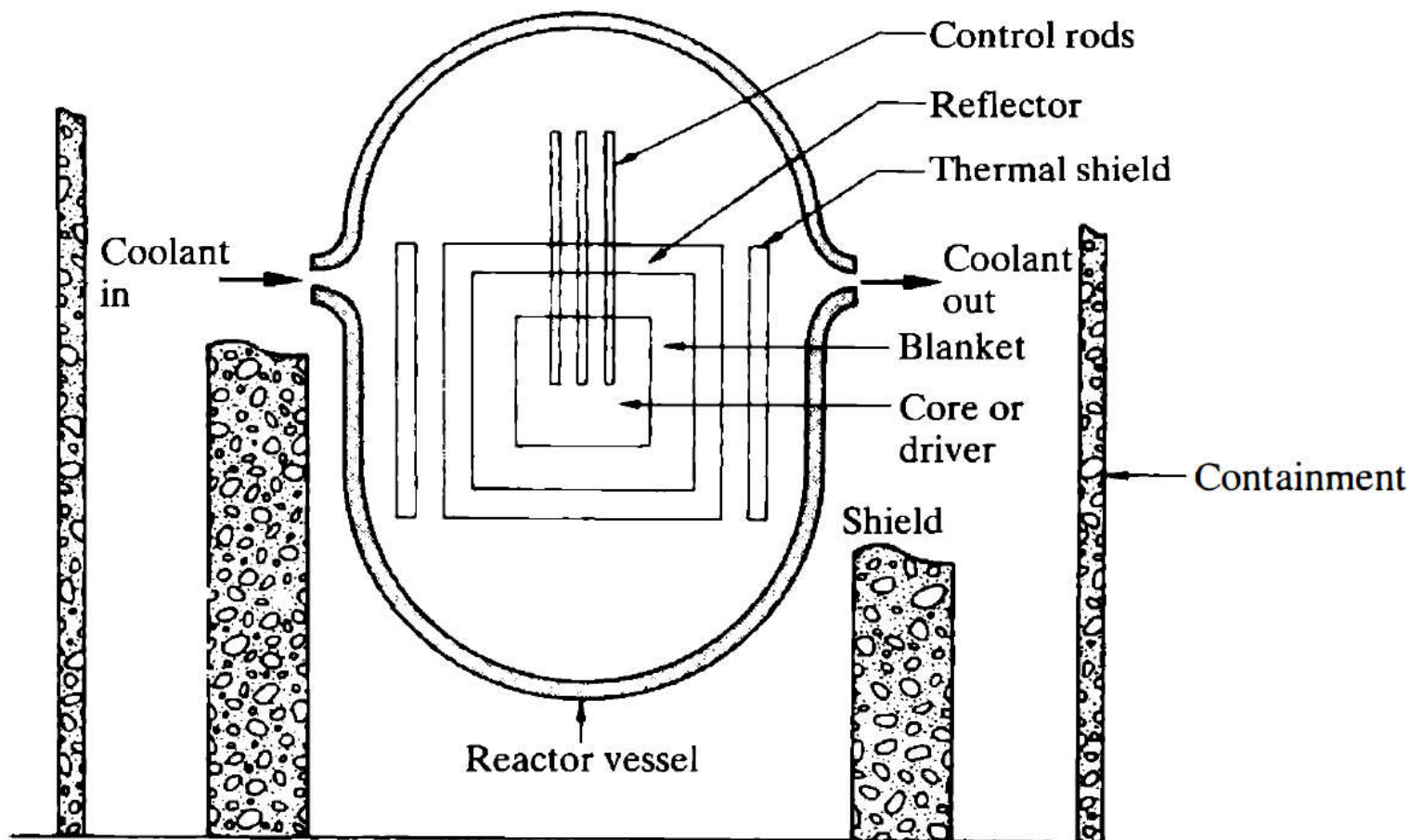


Tecnologías nucleares

Antonio González Fernández
Departamento de Física Aplicada III
Universidad de Sevilla

Parte 3. Reactores de agua ligera (PWR, BWR y VVER)

Esquema general de la parte nuclear de un reactor

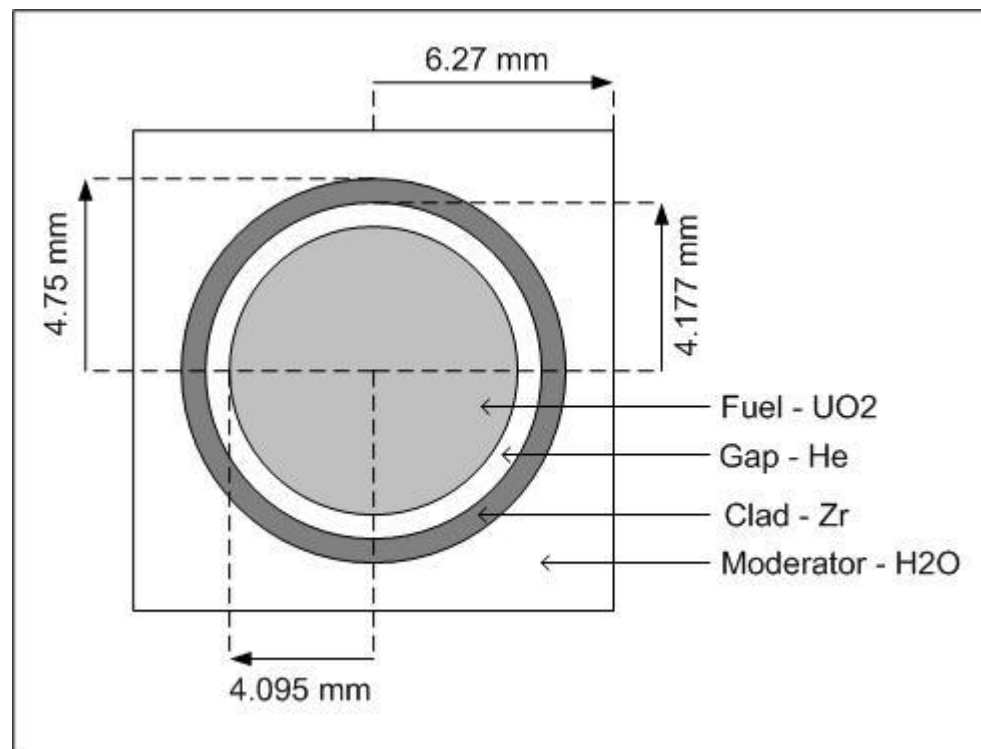


El fuel va en *pellets* o pastillas

El uranio se almacena en forma de dióxido de uranio (UO_2)



Se forman pequeñas piezas (*pellets*)



Cada pellet contiene energía para una casa en un mes

Si contiene plutonio se llama MOX (*mixed oxide*)

Distribución de temperaturas dentro de un *pellet*

El calor se genera en todo el volumen del *pellet*

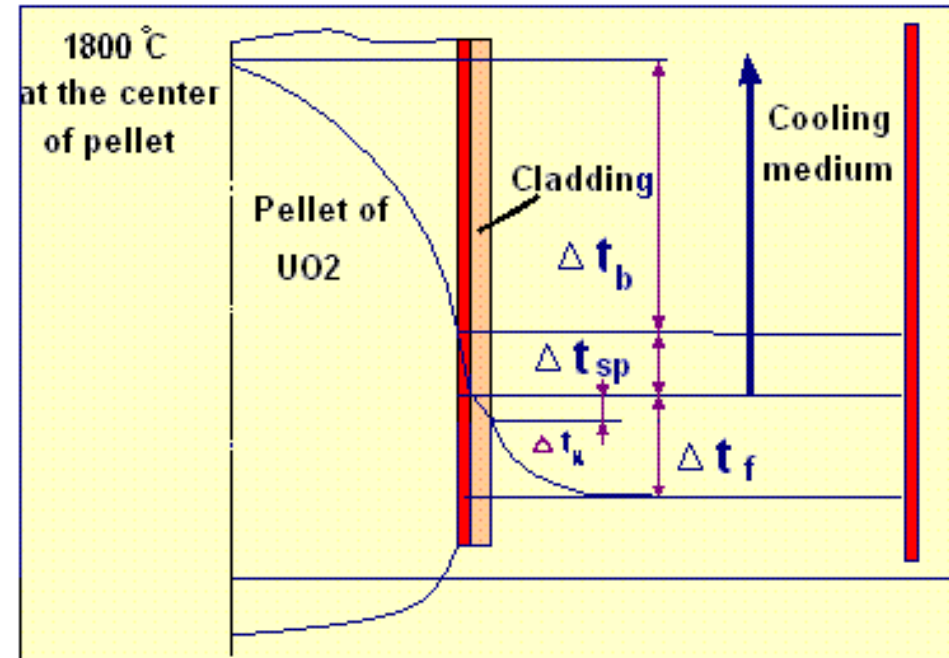
$$-\kappa \nabla^2 T = S$$

$$\frac{1}{r} \frac{\partial}{\partial r} \left(r \frac{\partial T}{\partial r} \right) = -\frac{S}{\kappa}$$

El refrigerante solo pasa por el exterior

$$-\kappa \vec{n} \cdot \nabla T = \frac{T - T_{\text{ext}}}{R}$$

Se genera una distribución parabólica de temperaturas con el máximo en el centro



El radio de los pellets está acotado (aumenta T_{max})

Distribución de temperaturas en el refrigerante (*coolant*)

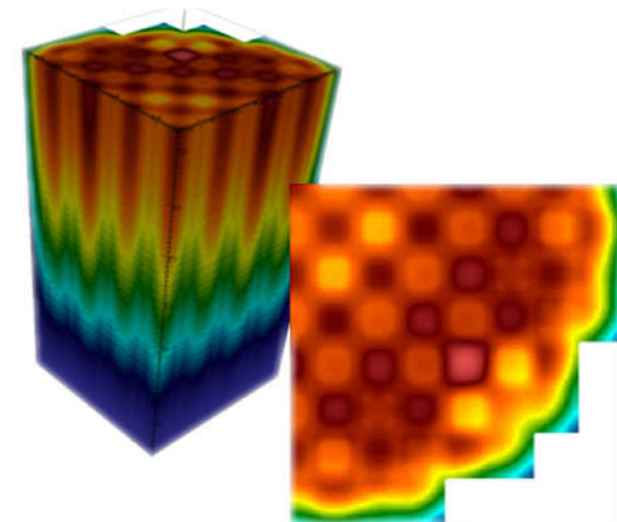
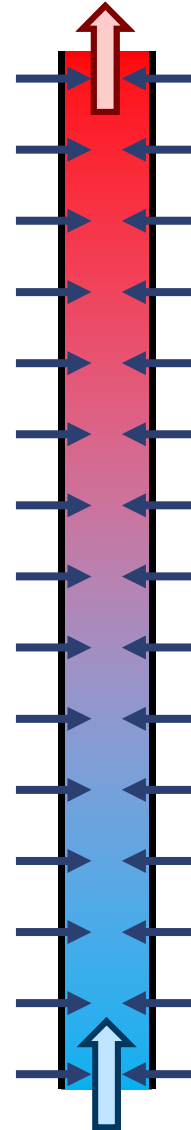
En los reactores de agua ligera el refrigerante es el mismo que el moderador: el agua que fluye entre las *fuel rods*.

Matemáticamente es un problema de difusión de con entrada de calor por la frontera

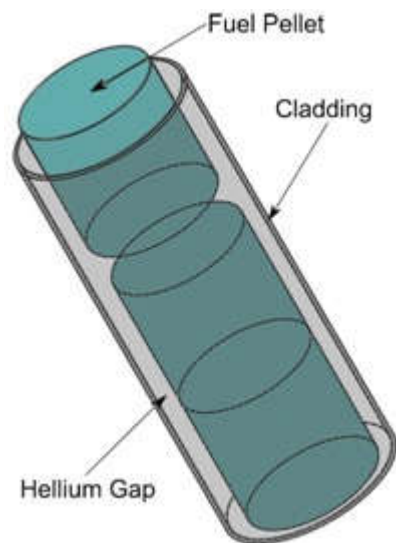
Dependencia en r y z (y t)

En un BWR además hay un cambio de fase

El problema real debe resolverse numéricamente



Ensamblado en una varilla (*fuel rod*)



Los *pellets* se introducen en una varilla de zircalloy, resistente a la corrosión

Impide que se liberen los fragmentos

Una varilla mide unos 4m y contiene unos 300 *pellets*

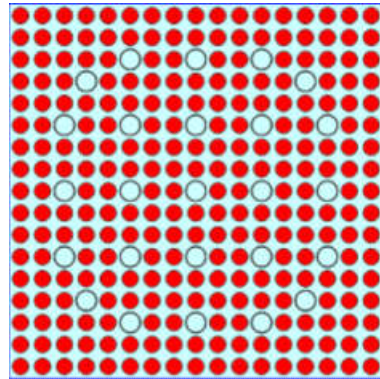
Entre los pellets y el recubrimiento se introduce helio a 3.4MPa, para permitir la dilatación o densificación del UO_2

La posición se fija con resortes y separadores (*spacers*)

En el momento de la recarga se saca la varilla entera (que contiene combustible y residuos)



La varillas se disponen en un elemento combustible (*fuel assembly*)



Fuel rod



Instrumentation thimble
Control rod guide thimble

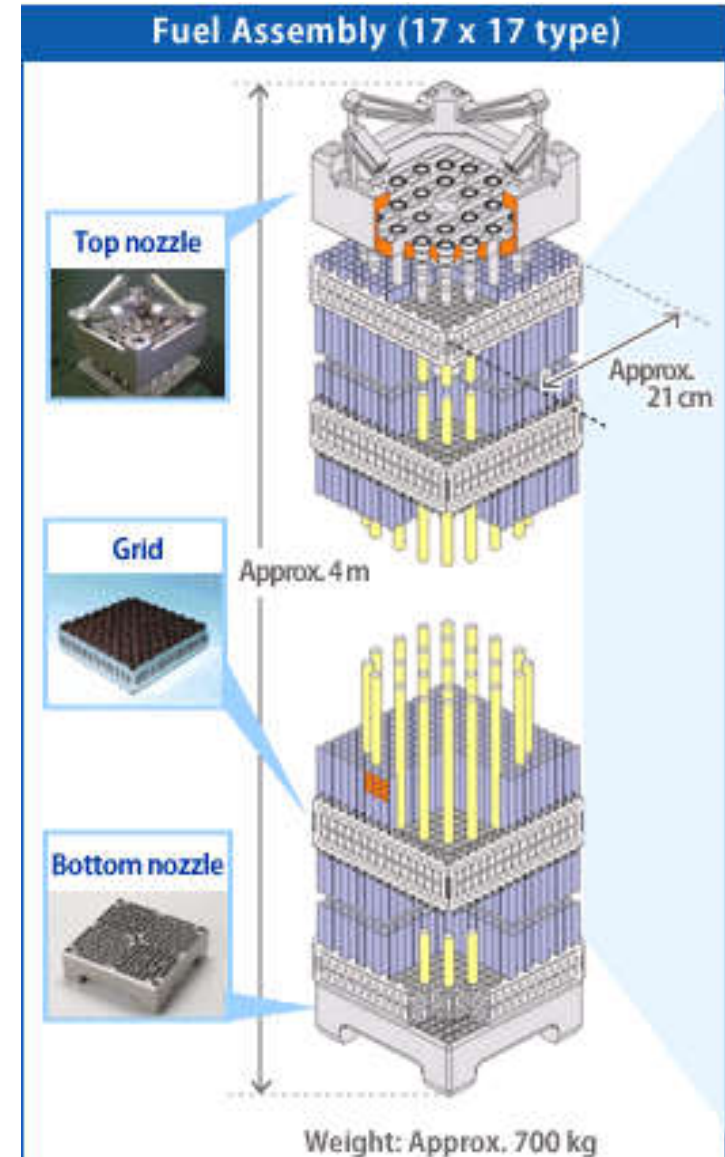
264 varillas de combustible

24 varillas de control

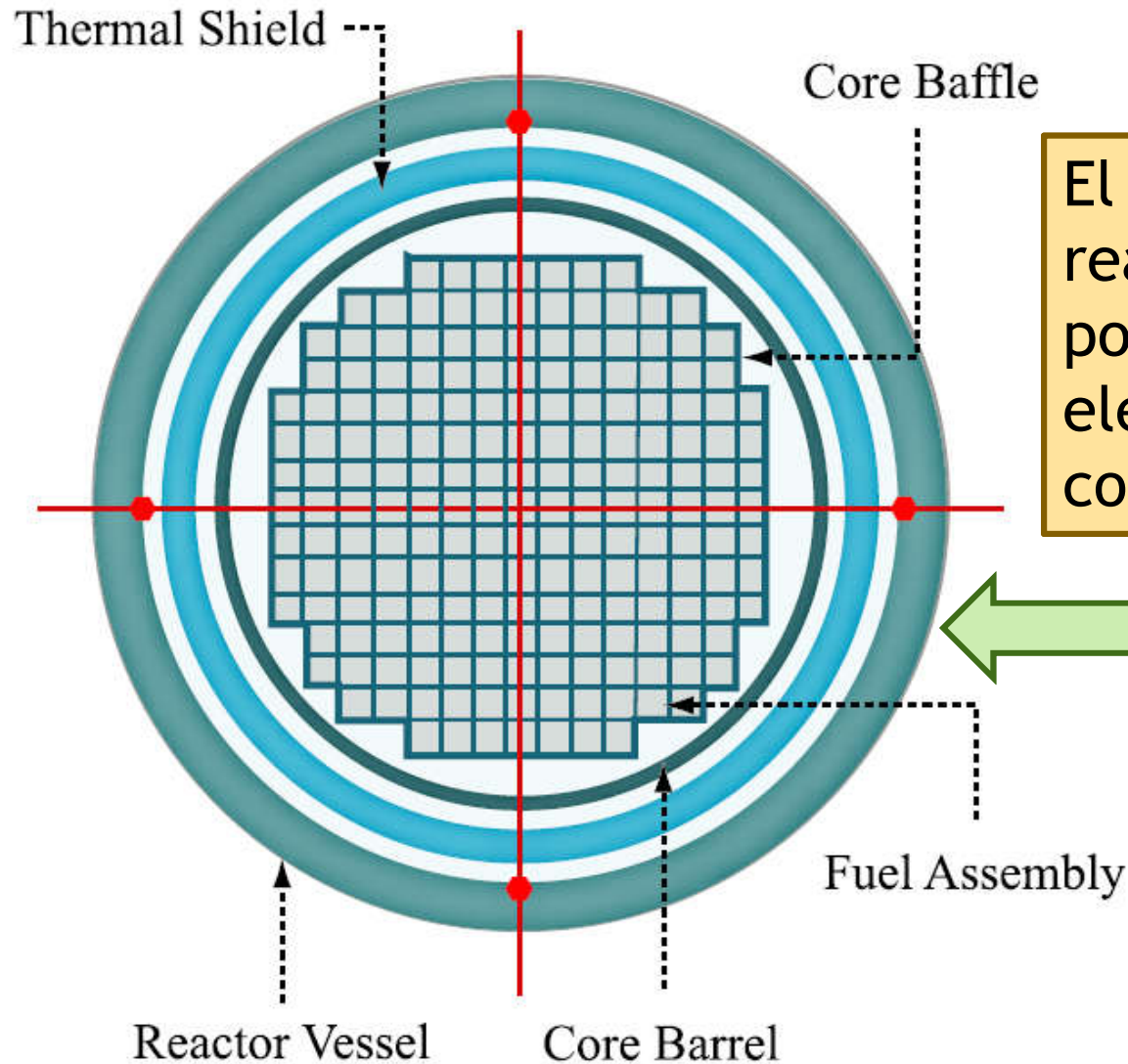
1 varilla de instrumentación

Entre las varillas fluye el moderador y el refrigerante

Los n escapan de una varilla, son moderados y entran en otra



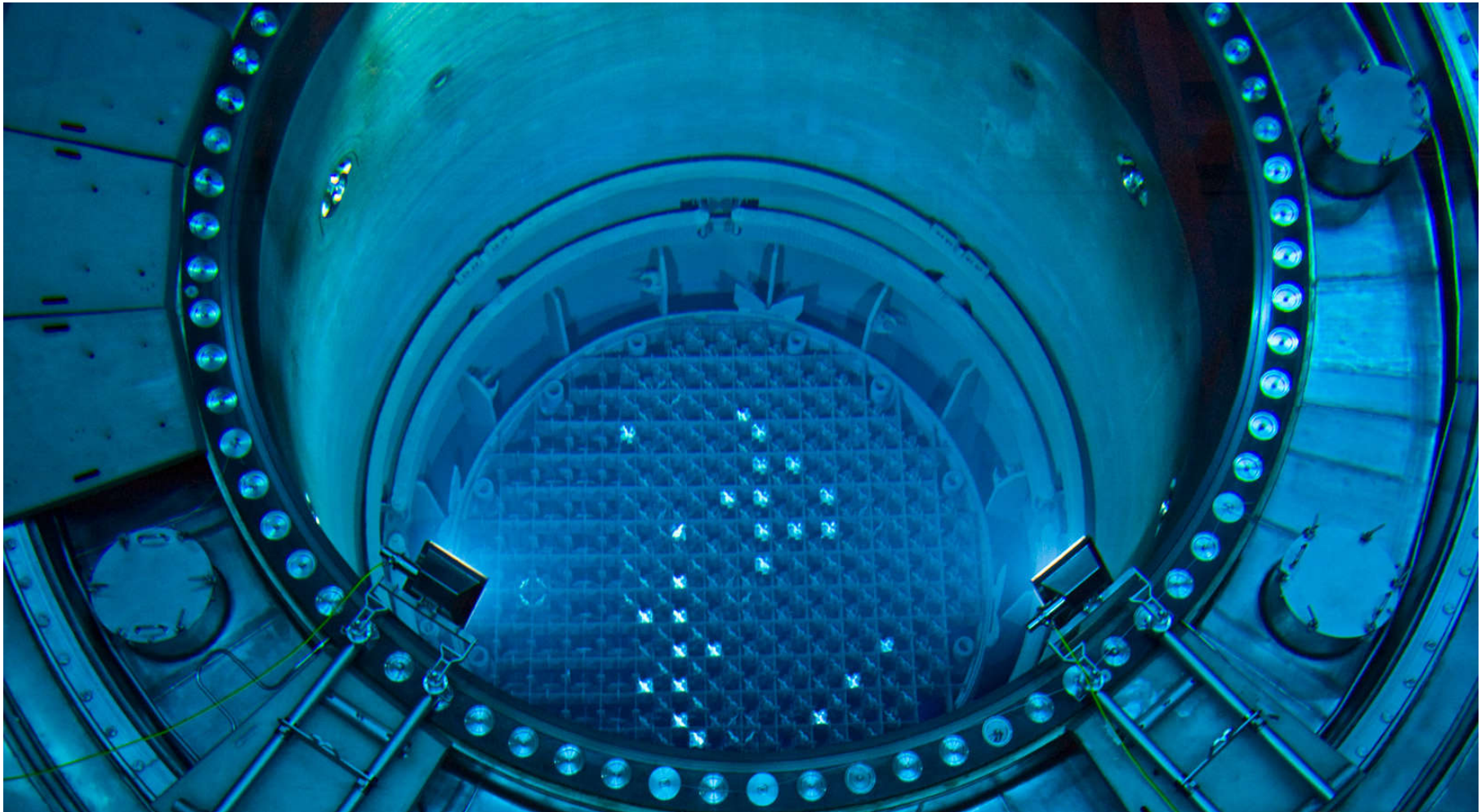
Los *fuel assemblies* se colocan formando racimos (*clusters*)



El núcleo de un reactor está formado por un conjunto de elementos combustibles

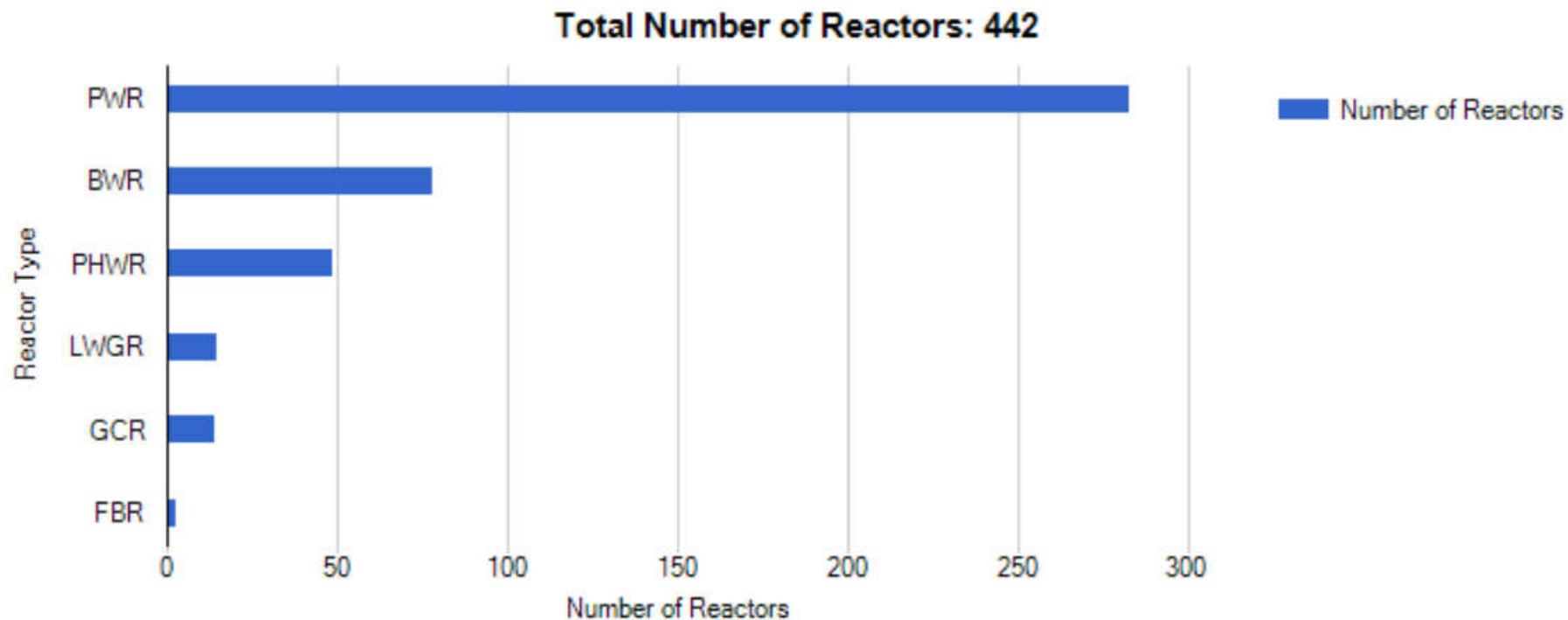
193 elementos

Aspecto real del núcleo de un reactor





Diferentes tipos de reactores en el mundo



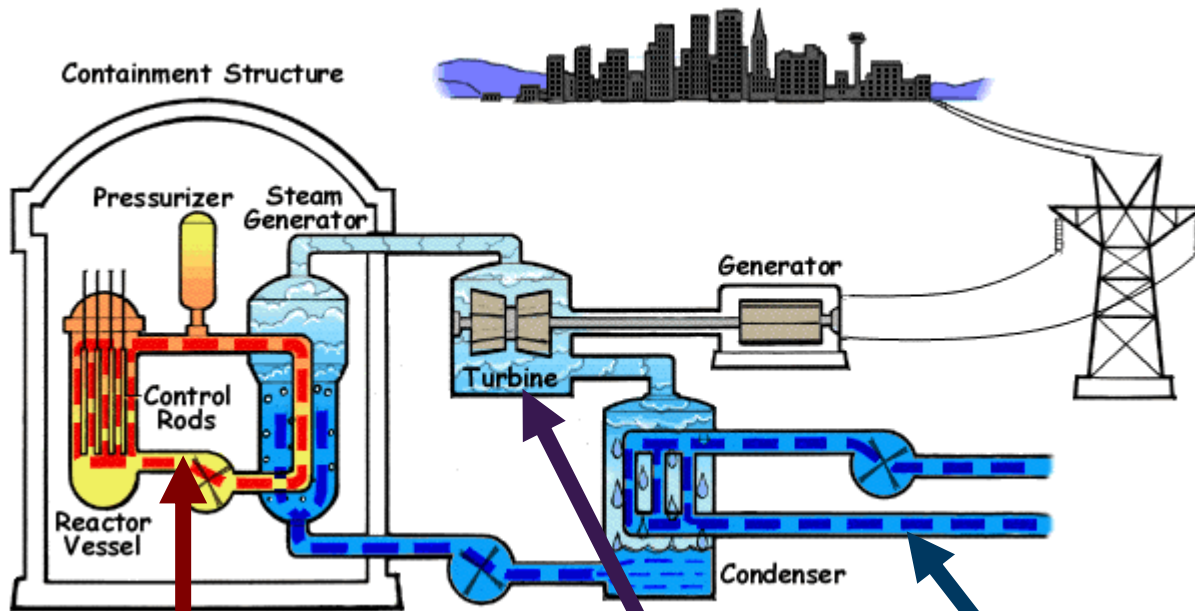
| Reactor Type | Reactor Type Descriptive Name | Nr of Reactors | Capacity (MW) |
|--------------|--|----------------|---------------|
| PWR | Pressurized Light-Water-Moderated and Cooled Reactor | 283 | 265020 |
| BWR | Boiling Light-Water-Cooled and Moderated Reactor | 78 | 75208 |
| PHWR | Pressurized Heavy-Water-Moderated and Cooled Reactor | 49 | 24592 |
| LWGR | Light-Water-Cooled, Graphite-Moderated Reactor | 15 | 10219 |
| GCR | Gas-Cooled, Graphite-Moderated Reactor | 14 | 7685 |
| FBR | Fast Breeder Reactor | 3 | 1369 |
| Total | | 442 | 384093 |



Características de los tipos de reactores

| | PWR | BWR | PHWR (CANDU) | HTGCR | LMFBR |
|-----------------|----------------------------|----------------------------|---------------------|----------------------------|---------------------------------|
| Combustible | UO ₂ | UO ₂ | UO ₂ | UC, ThC ₂ | PuO ₂ |
| Enriquecimiento | 3% U235 | 2.5% U235 | 0.7% U235 (natural) | 0.7% U235 (natural) | 15% Pu239 |
| Moderador | Agua | Agua | Agua pesada | Grafito | - |
| Refrigerante | Agua | Agua | Agua pesada | CO ₂ | Sodio líquido |
| Recubrimiento | zircaloy | zircaloy | zircaloy | grafito | acero |
| Control | Barras de B ₄ C | Cruces de B ₄ C | Nivel de moderador | Barras de B ₄ C | Barras de B ₄ C o Ta |

El reactor de agua a presión (*Pressurized Water Reactor, PWR*)



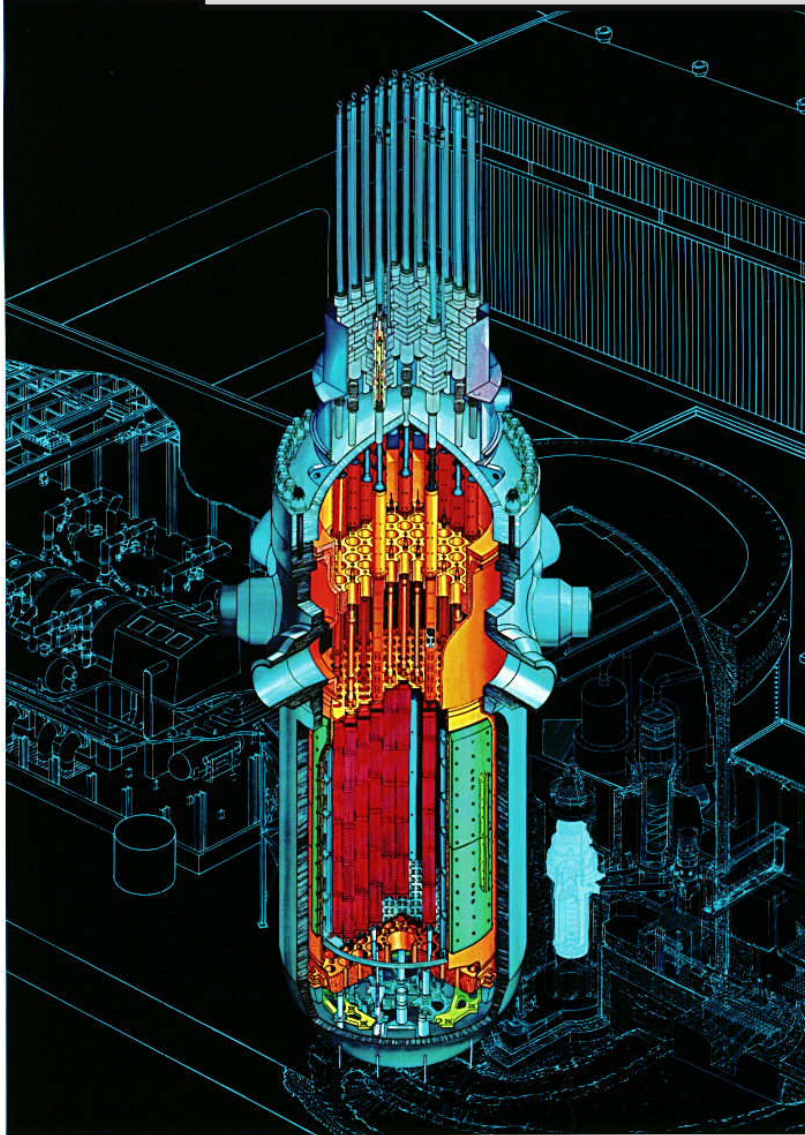
Se basa en tres circuitos de fluido

Agua a presión que pasa por el núcleo y la caldera

Agua-vapor por la caldera y las turbinas

Agua de refrigeración por el condensador

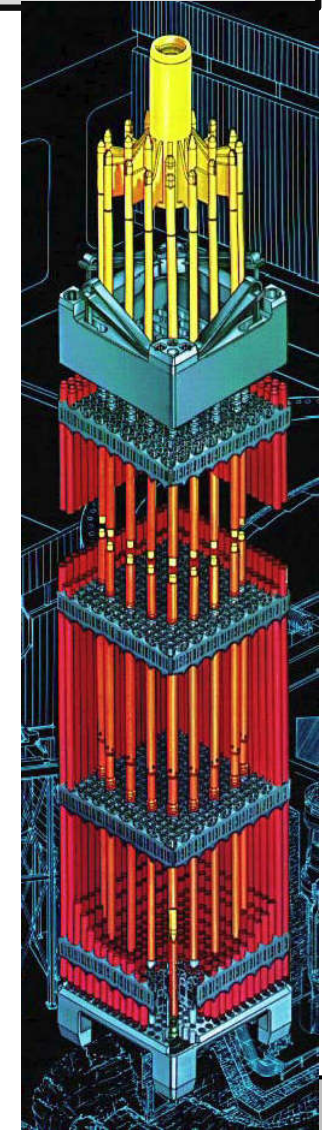
El núcleo de un reactor PWR



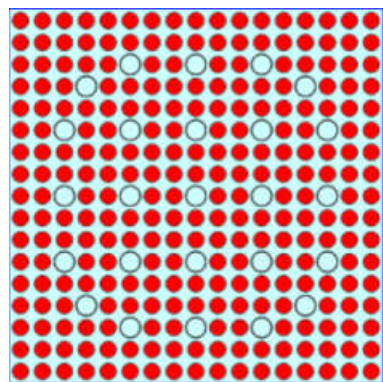
Está formado por cientos de elementos combustibles

Las varillas de control entran desde arriba

La gravedad ayuda



El núcleo de un reactor PWR: sección transversal



Fuel rod



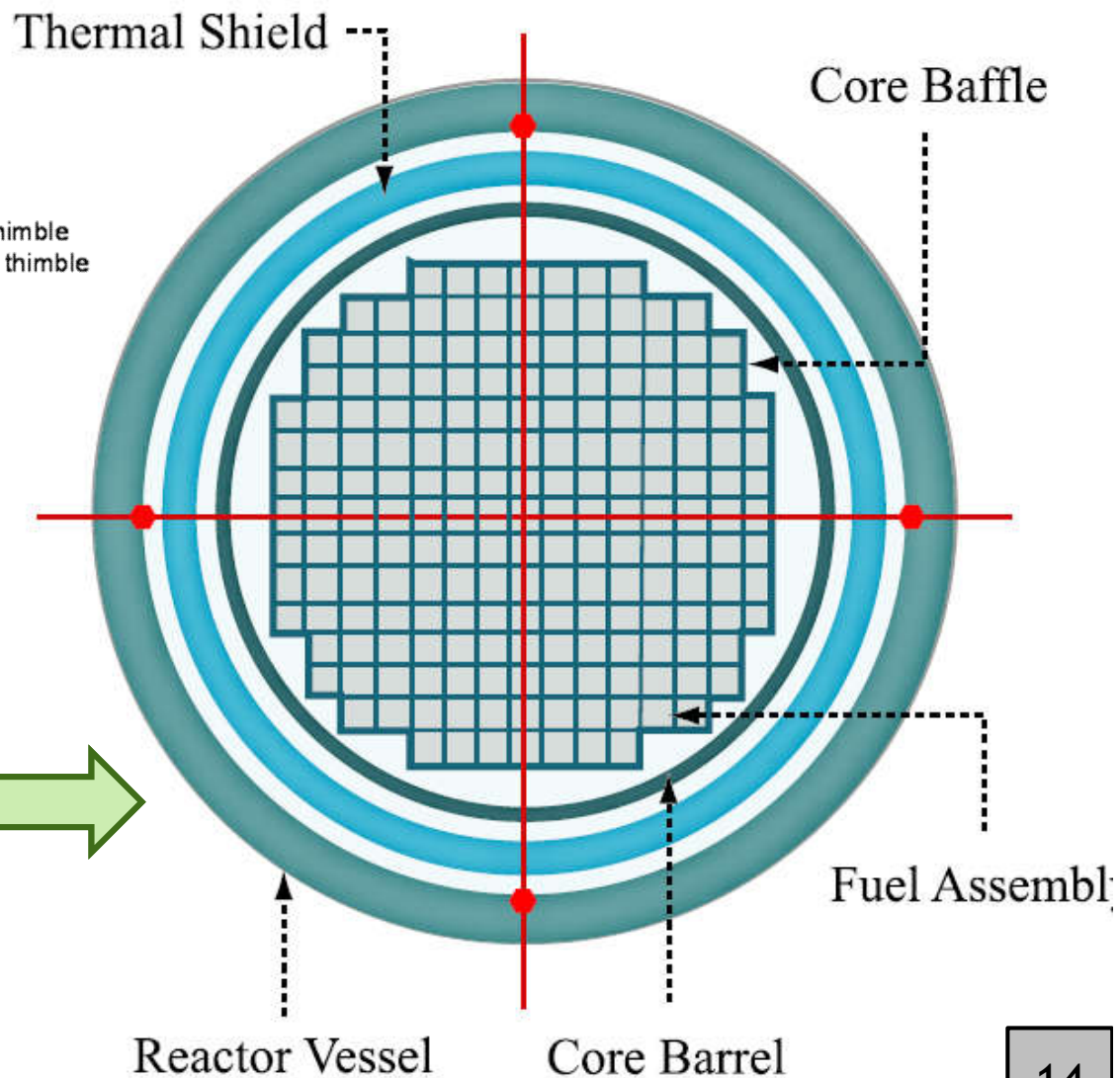
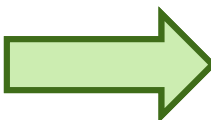
Instrumentation thimble
Control rod guide thimble

264 varillas de combustible

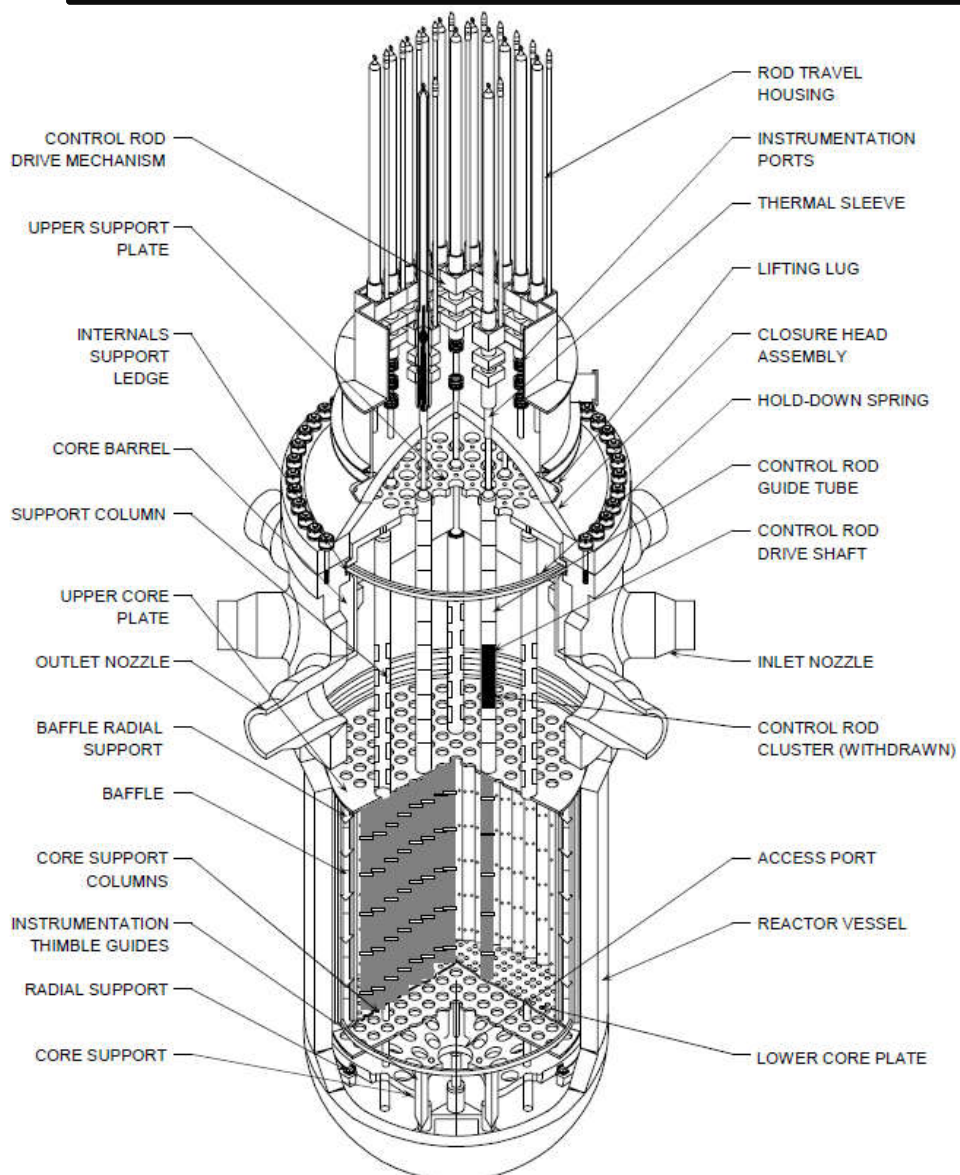
24 varillas de control

1 varilla de instrumentación

193 elementos



Corte del núcleo de un reactor PWR

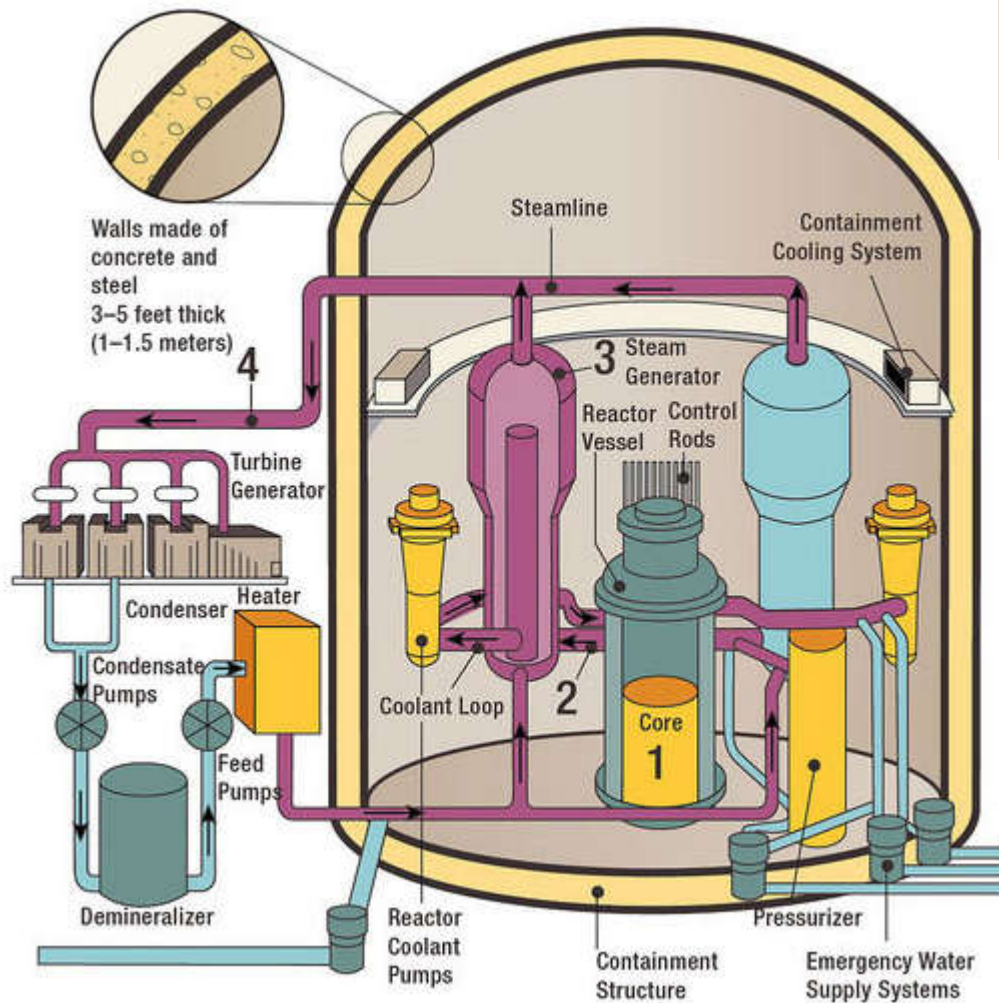


El agua a presión entra por el medio, baja y se va calentando mientras asciende

Así se evita que una fuga en una tubería vacíe la vasija

La capa de agua que baja hace de reflector

El circuito primario de una PWR



El agua entra a 560K y sale a 600K

Muy por encima de 100°C

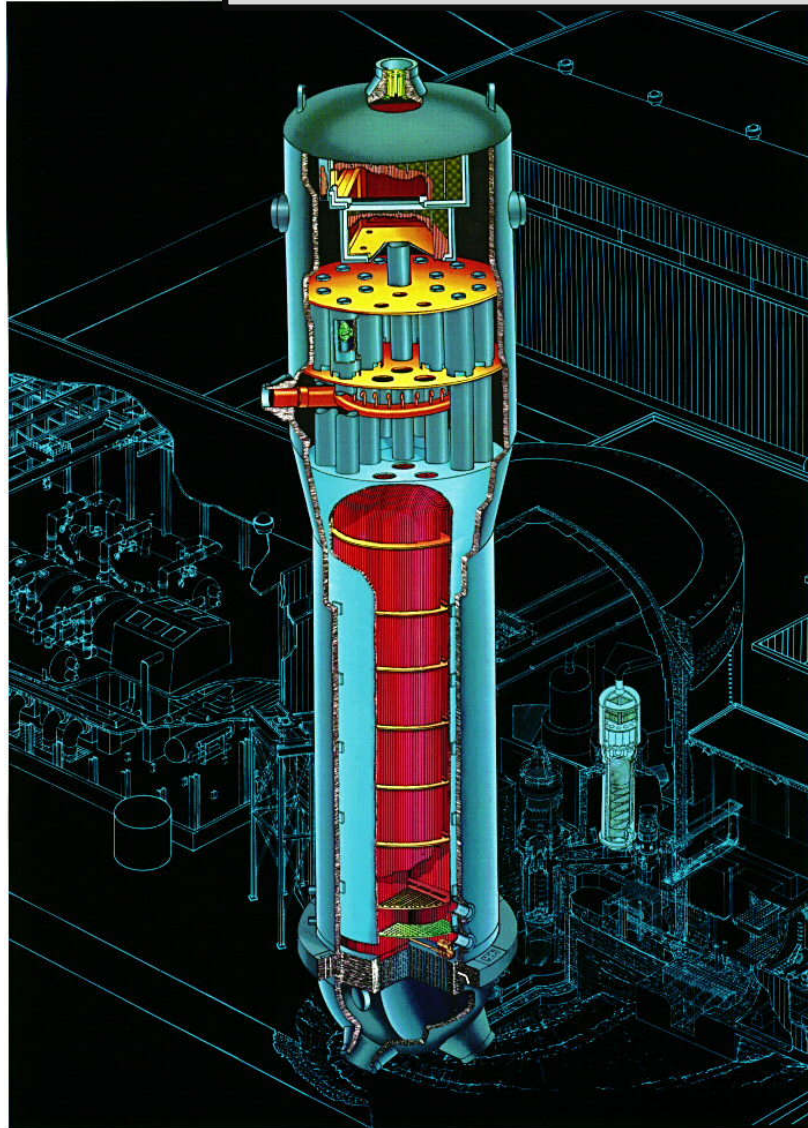
La presión es de 15.2MPa

$$T_{\text{sat}} = 616.5\text{K a esa } p$$

Para evitar que el agua hierva el sistema tiene un presurizador

Tiene un coeficiente de vacío negativo

El núcleo está conectado a varios generadores de vapor



El agua caliente que sale del núcleo se lleva a generadores de vapor (intercambiadores de calor)

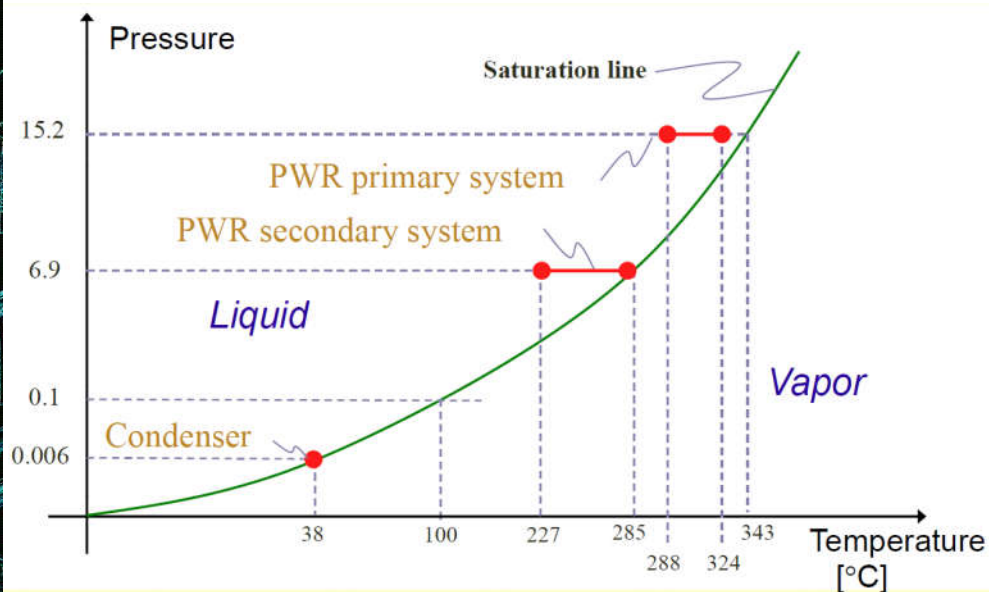
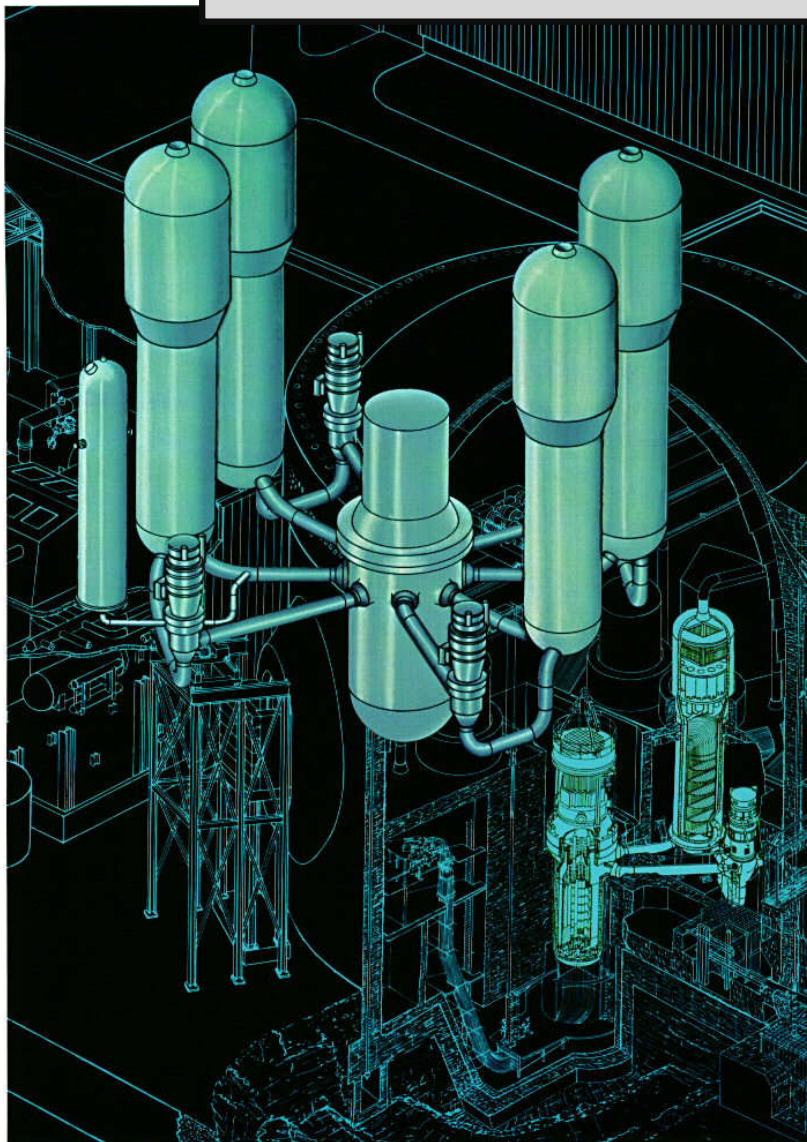
El agua del circuito secundario entra en el generador de vapor a 500K y sale a 558K (T_{sat} a $p = 6.9\text{MPa}$)

Hay producción de entropía: ineficiencia

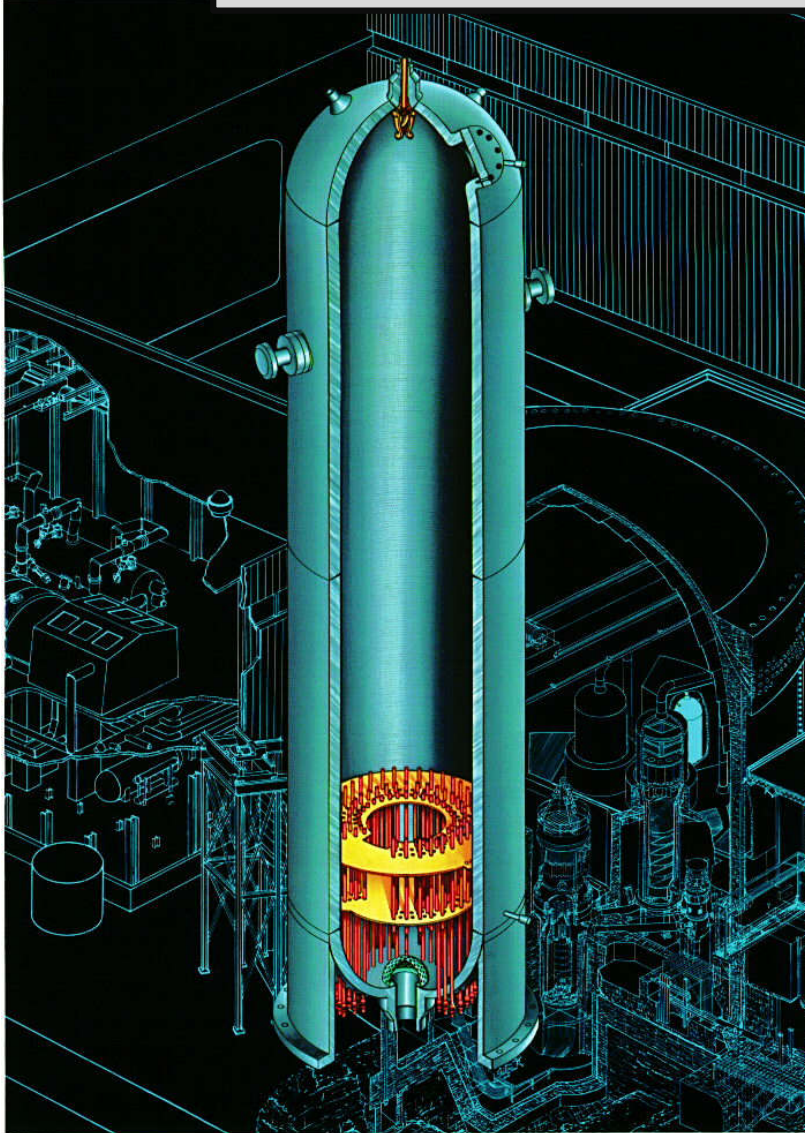
$$\dot{S}_{\text{gen}} = \frac{\dot{Q}}{T_F} - \frac{\dot{Q}}{T_C}$$

Los generadores de vapor son intercambiadores de calor

En un PWR típico puede haber 1, 2 o 4 generadores de vapor



El circuito primario incluye un presurizador



Si se produce un LOCA, la presión baja bruscamente



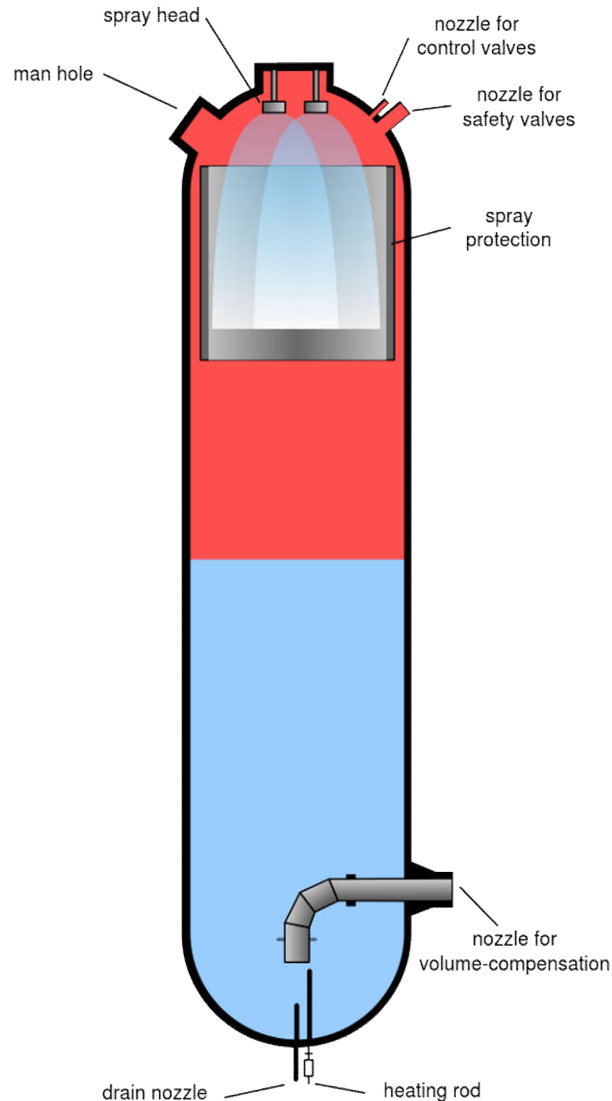
Se produce ebullición



Accidente

El presurizador regula la presión por feed-back

El circuito primario incluye un presurizador



Está parcialmente lleno de agua a la temperatura de saturación para esa presión, en equilibrio con vapor

El presurizador regula la temperatura por feed-back

Cambiando T , cambia p

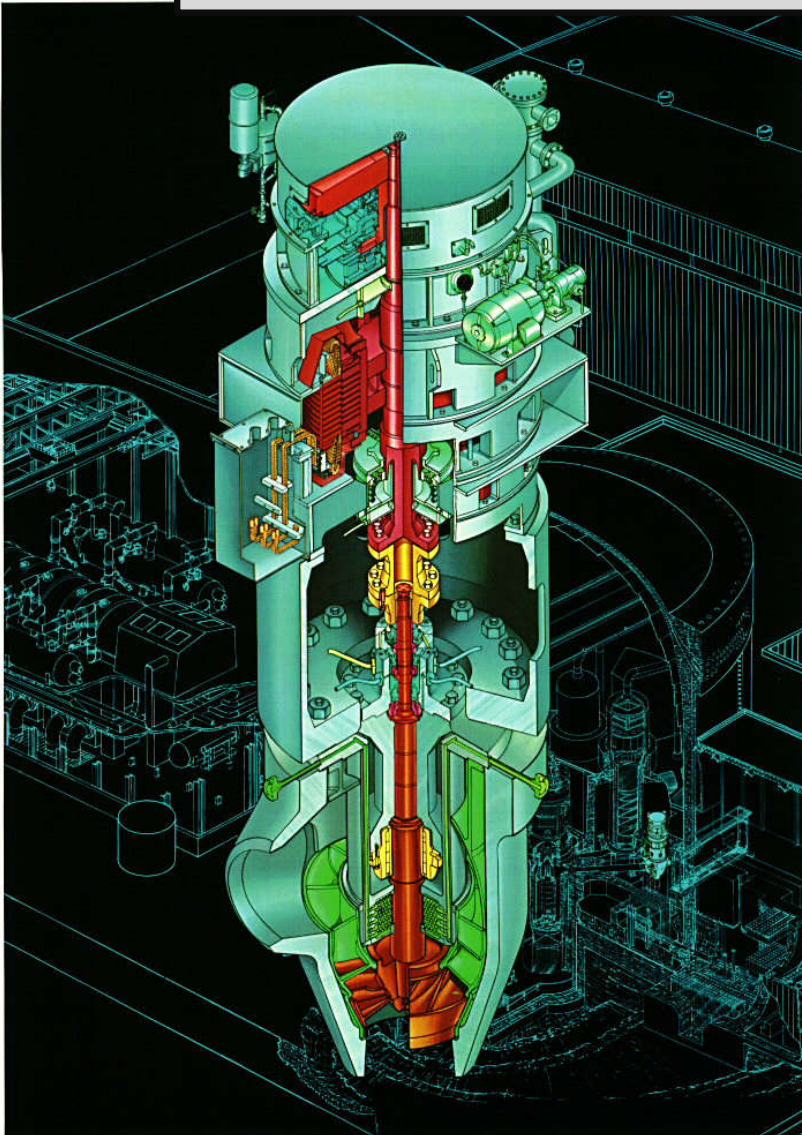
Calentador:

$p \uparrow$

Spray de gotas:

$p \downarrow$

El circuito primario se completa con bombas



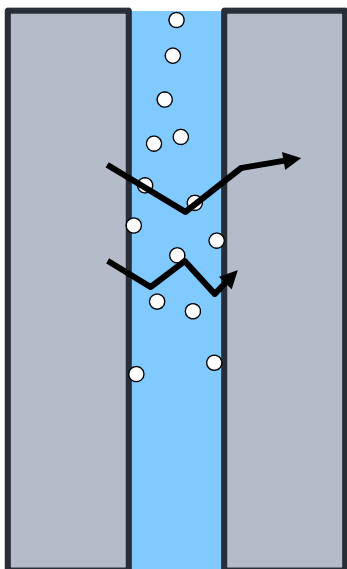
Alimentada eléctricamente desde el exterior

Entre 4500kw y 7500kw

Coeficiente de vacío en un reactor PWR

Un reactor PWR tiene un coeficiente de vacío negativo

Si se forman burbujas



Los neutrones pueden atravesar el moderador sin colisionar

Disminuye la absorción, $\rho \uparrow$

Disminuye la moderación, $\rho \downarrow$

La reducción de la moderación es dominante



Ejemplo de reactor PWR

The world's reactors
No. 68

SNUPPS

Standardized Nuclear Unit Power Plant System

| | | | |
|--|----------------------------------|--|---|
| Owner-operator: Kansas City Power & Light Co. Kansas Gas and Electric Co. | Northern States Power Co. | Reactors Gas and Electric Corp. | Union Electric Co. |
| Station name: Wolf Creek Unit 1 | Tyone Energy | Sterling Unit 1 | Callaway Units 1 & 2 |
| Location: Burlington, Kan. | Durand, Wisc. | Sterling, N.Y. | Fulton, Mo. |
| Commercial operation: April 1982 | April 1986 | April 1984 | 1 - October 1981 2 - April 1982 |
| Contractor: Daniel International | | | Daniel International |
| Site architect-engineer: Sargent & Lundy | Commonwealth Associates, Inc. | Bachler Associates Professional Corp. | Swickard & Peckel and Associates, Inc. |

*Operator
All other data same for each.

Contracts
Lead architect-engineer
Project management
Nuclear steam supply system
Turbine generator

Power
Net electrical output
Gross electrical output
Gross thermal output

Reactor core
Fuel element (equivalent)
Pellet diameter
Pellet length
Clad thickness
Linear fuel rating
Fuel enrichment
Fuel discharge burn-up (average)

Reactivity control
Control rods: Number - Full length
Neutron absorber
Cladding material
Moderator

Primary coolant system
Type
Operating pressure
Reactor outlet temperature
Reactor inlet temperature
Coolant pumps: Number
Type
Total reactor flow

Reactor pressure vessel
Inside diameter
Inside height
Wall thickness (core region)
Material
Design pressure
Design temperature

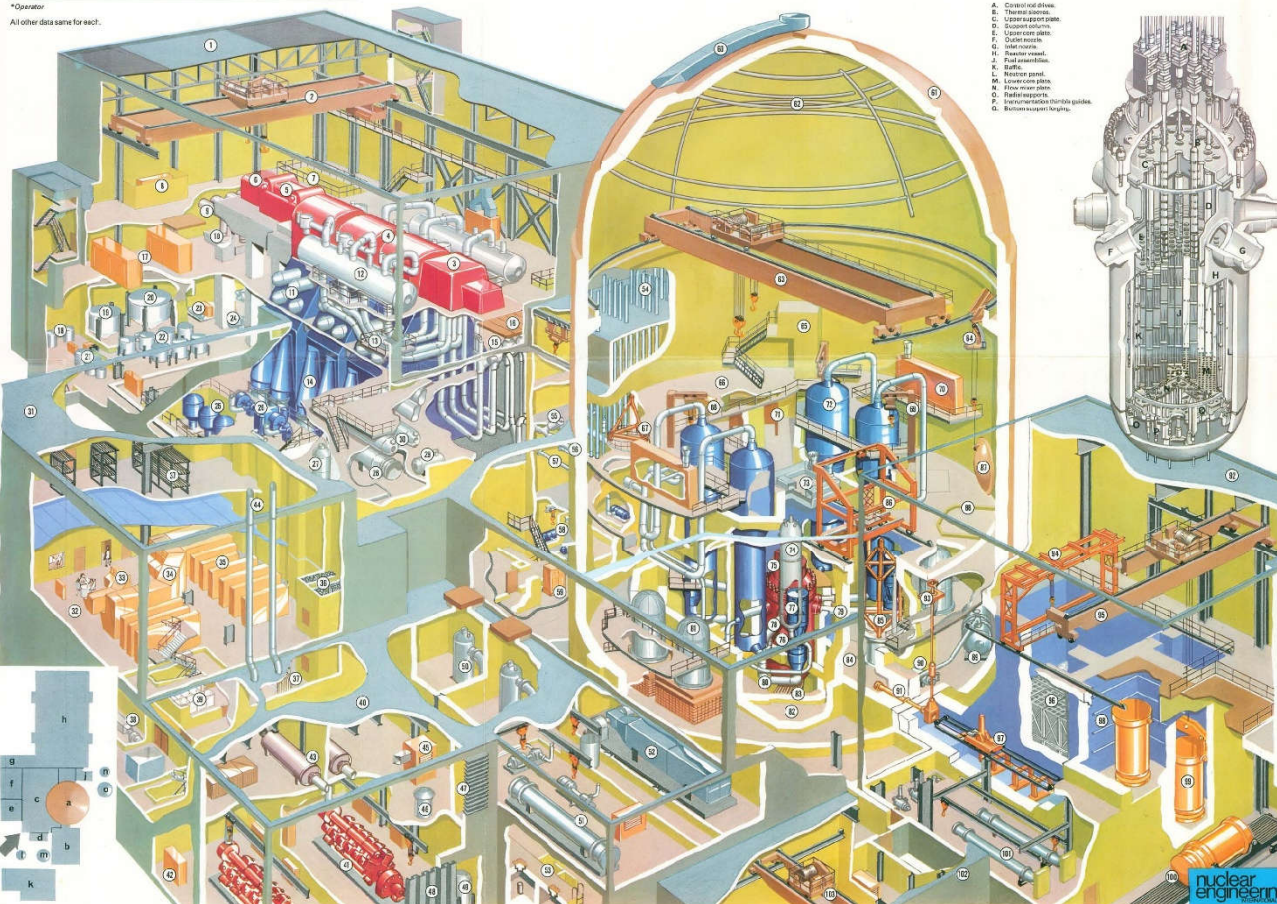
Containment
Type
Pressure suppression
Emergency cooling

Design pressure
Inside diameter
Inside height

Steam generators
Type
Number
Tube material
Thermal rating

Turbine-generator sets
Type
Rating
Borings
Generator cooling: Steam
Waste
TSV pressure
TSV temperature

NUCLEAR ENGINEERING INTERNATIONAL NOVEMBER 1975
67-68, Burlington Press Co., 1310
Nuclear Engineering International,
Deerfield House, Springfield, Mass.,
London SE1 8LU, England.



1. Turbine building
2. Fuel building
3. High pressure tank
4. Core cooling tank
5. Condenser
6. Turbine
7. Generator
8. Generator
9. Generator
10. Generator
11. Generator
12. Generator
13. Generator
14. Generator
15. Generator
16. Generator
17. Generator
18. Generator
19. High TSV tank
20. Low TSV tank
21. Fuel tank
22. Fuel tank
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122. Fuel tank
123. Fuel tank
124. Fuel tank
125. Fuel tank



Ejemplo de reactor PWR: Guandong

GUANGDONG NUCLEAR POWER PLANT

Twin unit PWR station located at Daya Bay, People's Republic of China

广东核电站

TECHNICAL DATA

Power
 NSSS thermal power: 2905 MWt
 Gross electrical output: 693.7 MWe
 Net electrical output: 550 MWe
 Frequency: 50 Hz

Reactor core

Fuel assembly: AFA
 Number of fuel assemblies: 153
 Total weight of uranium: 72.5 t

Reactor coolant system

Number of primary loops: 3
 RCS operating pressure: 15.5 bar
 Coolant temperature at RPV inlet: 232.4°C
 Coolant temperature at spray water: 227.4°C

Reactor vessel

Type: 3 loop
 Inner diameter: 3.99 m
 Weight (vessel + head): 251 t
 Manufacturer: Framatome

Steam generators

Type: SG1B
 Tube material: Ti-6Al-4V (90%)
 Tube diameter: 76 mm
 Steam pressure at SG outlet and nominal power: 15.5 bar
 Steam humidity at SG outlet: 0.25% max.
 Total weight (empty): 328 t
 Manufacturer: Framatome

Reactor coolant pumps

Number: 3
 Type: 30
 Maximal flow: 23,736 m³/h
 Voltage: 6.6 kV
 Total weight: 99 t
 Manufacturer: Aurant Schneider

Steam cycle

Steam flow rate: 163.85 kg/s @ 15.5 bar
 Steam pressure at SG outlet and 100% power: 15.5 bar
 Condenser pressure: 0.075 bar
 Main condenser pumps (3 x 50%): 75 m³/h
 Turbine driven: 1 motor driven

Condenser

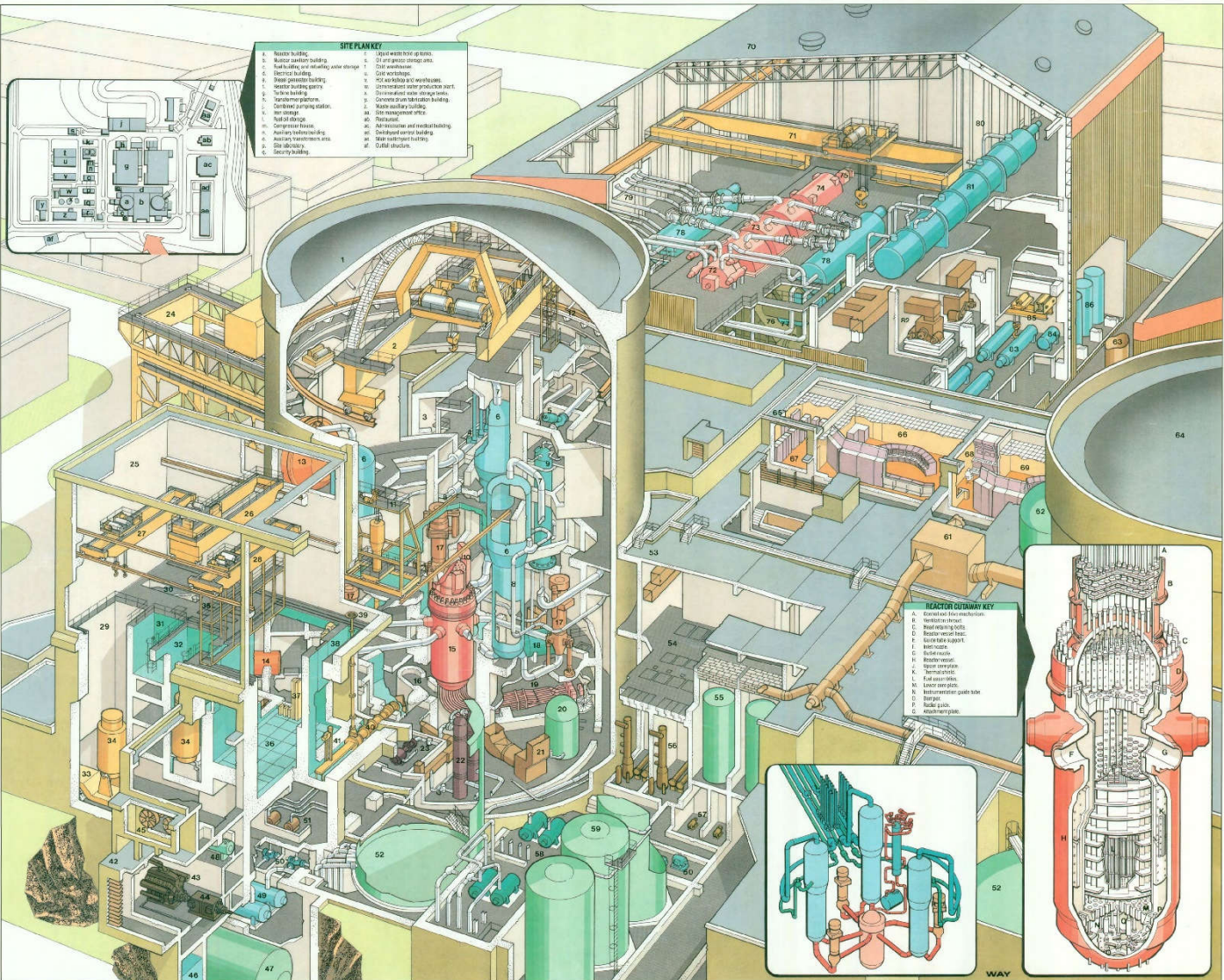
Tube material: Titanium
 Absolute pressure: 0.075 mbar
 Cooling water temperature: 23°C
 Cooling water flow rate: 44 m³/sec

Turbine generator

Maximum rating: 693.7 MVA
 Speed: 3000 rpm
 High pressure cylinder: 1 do. 26 bar
 Low pressure cylinders: 3 do. 26 bar
 Generator rating: 693 MVA, 2 poles
 Generator voltage: 20 kV
 Manufacturer: GEC

KEY

- 1. Reactor building (unit 1).
- 2. Fuel crane.
- 3. Steam radiator.
- 4. Steam safety valves.
- 5. Steam isolation valves.
- 6. Steam generator (SG).
- 7. Main steam pipe.
- 8. Feedwater pipe.
- 9. Pressure pipe.
- 10. Control rod drive mechanism ventilator shroud.
- 11. Fuel manipulator cranes.
- 12. Containment spray pipes.
- 13. Equipment hatch.
- 14. Personnel emergency air lock (ground level).
- 15. Reactor vessel.
- 16. Pressure relief valves.
- 17. Reactor coolant pump (RCP).
- 18. Pressurizer relief tank.
- 19. In-core instrumentation rooms.
- 20. Safety injection accumulator (SIA).
- 21. Ventilation fan.
- 22. Residual heat removal heat exchanger.
- 23. Residual heat removal pumps.
- 24. Reactor building gantry.
- 25. Fuel building.
- 26. Covered crane.
- 27. Auxiliary crane.
- 28. Spare fuel cranes.
- 29. Hoisting hatch.
- 30. New fuel assemblies reception area.
- 31. Shipping cask unloading pit.
- 32. Shipping cask loading pit.
- 33. Cask transporter.
- 34. Shipping cask.
- 35. New fuel storage racks.
- 36. Spent fuel pit.
- 37. Fresh fuel assemblies storage cells.
- 38. Fuel transfer cask.
- 39. Fuel transfer lock.
- 40. Fuel transfer tube.
- 41. Fuel transfer lifting frame.
- 42. Diesel generator building.
- 43. Diesel engine (DG - generator).
- 44. Generator.
- 45. Diesel exhaust fans.
- 46. Water storage.
- 47. Diesel fuel tanks.
- 48. Day tanks.
- 49. Containment spray heat exchangers.
- 50. Low head safety injection pumps.
- 51. Containment air recycler control fan.
- 52. Refueling water storage tank.
- 53. Nuclear auxiliary building.
- 54. Filter and demineralizer room.
- 55. Surge tanks.
- 56. Gas lift pumps.
- 57. Gas lift pumps.
- 58. Compressor cooling pumps.
- 59. Hot air tanks.
- 60. Evaporator test pumps and straining pump.
- 61. Exit seal air system.
- 62. Sare filter.
- 63. Bar-lift air stack.
- 64. Reactor building (unit 2).
- 65. Electrical building.
- 66. Control room (unit 1).
- 67. Computer room.
- 68. Switchgear control panel.
- 69. Control room (unit 2).
- 70. Turbine building.
- 71. Overhead crane.
- 72. High pressure turbine.
- 73. Low pressure turbine (LP).
- 74. Condenser.
- 75. Exciter.
- 76. Diesel generator.
- 77. Low pressure heaters.
- 78. Moisture separator-reheater.
- 79. Moisture separator-reheater pipes.
- 80. Separator bay.
- 81. Separator.
- 82. Ventilation plant.
- 83. Low pressure heaters.
- 84. Steam converter disintegrator.
- 85. Feed pump crane.
- 86. Condensate polishing plant.



SITE PLAN KEY

| | |
|--|---|
| 1. Reactor building. | 11. Reactor building (unit 2). |
| 2. Fuel crane. | 12. Electrical building. |
| 3. Steam radiator. | 13. Control room (unit 1). |
| 4. Steam safety valves. | 14. Computer room. |
| 5. Steam isolation valves. | 15. Switchgear control panel. |
| 6. Steam generator (SG). | 16. Control room (unit 2). |
| 7. Main steam pipe. | 17. Turbine building. |
| 8. Feedwater pipe. | 18. Overhead crane. |
| 9. Pressure pipe. | 19. Diesel generator building. |
| 10. Control rod drive mechanism ventilator shroud. | 20. Diesel engine (DG - generator). |
| 11. Fuel manipulator cranes. | 21. Generator. |
| 12. Containment spray pipes. | 22. Diesel exhaust fans. |
| 13. Equipment hatch. | 23. Water storage. |
| 14. Personnel emergency air lock (ground level). | 24. Diesel fuel tanks. |
| 15. Reactor vessel. | 25. Day tanks. |
| 16. Pressure relief valves. | 26. Containment spray heat exchangers. |
| 17. Reactor coolant pump (RCP). | 27. Low head safety injection pumps. |
| 18. Pressurizer relief tank. | 28. Containment air recycler control fan. |
| 19. In-core instrumentation rooms. | 29. Refueling water storage tank. |
| 20. Safety injection accumulator (SIA). | 30. Nuclear auxiliary building. |
| 21. Ventilation fan. | 31. Filter and demineralizer room. |
| 22. Residual heat removal heat exchanger. | 32. Surge tanks. |
| 23. Residual heat removal pumps. | 33. Gas lift pumps. |
| 24. Reactor building gantry. | 34. Gas lift pumps. |
| 25. Fuel building. | 35. Compressor cooling pumps. |
| 26. Covered crane. | 36. Hot air tanks. |
| 27. Auxiliary crane. | 37. Evaporator test pumps and straining pump. |
| 28. Spare fuel cranes. | 38. Exit seal air system. |
| 29. Hoisting hatch. | 39. Sare filter. |
| 30. New fuel assemblies reception area. | 40. Bar-lift air stack. |
| 31. Shipping cask unloading pit. | 41. Reactor building (unit 2). |
| 32. Shipping cask loading pit. | 42. Electrical building. |
| 33. Cask transporter. | 43. Control room (unit 1). |
| 34. Shipping cask. | 44. Computer room. |
| 35. New fuel storage racks. | 45. Switchgear control panel. |
| | 46. Control room (unit 2). |
| | 47. Turbine building. |
| | 48. Overhead crane. |

REACTOR COOLANT KEY

| |
|---------------------------|
| A. Generator feedwater. |
| B. Ventilation duct. |
| C. Diesel engine exhaust. |
| D. Reactor vessel head. |
| E. Diesel fuel tank. |
| F. Diesel engine. |
| G. Diesel engine exhaust. |
| H. Diesel engine exhaust. |
| I. Diesel engine exhaust. |
| J. Diesel engine exhaust. |
| K. Diesel engine exhaust. |
| L. Diesel engine exhaust. |
| M. Diesel engine exhaust. |
| N. Diesel engine exhaust. |
| O. Diesel engine exhaust. |
| P. Diesel engine exhaust. |
| Q. Diesel engine exhaust. |
| R. Diesel engine exhaust. |
| S. Diesel engine exhaust. |
| T. Diesel engine exhaust. |
| U. Diesel engine exhaust. |
| V. Diesel engine exhaust. |
| W. Diesel engine exhaust. |
| X. Diesel engine exhaust. |
| Y. Diesel engine exhaust. |
| Z. Diesel engine exhaust. |

FRAMATOME
 ELECTRICITE DE FRANCE
 SBC TURBINE GENERATORS
 This drawing was produced by the magazine Nuclear Engineering International in collaboration with Framatome, GEC Turbine Generators and Electricite de France. It was published in the September 1987 issue of Reed Business Publishing Ltd 1987. Overhead House, The Quadrant, Sutton, Surrey, SM2 5AS, United Kingdom.

WAY



Ejemplo de reactor PWR: Ulchin

ULCHIN 3 & 4

KEY TO POWER STATION CUTAWAY

- | | |
|---|---|
| 1 ▶ Turbine building | 52 ▶ Computer room |
| 2 ▶ 250-ton bridge crane | 53 ▶ Control element room |
| 3 ▶ 75-ton bridge crane | 54 ▶ Access control building |
| 4 ▶ Air handling unit | 55 ▶ Containment building |
| 5 ▶ Special tool room and workshop | 56 ▶ Containment spray system |
| 6 ▶ Heater bay surge tank | 57 ▶ Polar crane |
| 7 ▶ Condensate polishing cation bed vessels and filters | 58 ▶ HVAC duct |
| 8 ▶ Generator | 59 ▶ ROT Unit |
| 9 ▶ Low pressure turbines | 60 ▶ CSA change platform |
| 10 ▶ High pressure turbine | 61 ▶ Personnel access |
| 11 ▶ Deaerator storage tank | 62 ▶ CSA elevator drive |
| 12 ▶ Deaerator | 63 ▶ Refuelling pool |
| 13 ▶ Moisture separator reheater | 64 ▶ Pressuriser |
| 14 ▶ Low pressure feedwater heaters | 65 ▶ Control element assembly air handling unit |
| 15 ▶ High pressure feedwater heaters | 66 ▶ Safety injection tank |
| 16 ▶ Feedwater pump turbine exhaust duct | 67 ▶ Steam generator |
| 17 ▶ Motor driven feedwater pump | 68 ▶ Incore instrumentation seal table |
| 18 ▶ Turbine driven feedwater pump | 69 ▶ Reactor cooling pump |
| 19 ▶ Feedwater booster pump | 70 ▶ Reactor vessel |
| 20 ▶ Hot ducts | 71 ▶ Reactor support structure |
| 21 ▶ Combined intermediate valve | 72 ▶ Incore instrumentation guide tube |
| 22 ▶ Condenser | 73 ▶ Reactor coolant piping hot leg |
| 23 ▶ Low pressure feedwater heater | 74 ▶ Reactor coolant piping cold leg |
| 24 ▶ Main steam stop valves | 75 ▶ BOP instrumentation or collector tank |
| 25 ▶ Condensate water outlets | 76 ▶ Refuelling machine |
| 26 ▶ Water bay | 77 ▶ CSA elevator |
| 27 ▶ HVAC room | 78 ▶ Fuel transfer carriage and undercarriage in containment building |
| 28 ▶ Filter room ducting | 79 ▶ Fuel transfer tube |
| 29 ▶ New generator exhaust | 80 ▶ Emergency personnel lock |
| 30 ▶ Main steam | 81 ▶ Fuel building |
| 31 ▶ Feedwater | 82 ▶ Swing gate |
| 32 ▶ Unit heater | 83 ▶ Spent fuel handling machine |
| 33 ▶ Primary auxiliary building | 84 ▶ Cask handling crane |
| 34 ▶ Tank room unit heater | 85 ▶ Spent fuel storage pit |
| 35 ▶ Battery racks | 86 ▶ New fuel elevator |
| 36 ▶ CCTV control unit | 87 ▶ New fuel storage pit |
| 37 ▶ Battery charger | 88 ▶ New fuel inspection area |
| 38 ▶ Diesel generator | 89 ▶ Cask loading pit |
| 39 ▶ Emergency diesel generator control room | 90 ▶ Refuelling crane |
| 40 ▶ Load centre | 91 ▶ Fuel transfer carriage and undercarriage in fuel building |
| 41 ▶ New fuel storage tank | 92 ▶ Shipping cask |
| 42 ▶ Shutdown cooling heat exchanger | 93 ▶ Cask decontamination pit |
| 43 ▶ Load centre | 94 ▶ Spent fuel pool cooling heat exchangers |
| 44 ▶ Post-accident sample pump | 95 ▶ Spent fuel pool pump room |
| 45 ▶ Fire water storage tanks | 96 ▶ Fuel loading and unloading bay |
| 46 ▶ Pipe tunnel | 97 ▶ Refuelling water tank |
| 47 ▶ Star well | 98 ▶ Fuel building air handling unit |
| 48 ▶ Main steam vents | 99 ▶ Reactor make-up water tank |
| 49 ▶ Component cooling surge tank | 100 ▶ Secondary auxiliary building |
| 50 ▶ Dump water | |
| 51 ▶ Control room | |

MAIN TECHNICAL DATA

| REACTOR | | REACTOR COOLANT SYSTEM | |
|-----------------------|-------------------------------------|----------------------------|------------------------------|
| Type | 2BWR | No. of loops | 2 |
| Core thermal output | 2815 MWt | Core flow rate | 121.5 x 10 ³ lb/h |
| Design pressure | 2500 lb/in ² (172.4 bar) | Design thermal power | 2825 MWt |
| Design temperature | 650°F (343.3°C) | Reactor inlet temperature | 554.3°F (295.8°C) |
| Reactor vessel volume | 3521.9 m ³ | Reactor outlet temperature | 611.2°F (327.3°C) |
| | | Normal operating pressure | 2250 lb/in ² |

| REACTOR COOLANT PUMPS | | CONTAINMENT | |
|--------------------------|--------------|------------------------------|---|
| Number | 4 | Type | Prestressed cylindrical concrete with steel liner |
| Pump speed | 1190 RPM | Inside diameter | 164 ft |
| Motor type | AC induction | Height | 219 ft |
| Voltage | 13,200 V | Normal operating temperature | < 120°F (49.3°C) |
| Rated total dynamic head | 545 ft | Liner thickness | 0.25 in |
| Rated flow rate | 85,400 gpm | | |
| Frequency | 60 Hz | | |

| FUEL | | TURBINE | |
|------------------------|----------------------------|---------|--|
| No. of fuel assemblies | 177 | Number | 1 (double flow high pressure) + 3 (double flow low pressure) + 6 flow, tandem compound |
| Fuel weight | 189.9 x 10 ³ lb | RPM | 1800 |
| No. of fuel rods | 41,182 | | |
| Core diameter | 123 in | | |
| Clad material | Zircaloy-4 | | |
| Clad thickness | 0.023 in | | |

| STEAM GENERATOR | | GENERATOR | |
|----------------------------|---|---------------------|--------------------------------|
| Type | Vertical U-tube | Number | 1 |
| No. of units | 2 | Type | Direct driven/Conductor cooled |
| Primary/secondary pressure | 2250/1070 lb/in ² | Voltage | 22 kV, 5 phase |
| Coolant volume each SG | 1024 ft ³ (31.9 m ³) | Frequency | 60 Hz |
| Tube thickness | 0.042 in (1.07 mm) | Net electric output | 1000 MW _e |
| Steam quality | 99.7% | | |
| Feedwater temperature | 450°F (232.2°C) | | |

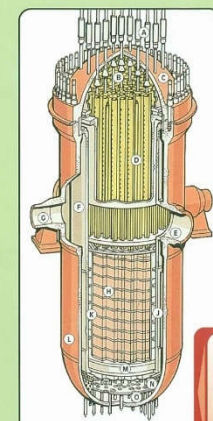
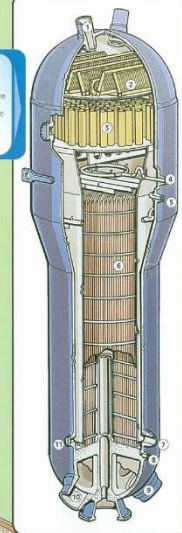
This walkchart was produced by the magazine Nuclear Engineering International in collaboration with KOPIC. It was published in the April 1988 issue.

nuclear engineering

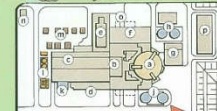


REACTOR COOLANT SYSTEM

- ### STEAM GENERATOR KEY
- 1 Steam generator
 - 2 Drums
 - 3 Separators
 - 4 Recirculation nozzle
 - 5 Downcomer feedwater nozzle
 - 6 Tube bundle
 - 7 Economiser feedwater nozzle
 - 8 Blowdown nozzle
 - 9 Reactor coolant inlet
 - 10 Reactor coolant outlet
 - 11 Reflowdrums



- ### REACTOR PRESSURE VESSEL KEY
- 1 Control element drive mechanism
 - 2 Control element assembly extension shafts
 - 3 Reactor vessel closure head assembly
 - 4 Upper guide structure
 - 5 Core nozzle
 - 6 Core support barrel
 - 7 Inlet nozzle
 - 8 Fuel assemblies
 - 9 Fuel assembly support
 - 10 Core shroud
 - 11 Reactor vessel
 - 12 Lower support structure
 - 13 Flow shift
 - 14 Bottom head nozzles



- ### SITE PLAN KEY
- 1 Containment building
 - 2 Primary auxiliary building
 - 3 Turbine building
 - 4 Turbine building reactor bay
 - 5 Access control building
 - 6 Secondary auxiliary building
 - 7 Fuel building
 - 8 Reactor make-up water tanks
 - 9 New water coast
 - 10 Condensate storage tanks
 - 11 Transformer plant
 - 12 Chemical storage tank area
 - 13 Gatehouse
 - 14 Diesel fuel storage tanks
 - 15 Radwaste building



Algunos datos técnicos de un reactor PWR típico

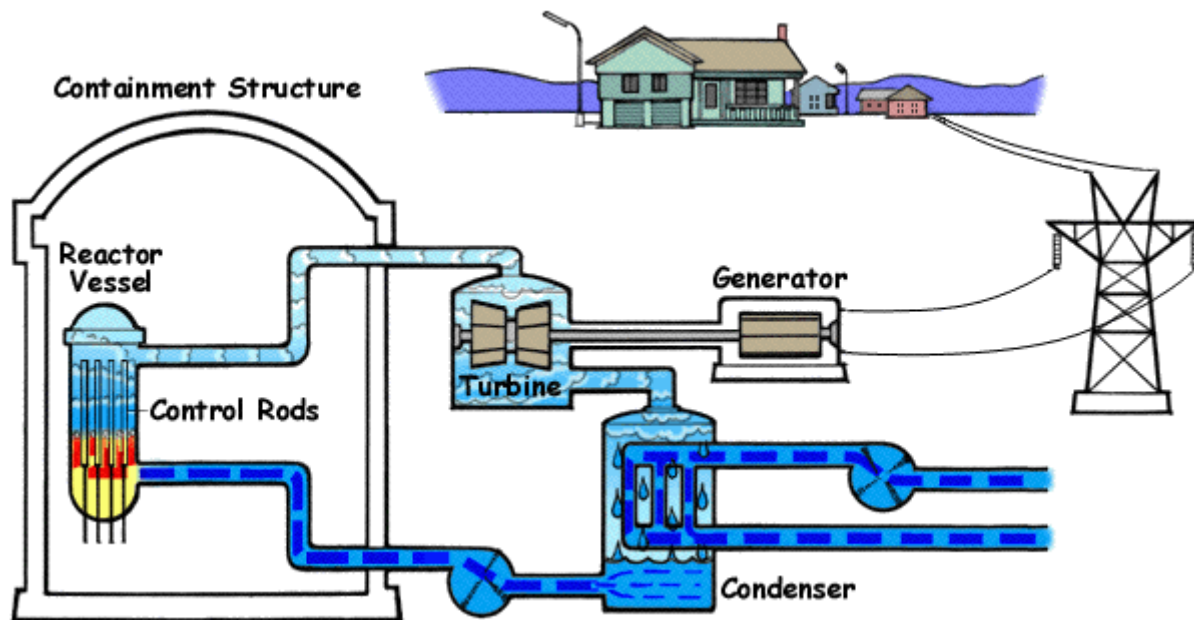
| Parameter | 4-loop PWR |
|--|------------|
| 1. Plant | |
| Number of primary loops | 4 |
| Reactor thermal power (MWth) | 3411 |
| Total plant thermal efficiency (%) | 34 |
| Plant electrical output | 1150 |
| Power generated directly in coolant (%) | 2.6 |
| Power generated in the fuel (%) | 97.4 |
| 2. Core | |
| Core barrel inside diameter/outside diameter (m) | 3.76/3.87 |
| Rated power density (kW/L) | 104.5 |
| Core volume (m ³) | 32.6 |
| Effective core flow area (m ²) | 4.747 |
| Active heat transfer surface area (m ²) | 5546.3 |
| Average heat flux (kW/m ²) | 598.8 |
| Design axial enthalpy rise peaking factor (F _{AD}) | 1.65 |
| Allowable core total peaking factor (F _Q) | 2.5 |
| 3. Primary Coolant | |
| System pressure (MPa) | 15.51 |
| Core inlet temperature (°C) | 292.7 |
| Average temperature rise in reactor (°C) | 33.4 |
| Total core flow rate (Mg/s) | 18.63 |
| Effective core flow rate for heat removal (Mg/s) | 17.7 |
| Average core inlet mass flux (kg/m ² -s) | 3,729 |
| 4. Fuel Rods | |
| Total number | 50,952 |
| Fuel density (% of theoretical) | 94 |
| Fuel pellet diameter (mm) | 8.19 |
| Fuel rod diameter (mm) | 9.5 |
| Cladding thickness (mm) | 0.57 |
| Cladding material | Zircaloy-4 |
| Active fuel height (m) | 3.66 |

| Parameter | 4-loop PWR |
|--|-------------|
| 5. Fuel Assemblies | |
| Number of assemblies | 193 |
| Number of heated rods per assembly | 264 |
| Fuel rod pitch (mm) | 12.6 |
| Fuel assembly pitch (mm) | 215 |
| Number of grids per assembly | 7 |
| Fuel assembly effective flow area (m ²) | 0.02458 |
| Location of first spacer grid above beginning of heated length (m) | 0.3048 |
| Grid spacing (m) | 0.508 |
| Grid type | L-grid* |
| Number of control rod thimbles per assembly | 24 |
| Number of instrument tubes | 1 |
| Guide tube outer diameter (mm) | 12.243 |
| 6. Rod Cluster Control Assemblies | |
| Neutron absorbing material | Ag-In-Cd |
| Cladding material | Type 304 SS |
| Cladding thickness (mm) | 0.46 |
| Number of clusters Full/Part length | 53/8 |
| Number of absorber rods per cluster | 24 |
| *Employs mixing vanes | |

Fabricantes:
 Westinghouse
 Framatome
 Babcock & Wilcox
 Combustion
 Engineering
 ABB
 Mitsubishi

Fuente: [MIT](http://www.mit.edu)

El reactor de agua en ebullición (*boiling water reactor, BWR*)



Inicialmente, se creyó imposible un reactor que produjera vapor directamente

A alta presión es posible

Ventajas:

Aprovechamiento del calor

Eficiencia

Simplicidad

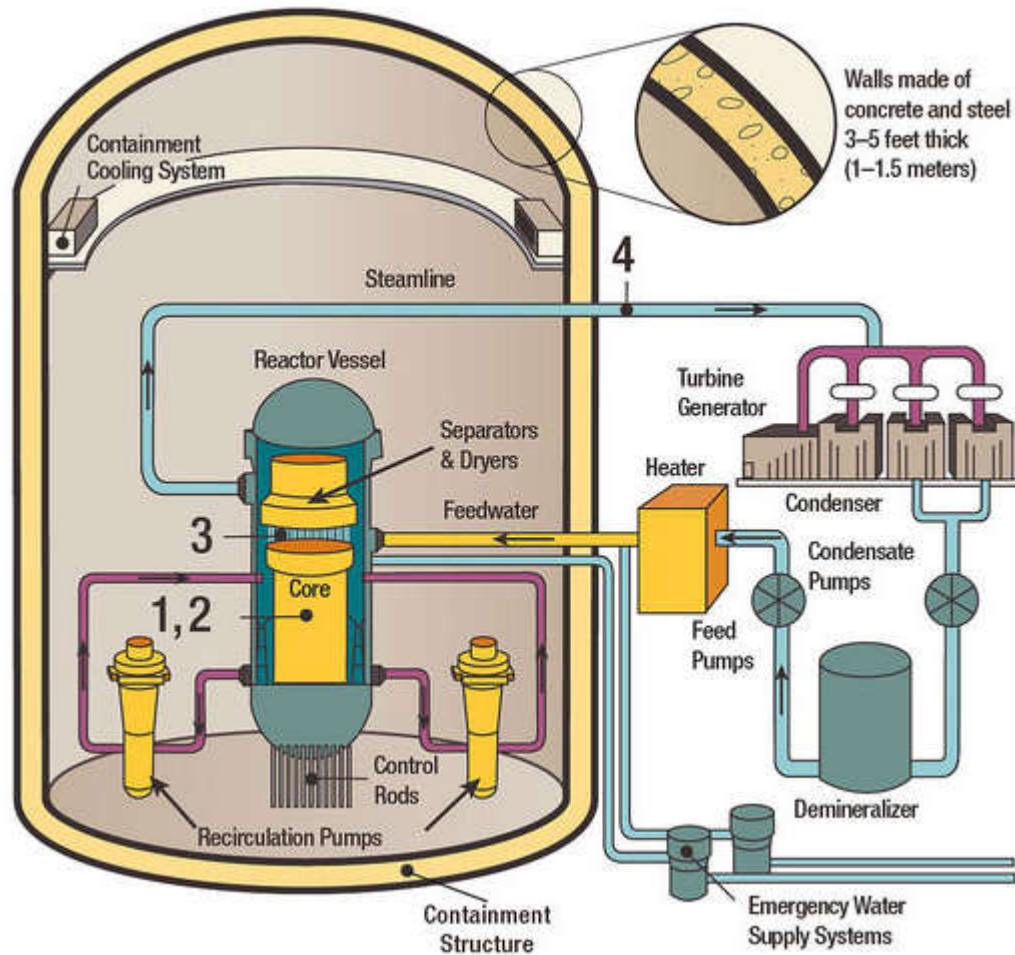
Presión más baja (1/2 de PWR)

Inconvenientes:

Debe tener mayor tamaño

Turbinas deben blindarse

Esquema general de una central BWR



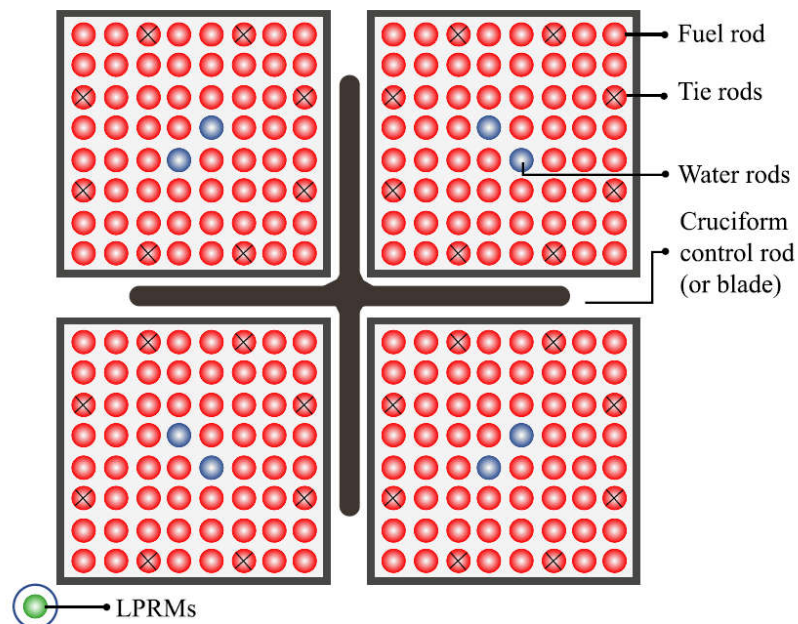
El circuito primario conecta la vasija del reactor con las turbinas

Además hay un circuito refrigerante

las varillas de control entran desde abajo

Fuel assembly de un BWR

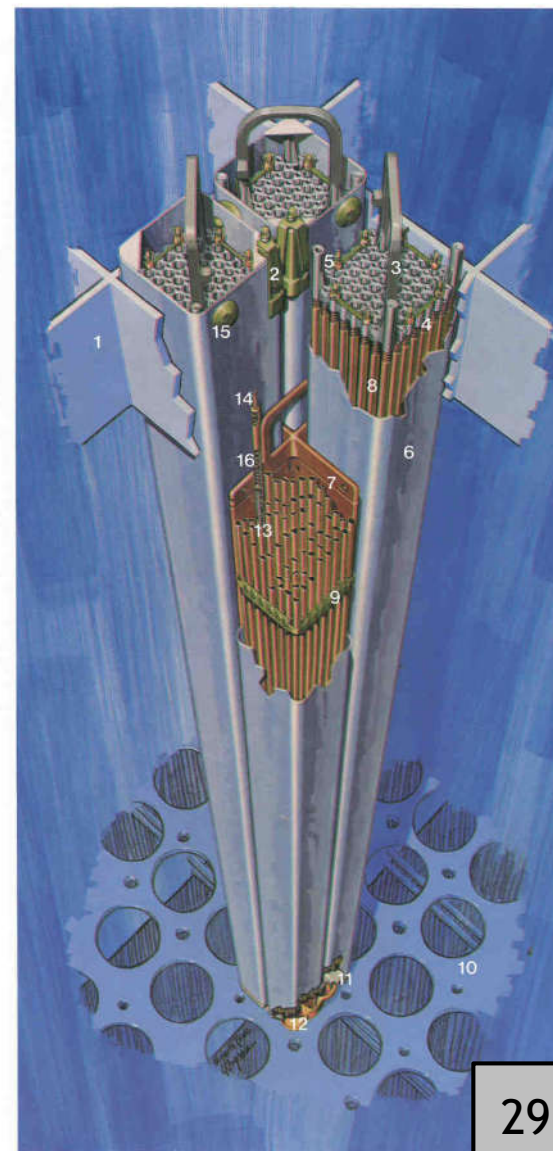
En un BWR típico hay elementos más pequeños que en un PWR



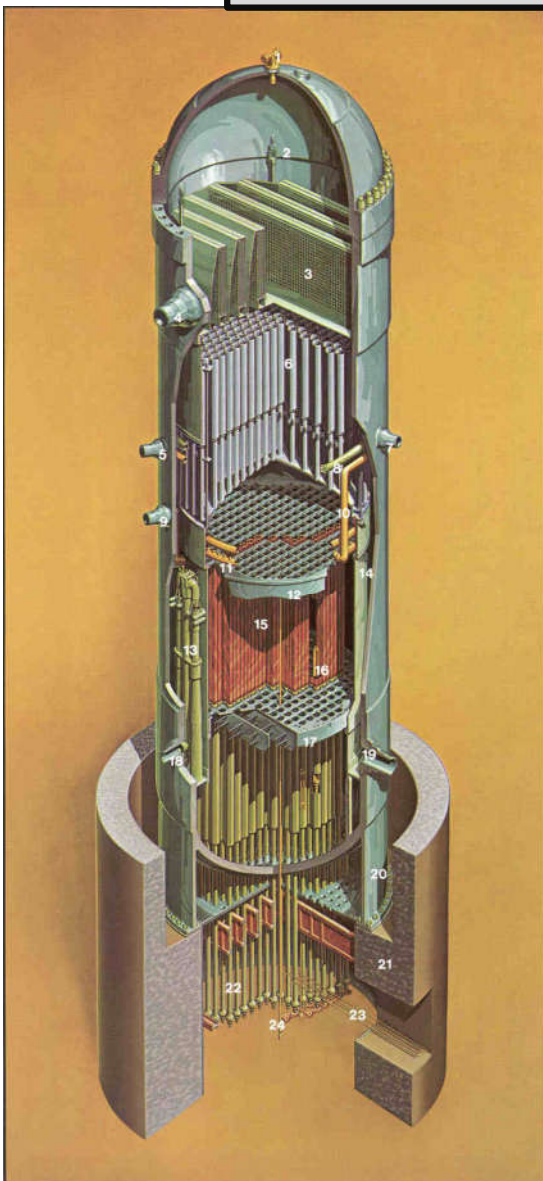
En lugar de varillas de control pueden tener hojas cruciformes

BWR/6 FUEL ASSEMBLIES & CONTROL ROD MODULE

- 1.TOP FUEL GUIDE
- 2.CHANNEL FASTENER
- 3.UPPER TIE PLATE
- 4.EXPANSION SPRING
- 5.LOCKING TAB
- 6.CHANNEL
- 7.CONTROL ROD
- 8.FUEL ROD
- 9.SPACER
- 10.CORE PLATE ASSEMBLY
- 11.LOWER TIE PLATE
- 12.FUEL SUPPORT PIECE
- 13.FUEL PELLETS
- 14.END PLUG
- 15.CHANNEL SPACER
- 16.PLENUM SPRING



El núcleo de un reactor BWR



BWR/6 REACTOR ASSEMBLY

1. VENT AND HEAD SPRAY
2. STEAM DRYER LIFTING LUG
3. STEAM DRYER ASSEMBLY
4. STEAM OUTLET
5. CORE SPRAY INLET
6. STEAM SEPARATOR ASSEMBLY
7. FEEDWATER INLET
8. FEEDWATER SPARGER
9. LOW PRESSURE COOLANT INJECTION INLET
10. CORE SPRAY LINE
11. CORE SPRAY SPARGER
12. TOP GUIDE
13. JET PUMP ASSEMBLY
14. CORE SHROUD
15. FUEL ASSEMBLIES
16. CONTROL BLADE
17. CORE PLATE
18. JET PUMP / RECIRCULATION WATER INLET
19. RECIRCULATION WATER OUTLET
20. VESSEL SUPPORT SKIRT
21. SHIELD WALL
22. CONTROL ROD DRIVES
23. CONTROL ROD DRIVE HYDRAULIC LINES
24. IN-CORE FLUX MONITOR

GENERAL ELECTRIC

6. El vapor sale por arriba

5. Un secador elimina los restos de agua

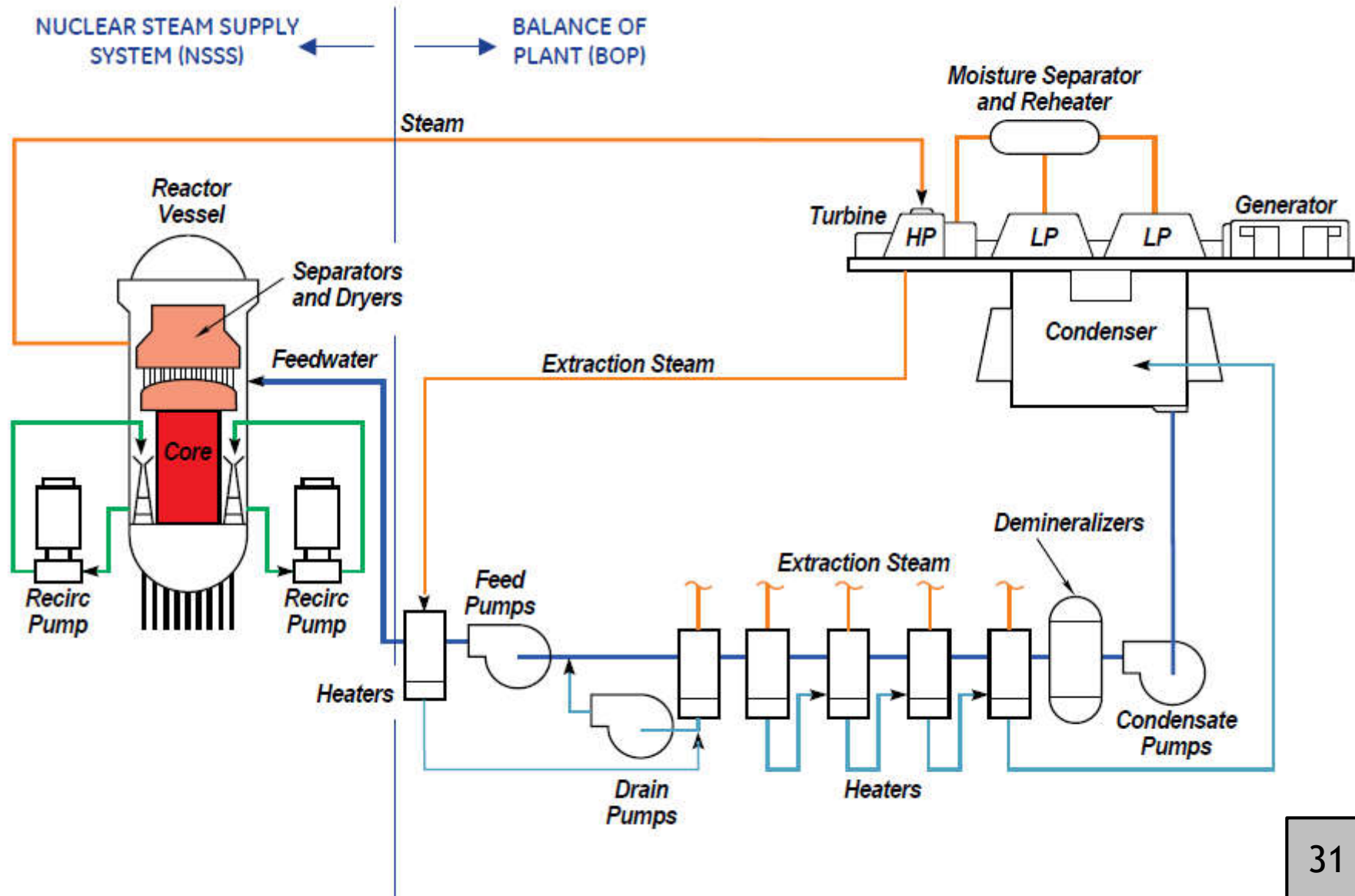
4. Un separador extrae el vapor del líquido

3. Ascende mientras se calienta y evapora

2. desciende y vuelve a subir

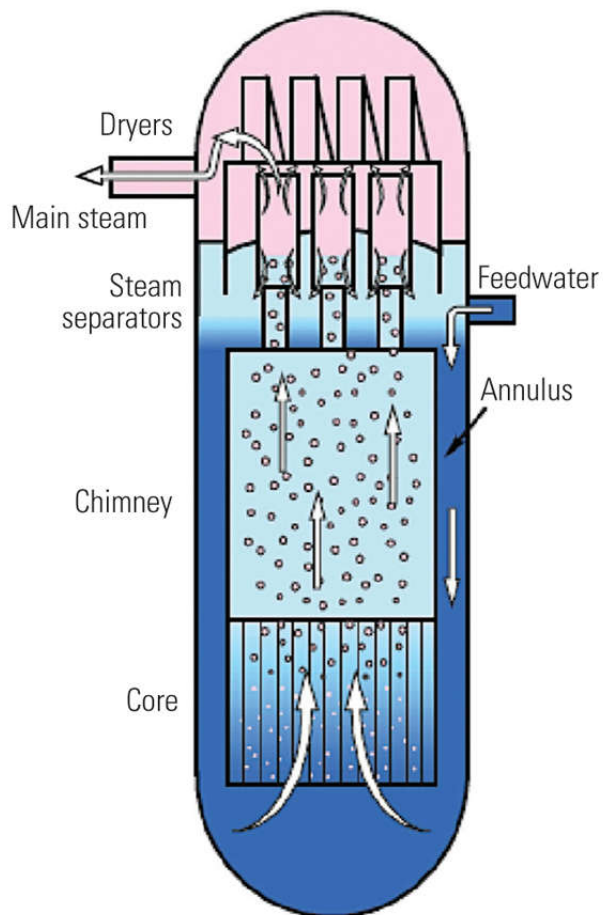
1. El agua entra a media altura

Los reactores BWR tienen un *recirculation loop*



Coeficiente de vacío en una central BWR

- Saturated water
- Subcooled water
- Saturated steam



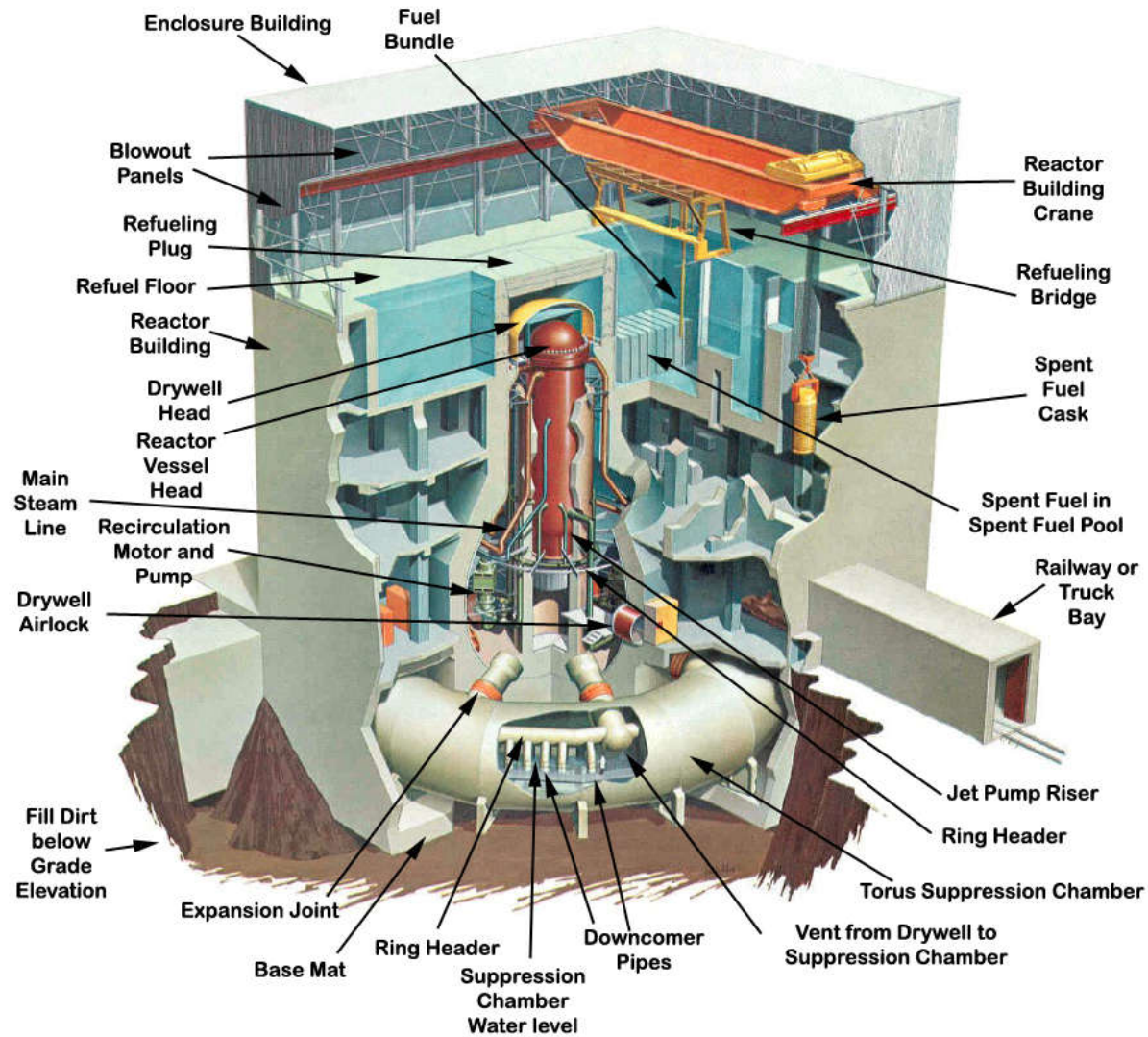
Posee un coeficiente de vacío negativo

Puede ser peligroso

Si por un atasco aumenta la cantidad de líquido o la presión



El edificio de contención de un BWR



Ejemplo de reactor BWR: Douglas Point

The World's Reactors No. 60

DOUGLAS POINT BWR/6

OWNER OPERATOR
Potomac Electric Power Company

MAIN CONTRACTOR
Bechtel Services Inc. Architect Engineer

LOCATION
Douglas Point, Chesapeake County, Maryland, U.S.A.
East bank of Potomac River, approximately 5.7 mile (9.2 km) SSE of Quantico, Virginia, and 54 mile (87 km) SSW of Centreville, Washington D.C.

TYPE
Two units equipped with boiling water reactor (BWR 6) nuclear steam supply systems designed and fabricated by General Electric Company and incorporating Mark III Containment.

| SCHEDULE | Unit 1 | Unit 2 |
|------------------------|-------------|-------------|
| Commenced construction | March, 1975 | March, 1975 |
| Commercial operation | March, 1980 | March, 1982 |

of data listed below refers to one reactor turbine and the values for each of the two units being identical.

POWER
Net electrical output
Gross electrical output
Gross thermal output

REACTOR CORE
Thermal output at max. core power
Core diameter (equivalent)
Core height (active)
Number of fuel assemblies
Fuel pin lattice pitch
Average heat flux
Maximum heat flux

FUEL ASSEMBLIES
Number in core
Fuel pin material
Fuel pin diameter
Clad material
Clad thickness
Pin diameter
Number of pins per assembly
Maximum fuel center temperature
Fuel discharge thermal equilibrium

CONTROL RODS
Minimum absorber
Cooling material
Number in core
Shape
Overall length
Length of poison section

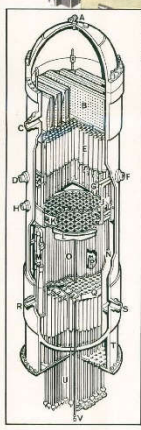
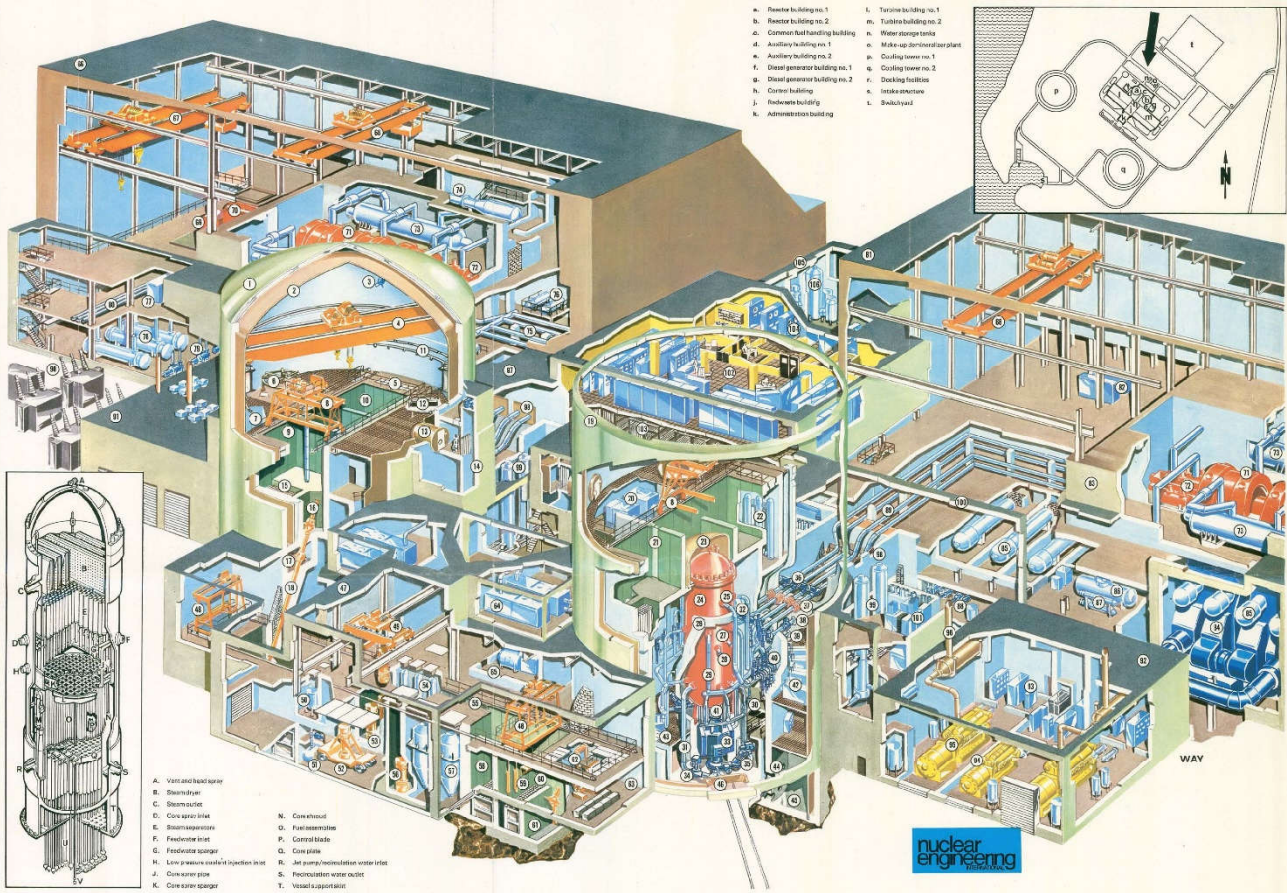
PRIMARY COOLANT SYSTEM
TYPE
Operating pressure
Reactor inlet temperature
Reactor outlet temperature
Coolant pump
Total core flow
Total core flow

REACTOR PRESSURE VESSEL
Inside diameter
Outside diameter
Wall thickness (conforming)
Material
Design pressure
Design temperature

CONTAINMENT BUILDING
Pressure suppression
Design pressure
Inside diameter (steel vessel)
Outside diameter (steel vessel)

TURBOGENERATOR
Rating
Speed
TSV pressure
TSV temperature

NUCLEAR ENGINEERING INTERNATIONAL
© IPEC Business Press Ltd., 1973
Nuclear Engineering International
Dorset House, Strand Road
London WC2R 2LJ, England



- A. Vent and head support
- B. Steamdrifter
- C. Steamdrifter
- D. Core support skirt
- E. Steam generator
- F. Fuel element inlet
- G. Fuel element outlet
- H. Low pressure sodium injection inlet
- J. Downcomer pipe
- K. Core cover support
- L. Top guide
- M. Jet pump
- N. Core shroud
- O. Fuel assemblies
- P. Control blades
- Q. Core plate
- R. Jet pump/induction water inlet
- S. Preheated water outlet
- T. Vessel support
- U. Control rod drive
- V. In-core flux monitor
- 1. Reactor building no. 2
- 2. Site containment building
- 3. Fuel element inlet
- 4. Fuel element outlet
- 5. Auxiliary water inlet and outlet
- 6. Reactor pressure vessel head
- 7. Equipment hatch access area
- 8. Refueling platform
- 9. Steam generator inlet
- 10. Reactor pressure vessel head
- 11. Core support skirt
- 12. Support platform
- 13. Fuel element
- 14. Reactor building
- 15. Fuel storage tank
- 16. Fuel transfer vehicle
- 17. Fuel transfer vehicle
- 18. Fuel transfer vehicle
- 19. Reactor building no. 1
- 20. Refueling, operation and maintenance vehicle
- 21. Fuel transfer platform
- 22. Reactor water storage heat exchanger
- 23. Dry well head
- 24. Reactor vessel
- 25. Main steam outlet
- 26. Reactor vessel head
- 27. Main steam outlet
- 28. Main steam outlet
- 29. Main steam outlet
- 30. Main steam outlet
- 31. Main steam outlet
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- 92. Main steam outlet
- 93. Main steam outlet
- 94. Main steam outlet
- 95. Main steam outlet
- 96. Main steam outlet
- 97. Main steam outlet
- 98. Main steam outlet
- 99. Main steam outlet
- 100. Main steam outlet

Ejemplo de reactor BWR: Grand Gulf

The World's Reactors no.77 GRAND GULF

OWNER OPERATOR
Mississippi Power and Light

MAIN CONTRACTORS
Bachtel Power Corp. (Architect Engineer), General Electric (NSSS)

LOCATION
Near Port Gibson, 65 miles south west of Jackson, Mississippi, USA

TYPE
Two units equipped with boiling water reactor (BWR) nuclear steam assembly systems, incorporating Mark III Containment.

SCHEDULE

| | |
|-------------------------------------|------------|
| Unit 1 | Unit 2 |
| Commence construction: April 1974 | April 1974 |
| Commercial operation: February 1982 | April 1986 |

TECHNICAL DATA
All data listed below refers to one reactor turbine unit, the values for each of the two units being identical.

POWER

| | |
|-------------------------|------------|
| Net electrical output | 1254 MW(e) |
| Gross electrical output | 1385 MW(e) |
| Gross thermal output | 4640 MW(t) |
| Maximum net output | 1400 MW(e) |

REACTOR CORE

| | |
|-----------------------------------|---|
| Thermal output at max. core power | 13,400 (11,644 MW) (m) |
| Core diameter | 301.30 (1,021.0) |
| Core height | 7626 (25,018) |
| Number of fuel assemblies | 800 |
| Fuel pin length | 608 inches (15,451) |
| Average heat flux | 80,220 Btu/h ft ² (253,829 W/m ²) |
| Maximum heat flux | 382,000 Btu/h ft ² (1,174,229 W/m ²) |
| Weight of fuel in core | 260,000 lbs (118,000 kg) |

FUEL ASSEMBLIES

| | |
|--|----------------------|
| Number in core | 800 |
| Full length | 142 |
| Full diameter | 5.470 in (140.41 mm) |
| Clad material | Zircaloy 2 |
| Clad thickness | 0.020 in (0.508 mm) |
| Number of fuel water rods per assembly | 17 |
| Maximum fuel rod tip temperature | 3237°F (1786°C) |
| Initial average UO ₂ enrichment | 3.7% wt |
| Full average discharge reactivity | 25,900 MWd/short ton |
| | 128,400 MWd/t |

CONTROL RODS

| | |
|----------------------------|------------------------------|
| Neutron absorber | B ₄ C granules |
| Cladding material | 316 stainless steel type 304 |
| Number in core | 133 |
| Shape | Cylindrical |
| Overall length | 174 in (4,426) |
| Length of position section | 154 in (3,912) |

PRIMARY COOLANT SYSTEM

| | |
|----------------------------|--|
| Type | Forced circulation, secondary loops, two recirculating loops |
| Operating pressure | 1062.0 psia (7.27 bar) |
| Reactor inlet temperature | 539°F (276°C) |
| Reactor outlet temperature | 571°F (299°C) |
| Total core flow | 113,534 GPM (425,758 l/h) |
| Core inlet/outlet | 2 |

REACTOR PRESSURE VESSEL

| | |
|------------------------------|---|
| Material | Low alloy steel, stainless steel cladding |
| Inside diameter | 287.16 (7,283) |
| Inside height | 7291.30 (222,246) |
| Wall thickness (core region) | 1.5 in (38.1 mm) |
| Design pressure | 1250.0 psia (86.0 bar) |
| Design temperature | 570°F (300°C) |

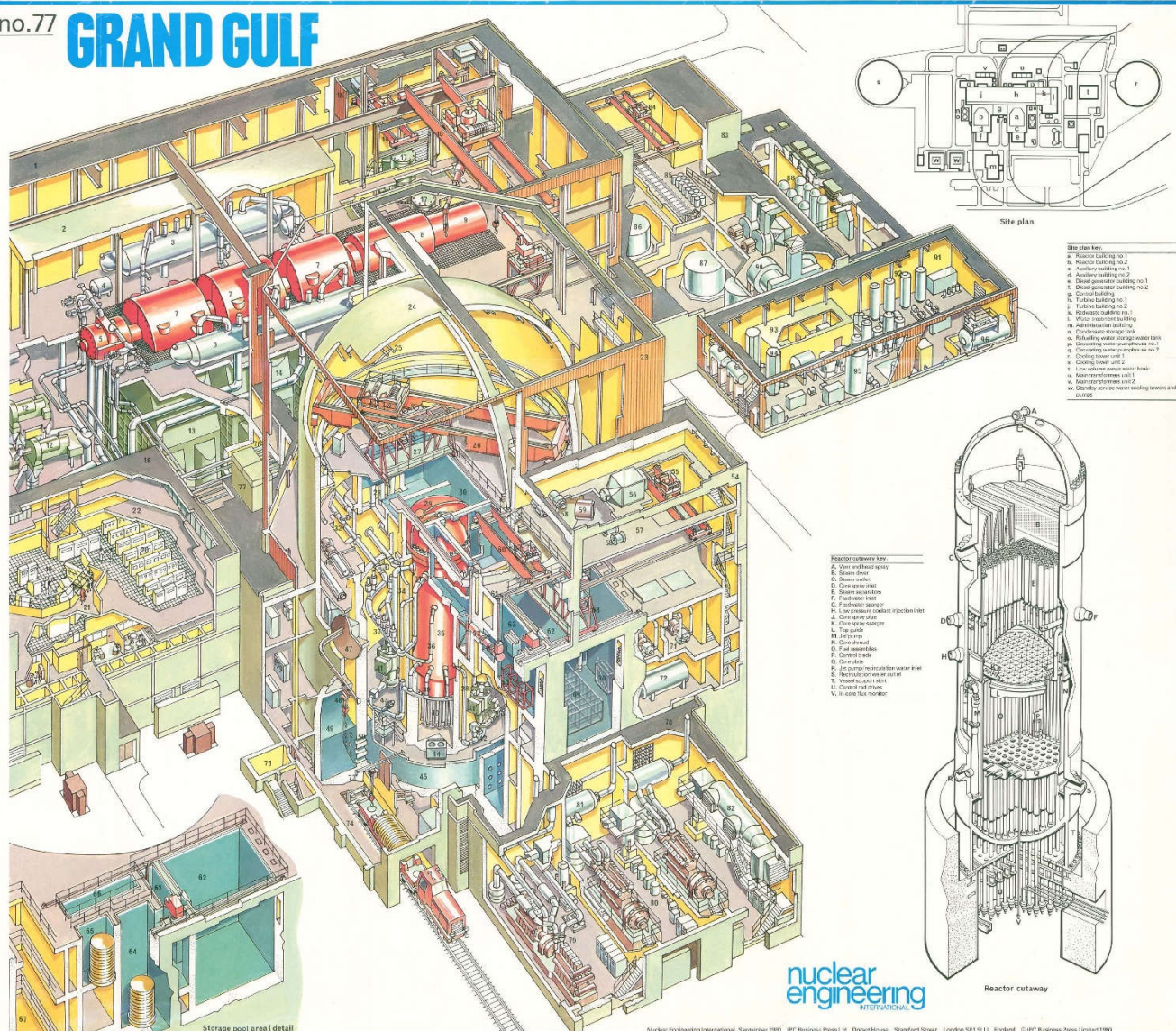
CONTAINMENT BUILDING

| | |
|------------------------------|---|
| Type | Cylindrical, with hemispherical head, reinforced concrete, steel lined water pool |
| Design pressure | 1250 psia (86.0 bar) |
| Head volume | 1.47 x 10 ⁶ ft ³ (41,900 m ³) |
| Head diameter (total vessel) | 1241 (317 m) |
| Head height (total vessel) | 2000 (610 m) to outside of dome |

TURBOGENERATOR

| | |
|---------------------------|--|
| Rating | 1250 MW (at 85% S.F.) |
| Speed | 1800 rpm |
| Turbine pressure | 595 psia (41.2 bar) |
| Turbine inlet temperature | 571°F (299°C) |
| Turbine configuration | 1.5 up, 2.5 up, double flow, tandem, counterflow, multiple pressure condensers |

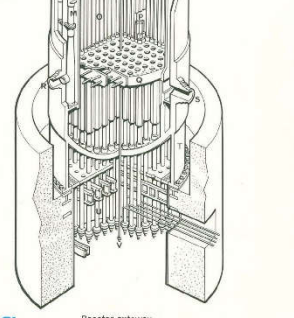
- Power station cutaway key**
1. Turbine building
 2. Reactor building
 3. Reactor building
 4. 2nd stage water storage tank
 5. 1st stage water storage tank
 6. Main steam stop and control valves
 7. Low pressure condenser
 8. Condenser
 9. Cooling tower
 10. Turbine building
 11. Turbine building
 12. High pressure condenser
 13. High pressure condenser
 14. Cooling water pump house
 15. Cooling tower
 16. Cooling tower
 17. Cooling tower
 18. Cooling tower
 19. Cooling tower
 20. Cooling tower
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 46. Cooling tower
 47. Cooling tower
 48. Cooling tower
 49. Cooling tower
 50. Cooling tower



Site plan

- Site plan key**
1. Reactor building no. 1
 2. Reactor building no. 2
 3. Auxiliary building no. 1
 4. Auxiliary building no. 2
 5. Diesel generator building no. 1
 6. Diesel generator building no. 2
 7. Control building
 8. Turbine building no. 1
 9. Turbine building no. 2
 10. Reactor building no. 1
 11. Water treatment building
 12. Administration building
 13. Control room storage tank
 14. Fueling water storage tank
 15. Fueling water storage tank
 16. Cooling tower no. 1
 17. Cooling tower no. 2
 18. Low pressure water tank
 19. Cooling tower no. 1
 20. Cooling tower no. 2
 21. Main transformer no. 1
 22. Main transformer no. 2
 23. Cooling tower no. 1
 24. Cooling tower no. 2

- Reactor cutaway key**
- A. Core and fuel pins
 - B. Steam generator
 - C. Steam generator
 - D. Condenser
 - E. Fuel element
 - F. Fuel element
 - G. Fuel element
 - H. Fuel element
 - I. Fuel element
 - J. Fuel element
 - K. Fuel element
 - L. Fuel element
 - M. Fuel element
 - N. Fuel element
 - O. Fuel element
 - P. Fuel element
 - Q. Fuel element
 - R. Fuel element
 - S. Fuel element
 - T. Fuel element
 - U. Fuel element
 - V. Fuel element



Reactor cutaway

nuclear engineering INTERNATIONAL



Ejemplo de reactor BWR: Krümmel (cerrada)

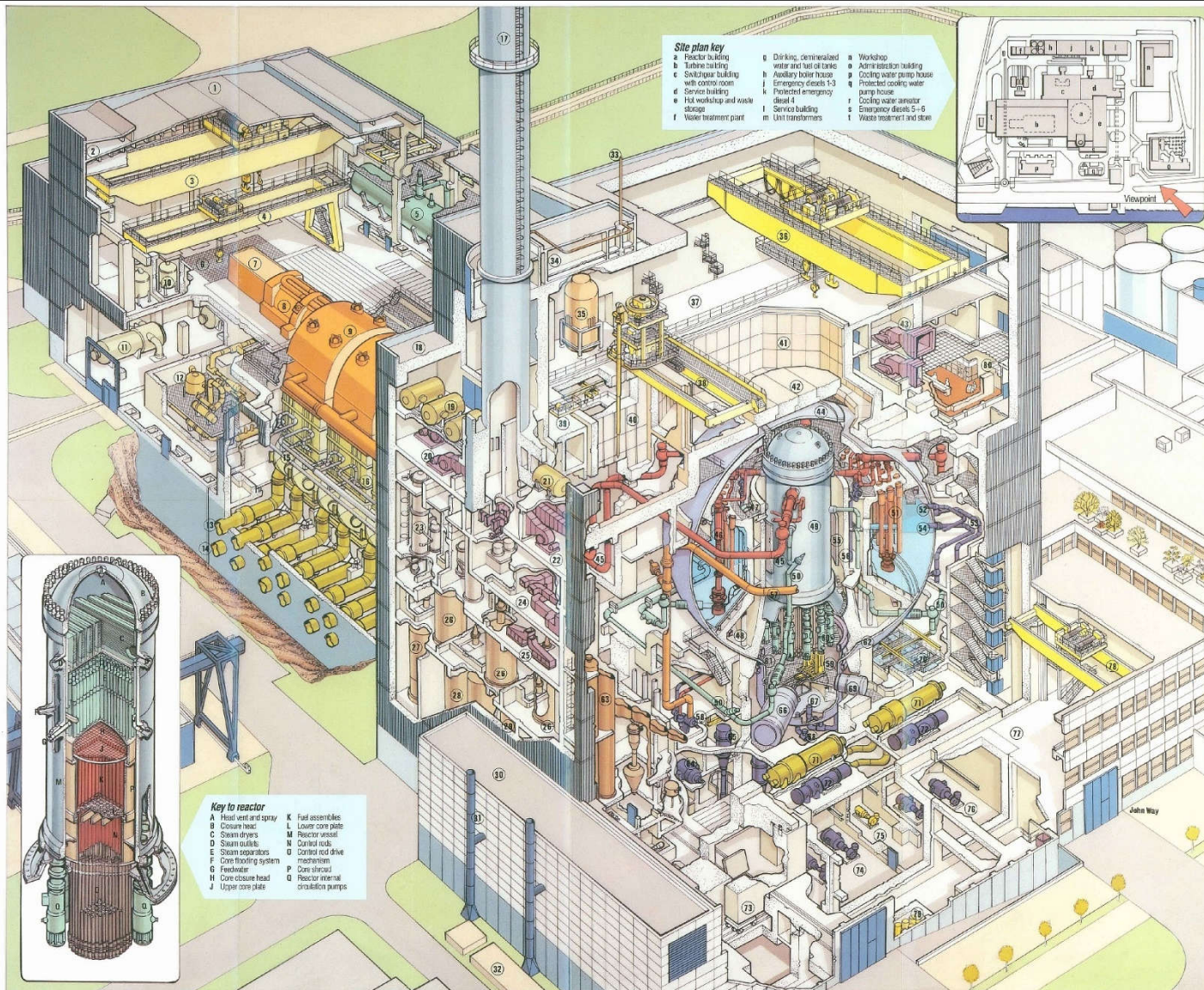
KERNKRAFTWERK KRÜMMEL

Technical data

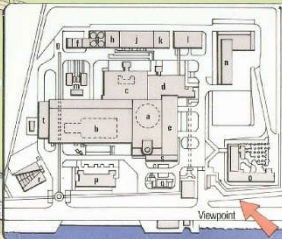
| | | | |
|---|--------------------------|---|----------------------------------|
| Power station plant | | | |
| Thermal reactor power | 3800 MW | Mean power density | 51.6 W/cm ² |
| Gross electric power | 1316 MW | Heat loss (excession area in the core) | 17 660 MW/MSWU |
| Net electric power | 1020 MW | Discharge burn-up (balanced core approx.) | 40 000 MWU/MSWU |
| Net efficiency | 34.1% | Number of control rods | 295 |
| | | Absorber material | boron carbide (B ₄ C) |
| | | Shutdown time (normal) | 112 s |
| | | Shutdown time (emergency shutdown) | 3.7 s |
| Nuclear plant CONTAINMENT | | | |
| Design pressure (at 5.3 bar) | 3.5 bar | | |
| Design temperature | 146°C | | |
| Internal diameter | 26.6 m | | |
| Wall thickness | 25-70 mm | | |
| Volume of water in the condensation chamber | 3770 m ³ | | |
| REACTOR VESSEL | | | |
| Operating pressure | 70.6 bar | | |
| Operating temperature | 290.4°C | | |
| Steam flow | 7186 t/h | | |
| Feedwater temperature | 125°C | | |
| Internal diameter | 6.7 m | | |
| Overall height including cover | 22.38 m | | |
| Thickness, cylinder casing | 77 mm | | |
| Thickness, floor | 24.2 cm | | |
| Overall weight | approx. 752 t | | |
| REACTOR CORE | | | |
| Core diameter | 4.95 m | | |
| Core height | 3.81 m | | |
| Flow of coolant through the core | 55 639 m ³ /h | | |
| Overall neutron yield in the core | 150 t | | |
| Number of fuel elements | 840 | | |
| Type of fuel element (incl. water box) | 9x9 | | |
| Mean specific uranium load | 25.30 W/kg U | | |
| Generator | | | |
| Rated output | 1300 MW | | |
| Power factor | 0.95 | | |
| Frequency | 50 Hz | | |
| Terminal voltage | 27 kV | | |
| Cooling system (rotors and stator) | water | | |

Key to power station cutaway

- | | | | |
|--|--|--|--|
| 1 Turbine building | 23 Liquid waste evaporator and vapour cooler | 45 Main steam to turbine | 64 Core injection system (Electrically driven) |
| 2 Supply and exhaust air duct | 24 Pumping air compressor | 46 Pressure relief stack | 65 Reactor building return purging system |
| 3 Main turbine building crane | 25 Chemical oxidizer | 47 Upper annulus | 66 Main air lock |
| 4 Gantry crane | 26 Evaporator feed tanks | 48 Lower annulus | 67 Containment sump |
| 5 Feedwater tank | 27 Urillate vessel | 49 Reactor vessel | 68 Containment sump suction pipe |
| 6 Construction opening | 28 Feedwater pipes | 50 Condensing pipes | 69 Emergency air lock |
| 7 Reactor | 29 Inboard water vessel | 51 Suppression pool scoping pipe | 70 Shutdown system tank room |
| 8 Generator | 30 Diesel generator building | 52 Containment return pipe | 71 Shutdown interlocks |
| 9 Low pressure turbines (5 flow LP turbines) | 31 Diesel exhaust stacks | 53 Suppression pool cooling pipe | 72 Residual heat removal coolers |
| 10 Condenser purification filter | 32 Construction opening | 54 Reactor shield | 73 Reactor building gate (protected against air crash) |
| 11 Coolers (process coolers) | 33 Venting stack | 55 Exhaust steam from suppression pool | 74 Containment return system pump |
| 12 Off-gas system | 34 Casualty air instrument room | 56 High pressure injection system (steam driven) | 75 Shutdown interlock system pump |
| 13 Circulating water inlet | 35 Containment venting vessel | 57 Control rod drive room | 76 Residual heat removal pump |
| 14 Circulating water outlet | 36 Reactor building overhead crane | 58 Control rod drive (instrumentation) | 77 Hot workshop |
| 15 Turbine bypass | 37 Reactor service floor | 59 Feedwater | 78 Hot workshop overhead crane |
| 16 Condensers | 38 Fuel handling machine | 60 Core cooling head | 79 Waste storage |
| 17 Exhaust air stack (reactor building) | 39 Churner stoppage machine drive motor | 61 Core flooding system | 80 Control room |
| 18 Closed cooling water tanks | 40 Fuel pool | 62 Reactor internal circulation pumps | |
| 19 Exhaust air fan system (reactor building) | 41 Set down and flood pool | | |
| 20 Make up water tank (reactor building) | 42 Shielding cabs | | |
| 21 Exhaust air fan system (waste building) | 43 Inlet air fan | | |
| 22 Inlet air fan system (waste building) | 44 Fuel building closure head | | |



- ### Site plan key
- | | | |
|---|--|--------------------------------------|
| a Reactor building | g Drinking, demineralized water and fuel oil tanks | n Workshop |
| b Turbine building | h Auxiliary boiler house | o Admin. reception building |
| c Switchgear building with control room | i Emergency diesels 1-3 | p Protected cooling water pump house |
| d Service building | j Protected emergency diesel 4 | q Cooling water generator |
| e Hot working and waste storage | k Service building | r Emergency diesels 5-6 |
| f Water treatment plant | l Unit transformers | s Waste treatment and sludge |



- ### Key to reactor
- | | |
|------------------------|--------------------------------------|
| A Head vent and spray | K Fuel assemblies |
| B Closure head | L Lower core plate |
| C Steam dryers | M Reactor vessel |
| D Steam outlets | N Control rods |
| E Steam separators | O Control rod drive mechanism |
| F Core flooding system | P Core shroud |
| G Feedwater | Q Reactor internal circulation pumps |
| H Core closure head | |
| J Upper core plate | |

nuclear engineering

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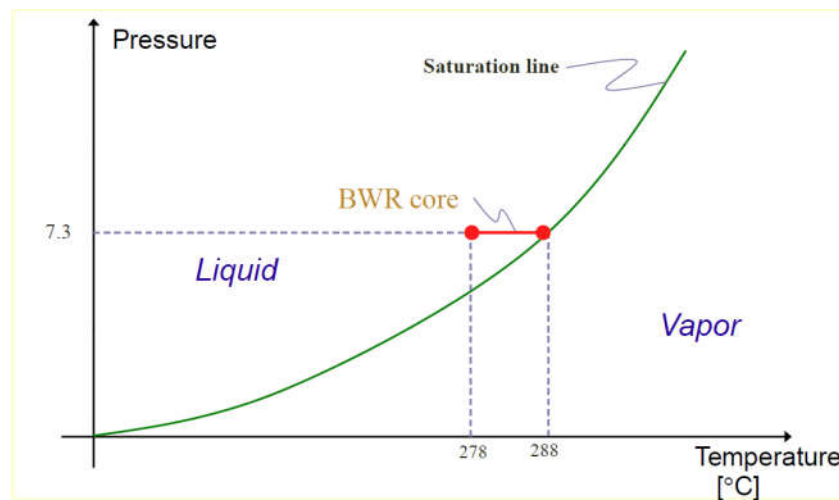
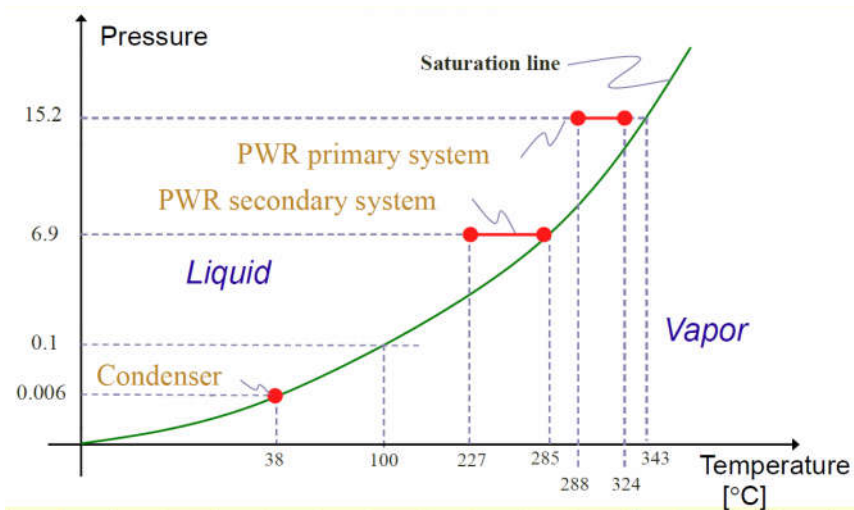
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Comparación de los diagramas de fase de PWR y BWR

PWR

BWR





Reactores VVER: *Vodo-Vodyanoi Energetichesky Reaktor*

Son reactores PWR de diseño soviético ([lista](#))

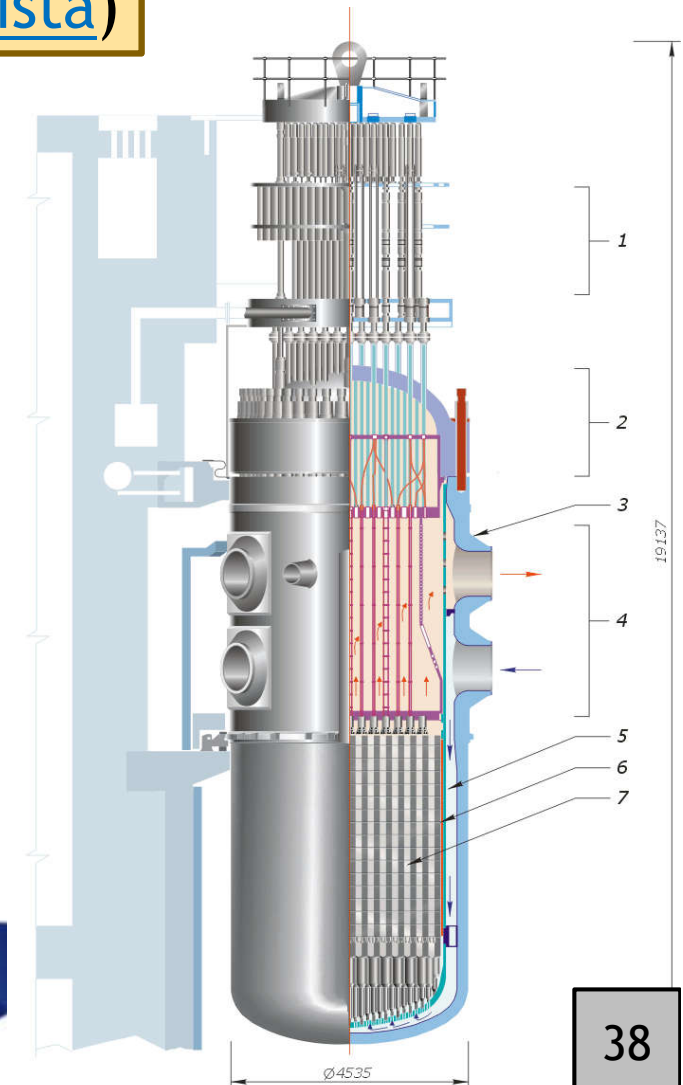
Potencias desde 300MWe a 1700MWe



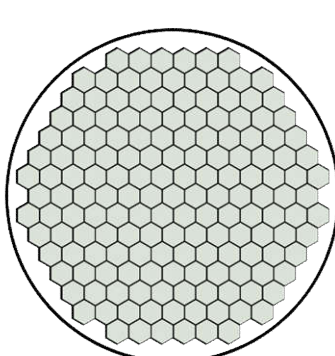
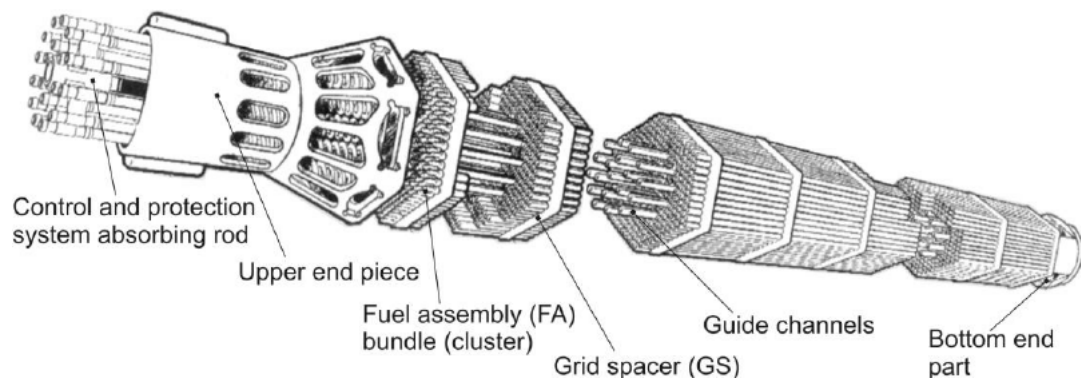
VVER-1200 for AES-2006

Main parameters of reactor plant

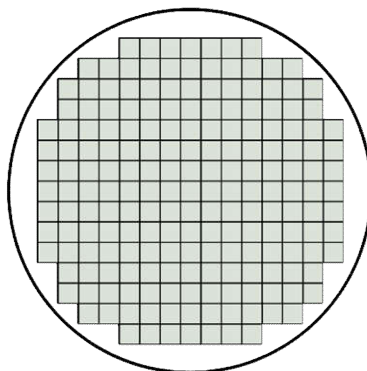
| Parameters | V-428 | VVER-1200 |
|---|-------|------------|
| Reactor nominal thermal power, MW | 3000 | 3200 |
| Availability factor | 0,8 | 0,9 |
| Coolant pressure at the reactor outlet, MPa | 15,7 | 16,2 |
| Coolant temperature at the reactor inlet, °C | 290 | 298,6 |
| Coolant temperature at the reactor outlet, °C | 320 | 329,7 |
| Maximum linear heat rate, W/cm | 448 | 420 |
| Steam pressure at the outlet of SG steam header (absolute) MPa | 6,27 | 7,0 |
| Primary design pressure, MPa | 17,64 | 17,64 |
| Secondary design pressure, MPa | 7,84 | 8,1 |
| Maximum fuel burnup fraction over FAs in the FAs unloaded (in base equilibrium fuel cycle), MWD/kgU | 49 | до 70 |
| Refueling period, month | 12 | 12/(18-24) |
| Time of fuel residence in the core, year | 4 | 4,5 |



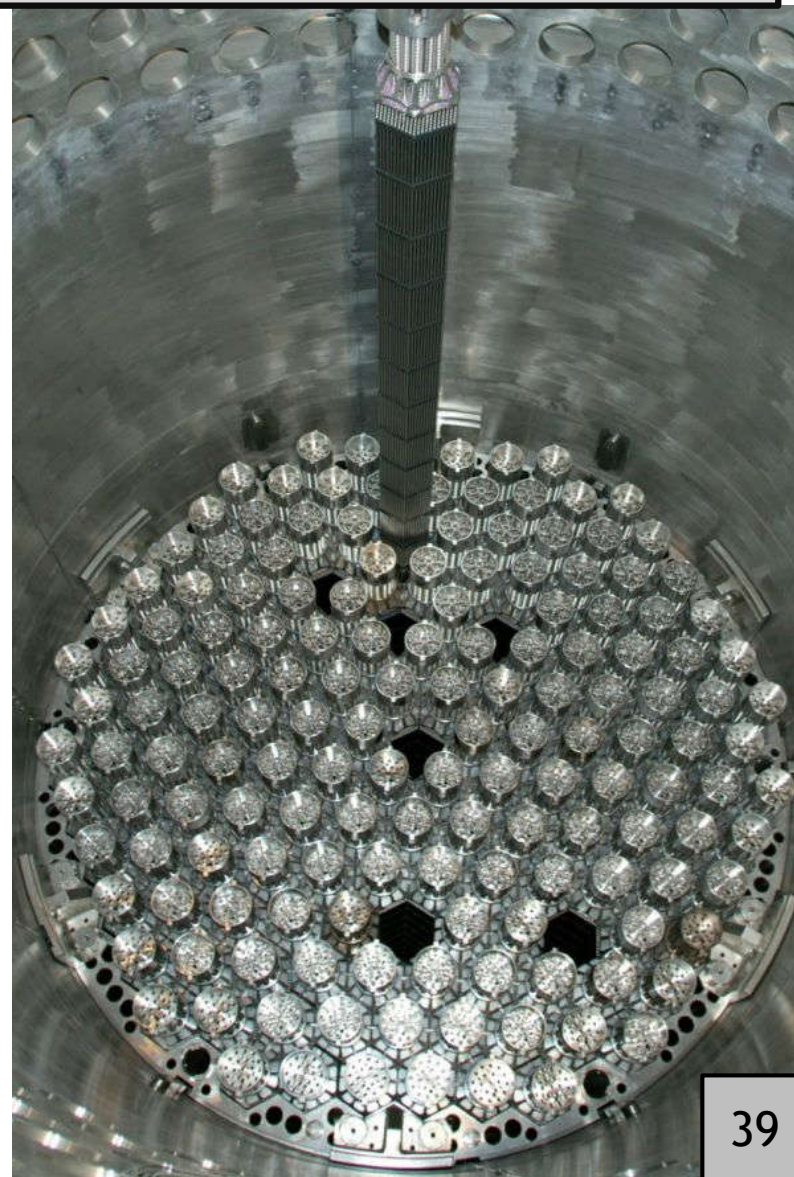
El núcleo de un reactor VVER



BB3P-1000

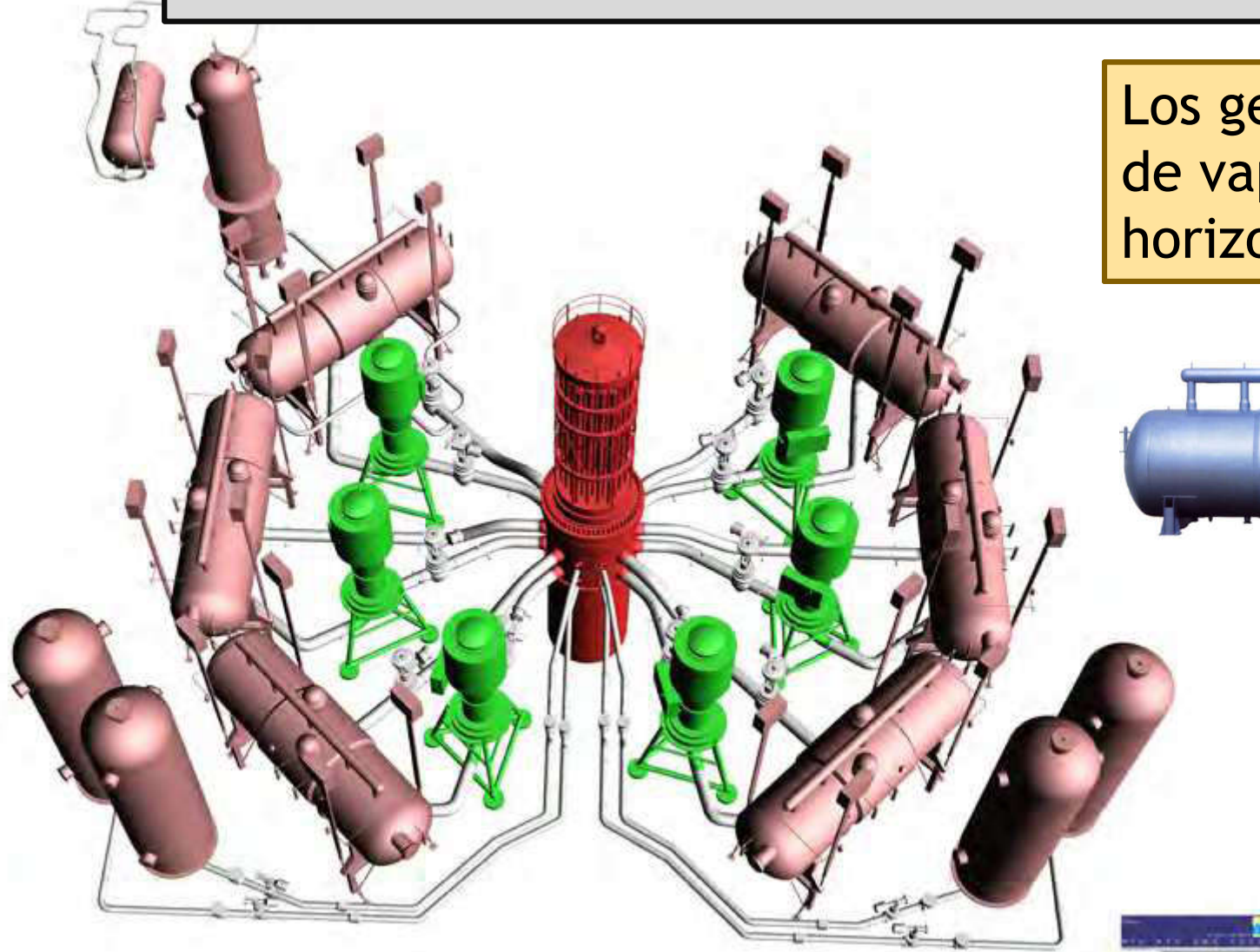


Westinghouse 4-loop PWR



El assembly de elementos combustibles es hexagonal

Generadores de vapor y presurizador



Los generadores de vapor son horizontales

