



Reactor Coolant System

ACADs (08-006) Covered

1.2.1.17 1.1.4.6 1.1.9.1.4 1.1.9.1.5 2.1.11.1 3.1.1.12 3.1.1.15
4.2.7.9 4.2.7.27

Keywords

Interfaces, modes of operation, fission product release barrier, reactor vessel, coolant pumps, steam generators, pressurizer, loops, flow path, fuel rods, control element.

Description

This document contains information and links to materials which can be used to create a lesson on reactor coolant systems.

Supporting Material

Systems Training Manual Volume 39 "Reactor Coolant System"

PVNGS Final Safety Analysis Report, Chapter 5

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***PALO VERDE
NUCLEAR GENERATING STATION***

Instrumentation & Controls Training

Classroom Lesson

I&C Program		Date: 07/12/2000
LP Number: NIA9902XC002	Rev. : 01	Rev Author: Norman R. Cooley
Title: Reactor Coolant System		Technical Review:Robin T. Meredith
Duration : 2.5 Hours		
		Teaching Approval:

INITIATING DOCUMENTS:

Site Maintenance Training Program Description

PROCEDURES

NONE

REQUIRED TOPICS

NONE

CONTENT REFERENCES

Systems Training Manual Volume 39 "Reactor Coolant System"
PVNGS Final Safety Analysis Report, Chapter 5

Tasks Covered

The following tasks are covered in Reactor Coolant System:

Task Number*	Task Statement
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Total tasks: 0

TERMINAL OBJECTIVE:

- 1.0** Given the appropriate references,, the participant will be able to recognize the components, purposes and capabilities of the Reactor Coolant System.
 - 1.1** Identify the basic function of the Reactor Coolant System (RCS)
 - 1.2** Identify the major components and system interfaces of the Reactor Coolant System.
 - 1.3** Recognize the modes of RCS operation.
 - 1.4** Recognize the first and second fission product release barriers within the Reactor Coolant System.

Lesson Introduction: Reactor Coolant System

CLASSROOM GUIDELINES

- If applicable, remind students of class guidelines as posted in the classroom.
- Attendance Sheet
- Pass the attendance sheet around and have it signed in black ink.
- Materials
- Ensure that student materials needed for the class are available for each student. (For materials required, refer to the list of materials on the cover page.)
- Questions and Participation
- Emphasize student participation and remind them of your philosophy on asking and answering questions, if applicable.

ATTENTION STEP

- Give a brief statement or story to get student concentration focused on the lesson subject matter.

LESSON INTRODUCTION

- Give a brief statement which introduces the specific lesson topic. Should be limited to a single statement.

MOTIVATION

- Focus students attention on the benefits they derive from the training. At Instructors discretion. The need for remotivation in each succeeding lesson must be analyzed by the Instructor and presented as necessary.
- Instructor should include how the STAR process can be used to improve or enhance Operator Performance, if applicable.
- Lesson Terminal Objective
- Read and discuss lesson terminal objective and review lesson enabling objectives, if desired.
- Topic
- If applicable, briefly preview the lesson topic outline and introduce the major points to be covered. The objectives review may have been sufficient.
- REINFORCE the following PVNGS management expectations as opportunities become available
- Nuclear Safety
- Industrial Safety Practices
- STAR and Self-Checking
- Procedure Compliance
- Communication Standards
- ALARA
- Prevent Events

Course Terminal Objective

Given the appropriate references, the participant will be able to recognize the components, purposes and capabilities of the Plant Systems and Components as demonstrate by 80% overall proficiency on a series of three written examinations.

T.Obj 1.0	Given the appropriate references,, the participant will be able to recognize the components, purposes and capabilities of the Reactor Coolant System.
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EO 1.1	Identify the basic function of the Reactor Coolant System (RCS)
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1.1.1 Main Idea

A. Purpose

1. Contain Reactor Coolant at High Pressure (2250 PSIA).
 - a. Prevents Coolant Bulk Boiling
 - b. Enhances Thermal Energy Transfer
 - 1) Reflector, to reduce thermal neutron leakage.
 - 2) Moderator, to slow down fast neutrons to enhance thermal fission.
2. Transfers Thermal Energy from Fuel Assemblies to Steam Generators (12.97×10^9 BTU/HR, 3800 MW thermal).

NOTE: Additional 17 MW Thermal (5.8×10^7 BTU/HR) from RCP's.

3. Second Fission product release barrier (first is fuel cladding).

EO 1.2	Identify the major components and system interfaces of the Reactor Coolant System.
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1.2.1 Main Idea

A. Components

Show T001

1. Reactor Vessel and Internals
(contain the core; heat "source")
2. (4) Reactor Coolant Pumps
(provide reactor coolant circulation)
3. 2) Steam Generators
(produce steam; heat "sink")
4. Pressurizer
(provide overpressure to keep RCS slightly subcooled)
5. Associated Piping

B. Description

1. Two closed loops, each loop contains

T001, show flow paths

- a. 1) Reactor Outlet Pipe (Hot Leg, T_h).
 - b. (2) Reactor Inlet Pipes (Cold Legs, T_c).
 - c. (1) Steam Generator and (2) RCP's.
 - d. Pressurizer is connected to loop one reactor T_h by surge line.
2. Temperatures (Full Power).
 - a. T_H 611°F
 - b. T_C 555°F
 - c. T_{AVE} 583°F

C. Reactor Coolant System Components

1. Reactor Vessel
 - a. Purpose
 - 1) Contain and support the reactor core and vessel internals.
 - 2) Contain and direct the flow of reactor coolant through the core.
 - b. Components

- 1) Vertically mounted manganese molybdenum steel pressure vessel supported by (4) vertical columns to floor of containment.
 - 2) Welded hemispherical lower head.
 - 3) Removable hemispherical upper closure head permitting access to fuel assemblies.
 - a) Attached by (54) studs and nuts.
 - b) Sealed by (2) "O"-Rings (Hollow silver plated Inconel, self-energizing).
 - 4) Penetrations
 - a) (2) Coolant outlet nozzles
 - b) (4) Coolant inlet nozzles
 - c) Control element assembly nozzles.
 - d) In-core instrumentation nozzles.
 - e) Reactor heat vent to reactor drain tank.
2. Reactor Vessel Internals
- a. Purpose
 - 1) Support and orient the fuel, control element assemblies and incore instrumentation.
 - 2) Direct reactor coolant flow through the fuel assemblies.
 - 3) Provide a coolable geometry for the fuel.
 - 4) Absorb control rod dynamic loads and transmit these and other loads to the reactor vessel.
 - b. Components
 - 1) Core support barrel assembly.
 - 2) Lower support structure.
 - 3) Core shroud.
 - 4) Upper guide structure assembly.
 - 5) Flow baffle.
 - c. Description
 - 1) Core and Internals supported from flange on core support barrel with alignment ensured by keying to reactor vessel flange.
 - 2) Fuel Assembly aligned by pins on lower support structure.
 - 3) Core Shroud establishes core shape and limits bypass coolant flow.
 - 4) Upper guide structure aligns upper end of fuel assemblies, CEA's; keyed to vessel.

T003

T004

5) Flow baffle ensures uniform coolant flow through perforated, cylindrical plate.

3. Reactor Fuel Assemblies (241)

T005

a. Purposes

- 1) Support and maintain fuel containing rods in a coolable geometry.
 - a) Fuel rods provide heat transfer surface to the coolant.
 - b) Fuel rod cladding constitute first level fission product release boundary.
- 2) Support and provide access for CEA and incore instrumentation guide tubes.

b. Components

- 1) Fuel rods (236 maximum per assembly)
- 2) Burnable poison rods (0, 12 or 16 per assembly)
- 3) Guide tubes (4 CEA, 1 incore instruments)
- 4) Upper and lower end fittings (1 per assy.)
- 5) Spacer grids (12 per assembly)

c. Description

- 1) Fuel rods contain fuel pellets pressurized with Helium, Clad in Zircaloy - 4.
 - a) Helium enhances.
 - (i) Thermal energy transfer.
 - (ii) Internal corrosion prevention.
 - (iii) Differential pressure reduction (380 psia internal pressure at standard temperature).
 - b) Zircaloy Cladding (0.025 inches thick).
 - c) 150 inches active fuel length, 0.382 outside diameter.
 - d) Fuel Pellets.
 - (i) Slightly enriched ($\approx 4\%$ nominal) Uranium Dioxide Powder.
 - (ii) Slightly dished to allow greater axial expansion at center and reduce radiation induced swelling
 - e) Burnable poison rods (136" Poison Shim Length).
 - (i) $B_4C - Al_2O_3$ Pellets.
 - (ii) Number in given assembly varies with core characteristics.
 - (iii) Control excess reactivity at beginning of core life, reduce initial reactor coolant boron concentration and suppress flux peaks.
 - f) Guide tubes, major structural member.

- (i) Connect lower, upper end fittings.
- (ii) Support spacer grids.
- (iii) Center guide tube for incore inst. channel.
- (iv) CEA guide tubes provide path and shock absorption for inserted CEA's.
- g) Upper and lower end fittings.
 - (i) Upper; hold down and align fuel assembly.
 - (ii) Lower; seating surface for fuel rods and align lower end of fuel assembly.
- h) Spacer Grids: maintain acceptable fuel rod array.

4. Control Element Assemblies (89)

T007

- a. Purpose
 - 1) Mechanical means to shutdown the reactor - rods inserted.
 - 2) Withdrawal from core to achieve criticality.
 - 3) Regulate reactor power (core reactivity).
- b. Components
 - 1) Each CEA consists of:
 - a) Spider
 - b) Control Rods
 - c) Extension Shaft Assembly
 - 2) 48 - Twelve Element Full Length CEA's.

Safe Shutdown Margin - normally fully withdrawn.

- 3) 28 - Four Element Full Length CEA's.

Reactor Power Control - full in, full out or partial insertion.

- 4) 13 - Four Element Part Length CEA's.

T008

Xenon Power Oscillation Control.

- a) Contain less neutron absorption material.

T009

- c. Description
 - 1) Spider provides rigid lateral and axial support for control elements; stainless steel.
 - 2) Control rods attached to spider at upper end (threaded, crimped, locking nut).
 - a) 73% Boron Carbide.
 - b) 20 foot long Inconel Tube.

- c) Helium Expansion Plenum Above Poison.
- d) Extensions Shaft Assembly connects Spider to Control Element Drive Mechanism (CEDM).
 - (i) Consists of Drive Shaft Sub-Assembly and Gripper Sub-Assembly.
 - (a) Gripper Sub-Assembly latches ext. Shaft Assembly to Spider by Spring Loaded Coupling.
 - (ii) CEA is positioned inside the Fuel Assembly Guide Tubes by a Magnetic Jack.

Electromagnets surround ext. shaft, supplied with ferrous pads, and are sequentially activated to lift or drop CEA. Loss of power, CEA drops to bottom of Fuel Assy.

5. Steam Generators

T010

- a. Purpose
 - 1) Transfer heat from primary system to the secondary system.
 - 2) Provide barrier between radioactive and non-radioactive systems.
- b. Components
 - 1) (2) C.E. Steam Generators, one in each loop.
 - 2) Each a vertical, shell and U-Tube Heat Exchanger with an integral economizer (11,012 Tubes).
 - 3) Vertical divider plate separates inlet and outlet plenums of primary head.
 - 4) Primarily low alloy steel with Inconel Heat Transfer Tubes and Inconel Clad Tube Sheet (23" thick).
 - 5) Mounted on Bearing Plates to allow motion parallel to hot leg due to thermal expansion of RCS piping.
 - 6) Top Restrained from sudden lateral motion by key brackets and energy absorbers.
- c. Description
 - 1) Hot reactor coolant passes through U-tubes, transfer heat through tube walls to water-steam mixture.
 - 2) Coolant enters and leaves U-tubes through nozzles in primary head inlet and outlet Plenum.
 - 3) Steam generated on shell side and flows through moisture separators, and steam dryers to steam outlet nozzles.

T010A

6. Reactor Coolant Pumps

T011

- a. Purpose

- 1) Provide the head necessary to maintain required flow through the RCS during normal operation (111,400 GPM/Pump Capacity).
 - 2) Add heat to the primary system during plant heatups (17Mw).
- b. Components
- 1) Pump Casing
 - 2) Diffuser
 - 3) Impeller
 - 4) Shaft Seal Assembly
 - 5) Thrust Bearing Assembly
 - 6) Oil Supply Systems
 - 7) Motor
- c. Description
- 1) General
 - a) Four, one in each cold leg.
 - b) Vertical, single stage, centrifugal type.
 - c) Driven by 12,000 HP squirrel-cage induction motor.

17 MW = thermal work on RCS utilized during startup to preheat RCS through Modes 5, 4 and 3.

- 2) Pump Casing
 - a) Spherical, carbon steel clad with stainless steel.
 - b) Pump-to-casing leakage presented by spiral wound gasket and clamping ring.
 - c) Pump shaft, seal housing assy. and motor support secured to casing by (16) pump casing studs and clamping ring.
- 3) Diffuser
 - a) Eleven blade, two piece, removable.
 - b) Converts velocity head from impeller into a pressure head.
- 4) Impeller
 - a) Six bladed, radial flow, double keyed on pump shaft.
 - b) Imparts a velocity head to the reactor coolant.
- 5) Shaft Seal Assembly
 - a) Pressure Boundary between RCS and Containment.
 - b) Minimizes leakage along pump shaft.

T012 and T012A

- c) Three Tandem mechanical pressure reduction seals, a low-pressure vapor seal, auxiliary impeller.

Seal water 1st Stage = 2250 psig, 2nd Stage = 1305 psig, 3rd Stage = 360 psig, Endpoint = 100 psig.

- d) Mating surfaces: Carbon Rotating; Titanium Carbide Stationary.
- e) Seal injection water supplied at approximately (6.6) GPM to makeup for normal leakage (4.6) GPM into pump casing, (2) GPM into seal cavity.

4.6 GPM controlled leakage into RCS through pump casing to put positive pressure on RCS water seals, 2 GPM leakage into seal cavity drains to VCT.

- f) Controlled bypass flow through labyrinth flow restrictions divides total pressure drop across first three seals so that each seal has some pressure differential.

6) Thrust Bearing Assembly

T013

- a) One pivoted pad, double-acting, kingsbury type thrust bearing.
- b) Two segmented pad radial journal bearings.
- c) Compensate for resulting upward thrust exerted on pump.

7) Oil Supply System

- a) Main oil supply system provides lubrication for journal and thrust bearings.
- b) Lift oil system provides oil to upper and lower thrust bearings thrust pads at pump start/stop.

8) Motor

- a) Vertical six pole, air cooled, squirrel-cage induction type; 12,000 HP, 1185 RPM.
- b) Operates on 3 phase, 60 Hz 13,800 volt power supply (non-class 1E).
- c) One-piece flywheel, below upper bearings, increases rotating inertia of RC pump assembly (increases pump coastdown, decreases rate of coolant flow decay after electrical power loss).
- d) Anti-reverse rotation device on top of rotor to stop pump at zero speed while other pumps running.

7. Pressurizer System

T015

a. Purpose

- 1) Maintain high RCS pressure (2250 PSIA) thus preventing bulk boiling in core.

Note: water boils at 652.7°F at 2250 psia.

- 2) Act as surge volume to minimize pressure changes during load changes.
- 3) Ensure primary system integrity by preventing over-pressurization

b. Components

- 1) Pressurizer

- a) C.E. 1800 ft³ volume (900 ft³ normal water volume, 900 ft³ normal steam volume at saturated conditions).
- b) Large cylindrical vessel of carbon steel clad in austenitic stainless steel.
- 2) Pressurizer Heaters located below water level, (36) single-unit sheath-type, 50 KW each.
- 3) Pressurizer surge line, (12) inch connecting the bottom of pressurizer to reactor coolant loop (1) hot leg. Provided with thermal sleeve and surge screen.

T001, trace the surge line.

- 4) Pressurizer spray line penetrates upper head, terminates at spray nozzle.

Trace the spray line on T001.

- a) Connected to cold legs of loop 1A and 1B.

Note: Normal spray flow requires that a loop 1 RCP pump be run.

- b) Controlled by (2) modulating diaphragm - operated spray control valves.
- c) Manual bypass valve on each spray control valve; (1.5 gpm).
- 5) Primary Safety Valves.

T001

- a) Four totally enclosed, back-pressure compensated, spring loaded, self-actuated, pop-type, bellows equipped PSV's.
- b) Set to open at 2500 PSIA plus or minus 25 PSIA.

Design Pressure = 2500 lbs., Safety Limit = 2750 lbs.

c. Description

- 1) PZR limits pressure variations in RCS caused by expansion or contraction of reactor coolant during load changes.
 - a) RCS temperature varies as a function of load.
 - (i) Increase load: T_{ave} drops, RCS contracts, PZR water level drops, RCS pressure drops.
 - (ii) Reduce Load: T_{ave} rises, RCS expands, PZR water level rises, RCS pressure rises.
 - b) Increased load effects compensated by operation of PZR Heaters and CVCS Charging Pump.
 - (i) Heaters raise PZR pressure by causing additional coolant to become steam.
 - (ii) CVCS charging pump restores PZR level.
 - c) Reduced load effects compensated by operation of PZR Spray and CVCS Letdown Valves.
 - (i) Relatively cool spray water condenses some of the PZR steam.
 - (ii) Letdown valves allow more reactor coolant to leave RCS.

- d) Surge line provides flowpath to and from PZR and RCS.
 - e) (4) Primary safety valves provide over pressure protection.
 - (i) Discharge into reactor drain tank where steam is discharged underwater and condensed.
 - (ii) Undesirable to have PSV's lift because they may fail to reseat and control room operator has no means to reseat them as they are spring-loaded
8. Associated Piping
- a. Components per loop.
 - 1) (1) Hot Leg, (42) inch internal diameter.
 - 2) (2) Suction Legs, (30) inch internal diameter.
 - 3) (2) Discharge Legs, (30) inch internal Diameter.
 - 4) All loop piping is carbon steel clad with stainless steel.
 - 5) Many service system and detector penetrations.
 - a) Surge, safety injection, and charging nozzles equipped with thermal sleeves.
 - b) Sample and instrument lines equipped with flow restrictors.

EO 1.3	Recognize the modes of RCS operation.
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1.3.1 Main Idea

A. Basic RCS Operation Modes.

Write Modes of Operation on board.

1. Mode 6: refueling, reactor vessel head is less than fully tensioned.
 - a. K_{eff} less than or equal to 0.95.
 - b. % Power - Zero
 - c. T_c less than or equal to 135°F.
 - d. Shutdown cooling system removing decay heat from RCS.
2. Mode 5: cold shutdown, maintenance and surveillances are performed, head tensioned.
 - a. K_{eff} less than or equal to 0.99.
 - b. % Power - Zero
 - c. T_c less than or equal to 210°F.
 - d. Shutdown cooling system removing decay heat from RCS.
 - e. Up to (2) reactor coolant pumps operating to add heat to RCS as needed.
3. Mode 4: Hot Shutdown, maintenance and surveillances are performed.
 - a. K_{eff} less than 0.99.
 - b. % Power - Zero.
 - c. T_c - 210°F to 350°F.
 - d. Shutdown cooling is placed in or out of service in this mode.
 - e. Up to (3) reactor coolant pumps operating to add heat to RCS as needed.
 - f. Main steam system is placed in or out of service as required to remove RCS heat.
4. Mode 3: Hot Standby, entered upon reactor trip or prior to reactor startup.
 - a. K_{eff} less than 0.99.
 - b. % Power - Zero
 - c. T_c greater than or equal to 350°F.
 - d. Main steam system removing RCS heat.
 - e. Up to (4) reactor coolant pumps operating to add heat to RCS.
5. Mode 2: Startup, Boron dilution, CEA withdrawal.
 - a. K_{eff} Greater than or equal to 0.99.

- b. % Power less than or equal to 5%.
 - c. T_c greater than or equal to 350°F.
 - d. Reactor is started up to add heat to RCS along with RCP's.
 - e. Main steam system removing RCS heat.
6. Mode 1: Power operations; reactor power high enough to run steam cycle.
- a. K_{eff} Greater than or equal to 0.99.
 - b. % Power greater than 5%.
 - c. T_c greater than or equal to 350°F
 - d. Reactor power controlled primarily by Turbine Loading.
 - e. (4) RCP's, (2) Steam Generators must be operating.
 - f. RCS pressure controlled by pressurizer.

EO 1.4	Recognize the first and second fission product release barriers within the Reactor Coolant System.
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1.4.1 Main Idea

- A. Review of RCS Fission Product Release Barriers
 - 1. Boundary One: The Fuel Rods
 - a. Fuel Pellets provide main barrier to release of fission fragments though 25% of the gases escape.
 - b. Fuel rod cladding is actual boundary to the release of fission products.
 - 2. Boundary Two: The Reactor Coolant System and Associated Components.

SUMMARY OF MAIN PRINCIPLES

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 which 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 which 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.