

Standardized RP Task Qualifications

Module

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LP Number: RPFUN2	
Title: RP Fundamentals for Senior Task Qualifications	

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Qualifications**

Lesson Plan #: RPFUN2

INITIATING DOCUMENTS

None

REQUIRED TOPICS

None

CONTENT REFERENCES

DOE Fundamentals

10 CFR 20, Standards for Protection Against Radiation

DOE-STD-1098-99, Radiological Control

DOE-HDBK-1130-2008, Radiological Worker Handbook

DOE-HDBK-1122-2009, Radiological Control Technician Training

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REVISION COMMENTS

Jun 16, 2017 Ted Green

Record created

Title: RP Fundamentals for Senior Task Qualifications

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Tasks and Topics Covered

The following tasks are covered in RP Fundamentals for Senior Task Qualifications :

Task or Topic Number*	Task Statement
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Lesson: RP Fundamentals for Senior Task Qualifications

Total task or topics: 0

TERMINAL OBJECTIVE:

- 1 From memory, the trainee will demonstrate Radiation Protection fundamentals as outlined in NISP-RP-012, Training and Qualifications for Supplemental Radiation Protection Technicians.

Mastery of the training material will be demonstrated by a score of 80% or greater on the RP Senior Fundamentals Exam.
 - 1.1 Authority and responsibilities of the NRC
 - 1.2 Purpose and significance of site technical specifications
 - 1.3 List the isotopes and their production mechanism that contributes to worker exposures from gamma and neutron radiation. .
 - 1.4 Identify plant systems contributing to the radiological source term of a plant and:
 - State the purpose of each system.
 - Identify major components and equipment contributing to the radiological source term.
 - Identify conditions that preclude safe work near system components.
 - Describe the radiological precautions associated with maintenance tasks
 - 1.5 Discuss the normal uses, locations, advantages, disadvantages, and relative sensitivity of a portable frisker, whole-body contamination monitor, portal monitor, bag counters, tool monitors, and conveyor type contamination monitors

Title: RP Fundamentals for Senior Task
Qualifications

Lesson Plan #: RPFUN2

TO: 1 From memory, , the trainee will demonstrate Radiation Protection fundamentals as outlined in NISP-RP-012, Training and Qualifications for Supplemental Radiation Protection Technicians.

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EO: 1.1 Authority and responsibilities of the NRC**Main Idea****Atomic Energy Commission (AEC)**

Before the Nuclear Regulatory Commission (NRC) was created, nuclear regulation was the responsibility of the AEC, which Congress first established in the Atomic Energy Act of 1946. Eight years later, Congress replaced that law with the Atomic Energy Act of 1954, which for the first time made the development of commercial nuclear power possible. The act assigned the AEC the functions of both encouraging the use of nuclear power and regulating its safety. The AEC's regulatory programs sought to ensure public health and safety from the hazards of nuclear power without imposing excessive requirements that would inhibit the growth of the industry. This was a difficult goal to achieve, especially in a new industry, and within a short time the AEC's programs stirred considerable controversy. An increasing number of critics during the 1960s charged that the AEC's regulations were insufficiently rigorous in several important areas, including radiation protection standards, reactor safety, plant siting, and environmental protection.

AEC to NRC

By 1974, the AEC's regulatory programs had come under such strong attack that Congress decided to abolish the agency. Supporters and critics of nuclear power agreed that the promotional and regulatory duties of the AEC should be assigned to different agencies. The Energy Reorganization Act of 1974 created the Nuclear Regulatory Commission; it began operations on January 19, 1975.

The NRC (like the AEC before it) focused its attention on several broad issues that were essential to protecting public health and safety.

Radiation Protection

The primary danger of the use of nuclear materials for the production of electrical power and a variety of industrial, medical, and research applications is that workers or members of the general public could be exposed to hazardous levels of radiation. The AEC and the NRC published standards that were intended to provide an ample margin of safety from radiation that was generated by the activities of its licensees. The radiation standards embodied available scientific information and the judgment of leading authorities in the field. But since the hazards of exposure to low levels of radiation remained an open and often controversial scientific question, the standards proved to be perpetual sources of debate.

In addition to the Nuclear Regulatory Commission, additional regulations may be implemented or modified by state or local authorities.

EO: 1.2 Purpose and significance of site technical specifications

Main Idea

Technical Specifications

Part of an NRC license authorizing the operation of a nuclear production or utilization facility. A Technical Specification establishes requirements for items such as safety limits, limiting safety system settings, limiting control settings, limiting conditions for operation, surveillance requirements, design features, and administrative controls.

NRC staff guidance on model technical specifications for an operating license.

Example of Technical Specifications that have a direct impact on the Radiation Protection organization

6.13 HIGH RADIATION AREA

6.13.1 In lieu of the "control device" or "alarm signal" required by paragraph 20.203(c)(2) of 10 CFR 20:

- a. Each High Radiation Area in which the intensity of radiation is greater than 100 mr/hr, but equal to or less than *1000mr/hr* when measured at 30 centimeters (cm) from a source within the area, shall be barricaded and conspicuously posted as a High Radiation Area and entrance thereto shall be controlled by issuance of a Radiation Work Permit. Any individual or group of individuals permitted to enter such areas shall be provided with a radiation monitoring device which continuously indicates the radiation exposure rate.

- b. Each High Radiation Area in which the intensity of radiation is greater than 1000 mr/hr when measured at 30 cm from a source within the area shall be subject to the provisions of 6.13.1(a) above. In addition, locked doors shall be provided to prevent unauthorized entry into such areas and the keys shall be maintained under the administrative control of the Shift Foreman on duty and/or the Radiation Control Foreman.

The Technical Specifications provide an approved alternative to the limiting requirements of 10CFR20 for the control of High Radiation areas. Each plant may have slight variations in their Tech Specs. Site-specific procedures may contain specific requirements for High Radiation area control that reflect a site's Technical Specifications requirements and these may differ somewhat from the standard industry controls described in NSIP-RP-05, Access Controls for High Radiation Areas.

Standard Technical Specifications

**Title: RP Fundamentals for Senior Task
Qualifications****Lesson Plan #: RPFUN2**

In addition to the site specific technical specifications, Standard Technical Specifications (STS) are published for each of the five reactor types as a NUREG-series publication. Plants are required to operate within these specifications. Improved Standard Technical Specifications (STS) were developed based on the criteria in the Final Commission Policy Statement on Technical Specification Improvements for Nuclear Power Reactors. These standard technical specifications may have additional requirements that are site specific e.g., off-site dose calculations.

EO: 1.3 List the isotopes and their production mechanism that contributes to worker exposures from gamma and neutron radiation.

Main Idea

All metallic surfaces of the plant, in contact with coolant, will oxidize or corrode to some extent to form metal oxides. A small portion of these oxides will either go into solution ions or be deposited on system surfaces as insoluble matter. These metal oxides are referred to as **CRUD**.

CRUD is undesirable for two reasons.

1. Deposits throughout the system will increase general radiation levels. (Particularly important during maintenance outages due to ALARA concerns).
2. CRUD will also cause the fouling of the core heat transfer surfaces.

Some common corrosion product activations are:

<u>Radionuclide</u>	<u>Production Reaction, shorthand</u>	<u>Production Reaction, longhand</u>
Cr-51	$^{50}\text{Cr}(n_{th}, \gamma)^{51}\text{Cr}$	$^{50}_{24}\text{Cr} + ^1_0n_{th} \rightarrow ^{51}_{24}\text{Cr} + \gamma + \Delta E$
Fe-59	$^{58}\text{Fe}(n_{th}, \gamma)^{59}\text{Fe}$	$^{58}_{26}\text{Fe} + ^1_0n_{th} \rightarrow ^{59}_{26}\text{Fe} + \gamma + \Delta E$
Mn-54	$^{53}\text{Mn}(n_{th}, \gamma)^{54}\text{Mn}$	$^{53}_{25}\text{Mn} + ^1_0n_{th} \rightarrow ^{54}_{25}\text{Mn} + \gamma + \Delta E$
Mn-56	$^{55}\text{Mn}(n_{th}, \gamma)^{56}\text{Mn}$	$^{55}_{25}\text{Mn} + ^1_0n_{th} \rightarrow ^{56}_{25}\text{Mn} + \gamma + \Delta E$
Co-58	$^{58}\text{Ni}(n_{th}, p)^{58}\text{Co}$	$^{58}_{28}\text{Ni} + ^1_0n_{th} \rightarrow ^{58}_{27}\text{Co} + ^1_1p + \Delta E$
Co-60	$^{59}\text{Co}(n_{th}, \gamma)^{60}\text{Co}$	$^{59}_{27}\text{Co} + ^1_0n_{th} \rightarrow ^{60}_{27}\text{Co} + \gamma + \Delta E$

Activation of Trace Impurities in Water - Several nuclides are available in trace amounts in the reactor coolant and will enter the core where they become activated.

Common activated impurities are:

<u>Radionuclide</u>	<u>Production Reaction</u>	<u>Origin</u>
H-3	$^6\text{Li}(n, \alpha)^3\text{H}$	Lithium addition for pH control
Na-24	$^{23}\text{Na}(n, \gamma)^{24}\text{Na}$	Impurity in Water
Ar-41	$^{40}\text{Ar}(n, \gamma)^{41}\text{Ar}$	Air dissolved in water

Activation of Water - Several nuclides are produced from the activation of the water of the RCS itself.

Title: RP Fundamentals for Senior Task Qualifications

Lesson Plan #: RPFUN2

The common nuclides from the activation of water

<u>Radionuclide</u>	<u>Production Reaction</u>	<u>Origin</u>
N-16	$^{16}\text{O}(n,p)^{16}\text{N}$	Water molecule
N-17	$^{17}\text{O}(n,p)^{17}\text{N}$	Water molecule
F-18	$^{18}\text{O}(p,n)^{18}\text{F}$	Water molecule
N-13	$^{16}\text{O}(p,\alpha)^{13}\text{N}$	Water molecule

Fission Products

<u>Radionuclide</u>	<u>Production Reaction</u>	<u>Half life</u>
Cs-135	$\text{Xe}^{135} \rightarrow \text{Cs}^{135} + \beta^- + \gamma$	9.2 hours
Kr-88	$\text{Kr}^{88} \rightarrow \text{Rb}^{88} + \beta^- + \gamma$	2.8 hours
Kr-85	$\text{Kr}^{85} \rightarrow \text{Rb}^{85} + \beta^- + \gamma$	10.7 years

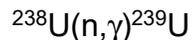
Transuranics

Transuranic refers to any element with an atomic number greater than that of uranium. The transuranic nuclides are produced from neutron capture reactions of ^{238}U and other transuranic nuclides in the fuel. Since these are heavy nuclei, a large number of these radionuclides are fissionable and/or alpha emitters. As alpha emitters, these isotopes can have a significant impact on the radiological controls required.

Transuranics include the following;



Transuranics are formed as the result of neutron capture and several sequential decays, such as:



- EO: 1.4 Identify plant systems contributing to the radiological source term of a plant and:**
- State the purpose of each system.
 - Identify major components and equipment contributing to the radiological source term.
 - Identify conditions that preclude safe work near system components.
 - Describe the radiological precautions associated with maintenance tasks

Main Idea

There are two primary types of commercial reactors used in the US, Pressurized Water Reactor commonly referred to as a PWR, and Boiling Water Reactor or BWR. This material covers both types of reactors. Why the system names may be slightly different the function of the system is the same.

Pressurized Water Reactor (PWR)

There are two major systems utilized to convert the heat generated in the fuel into electrical power for industrial and residential use. The primary system transfers the heat from the fuel to the steam generator, where the secondary system begins. The steam formed in the steam generator is transferred by the secondary system to the main turbine generator, where it is converted into electricity. After passing through the low pressure turbine, the steam is routed to the main condenser. Cool water, flowing through the tubes in the condenser, removes excess heat from the steam, which allows the steam to condense. The water is then pumped back to the steam generator for reuse. In order for the primary and secondary systems to perform their functions, there are approximately one hundred support systems. In addition, for emergencies, there are dedicated systems to mitigate the consequences of accidents.

Primary Loop

The primary loop consists of a Reactor, Steam Generators, Reactor Coolant Pumps and a Pressurizer.

The Reactor produces a large amount of heat through the fission of Uranium 235. The heat is transferred to the primary coolant and taken to the Steam Generator. The Steam Generator is a simple heat exchanger that has water both inside the tubes and on the outside of the tubes. The primary coolant is inside the tubes and gives it heat to the water on the outside of the tubes turning it into steam. The primary coolant that exits the Steam Generator is now colder and flows to the suction of the Reactor Coolant Pump which circulates the water through the entire loop. The Pressurizer maintains the hot water in the loop in a liquid state.

Secondary Loop

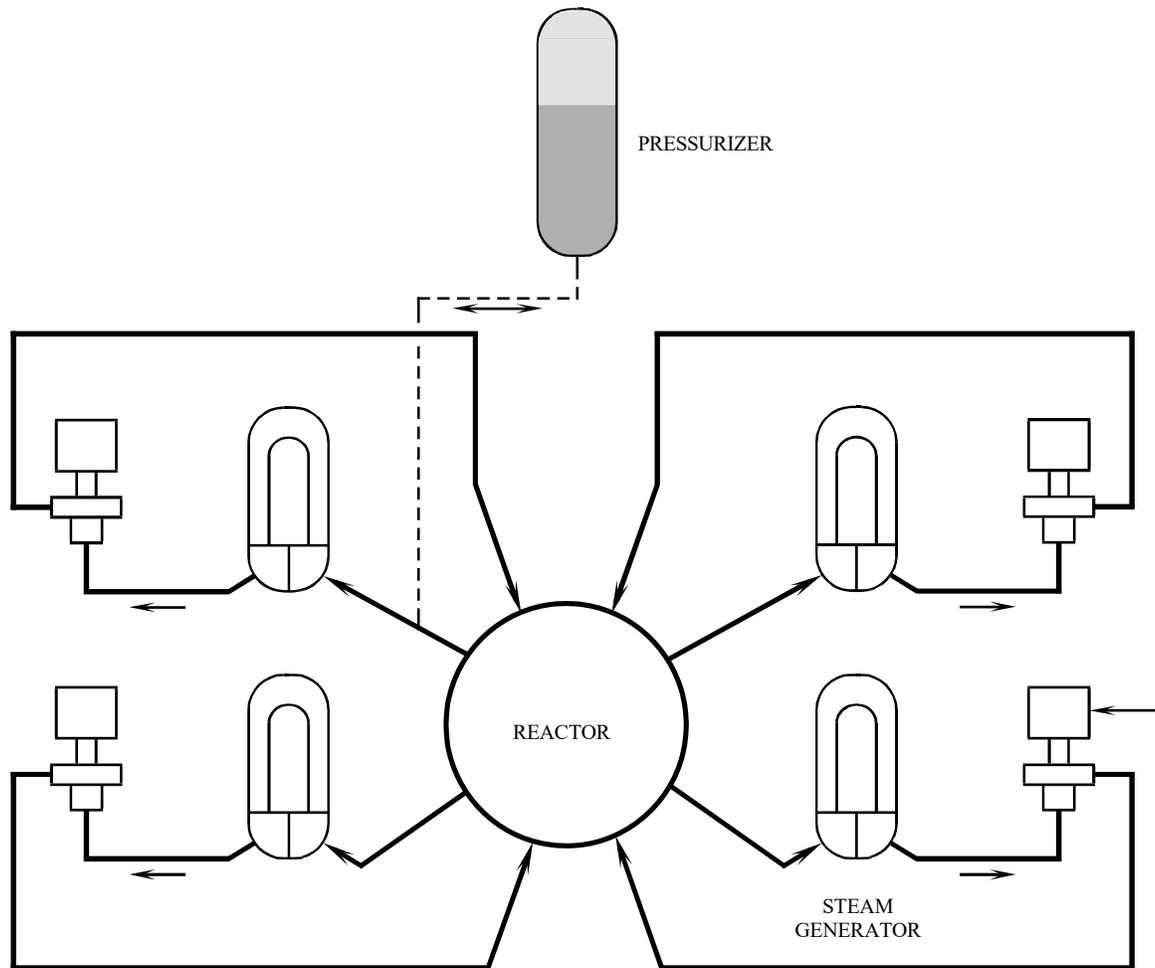
The secondary loop consists of a Steam Generators, Turbines, Condenser, Condensate and Feedwater Pumps.

The heat transferred from the primary coolant inside the tubes of the Steam Generator to the water on the secondary side of the Steam Generator produces steam. This steam, or thermal energy, is converted to mechanical energy in the Turbine causing it to rotate. The mechanical energy is ultimately converted into electrical energy in the Main Generator. The steam that exits the Turbine is condensed back into water in the Condenser. The water is fed back to the Steam Generator by the Feedwater Pump and the process repeats itself.

Circulating Water Loop

The circulating water loop consists of a Condenser, a Cooling Towers, and Circulating Water Pumps.

Circulating water flows through the tubes of the Condenser. This water removes the heat from the steam exiting the Turbine and the steam condenses. The heat that is transferred into the circulating water is sent to the Cooling Tower. The Cooling Tower transfers the heat from the circulating water to the surrounding atmosphere. This process cools the water and a Circulating Water Pump returns the cooled water back to the Condenser to continually exhaust waste heat to the surrounding atmosphere.



Reactor Coolant System

Function:

The function of the Reactor Coolant System (RCS) is to cool the reactor core by transferring the heat generated in the core to the Steam Generators. The purpose of the reactor coolant system is to remove heat from the reactor core and transfer it to the steam generators. It is the second barrier to prevent release of fission products into the environment.

System Components:

The Reactor Coolant System consists of the following major components:
 Reactor Vessel and Internals, Steam Generators (S/Gs), Reactor Coolant Pumps (RCPs), Pressurizer (PZR)

Normal System Operation:

At 100% power the reactor is producing the maximum amount of heat. Hot water exits the core and flows through the hot leg to the Steam Generators. The Steam Generators remove the heat from the Reactor Coolant System. The cold water leaves the Steam Generators and goes to a Reactor

Coolant Pumps where the water is then returned to the core so that the cycle can continue. The water is kept from boiling by the Pressurizer maintaining the Reactor Coolant System pressure greater than the saturation pressure for the high temperature.

Component Descriptions:

The primary system (also called the Reactor Coolant System) consists of the reactor vessel, the steam generators, the reactor coolant pumps, a pressurizer, and the connecting piping. A reactor coolant loop is a reactor coolant pump, a steam generator, and the piping that connects these components to the reactor vessel. The primary function of the reactor coolant system is to transfer the heat from the fuel to the steam generators. A second function is to contain any fission products that escape the fuel. All of the systems consist of the same major components, but they are arranged in slightly different ways. For example, Westinghouse has built plant with two, three, or four loops, depending upon the power output of the plant. The Combustion Engineering plants and the Babcock & Wilcox plants only have two steam generators, but they have four reactor coolant pumps. A two-loop Westinghouse plant has two steam generators, two reactor coolant pumps, and a pressurizer. A three-loop Westinghouse plant has three steam generators, three reactor coolant pumps, and a pressurizer. A four-loop Westinghouse plant has four steam generators, four reactor coolant pumps, and a pressurizer. A Babcock & Wilcox plant has two once through steam generators, four reactor coolant pumps, and a pressurizer. A Combustion Engineering plant has two steam generators, four reactor coolant pumps, and a pressurizer.

Reactor Vessel

The reactor core, and all associated support and alignment devices, is housed within the reactor vessel. The major components are the reactor vessel, the core barrel, the reactor core, and the upper internals package. The reactor vessel is a cylindrical vessel with a hemispherical bottom head and a removable hemispherical top head. The top head is removable to allow for the refueling of the reactor. There will be one inlet (or cold leg) nozzle and one outlet (or hot leg) nozzle for each reactor coolant system loop.

The reactor vessel is constructed of a manganese molybdenum steel, and all surfaces that come into contact with reactor coolant are clad with stainless steel to increase corrosion resistance.

Reactor Vessel and Internals

The Reactor Vessel and Internals are made of strong materials such as stainless steel or carbon steel and then clad with stainless steel for corrosion resistance. The internals are divided up into two sections; the lower core support area and the upper guide structure.

The lower core support area contains the fuel assemblies and the equipment to align and support the weight of the fuel assemblies. It also directs the water through the core and provides for an even distribution of the flow through the fuel assemblies. The upper guide structure supports the weight of the control element assemblies, their shroud, and the extension shaft guides.

The purpose of the reactor vessel and internals is to hold fuel, direct flow through the fuel, provide a pressure boundary and to control criticality in the core with the control element drive mechanism connection.

The radiological precautions associated with most common maintenance tasks are as follows:

- CEDM work- High Radiation Area and potential for high contamination levels
- Fuel Moves- The highest radiological concern due to a fuel handling issue would be- High / Locked or Very High Radiation levels if fuel is brought to close the surface of the water or if irradiated fuel is brought out of the water. Outside of a fuel handling accident, radiological concerns would be the potential for high contamination levels or discrete radioactive particles.
- Core offload and reload- potential for High dose rates, high contamination levels, discrete radioactive particles or airborne
- ICI wires removal, cut-up- potential for High dose rates, high contamination levels, discrete radioactive particles or airborne

Reactor Coolant Pump

The purpose of the reactor coolant pump is to provide forced primary coolant flow to remove the amount of heat being generated by the fission process. Even without a pump, there would be natural circulation flow through the reactor. However, this flow is not sufficient to remove the heat being generated when the reactor is at power. Natural circulation flow is sufficient for heat removal when the plant is shutdown (not critical). The reactor coolant enters the suction side of the pump from the outlet of the steam generator. The water is increased in velocity by the pump impeller. This increase in velocity is converted to pressure in the discharge volute. At the discharge of the reactor coolant pump, the reactor coolant pressure will be approximately 90 psi higher than the inlet pressure.

After the coolant leaves the discharge side of the pump, it will enter the inlet or cold leg side of the reactor vessel. The coolant will then pass through the fuel to collect more heat and is sent back to the steam generators.

The seal package is located between the motor and the hydraulic section and prevents any water from leaking up the shaft into the containment atmosphere. Any water that does leak up the shaft is collected and routed to the seal leakoff system for collection in various systems.

The radiological precautions associated with most common maintenance tasks are as follows:

- Reactor coolant pump motor replacement- High Radiation Area
- Reactor coolant pump seal replacement- High Radiation Area, high contamination levels and potential for > 1 DAC airborne

Steam Generators (S/Gs)

The purpose of the Steam Generators is to transfer the heat from the primary system to the secondary system. They provide a barrier between the radioactive and non-radioactive systems. The Steam Generators are vertical, U-tube heat exchangers. Primary coolant is in the tubes and

transfers the heat to the water on the outside of the tubes turning it into steam. Steam flows upward through the moisture separators and dryers before leaving.

The radiological precautions associated with most common maintenance tasks are as follows:

- Steam generator sludge lancing- High dose rates, high contamination levels, discrete radioactive particles or airborne
- Steam generator nozzle dam install/removal- potential for High dose rates, high contamination levels, discrete radioactive particles or airborne
- Eddy Current Testing- High dose rates

Pressurizer

The pressurizer is the component in the reactor coolant system which provides a means of controlling the system pressure. Pressure is controlled by the use of electrical heaters, pressurizer spray, power operated relief valves, and safety valves.

The pressurizer operates with a mixture of steam and water in equilibrium. If pressure starts to deviate from the desired value, the various components will actuate to bring pressure back to the normal operating point. The cause of the pressure deviation is normally associated with a change in the temperature of the reactor coolant system. If reactor coolant system temperature starts to increase, the density of the reactor coolant will decrease, and the water will take up more space. Since the pressurizer is connected to the reactor coolant system via the surge line, the water will expand up into the pressurizer. This will cause the steam in the top of the pressurizer to be compressed, and therefore, the pressure to increase.

The opposite effect will occur if the reactor coolant system temperature decreases. The water will become more dense, and will occupy less space. The level in the pressurizer will decrease, which will cause a pressure decrease. For a pressure increase or decrease, the pressurizer will operate to bring pressure back to normal.

For example, if pressure starts to increase above the desired setpoint, the spray line will allow relatively cold water from the discharge of the reactor coolant pump to be sprayed into the steam space. The cold water will condense the steam into water, which will reduce pressure (due to the fact that steam takes up about six times more space than the same mass of water). If pressure continues to increase, the pressurizer relief valves will open and dump steam to the pressurizer relief tank. If this does not relieve pressure, the safety valves will lift, also discharging to the pressurizer relief tank. If pressure starts to decrease, the electrical heaters will be energized to boil more water into steam, and therefore increase pressure. If pressure continues to decrease, and reaches a predetermined setpoint, the reactor protection system will trip the reactor.

The pressurizer relief tank is a large tank containing water with a nitrogen atmosphere. The water is there to condense any steam discharged by the safety or relief valves. Since the reactor coolant system contains hydrogen, the nitrogen atmosphere is used to prevent the hydrogen from existing in a potentially explosive environment

The radiological precautions associated with most common maintenance tasks are as follows:

- PZR manway removal / replacement- High Radiation Area, high contamination levels and the potential for > 1 DAC airborne
- PZR insulation removal/install- High Radiation Area, high contamination levels and the potential for > 1 DAC airborne
- Surge line shielding install / removal- High Radiation Area

Plant Operation

The reactor is normally operating at 100% power with all rods withdrawn above the fuel region. There is enough fuel loaded into the core for 12, 18 months of operation at full power. Each day some of the fuel burns up and there is less fuel to compete for the neutrons. This adds negative reactivity to the core and the core will produce less power.

With less power being produced the temperature of the water leaving the reactor will decrease and colder water will be returned to the core to add positive reactivity to balance the total core reactivity. The plant cannot operate day after day with the temperature decreasing. This would cause steam pressure to decrease and also put the temperature out of the range that where the safety analysis was conducted. To keep the temperature from lowering, some of the boron needs to be removed from the water in the Reactor Coolant System to add the positive reactivity. The Chemical Volume & Control System maintains the balance by receiving Letdown at the current Reactor Coolant System boron concentration and Charging back water into the Reactor Coolant System at a slightly lower concentration. This is the dilution process.

Decay Heat

Even when the reactor is shutdown there is a large amount of energy (heat) that is still being produced for years. The energy produced is referred to as Decay Heat and it must be removed to protect the fuel. Immediately upon a Reactor Trip the core is producing ~ 7% power, 1 hour after the reactor is shutdown ~ 1% power, and the power being produced goes down by ½ for every time interval. (1 hour = 1 %, 1 day = .5%, 1 week = .25%, 1 month = .125%, etc.)

Detailed System Operation

The reactor is normally operating at 100% power with all rods withdrawn above the fuel region. The core heats up the borated water to ~ 615°F and delivers it to the Steam Generators through two hot legs. The Steam Generator is a big u-tube heat exchanger.

Primary coolant is on the inside of the tubes and secondary feedwater is on the shell side. *The primary piping is the SECOND Fission Product Barrier.* The primary coolant heats the feedwater and causes it to boil, generating steam to drive the Main Turbine (MT). The now colder primary coolant leaves each Steam Generator through 2 cold legs at ~ 555°F. The water enters each Reactor Coolant Pump and is then pumped backed to the core.

The plant consists of 3 loops when operating and 3 different loops when shutdown. Although the goal above concentrates on operating the plant, it's just as important, if not more, to understand how the plant works when shutdown because there are fewer systems available and the potential for core damage still exists.

Plant Operating

When the plant is operating there are 3 loops working together to take the heat generated in the core from fission and convert it into electrical energy.

- Primary Loop
- Secondary Loop
- Circulating Water Loop

Radiological Conditions during normal operations-

- Extremely high dose rates due to gamma radiation from fission and Nitrogen-16 (fast) neutrons from the reactor. Only the upper Pressurizer is accessible at 100% power due to dose rates. Other areas like the inside of the Pump Bays and Reactor cavity have dose rates too high for personnel access. Dose rates on lowest level of containment may range from less than 100 mrem/hr combined gamma and neutron behind shield walls to several rem/hr under the loop piping and near the Pump Bay stairs.
- RCS Leaks would contain short lived nuclides, but the long lived nuclides would result in mrad/hr contamination levels depending on the leak severity. Technical specifications will determine the leak rates for identified and unidentified leak rates.
- Normally, only noble gases (Xe-133 and Kr-85) but more significant leaks could result in iodine or particulates. Containment airborne levels are less than 1 DAC at 100% power. This includes little or no detectable particulates (sometimes low levels of noble gas daughter products are found), little or no detectable iodines, and noble gas levels up to 1 DAC.

Plant Shutdown

When the plant is shutdown there are 3 different loops that work together to remove the heat from the core from prior fission events and transfer that heat to the atmosphere.

- Shutdown Cooling Loop
- Essential Cooling Water Loop
- Ultimate Heat Sink Loop

Residual Heat Removal (RHR) Loop or Decay Heat Removal or Shutdown Cooling

The shutdown cooling loop consists of a Reactor, a Residual Heat Removal Pump (this can be a Low Pressure Safety Injection Pump or a Containment Spray Pump), and a Residual Heat Removal Heat Exchanger.

Title: RP Fundamentals for Senior Task Qualifications

Lesson Plan #: RPFUN2

Even with the reactor shutdown there is a considerable amount of heat still being generated for years, called decay heat that must be removed. Hot water is taken from the core by the Residual Heat Removal Pump and sent to the Residual Heat Removal Heat Exchanger. The decay heat is transferred to the essential cooling water loop in the Residual Heat Removal Heat Exchanger and the cooled water is sent back to the core.

Component Cooling Water (CCW) Loop

The component cooling water loop consists of a Residual Heat Removal Heat Exchanger, a Component Cooling Water Pump and an Component Cooling Water Heat Exchanger.

The Component Cooling Water Pump circulates the water through the Residual Heat Removal Heat Exchanger where the heat is transferred from the primary coolant to the water in the component cooling water loop. The water is then sent to the Component Cooling Water Heat Exchanger where the heat is then transferred to the Service Water System. The cooled water is sent back to the Residual Heat Removal Heat Exchanger.

Service Water (SW) Loop

The Service Water loop consists of a Service Water Pump, an Component Cooling Water Heat Exchanger and the ultimate heat sink may be an ocean, river, sea, or and onsite cooling pond.

The Service Water Pump circulates water through the Component Cooling Water Heat Exchanger and removes heat from the component cooling water loop. The heated water is returned to the ocean, river, sea, or and onsite cooling pond where the water transfers the heat to the atmosphere.

One thing to remember is that ultimately all of the heat generated from the reactor must be removed and transferred to the atmosphere. When the plant is operating, approximately 65% of the heat is rejected to the atmosphere through the cooling towers. When the plant is shutdown 100% of the heat is transferred to the atmosphere through the RHR/CCW/SW systems.

Chemical and Volume Control System or Makeup and Purification System

The chemical volume and control system has two subsystems, letdown and charging. The purpose of this system is to provide the method for controlling pressurizer levels, RCS volume and chemistry control and a method for borating for shutdown. The water from the RCS is removed by the letdown subsystem. The purpose of letdown is to cool the RCS water and reduce its pressure to allow purification and chemical addition. It also compensates for volume changes caused by the RCS temperature driven density changes. Letdown water is reduced in pressure and temperature. The water is purified through the use of filters and ion exchangers. It is through this system interface that the RCS water can be directed through the waste systems. Waste systems consist of solid, liquid, and gaseous. The waste portion will be discussed later in the objective.

The letdown system starts in containment with the letdown isolation valves. The letdown system will direct the RCS flow through the following components in this order- letdown isolation valves, regenerative heat exchanger, letdown flow control valves, letdown heat exchanger, CVCS filters, CVCS ion exchangers and the volume control tank. The letdown isolation valves and the regenerative heat exchanger are located in containment. The remaining components are located in the auxiliary building.

The radiological precautions associated with most common maintenance tasks are as follows:

Title: RP Fundamentals for Senior Task Qualifications

Lesson Plan #: RPFUN2

- Letdown heat exchanger maintenance- High dose rate, high contamination and potential for airborne > 1 DAC
- Letdown flow control valve maintenance- High dose rates and high contamination levels
- CVC filters removal maintenance- High dose rate, high contamination, discrete radioactive particles and potential for airborne > 1 DAC
- CVCS filter replacement- Work in high dose rated areas
- CVCS Ion exchanger transfers- High dose rates
- VCT area work- High dose rates and potential explosive atmospheric area

The charging system allows for chemical additions and provides a method for returning water to the RCS. Some nuclear plants also called this subsystem as the make-up system. RCS water that has been treating through the letdown system will enter the charging pumps from the VCT. After leaving the charging pumps the water will then return to the RCS through the letdown isolation valves to the regenerative heat exchanger back to the reactor. Some plants have delay loops in Letdown so N-16 outside of containment is not a radiological concern.

The radiological precautions associated with most common maintenance tasks are as follows: If failed fuel has been indicated radiological concerns will raise for contamination levels to be increased greater than anticipated and increase the potential for alpha concerns.

Charging pump maintenance- high dose rates, high contamination levels and the potential for airborne radioactivity.

The make-up portion of this system will consist of four modes of make-up to the VCT.

Manual- used most often and is the blending of demineralized water and boric acid

Borate- used if raising boron concentrations

Dilute- user if lowering boron concentrations

Auto- used when not at power and anticipating large volume of makeup will be needed such as cool down. This auto starts pumps and operates valves to blend boric acid and demineralized water.

Normal process pumps boric acid or blended boric acid and demineralized water directly to the VCT. For fast boration, boric acid is pumped directly to the charging pump suction from the boric acid storage tanks or the refueling water tank. Other chemicals can be added to control the RCS water chemistry through the chemical addition tank and the zinc addition skid.

The chemical addition tank provides the ability to add chemicals like the following:

Lithium- PH Control

Hydrazine- Oxygen removal

Boric Acid- Reactivity control

Hydrogen Peroxide- Source term control

The zinc addition skid adds zinc to the RCS to prevent stress corrosion cracking and to replace CO-58 in the RCS piping crud layers for source term reduction.

Liquid Radwaste

The purpose of the RC waste system is to provide controlled handling and disposal of radioactive liquid waste from the reactor coolant system. This is accomplished by providing temporary storage for reactor coolant waste, process liquid waste prior to disposal to minimize releases to the environment and keeps effluence concentrations below regulatory limits. Sources of reactor coolant waste include the reactor coolant drain tanks, regenerative heat exchanger drain, safety injection system tank, Cold leg loop drains, quench tank drain, reactor coolant pump controlled bleed off relief valve, PASS return, hot leg drain, leak off from containment valves, reactor coolant pump vapor seal leak off and diversions from CVCS letdown. The reactor coolant drain tank pumps, pump water through the degasifier filters to the degasifier tank. The degasifier filters remove suspended impurities from waste liquid prior to it entering the degasifier tanks. Both waste from the reactor coolant drain tank and the letdown diversion passes through these filters. The degasifier tank's purpose is to remove hydrogen and other dissolved gases from the reactor coolant waste liquid. Incoming liquid is sprayed into the top of the degasifier through 4 nozzles to remove entrained gases. A vacuum pump is used to remove the gases. The result is liquid falling into a collection chamber at the bottom of the degasifier essentially free of gas. The pump removes water from the degasifier and transfers it to the in-service reactor coolant waste receive tank. We will discuss the waste gas system after the liquid waste portion of this lesson. Next in our flow path is the reactor coolant waste ion exchangers. Their purpose is to remove ionic impurities from the reactor coolant waste water prior to collection in the reactor coolant waste receiving tank or the reactor coolant waste monitoring tanks. The reactor coolant waste receiving tanks purpose is to serve as the initial auxiliary building collection point for reactor coolant waste. Liquid waste is then pumped to the reactor coolant waste monitoring tank via the reactor coolant ion exchanger. Reactor coolant ion exchangers are after the receiving tanks and after the monitoring tanks. Their purpose is to remove ionic impurities from reactor coolant waste water prior to collection in the receiver tank and monitoring tank. The reactor coolant waste monitoring tank's purpose is to provide a holding location for liquid waste to be sampled prior to disposal. Following sampling, two options exist: process the tank again to lower the concentrations of the radioactive materials or release the tank using circulating water flow for dilution. Reactor coolant waste is discharged using the same process as the miscellaneous liquid waste system. Rad monitors are used to ensure water being discharged do not exceed pre-established limits. Solid waste system can be further used to reduce concentrations prior to disposal. This system uses additional ion exchangers and filters for further reduction of concentrations from both the reactor coolant waste system and the miscellaneous waste system.

Radiological concerns with normal maintenance work include the following:

- Pump and valve overhaul and filter replacements- high levels of contamination, high dose rates, work in high dose rated areas, and potential for airborne radioactivity.
- Resin transfers- high dose rates and work in high dose rated areas

Radioactive Gas Storage

The waste gas system's purpose is to provide controlled handling and disposal of radioactive gaseous waste from the unit. This includes containment and auxiliary building sources. The

containment collection header will transfer gaseous waste from the reactor coolant drain tank and the quench tank vents. The primary auxiliary building header will transfer gaseous waste from the Volume control tank (Major source), Degasifier vacuum pumps (major source), degasifier relief valves, Primary sample hoods and the O₂ gas analyzer. Once the gaseous waste has been removed, it is transferred to the waste gas surge tank. The purpose of the waste gas surge tank is to provide a collection point for incoming gases and is the suction head and reservoir for the waste gas compressors. The purpose of the waste gas compressors is to transfer gas from the waste gas surge tank and to compressor the gas into the in-service waste gas storage tank. These storage tanks are sometimes referred to as the waste gas decay tanks. Their purpose to store radioactive gaseous waste to allow time for decay prior to release to the atmosphere. This goal is to allow enough time for decay of Xe-133 and shorter lived noble gases. This leaves Kr-85 as the primary noble gas released. After the waste gaseous have had time for decay, the gaseous waste passes through the waste gas HEPA filter. Then the gaseous waste will pass through an installed Radiation Monitoring System prior to being released through the main vent to the atmosphere. Radiological concerns with normal maintenance work include the following:

- Maintenance activities on the waste gas surge tank- high dose rates and the potential for airborne radioactivity concerns.

Basic Plant Components

In its simplest terms the plant operates by moving water from one location to another. In order to do this a variety of components are used to move the water through a system, from one system to another system, to control the temperature or phase of the water, or stop the flow of water altogether.

Valves and pumps were covered in the RP Junior Fundamental training, another component is a heat exchanger, demineralizers,

Heat Exchanger

A heat exchanger is a component that transfers heat between two substances at a different temperature. Heat is transferred from the hotter substance to the colder.

The heat transfer mechanism used in the plant heat exchangers is convection heat transfer. Convection heat transfer is a combination of conduction heat transfer, heat transfer through a solid, and the transfer of heat with a fluid in motion.

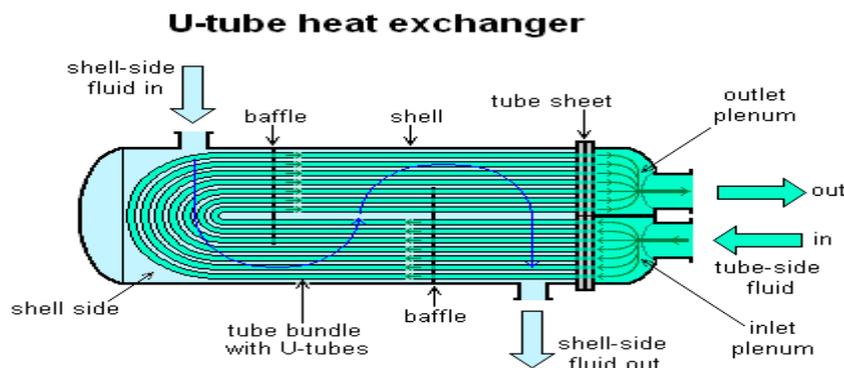
Metals are usually the best conductors of thermal energy. This is due to the way that metals are chemically bonded: metallic bonds (as opposed to covalent or ionic bonds) have free-moving **electrons and form a crystalline structure, greatly aiding in the transfer of thermal energy.**

As density decreases so does conduction. Therefore, fluids (and especially gases) are less conductive. This is due to the large distance between the atoms: fewer collisions between atoms means less conduction. Conduction does not occur at all in a perfect vacuum.

Forced convection occurs when a pump, fan or other means is used to propel the fluid and create the convection current.

In natural convection, or natural circulation, the fluid surrounding a heat source receives heat, becomes less dense and rises. The surrounding, cooler fluid then moves in to replace it. This cooler fluid is then heated and the process continues, forming a convection current. The driving force for natural convection is buoyancy, a result of differences in fluid density when gravity or any type of acceleration is present in the system.

Most of the heat exchangers that we use are counter flow. This means that the fluid that is being cooled and the cooling medium enter from opposite ends of the heat exchanger and travel towards each other. The major benefit from this type of heat exchanger is that the fluid being cooled can be cooled below the outlet temperature of the cooling medium.



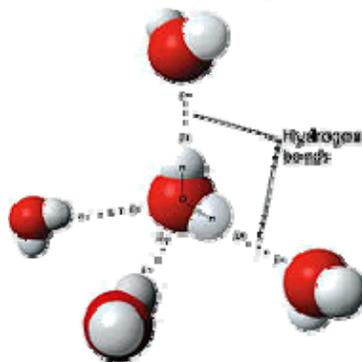
In most heat exchangers the higher pressure fluid is inside the tubes and the lower pressure is on the shell side because there will be less force on the shell side that has such a large surface area. As the high pressure enters the heat exchanger there are several different things that can happen.

- The fluid can pass straight through the tubes from one side to the other. (Inlet and Outlet are on opposite ends.)
- There can be a divider on the inlet that forces the fluid to the other end where it can mix again and then returned back to the inlet end. (Inlet and Outlet on the same end.)
- There can be a divider on the inlet that forces the fluid into U-tubes that doesn't allow the water to mix at the other end but returns the fluid back to the inlet end.

There are two types of cooling water systems, open and closed. Open cooling water systems are open to atmosphere. They need a regular source of makeup and you can touch the liquid in the system. Closed cooling water systems may need makeup once in a while but they have a surge tank to compensate for small volume changes.

Water

In typical usage, water refers only to its liquid form or state, but the substance also has a solid state, (ice) and a gaseous state (water vapor). Water is a chemical substance with the chemical formula H_2O : one molecule of water has two hydrogen atoms bonded to a single oxygen atom.



The major chemical and physical properties of water are:

Water is virtually incompressible. This fact enables you to increase the pressure of water without having to perform much work on the substance.

Water has the second highest specific heat capacity of any known chemical compound, after ammonia, as well as a high heat of vaporization, both of which are a result of the extensive hydrogen bonding between its molecules.

Pure water has a low electrical conductivity, but this increases significantly when a small amount of ionic material such as sodium chloride is added.

Saturation temperature (T_{Sat}) means *boiling point*. The saturation temperature is the temperature for a corresponding saturation pressure at which a liquid boils into its vapor phase.

Saturation pressure (P_{Sat}) is the pressure for a corresponding saturation temperature at which a liquid boils into its vapor phase. Saturation pressure and saturation temperature have a direct relationship: as saturation pressure is increased so is saturation temperature.

The boiling point of water is 212 °F at sea level. If the pressure is lowered, for example, on the top of Mt. Everest water boils at about 154 °F. If the pressure is raised then the boiling point will also rise.

Water sticks to itself. Water has a high surface tension caused by the strong cohesion between water molecules. Water also has a high adhesion property. Water is a very strong solvent referred to as *the universal solvent* dissolving many types of substances. The maximum density of water is at 39.16 °F. Water becomes even less dense upon freezing expanding 9%.

It may be weird to think of water as a component of the plant but it's the most vital component that we have. We accomplish our goal by moving water around or changing its state.

Steam

Steam refers to vaporized water. It is a pure, completely invisible gas. At standard temperature and pressure, pure steam (unmixed with air, but in equilibrium with liquid water) occupies about 1,600 times the volume of liquid water.

Steam most often refers to the white mist that condenses above boiling water as the hot vapor ("steam" in the first sense) mixes with the cooler air. This mist is made of tiny droplets of liquid water, not gaseous water, so it is no longer technically steam. In the spout of a steaming kettle, the spot where there is no condensed water vapor, where there appears to be nothing there, is steam.

A steam engine uses the expansion of steam in order to drive a turbine to perform mechanical work. Steam is a great reservoir for energy because of water's high heat of vaporization. The ability to return condensed steam as water-liquid to the boiler at high pressure with relatively little expenditure of pumping power is also important.

Understanding these basic components is essential to understanding the plant. The individual systems that make up the plant merely use these components in different combinations to achieve their function.

Fuel Assembly Construction

Basics

The fuel we use is Uranium 235. Natural Uranium is ~ 0.7% U^{235} and about 99.3% U^{238} . We enrich the fuel until the concentration of U^{235} is ~ 4%.

Most of the world's Uranium is mined in 4 major areas: Canada (27.9% of world production) Australia (22.8%) Kazakhstan (10.5%), Russia (8.0%). The US has only about 2.5% of the world's Uranium production.

Cladding material is made of high temperature alloy to support the fuel pellets. A common metal used is zirconium. The cladding is the first barrier to the release of fission products. In earlier plant designs the cladding would have residual amounts of uranium due to the mining and manufacturing process. Over the years the manufactures have improved this process to reduce and even eliminate this contamination. This was often referred to as *tramp uranium*. Radiation Protection will be responsible to oversee new fuel receipt inspections as well as inspections of fuel that has been in the core and may have a leak or foreign material lodged in the flow channels. Foreign material can reduce heat transfer which can lead to hot channels and ultimately fuel failures.

Processing

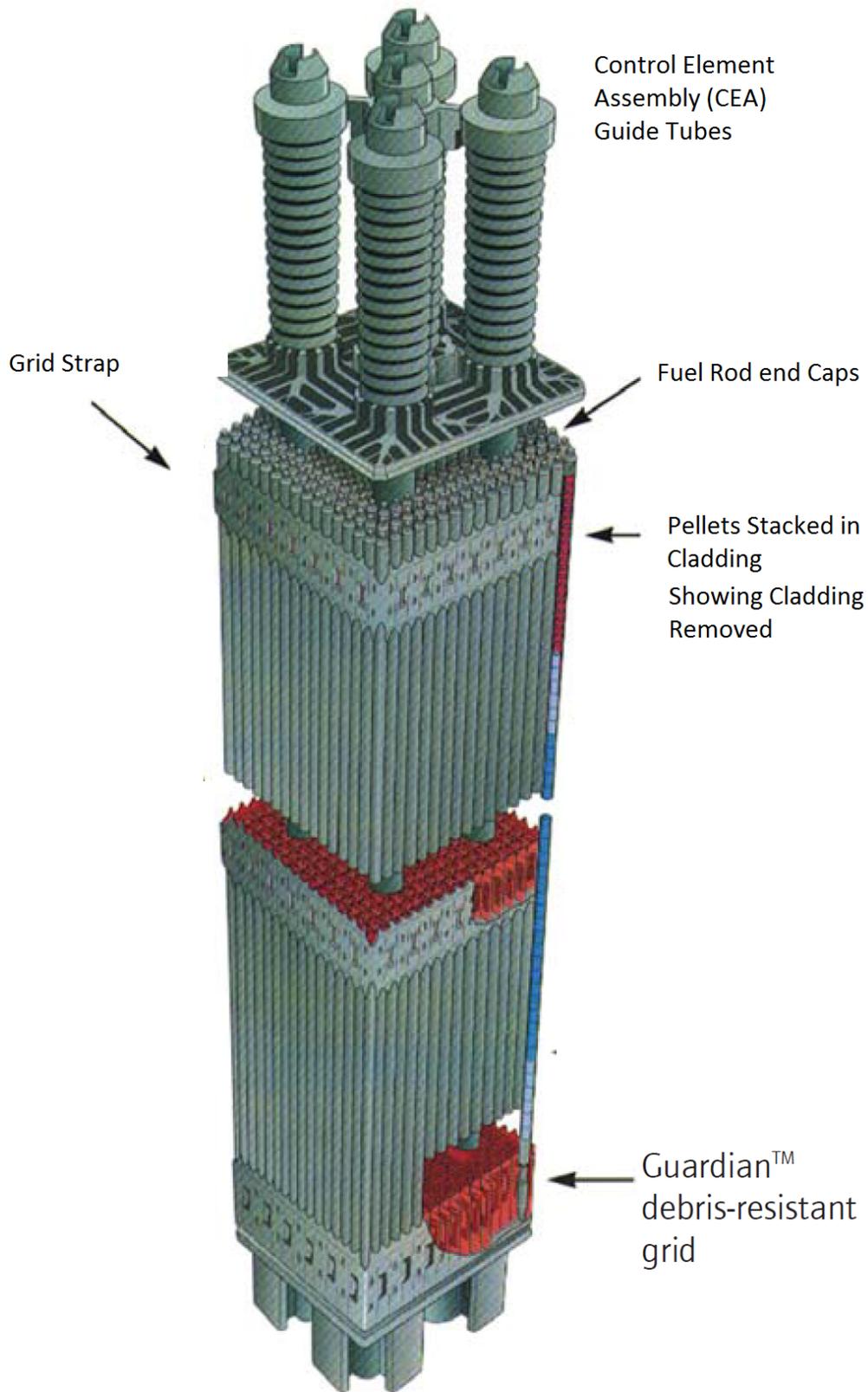
Uranium is mined out of the ground as an ore (rock) called Pitchblende.

The ore is taken to a facility and processed for packaging. The first step of the process is to put it into a sorter where the Uranium is separated from the other rock. Then it goes to a crusher that turns it into sand, a grinder then turns it into a powder. The powder is sent to a leach tank where it's made into slurry (a fluid mixture of a pulverized solid with a liquid). The good slurry is sent on to thickening and precipitations tanks so that it will settle into layers. At this point, the "Yellow Cake" layer is taken and dried and filtered so that the powder can be packaged for shipping to a conversion facility.

A conversion facility takes the yellow cake powder, U_3O_8 , and turns it into UF_6 gas. The gas is cooled down and turns back into a powder for shipping to the enrichment facility.

At an enrichment facility the UF_6 powder is heated and turned back into a gas and sent through many huge centrifuges. The centrifuges separate the heavier U^{238} from the U^{235} so that we get the proper concentration. The enriched gas is cooled down and turned back into a powder so it can be shipped to the fabrication facility.

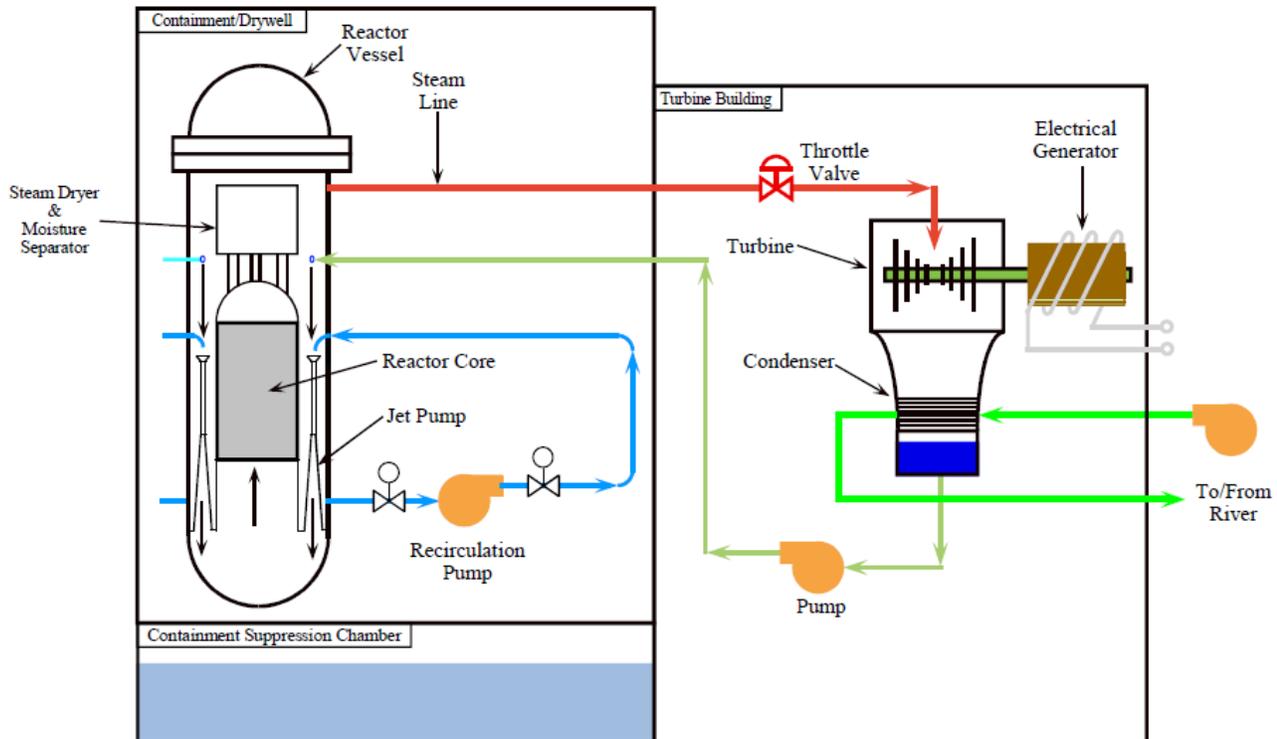
The fabrication facility takes the UF_6 powder and converts it into a UO_2 powder. This powder is pressed into pellets that are baked and cut to the right shape. The pellets are loaded into the fuel rods and the fuel rods are loaded into the cages to form an assembly. After the assemblies are inspected they are shipped to us by truck.



FUEL ASSEMBLY

Fuel Pellet



Boiling Water Reactor

Inside the boiling water reactor (BWR) vessel, a steam water mixture is produced when very pure water (reactor coolant) moves upward through the core absorbing heat. The major difference in the operation of a BWR from other nuclear systems is the steam void formation in the core. The steam-water mixture leaves the top of the core and enters the two stages of moisture separation, where water droplets are removed before the steam is allowed to enter the steam line. The steam line, in turn, directs the steam to the main turbine causing it to turn the turbine and the attached electrical generator. The unused steam is exhausted to the condenser where it is condensed into water. The resulting water is pumped out of the condenser with a series of pumps and back to the reactor vessel. The recirculation pumps and jet pumps allow the operator to vary coolant flow through the core and change reactor power.

The reactor vessel assembly consists of the reactor vessel and its internal components, including the core support structures, core shroud, moisture removal equipment, and jet pump assemblies. The purposes of the reactor vessel assembly are to:

- House the reactor core,
- Serve as part of the reactor coolant pressure boundary,
- Support and align the fuel and control rods,
- Provide a flow path for circulation of coolant past the fuel,
- Remove moisture from the steam exiting the core, and
- Provide a refloodable volume for a loss of coolant accident.

The reactor vessel is vertically mounted within the drywell and consists of a cylindrical shell with an integral rounded bottom head. The top head is also rounded in shape but is removable via the stud

and nut arrangement to facilitate refueling operations. The vessel assembly is supported by the vessel support skirt which is mounted to the reactor vessel support pedestal.

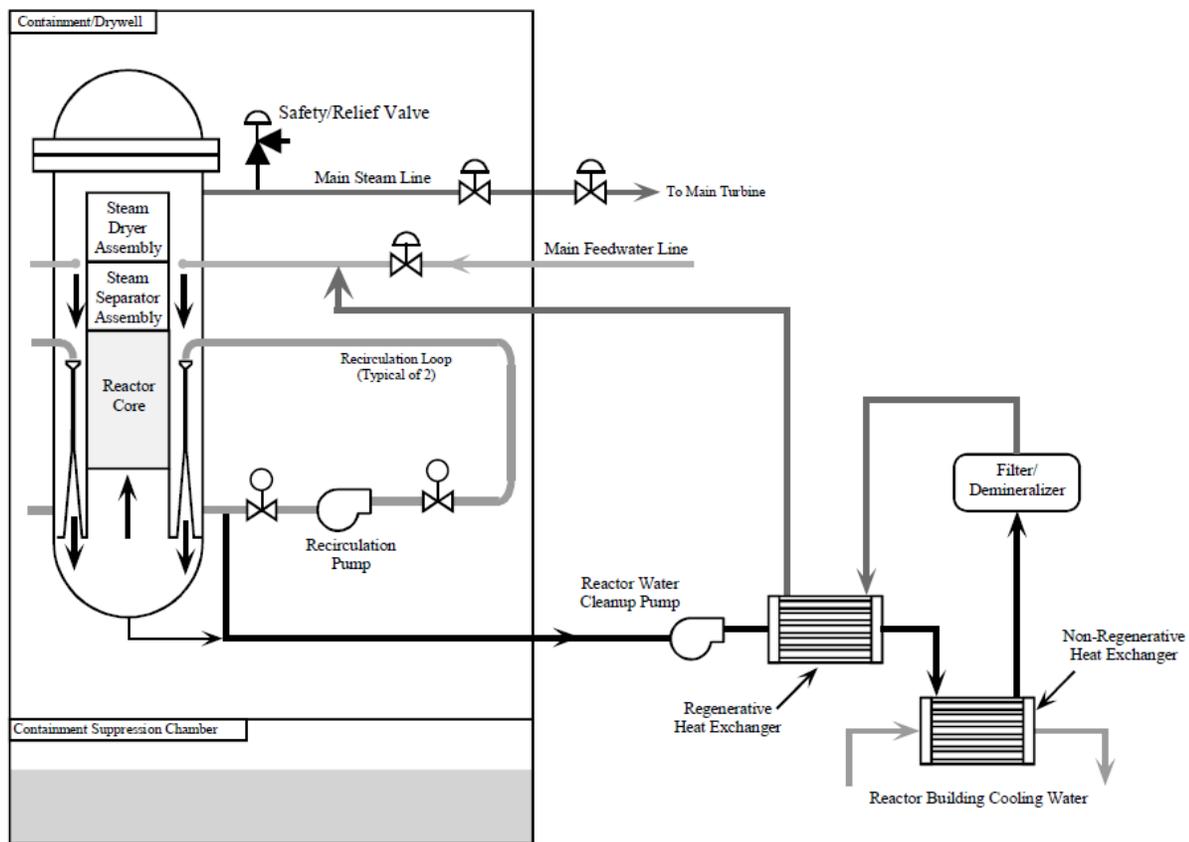
The internal components of the reactor vessel are supported from the bottom head and/or vessel wall. The reactor core is made up of fuel assemblies, control rods, and neutron monitoring instruments. The structure surrounding the active core consists of a core shroud, core plate, and top guide. The components making up the remainder of the reactor vessel internals are the jet pump assemblies, steam separators, steam dryers, feedwater spargers, and core spray spargers. The jet pump assemblies are located in the region between the core shroud and the vessel wall, submerged in water. The jet pump assemblies are arranged in two semicircular groups of ten, with each group being supplied by a separate recirculation pump.

The emergency core cooling systems, and the reactor vessel designs are compatible to ensure that the core can be adequately cooled following a loss of reactor coolant. The worst case loss of coolant accident, with respect to core cooling, is a recirculation line break. In this event, reactor water level decreases rapidly, uncovering the core. However, several emergency core cooling systems automatically provide makeup water to the nuclear core within the shroud, providing core cooling.

Each control cell consists of a control rod and four fuel assemblies that surround it. Unlike the pressurized water reactor fuel assemblies, the boiling water reactor fuel bundle is enclosed in a fuel channel to direct coolant up through the fuel assembly and act as a bearing surface for the control rod. In addition, the fuel channel protects the fuel during refueling operations. The power of the core is regulated by movement of bottom entry control rods.

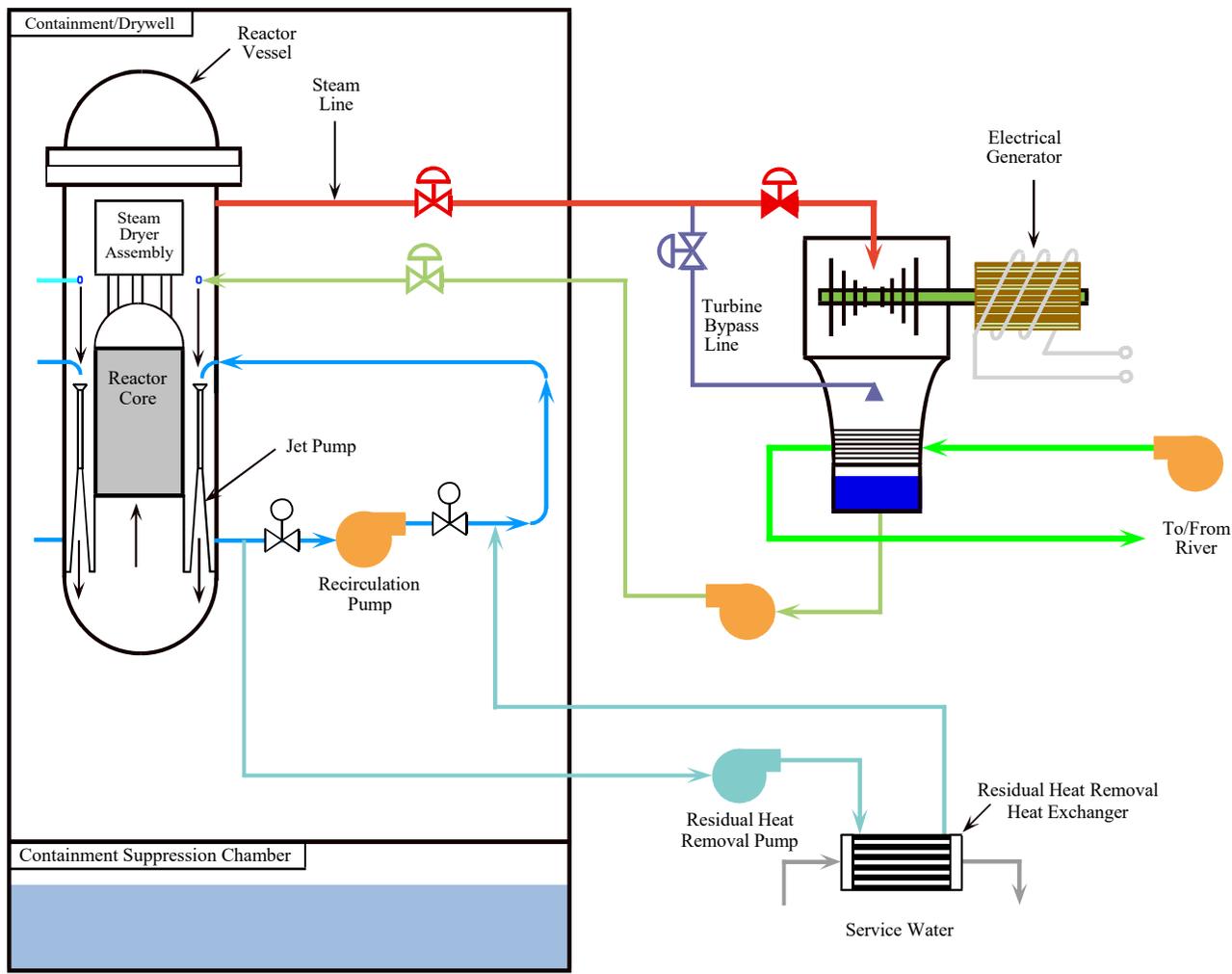
Reactor Water Cleanup System

The purpose of the reactor water cleanup system (RWCU) is to maintain a high reactor water quality by removing fission products, corrosion products, and other soluble and insoluble impurities. The reactor water cleanup pump takes water from the recirculation system and the vessel bottom head and pumps the water through heat exchangers to cool the flow. The water is then sent through filter/demineralizers for cleanup. After cleanup, the water is returned to the reactor vessel via the feedwater piping.



Decay Heat Removal

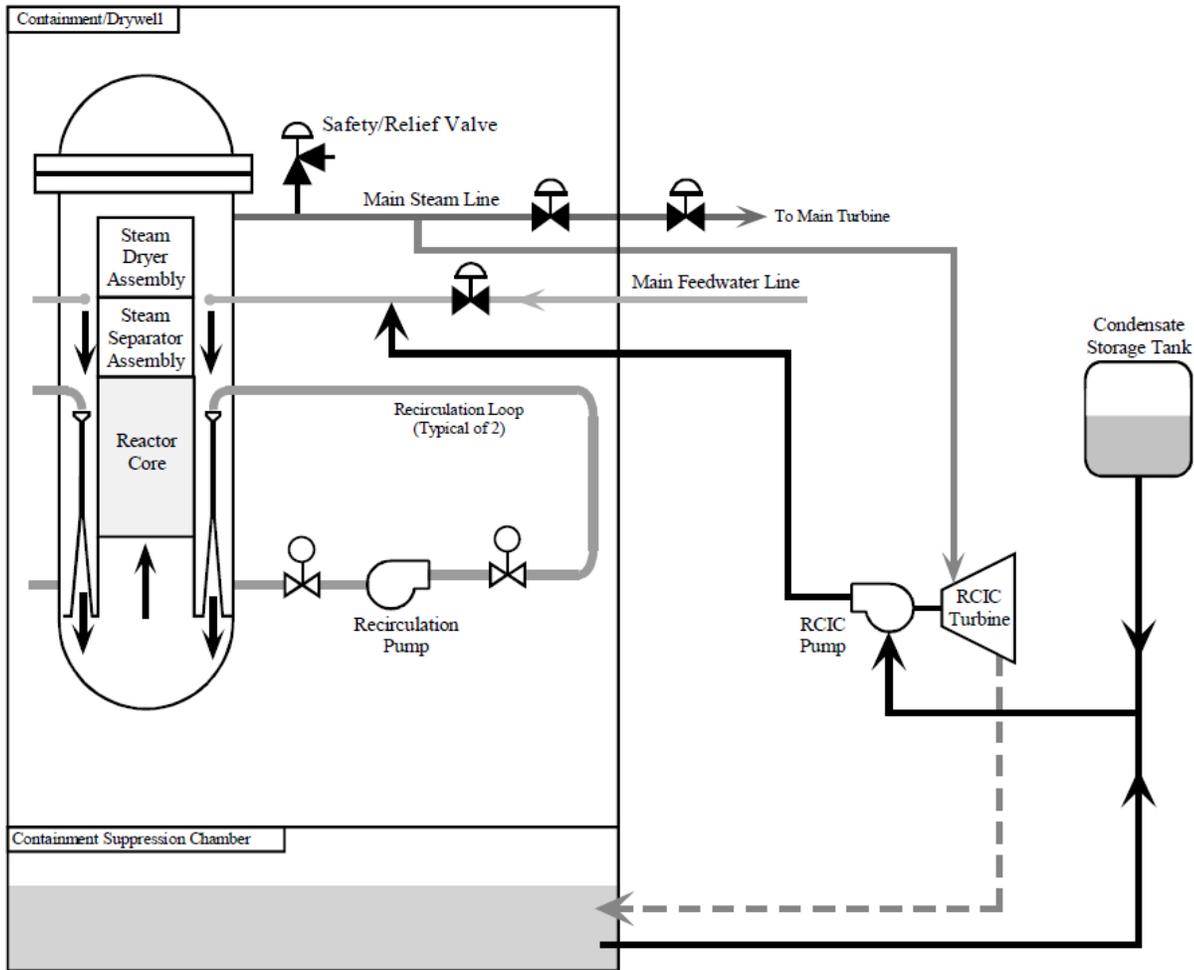
Heat is removed during normal power operation by generating steam in the reactor vessel and then using that steam to generate electrical energy. When the reactor is shutdown, the core will still continue to generate decay heat. The heat is removed by bypassing the turbine and dumping the steam directly to the condenser. The shutdown cooling mode of the residual heat removal (RHR) system is used to complete the cooldown process when pressure decreases to approximately 50 psig. Water is pumped from the reactor recirculation loop through a heat exchanger and back to the reactor via the recirculation loop. The recirculation loop is used to limit the number of penetrations into the reactor vessel.



Reactor Core Isolation Cooling

The reactor core isolation cooling (RCIC) system provides makeup water to the reactor vessel for core cooling when the main steam lines are isolated and the normal supply of water to the reactor vessel is lost. The RCIC system consists of a turbine-driven pump, piping, and valves necessary to deliver water to the reactor vessel at operating conditions.

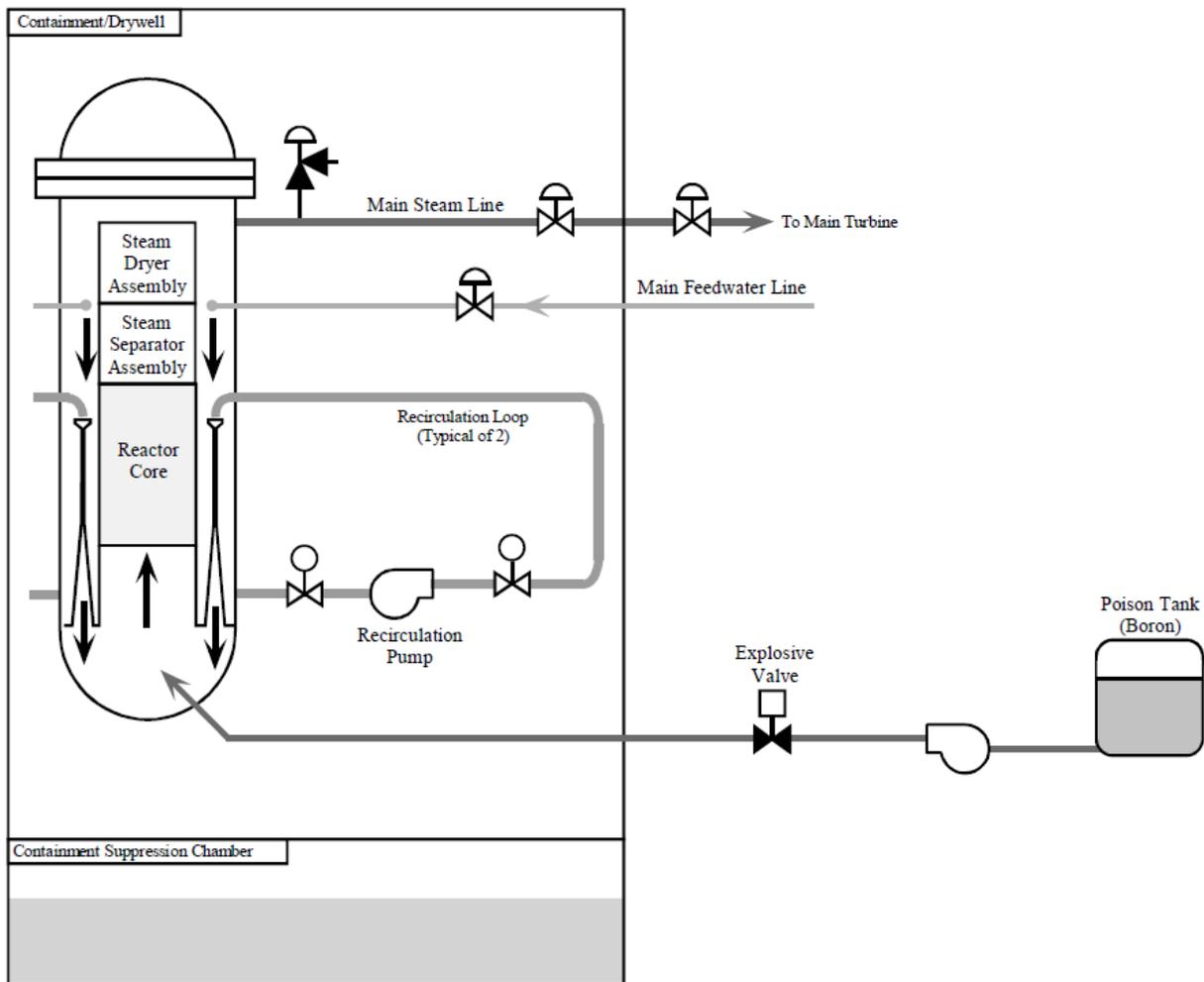
The turbine is driven by steam supplied by the main steam lines. The turbine exhaust is routed to the suppression pool. The turbine-driven pump supplies makeup water from the condensate storage tank, with an alternate supply from the suppression pool, to the reactor vessel via the feedwater piping. The system flow rate is approximately equal to the steaming rate 15 minutes after shutdown with design maximum decay heat. Initiation of the system is accomplished automatically on low water level in the reactor vessel or manually by the operator.



Standby Liquid Control System

The standby liquid control system injects a neutron poison (boron) into the reactor vessel to shut down the chain reaction, independent of the control rods, and maintains the reactor shutdown as the plant is cooled to maintenance temperatures.

The standby liquid control system consists of a heated storage tank, two positive displacement pumps, two explosive valves, and the piping necessary to inject the neutron absorbing solution into the reactor vessel. The standby liquid control system is manually initiated and provides the operator with a relatively slow method of achieving reactor shutdown conditions.



Emergency Core Cooling Systems

The emergency core cooling systems (ECCS) provide core cooling under loss of coolant accident conditions to limit fuel cladding damage. The emergency core cooling systems consist of two high pressure and two low pressure systems. The high pressure systems are the high pressure coolant injection (HPCI) system and the automatic depressurization system (ADS). The low pressure

systems are the low pressure coolant injection (LPCI) mode of the residual heat removal system and the core spray (CS) system.

The manner in which the emergency core cooling systems operate to protect the core is a function of the rate at which reactor coolant inventory is lost from the break in the nuclear system process barrier. The high pressure coolant injection system is designed to operate while the nuclear system is at high pressure. The core spray system and low pressure coolant injection mode of the residual heat removal system are designed for operation at low pressures. If the break in the nuclear system process barrier is of such a size that the loss of coolant exceeds the capability of the high pressure coolant injection system, reactor pressure decreases at a rate fast enough for the low pressure emergency core cooling systems to commence coolant injection into the reactor vessel in time to cool the core.

Automatic depressurization is provided to automatically reduce reactor pressure if a break has occurred and the high pressure coolant injection system is inoperable. Rapid depressurization of the reactor is desirable to permit flow from the low pressure emergency core cooling systems so that the temperature rise in the core is limited to less than regulatory requirements.

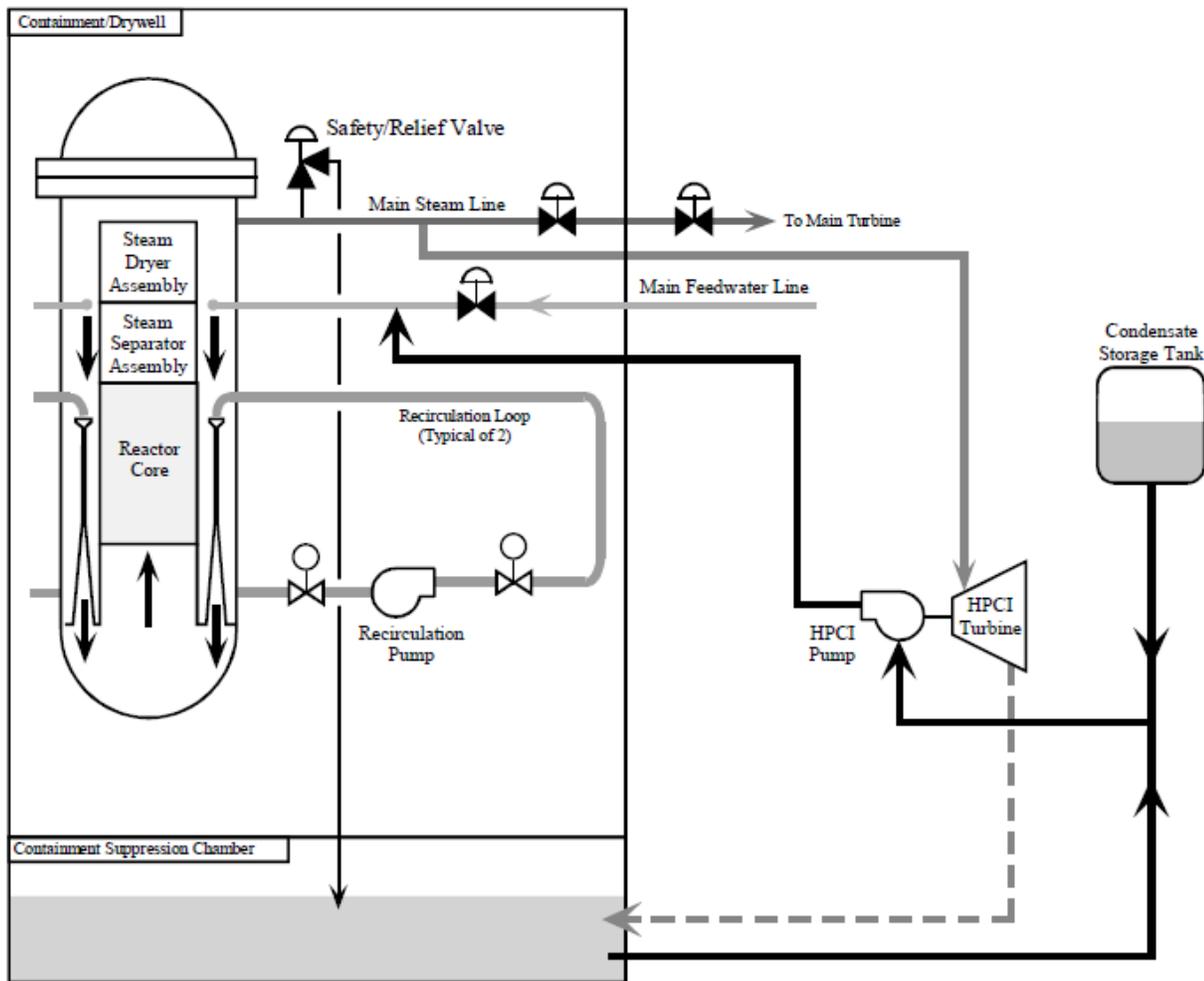
If, for a given break size, the high pressure coolant injection system has the capacity to make up for all of the coolant loss, flow from the low pressure emergency core cooling systems is not required for core cooling protection until reactor pressure has decreased below approximately 100 psig.

The performance of the emergency core cooling systems as an integrated package can be evaluated by determining what is left after the postulated break and a single failure of one of the emergency core cooling systems. The remaining emergency core cooling systems and components must meet the 10 CFR requirements over the entire spectrum of break locations and sizes.

High Pressure Emergency Core Cooling Systems

The high pressure coolant injection (HPCI) system is an independent emergency core cooling system requiring no auxiliary ac power, plant air systems, or external cooling water systems to perform its purpose of providing make up water to the reactor vessel for core cooling under small and intermediate size loss of coolant accidents. The high pressure coolant injection system can supply make up water to the reactor vessel from above rated reactor pressure to a reactor pressure below that at which the low pressure emergency core cooling systems can inject.

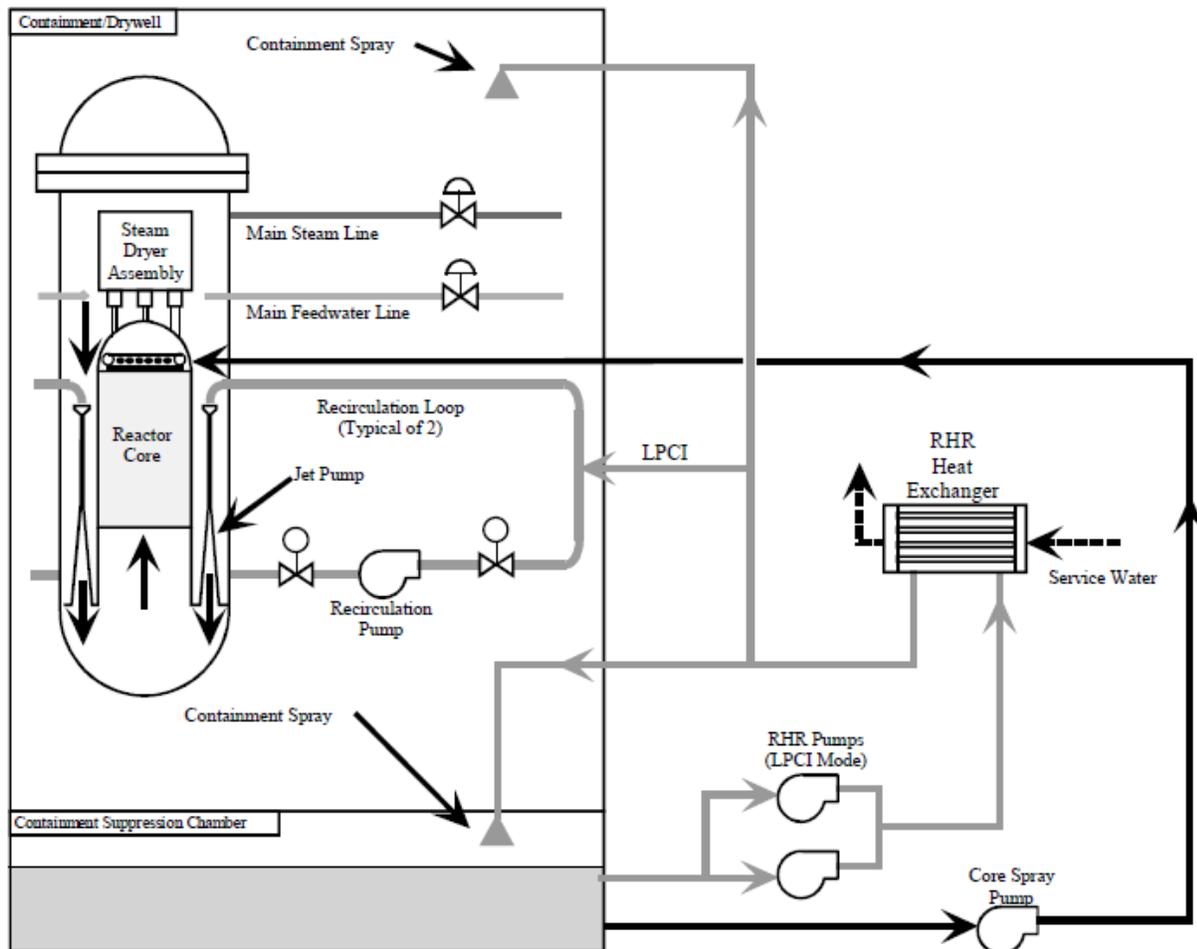
The automatic depressurization system (ADS) consists of redundant logics capable of opening selected safety relief valves, when required, to provide reactor depressurization for events involving small or intermediate size loss of coolant accidents if the high pressure coolant injection system is not available or cannot recover reactor vessel water level.



Low Pressure Emergency Core Cooling Systems

The low pressure emergency core cooling systems consist of two separate and independent systems, the core spray system and the low pressure coolant injection (LPCI) mode of the residual heat removal system. The core spray system consists of two separate and independent pumping loops, each capable of pumping water from the suppression pool into the reactor vessel. Core cooling is accomplished by spraying water on top of the fuel assemblies.

The low pressure coolant injection mode of the residual heat removal system provides makeup water to the reactor vessel for core cooling under loss of coolant accident conditions. The residual heat removal system is a multipurpose system with several operational modes, each utilizing the same major pieces of equipment. The low pressure coolant injection mode is the dominant mode and normal valve lineup configuration of the residual heat removal system. The low pressure coolant injection mode operates automatically to restore and, if necessary, maintain the reactor vessel coolant inventory to preclude fuel cladding temperatures in excess of 2200 °F. During low pressure coolant injection operation, the residual heat removal pumps take water from the suppression pool and discharge to the reactor vessel.



Boiling Water Reactor Containments

The primary containment package provided for a particular product line is dependent upon the vintage of the plant and the cost-benefit analysis performed prior to the plant being built. During the evolution of the boiling water reactors, three major types of containments were built. The major containment designs are the Mark I, Mark II, and the Mark III. Unlike the Mark III, that consists of a primary containment and a drywell, the Mark I and Mark II designs consist of a drywell and a wetwell (suppression pool). All three containment designs use the principle of pressure suppression for loss of coolant accidents. The primary containment is designed to condense steam and to contain fission products released from a loss of coolant accident so that offsite radiation doses specified in 10 CFR 100 are not exceeded and to provide a heat sink and water source for certain safety related equipment.

The Mark I containment design consists of several major components. These major components include:

- The drywell, which surrounds the reactor vessel and recirculation loops,
- A suppression chamber, which stores a large body of water (suppression pool),
- An interconnecting vent network between the drywell and the suppression chamber, and
- The secondary containment, which surrounds the primary containment (drywell and suppression pool) and houses the spent fuel pool and emergency core cooling systems.

The Mark II primary containment consists of a steel dome head and either a post-tensioned concrete wall or reinforced concrete wall standing on a base mat of reinforced concrete. The inner surface of the containment is lined with a steel plate that acts as a leak-tight membrane. The containment wall also serves as a support for the floor slabs of the reactor building (secondary containment) and the refueling pools. The Mark II design is an over-under configuration. The drywell, in the form of a frustum of a cone or a truncated cone, is located directly above the suppression pool. The suppression chamber is cylindrical and separated from the drywell by a reinforced concrete slab. The drywell is topped by an elliptical steel dome called a drywell head. The drywell inerted atmosphere is vented into the suppression chamber through a series of downcomer pipes penetrating and supported by the drywell floor.

The Mark III primary containment consists of several major components.

The drywell is a cylindrical, reinforced concrete structure with a removable head. The drywell is designed to withstand and confine steam generated during a pipe rupture inside the containment and to channel the released steam into the suppression pool via the weir wall and the horizontal vents. The suppression pool contains a large volume of water for rapidly condensing steam directed to it. A leak tight, cylindrical, steel containment vessel surrounds the drywell and the suppression pool to prevent gaseous and particulate fission products from escaping to the environment following a pipe break inside containment.

Main Steam System

The BWR Main Steam System directs the flow of steam, which has been produced in the reactor, to the main turbine and other equipment which make use of the primary steam.

As water boils in the reactor, steam flows through the Moisture Separator and the Steam Dryer before exiting the reactor via the main steam lines. Main Steam Isolation Valves (MSIV) inside and outside containment ensure that containment can be isolated, and the flow of steam positively stopped. Steam flows past the MSIVs and to the Main Turbine via the Main Steam Lines. MSIVs are designed to fail closed very quickly, in about 3 to 5 seconds, to ensure the flow of steam is stopped and containment is isolated very quickly.

Safety Relief Valves and Emergency Relief Valves are located on the steam lines and will open to exhaust the reactor in the case of an over-pressurization event, which could occur upon closure of the MSIVs. These valves exhaust to the suppression pool, or on some units, the Torus, or the containment itself. The steam contains radioactive material and creates a contamination issue if not controlled or anticipated prior to personnel entries to affected areas.

A series of valves controls the flow of steam to the High-Pressure Turbine and three Low Pressure Turbines. This ensures the right amount of steam is introduced to each turbine at the right time to maximize driving force and minimize torsional strain along the Main Turbine Shaft. The steam driving the turbine flows through Moisture Separators which remove any droplets of water that have formed as the steam progresses through the piping and the turbine internals.

Steam found in the Main Steam System is highly radioactive, containing short-lived isotopes that create dose rates and cause radiological conditions requiring position and controls for Locked High Radiation Areas. The principal contributor to dose rates in the first minute that the steam is in the system is N-16, which emits significantly high energy gamma photons during decay.

Main Condenser

The BWR Main Condenser condenses and de-aerates exhaust steam from the Main Turbine, the Reactor Feed Pump Turbines (RFPTs) and the Main Turbine Bypass Valves (BPVs). It is the heatsink for hot water/steam from various feedwater heaters and related system drains as well. The condenser drains to the hotwell, which collects water and allows for a period of decay to minimize the presence of short-lived radioisotopes. The hotwell provides a suction head for the condensate pumps. The condenser, hotwell, and associated equipment contain radioactive primary coolant, and have dose rates creating Radiation Areas and High Radiation areas. The water is a source of contamination due to the presence of radioisotopes.

Air Ejector System

Non-condensable gasses must be removed by the Steam Jet Air Ejectors, which use steam to draw a suction on the air-filled portions of the condenser. The gasses removed are highly radioactive and create Locked High Radiation Areas in the rooms associated with the Air Ejector system.

The Air Ejector system feeds highly radioactive gasses to the Off-Gas system where decay time and filtration is designed into the flow path. A catalytic converter or Recombiner, acts to 'recombine' hydrogen and oxygen, those gases which make up water. Radioactive gasses that are not able to be recombined into water are eventually released to the atmosphere as off-gas. Release rates and radioactivity concentrations are subject to controls of the Offsite Dose Calculation Manual (ODCM) which ensures the plant stays within release rate limits of Federal, state and local requirements. Filters and charcoal beds, as well as 'hold up times' act to minimize the amount of radioactivity released. The radioactivity that is eventually released includes isotopes of Krypton and Xenon, which are short-lived and quickly decay to non-radioactive forms.

Condensate and Feedwater Systems

The Condensate System in a BWR uses condensate pumps to remove water from the hotwell and send it under pressure through water purifying demineralizers and heaters to bring it to temperature, pressure and quality suitable to return to the reactor. The demineralizers may be Deep Bed Demins or Filter Demins, or a combination of both. All primary system water in the Condensate System is radioactive in a BWR which distinguishes it from the Condensate System of a PWR.

The Feedwater System receives water from the demineralizers and heats it to a temperature suitable to be reintroduced to the reactor. This involves routing the feedwater through a series of heat exchangers where it is heated to a higher temperature in preparation for its return to the reactor. Though purified by the demineralizers, this water remains radioactive and presents a contamination hazard if leaked or spilled and highlighting the principle difference from a similar system in a PWR.

Reactor Feedwater

BWR Reactor Feed Pumps (RFP), which return the feedwater to the reactor, may be driven by main steam or other motive force. When main steam is used as a driver, the RFPs are connected to turbines that use radioactive steam to drive the pumps. The presence of main steam presents a potential for spread of contamination and the possibility of airborne radioactivity when steam leaks occur. Even a minor, almost undetectable leak can create areas of short-lived gaseous activity that will affect personnel contamination monitoring and may require posting for airborne conditions.

Traversing In-core Probes (TIPs)

The TIPs in a BWR are retractable detectors used to provide calibration data for the Power Range Monitors, which are used to ascertain the power level of the reactor by measuring neutron and gamma flux. Each TIP is either a fission chamber or a gamma detector that is normally housed in a shield cave outside of containment. The detectors are mechanically inserted into the core at power to gather live-time information about neutron flux that is used to calibrate the various types of Power Range Monitors. The TIP detectors become activated themselves and in the case of the fission chambers, are subject to fission while in use. This requires extreme care and control of the

**Title: RP Fundamentals for Senior Task
Qualifications****Lesson Plan #: RPFUN2**

TIPS when they are withdrawn from the core. They create a Locked High Radiation Area and may actually create a Very High Radiation Area, sometimes requiring the 'Grave Danger' posting and LHRA controls. Extreme caution must be exercised by personnel entering areas where TIPS are located. Additionally, work around the drive mechanisms must also be conducted with proper planning and controls as the loss of control of the drive controls has resulted in withdrawal of TIPS from shields into general areas of the Reactor Building. RP Technicians who are assigned to cover work or complete surveys in these areas must be aware of the dose rates and their impact to personnel stay times and other exposure controls.

EO: 1.5 Discuss the normal uses, locations, advantages, disadvantages, and relative sensitivity of a portable frisker, whole-body contamination monitor, portal monitor, bag counters, tool monitors, and conveyor type contamination monitors

Whole Body Contamination Monitors (WBCM)

Prior to exiting a radiologically controlled area workers normally self-monitor using non-portable contamination monitors.

Most whole-body contamination monitors (WBCMs) are microprocessor-based radiation detection systems that use an array of gas flow proportional detectors that provide an excellent geometry for surface beta-gamma contamination detection with options for alpha capabilities.

The normal monitoring process consists of a two part (front – back) survey that ensures the whole body is monitored. When an individual enters the WBCM and is properly positioned the counting process will begin. If no alarm set points are exceeded the unit will inform the individual to re-position to begin the second count. If no alarms set points are exceeded the unit will inform the individual that they are cleared to exit.

The PCM has body position indicators that will stop the count if individual to not maintain the proper position relative to the detectors.

If any alarm set points are exceeded the WBCM will inform the individual that they are contaminated. Radiation Protection technicians can review the WBCM display to determine the general location and levels of contamination on the individual.

Individuals who clear the WBCM normally are directed to pass through a portal monitor (PM) prior to final exit of the RCA.

Portal monitors

The Gamma-Sensitive portal monitor (PM) provides personnel with an external whole body monitoring system. The contamination detectors within the monitors are capable of performing a survey of the whole body in a period of a few seconds, dependent upon background radiation levels present in the area and the personnel contamination limit of concern. These automated systems typically provide a more reliable method of locating personnel contamination over hand-held instruments.

The portal monitor is a "door frame" type device which provides a final monitoring point to ensure contamination is not spread outside the facility to other facilities or the general public. These types of monitors are typically used only for gamma monitoring.

Portal Monitors are micro-process controlled units containing five to eight gamma-sensitive plastic scintillation detectors.

Photo-electric switches sense when individuals enter the portal and will initiate the counting process. If contamination is detected the unit will alarm and indicate which detectors are in alarm. If no contamination is detected the individual will be directed to exit the PM.

Tool Monitors

Tool Equipment Monitors (TEM) are normally used to monitor small hand-held items for unconditional release from radiological controlled areas. Additionally, there are larger TEMs that have the capability to monitor large items, such as bags and drums. These monitors use from four to six large area gamma scintillation detectors to monitor items that can be placed inside the sample chamber. The chamber is lined with lead and the monitor is extremely heavy.

Individuals exiting the RCA are normally permitted to place personal items inside the TEM for prior to release. Items that alarm the TEM shall be disposition by an ANSI qualified Radiation Protection technician.

Non-personnel items can be released per NISP-RP-07 Control of Radioactive Material.

Portable Frisker

Portable friskers are used for beta, gamma or alpha contamination surveys and may be Geiger-Mueller or scintillation detectors.

Recommended requirements using a portable frisker:

1. General guidelines for handheld monitoring using a hand-held radioactive contamination survey instrument include the following:
 - a. Verify the instrument is on, set to the proper scale, and within the calibration date.
 - b. Verify instrument response and source check.
 - c. Ensure the audible function of the instrument is on and can be heard.
 - d. Determine the instrument background. (Insert facility/site-specific information concerning acceptable background rates).
 - e. Survey hands before picking up the probe.
 - f. Hold the probe approximately $\frac{1}{2}$ " from the surface being surveyed for beta/gamma and $\frac{1}{4}$ " for alpha radiation.
 - g. Move probe slowly over the surface, approximately 2" per second.
 - h. If the count rate increases during frisking, pause for 5 to 10 seconds over the area to provide adequate time for instrument response. When scanning for contamination there is a delay in instrument response and the cause of the increased count rate might be back a short distance from where the increased count rate was observed.
2. The consequences of not performing an adequate contamination survey may include: unnecessary dose to the worker; spread of contamination; the potential for inadvertent release of RAM; regulatory action and potential for violations.

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The preferred method for exiting a radiologically controlled area is via the Whole-Body Contamination Monitor (WBCM) and Gamma Sensitive Portal Monitor (PM) with the frisker as the least preferred.

SUMMARY OF MAIN PRINCIPLES

The following items are things to consider in your lesson summary. They are not mandatory. You should develop your own summary.,

Objectives Review

Review the Lesson Objectives

Topic Review

Restate the main principles or ideas covered in the lesson. Relate key points to the objectives. Use a question and answer session with the objectives.

Questions and Answers

Oral questioning

Ask questions that implement the objectives. Discuss students answers as needed to ensure the objectives are being met.

Problem Areas

Review any problem areas discovered during the oral questioning, quiz, or previous tests, if applicable. Use this opportunity to solicit final questions from the students (last chance).

Concluding Statement

If not done in the previous step, review the motivational points that apply this lesson to students needs. If applicable, end with a statement leading to the next lesson.

You may also use this opportunity to address an impending exam or practical exercise.

Should be used as a transitional function to tie the relationship of this lesson to the next lesson. Should provide a note of finality.