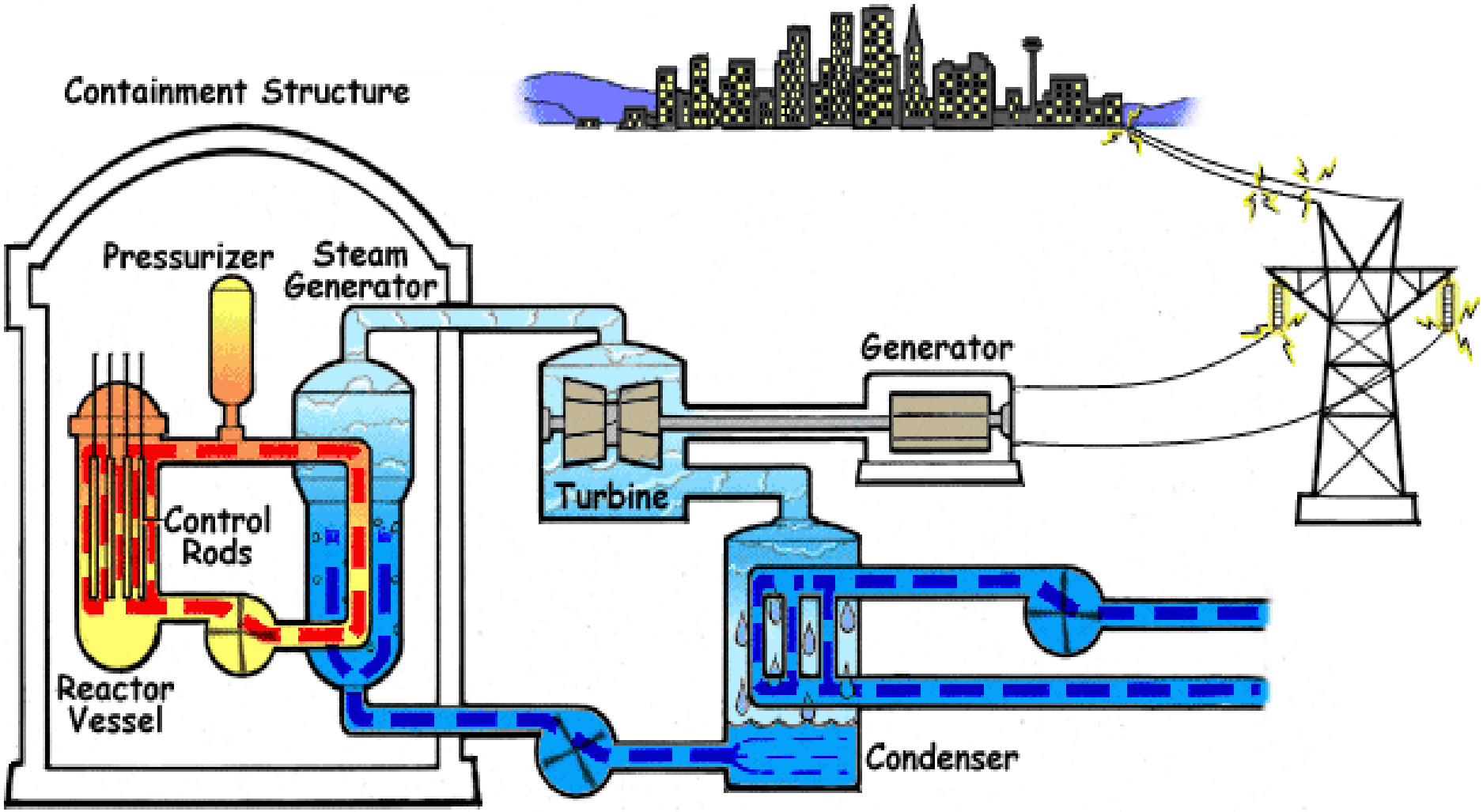
BWRs heat water to steam in the reactor. The steam is transferred out of the reactor vessel by steam lines. The steam turns the blades of turbines. Actually there are several turbines. The turbines are connected to a generator which produces the electricity. After the energy has been extracted from the steam, the steam is condensed back to water in the condenser. The water is then pumped back into the reactor to close the cycle.

PWRs

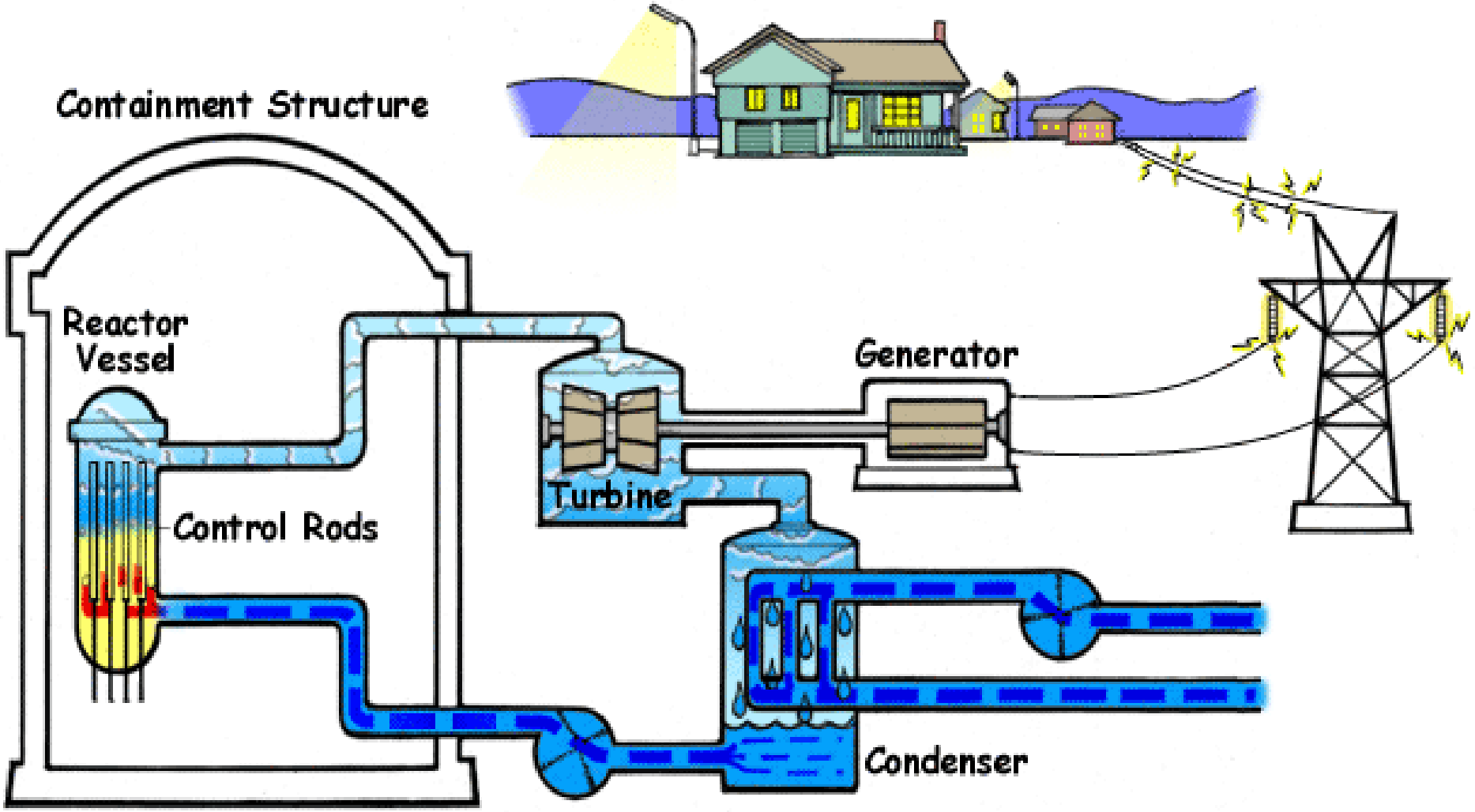
PWRs also create electricity by steam turning a turbine connected to a generator. PWRs differ from BWRs in that the heated water in the reactor is not allowed to boil. Rather, it is pumped through a "steam generator." The water passes through thousands of tubes in the steam generator. The water that receives this transferred heat is allowed to boil which is then piped to the turbine/generator. The steam is condensed and the water is returned to the steam generator. The heat-depleted water exiting the steam generator is returned to the reactor to be reheated.

PWRs have a "pressurizer" which is used to maintain the pressure in the system. The pressurizer is part water and partially filled with steam. The pressure in the system is maintained by adjusting the temperature in the pressurizer using heating elements and water spray nozzles.

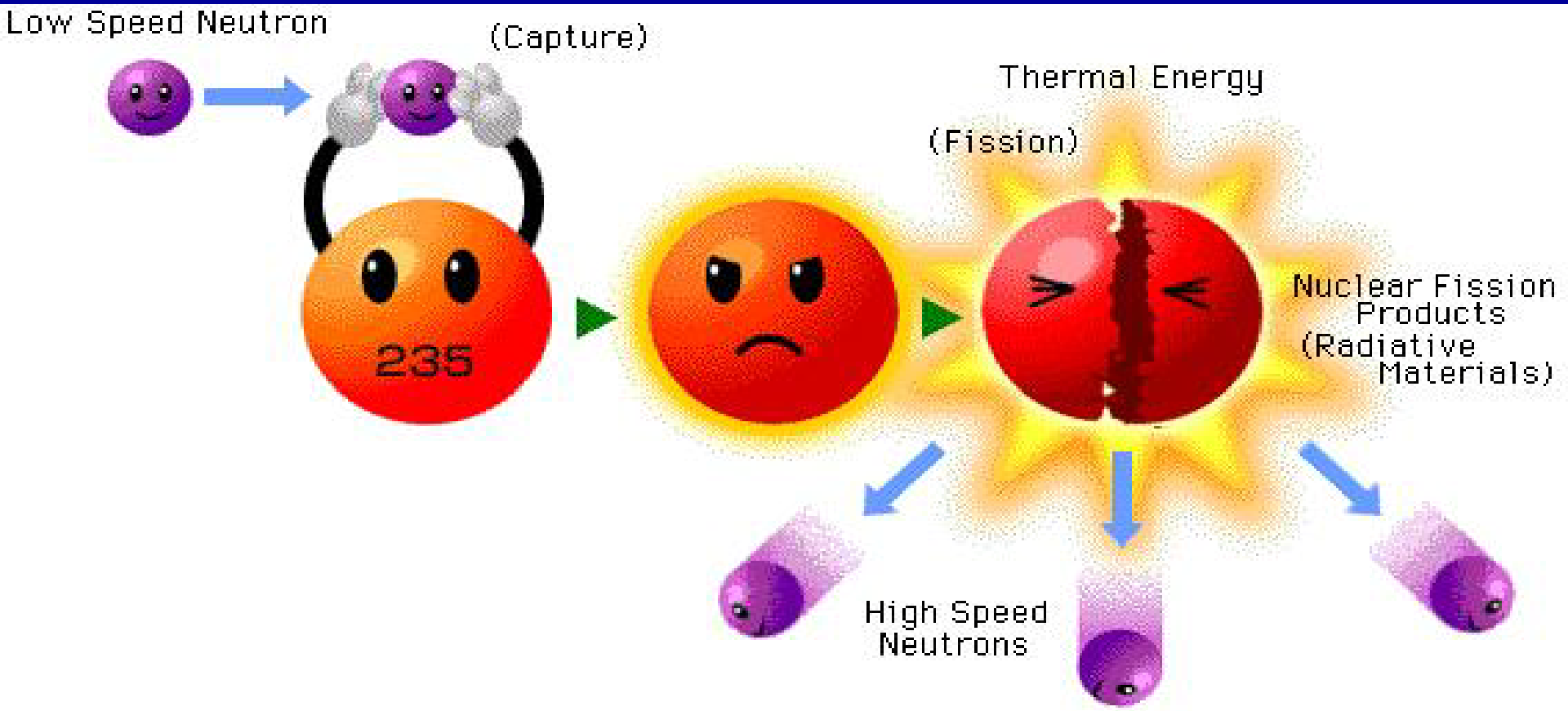
PWR Simple Diagrams



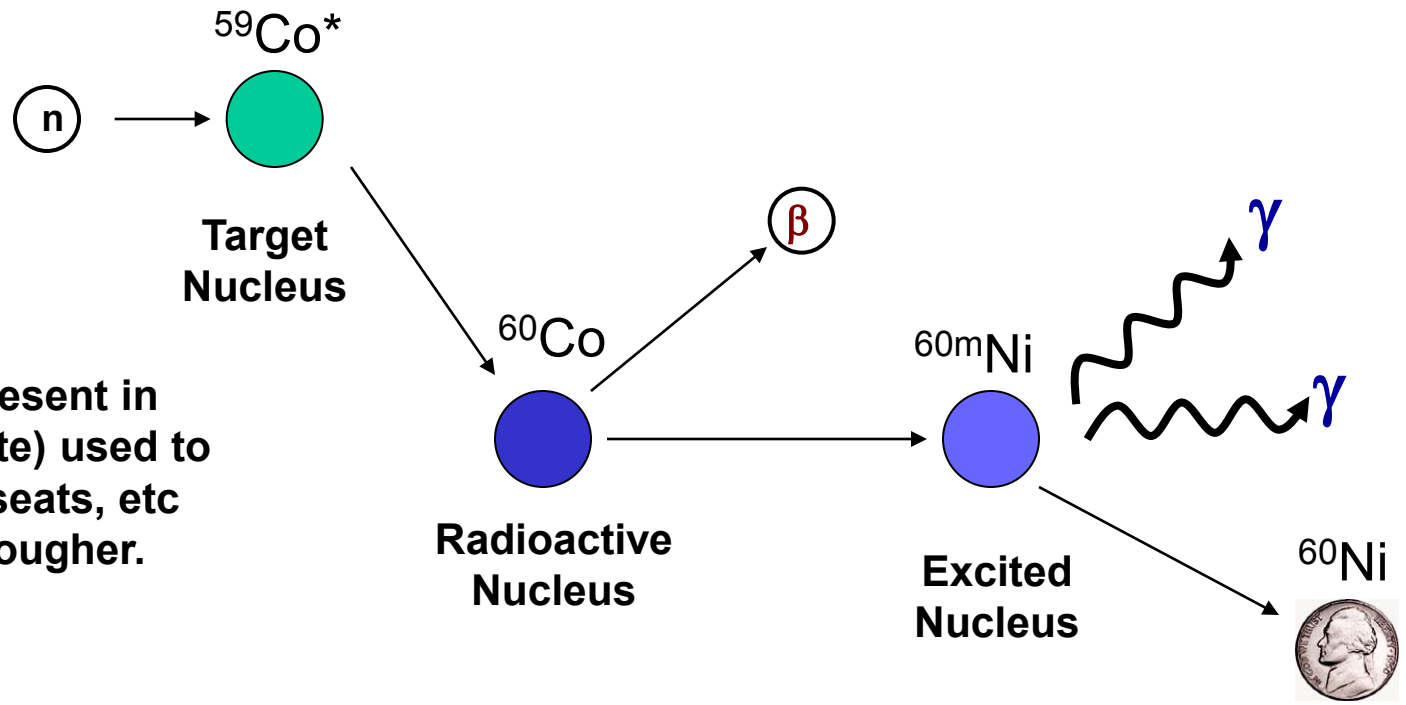
BWR Simple Diagrams



Sources of Radiation: Fission



Sources of Radiation: Activation



***Cobalt is present in alloys (Stellite) used to make valve seats, etc harder and tougher.**

Fission & Activation Products

BWRs & PWRs utilize fissioning of U-235 atoms, which produces radioactive fission products. Ideally, they are retained in the fuel elements, but some can be released. Examples of fission products: Cs-137, I-131, & Sr-90.

In addition, non-radioactive material that enters the reactor can become activated. Activation is the process of a non-radioactive material becoming radioactive due to the absorption of a neutron.

Fission & Activation Products

N-16 is produced in reactors from activation of the oxygen in water, presenting a hazard in BWR areas. The high energy γ radiation requires substantial shielding. It has a short half-life (7 seconds) so it is not a problem when the reactor is shutdown.

Most dose in LWRs is from Co-60, an activation product. (Cobalt is from stainless steel; enters the reactor via erosion/corrosion of metal.

Other examples of activation products include Fe-59, Mn-54, and Zn-65.

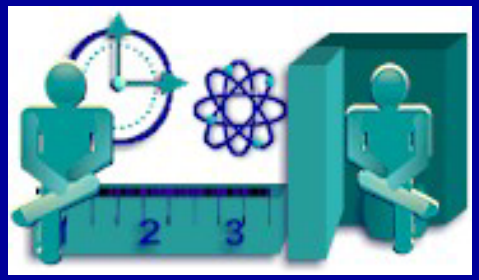
Radiation Dose Rates

The following are examples of sources of radiation and radiation dose rates encountered in commercial reactors:

Location:	Dose rate (Rad/hr):
Spent fuel (in pool)	100,000 – 1,000,000
Radwaste Resin Tank	5,000
Steam generator channel head	10-40
TIPS and cables-incore reactor instrumentation	1 – 100,000
Thimbles	50,000
Reactor cavity	> 1,000

Ref: Reg. Guide 8.38, Rev. 1, May 2006.

ALARA



ALARA means "As Low As is Reasonably Achievable." The concept is that any radiation dose has a risk associated with it. For this reason, it is essential that doses be maintained ALARA. The basic means of accomplishing ALARA are: time, distance, and shielding.

An example of ALARA is that in 2008 the average measurable dose to workers at 104 commercial reactors was 130 mrem; in 1995 this average was 310 mrem. (NUREG-0713 see www.reirs.com).

Note: In 2008, no exposures exceeded the 5 rem limit.

ALARA - Time

- Your dose is equal to the product of the dose rate (that is the rate of your exposure to radiation) and the time of your exposure (how long you are exposed to radiation). The dose rate is typically in millirem per hour (mrem/hr). Multiplying the dose rate by time (mrem/hr) x (hr), equals dose (mrem). For this reason it is important that you be aware of the dose rate where you are. By decreasing your time in an area you may decrease your dose.
- Some ways to decrease your time are to prepare what you will need for your work in advance of the job, and to rehearse in advance by mockup training.

ALARA - Distance

- For small radiation sources, the dose rate is quickly reduced the farther you are from the source of radiation. This is called an "inverse-square" relationship because the dose rate from small point sources drops off inversely to the square of the distance. For instance, if you move from 1 to 2 feet from a source, the dose rate at 2 feet will be ¼ the rate at 1 foot - [(1 x 1)/(2 x 2)] = 1/4th.
- If you are not able to get away from the sources of radiation, it may be possible to bring the work component out of the radiation field as a means of reducing the dose.

ALARA - Shielding

- Matter or "shielding" between you and the source of radiation will decrease your dose rate and, consequently, your dose. The effectiveness will depend on the type of radiation and the shield material. For instance, dense materials like lead or concrete are good shielding materials for gamma radiation. Materials with hydrogen atoms, like paraffin or water, are effective shielding materials for neutron radiation.
- Water makes a good shield - it may help to flood piping with water during outages as a way of reducing dose rates through shielding. Lead blankets are used to provide temporary shielding. In some cases it may be helpful to shield the person rather than the source of radiation using a "shadow shield."

ALARA

Other means of reducing "source term" include:

- Ultrasonic fuel cleaning,
- Mechanically and electro-polishing component surfaces followed by preoxidizing to reduce erosion/corrosion,
- Use of elevated pH in PWRs (pH 7.2) reduces "crud" deposition,
- Installing permanent scaffolding,
- Remote monitoring of personnel to reduce HP dose,
- Chemical decontamination of systems,
  - Note: cost to remove 1/10th gram of Co-60 is ~ $2,000,000.
- Zinc injection to reduce deposition of Co-60,
- Removal of components that create Co-60 (Stellite, w/Co-59)
  - Note: 1 g Co-60 = 1,132 Ci = 1,500 rad/hr @ 1 m,
- "Lightning bolts" installed in nozzle dams,
- Use of "risk significant" inspections to reduce dose during outage.

Contamination

The fission and activation products in the plant systems may be released to the work environment during a refueling outage. This radioactive material is called contamination. Some contamination is easily removed from surfaces, it is called "smearable" contamination. Other contamination is not removable, and so is called "fixed" contamination.

Contamination is a concern because you may receive both an external and internal dose from this material. A survey is used to indicate the level of contamination present, it is generally expressed in units of dpm/100 cm^2 or cpm/100 cm^2.

Contamination is Radioactive Mat'l where you don't want it!

Contamination

You can reduce your risk of becoming contaminated by:

- Entering areas only when necessary and authorized,
- Using protective clothing properly,
- Study the RWP to learn what contamination levels are in the area you are entering,
- Avoiding higher contamination level areas when possible,
- Avoid stepping in water or on floor drains, and contamination control boundaries,
- Conducting a thorough whole body survey when exiting contaminated areas (more on this later).

Radiation Work Permit (RWP)

An RWP provides important information about the radiation levels in various work areas - dose rate, contamination levels, and concentrations of airborne radioactive materials. It also provides information on protective clothing requirements, dosimetry and survey instrument and dosimetry requirements.

Some RWPs have an “administrative limit” that is used to restrict the dose you are allowed to receive per entry or per day.

Radiation Work Permits (RWP)

RWPs are:

- Issued for areas and work - someone with you may be assigned to a different RWP than you;
- Used to monitor and control dose;
- Provide information on radiation levels (dose rate and contamination);
- Specify work requirements-dosimetry, protective clothing, administrative dose levels;
- Are subject to change with changing conditions; and,
- Are a license requirement.

RWP Operating Experience

Example of Failure to Comply with Radiation Work Permit Requirements

The inspectors reviewed a self-revealing, non-cited violation of TS 5.4.1 for the failure of workers to comply with radiation work permit (RWP) requirements. The first example occurred on March 22, 2004, when an operator entered a posted high radiation area on an RWP that did not allow entry into high radiation areas. The operator received an electronic dosimeter dose rate alarm. Radiation dose rates in the area were 600 mrem per hour on contact and 300 mrem per hour at 30 cm from the radiation source.

RWP Operating Experience

FAILURE TO OBTAIN A RADIATION PROTECTION BRIEFING PRIOR TO AN ENTRY INTO A HIGH RADIATION AREA.

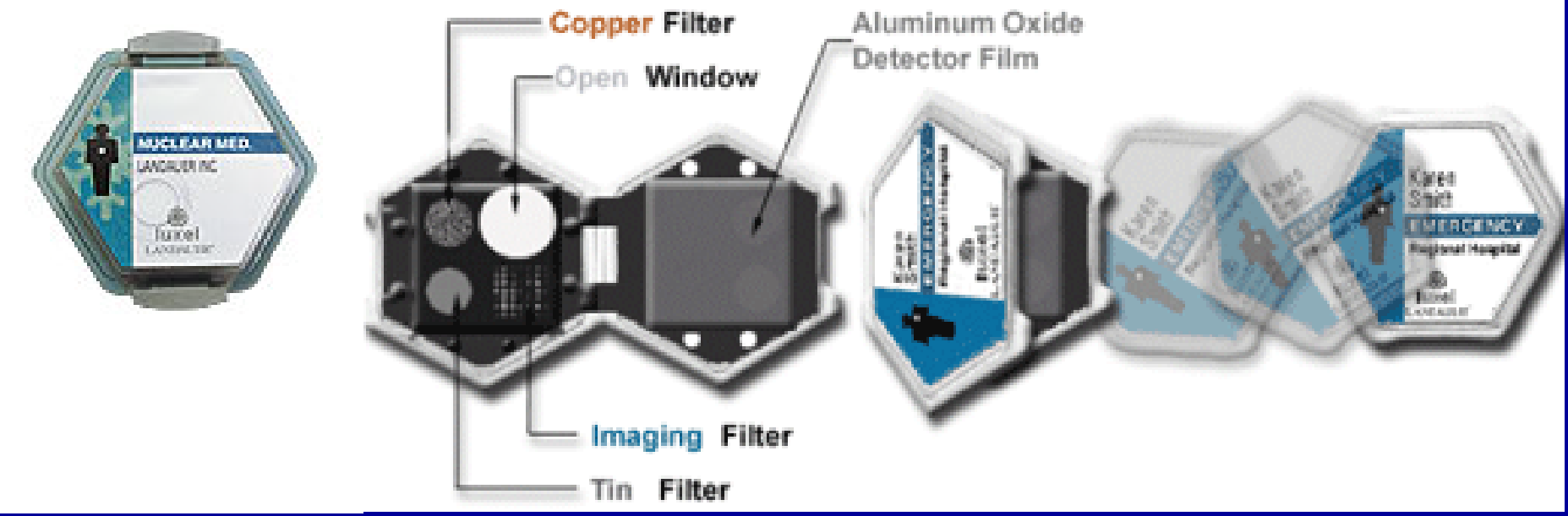
- **One self-revealed finding of very low safety significance and an associated NCV was identified when, on March 9, 2005, a contract radiation worker, while supporting polar crane movement of equipment used for the upper internals split pin modification, entered a High Radiation Area (HRA) without receiving a high radiation area brief from the radiation protection staff as required by the Radiation Work Permit.**
  (Byron)

Exposure Monitoring

- RWPs will specify dosimetry monitoring requirements.
- Dosimeters may provide information on dose rate (mrem/hour), on accumulated dose, or both.
- Those providing information on dose rate include alarming dosimeters, such as “electronic dosimeters” (EDs) or digital alarming dosimeters, “DADS” as they are called at some facilities.
- TLDs, film badges, and OSLs all provide information on your accumulated dose. These have to be processed. They do not tell you the dose rate.
- Pocket ionization chambers (often called PCs, or PICs) provide immediate visual information on your accumulated dose, but not dose rates.

Optically Stimulated Luminescence Dosimeters (OSLs)

OSL dosimeters are very sensitive and provide dose information (DDE, LDE, SDE). However, since they have to be processed, they do not provide information that is readily available.



Thermoluminescent Dosimeters (TLDs)

- Like OSLs, TLDs provide dose information on DDE, LDE, and SDE. They also require processing to obtain dose information.

Pocket Ionization Dosimeter

- Pocket dosimeters (a.k.a. pocket ionization chambers, PICs; pocket dosimeters, PDs); provide immediate information on your dose.
- They are fragile in that the reading can be disrupted if they are dropped. They are available in a variety of ranges, e.g., 0 to 200 mrem, and 0 to 500 mrem. If your PIC is ever "off-scale," leave the area immediately and notify a health physics technician (HP/RP tech).
- They are "rezeroed" when they reach 75% of the maximum scale value (e.g., 150 mrem on a 0-200 mrem chamber).

Electronic Dosimeters

- Electronic dosimeters may provide information on your accumulated dose (mrem) as well as the dose rate (mrem/hr).
- In addition, they may have alarms that warn you if you exceed a dose limit (mrem) or preselected dose rate (mrem/hr).

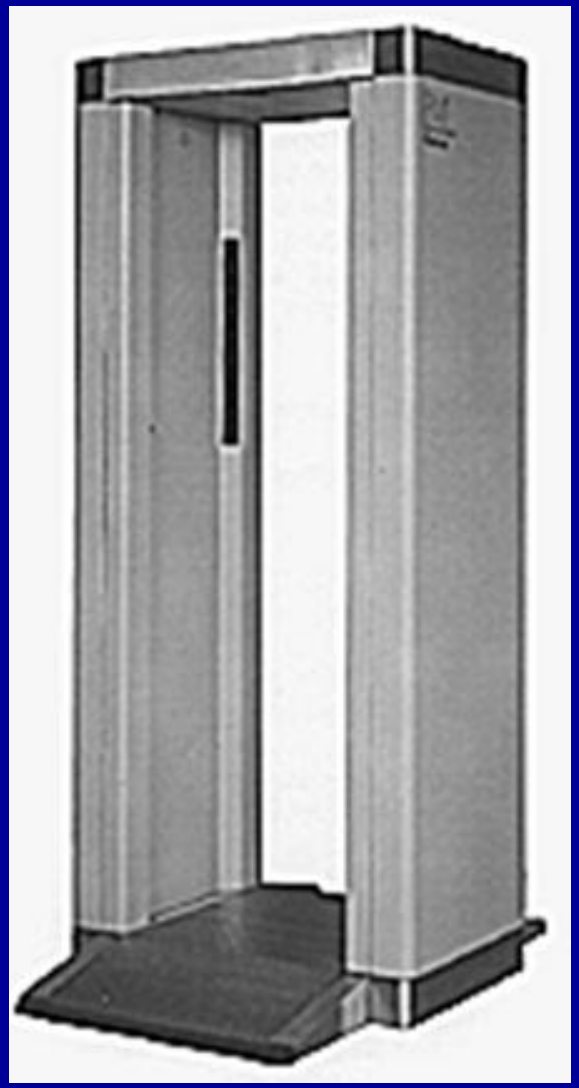
Whole Body Frisker

- Whole body friskers are sensitive to alpha, beta, and gamma radiation.
- The initial count is conducted facing the detector. It will instruct you when to turn.
- By counting each side, it provides a frisking check of your whole body. These may be available when you exit some contaminated areas, and/or when you exit the RCA.

Other Types of Friskers

Hand & Foot Monitor

Pause Monitor



Review

- Using ALARA and time/distance/shielding, together or in parts, you can reduce your dose.
- It is important to know the sources & magnitude of radiation present. You can learn information about this by reviewing the RWP.
- The RWP will also inform you about protective clothing requirements, administrative dose limits, and contamination levels.
- Radiological conditions may change, so it is important to review the RWP and survey information each time you enter an area.

Review

- Contamination is a source of both external and internal dose. Use of protective clothing is an important part of an ALARA program.
- Dosimeters such as TLD/OSL/film badges must be processed to give you your dose information.
- Dosimeters such as EPDs and PDs provide you with immediate information on your dose.
- All items (including people) that enter the RCA must be surveyed for the presence of contamination.