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GALE User's Group Meeting

KEN GEELHOOD

Pacific Northwest National Laboratory

Richland, WA

Agenda - Thursday

- GALE Overview
  - Purpose of Code
  - Code Requirements
  - History of Code Development
- GALE-2.0: Features and Validation
- Basics of Reactor Cleanup
- Code Demonstration
- Participants Set Up and Run GALE
- Q&A with GALE developers

Agenda - Friday

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- GALE User's Group
  - Website
  - Training
  - Member Presentations
  - Technical Support
- Updates to ANS-18.1
- Activities Associated with GALE and SMRs
- Q&A and Wrap Up

Purpose of Code

- GALE-2.0 Code is a computerized mathematical model for calculating the releases of radioactive material in gaseous and liquid effluents (i.e., the gaseous and liquid source terms).
- The U.S. Nuclear Regulatory Commission uses the GALE-2.0 PWR Code to determine conformance with the requirements of Appendix I to 10 10 Code of Federal Regulations (CFR) Part 50.
- With the nuclear power generating facilities that have been proposed for operation in the United States using new reactor core designs, a comprehensive review of the GALE code was completed to verify applicability to both the current and proposed designs.
  - Upon review, it was determined the code was applicable to both current and future designs
  - Updates to the code to comply with recent standards and operational data were required. Hard-coded parameters were updated to reflect recent plant operations data
- Updates have been made to make the output of GALE more flexible to link with other NRC codes such as GASPAR, LADTAP, and GENII

Code Requirements

- Code runs on Microsoft Windows PCs
  - Graphical user interface uses standard Windows dialog boxes
- Code output is via text file
- Microsoft Excel worksheet has been included to visualize output and to facilitate use of output data in other calculations

History of Code Development

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- Code originally developed by NRC staff
  - GALE-86
  - Documented by NUREG-0016 (BWR) and NUREG-0017 (PWR)
- Code Development moved to PNNL in 2008
- Several internal versions were released with no NUREG-series documentation

- GALE-08
  - Built in nuclide concentrations from ANS-18.1 were updated to those in latest (1999) standard
  - Recommended parameters from ANS-55.6 and Regulatory Guide 1.140 were updated to values from current versions

History of Code Development (cont.)

- GALE-09
  - A review of recent reactor operational experience was performed and recommendations for updates to the GALE source codes and their user guidance were made.
- Official GALE release with NUREG/CR documentation was made in 2015
- GALE-2.0
  - Code results are identical to GALE-09
  - Graphical user interface was added to facilitate user interaction
  - Excel worksheet was included to help visualize results
  - Code benchmarking was performed to validate GALE-2.0 results to recent reactor experience

GALE-2.0 Features

- Graphical User Interface
  - Uses standard Windows Dialog Boxes
- Specific Features
  - Ability to save input information and read previously set up input
  - Ability to read legacy input files from GALE
  - Built-in calculators to combine liquid waste from various sources
  - Built-in calculators to calculate liquid waste collection, processing, and discharge times
- Microsoft Excel worksheet has been included to visualize output and to facilitate use of output data in other calculations

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Basics of Reactor Cleanup Systems

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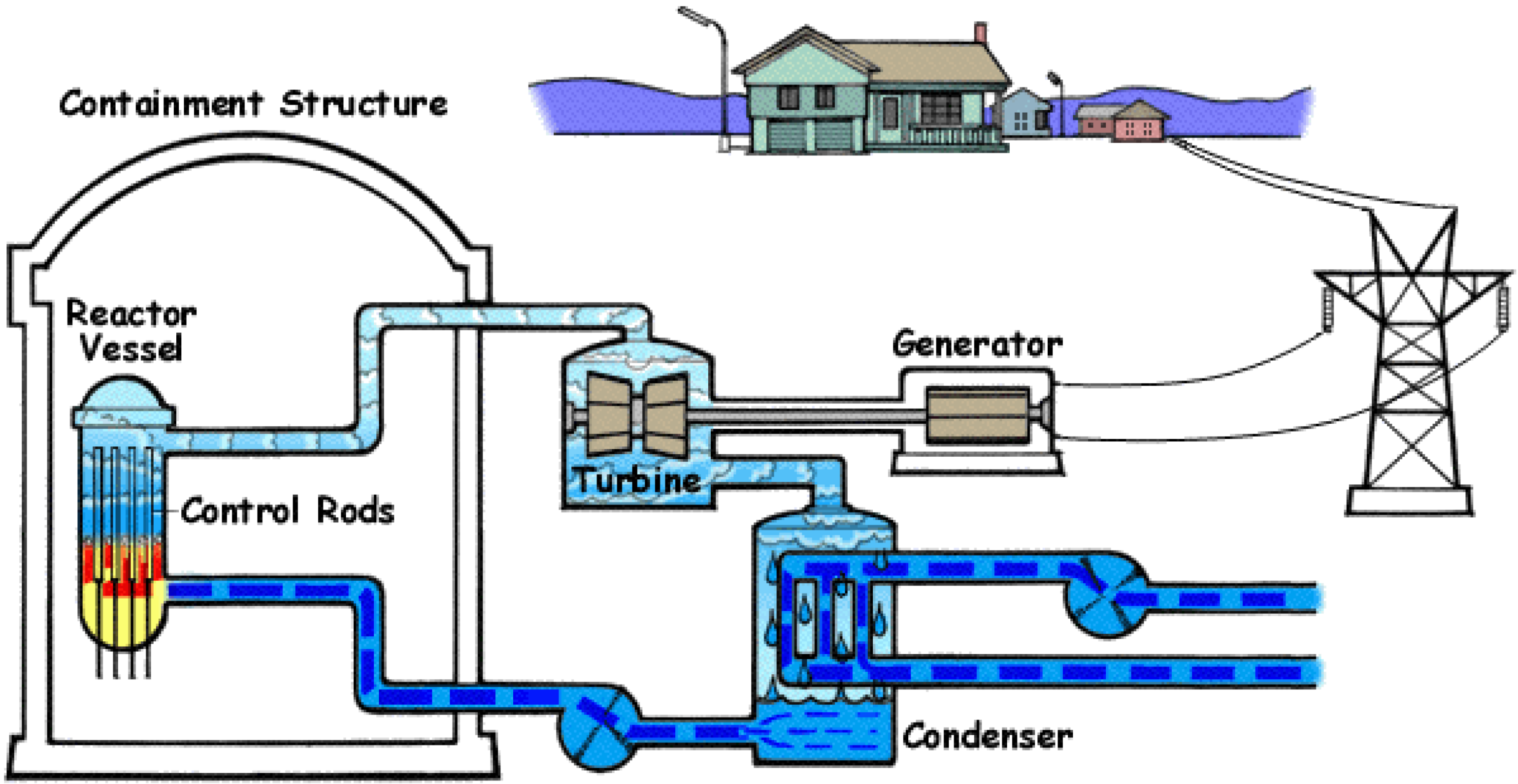
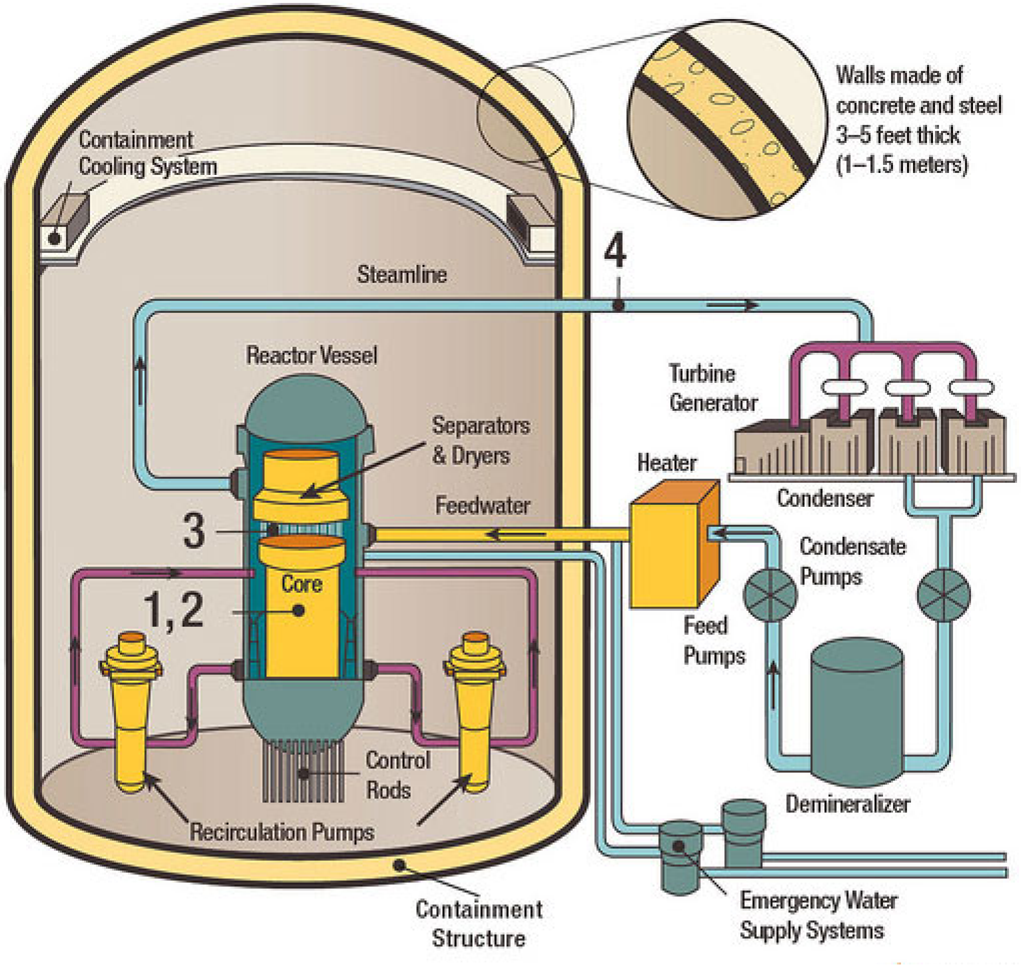
Introduction

- BWR
- PWR

Boiling Water Reactor



Boiling Water Reactor



Boiling Water Reactor: Liquid Waste Streams

- High Purity Waste
  - Liquid of low electrical conductivity
  - Equipment drains from
    - Drywell
    - Reactor building
    - Turbine building
    - Radwaste building
    - Auxiliary building
    - Fuel pool building
  - Ultrasonic resign cleaner overheads
  - Resin backwash
  - Transfer water
  - Filter backwash
  - Phase separator decant liquid
  - Radwaste evaporator condensate

Boiling Water Reactor: Liquid Waste Streams (cont.)

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- Low Purity Waste
  - Liquid of moderate to high electrical conductivity
  - Floor drains from
    - Drywell
    - Reactor building
    - Turbine building
    - Radwaste building
    - Fuel pool building
  - Uncollected valve and pump seal leakoffs
  - Water resulting from dewatering of slurry wastes
- Chemical Waste
  - Liquid of high conductivity and high total solids content
  - Laboratory drains
  - Non-detergent chemical decontamination wastes
- Regenerant Solutions Waste
  - Regenerant solution from ion exchange columns (condensate polishers)

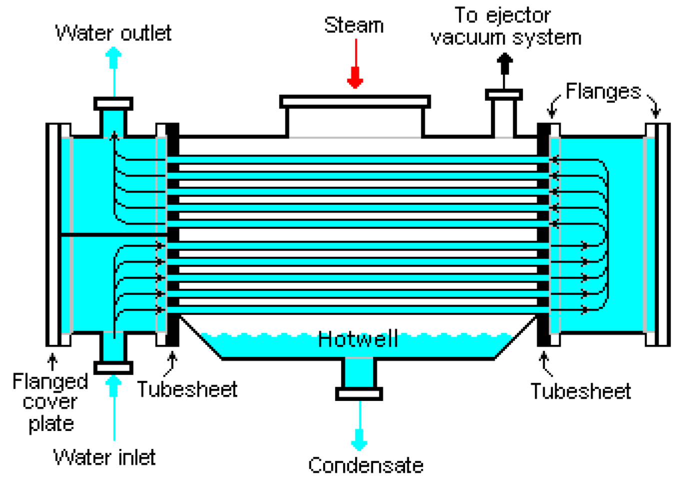
Boiling Water Reactor: Buildings

- Containment Building
  - A building designed to sustain pressures of about 50 psi. Normally houses the reactor and the related cooling system that contains highly radioactive fluids. Building is of steel construction. Sometimes the building is surrounded by a concrete structure that is designed for much lower pressures (3 psi). The area between the steel and concrete building is called the annulus.
- Auxiliary or Reactor Building
  - A building separate from the containment that houses much of the support equipment that may contain radioactive liquids and gases. Emergency equipment is also normally located in this building. In BWRs, the drywell is located in this building.
- Radwaste Building
  - A building that houses various systems provided to process liquid, solid and gaseous radioactive wastes generated by the plant.
- Turbine Building
  - A building that houses the turbine, generator, condenser, condensate and feedwater systems.

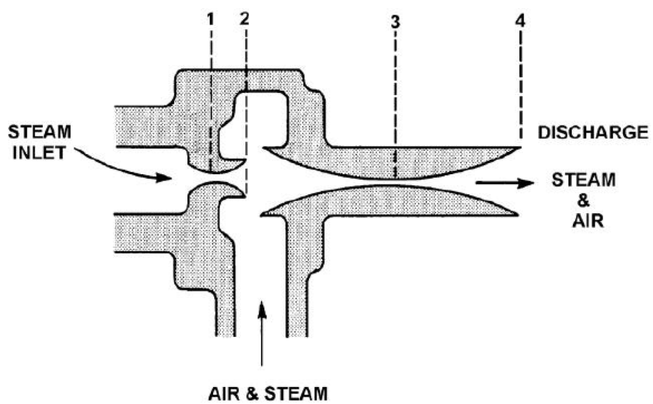
Boiling Water Reactor: Turbine Systems

Two special auxiliary systems that are potential sources of effluents are:

- Air Ejector
  - Passes steam through a series of nozzles and creates a vacuum that removes air from the condenser
- Turbine Gland Seal System
  - Gland seal steam is used to seal the main turbine by passing high pressure steam over a series of ridges and evacuating the steam when it reaches a low pressure.

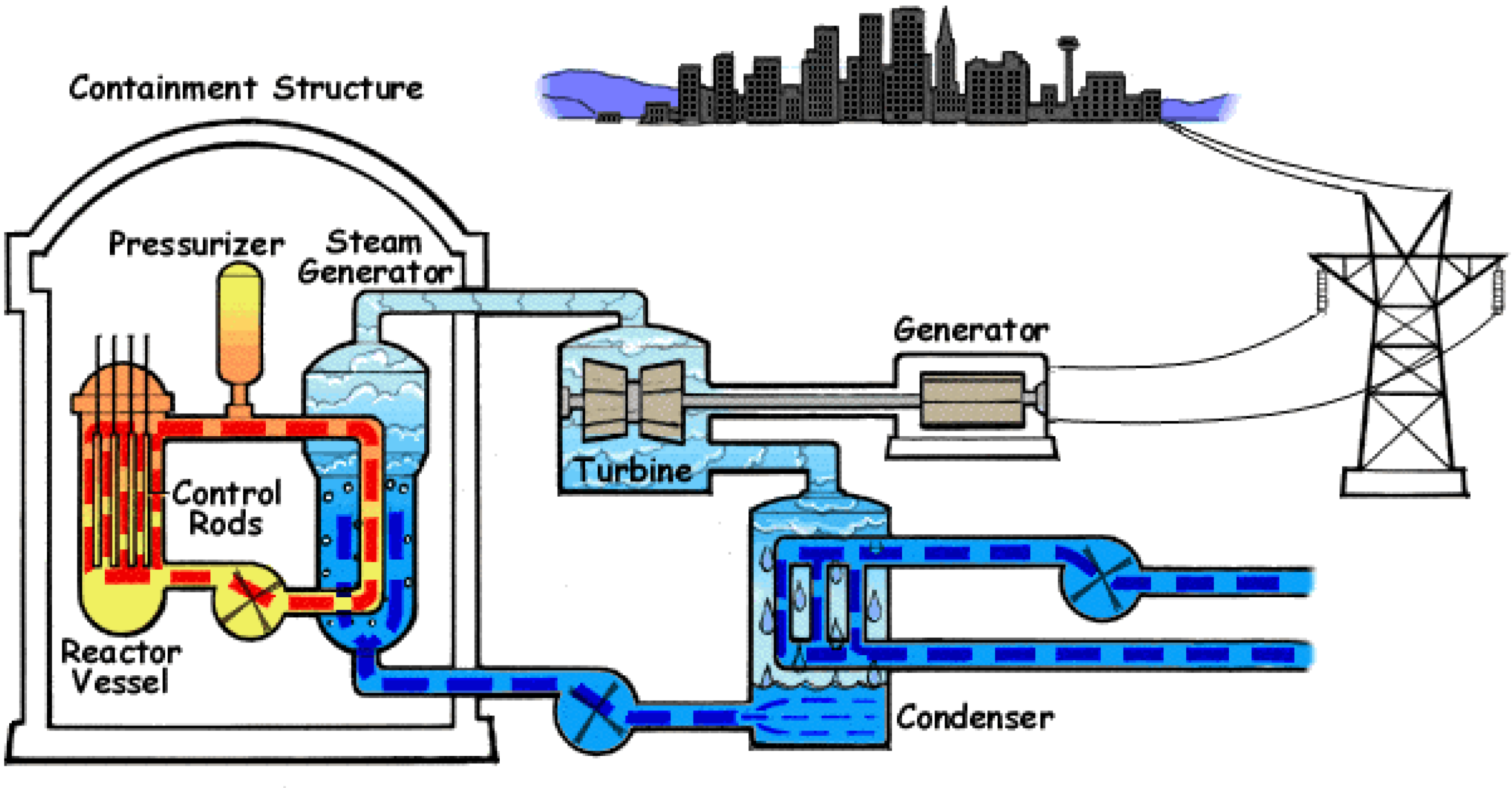


Condenser

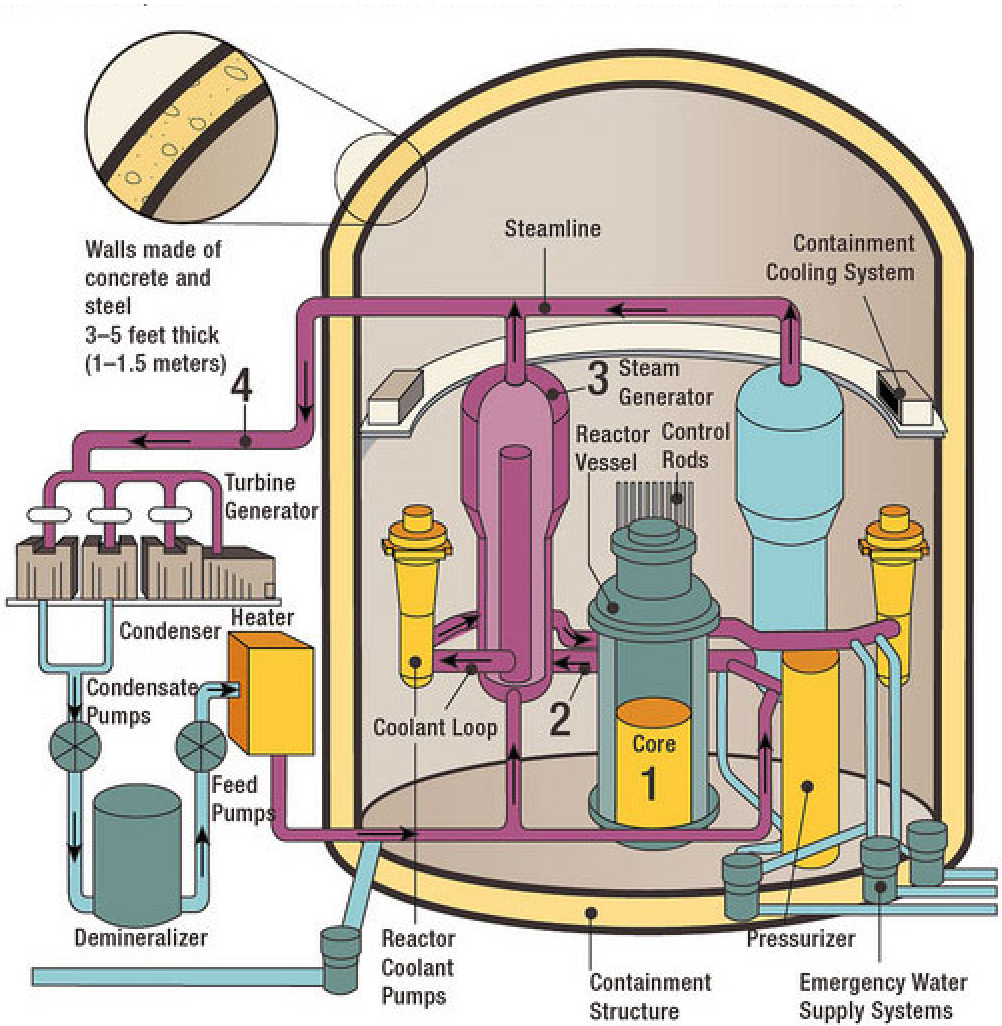


STEAM-JET AIR EJECTOR

Pressurized Water Reactor



Pressurized Water Reactor



Pressurized Water Reactor: Letdown

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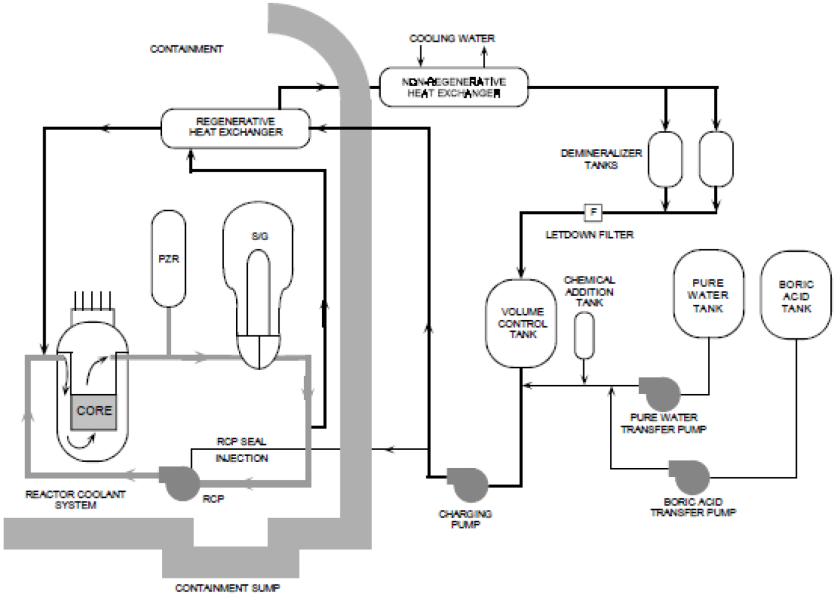
- The chemical and volume control system (CVCS) is a major support system for the reactor coolant system. Some of the functions of the system are to:
  - Purify the reactor coolant system using filters and demineralizers
  - Add and remove boron as necessary
  - Maintain the level of the pressurizer at the desired setpoint.
- A small amount of water (about 75 gpm) is continuously routed through the chemical and volume control system (called letdown). This provides a continuous cleanup of the reactor coolant system which maintains the purity of the coolant and helps to minimize the amount of radioactive material in the coolant.



Pressurized Water Reactor: Steam Generator

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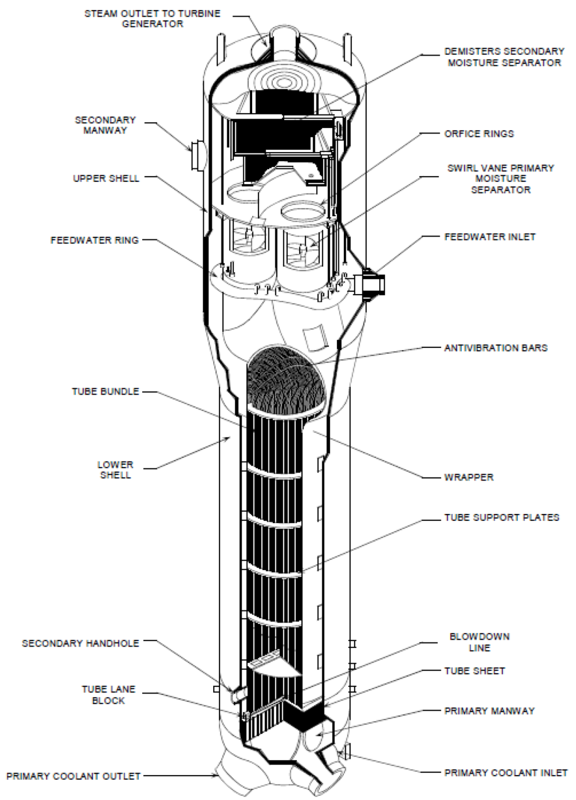
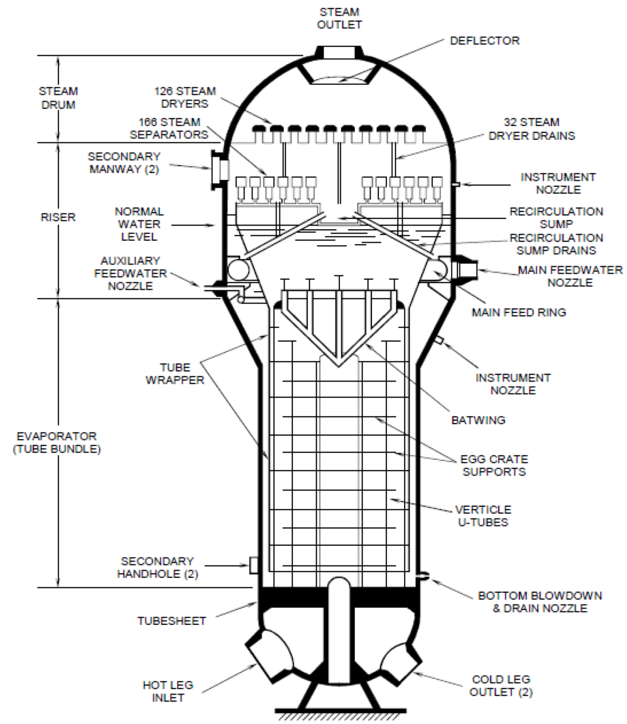
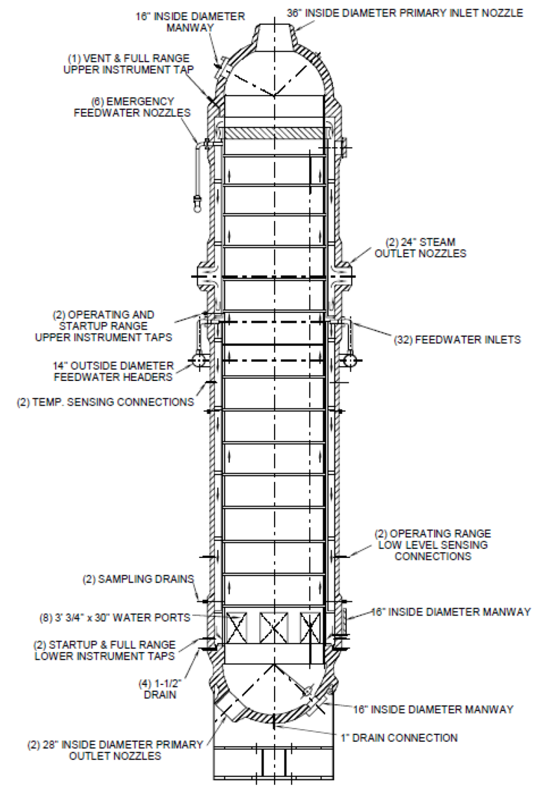


Cutaway View of A Westinghouse Steam Generator



Cutaway View of a Combustion Engineering Steam Generator



Cutaway View of a Babcock & Wilcox Once Through Steam Generator

Pressurized Water Reactor: Steam Generator – U-tube

- In the Westinghouse and Combustion Engineering designs, the steam/water mixture passes through multiple stages of moisture separation. One stage causes the mixture to spin, which slings the water to the outside. The water is then drained back to be used to make more steam. The drier steam is routed to the second stage of separation. In this stage, the mixture is forced to make rapid changes in direction. Because of the steam's ability to change direction and the water's inability to change, the steam exits the steam generator, and the water is drained back for reuse. The two stage process of moisture removal is so efficient at removing the water that for every 100 pounds of steam that exits the steam generator, the water content is less than 0.25 pounds. It is important to maintain the moisture content of the steam as low as possible to prevent damage to the turbine blading.

Pressurized Water Reactor: Steam Generator – Blowdown

- **Steam Generator blowdown** is water intentionally discharged from the steam generator to avoid concentration of impurities during continuing evaporation of steam.

Pressurized Water Reactor: Steam Generator – Once Through

- The Babcock & Wilcox design uses a once through steam generator. In this design, the flow of primary coolant is from the top of the steam generator to the bottom, instead of through U-shaped tubes as in the Westinghouse and Combustion Engineering designs. Because of the heat transfer achieved by this design, the steam that exits the once through steam generator contains no moisture. This is done by heating the steam above the boiling point, or superheating.

Pressurized Water Reactor: Liquid Waste Streams

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- Shim Bleed – Controls reactivity by bleeding out borated water
- Equipment Drain Waste
  - Equipment drains from
    - Drywell
    - Reactor building
    - Turbine building
    - Radwaste building
    - Auxiliary building
    - Fuel pool building
- Clean Waste
  - Deaerated or tritiated
- Dirty Waste
  - Aerated or non tritiated
- Blowdown Waste
- Regenerant Waste
  - Regenerant solution from ion exchange columns (condensate polishers)

Pressurized Water Reactor: Buildings

- Containment or Drywell Building
  - A building designed to sustain pressures of about 50 pounds per square inch. Normally houses the reactor and the related cooling system that contains highly radioactive fluids. Building is of steel construction. Sometimes the building is surrounded by a concrete structure that is designed for much lower pressures (3 pounds per square inch). The area between the steel and concrete building is called the annulus.
- Auxiliary or Reactor Building
  - A building separate from the containment that houses much of the support equipment that may contain radioactive liquids and gases. Emergency equipment is also normally located in this building.

Pressurized Water Reactor: Buildings

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- Turbine Building
  - A building that houses the turbine, generator, condenser, condensate and feedwater systems. Some PWRs in the United States have a structure without the traditional roof and wall structure.
- Fuel Handling Building
  - A building separate from the containment that is used to spent fuel assemblies in steel racks in a large 40 foot deep storage pool. Casks for shipping or onsite dry storage of spent fuel assemblies will be loaded (or unloaded in this pool). A new fuel storage area is provided for receipt of new assemblies and storage prior to going into the containment and subsequently into the reactor during a refueling.

Pressurized Water Reactor:

- Gas stripping
  - Goes with letdown
- Blowdown tanks vent
  - Goes with steam generator
- Air ejector
  - Discussed under BWR section

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GALE 2.0 Sample Problems

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Summary

- PWR Sample Problem
- BWR Sample Problem

PWR Sample Problem Information: Basic Plant Information

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Parameter	Value
Thermal power level	3400 MW(th)
Mass of coolant in primary system	550 thousand lbs
Primary system letdown rate	75 gal/min
Letdown cation demineralizer flow rate	7.5 gal/min
Number of steam generators	4
Total steam flow	15 million lbs/hr
Mass of liquid in each steam generator	112.5 thousand lbs
Steam generator blowdown treatment method	Recycled after treatment
Type of steam generator	U-Tube
Blowdown rate	75 thousand lbs/hr
Condensate demineralizer regeneration time	8.4 days
Fraction of feedwater through condensate demineralizers	0.65

PWR Sample Problem Information: Liquid Waste – Shim Bleed

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Parameter	Value
Flow rate	1440 gal/day
Iodine Decontamination Factor	5×10^3
Cs and Rb Decontamination Factor	2×10^3
Other Decontamination Factor	1×10^5
Waste collection time prior to processing	22.6 days
Waste processing and discharge times	0.93 days
Average fraction of wastes to be discharged after processing	0.1

PWR Sample Problem Information: Liquid Waste – Equipment Drain Waste

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Parameter	Value
Flow rate	330 gal/day
Activity of Inlet Stream	0.97 fraction of PCA
Iodine Decontamination Factor	5×10^3
Cs and Rb Decontamination Factor	2×10^3
Other Decontamination Factor	1×10^5
Waste collection time prior to processing	22.6 days
Waste processing and discharge times	0.93 days
Average fraction of wastes to be discharged after processing	0.1

PWR Sample Problem Information: Liquid Waste – Clean Waste

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Parameter	Value
Flow rate	980 gal/day
Activity of Inlet Stream	0.093 fraction of PCA
Iodine Decontamination Factor	$5x10^2$
Cs and Rb Decontamination Factor	$1x10^3$
Other Decontamination Factor	$1x10^4$
Waste collection time prior to processing	5.7 days
Waste processing and discharge times	0.13 days
Average fraction of wastes to be discharged after processing	0.1

PWR Sample Problem Information: Liquid Waste – Dirty Waste

Parameter	Value
Flow rate	2100 gal/day
Activity of Inlet Stream	0.001 fraction of PCA
Iodine Decontamination Factor	$5x10^2$
Cs and Rb Decontamination Factor	$1x10^3$
Other Decontamination Factor	$1x10^4$
Waste collection time prior to processing	3.8 days
Waste processing and discharge times	0.19 days
Average fraction of wastes to be discharged after processing	1.0

PWR Sample Problem Information: Liquid Waste – Blowdown Waste

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Parameter	Value
Fraction of Steam Processed	1
Iodine Decontamination Factor	$5x10^2$
Cs and Rb Decontamination Factor	$1x10^3$
Other Decontamination Factor	$1x10^4$
Waste collection time prior to processing	0 days
Waste processing and discharge times	0 days
Average fraction of wastes to be discharged after processing	0

PWR Sample Problem Information: Liquid Waste – Regenerant Waste

Parameter	Value
Flow rate	3400 gal/day
Iodine Decontamination Factor	$5x10^2$
Cs and Rb Decontamination Factor	$1x10^3$
Other Decontamination Factor	$1x10^4$
Waste collection time prior to processing	4.7 days
Waste processing and discharge times	0.37 days
Average fraction of wastes to be discharged after processing	0.1

PWR Sample Problem Information: Liquid Waste – Laundry

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Parameter	Value
Detergent Waste Partition Factor	1

PWR Sample Problem Information: Gaseous Waste – Building Vents

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Parameter	Value
Waste Gas particulate release •HEPA?	 Yes
Fuel Handling building •Charcoal adsorbers? •HEPA?	 Yes 90% efficient Yes
Auxiliary Building •Charcoal adsorbers? •HEPA?	 Yes 90% efficient No
Containment Building •Charcoal adsorbers? •HEPA? •Free volume •Flow rate through internal cleanup system	 No No 2.715 million ft^3 0 ft^3/min

PWR Sample Problem Information: Gaseous Waste – Containment Purges

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Parameter	Value
Containment large volume purge •Charcoal adsorbers? •HEPA? •Number of purges per year	 Yes 90% efficient Yes 2 at shutdown
Containment low volume purge •Charcoal adsorbers? •HEPA? •Continuous purge rate	 Yes 90% efficient Yes 1000 ft^3/min

PWR Sample Problem Information: Gaseous Waste – Misc.

Parameter	Value
Letdown System	Continuous degasification of full letdown flow
Holdup time for Xe stripped from primary coolant	60 days
Holdup time for Kr stripped from primary coolant	3.54 days
Fill time of decay tanks for gas stripper	0 days
Fraction of iodine released from blowdown tank vent	0.0
Fraction of iodine released from air ejector release	0.0

BWR Sample Problem Information: Basic Plant Information

Parameter	Value
Thermal power level	3400 MW(th)
Total steam flow	15 million lbs/hr
Mass of water in reactor vessel	0.38 million lbs
Cleanup demineralizer flow	0.13 million lbs/hr
Condensate demineralizer regeneration time	56 days
Copper tubing for condenser	No
Fraction of feedwater through condensate demineralizers	1.0

BWR Sample Problem Information: Liquid Waste – High Purity Waste

Parameter	Value
Flow rate	28640 gal/day
Activity of Inlet Stream	0.15 fraction of PCA
Iodine Decontamination Factor	$1x10^3$
Cs and Rb Decontamination Factor	$1x10^2$
Other Decontamination Factor	$1x10^3$
Waste collection time prior to processing	1 days
Waste processing and discharge times	0.07 days
Average fraction of wastes to be discharged after processing	0.01

BWR Sample Problem Information: Liquid Waste – Low Purity Waste

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Parameter	Value
Flow rate	5700 gal/day
Activity of Inlet Stream	0.13 fraction of PCA
Iodine Decontamination Factor	1×10^3
Cs and Rb Decontamination Factor	1×10^4
Other Decontamination Factor	1×10^4
Waste collection time prior to processing	3.1 days
Waste processing and discharge times	0.6 days
Average fraction of wastes to be discharged after processing	1.0

BWR Sample Problem Information: Liquid Waste – Chemical Waste

Parameter	Value
Flow rate	600 gal/day
Activity of Inlet Stream	0.02 fraction of PCA
Iodine Decontamination Factor	1×10^3
Cs and Rb Decontamination Factor	1×10^4
Other Decontamination Factor	1×10^4
Waste collection time prior to processing	3.1 days
Waste processing and discharge times	0.6 days
Average fraction of wastes to be discharged after processing	1.0

BWR Sample Problem Information: Liquid Waste – Regenerant Waste

Parameter	Value
Flow rate	1700 gal/day
Iodine Decontamination Factor	1×10^4
Cs and Rb Decontamination Factor	1×10^5
Other Decontamination Factor	1×10^5
Waste collection time prior to processing	9.4 days
Waste processing and discharge times	0.44 days
Average fraction of wastes to be discharged after processing	1.0

BWR Sample Problem Information: Liquid Waste – Laundry

Parameter	Value
Detergent Waste Partition Factor	1

BWR Sample Problem Information: Gaseous Waste – Building Vents

Parameter	Value
Containment Building •Charcoal adsorbers? •HEPA?	 Yes 90% efficient Yes
Auxiliary building •Charcoal adsorbers? •HEPA?	 No No
Radwaste Building •Charcoal adsorbers? •HEPA?	 No Yes
Turbine Building •Charcoal adsorbers? •HEPA?	 No No

BWR Sample Problem Information: Gaseous Waste – Turbine Systems

Parameter	Value
Gland Seal •Gland seal steam flow •Gland seal holdup time •Fraction iodine release from condenser vent	 0.0 lbs/hr 0 hrs 0
Air Ejecector Offgas •Air Ejector holdup time •Fraction iodine released from air ejector vent •Charcoal delays system? •Kr dynamic adsorption coefficient •Xe dynamic adsorption coefficient •Mass of charcoal	 0.167 hrs 1.0 Yes 105 cm^3/g 2410 cm^3/g 48 thousand lbs

Users Group

- GALE Website Demonstration
- GALE Training
  - GALE training will be available at annual RAMP users group meeting to RAMP members
  - Onsite training is available under contract
- Member Presentations
  - As membership grows, members are encouraged to give presentations of activities with GALE at RAMP users group meeting
- Technical Support
  - Limited technical support is available to RAMP members by e-mailing GALE@pnnl.gov

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ANS-18.1 Updates

KEN GEELHOOD

Pacific Northwest National Laboratory

Richland, WA

Summary

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- Scope and History of ANS-18.1
- Use of ANS-18.1 in GALE
- Restart of ANS-18.1 Working Group
  - Near term plans
  - Long term plans

Scope and History of ANS-18.1

- Scope
  - Provides primary and secondary coolant concentrations of various radionuclides
  - Provides methodology to scale nuclide concentrations based on reactor parameters
- History
  - ANS-18.1 (1984) – used in GALE86
  - ANS-18.1 (1999) – used in GALE08 and GALE09
  - Standard considered delinquent after 10 years with no update or reaffirmation

Used of ANS-18.1 in GALE

- Nuclide concentrations for ANS-18.1 reference reactor included in GALE for
  - BWR water and steam
  - PWR primary and secondary coolant for U-tube steam generators
  - PWR primary and secondary coolant for once-through steam generators
- Adjustment methodology included in GALE to adjust concentrations for given reactor parameters

Restart of ANS-18.1 Working Group

- First meeting held June 10, 2015 in San Antonio
  - Ken Geelhood Chair
  - Working group members from NRC, GNF, EPRI, and NuScale
  - Current and futures uses for standard were established
  - EPRI presented results from recent project to collect effluent release data
- Path-forward for new standard releases were established
  - Near term: Release a new version of the standard changing only nuclide concentrations based on recent EPRI data
    - Standard will go back to active status
  - Long term: work on the development of a new standard that would provide nominal concentrations plus uncertainty bands. Also, investigate updates to scaling methodology recommended in the standard.
- Next meeting November 11, 2015 in Washington DC
  - Plan is for working group to propose a new standard for near term

Development of GALE version for Small Modular Reactors

KEN GEELHOOD

Pacific Northwest National Laboratory
Richland, WA

Summary

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- SMR Designs
- Previous study and recommendations
- Current status of NuScale

SMR Designs

- Each SMR consists of a fully integrated reactor vessel, pressurizer, steam generator, and containment vessel, and is accompanied by a companion turbine

- NuScale
  - 50 MWe (gross).
- B&W mPower
  - 530 MWth, 155-180 MWe
- Westinghouse
  - 225 MWe
- Holtec HI-SMUR SMR-160
  - 160 MWe

Previous Study and Recommendations

- In 2012 a study was performed on the applicability of GALE to SMRs (PNNL-21386)
- mPower reactor was selected as the baseline as this design was the most mature at that time
- It was determined that the scaling factors in ANS-18.1 should be applicable to SMRs
- PNNL recommended that the following changes be made to the PWR GALE codes to make them applicable to the mPower® design and other iPWR designs:
  - changes already made and documented in GALE-08 and GALE-09 (now in GALE 2.0)
  - addition of new nuclides to GALE output (if desired)
  - hardwired parameters in GALE that should be changed
  - changes to GALE input and output format (if more precision is desired)
  - tritium production and release from plants without soluble boron
  - carbon-14 production and release

Current Status of NuScale

- PNNL has been in contact with NuScale staff
  - The current decision is that they cannot use the existing GALE code for the license submittal, because their plant is just outside of its applicable range.
  - Plant specific tritium calculations significantly different than NUREG-0017 says they should be based on the power level.
  - Staff thinks some things will be the same
  - NuScale is developing alternate methodology to GALE for the submittal, but wants to use GALE's methodology as much as possible and only deviate where there are differences.
- NuScale is interested in helping the NRC develop a GALE-iPWR