



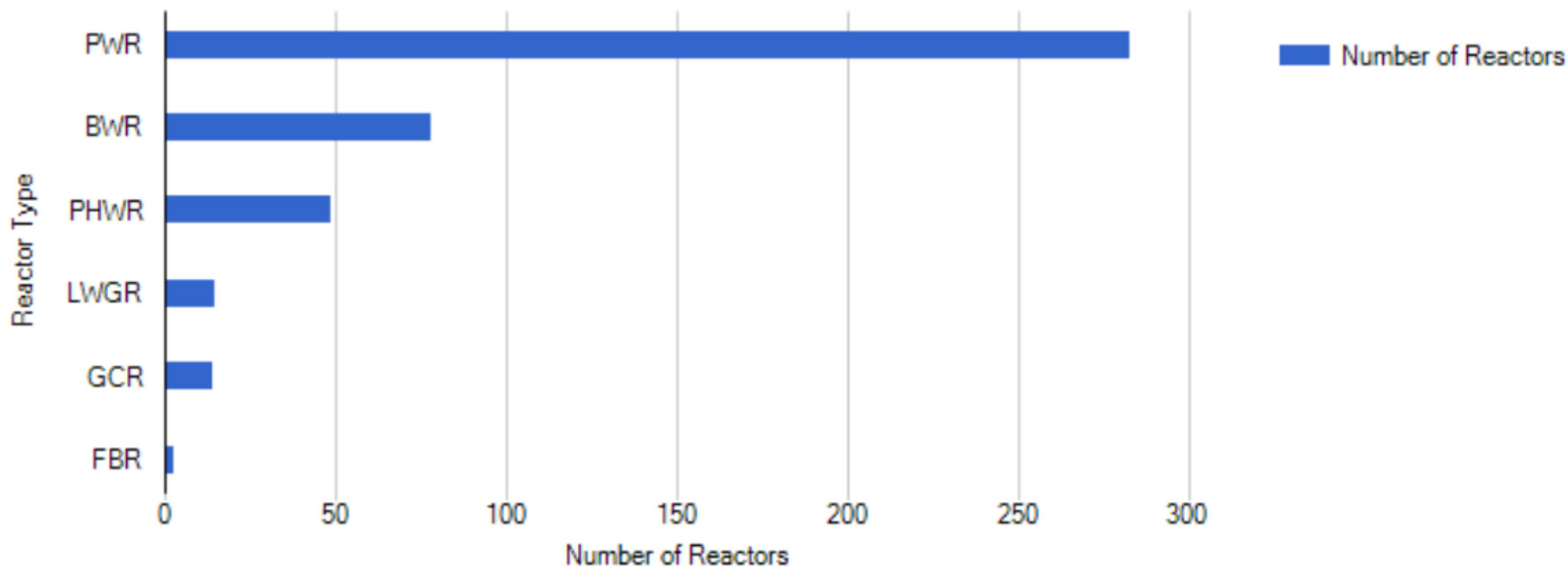
# Tecnologías nucleares

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## Parte 4: Otros tipos de reactores nucleares

# Diferentes tipos de reactores en el mundo

Total Number of Reactors: 442



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
<b>Total</b>		<b>442</b>	<b>384093</b>

# El reactor de agua pesada (HWCR o CANDU)

Es un PWR

Usa uranio natural (0.72%)

No puede usar H<sub>2</sub>O por la absorción

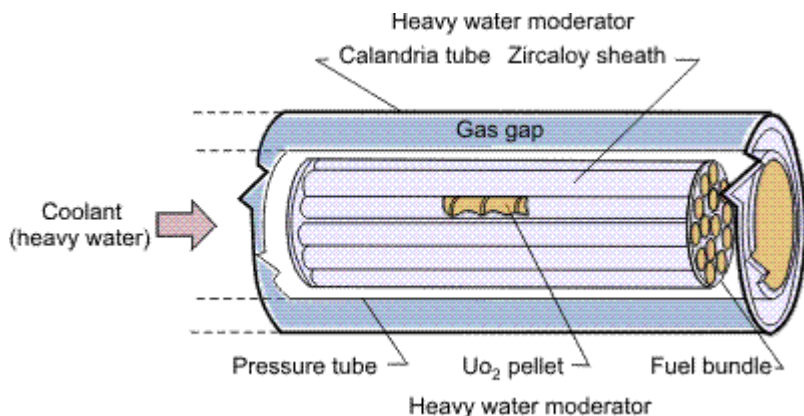
Usa agua pesada D<sub>2</sub>O

En lugar de una sola vasija, cada elemento combustible (*fuel bundle*) está rodeado por un tubo a presión

Menor moderación

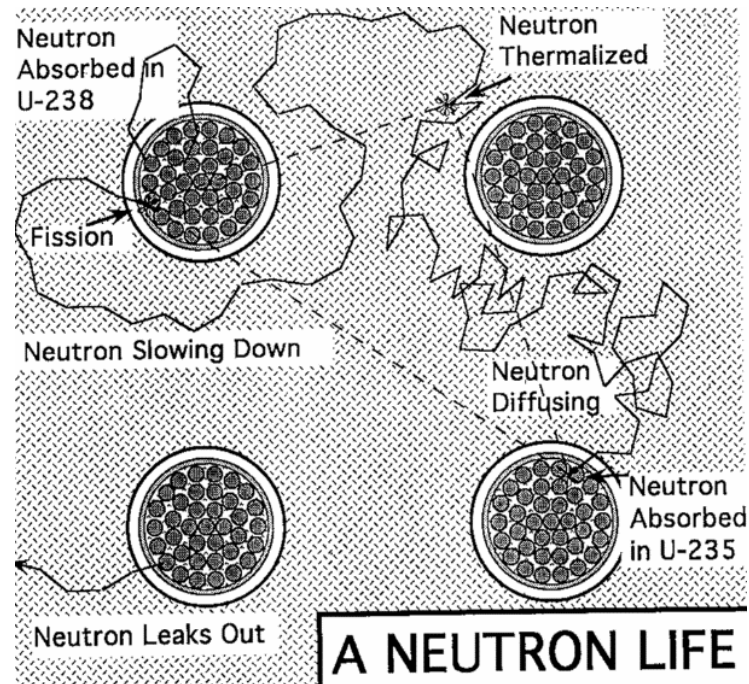
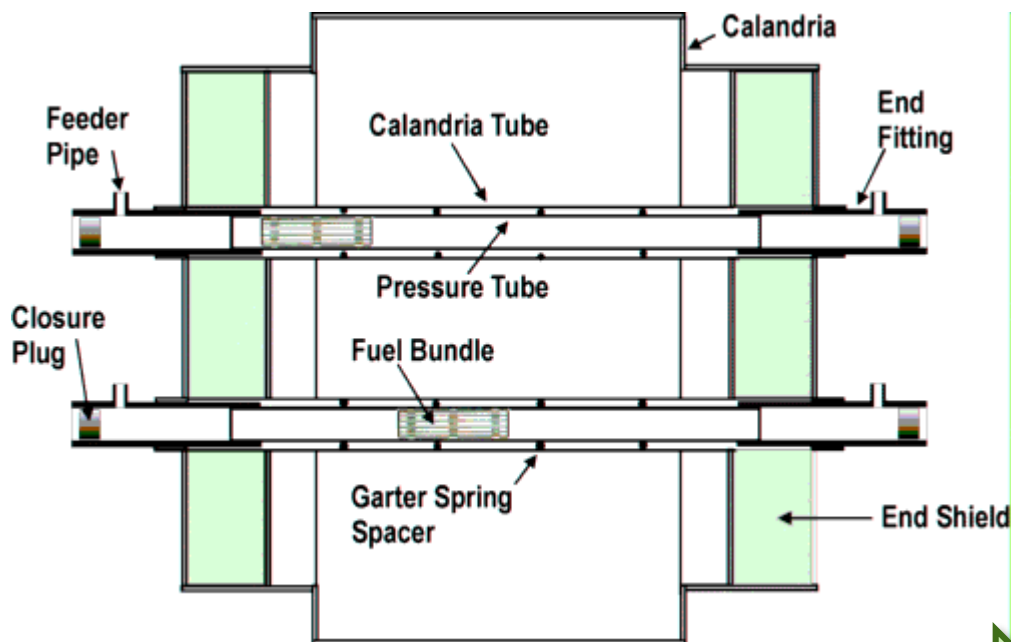
Núcleo más grande

Fuel bundle



# Los tubos a presión están inmersos en la *calandria*

La calandria es un tanque de agua pesada que actúa como moderador, pero no refrigerante

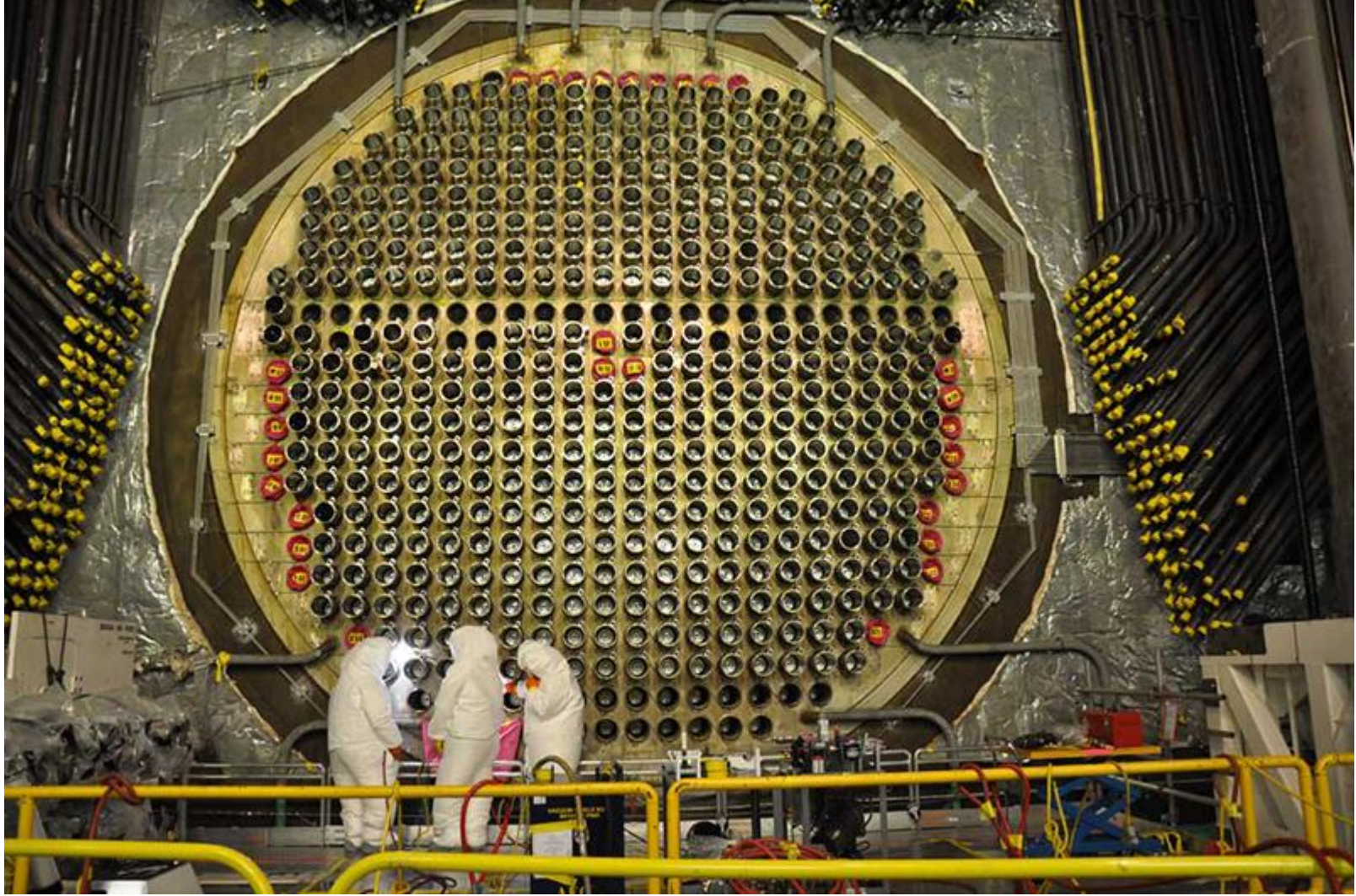


En un CANDU la recarga puede hacerse en marcha

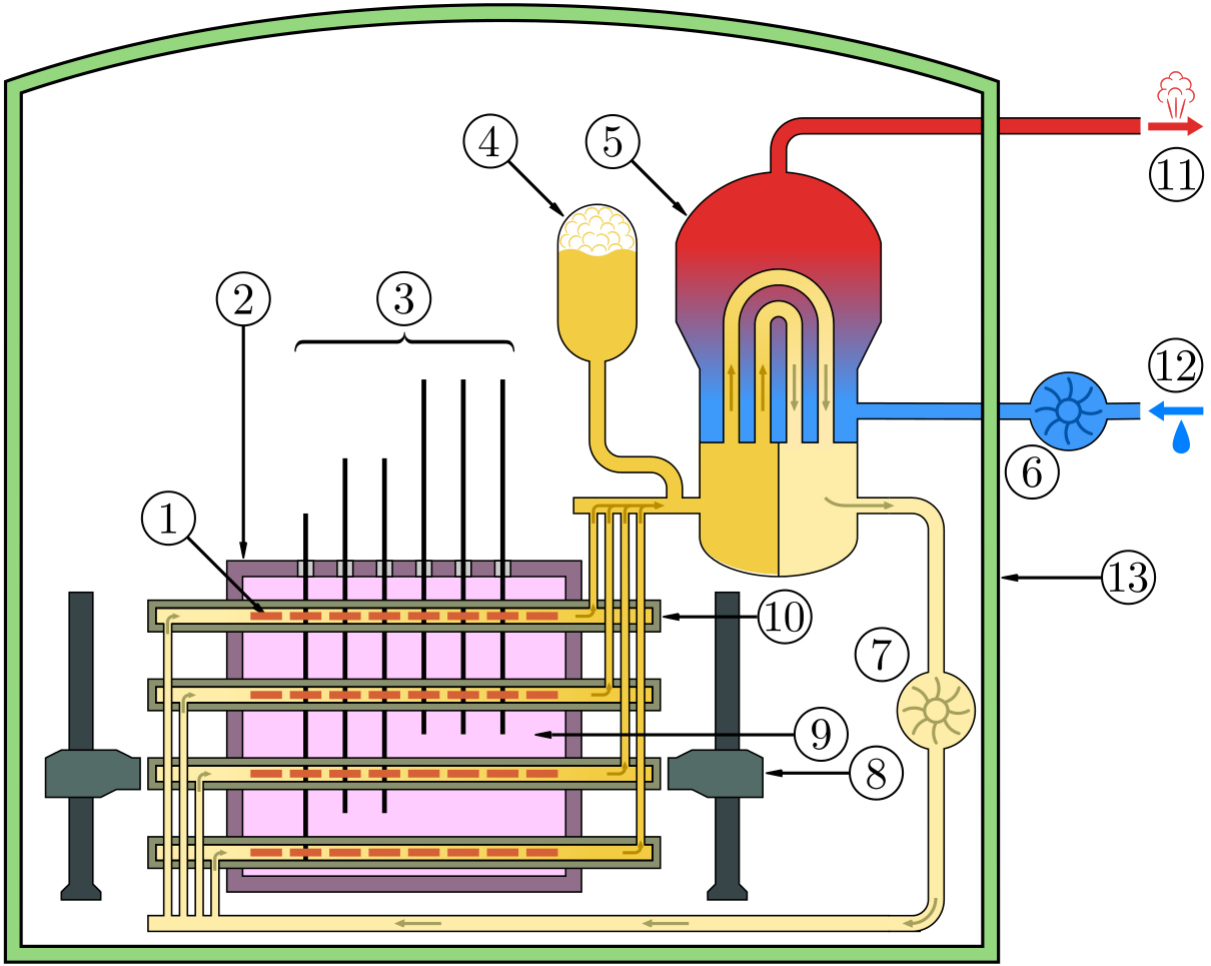
Mayor disponibilidad



# Aspecto de un reactor CANDU



# Partes de un reactor CANDU

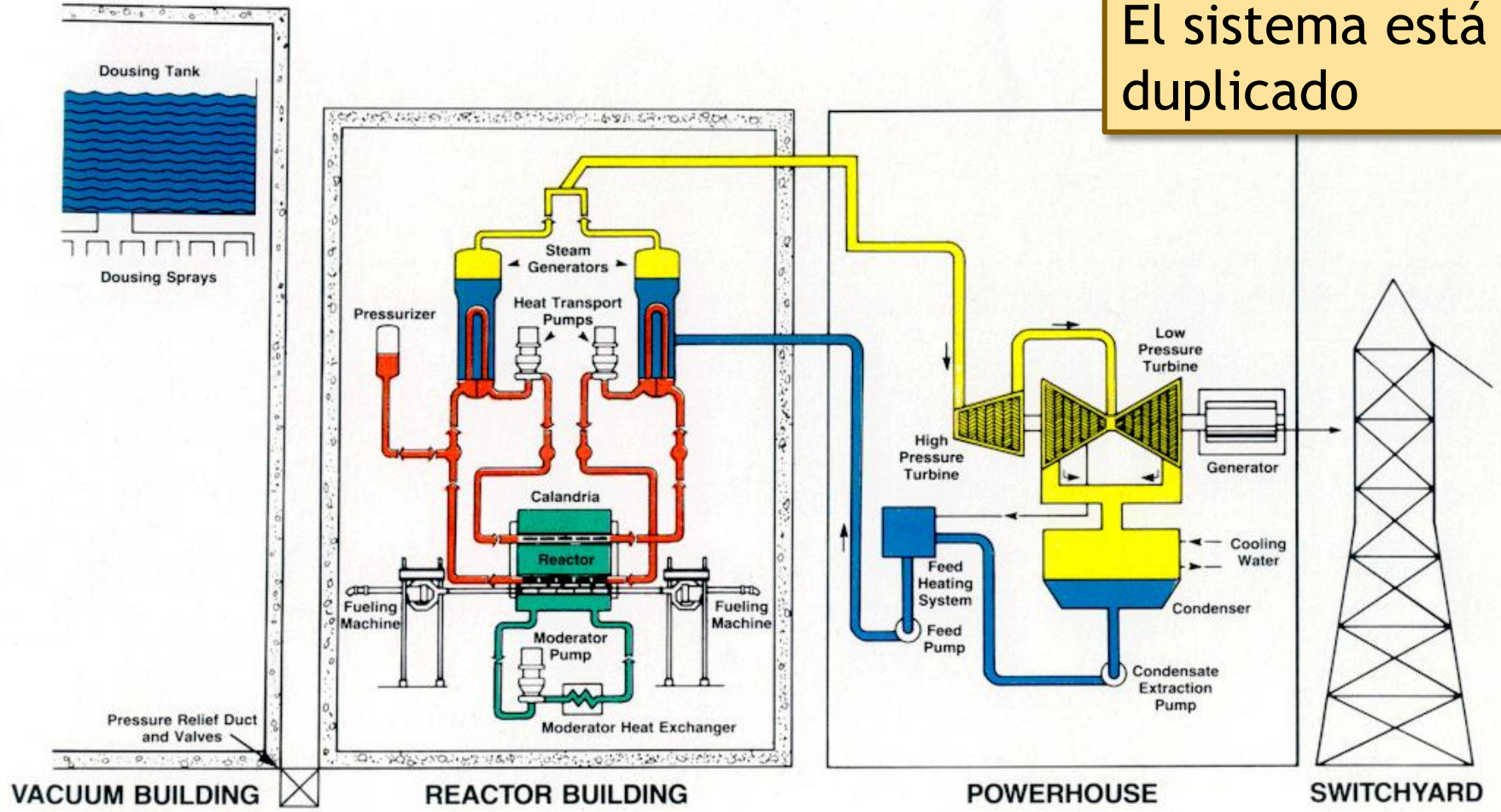






1. Fuel bundle
2. Calandria (reactor core)
3. Adjuster rods
4. Heavy water pressure reservoir
5. Steam generator
6. Light water pump
7. Heavy water pump
8. Fueling machines
9. Heavy water moderator
10. Pressure tube
11. Steam going to steam turbine
12. Cold water returning from turbine
13. Containment building



# El refrigerante hace un recorrido de ida y vuelta

El sistema está duplicado



 HEAVY WATER MODERATOR	 STEAM
 HEAVY WATER HEAT TRANSPORT SYSTEM	 WATER

Hay que refrigerar el moderador

# Características de los reactores de agua pesada CANDU

Parte de los neutrones procede de la división del deuterio por incidencia de rayos  $\gamma$

El tiempo de vida media es de segundos o incluso horas

Hay más neutrones diferidos

Mejora el control

Baja radiactividad del uranio natural

Puede recargarse en marcha

Se empuja el *bundle*

Entra combustible

Sale residuo

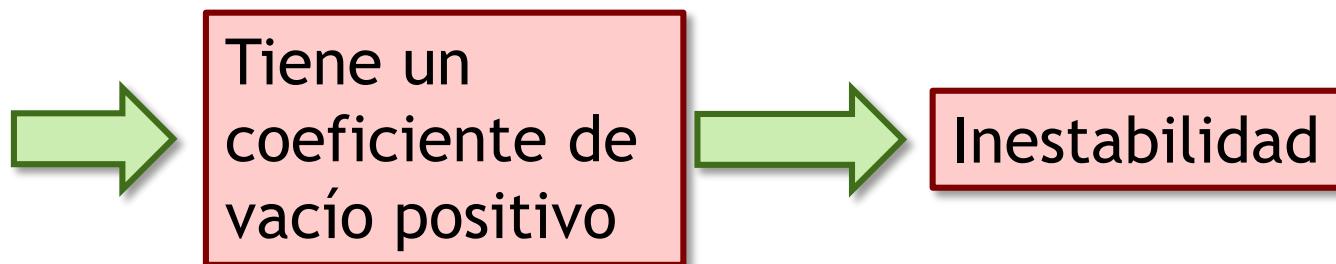


# El coeficiente de vacío en un reactor CANDU

Si se forman burbujas en el refrigerante ( $D_2O$ )

Disminuye la absorción

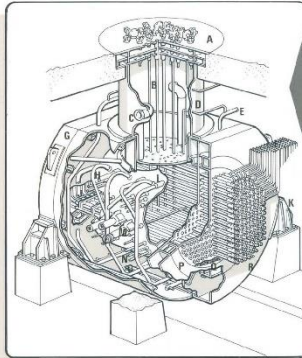
Se mantiene la moderación (que ocurre en el  $D_2O$  de la calandria)



Su efecto es pequeño por el mayor control

# Ejemplo de reactor CANDU

## CANDU 3



- REACTOR CUTAWAY KEY**
- A. Reactivity mechanisms deck.
  - B. Vertical reactivity control units.
  - C. Overpressure protection pipe.
  - D. Shield tank extension.
  - E. Shield cooling piping inlet.
  - F. Feeder pipe outlet.
  - G. Shield tank.
  - H. Moderator piping system.
  - J. Feeder pipe inlet.
  - K. Reactor assembly support.
  - L. Calandria sheet.
  - M. Ion chamber unit.
  - N. Horizontal fuel extension unit.
  - O. Liquid injection shutdown unit.
  - P. End shield.
  - Q. Shield bolts.
  - R. Fuel channel assembly.

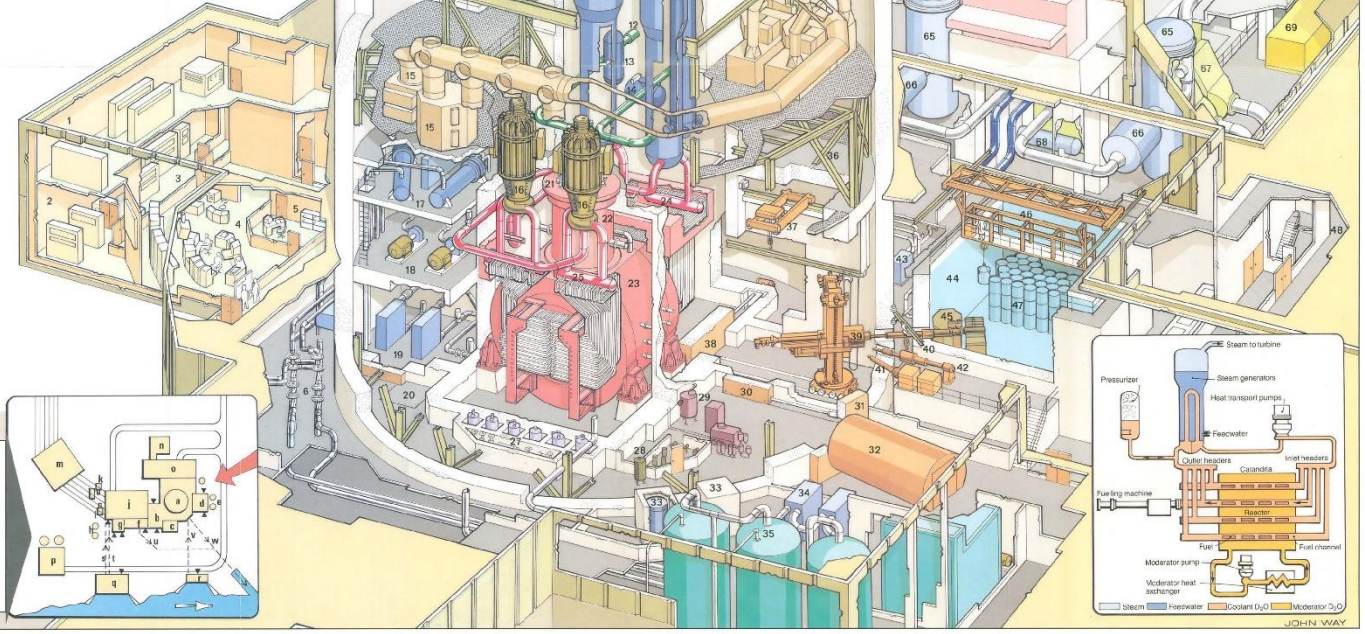
**POWER STATION KEY**

1. Control equipment room.
2. Computer room.
3. Computer maintenance room.
4. Control room.
5. Shift supervisor's office.
6. Flooded cooling water system valves.
7. Reactor containment building.
8. Main steam pipes.
9. Steam generators.
10. Main crane.
11. Pressurizer.
12. Feedwater pipes.
13. Diesel compressor.
14. Shield cooling system tank.
15. Vent system equipment.
16. Heat transport pumps.
17. Shutdown cooling system.
18. Pressure and inventory system.
19. Moderator system.
20. Sump.
21. Reactivity mechanisms deck.
22. Shield tank extension.
23. Reactor.
24. Outlet headers.
25. Wet headers.
26. Vapor recovery system.
27. Purification system.
28. Ammonia gas system.
29. Liquid injection shutdown system.
30. Shield door.
31. Equipment hatch.
32. Air lock.
33. Emergency core cooling system pumps.
34. Emergency core cooling heat exchanger.
35. Water and accumulator tanks.
36. Modular construction units.
37. Fuel handling system crane.
38. Outlet vault shield door.
39. Fuel handling mech. inc.
40. Jib crane.
41. Helicoptersport.
42. Fuel loading mechanism.
43. Shield cooling system.
44. Modular fuel storage bay.
45. Defective fuel covecort.
46. Pond bridge crane.
47. Scaled module storage area.
48. Maintenance building.
49. Diesel generator building.
50. Turbine building.
51. Turbine building crane.
52. Deaerator.
53. Deserator storage tank.
54. Reverse flowwater tank.
55. Elevator.
56. Auxiliary boiler feed pump.
57. Air receivers.
58. Boiler feedwater pumps.
59. Air dryer.
60. Steam chest.
61. High pressure turbine.
62. Low pressure turbines.
63. Reheater.
64. Bus ducts.
65. Reheater.
66. Separator.
67. Condenser.
68. Reheater drain tank.
69. Lub oil and seal oil tank.
70. Floor opening.

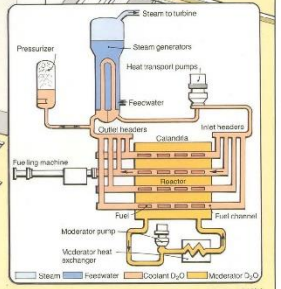
**TECHNICAL DATA**

<b>Reactor</b>	Type	Horizontal pressure tube
	Coolant	Pressurized heavy water
	Moderator	Heavy water
	Number of fuel channels	232
<b>Fuel</b>	Fuel	Compacted and sintered natural UO <sub>2</sub> pellets
	Form	Fuel bundle assembly of 37 elements
	Length of bundle	4163 mm
	Outside diameter	432 mm
	Bundle weight	23.5 kg (includes 16.1 kg U)
	Bundles per fuel channel	12
<b>Heat transport system</b>	Number of steam generators	2
	Steam generator type	Vertical U-tube with integral steam drum and preheater
	Number of heat transport pumps	2
	Heat transport pump type	Vertical, centrifugal, single suction, coil driven, large
	Reactor outlet header pressure (gauge)	0.96 MPa
	Reactor outlet temperature	310°C
	Reactor outlet flow	5.3 Mkg/s
	Steam temperature (nominal)	267°C
	Steam quality (minimum)	96.75%
	Steam pressure (gauge)	4.8 MPa
	Total fission heat	1440.3 MW
	Net electrical output (nominal)	403 MW <sub>e</sub>

\*Typical for a cold water site; net electrical output is dependent on cooling water temperature and turbine-generator and condenser design.



- SITE PLAN KEY**
- a. Reactor building.
  - b. Reactor auxiliary building.
  - c. Main control room.
  - d. Group 2 service building.
  - e. Diesel fuel oil tanks.
  - f. Group 1 service building.
  - g. Group 1 units.
  - h. Fuel oil sump.
  - i. Turbine building.
  - k. Main output and unit service transformer.
  - l. Station service transformer.
  - m. Switchyard.
  - n. Administration building.
  - o. Maintenance building.
  - p. Water treatment plant.
  - q. Group 1 pump house.
  - r. Group 2 pump house.
  - s. Main cooling water.
  - t. Group 1 raw service water.
  - u. Cooling water discharge.
  - v. Group 2 raw service water transformer.
  - w. Group 2 raw service water discharge.
  - A. Truck access.

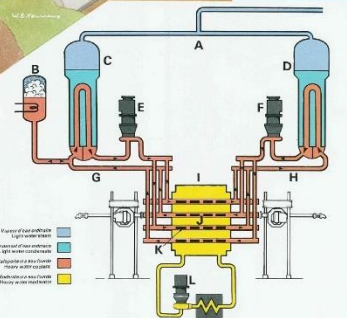
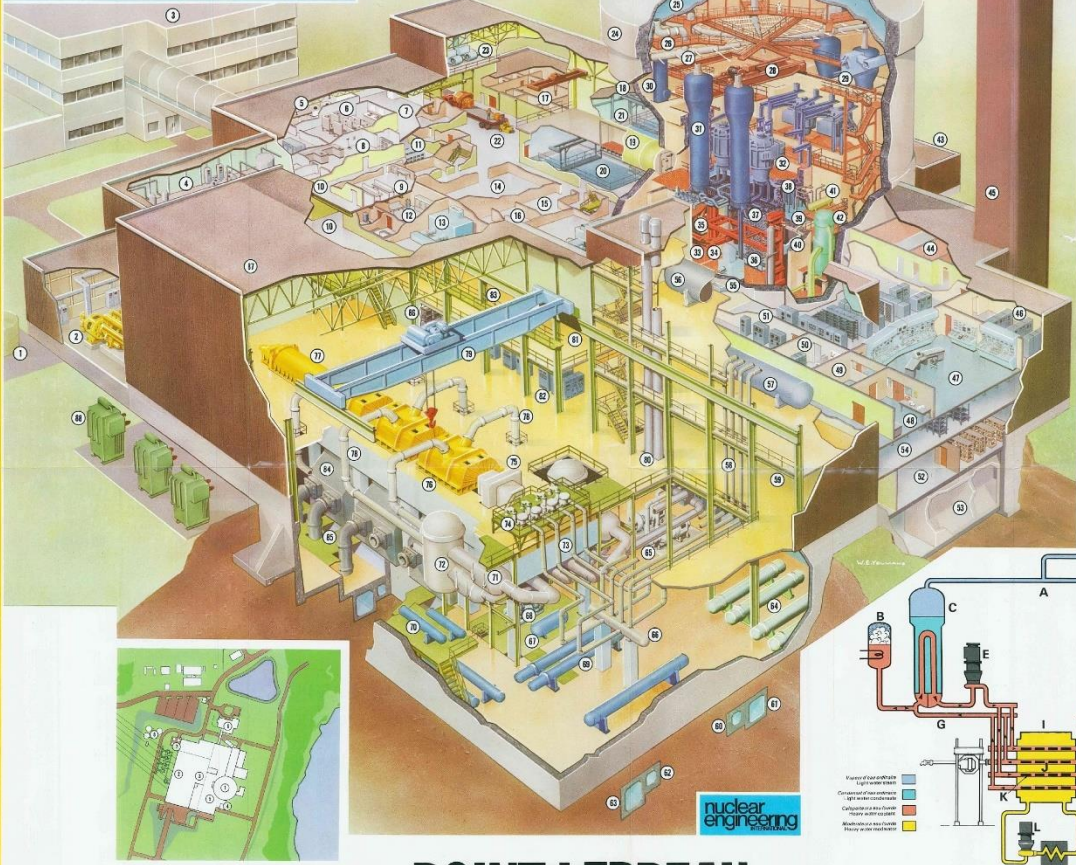




# Ejemplo de reactor CANDU

POINT LEPREAU GENERATING STATION CENTRALE NUCLÉAIRE POINT LEPREAU	
<b>OWNER/OPERATOR</b> PROPRIÉTAIRE/ EXPLOITANT	New Brunswick Electric Power Commission La Commission Électrique du Nouveau-Brunswick
<b>DESIGNERS</b> CONCEPTEURS	Atomic Energy of Canada Limited L'Énergie Atomique du Canada, Limited
<b>CONVENTIONAL PLANT</b> Partie classique	Canatom Limited Canatom Limitee
<b>LOCATION</b> EMPLACEMENT	Point Lepreau, New Brunswick Pointe Lepreau, Nouveau-Brunswick
<b>SCHEDULE</b> CALENDRIER	Construction start (first) May 1975 Début de la construction (première module du bâtiment) Mai 1975 Reactor critical (criticalité) December 1979 Reactor critical (criticalité) Décembre 1979 Full power (pleine puissance) May 1980 Full power (pleine puissance) Mai 1980
<b>POWER AND EFFICIENCY</b> PUISSANCE ET RENDEMENT	Thermal power (puissance de réaction) 2181 MW (th) Power output, net (puissance électrique, nette) 633 MW (e) Thermal efficiency (rendement thermique) 29.0%
<b>REACTOR TYPE</b> TYPE DE REACTEUR	CANDU (pressurized heavy water) CANDU à eau lourde pressurisée
<b>PRESSURE TUBES</b> TUBES DE FORCE	Quantity (quantité) 380 Material (matériau) Zr-2.25Nb Inside diameter (diamètre intérieur) 103.4 mm Thickness (épaisseur) 4.34 mm average Lattice pitch (pas du réseau) 28.86 cm
<b>CORE</b> CŒUR	Radius (rayon) 314.3 cm Length (longueur) 64.36 cm
<b>MODERATOR SYSTEM</b> SYSTEME DU MODÉRATEUR	Material (matériau) D <sub>2</sub> O Weight (poids) 260Mq Flow (débit) 938.5 t/s (12400 IGPM) Design temperature (température de conception) 93.3°C
<b>HEAT TRANSPORT SYSTEM</b> SYSTEME DE CALORIFÉRAGE	Type (type) Indirect cycle Type (type) Cycle indirect Coolant material (matériau du fluide caloporteur) D <sub>2</sub> O Weight (poids) 194.2 Mt Flow (débit) 8912 t/s (117,800 IGPM) Reactor inlet/outlet temperature (température à l'entrée et à la sortie du réacteur) 266°C/310°C Pressure, reactor outlet (pression à la sortie du réacteur) 0.93 MPa (14 psi)
<b>STEAM GENERATORS</b> GÉNÉRATEURS DE VAPEUR	Quantity (quantité) 4
<b>Total steam output</b> Débit total de vapeur	1047 kg/s
<b>Feedwater inlet temperature</b> Température d'admission de l'eau d'alimentation	187°C
<b>Steam pressure</b> Pression de la vapeur	4.7 MPa (68 psi)
<b>Steam temperature</b> Température de la vapeur	250°C
<b>Steam quality</b> Teneur de la vapeur	99.76%
<b>HEAT TO TURBINE CYCLE</b> Chaleur du cycle de la turbine	2063 MW (th)
<b>REACTOR COOLANT PUMPS</b> POMPES DE CALORIFÉRAGE	Quantity (quantité) 4 Capacity per pump (débit par pompe) 2228 t/s (29,400 IGPM) Drive horsepower (puissance motrice) 9000 HP
<b>FUEL COMBUSTIBLE</b>	Type (type) Natural uranium Form (forme) 37 elements bundle Number of bundles per channel (nombre de grappes par canal) 12 Cladding (gaine) Zircaloy 4 Diameter (diamètre) 13.08 mm Thickness (épaisseur) 0.418 mm UO <sub>2</sub> pellet diameter (diamètre des pastilles de UO <sub>2</sub> ) 12.614 mm Core fuel inventory (inventaire du combustible dans le cœur) 4560 bundles Bundle diameter (diamètre du bundle) 102.4 mm Heat flux, nominal (flux nominal de chaleur) 1241.7 KW/m <sup>2</sup> Temperature nominal maximum (température nominale maximale) 328°C outside sheath 328°C à l'extérieur de la gaine
<b>CONTROL</b> CŒUR	Burnup (combustion) 7500 MWd/t (U) 7000 MWd/t (U)
<b>CONTROL</b> CŒUR	Reactor control (contrôle du réacteur) Direct control by dual digital computers with CRT display Contrôle direct par deux ordinateurs numériques avec affichage sur écran cathodique Reactivity control (contrôle de la réactivité) On line reactivity Schéma position, le moderator Adjustment rods Mechanical control absorbers Light water zone control Rechargement de combustible en ligne Poisons (poisons) dans le réacteur Bares de compensation Batteries absorbentes de réactivité Contrôle zonal à eau légère
<b>TURBINE</b> TUBINE	Type (type) Tandem compound, Direct coupled Type (type) Type à couple direct High pressure cylinder (corps haute pression) 1 Low pressure cylinder (corps basse pression) 3 Speed (vitesse) 1900 rpm Steam temperature (température de la vapeur) 250°C Steam pressure (pression de la vapeur) 4.56 MPa (660 psi)

- 1. Storage Tanks
- 2. Diesel Engine Generator
- 3. Instrumentation Building
- 4. Waste Treatment Plant
- 5. Control Room
- 6. Turbine Room
- 7. Chemical Waste Treatment
- 8. Health Physics
- 9. Control Room
- 10. Control Room
- 11. Control Room
- 12. Control Room
- 13. Waste and Exhaust Room
- 14. Reactor Pressure Vessel
- 15. Moderator and Fuel
- 16. Moderator and Fuel
- 17. Moderator and Fuel
- 18. Moderator and Fuel



- 1. Reactor Building
- 2. Turbine Hall
- 3. Turbine Auxiliary Bay
- 4. D<sub>2</sub>O Upgrading Tower
- 5. Service Wing
- 6. Administration Building
- 7. D<sub>2</sub>O Tanks
- 8. Cooling Water Tanks
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- 100. Cooling Water Tanks

## POINT LEPREAU CANDU 600 MWe

- A. Steam Pipes
- B. Pressure
- C. Steam Generators
- D. Turbine
- E. Heat Transport Pump
- F. Moderator Pump
- G. Moderator
- H. Moderator
- I. Condenser
- J. Reactor
- K. Fuel
- L. Moderator
- M. Moderator

- 14. New Fuel Storage
- 15. Analysis and 16. Addition
- 17. D<sub>2</sub>O Upgrading Tower
- 18. Decommissioning Area
- 19. Spent Fuel Storage Bay
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- 100. Spent Fuel Storage Bay



# Ejemplo de reactor CANDU

The World's Reactors no. 79

## CANDU 950

**CANDU 950: Technical Data**  
The first below water to one reactor building unit of a typical reactor station.

**REACTOR TYPE**  
Heavy water cooled and moderated horizontal pressure tube reactor. Depleted <sup>235</sup>U fuel.

**POWER AND EFFICIENCY**  
Fuel power: 3384 MWt  
Net power output: 950 MWe  
Typical thermal efficiency: 30.2 per cent

**REACTOR CORE**  
Element height: 3650 mm  
Length: 5544 mm  
Core diameter: 12.8 m  
Lattice pitch: 226 mm  
Reflector thickness: 700 mm, average at midpoint  
Fuel channels: 500  
Structure (2% w) modulus: 2000 MPa  
Min. inside dia.: 104 mm  
Shield and core plug: stainless steel

**CALANDRIA**  
Length: 7680 mm overall  
Shield: all welded stainless steel  
Tube: annealed austenitic

**SHIELD TANK**  
Construction: mild-steel  
Material: carbon steel  
Shielding: deuterated water, deuterated carbon steel plate, and carbon steel balls

**FUEL ASSEMBLIES**  
Cladding: natural UO<sub>2</sub>  
Fuel pellet diameter: 12.8 mm  
No. in element: 37  
Element length: 463.3 mm, dia. 902.4 mm  
Normal bundle size: No. in core: 400  
Average bundle weight: 125 kg  
Normal rate of U in reactor: 100 MWt/kgU

**REACTOR CONTROL**  
Absorber rods: 27 stainless steel  
Mechanism control absorbers: 4 cadmium/epoxy steel  
Liquid zone control: 8K, gadolinium nitrate  
Control rods: 36 cadmium/alumina steel  
Liquid zone control: 8K, gadolinium nitrate  
Poison: gadolinium nitrate

**MODERATOR SYSTEM**  
Moderator: D<sub>2</sub>O  
Moderator volume: 360,000 m<sup>3</sup>  
Design temperature: 100°C

**PRIMARY COOLANT SYSTEM**  
Moderator: D<sub>2</sub>O  
Moderator volume: 360,000 m<sup>3</sup>  
Design temperature: 100°C

**STEAM GENERATOR**  
Type: 1 double flow h.v., 3 double flow l.v. calorifiers  
Steam conditions at t.a.s.: 190°C  
Pressure: 4.8 MPa abs; 203°C  
Generator: 4 stainless steel, H<sub>2</sub>O/D<sub>2</sub>O  
1320 MVA, p.l. 0.85, 22 kv, 60 Hz

**REACTOR BUILDING**  
Containment structure: cylindrical, precast concrete  
Internal structure: reinforced concrete  
Height (top of base slab): 62.5 m  
Area (underside of upper dome): 138,000 m<sup>2</sup>  
Containment (lower dome): 100,000 m<sup>2</sup>

**Site Plan and Station Layout**

1. Reactor building  
2. Service building  
3. Turbine building  
4. Administration building  
5. Electricity power generators  
6. Emergency power generators  
7. Main house  
8. Pump house  
9. Circulating water supply  
10. Circulating water return  
11. Circulating water discharge  
12. Bathing yard  
13. Water treatment plant  
14. Deaerator bay

15. Reactor building no. 1  
16. Reactor building no. 2  
17. Administration building  
18. Deaerator bay  
19. Electricity power generators  
20. Emergency power generators  
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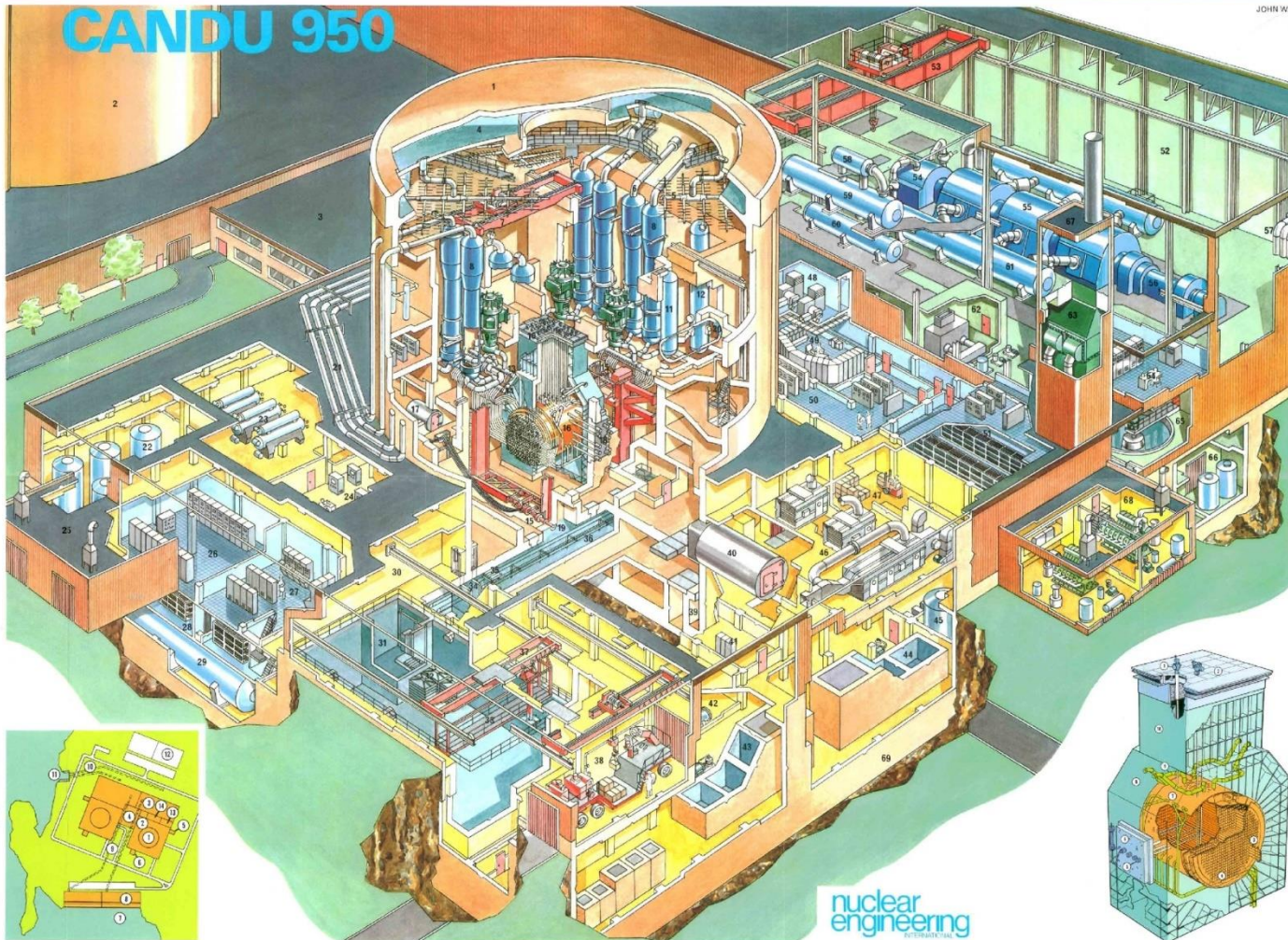
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JOHN WAY

**CANDU 950 power station cutaway key**

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# Reactores refrigerados por gas (GCR)

Refrigerante:

CO<sub>2</sub>

Moderador:

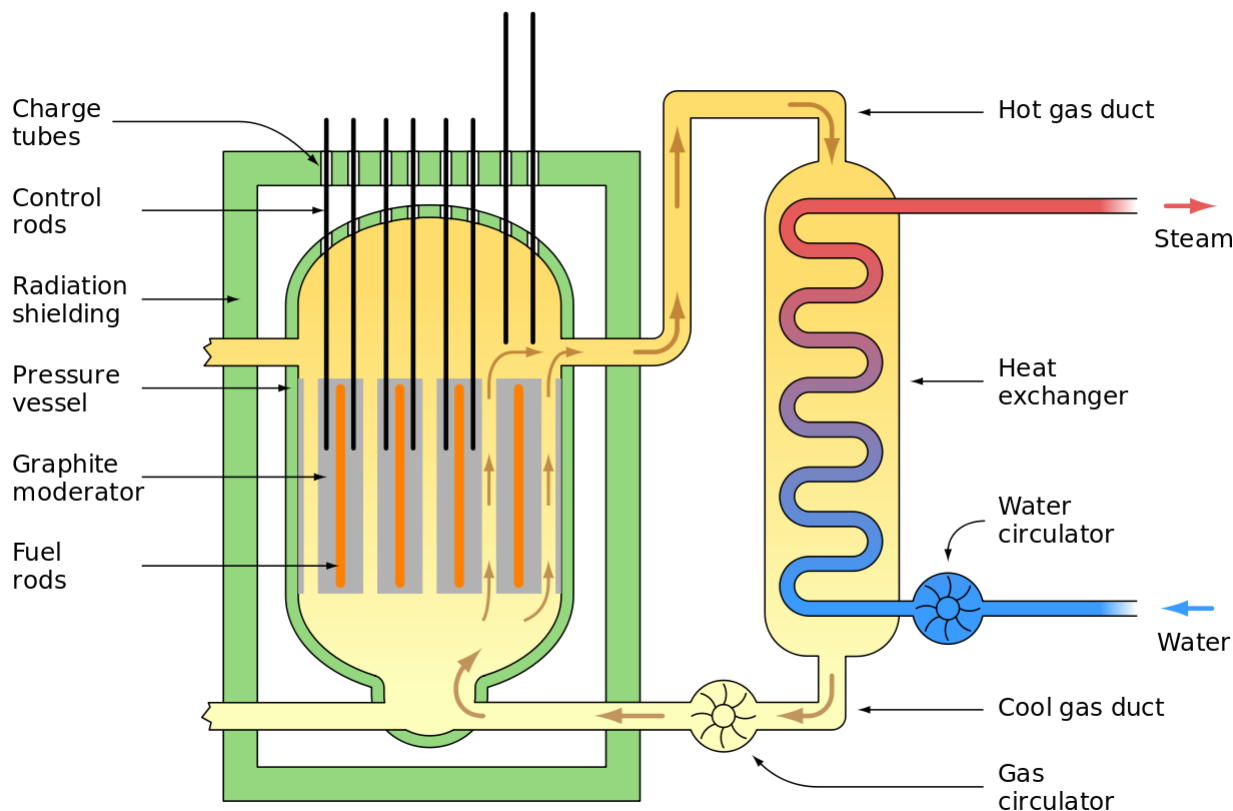
Grafito

Existen varios diseños

MAGNOX (UK)

UNGG (Fr)

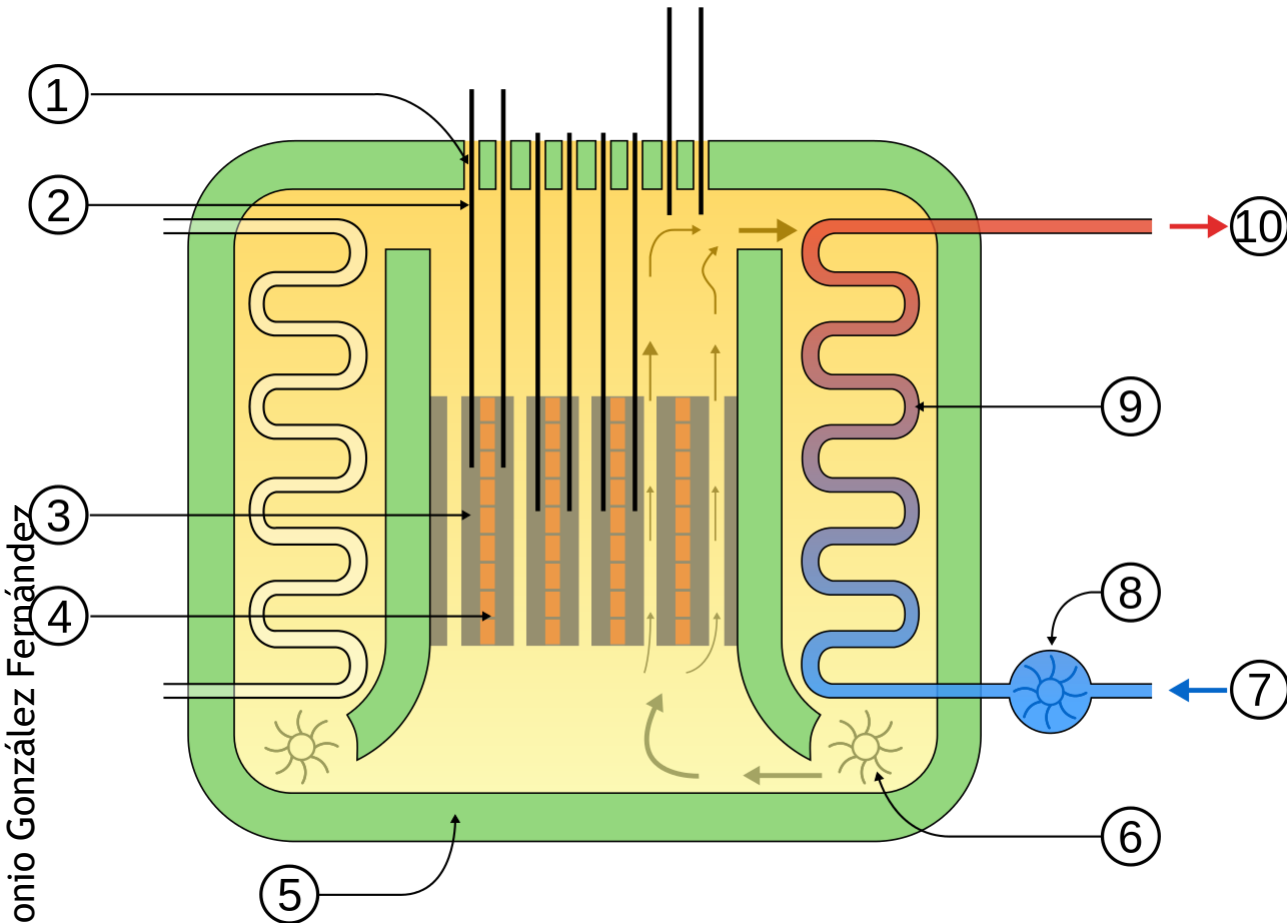
AGCR (UK)



El reactor es refrigerado por gas que va a un intercambiador de calor

Vandellós-1 era un UNGG

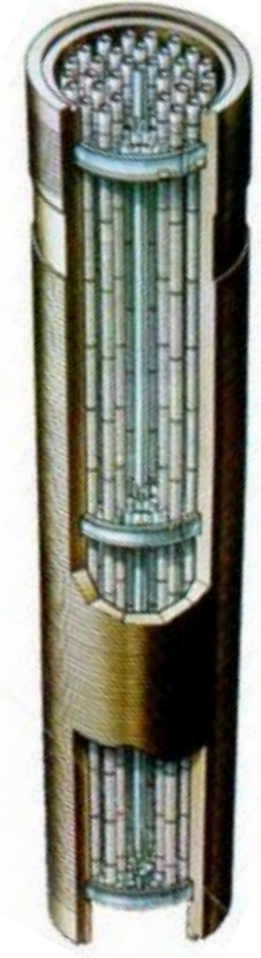
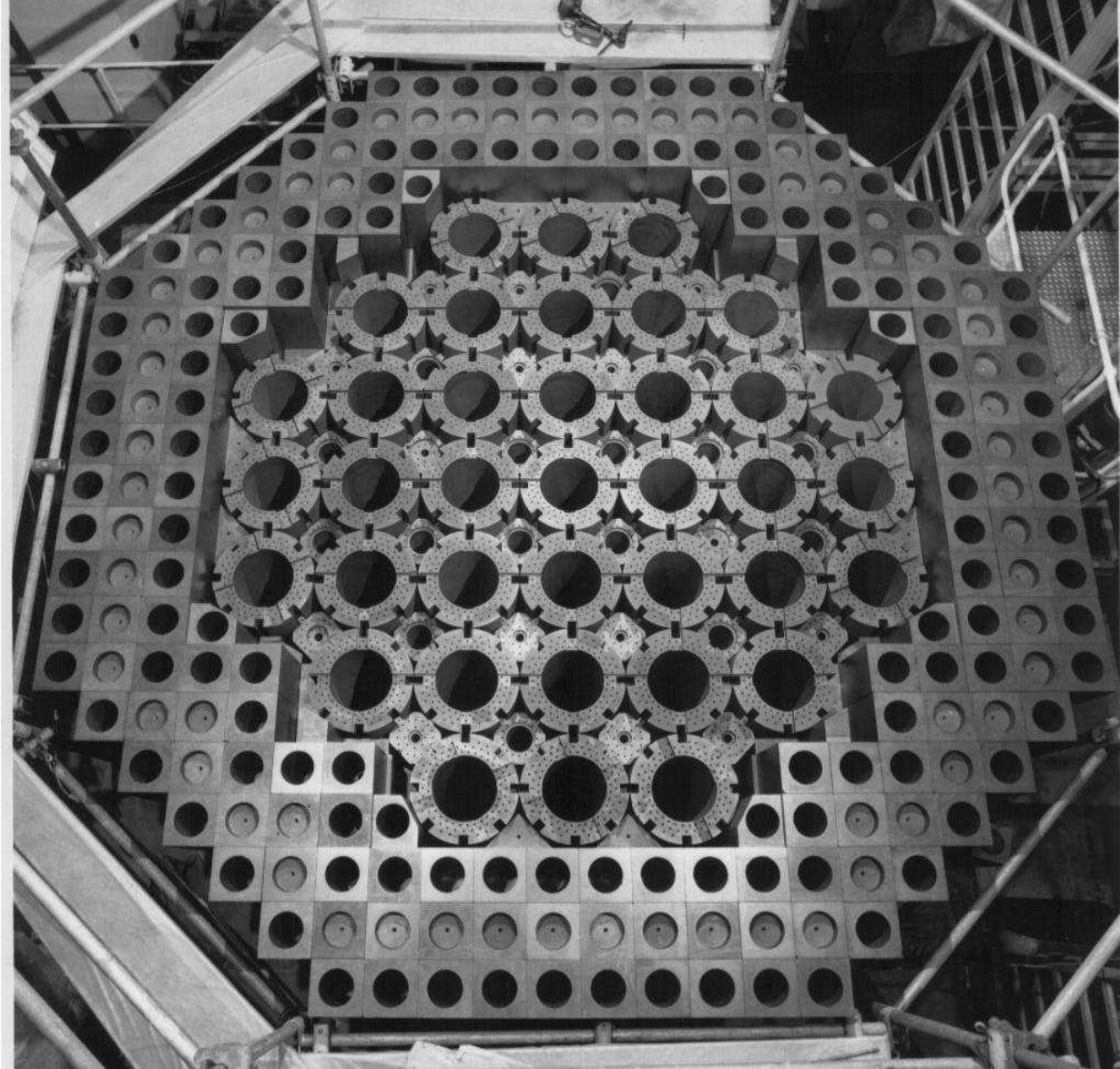
# Reactores refrigerados por gas avanzados (AGCR o AGR)



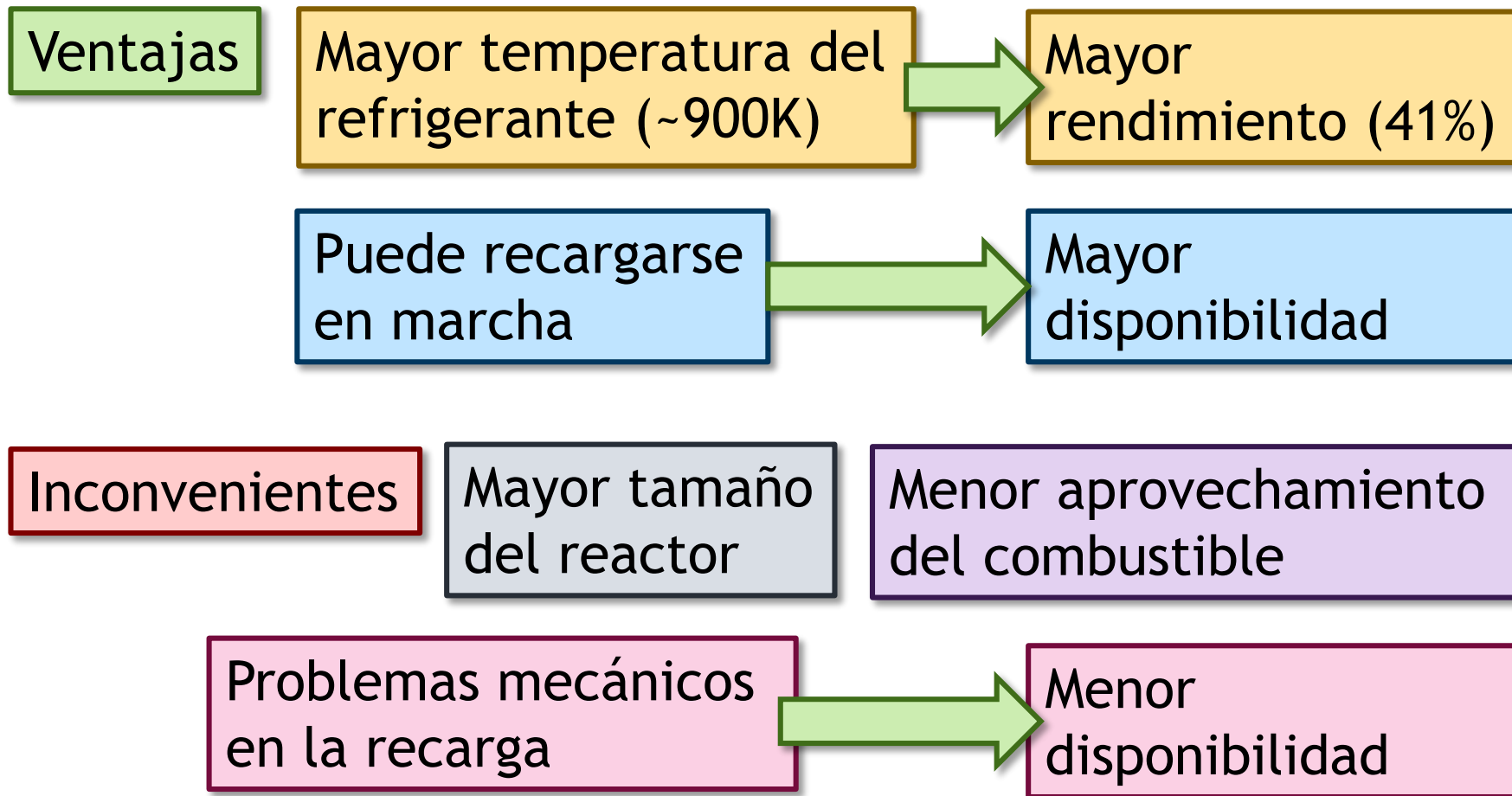
- AGR**
1. Charge tubes
  2. Control rods
  3. Graphite moderator
  4. Fuel assemblies
  5. Concrete pressure vessel and radiation shielding
  6. Gas circulator
  7. Water
  8. Water circulator
  9. Heat exchanger
  10. Steam

Diseñado para ser compatible con las turbinas de una central de carbón

# Núcleo y elemento combustible de un reactor AGR



# Ventajas e inconvenientes de los AGR





# Ejemplo de reactor AGCR: Dungeness

## The World's Reactors No. 41 DUNGENESS B

**DESIGN AND CONTRACTOR:** Atomic Power Constructors Limited.  
**OWNER AND OPERATOR:** Central Electricity Generating Board.  
**LOCATION:** Dungeness, Kent, England.  
**TYPE:** Advanced Gas-cooled Reactor.  
**PROGRAMME:** Site entry preliminary work: October, 1965. Work extraction commenced: January, 1966. First reactor commissioning: July, 1970. Second reactor commissioning: July, 1975.  
**CAPACITY:** Net electrical output: 1,213 MW. Gross generation: 1,200 MW. Number of reactors: Two, 600 MW. Net electrical per reactor: 600 MW. Overall station efficiency: 41.6%.  
*All figures given below are for one reactor.*

**FUEL:** Material: Uranium dioxide. Pellet diameter: 8.27 in (21.05 cm). Cladding: 0.015 in (0.38 mm) Type of cladding: 38 pin 3-ring cluster in graphite. Internal sleeve diameter: 7 in (17.8 cm). Elements in one element: per channel: eight. Average axial enrichment: 1.4%. U<sub>235</sub> U<sub>238</sub> Average fuel enrichment: 2.76%. U<sub>235</sub> U<sub>238</sub> Fuel rod length at equilibrium: 6.6 MW U<sub>235</sub> U<sub>238</sub> Channel inlet temperature: 18,000 MW/Ch. Overall weight of fuel: 123 in U<sub>235</sub> U<sub>238</sub>

**FUEL HANDLING:** Refuelling cycle: Axial and radial shuffling. Fuel and control rod handling: in fuel handling machine extraction: one machine using constant charge line for both reactors. Type of fuel: four zone: mixed.

**REACTOR CORE:** Moderator material: isotropic graphite. Side reflector: carbon and steel. Weight of graph-ite in core and reflector: 1,122 tons. Lattice geometry: square. Lattice pitch: 1.6 in (40.6 mm). Number of fuel channels: 48. Diameter of core channel: 9.6 in (244 mm). Number of control channels: 9. Active core diameter: 31 ft (9.4 m). Active core height: 27 ft (8.2 m).

**REACTOR CONTROL:** Control: Crane shut-down, central boron control rods. Control system: automatic, manual control rods. Number of control rods: 48. Active length: 23 ft (7.0 m).

**PRESSURE VESSEL:** Type: right cylinder, pressurized cover. Internal diameter: 65.02 m. External height: 26 ft (7.9 m). Top wall thickness: 2.0 in (51 mm). Side wall thickness: 1.5 in (38 mm). Pressurizing method: B.B.R.V., 975 ton minimum capacity.

**COOLANT:** Gas: carbon dioxide. Reactor gas inlet temperature: 529°C. Reactor gas outlet temperature: 475°C. Circulator outlet gas pressure: 488 lbf/in<sup>2</sup> abs (34.2 kg/cm<sup>2</sup> abs). Charge gas flow: 7,500 ft<sup>3</sup>/hr (210 m<sup>3</sup>/hr).

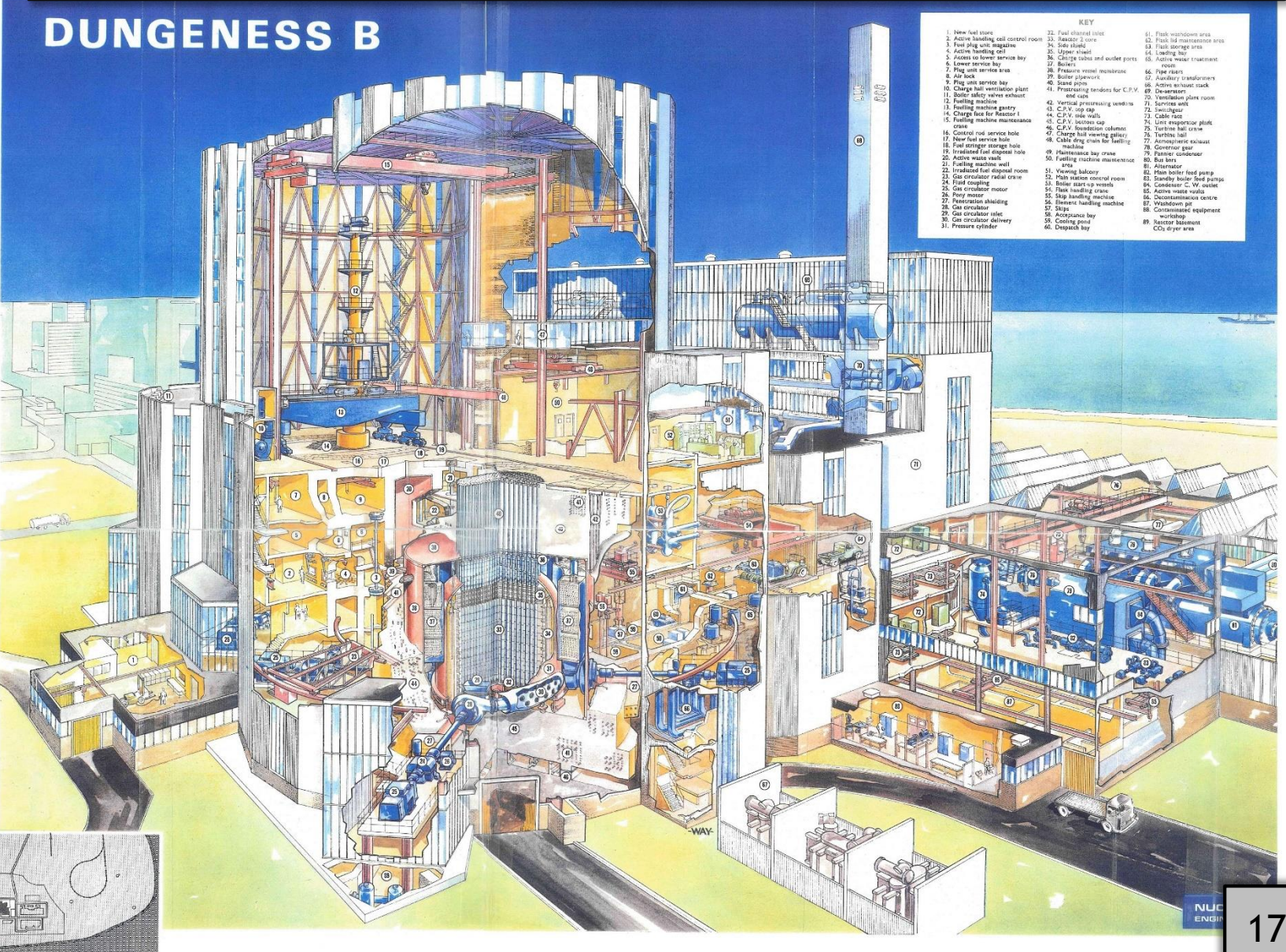
**GAS CIRCULATION:** Number of fuel channels: 48. Circulating speed at full load: 1,200 ft/min. Fuel channel inlet temperature: 529°C. Normal operating control range: 20% to full speed. Main drive motor: induction motor. Inlet gas pressure: 4,600 psi. Auxiliary drive: AC pump motor.

**BOILERS:** Number: Four. Type: once through. Heat exchanger flow: 374 t/hr (1,000 t/hr). Reheat steam flow: 3,000 t/hr (1,500 t/hr). Feed temperature: 143°C. Lower section tube material: Carbon steel. Middle section tube material: 1% chromium alloy steel. Upper section tube material: EN 316 stainless steel. Base tube diameter: 1.8 in (46 mm). Internal tube outside flow: low.

**TURBINE:** Number: One. Type: impulse. Number of cylinders: Five. Inlet steam pressure: 1,200 psi at turbine stop valve. Specific steam consumption at turbine stop valve: 5.315 lb/h at 170 kg/cm<sup>2</sup> abs. Inlet steam temperature: 566°C. Lower section temperature: 180°C. Number of feed heaters: Four. Boiler feed pump drive rating: 2,000 BHP. Condenser type: shell and tube. Turbine exhaust pressure: 1.1 in Hg (28 mm Hg). CW flow: 25,000 gpm (95 m<sup>3</sup>/min).

**ALTERNATOR:** Output at peak: continuous rating: 660 MW. Rating at 0.85 PF: 774 MVA. Power factor: 0.85. Terminal voltage: 25 kV. Cooling: water cooled. Motor: hydrogen cooled.

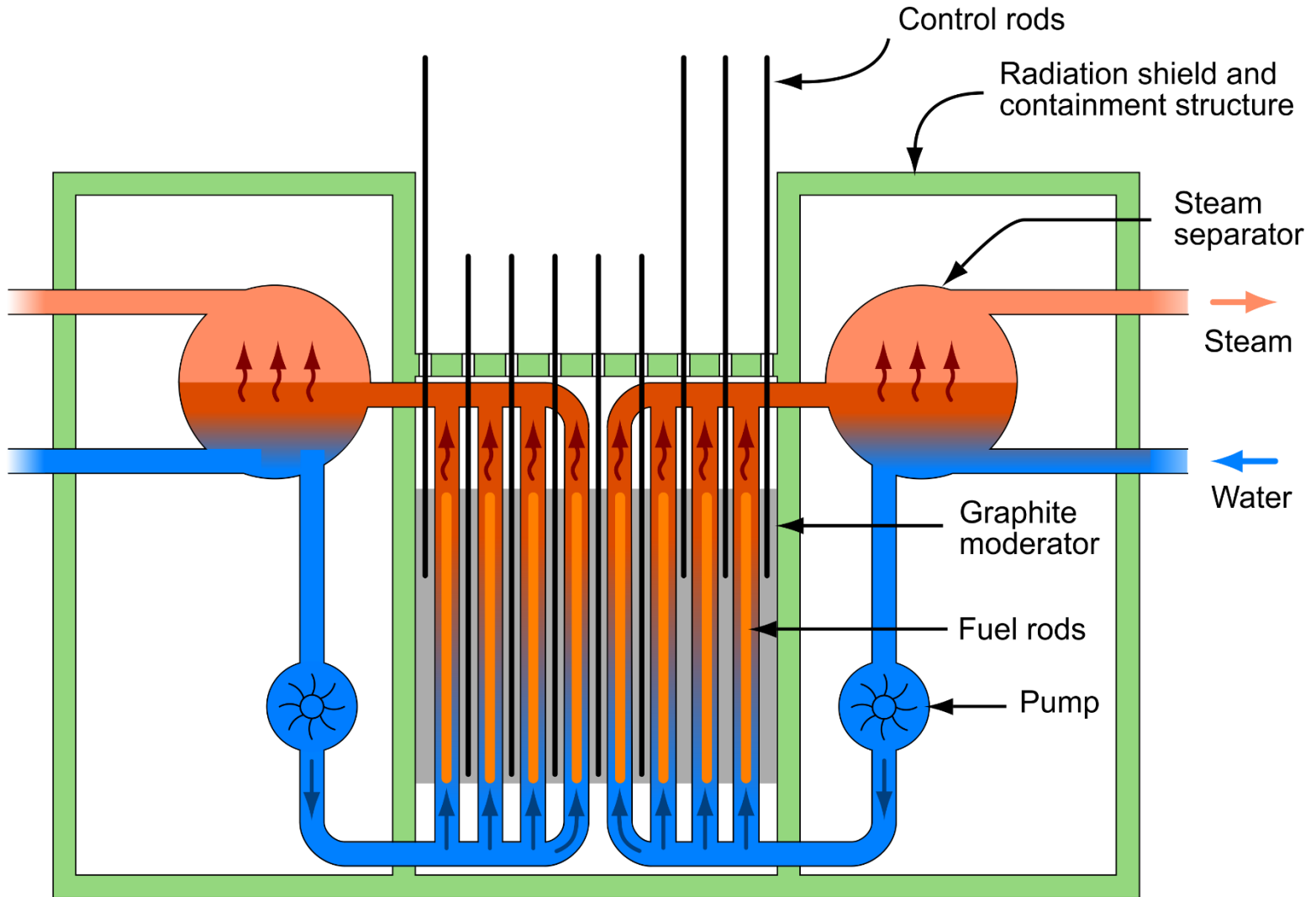
**STATION CONTROL:** Centralized control of the station is provided. A comprehensive computer system is used for digital control of the reactor, turbine and auxiliary equipment. Cathode ray tube display of the plant variables in the control room and the computer are also used for alarm sources.



- | KEY                                  |  |                                 |
|--------------------------------------|--|---------------------------------|
| 1. New fuel store                    | 32. Fuel channel inlet                                 | 61. Flank windown area          |
| 2. Active handling cell control room | 33. Reactor core                                       | 62. Flank maintenance area      |
| 3. Fuel plug unit magazine           | 34. Side shield  | 63. Flank storage area          |
| 4. Active handling cell              | 35. Upper shield                                       | 64. Loading bay                 |
| 5. Access to lower service bay       | 36. Cladding tubes and outlet ports                    | 65. Active waste treatment room |
| 6. Lower service bay                 | 37. Inlet air  | 66. Type 1200                   |
| 7. Plug unit service area            | 38. Pressure vessel maintenance area                   | 67. Auxiliary transformers      |
| 8. Plug unit service bay             | 39. Sealed pressure                                    | 68. Active exhaust stack        |
| 9. Plug unit service bay             | 40. Sealed pressure                                    | 69. Desorbers                   |
| 10. Charge hall ventilation plant    | 41. Processing tenders for C.P.V. end use              | 70. Ventilation plant room      |
| 11. Boiler safety valves exhaust     | 42. Vertical processing tenders                        | 71. Service unit                |
| 12. Fueling machine gantry           | 43. C.P.V. end use                                     | 72. Switchgear                  |
| 13. Charge line for Reactor 1        | 44. C.P.V. side walls                                  | 73. Cable rack                  |
| 14. Fueling machine maintenance area | 45. C.P.V. bottom column                               | 74. Lure response plant         |
| 15. Fueling machine maintenance area | 46. Charge hall evening gallery                        | 75. Turbine hall crane          |
| 16. Control rod service hole         | 47. Charge hall evening gallery                        | 76. Atmospheric exhaust         |
| 17. New fuel service hole            | 48. Cable drag chain for fueling maintenance bay crane | 77. Governor gear               |
| 18. Fuel stringer storage hole       | 49. Fueling machine maintenance area                   | 78. Fanter condenser            |
| 19. Irradiated fuel disposal room    | 50. Fuel line  | 79. Alternator                  |
| 20. Active waste vault               | 51. Viewing balcony                                    | 80. Steam boiler feed pump      |
| 21. Fueling machine waste vault      | 52. High station control room                          | 81. Standby boiler feed pumps   |
| 22. Irradiated fuel disposal room    | 53. Boiler start up vaults                             | 82. Condenser C.V. system       |
| 23. Gas circulator motor             | 54. Tank handling crane                                | 83. Active waste vault          |
| 24. Fuel coupling                    | 55. Skip handling machine                              | 84. Accumulation centre         |
| 25. Gas circulator motor             | 56. Inertent handling machine                          | 85. Washdown pit                |
| 26. Pump motor                       | 57. Skips  | 86. Communications equipment    |
| 27. Pressurized shielding            | 58. Gas circulator outlet                              | 87. Workshop                    |
| 28. Gas circulator                   | 59. Acceptance bay                                     | 88. Reactor basement            |
| 29. Gas circulator outlet            | 60. Dispatch bay                                       | 89. CO <sub>2</sub> dry area    |
| 30. Gas circulator delivery          |  |                                 |
| 31. Pressure cylinder                |  |                                 |



# Reactor tipo canal (*Reaktor Bolshoy Moshchnosti Kanalnyy, RBMK*)



# Propiedades de un RBMK

Moderador: grafito

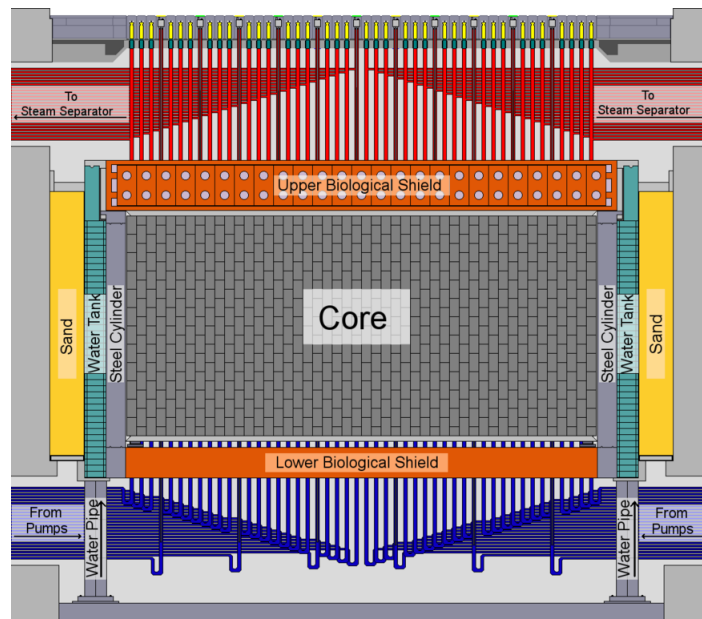
Refrigerante: agua (dos circuitos)

El agua a presión pasa por los tubos que atraviesan un bloque de grafito

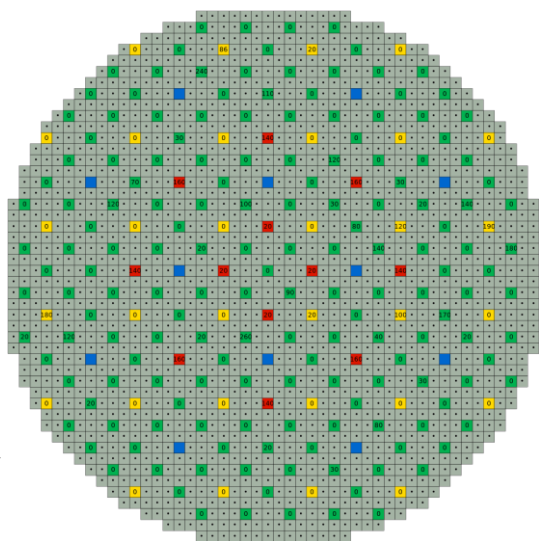
Permite recarga en operación

Las varillas de control entran desde arriba

Hay varillas permanentes



El coeficiente de vacío es positivo





1. РЕАКТОР
2. ТРАКТЫ ТЕХНОЛОГИЧЕСКИХ КАНАЛОВ
3. ПАРОВОДНЫЕ КОММУНИКАЦИИ
4. БАРАБАН-СЕПАРАТОР
5. ПАРОВЫЕ КОЛЛЕКТОРЫ
6. ОПУСКАЮЩИЕ ТРУБОПРОВОДЫ
7. ГЛАВНЫЕ ЦИРКУЛЯЦИОННЫЕ НАСОСЫ [ГЦН]
8. РАЗДАТОЧНЫЕ ГРУППОВЫЕ КОЛЛЕКТОРЫ [РГК]
9. ВОДНЫЕ КОММУНИКАЦИИ
10. СИСТЕМА КОНТРОЛЯ ГЕРМЕТИЧНОСТИ ОБОЛОЧКИ ТЕПЛОГЕНЕРАТОРОВ ЭЛЕМЕНТОВ [КГО ТЭЭО]
11. ВЕРХНЯЯ БИОЛОГИЧЕСКАЯ ЗАЩИТА
12. БОКОВАЯ БИОЛОГИЧЕСКАЯ ЗАЩИТА
13. НИЖНЯЯ БИОЛОГИЧЕСКАЯ ЗАЩИТА
14. БАССЕЙН ВЫДЕРЖКИ
15. РАЗГРУЗОЧНО-ЗАГРУЗОЧНАЯ МАШИНА [РЗМ]
16. МОСТОВЫЙ КРАН

ОСНОВНЫЕ ХАРАКТЕРИСТИКИ РЕАКТОРА РБМК-1000

ЭЛЕКТРИЧЕСКАЯ МОЩНОСТЬ	1000 МВт
ТЕПЛОВАЯ МОЩНОСТЬ	1150 МВт
РАСХОД ТЕПЛОНОСИТЕЛЯ	$37,5 \cdot 10^3$ Т/ч
ПАРПРОИЗВОДИТЕЛЬНОСТЬ	$5,1 \cdot 10^3$ Т/ч
ТЕМПЕРАТУРА НАСЫЩЕННОГО ПАРА	284 °С
ТЕМПЕРАТУРА ВОДЫ НА ВХОДЕ В РЕАКТОР	270 °С
ДАВЛЕНИЕ В СЕПАРАТОРЕ	70 МПа
НАЧАЛЬНОЕ ОБОГАЩЕНИЕ ТОПЛИВА [UO <sub>2</sub> ]	1,8 %

**РБМК-1000**

ГЕТЕРОГЕННЫЙ УРАН-ГРАФИТОВЫЙ РЕАКТОР РБМК-1000 КАНАЛЬНОГО ТИПА ПРЕДУСМАТРИВАЕТ ДВА ЦИКЛА ПРИ НАСЫЩЕННОМ ПАРА С ПОСЛЕДУЮЩЕЙ ПОДАЧЕЙ ЕГО К ТУРБОГЕНЕРАТОРАМ ЭЛЕКТРОСТАНЦИИ. АЭС С РЕАКТОРАМИ РБМК РАБОТАЮТ ПО ОДНОЦИКЛОВОЙ СХЕМЕ.

РАБОТУ КОНТРОЛЬ ПРИНУДИТЕЛЬНОГО ЦИРКУЛЯЦИИ ОБЕСПЕЧИВАЮТ ГЛАВНЫЕ ЦИРКУЛЯЦИОННЫЕ НАСОСЫ [ГЦН]. РАБОТА РЕАКТОРА ОБЕСПЕЧИВАЕТСЯ РАЗЛИЧНЫМИ СИСТЕМАМИ, СРЕДИ КОТОРЫХ ОСНОВНЫМИ ЯВЛЯЮТСЯ СИСТЕМА УПРАВЛЕНИЯ И ЗАЩИТЫ [СУЗ], ОБЕСПЕЧИВАЮЩАЯ УСТОЙЧИВОЕ АВТОМАТИЧЕСКОЕ ПОДДЕРЖАНИЕ МОЩНОСТИ НА ЗАДАННОМ УРОВНЕ; СИСТЕМА ТЕХНОЛОГИЧЕСКОГО КОНТРОЛЯ, ОБЪЕДИНЯЮЩАЯ СИСТЕМУ ФИЗИЧЕСКОГО КОНТРОЛЯ ЗА РАСПРЕДЕЛЕНИЕМ ЭНЕРГОВЫДЕЛЕНИЯ [СФКРЭ] СИСТЕМУ ПОКАНАЛЬНОГО КОНТРОЛЯ РАСХОДА ВОДЫ ЧЕРЕЗ КАНАЛЫ СИСТЕМУ КОНТРОЛЯ ГЕРМЕТИЧНОСТИ ТРЕЛОВ [КГО], СИСТЕМУ КОНТРОЛЯ ЦЕЛОСТНОСТИ ТРУБНЫХ КАНАЛОВ [КЦТК], СИСТЕМУ КОНТРОЛЯ ТЕМПЕРАТУРЫ ТЕПЛОНОСИТЕЛЯ И ЭЛЕМЕНТОВ КОНСТРУКЦИИ РЕАКТОРА.

БИОЛОГИЧЕСКАЯ ЗАЩИТА РЕАКТОРА ОБЕСПЕЧИВАЕТ ДОПУСТИМУЮ САНИТАРНЫМИ НОРМАМИ РАДИАЦИОННУЮ ОБСТАНОВКУ ВО ВСЕХ ПОМЕЩЕНИЯХ.

ВЫГРУЗКА ИЗ ТОПЛИВНЫХ КАНАЛОВ НАСЕТС С ВЫГОРЕВШИМ ТОПЛИВОМ И ТРАНСПОРТИРОВКА К МЕСТУ УХРАНЕНИЯ, А ТАКЖЕ УСТАНОВКА НА ИХ МЕСТЕ СВЕЖИХ, МОЖЕТ ПРОИЗВОДИТЬСЯ НА РАБОТАЮЩЕМ РЕАКТОРЕ. ПЕРЕГРУЗКА ПРОИЗВОДИТСЯ С ПОМОЩЬЮ СПЕЦИАЛЬНОЙ РАЗГРУЗОЧНО-ЗАГРУЗОЧНОЙ МАШИНЫ [РЗМ].

РЕАКТОРЫ ТИПА РБМК ЯВЛЯЮТСЯ БАЗИСОМ ДЛЯ РАЗВИТИЯ БОЛЕЕ МОЩНЫХ РЕАКТОРОВ БЛОЧНОГО ТИПА С ПЕРЕГРЕВОМ ПАРА.





# Los RBMK tras el accidente de Chernobyl

Siguen funcionando 11 RBMK en el mundo (todos en Rusia)

Se instalaron varillas de control permanentes

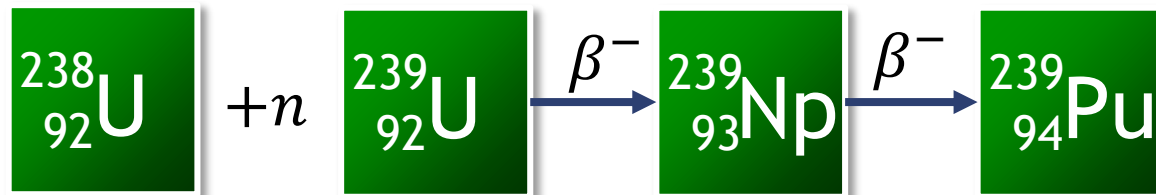
Se aumento el número de varillas de control móviles

Se han sustituido todos los tubos de presión

Se actualizó la electrónica y se impidió la desconexión de los sistemas de seguridad

# Reactores reproductores (*liquid metal fast breeder reactors, LMFBFR*)

El  $^{238}\text{U}$  es un material fértil



Si una manta (*blanket*) de  $^{238}\text{U}$  es bombardeada con neutrones rápidos, se transforma parcialmente en  $^{239}\text{Pu}$

Después puede separarse químicamente ( $\text{Pu} \neq \text{U}$ )

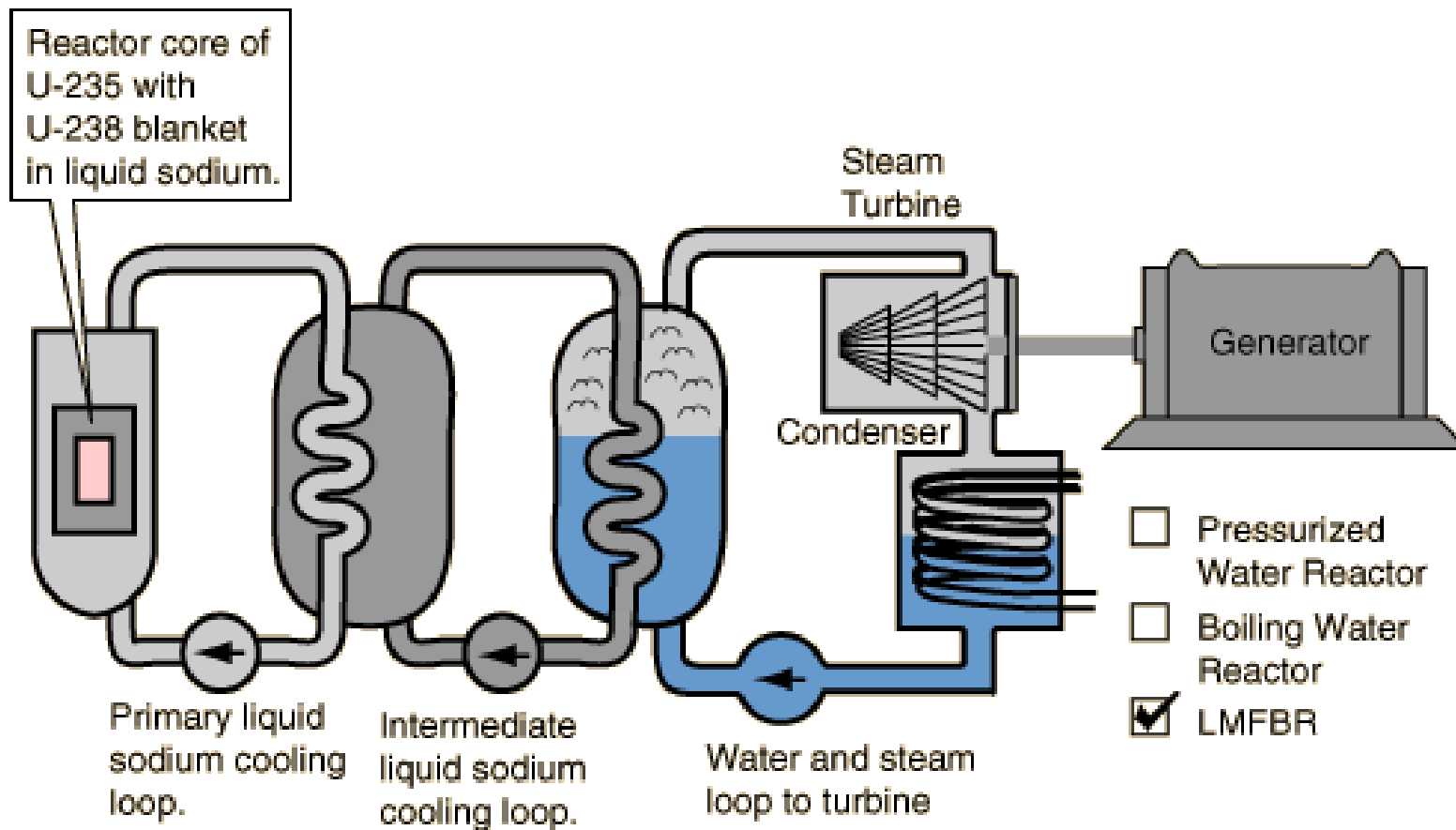
No puede tener moderador, y absorber lo menos posible

➡ No puede usar agua como refrigerante

Se usa sodio líquido

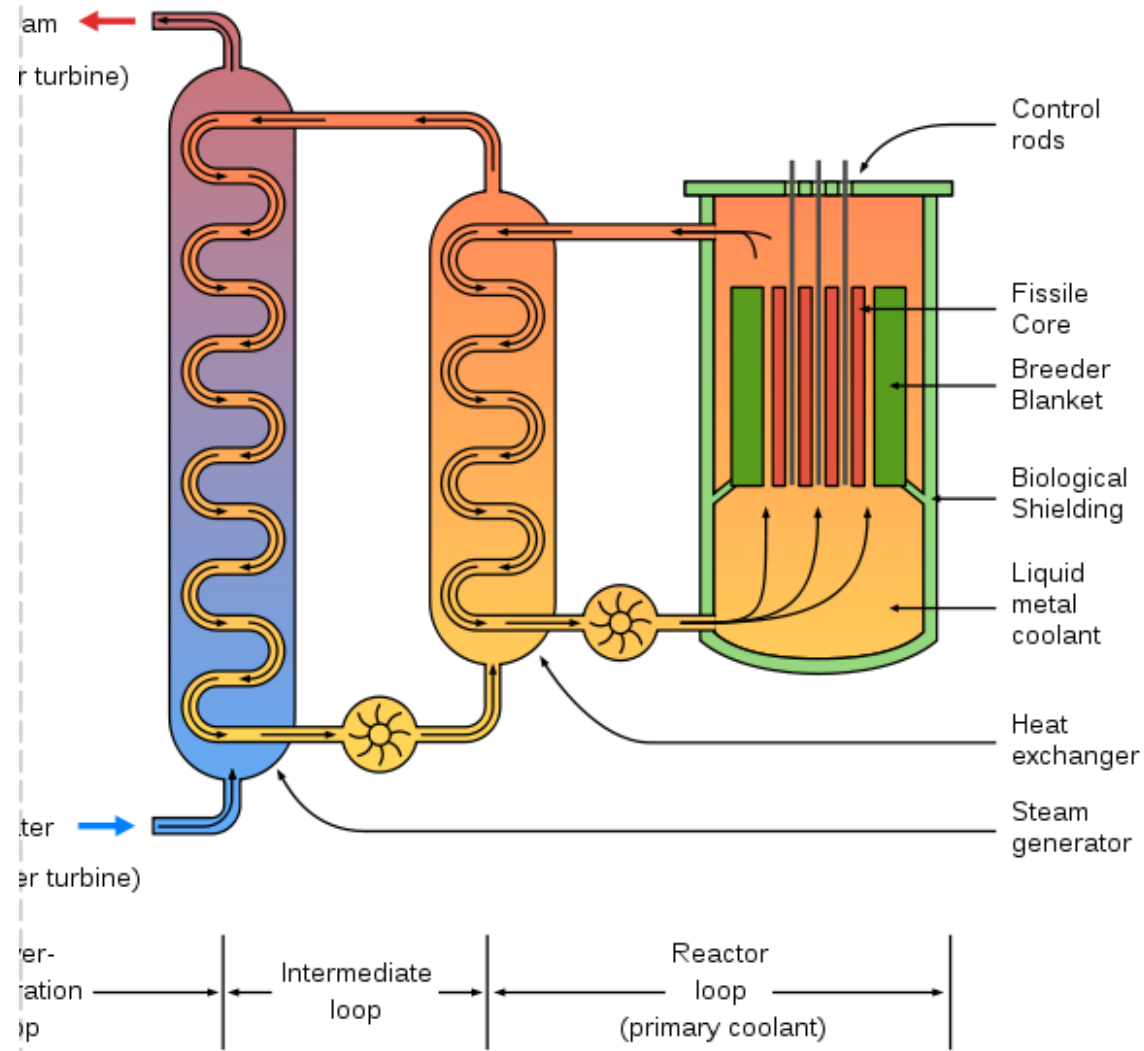


# Esquema básico de un LMFBR



# Reactores reproductores (diseño *loop*)

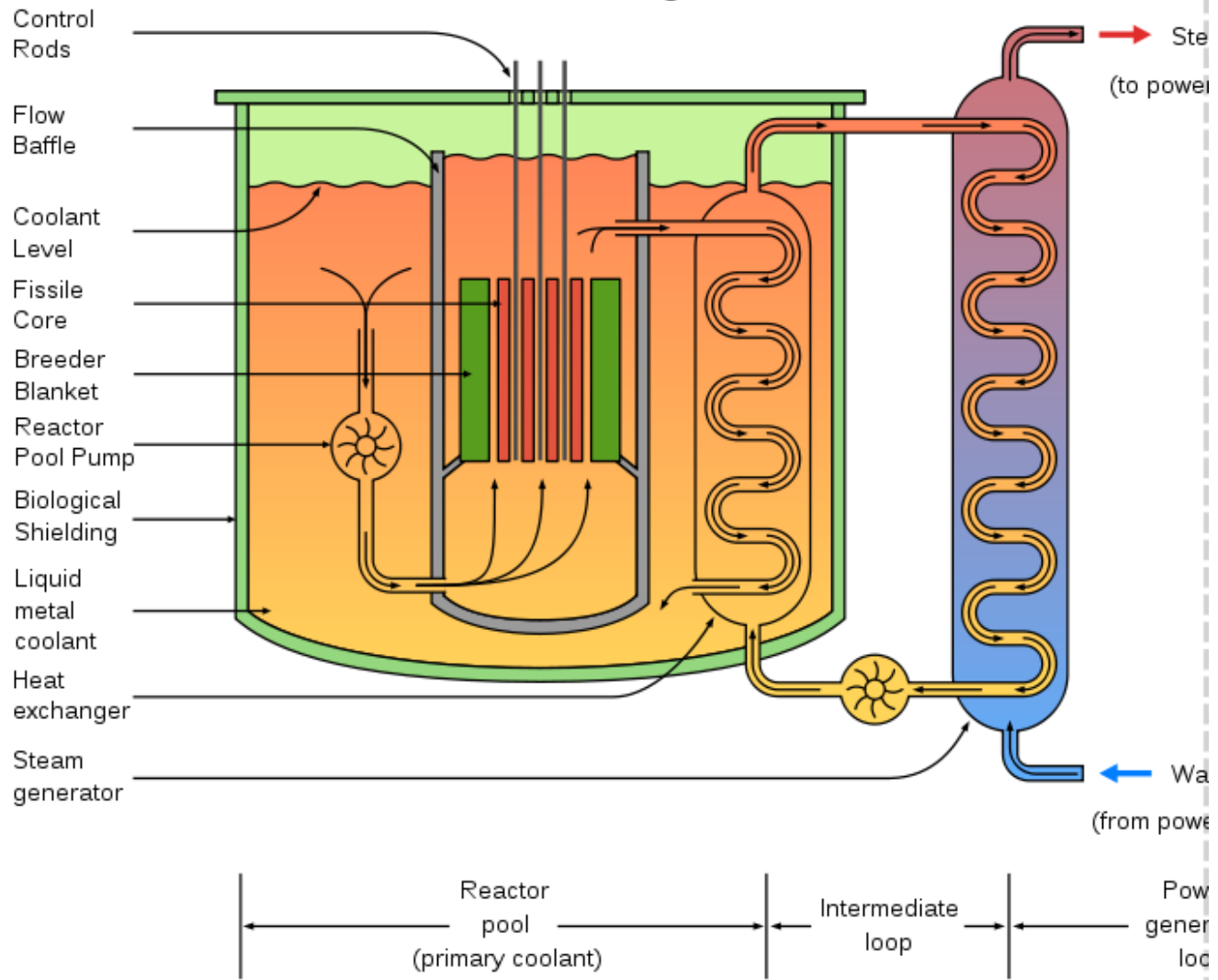
"Loop" Design





# Reactores reproductores (diseño en *pool*)

"Pool" Design



Usa  $^{239}\text{Pu}$  como combustible

# Ventajas e inconvenientes de los reactores reproductores

## Ventajas

Producen energía y combustible

Permiten aprovechar el  $^{238}\text{U}$

De décadas se pasa a siglos de reservas

## Inconvenientes

El sodio líquido requiere que todo el circuito sea calentado a  $>98^\circ\text{C}$

El uso de sodio líquido es peligroso (reactivo)

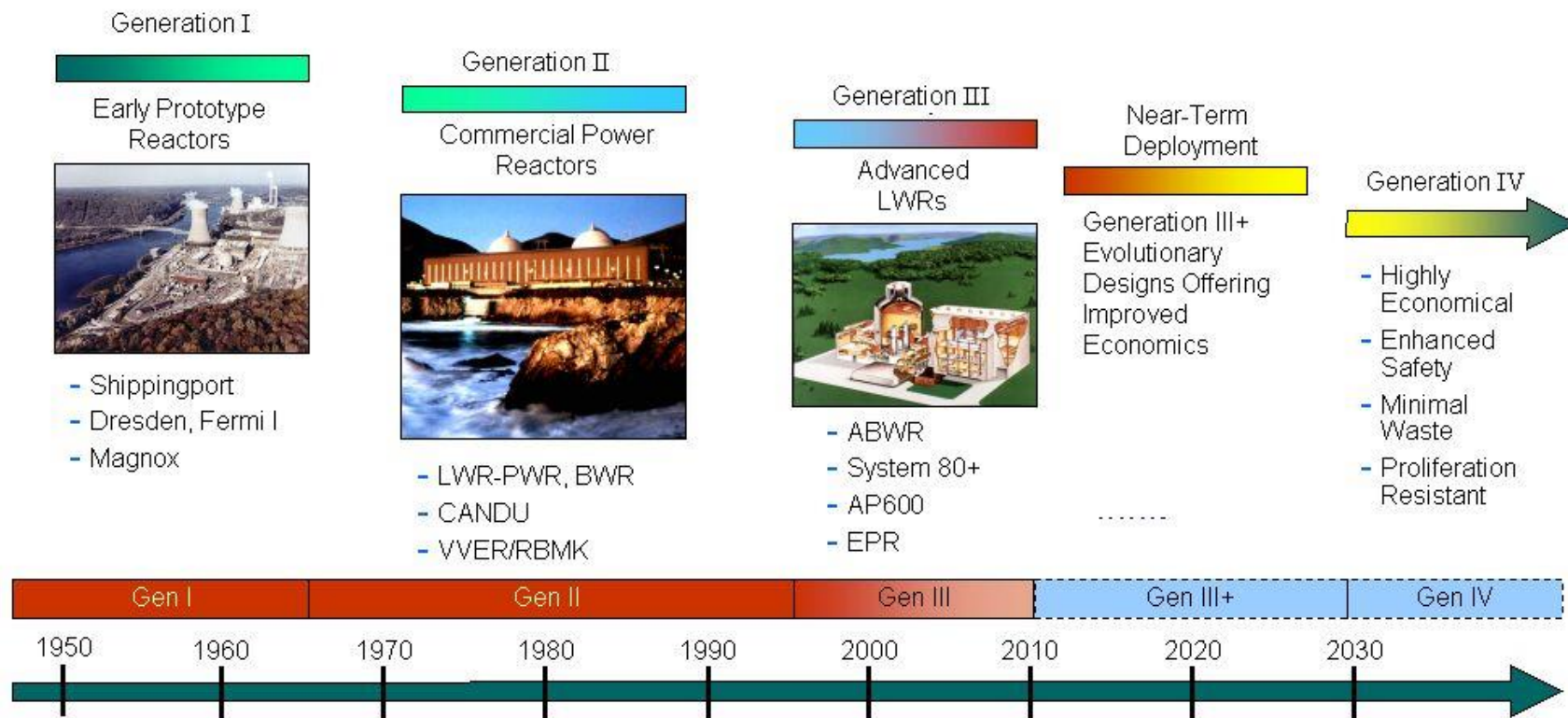
Usan y generan plutonio

Impopular

Riesgo de proliferación nuclear

No es rentable mientras el  $^{235}\text{U}$  sea barato

# Las generaciones de los reactores



El cambio en el mercado nuclear requiere nuevos diseños más seguros y más eficientes

Estamos en la generación II y parte de la III



# Reactores evolucionarios (Generación III)

## Evoluciones de los ya existentes

APWR: Advanced Pressurized Water Reactor

ABWR: Advanced Boiling Water Reactor

CANDU mejorado

AP600 (de Westinghouse, sustituido por la AP1000)

System 80+ (otra variante de APWR)

Advanced Heavy Water Reactor (India): Similar a CANDU, pero usa torio

Más en [ARIS](#) (IAEA)

# Generación III+ y Generación IV

Generación III+:

Cambios sustanciales en los diseños

CANDU avanzado

AP1000

EPR: European Pressurized Reactor

Economic Simplified Boiling Water Reactor: evolución del ABWR

Generación IV:

nuevos diseños

VHTR: Very High Temperature reactor

MSR: Molten Salt Reactor

Varios reactores reproductores

# Mejoras en los PWR

APWR (Mitsubishi):

Incluye reflector

1700MWe

**CANCELADO**

Más medidas de seguridad

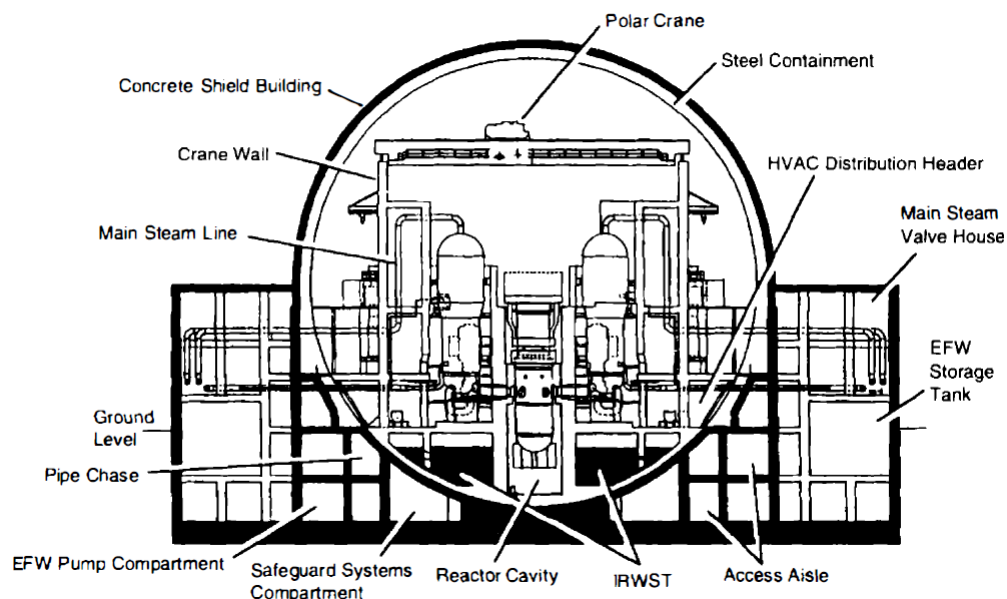
System 80+

Edificio esférico

Más agua en el primario

Varillas de control parciales

Hay en EEUU y Corea





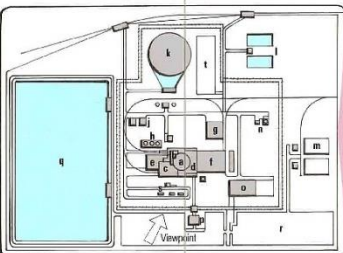
# Sistema 80+

# SYSTEM 80+

## STANDARD DESIGN



This drawing was produced by the magazine Nuclear Engineering International, in collaboration with ABB CE. It was published in the November 1992 issue.



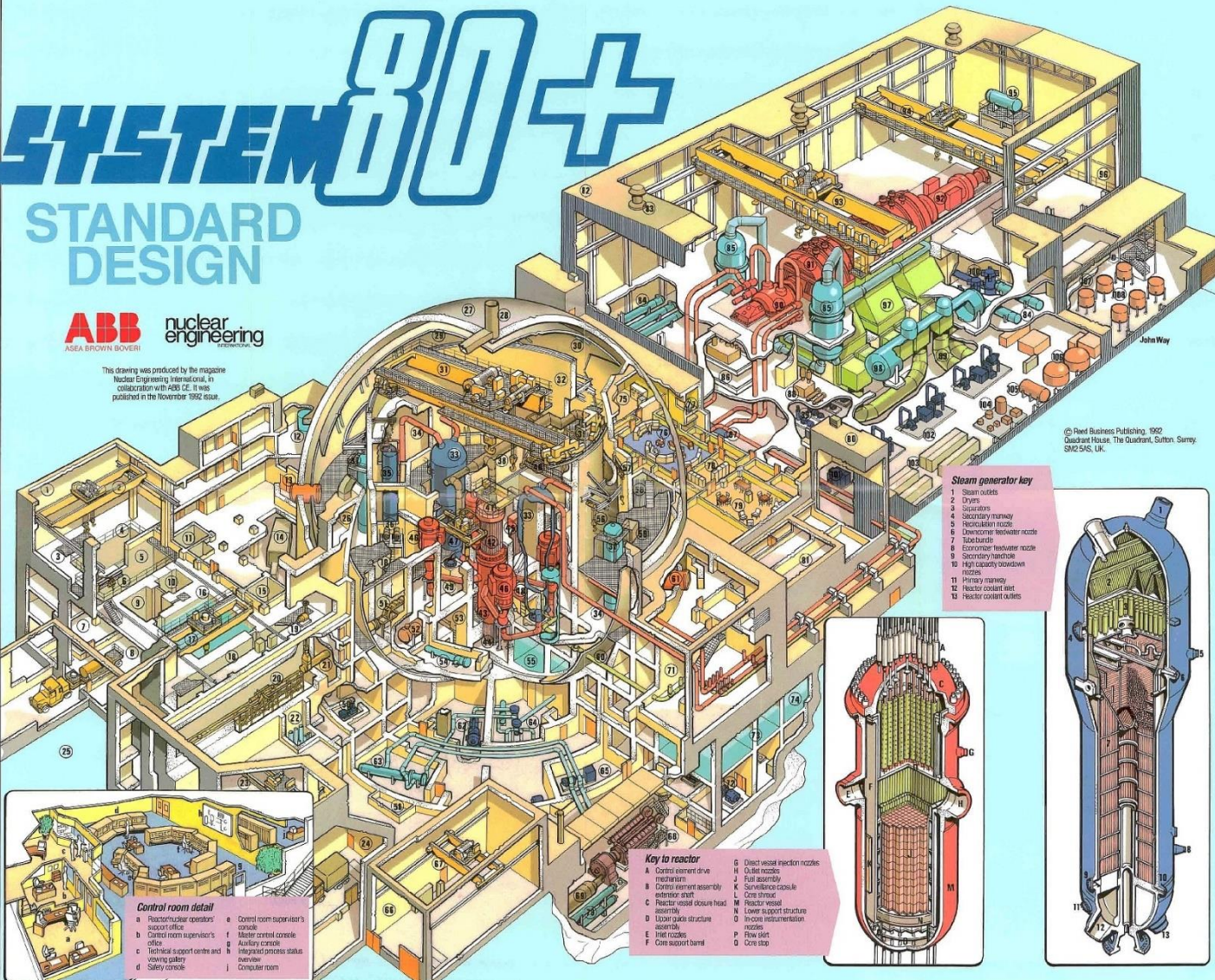
- Site plan key**
- a Reactor building
  - b Fuel pool area
  - c Maintenance and outage area
  - d Control area
  - e Refuelex building
  - f Turbine building
  - g Service building
  - h Storage tanks
  - i Pump and heat exchanger structures
  - j Cooling tower
  - k Sewage treatment
  - l Substation
  - m Alternate AC source gas turbine
  - n Warehouse
  - o Administration
  - p Pond
  - q Parking
  - r Bulk gas storage
  - s Spent fuel storage

**Technical data**

<b>TYPE</b>	Pressurized water reactor, fuel - slightly enriched $UO_2$ , direct cycle, closed loop, 1382 MWe Standard System 80+™	<b>Thickness of SS cladding</b>	0.15in (3.8mm)
<b>CONSTRUCTION SCHEDULE</b>	First structural concrete to fuel load 48 months Startup 6 months	<b>Design pressure</b>	2500psi (170kg/cm <sup>2</sup> )
<b>CAPACITY</b>	Gross generation 1382 MWe Net electrical 1300 MWe Overall station net efficiency 34.2	<b>Design temperature</b>	550°F (300°C)
<b>REACTOR CORE</b>	Reactor output 3800 MWt Core length 550in (13.9m) Core diameter 144in (3.65m) Number of fuel assemblies 24	<b>Material</b>	SA 508 1.123.000b (300 000kg)
<b>FUEL</b>	Fuel material Slightly enriched $UO_2$ Total quantity of $UO_2$ 257 088lb (116 300kg) Number of pins per assembly 236 Pin diameter 0.325in (8.3mm) Clad material Zircaloy-4 Clad thickness 0.025in (0.64mm) Enrichment (initial core) 3.3, 2.6, 1.9 w/o	<b>Height (incl. vessel head)</b>	
<b>CONTROL</b>	Number of control element assemblies 80 Absorber material B <sub>4</sub> C (40) Age-28 (20) Incore (25) Magnatic jack 4 or 12	<b>TURBINE</b>	Tandem-compound, 100 hp turbine 1902 valves
<b>DRIVE TYPE</b>	Number of fingers per assembly 17 or 12	<b>Speed</b>	3600 rpm
<b>THERMAL DATA</b>	Steam flow 17.63 x 10 <sup>6</sup> lb/h (7.96 x 10 <sup>6</sup> kg/h) Steam temperature 547°F (292°C) Secondary steam generator feed water temperature 501°F (262°C)	<b>Design</b>	958hp (708 kg/hour) 539°F (282°C)
<b>REACTOR PRESSURE VESSEL</b>	Inside diameter 180.25in (4.58m) Overall height 622in (15.8m) Average wall thickness 9in (229mm)	<b>CONDENSER</b>	Type: Three shell, three pass, shell water cooled Design: Heat transfer 0.438 x 10 <sup>6</sup> Btu/h (2.331 x 10 <sup>6</sup> W) 1.070.000m <sup>2</sup> (99 500m <sup>2</sup> ) Design pressure: 2.292.000.200 Pa (77.492 x 10 <sup>2</sup> kg/cm <sup>2</sup> ) Shell: 25 lb/hr (1.20 kg/cm <sup>2</sup> ) Water box: 25 lb/hr (1.20 kg/cm <sup>2</sup> )
		<b>GENERATOR</b>	Design: Hydrogen inner cooled Speed: 1800 rpm Rating: 1973.9 kVA Terminal voltage: 0.9 Power factor: 0.9 Frequency: 60 Hz
		<b>MAIN TRANSFORMER</b>	Rating: 760 MVA Voltage: 230 kV High voltage rating: 240 kV Low voltage: 22.8 kV
		<b>CONTAINMENT</b>	Type: Spherical steel containment vessel, reinforced concrete shield building Diameter: 276in (6.96m) Shell building: 200in (5.1m) Containment vessel: 38in (0.9m) Foundation slab thickness: 100in (2.5m) Design pressure: 53.02psi (3.70kg/cm <sup>2</sup> ) Design temperature: 200°F (93°C) Free volume: 3.34 x 10 <sup>6</sup> ft <sup>3</sup> (95 x 10 <sup>3</sup> m <sup>3</sup> )

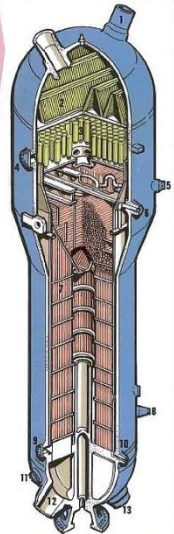
**Key to power station cutaway**

- |                                       |   |   |   |
|---------------------------------------|---|---|---|
| 1 Fuel building                       | 31 Polar crane                              | 66 Motorized crane                          | 82 Turbine building                                 |
| 2 Fuel building overhead crane        | 32 Core wall                                | 67 Jib crane                                | 83 Roof ventilation fans                            |
| 3 New fuel storage                    | 33 Steam generators                         | 68 Cable snaf                               | 84 Feedwater heaters                                |
| 4 New fuel inspection station         | 34 Main steam line                          | 69 Containment cooling ventilation unit     | 85 Main steam separator                             |
| 5 New fuel unloading area             | 35 Pressurizer                              | 70 Feedwater line                           | 86 Lubricating oil storage tank, pumps, and coolers |
| 6 Jib crane                           | 36 Pressurizer vent facility                | 71 Thermal access                           | 87 Control fluid unit and coolers                   |
| 7 Fuel pool storage                   | 37 Safety injection tanks                   | 72 Safety injection pump room               | 88 Containment spray heat exchanger                 |
| 8 Truck bay                           | 38 Control element drive mechanism (spring) | 73 Containment spray heat exchanger         | 89 Low pressure turbine                             |
| 9 Spent fuel pool                     | 39 Control element drive mechanism (spring) | 74 Control element drive mechanism (spring) | 90 Generator  |
| 10 Cask washdown                      | 40 Control element drive mechanism (spring) | 75 Control element drive mechanism (spring) | 91 Main steam valve house                           |
| 11 Electrical access shaft            | 41 Control element drive mechanism (spring) | 76 Control element drive mechanism (spring) | 92 Condensate cooling water pumps                   |
| 12 Component cooling water surge tank | 42 Control element drive mechanism (spring) | 77 Control element drive mechanism (spring) | 93 Emergency feedwater pumps                        |
| 13 Personnel access                   | 43 Heat area cooling fan system             | 78 Control element drive mechanism (spring) | 94 Low pressure turbine                             |
| 14 Air intake exhaust                 | 44 Control element drive mechanism (spring) | 79 Control element drive mechanism (spring) | 95 Diesel oil fuel oil separator                    |
| 15 HMI-CR case                        | 45 Reactor vessel                           | 80 Water and lubricating oil coolers        | 96 Overhead crane                                   |
| 16 Spent fuel pool                    | 46 In-core instrumentation tubes            | 81 Fuel transfer system operator            | 97 Auxiliary crane                                  |
| 17 Spent fuel pool bridge crane       | 47 Fuel transfer system operator            | 82 Reactor coolant pumps                    | 98 Reactor vessel cooling water surge tank          |
| 18 Windchamber                        | 48 Fuel transfer system operator            | 83 Reactor coolant pumps                    | 99 Water and lubricating oil coolers                |
| 19 Vent stack                         | 49 Reactor coolant pumps                    | 84 Reactor coolant pumps                    | 100 Condensate pumps                                |
| 20 Reactor building shield wall       | 50 In-core instrumentation tubes            | 85 Reactor coolant pumps                    | 101 Motor-driven feed and booster pumps             |
| 21 Vent stack                         | 51 Fuel transfer system operator            | 86 Reactor coolant pumps                    | 102 Motor-driven feed and booster pumps             |
| 22 Reactor building shield wall       | 52 Fuel transfer system operator            | 87 Reactor coolant pumps                    | 103 Condensate polishers                            |
| 23 Vent stack                         | 53 Fuel transfer system operator            | 88 Reactor coolant pumps                    |   |
| 24 Reactor building shield wall       | 54 Fuel transfer system operator            | 89 Reactor coolant pumps                    |   |
| 25 Vent stack                         | 55 Fuel transfer system operator            | 90 Reactor coolant pumps                    |   |
| 26 Reactor building shield wall       | 56 Fuel transfer system operator            | 91 Reactor coolant pumps                    |   |
| 27 Vent stack                         | 57 Fuel transfer system operator            | 92 Reactor coolant pumps                    |   |
| 28 Reactor building shield wall       | 58 Fuel transfer system operator            | 93 Reactor coolant pumps                    |   |
| 29 Vent stack                         | 59 Fuel transfer system operator            | 94 Reactor coolant pumps                    |   |
| 30 Containment spray lines            | 60 Fuel transfer system operator            | 95 Reactor coolant pumps                    |   |



**Steam generator key**

- 1 Steam outlets
- 2 Drives
- 3 Separators
- 4 Secondary pathway
- 5 Feedwater nozzles
- 6 Downcomer feedwater nozzle
- 7 Top bundle
- 8 Economizer feedwater nozzles
- 9 Secondary manifold
- 10 High capacity downflow nozzles
- 11 Primary pathway
- 12 Reactor coolant inlet
- 13 Reactor coolant outlet



**Key to reactor**

- |  |                                   |
|--|-----------------------------------|
| A Control element drive mechanism          | G Direct vessel injection nozzles |
| B Control element assembly extension shaft | H Outer nozzle                    |
| C Reactor vessel closure head assembly     | I Fuel assembly                   |
| D Upper gask structure assembly            | J Control element cable           |
| E Inlet nozzles                            | K Core drive                      |
| F Core support barrel                      | L Reactor vessel                  |
|  | M Lower support structure         |
|  | N In-core instrumentation nozzles |
|  | O Flow slot                       |
|  | P Core cap                        |

**Control room detail**

- |  |                                      |
|--|--------------------------------------|
| a Reactor/turbine operators' control room      | e Control room supervisor's console  |
| b Control room supervisor's office             | f Meter control console              |
| c Technical support centre and viewing gallery | g Auxiliary console                  |
| d Safety console                               | h Integrated process status overview |
|  | i Control room                       |

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Quadrant House, The Quadrant, Sutton, Surrey, SM2 5AS, UK.



# El EPR (*European Pressurized Reactor*)



4 sistemas de refrigeración

17% menos U

1650MWe

Varios en construcción

Costes desorbitados

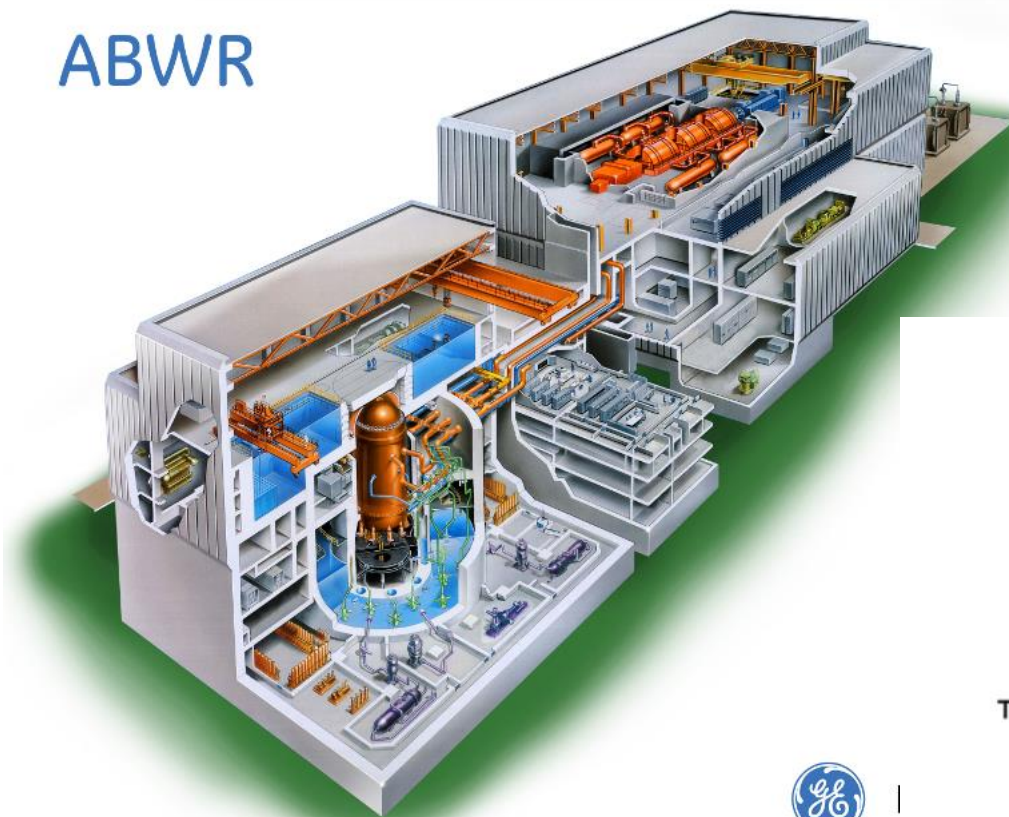
Retrasos

Sin certificación en EEUU

# El Advanced Boiling Water Reactor

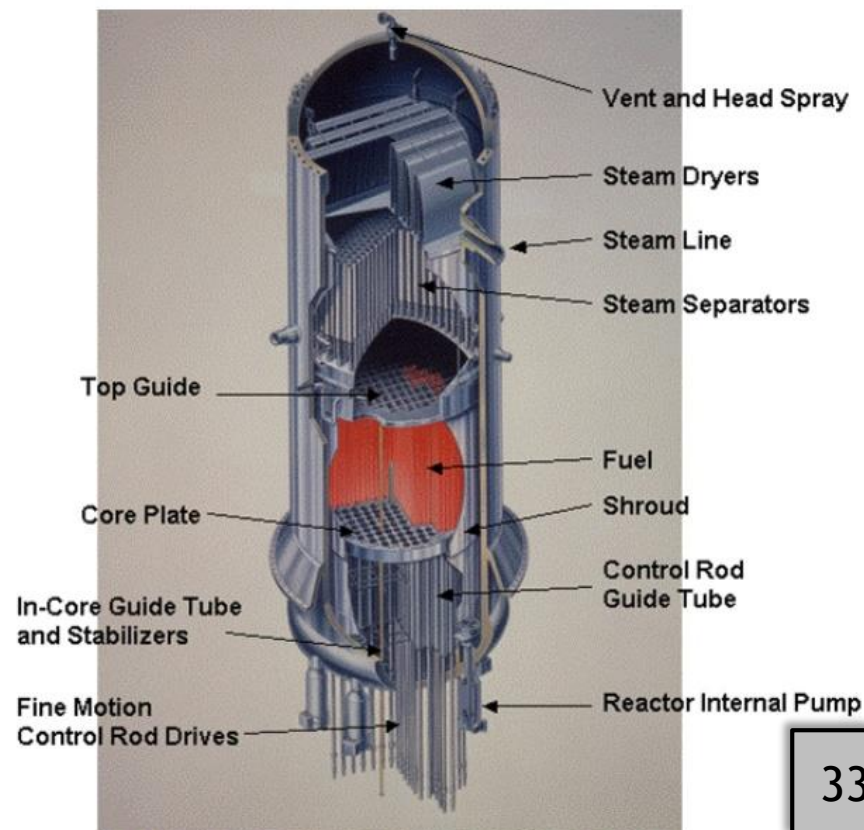
ABWR

Más en [ARIS](#)



Incluye bombas dentro de la vasija

Evita la recirculación





# El reactor CANDU Avanzado (ACR-1000)

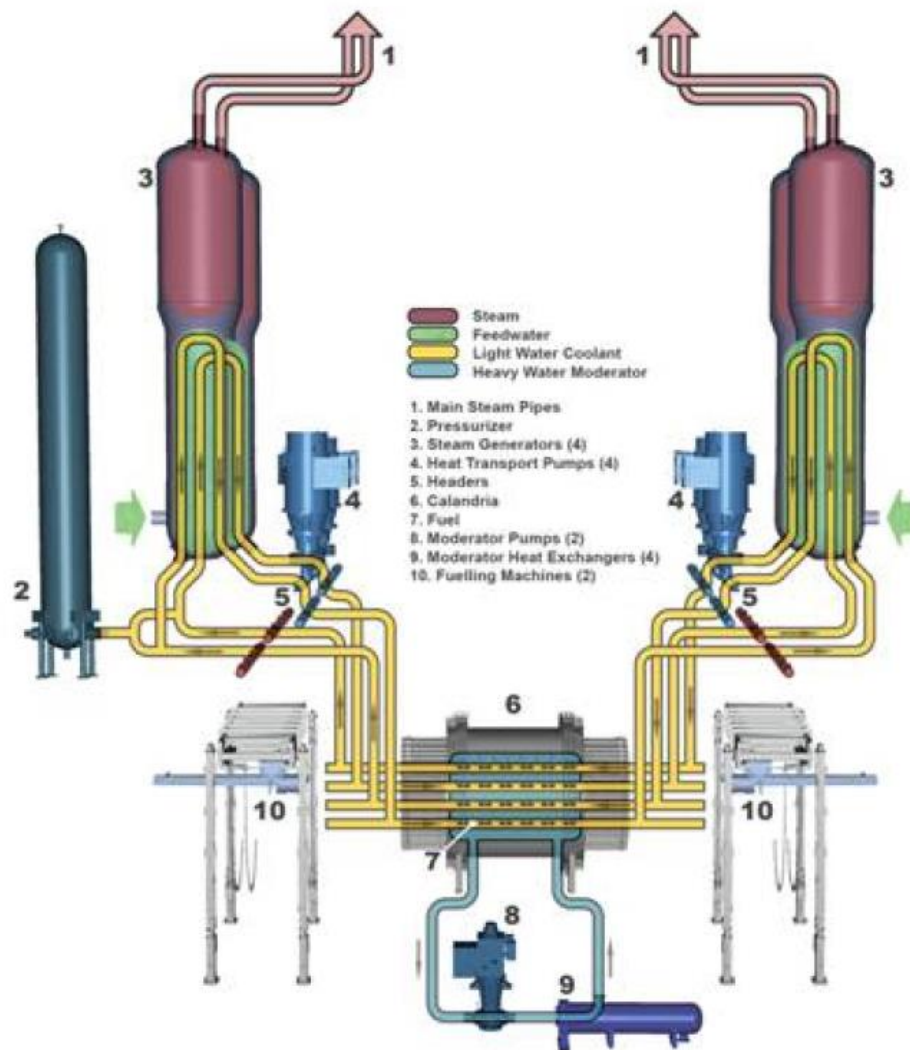
Usa agua ligera como refrigerante

Usa agua pesada como moderador

Requiere uranio enriquecido

Permite un núcleo más pequeño

Añade nuevos sistemas de seguridad



# El Advanced Heavy Water Reactor

Diseñado por la empresa india BARC

Similar en diseño al CANDU

Con tubos verticales

Tiene un depósito de agua en la parte superior

Usa torio como combustible

Más abundante que el uranio

