2. generációs nyomottvizes blokkok technológiája

Korszerű nukleáris energiatermelés

Dr. Yamaji Bogdán
Budapesti Műszaki és Gazdaságtudományi Egyetem
Nukleáris Technikai Intézet

Világ atomerőművi blokkjai

- Üzemelő

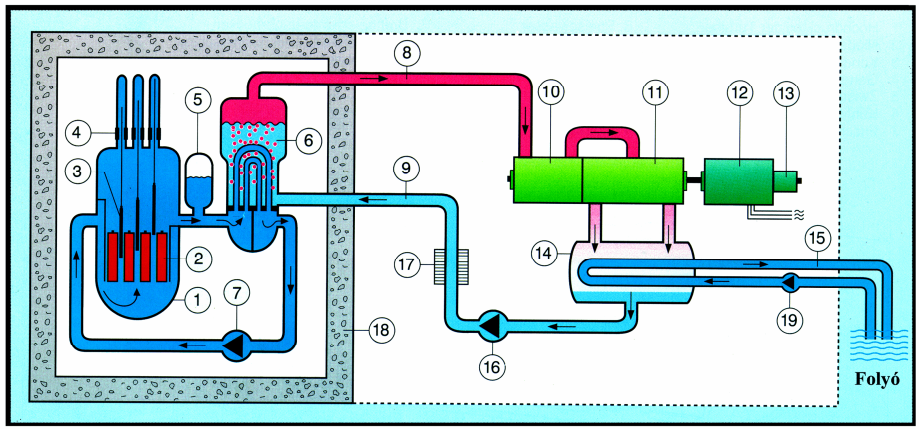
Típus	Blokkok száma	Össz MW(e)
BWR	70	69 713
FBR	3	1400
GCR	14	7725
LWGR	13	9283
PHWR	49	24 557
PWR	**300**	**286 209**
Összesen:	**449**	**398 887**

- Épülő

Típus	Blokkok száma	Össz MW(e)
BWR	4	5253
FBR	1	470
HTGR	1	200
PHWR	4	2520
PWR	**42**	**44 216**
Összesen:	**52**	**52 659**

PRIS database. Last update on 2019-10-27 (https://pris.iaea.org/PRIS/home.aspx)

Nyomottvizes atomreaktor (PWR)



1 Reaktortartály
2 Fűtőelempálcák
3 Szabályozórudak
4 Szabályozórúd hajtás
5 Nyomáskiegyenlítő
6 Gőzfejlesztő
7 Primer köri hűtővíz szivattyú
8 Frissgőz
9 Tápvíz
10 Nagynyomású turbina
11 Kisnyomású turbina
12 Generátor
13 Gerjesztőgép
14 Kondenzátor
15 Kondenzátor hűtővíz
16 Tápvíz szivattyú
17 Előmelegítő
18 Betonvédelem
19 Kondenzátor hűtővíz szivattyú

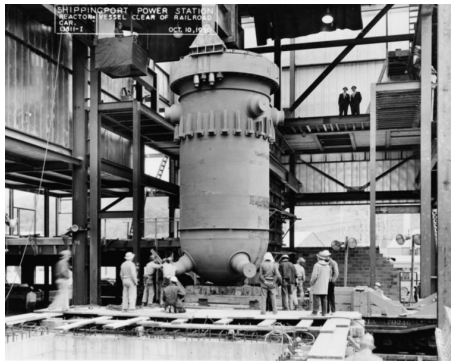
Nyomottvizes atomreaktor (PWR)

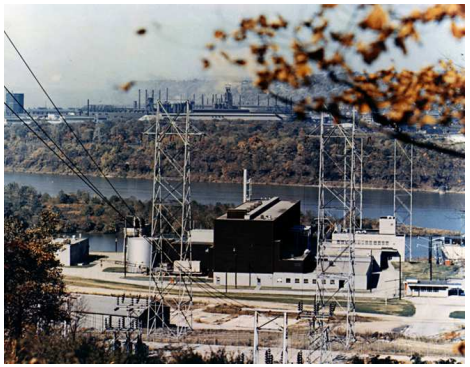
Üzemanyag	UO_2
Az U-235 dúsítása	1.9 % / 2.5% / 3.5 %
Fűtőelemek száma	193
A fűtőelempálcák száma fűtőelemenként	236
Az üzemanyag tömege	103 t
A fűtőelempálcák hossza összesen: aktív rész:	4,83 m 3,90 m
A fűtőelempálcák átmérője	10,75 mm
A szabályozórudak száma	61
Az abszorbens anyaga	In-Ag-Cd
Hűtőközeg és moderátor	desztillált víz
Termikus reaktorteljesítmény	3765 MW
Bruttó elektromos teljesítmény	1395 MW
Nettó elektromos teljesítmény	1 326 MW

Nettó hatásfok	kb. 35,5 %
A kiégetés mértéke	53 000 MWd / t U
Átlagos teljesítménysűrűség a reaktorzónában	93,2 kW / dm^3
A hőátadó felület a reaktorzónában	6 036 m^2
A kondenzátor hűtőfelülete	3*20 781 m^2
A turbina fordulatszáma	1 500 / min
Primer köri belépő hőmérséklet	291.3 °C
Primer köri kilépő hőmérséklet	326.1 °C
Primer köri víznyomás	157 bar
Gőzforgalom	67680 t/h
Göznyomás	66 bar
Gőzhőmérséklet	285 °C
Tápvíz hőmérséklet	218 °C

Első generációs atomerőművek

- Shippingport – az USA első kereskedelmi atomerőműve
- 60 MW elektromos teljesítmény
- Nyomottvizes reaktorral (PWR)
- 1957-1982 között üzemelt





Első generációs atomerőművek

(*)

- Shippingport

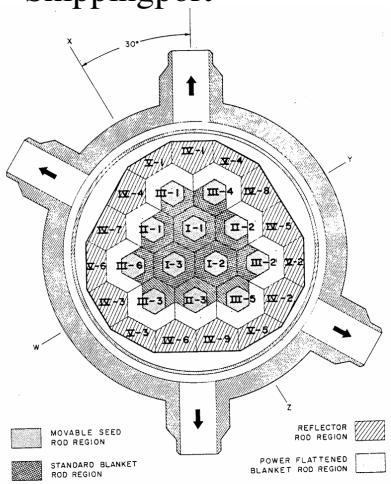


Figure 2-3. Light Water Breeder Reactor cross-section module identification (Sarber 1976, WAPD-TM-1336).

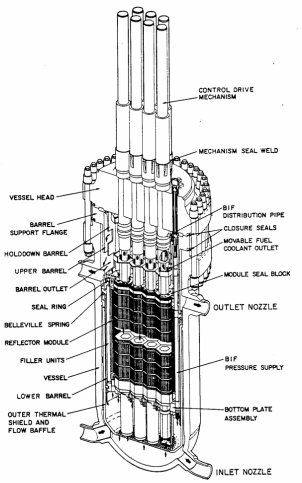
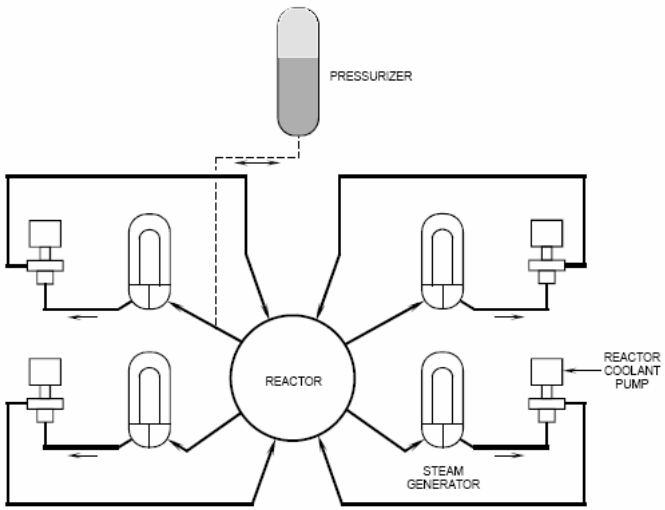


Figure 2-2. Light Water Breeder Reactor core in Shippingport Reactor Vessel (Connors et al. 1979, WAPD-TM-1208).

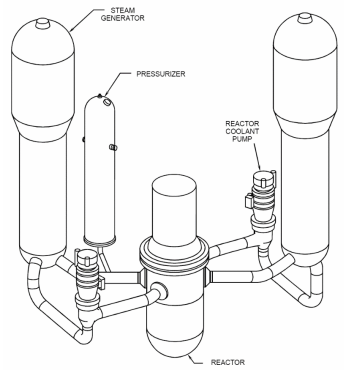
INEEL, Fuel Summary report: Shippingport Light Water Breeder Reactor, Sept 2002, INEELIEXT-98-00799
http://pbadupws.nrc.gov/docs/ML0923/ML092310709.pdf

Primer kör



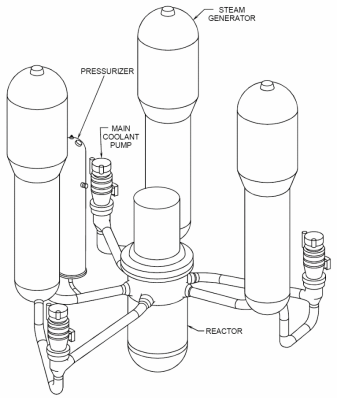
https://www.nrc.gov/reading-rm/basic-ref/students/for-educators/04.pdf

Primer kör, nyugati PWR (USA)



Kéthurkos Westinghouse

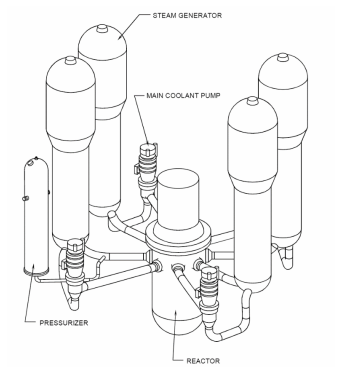
(pl. Point Beach 1, 2, Prairie Island 1, 2)
~500 MWe, 1 GF, 1 FKSZ/hurok
121 db 14x14 üzemanyag
reaktor $D_{belső}$= 132 in (335,3 cm)

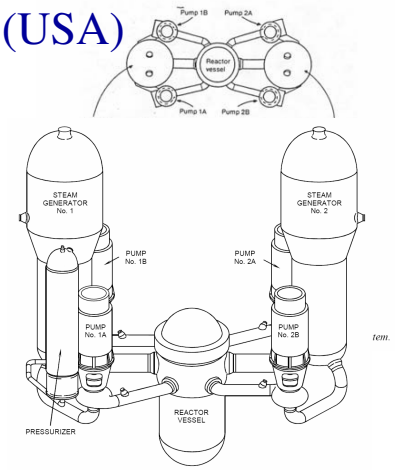


Háromhurkos Westinghouse

(pl. Beaver Valley 1, 2, North Anna 1, 2)
700-900 MWe, 1 GF, 1 FKSZ/hurok
157 db 15x15/17x17 üzemanyag
reaktor $D_{belső}$= 156-159 in /172 in/
(396,2-403,9 cm /436,9 cm/)

Primer kör, nyugati PWR (USA)





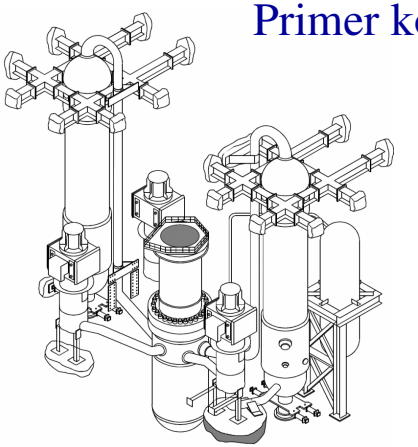
Négyhurkos Westinghouse

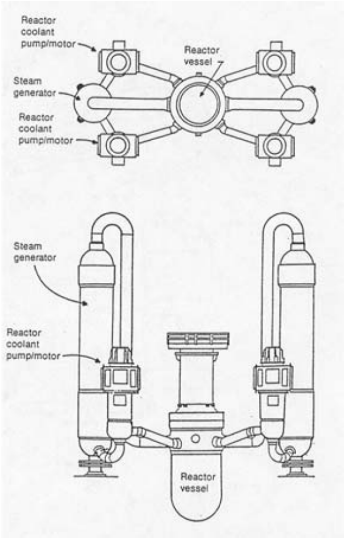
(pl. Byron 1, 2, STP 1, 2)
950-1250 MWe, 1 GF, 1 FKSZ/hurok
193 db 17x17 (15x15) üzemanyag
reaktor $D_{belső}$= 173 in /167 in (439,4 cm/424,2 cm)

Kéthurkos Combustion Engineering

(pl. Palo Verde 1, 2, Saint Lucie 1, 2)
<500 – 1200< MWe
2 hurok: 1 GF, 2 FKSZ/hurok

Primer kör, nyugati PWR (USA)





Kéthurkos Babcock & Wilcox

(pl. Davis Besse, TMI 1)
177 db üa. kazetta
850 MWe
2 hurok: 1 GF, 2 FKSZ/hurok

IG. 2-1. Schematic of a Babcock and Wilcox PWR reactor coolant system.

Primer kör, nyugati PWR (USA)

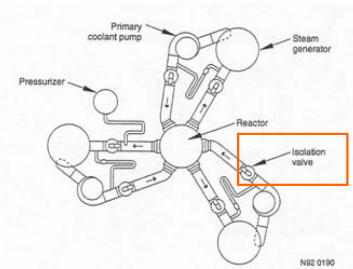


FIG. 2-3. Plan view of a combustion engineering three-loop reactor coolant system with an isolation valve.

- Főelzáró tolózár (FET)!

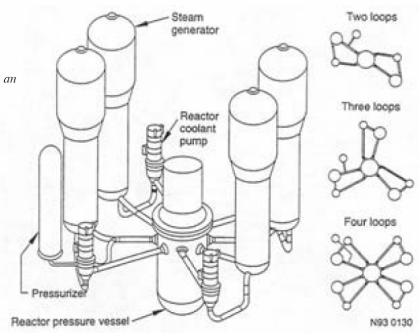


FIG. 2-4. Schematic of a Westinghouse PWR reactor coolant system.

Primer kör, nyugati PWR (USA) (*)

	Babcock & Wilcox		Combustion Engineering		Westinghouse (négyhurkos)	
Vezetékek	belső átmérő [mm]	falvastagság [mm]	belső átmérő [mm]	falvastagság [mm]	belső átmérő [mm]	falvastagság [mm]
Melegág	914,4	95,25	1066,8	95-104,7	743	59,2-63,5
Hidegág	711,2	63,5	762	63,5-80,16	698,5	56,1-65
Vízzár					310	63-73,1

Primer kör, nyugati PWR (Franciaország)

Framatome/Areva

900 MWe sorozat
- 910-960 MWe
- 3 hurok, 3 FKSZ,
- 157 üa. kazetta

1300 MWe sorozat
- 1362, 1382 MWe
- 4 hurok, 4 FKSZ,
- 193 üa. kazetta

1400 MWe – N4 – sorozat
- 1560 MWe
- 4 GF, 4 FKSZ
- 205 üa. kazetta

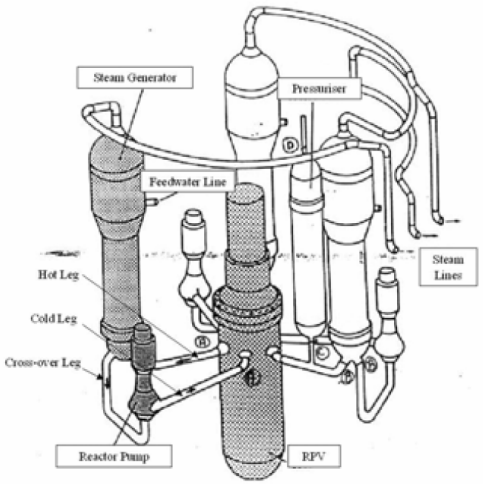


FIG. 2-20. Sketch of a typical French PWR reactor coolant loop.

Primer kör, nyugati PWR (Németország)

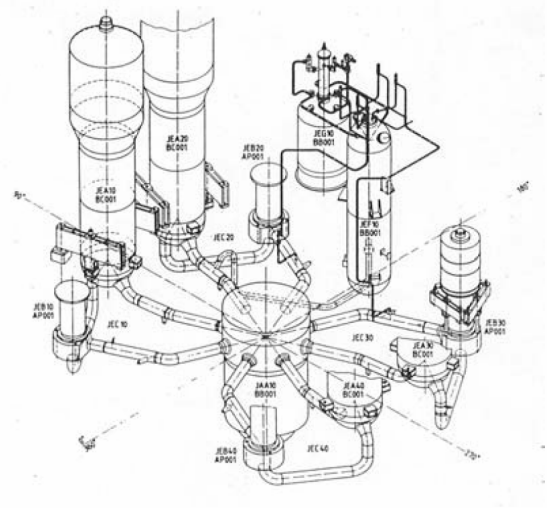


FIG. 2-26. Schematic of a typical German PWR primary coolant system.

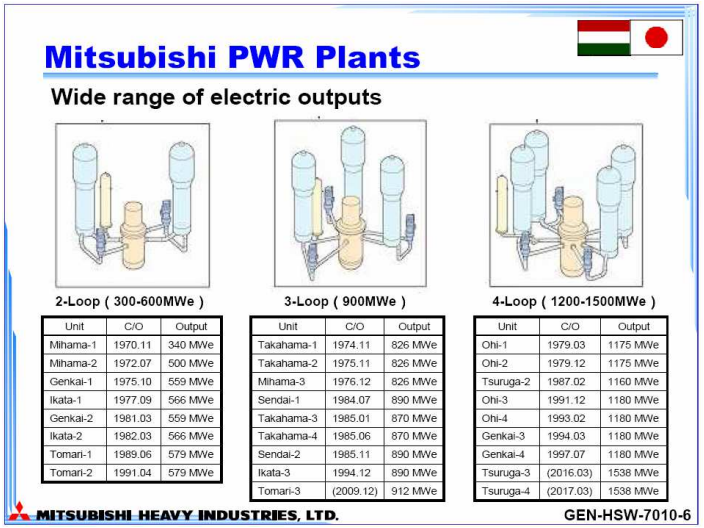
Primer kör, nyugati PWR (Japán)

MHI

600 MWe sorozat
- 2 hurok
- 121 üa. kazetta

900 MWe sorozat
- 3 hurok
- 157 üa. kazetta

1200 MWe sorozat
- 4 hurok
- 193 üa. kazetta



Mitsubishi PWR Plants

Wide range of electric outputs

2-Loop (300-600MWe)

Unit	C/O	Output
Mihama-1	1970.11	340 MWe
Mihama-2	1972.07	500 MWe
Genkai-1	1975.10	559 MWe
Ikata-1	1977.09	566 MWe
Genkai-2	1981.03	559 MWe
Ikata-2	1982.03	566 MWe
Tomari-1	1989.06	579 MWe
Tomari-2	1991.04	579 MWe

3-Loop (900MWe)

Unit	C/O	Output
Takahama-1	1974.11	826 MWe
Takahama-2	1975.11	826 MWe
Mihama-3	1976.12	826 MWe
Sendai-1	1984.07	890 MWe
Takahama-3	1985.01	870 MWe
Takahama-4	1985.06	870 MWe
Sendai-2	1985.11	890 MWe
Ikata-3	1994.12	890 MWe
Tomari-3	(2009.12)	912 MWe

4-Loop (1200-1500MWe)

Unit	C/O	Output
Ohi-1	1979.03	1175 MWe
Ohi-2	1979.12	1175 MWe
Tsuruga-2	1987.02	1160 MWe
Ohi-3	1991.12	1180 MWe
Ohi-4	1993.02	1180 MWe
Genkai-3	1994.03	1180 MWe
Genkai-4	1997.07	1180 MWe
Tsuruga-3	(2016.03)	1538 MWe
Tsuruga-4	(2017.03)	1538 MWe

MITSUBISHI HEAVY INDUSTRIES, LTD. GEN-HSW-7010-6

Primer kör, VVER-440

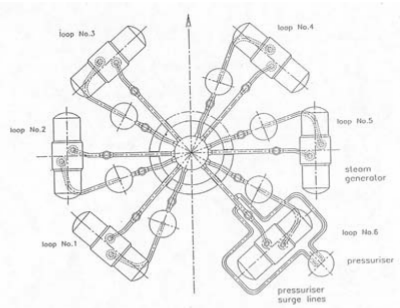


FIG. 2-29. Schematic view on the primary system layout of a WWER 440, Model 230 reactor.

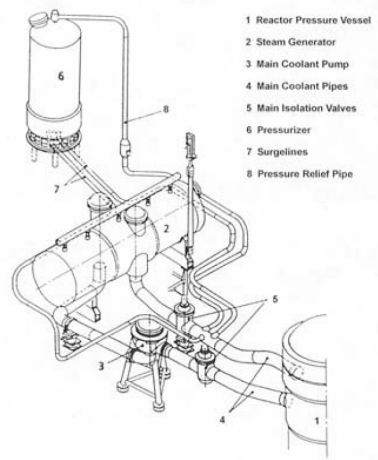


FIG. 2-30(a). Typical reactor coolant loop for a WWER 440, Model 230 plant.

Primer kör, VVER-440

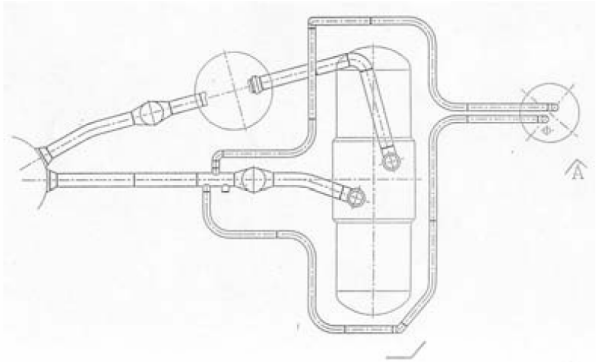


FIG. 2-30(b). Top view of a WWER 440, Model 230, reactor coolant loop with pressurizer surge lines.

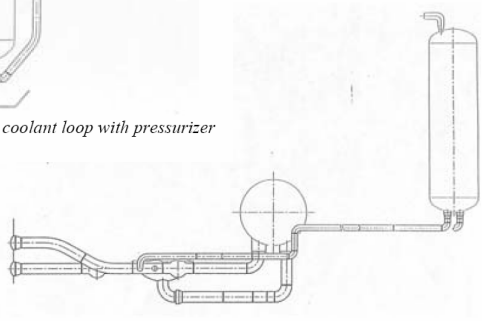


FIG. 2-30(c). Side view of a WWER 440, Model 230, pressurizer surge lines.

Primer kör, VVER-440

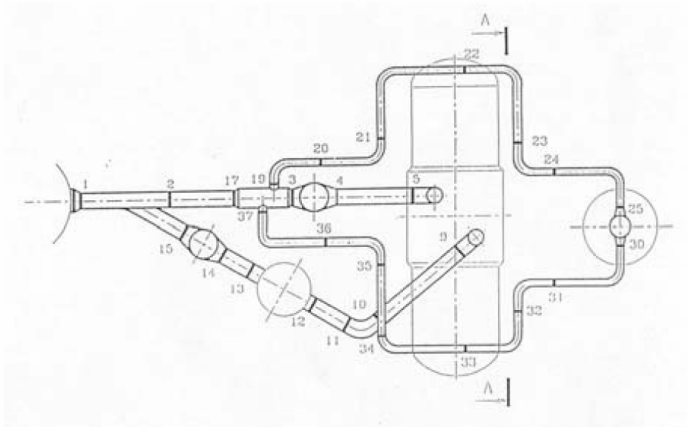
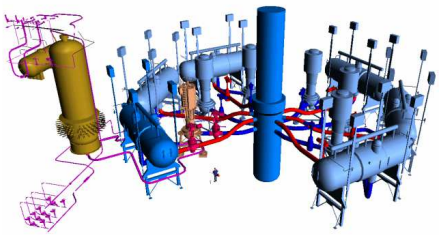
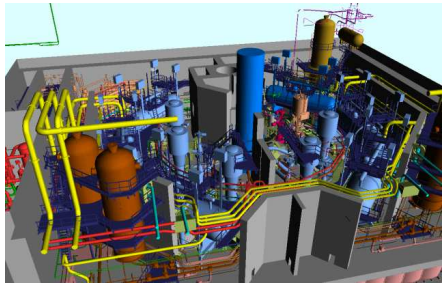
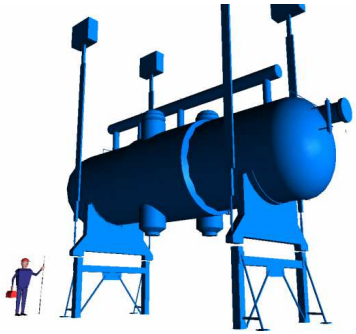


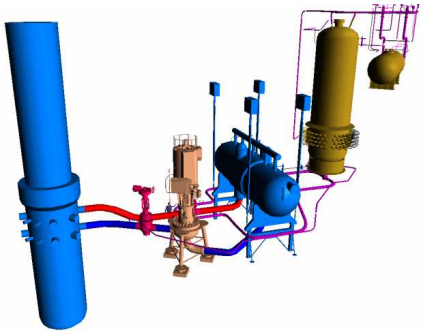
FIG. 2-33(a). Top view of a WWER 440, Model 213, reactor coolant loop with pressurizer surge lines.

Primer kör, VVER-440, Paks









Primer kör, VVER-1000

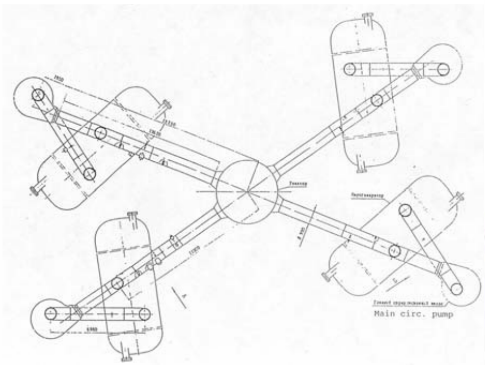


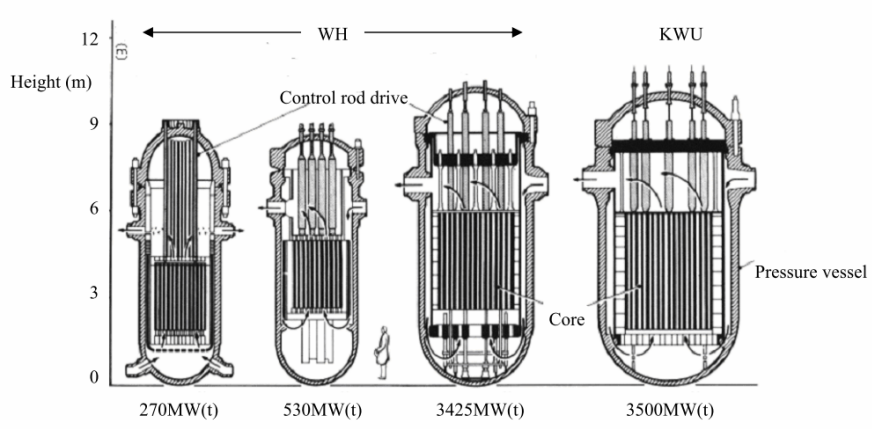
FIG. 2-35. Schematic of a typical primary coolant loop for WWER 1000, Model 320 reactor.

Primer kör, európai

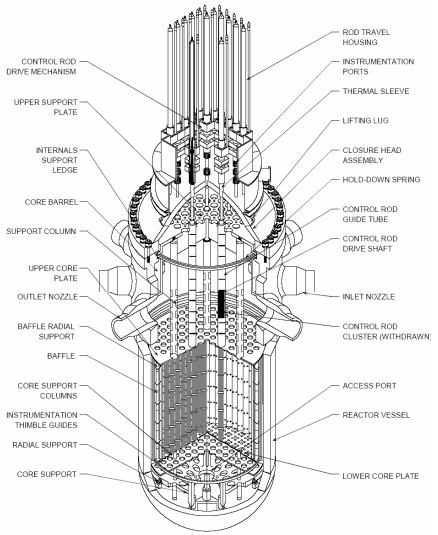
	Framatome		Siemens		VVER-440/230	
Vezetékek	belső átmérő [mm]	falvastagság [mm]	belső átmérő [mm]	falvastagság [mm]	belső átmérő [mm]	falvastagság [mm]
Melegág	740	72-78	780	40-57	500	32
Hidegág	700	68	780	40-57	500	32
Vízzár	780	78	780	40-57	500	32

Reaktortartály

(*)



Reaktortartály



Cutaway View of Reactor Vessel

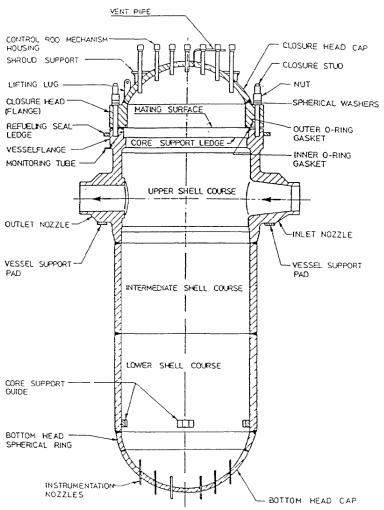


FIG. 1 A typical Westinghouse reactor pressure vessel

Reaktortartály

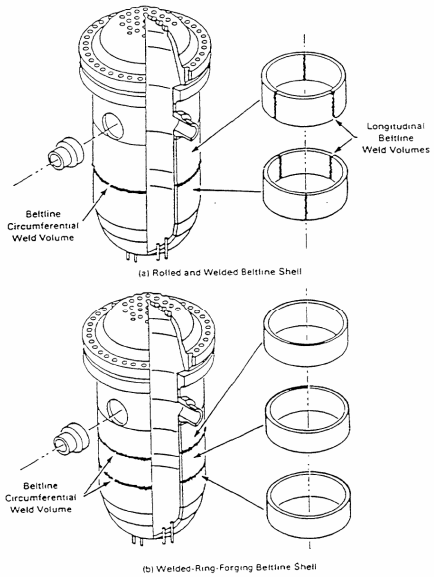


FIG. 9. Fabrication configuration of PWR beltline shells

Reaktortartály

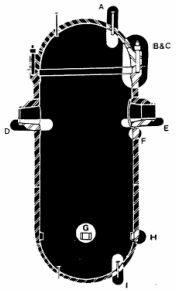


FIG. 13. Regions of a RPV to be analysed in order to determine compliance with the ASME Code.

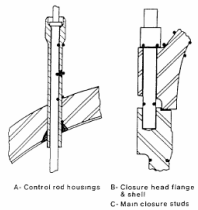


FIG 14 Typical control rod housing and closure head flange, shell and studs locations to be evaluated on an ASME stress analysis

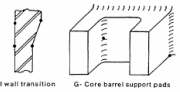


FIG. 16. A typical vessel wall transition and core barrel support pad locations to be analysed in order to determine compliance with the ASME Code.

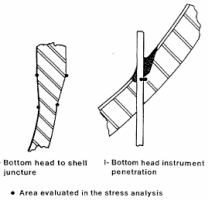


FIG. 17. Typical bottom head to shell juncture and bottom head instrument penetration locations to be analysed in order to determine compliance with the ASME Code.

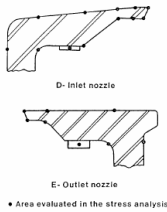


FIG 15 Typical inlet and outlet nozzle locations to be analysed in order to determine compliance with the ASME Code

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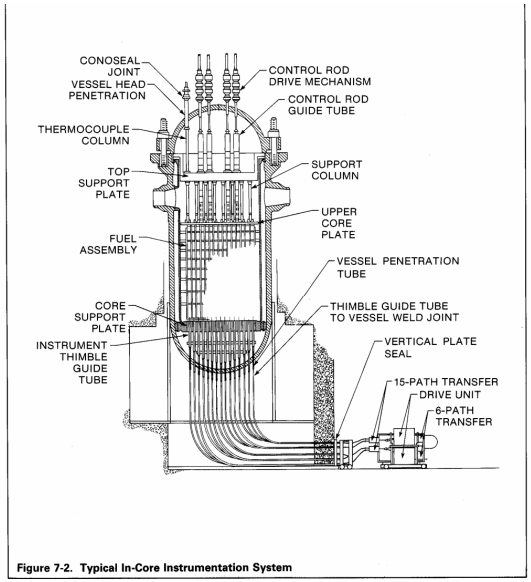

Figure 7-2. Typical In-Core Instrumentation System

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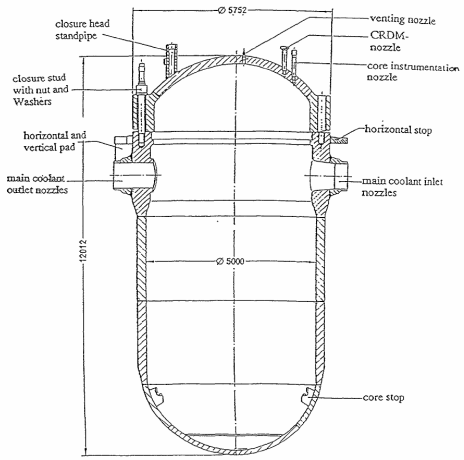

FIG 4. A typical Siemens/KWU reactor pressure vessel for a 1300 MWe plant.

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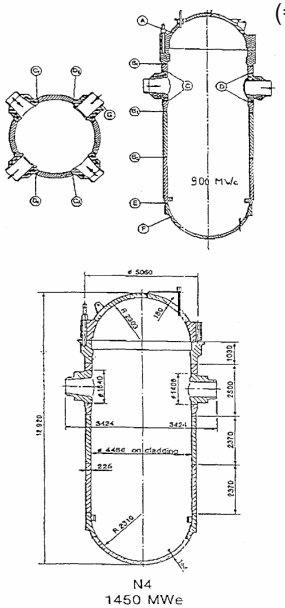

FIG. 5. Sketchs of French 3- and 4-loop RPVs; typical dimensions.

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- Csonk kialakítások

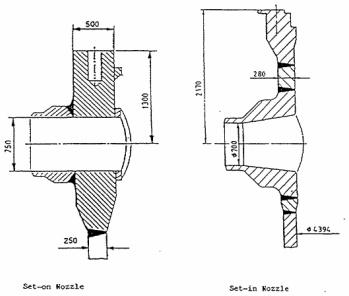

FIG. 2. Sketches of typical set-on and set-in nozzles used in reactor pressure vessels.

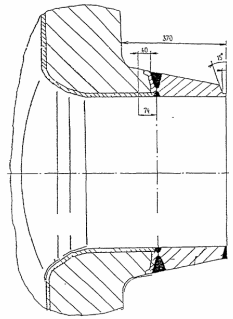

FIG. 7. Sketch of a typical forged and machined WWER-440 pressure vessel nozzle.

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- Tartályfedél

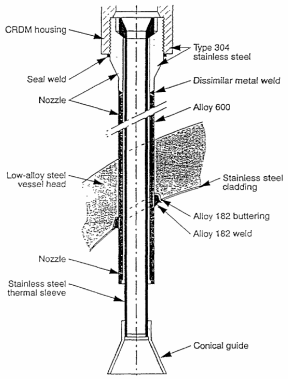

FIG. 26. Typical control rod drive mechanism penetration in a Westinghouse-type PWR (Buisine et al. 1994). Copyright the Minerals, Metals & Materials Society; reprinted with permission

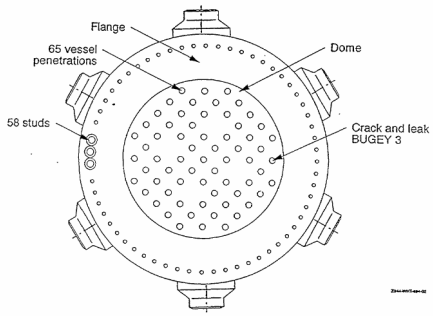

FIG. 27. Plan view of the PWR pressure vessel head (Buisine et al. 1994). Copyright the Minerals, Metals & Materials Society; reprinted with permission.

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- Példa 1: bórsavlerakódás a tartályfedélen
  - 1987, Turkey Point 4: mintegy 230 kg bórsavkristályt találtak a tartályfedélen, valamint az SZBV hajtások hűtésének csöveiben
  - az egyik átvezetés csövének szigetelése eresztett, ezt egy évvel korábbi karbantartás során felfedezték, mértékét „nem jelentős”-nek értékelték
  - a szivárgó primer hűtőközeg roncsolta a tartályfedelet
  - 58 fedélcsatlakozás elkorrodálódott
  - az SZBV hajtások csöveiben kondenzálódott a bóros víz

Reaktortartály

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- Példa 2: tartályfedél roncsolódás
  - 2002, Davis Besse: leállás ÜA átrakásra és karbantartásra
  - három SZBV hajtás átvezetés csőcsonkjában axiális törés nyomait fedezik fel, a fedél közepe környékén
  - miközben megpróbálták a csonkokat javítani és a hiba okát felderíteni, az egyik ilyen megbillent (eltörött), és a szomszédos csonkra dőlt. Amennyiben a csonk nem lett volna sérült (törött), ez nem történhetett volna meg.

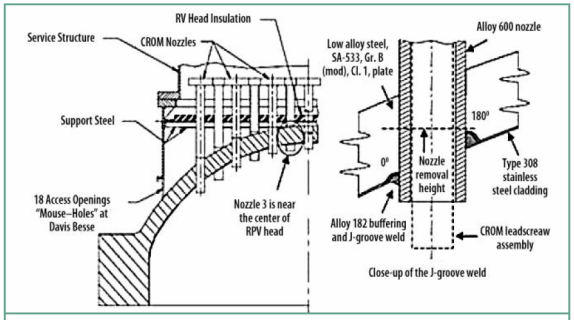

Figure 1b. Detail of vessel head penetration nozzles

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- Példa 2: tartályfedél roncsolódás
  - ebben az esetben is jelentős bórsavlerakódást találtak a fedélen,
  - valamint észlelték, hogy a tartályfedél jelentősen roncsolódott az érintett SZBV csonk környékén
  - a korróziós roncsolódás oka a szivárgó bóros (primer) víz volt
  - A tartályfedél vastagsága az üregben 3/8 in volt. A rozsdamentes acél réteg (a tartály belső felületén) névleges vastagsága: 3/8 in. (!!)
  - A rozsdamentes acél ellenáll a bórsav korrozív hatásának, de nem a strukturális integritás megőrzésére tervezték
  - Potenciálisan LOCÁ-hoz vezető állapot

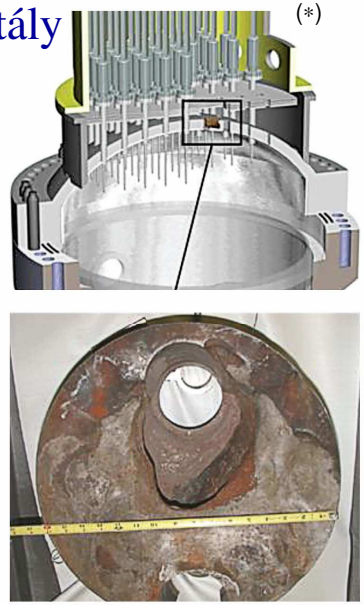

Figure 2. Region of the vessel head depicted by the model and photo of the cavity after it was removed from the vessel head

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- Példa 2: tartályfedél roncsolódás
  - az NRC nem engedélyezte a reaktor újraindítását (2002)
  - a hatósági vizsgálat megállapította, hogy az ilyen mértékű roncsolódás megelőzhető lett volna
  - a Davis Besse atomerőműben (többek között) azért nem észlelték a szivárgást, mert a lerakódott bórsav eltömítette a szivárgást figyelő detektorok szűrőit is
  - a tartályfedelet kicserélték
  - módosításokat végeztek a fedél átvezetés csonkok mintegy harmadán
  - módosítottak az üzemeltetési gyakorlaton is a korróziós-eróziós folyamatok elkerülése érdekében

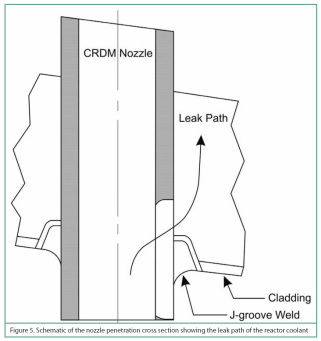

Figure 5. Schematic of the nozzle penetration cross section showing the leak path of the reactor coolant

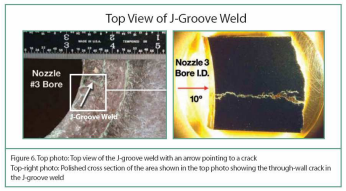

Figure 6. Top photo: Top view of the J-groove weld with an arrow pointing to a crack
Top-right photo: Polished cross section of the area shown in the top photo showing the through-wall crack in the J-groove weld

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- Példa 2: tartályfedél roncsolódás

Figure 3a. RPV head flange area showing significant amounts of boric acid deposits (photo taken during the 2000 refueling outage at DBNPS)

Figure 3b. Boric acid deposits accumulating near a CRDM nozzle (still photo of video taken during the 2000 refueling outage at DBNPS)

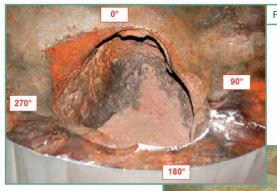

Figure 4a. Close-up view of the cavity

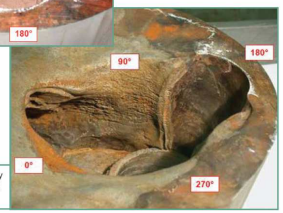

Figure 4b. Oblique view of the cavity partially showing the J-groove weld at the bottom of the cavity

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TABLE I. WESTERN REACTOR PRESSURE VESSEL DESIGN PARAMETERS

	French 4-loop N4 type plants	German Konvoi design values	Westinghouse 4-loop plant
Thermal power (MWth)	4270	3765	3411
Electric output (MWe)	1475	> 1300	1125
Number of loops	4	4	4
Type of fuel assembly	17 × 17	18 × 18–24	17 × 17
Active length (mm)	4270	3900	366 cm
Core diameter (mm)	4490	3910	337 cm
Water gap width* (mm)	424	545	51.2 cm
Linear heating rate (W/cm)	179	166.7	183
Number of control rods	73	61	53
Total flow rate (m^3/h)	98 000	67 680	86 800
Vessel outlet temperature (°C)	329.5	326.1	325.5
Outlet/inlet temperature difference (°C)	37.5	34.8	33.0
Specified RT_{NDT} at 30 L		–12°C	
ΔT_{41} at EOL (based on design values)	–	23°C	–

*Distance from the outer fuel element and the RPV inner surface.

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TABLE III CHEMICAL REQUIREMENTS (HEAT ANALYSIS) MAIN FERRITIC MATERIALS FOR REACTOR COMPONENTS IN WESTERN COUNTRIES

Designation	Elements (weight %)												
	C	Si	Mn	P_{max}	S_{max}	Cr	Mo	Ni	V_{max}	Cu_{max}	Al	Sn	N2	As
ASTM A 302B		0 15	1 15				0 45							
	0 25	0 30	1 50	0 035	0 040		0 60							
ASTM A 336, Code Case 1236	0 19	0 15	1 10				0 50	0 40						
	0 25	0 35	1 30	0 035	0 035	0 35	0 60	0 50						
ASME A 508 cl 2 (1971)		0 15	0 50			0 25	0 55	0 50						
	0 27	0 35	0 90	0 025	0 025	0 45	0 70	0 90	0 05					
ASME A 533 gr B (1971)		0 15	1 15				0 45	0 40						
	0 25	0 30	1 50	0 035	0 040		0 60	0 70						
ASME A 508 cl 2 (1989)[1]		0 15	0 50			0 25	0 55	0 50						
	0 27	0 40	1 00	0 015	0 015	0 45	0 70	1 00	0 05	0 15				
ASME A 508 cl 3 (1989)[1]		0 15	1 20				0 45	0 40						
	0 25	0 40	1 50	0 015	0 015	0 25	0 60	1 00	0 05					
ASME A 533 gr B (1989)		0 15	1 15				0 45	0 40						
	0 25	0 40	1 50	0 035	0 040		0 60	0 70						
16 MnD5 RCC M 2111[2]		0 10	1 15				0 43	0 50	0 01	0 20	0 040			
	0 22	0 30	1 60	0 02	0 012	0 25	0 57	0 80						
18 MnD5 RCC M 2112 (1988)		0 10	1 15				0 45	0 50						
	0 20	0 30	1 55	0 015	0 012	0 25	0 55	0 80	0 01	0 20	0 040			
20 Mn Mo Ni 5 5 (1983, 1990)[3] [3]	0 17	0 15	1 20				0 40	0 50			0 010			
	0 23	0 30	1 50	0 012	0 008	0 20	0 55	0 80	0 02	0 12[4]	0 040	0 011	0 013	0 036
22 Ni Mo Cr 3 7 (1991)[6]	0 17	0 15	0 50			0 25		0 60			0 010			
	0 23	0 35	1 00	0 012	0 008	0 50	0 60	1 20[7]	0 02	0 12[4]	0 050	0 011	0 013	0 036

[1] Supplementary Requirement S 9 1(2) and S 9 2 for A 508 cl 2 and 508 cl 3
[2] Forgings for reactor shells outside core region Restrictions for Core Region (RCC M 2111) S ≤0 008, P ≤0 008, Cu ≤0 08
[3] Vdl UV Material Specification 401, Issue 1983
[4] KTA 3201 1 Appendix A Issue 6/90
[5] Cu content for RPV (Core Region) shall be <0 10%
[6] According Siemens/KWU under consideration of SR 10 (MPa Stuttgart)
[7] For flanges and tube sheets the Ni content shall be ≤1 40%

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TABLE IV. MATERIALS SPECIFIED FOR PWR VESSEL COMPONENTS

Plants in the USA:

Closure head dome	Closure head flange	Lifting lugs	Shroud support ring	Closure head stud assembly	Vessel flange	Shells	Bottom head	Nozzles	CRDM housings	Stainless steel cladding	Leakage monitoring tubes	Core support pads (lugs)	Instrumentation tubes/ penetrations	Refueling seal ledge
SA302 GR B	SA336	SA302 GR B	SA212 GR B	SA320 L43	SA336	SA302 GR B	SA302 GR B	SA302 GR B	SA182 TYPES 304, 316	TYPE 308L, 309L	SA312 TYPE 316	SB166	SB166	SA212 GR B
SA533 GR B Class 1	SA508 Class 2 SA508 Class 3	SA533 GR B Class 1	SA516 GR 70	SA540 B23, B24	SA508	SA533 GR B Class 1	SA533 GR B Class 1	SA533 GR B Class 1	SB166	TYPE 304	SB166	SB167	SB167	SA516 GR 70
				SA320 L43 Class 3		SA336		SA336			SB167			SA533
						SA508 Class 2 SA508 Class 3		SA508 Class 2 SA508 Class 3						

French 4-loop N4 plants.

Shells, flanges, heads, nozzles	16MnD5
Safe ends, adapter flanges	Z2CND18-12
Adapter sleeves, instrumentation penetrations	NC15Fe/NC30Fe
Studs, nuts, washers	40NCDV7 03
Internal supports	NC15Fe

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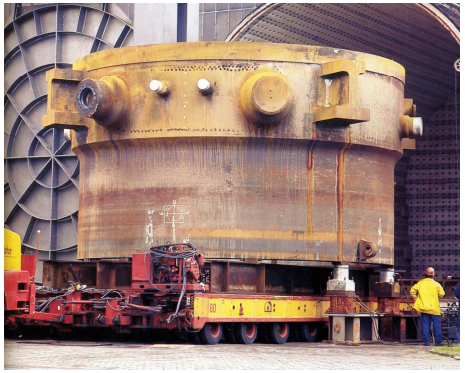

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A Biblis A reaktortartálya

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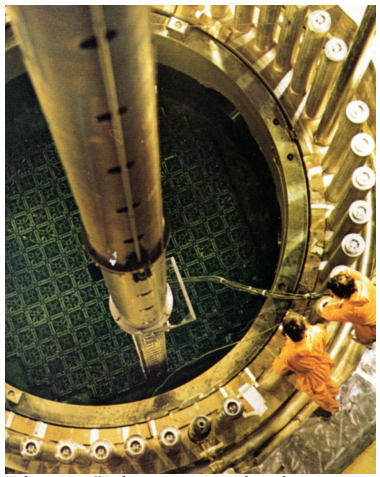
Felső csőblokk behelyezése a reaktortartálya



Zóna betöltése a melegjáratási próbák után

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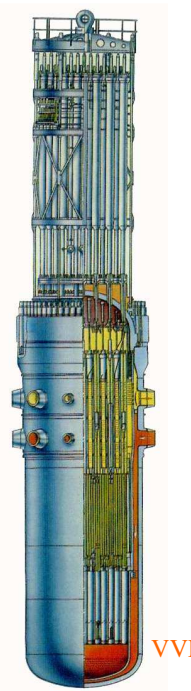


VVER-440

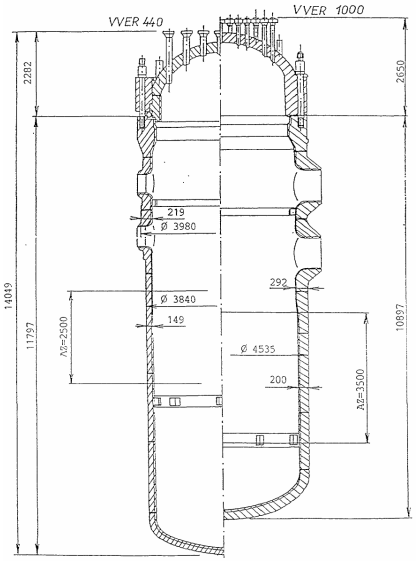
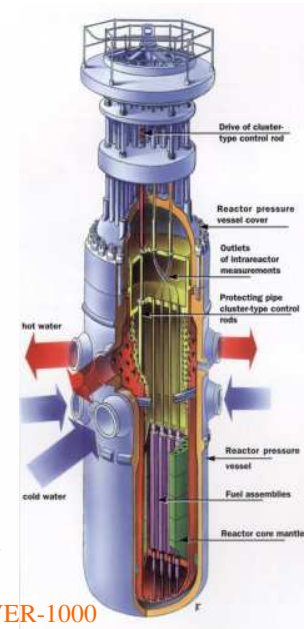


FIG. 6. WWER reactor pressure vessels (split diagram).



VVER-1000

Reaktortartály, VVER

TABLE IIa. WWER REACTOR PRESSURE VESSEL DESIGN PARAMETERS

Reactor	WWER-440		WWER-1000
	V-230	V-213	V-320
mass [t]	215		320
length [m]	11.800		11.000
outer diameter [m]:			
- in cylindrical part	3.840		4.535
- in nozzle ring	3.980		4.660
wall thickness (without cladding) [m]:			
- in cylindrical part	0.140		0.193
- in nozzle ring	0.190		0.285
number of nozzles	2×6 (1)	2×6 (1) + 2×3 (2)	2×4 (1) + 3 (2)
working pressure [MPa]	12.26		17.65
design pressure [MPa]	13.7		19.7
hydrotest pressure [MPa]	17.1	19.2(3)	24.6
Operating wall temperature [°C]	265		288
design wall temperature [°C]	325		350
vessel lifetime [year]	30	40	40
neutron fluence during design lifetime [n/m^2] (E_n greater 0.5 MeV)(4):			
- base metal	1.6×10^{24}	2.6×10^{24}	6.3×10^{23}
- weld metal	1.3×10^{24}	1.8×10^{24}	5.7×10^{23}
cover mass [t]	50		90
number of penetrations	37 + 18		61 + 30

(1) Primary nozzle.
(2) Emergency core cooling system (ECCS) nozzle.
(3) Test pressure has been recently decreased to 17.2 MPa in Hungary, the Czech Republic and Slovakia.
(4) The fast fluence at energies greater than 0.5 MeV is about 1.67 times the fast fluence at energies greater than 1.0 MeV.

Reaktortartály, VVER

(*)

TABLE VI. CHEMICAL COMPOSITION OF WWER REACTOR PRESSURE VESSEL MATERIALS (weight %)

MATERIAL	C	Mn	Si	P	S	Cr	Ni	Mo	V
15Kh2MFA	0.13 0.18	0.30 0.60	0.17 0.37	max 0.025	max 0.025	2.50 3.00	max 0.40	0.60 0.80	0.25 0.35
18Kh2MFA	0.15 0.21	0.30 0.60	0.17 0.37	max 0.025	max 0.025	2.50 3.00	max 0.40	0.60 0.80	0.25 0.35
25Kh3MFA	0.22 0.25	0.30 0.60	0.17 0.37	max 0.025	max 0.025	2.803.30	max 0.40	0.60 0.80	0.25 0.35
15Kh2NMFA	0.13 0.18	0.30 0.60	0.17 0.37	max 0.020	max 0.020	1.80 2.30	1.00 1.50	0.50 0.70	max 0.10
Sv-10KhMFT + AN-42	0.04 0.12	0.60 1.30	0.20 0.60	max. 0.042	max 0.035	1.20 1.80	max 0.30	0.35 0.70	0.10 0.35
Sv-10KhMFT + AN-42M	0.04 0.12	0.60 1.30	0.20 0.60	max 0.012	max 0.015	1.20 1.80	max 0.30	0.35 0.70	0.10 0.35
Sv-12Kh2N2MA + FC-16	0.05 0.12	0.50 1.00	0.15 0.45	max 0.025	max 0.020	1.402.10	1.20 1.90	0.45 0.75	–
Sv-12Kh2N2MA + FC-16A	0.05 0.12	0.50 1.00	0.15 0.45	max 0.012	max 0.015	1.40 2.10	1.20 1.90	0.45 0.75	–
Sv-13Kh2MFT + OF-6	0.11 0.16	0.40 0.70	0.17 0.35	max 0.030	max 0.030	1.40 2.50	–	0.40 0.80	0.17 0.37

Reaktortartályon belüli elemek

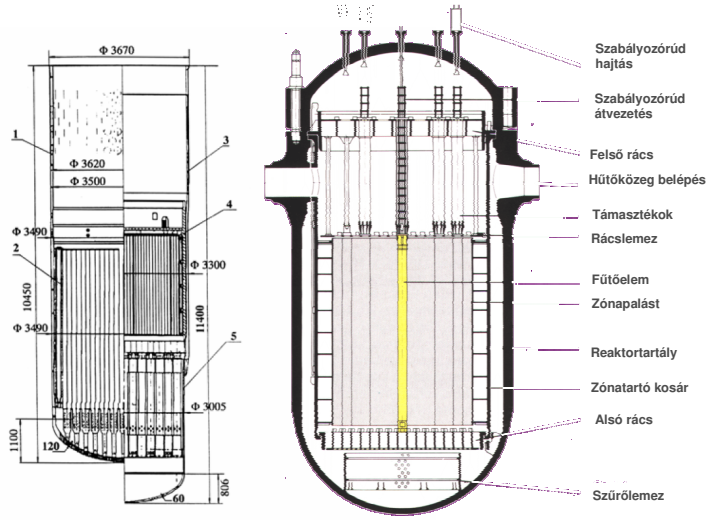


FIG.4. WWER-1000 (left half) and WWER-440 (right half) split RVI view. Number 1 designates the core barrel, number 2 the core shroud, number 3 the thermal shield, number 4 the core barrel and number 5 the lower core barrel.

Reaktortartályon belüli elemek

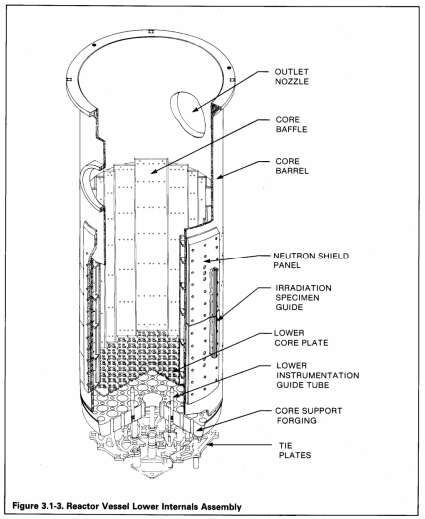


Figure 3.1-3. Reactor Vessel Lower Internals Assembly

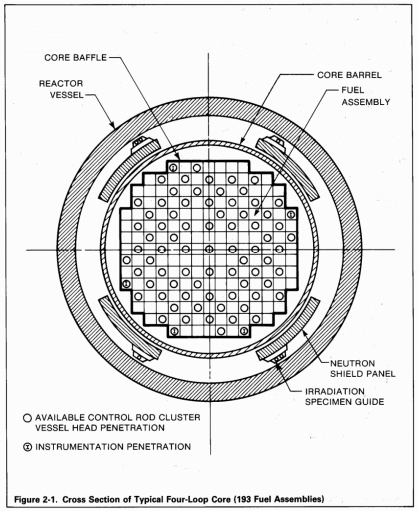
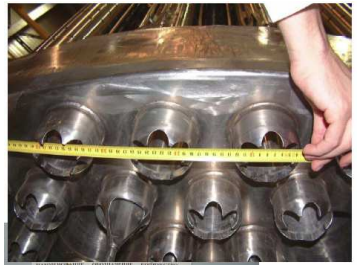


Figure 2-1. Cross Section of Typical Four-Loop Core (193 Fuel Assemblies)

Reaktortartály, belső elemek - Paks

Reaktortartály, belső elemek - Paks



Reaktortartályon belüli elemek (*)

TABLE I. TYPICAL RVI MATERIALS

Component	Standards and specifications		
	US type reactors (ASTM, ASME)	French type reactors (RCC-M, AFNOR)	German type reactors (KTA 3204)
Upper support forging	SA-182 Grade F304	Z2CN 18-10 N controlled (M 3302)	X6CrNiNb18-10 (1.4550)
Hold down spring	SA-182 Grade F403 (mod) or SA-182, Grade F304	Z2CN 18-10 N controlled (M 3301)	Inconnel X-750
Core barrel nozzles	SA-182, Grade F304	Z2CN 18-10 N controlled (M 3301)	X6CrNiNb18-10 (1.4550)
Lower support forging	SA-182, Grade F304	Z2CN 18-10 N controlled (M 3302)	X6CrNiNb18-10 (1.4550)
Radial keys	SA-182, Grade F304	Z2CN 18-10 N controlled (M 3301)	X6CrNiNb18-10 (1.4550)
Radial keys/hard facing	SA-182, Grade F304/Stellite	Z2CN 18-10 N controlled (M 3301)	Alloy 600/Stellite 6 or 1.4550 hard faced
Core barrel	SA-240, Type 304	Z2CN 18-10 N controlled (M 3310)	X6CrNiNb18-10 (1.4550)
Baffles & formers	SA-240, Type 304	Z2CN 18-10 N controlled (M 3310)	X6CrNiNb18-10 (1.4550)
Lower core plate	SA-240, Type 304	Z2CN 18-10 N controlled (M 3310)	X6CrNiNb18-10 (1.4550)
Neutron panels/thermal shield	SA-240, Type 304	Z2CN 18-10 N controlled (M 3310)	X6CrNiNb18-10 (1.4550)
BMI tie plates	SA-240, Type 304	Z2CN 18-10 N controlled (M 3310)	–
Flow distribution plate	–	–	X6CrNiNb18-10 (1.4550)
Upper support column	SA-479, Type 304	Z2CN 18-10 N controlled (M 3301)	X6CrNiNb18-10 Tube (1.4550)
Ucp alignment pins/hardfacing	SA-479, Type 304 / Stellite	Z2CN 18-10 N controlled (M 3301)	X6CrNiMoTi 17-12-3 (1.4571) hard faced
Guide tube cards	SA-479, Type 304	Z2CN 18-10 N controlled (M 3302)	–
Irradiation specimen guide	SA-479, Type 304	Z2CN 18-10 N controlled (M 3301)	X6CrNiNb18-10 (1.4550)
Head cooling nozzles	SA-479, Type 304	Z2CN 18-10 N controlled (M 3301)	X6CrNiNb18-10 (1.4550)
BMI columns	SA-479, Grade F304	Z2CN 18-10 N controlled (M 3301)	–
Secondary core support	SA-479, Type 304	Z2CN 18-10 N controlled (M 3301)	–
Upper instrumentation column	SA-213, Grade TP304LN	Z2CN 18-10 N controlled (M 3304)	X6CrNiNb18-10 (1.4550)
Upper & lower core plate fuel pins	SA-193, Type 316 (cold worked)	Z6CND17-12 or Z2CND17-12 or Z2CND17-12 N controlled, all cold worked (M330B)	X6CrNiMoTi 17-12-3 (1.4571) cold worked and hard faced Inconel X-750
Upper support column fastener	SA-193, Type 316 (cold worked)	Z6CND17-12 or Z2CND17-12 or Z3CND17-12 N controlled, all cold worked (M330B)	X6CrNiMoTi 17-12-3 cold worked (1.4571)

TABLE I. (cont.)

Component	Standards and specifications		
	US type reactors (ASTM, ASME)	French type reactors (RCC-M, AFNOR)	German type reactors (KTA 3204)
Baffle-barrel-former fastener	SA-193, Type 316 (cold worked)	Z6CND17-12 or Z2CND17-12 or Z3CND17-12 N controlled, all cold worked (M330B)	X6CrNiMoTi 17-12-2 cold worked (1.4571)
Neutron panel bolts	SA-193, Type 316 (cold worked)	Z6CND17-12 or Z2CND17-12 or Z2CND17-12 N controlled, all cold worked (M330B)	X6CrNiMoTi 17-12-2 cold worked (1.4571)
Guide tube holddown bolts	SA-193, Type 316 (cold worked)	Z6CND17-12 or Z2CND17-12 or Z2CND17-12 N controlled, all cold worked (M330B)	X6CrNiMoTi 17-12-2 cold worked (1.4571)
BMI bolts	SA-193, Type 316 (cold worked)	Z6CND17-12 or Z2CND17-12 or Z2CND17-12 N controlled, all cold worked (M330B)	–
BMI thimble tubes	SA-213, Type 316 (cold worked), SB-167 (Alloy 600)	NC15Fe Alloy 600 (M 4102)	–
Guide tube support pins & nuts	SA-193, Type 316 (cold worked) or W Spec. A6S7C02 (X-750)	Inconel X 750 (M 4104)	X6CrNiNb18-10 (1.4550) hard faced
Irradiation specimen guide spring	SB-637, UNS N07750 (X-750)	Inconel X 750 (M 4104)	–
Clevis insert fastener	SB-637, UNS N07750 (X-750)	Inconel X 750 (M 4104)	–
Flow mixing device	SA-351 GR CF8	Z3CN20-09M (M 3405)	X6CrNiNb18-10 (1.4550)
Lower support casting	SA-351 GR CF8	Z3CN20-09M (M 3405)	–
Clevis insert hardfacing	SB-166 (Ni-Cr-Fe) Arcasted Stellite	–	–
Weld metal 308 & 308l	ASME SCII Part C SFA 5.9	SFA 5.9 Class ER 308L	SFA 5.9 Class ER 308L

Reaktortartályon belüli elemek (*)

TABLE II. CHEMICAL COMPOSITION OF RVI MATERIALS — AUSTENITIC STAINLESS STEELS

Material	C	Mn	Si	S	P	Ni	Cr	Mo	Nb	Ti	Co	Cu	N	B
SA-182 Grade F 304	≤ 0.08	≤2.0	≤1.0	≤ 0.03	≤0.040	8.0–11.0	18.0–20.0	–	–	–	≤0.05	–	–	
SA-240 Type 304	≤ 0.08	≤2.0	≤0.75	≤0.03	≤0.045	8.0–10.5	18.0–20.0	–	–		≤0.05		≤0.10	
SA-479 Type 304	≤ 0.08	≤2.0	≤1.0	≤0.03	≤0.045	8.0–10.5	18.0–20.0	–	–		≤0.05		≤0.10	
SA-213 Grade TP304LN	≤ 0.035	≤2.0	≤0.75	≤0.03	≤0.040	8.0–11.0	18.0–20.0	–	–		≤0.05		0.10–0.16	
Z2CN 18-10 N controlled (M 3302 – M 3303 –M 3304– M 3307–M 3310) 304L	≤0.035	≤2.0	≤1.0	≤0.03	≤0.040	9.0–10.0	18.5–20.0	–	–	–	≤0.10	≤10 0	≤0.06	≤0.0018
Z2CN 18-10 N controlled (M 3302) 304L	≤0.040	≤2.0	≤1.0	≤0.03	≤0.040	9.0–11.0	18.5–20.0	–	–	–	≤ 0.10	≤10 0	≤0.06	≤0.0018
X6CrNiNb 18-10 (1.4550)	≤0.040	≤2.0	≤1.0	≤0.02	≤0.035	9.0–12.0	17.0–19.0	–	≤ 0.65	–	≤ 0.20	–	≤0.06	
SA-213 Grade TP316 cold worked	≤ 0.08	≤2.0	≤1.0	≤0.03	≤0.040	11.0–14.0	16.0–18.0	–	–					
SA-193 cold worked Type 316	0.04–0.080	≤2.0	≤0.75	≤0.03	≤0.045	10.0–14.0	16.0–18.0	2.0–3.0	–	–	≤ 0.25		≤0.10	–
Z6CND17-12 cold worked (M 330B) 316	0.03–0.080	≤2.0	≤1.0	≤0.03	≤0.035	10.0–14.0	16.0–18.0	2.25–3.00	–	–	≤ 0.20	≤1.0	–	–
Z2CND17-12 cold worked N controlled (M 330B) 316l	≤0.035	≤2.0	≤1.0	≤0.03	≤0.035	11.5–12.5	17.0–18.2	2.25–2.75	–	–	≤ 0.10	≤1.0	≤0.06	–
Z2CND17-12 cold worked (M 330B) 316l	≤0.030	≤2.0	≤1.0	≤0.03	≤0.040	10.0–14.0	16.0–19.0	2.25–2.75	–	–	≤ 0.10	≤1.0	≤0.06	–
X6CrNiMoTi 17-12-2 cold worked (1.4571)	≤0.060	≤2.0	≤1.0	≤0.02	≤0.035	10.5–13.5	16.5–18.5	2.0–2.5	–	≤ 0.7	≤ 0.20	–	–	–
Z3CN 20-09M N controlled (M 3302) 304L	≤0.040	≤2.0	≤1.0	≤0.03	≤0.040	9.0–11.0	18.5–20.0	–	–	–	≤ 0.10	≤10 0	≤0.06	≤0.0018
SA-351 Grade CF8	≤0.080	≤1.5	≤2.0	≤0.04	≤0.040	8.0–12.0	17.0–21.0	≤ 0.50	–	–	–	–	–	–

TABLE III. CHEMICAL COMPOSITION OF RVI MATERIALS — WELDS

Material	C	Mn	Si	S	P	Ni	Cr	Mo	Nb	Ti	Co	Cu	Others
Weld SFA 5.4 / 5.9 Class ER 308L	≤0.030	≤2.5	≤1.0	≤0.03	≤0.030	9.0–12.0	18.0–20.0	–	–	–	≤0.20	≤1.0	Ferrite content 5–15%
Weld (1.4576)	≤0.035	≤2.0	≤1.0	≤0.03	≤0.035	11.5–12.5	17.0–18.2	2.252.75	–	–	≤0.20	≤1.0	

TABLE IV. CHEMICAL COMPOSITION OF RVI MATERIALS — Ni BASED ALLOYS

Material	C	Mn	Si	S	P	Ni	Cr	Fe	Nb	Ti	Co	Cu	Al
SB-166 Alloy N06600	≤0.15	≤1.0	≤0.5	≤0.015		≥72	14.0–17.0	6.0–10				≤0.5	
NC15Fe Alloy 600 (M-4102)	≤0.10	≤1.0	≤0.5	≤0.015	≤0.025	≥72	14.0–17.0	6.0–10		≤ 0.5	≤0.2	≤0.5	≤0.5
SB-637 Alloy N07750 X-750	≤0.080	≤1.0	≤0.5	≤0.01		≥70	14.0–17.0	5.0–9.0	0.7–1.2	2.25–2.75	≤1.0	≤0.5	0.4–1.0
Inconnel X-750 (M-4104)	≤0.080	≤1.0	≤0.5	≤0.01	≤0.01	≥70	14.0–17.0	5.0–9.0	0.7–1.2	2.25–2.75	≤0.2	≤0.5	

Reaktortartályon belüli elemek (*)

TABLE V. TYPICAL RVI MATERIALS

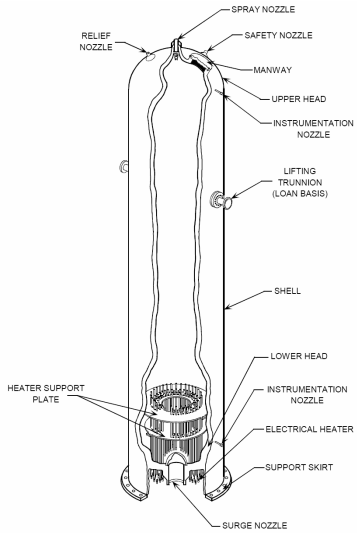
Component	Specification	Note
Core barrel		
Core barrel vessel, spacing grid, core barrel bottom, caps of supports, displacer	08Ch18N10T	Sheets, sheet stamped blanks
Keys, nuts, washers, plugs, pins	08Ch18N10T	Bar and forgings
Supports, tail pieces of supports, tubes	08Ch18N10T	Seamless tubes of improved quality
Studs	ChN35VT-VD	Bar, vacuum arc refined Ni based alloy
Core shroud		
Upper ring, middle ring, lower ring	08Ch18N10T	Forgings
Spacing grids	08Ch18N10T	Sheets
Studs, nuts, washers, reducers, tail pieces	08Ch18N10T	Bars and forgings
Tubes	08Ch18N10T	Seamless, high quality
Block of guide tubes		
Shells, slabs, cones	08Ch18N10T	Sheets
Grids, discs, flanges, sleeves	08Ch18N10T	Bars, forgings
Flanges, rods, tips, keys, bolts, pins	08Ch18N10T	Bars, forgings, enhanced mechanical properties
Tubes	08Ch18N10T	Seamless, high quality
Welding materials		
Argon arc welding	Sv-04Ch19N11M3	Welding wire
Submerged automatic welding	Sv-04Ch19N11M3 + flux 0F-6 or FC-17	Welding wire
Electroslag welding	Sv-04Ch19N11M3 + flux 0F-6	Welding wire
Manual arc welding	EN-400/10T EN-400/10V	Electrode rod, grade Sv-04Ch19N11M3
Wear resistant cladding	CN-6L	Electrode rod, grade Sv-04Ch19N9M3

Térfogatkompenzátor

- A teljesítményváltozásból eredő térfogatváltozások kiegyenlítésére
- Nyomásingadozások szabályozása
- Víz-gőz keverék egyensúlyban

Műszaki adatok

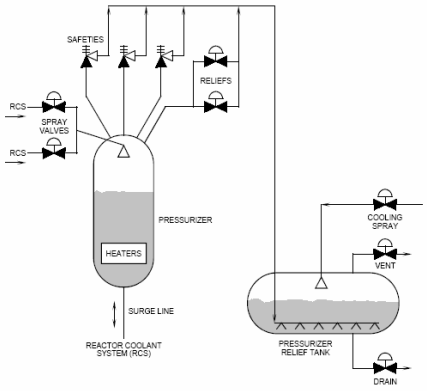
Tervezési nyomás	**175 bar**
Tervezési hőm.	**350 °C**
Térfogat	**65 m³**
(2/3 víz, 1/3 gőz)	
Magasság	**14 m**
Átmérő	**3 m**
Beépített fűtőteljesítmény	**2 MW**



Cutaway View of a Pressurizer

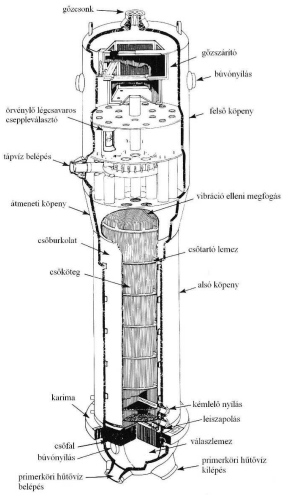
Térfogatkompenzátor

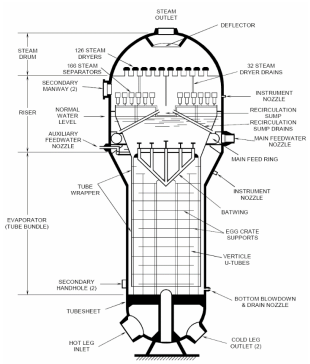
- TK lefúvató tartály
  - nitrogén atomszféra
    - hidrogén potenciálisan robbanásveszélyes környezetben
  - lefúvató szelepeken vagy biztonsági szelepeken távozó gőz kondenzációja



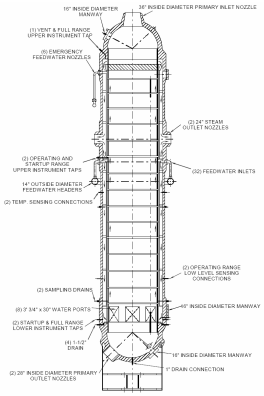
Pressurizer and Pressurizer Relief Tank

Gőzfejlesztő – álló (nyugati)





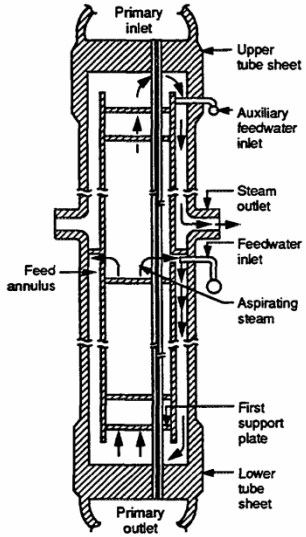
Cutaway View of a Combustion Engineering Steam Generator



Cutaway View of a Babcock & Wilcox Once Through Steam Generator

Gőzfejlesztő – álló (nyugati)

- Egyciklusú (once through) GF (B&W)
  - primer melegági közeg fentről lefelé van szivattyúzva, a szekunder tápvíz ellenáramban a köpenytérben.
  - A tápvíz egy gyűrűs aknába (*feed anulus*) jut be (a 9. távtartó magasságában), és a GF-ben jelen lévő gőzből kicsatolt gőzzel előmelegítik telítésig.
  - Leszálló gyűrűs aknában a GF aljára megy a telített tápvíz, és fordul vissza a köpenytérbe. Ott túlhevített gőz keletkezik, ez radiálisan kifelé áramlik a kilépőcsonk felé



Once-through steam generator

Gőzfejlesztő – álló (nyugati)

- Recirkulációs GF
  - a fő tápvíz betáplálás a GF alsó részén
  - U-csöves primer oldal
  - szekunder közeg a tápvíz csonkon érkezik, és egy leszálló gyűrűs aknában megy le a GF alsó részébe, majd az alsó keverőtéren keresztül a GF köpenytérbe
  - A leszálló gyűrűs aknában elkeveredik a recirkuláltatott, gőzszeparátorból származó tápvízzel, és ez a keverék jut a köpenytérbe
  - Átlagosan a tápvíz 25%-ából lesz gőz, a többi a recirkuláción keresztül újabb kört tesz meg a GF-ben
  - egyes típusokban előmelegítő a primer hidegági kilépésnél, előmelegített tápvíz keveredik a recirkulált közeggel

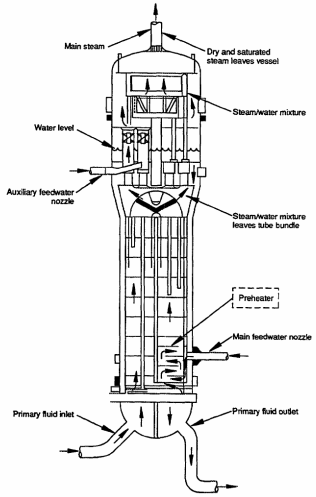


FIG. 2. Typical design of a steam generator with a preheater (CSGORG 1983).

Gőzfejlesztő – álló (nyugati)

Gőzfejlesztő gyártás Oberhausenben

Gőzfejlesztő – álló (nyugati)

(*)

TABLE I. TYPICAL US STEAM GENERATOR MODELS AND THEIR PARAMETERS

Manufacturer type and model	Westinghouse (recirculating)						
	24	27	33	44[a]	51 A–M[a,c]	D2/D3[d]	D4[d]
Heat transfer area (ft2)[b]	24 834	27 700	33 340	44 500	51 500	48 000	47 000
No of tubes	2604	3794	2604	3260	3388	4674	4578
No of row-1 tubes	82	100	82	92	94	114	114
Tube pattern	Square	Square	Square	Square	Square	Square	Square
Tube spacing (in)[b]	1 2187	1 026 or 1 031	1 25	1 200 or 1 234	1 281	1 063	1 063
Tube dimensions (in)	0 875x0 050	0 750x0 055	0 875x0 050	0 875x0 050	0 875x0 050	0 750x0 043	0 750x0 043
Tubing material	Alloy 600	Alloy 600	Alloy 600	Alloy 600	Alloy 600	Alloy 600	Alloy 600
Tubing heat treatment	Mill-annealed	Mill-annealed	Mill-annealed	Mill-annealed	Mill-annealed	Mill-annealed	Mill-annealed
Tubesheet expansion method	Part-depth rolled	Part-depth rolled	Part-depth rolled	Part-depth rolled	Part-depth rolled[e]	Full-depth rolled	Full-depth rolled
Tubesheet crevice depth (in)[c]	18 25	18	18	18 19 or 20	18 18 75 or 19[e]	None	None
Tube support type	Drilled hole	Drilled hole	Drilled hole	Drilled hole	Drilled hole	Drilled hole	Drilled hole
Tube support material	Carbon steel	Carbon steel	Carbon steel	Carbon steel	Carbon steelf	Carbon steel	Carbon steel
Preheater type	None	None	None	None	None	Split flow	Counterflow expanded preheater tubes
Flow distribution baffles	None	None	None	None	None[g]	D2 no D3 yes	Yes

* Replacement Models 44F 51F and 54F use hydraulically expanded, thermally treated Alloy 600 tubing and 405 stainless steel tube support plates except for the model 54Fs at D C Cook and Indian Point Unit 3 which have thermally treated Alloy 690 tubing The replacement models generally match the heat transfer area of the steam generators they replaced except for the 54 Fs with Alloy 690 tubing which are slightly larger than the original 51s due to the slightly lower thermal heat transfer properties at the Alloy 690 material vis-à-vis the Alloy 600 material

[b] 1 ft^2 = 0 093 m^2 1 in = 25 4 mm

[c] Later Model 51s used full-depth rolled or explosively expanded tubes The tubesheet thickness ranges from 525 to 610 mm

Gőzfejlesztő – álló (nyugati)

(*)

TABLE I. (cont.)

Manufacturer type and model	Westinghouse (recirculating)				B&W once-through	Combustion Engineering (recirculating)	
	D5	E[a]	F	Δ75	177	67	80
Heat transfer area (ft²)[a]	47 000	50 000	50 000	75 180	132 500	90 700	N/A
No of tubes	4570	4864	5626	6307	15 531	8519	11 012
No of row -1 tubes	114	120	122	70	—	167	N/A
Tube pattern	Square w/T slot	Square w/T slot	Square w/T slot	Triangle	Triangle	Triangle	Triangle
Tube spacing (in)[b]	1 063	1 080	0 980	0 980	0 875	0 974 1 00	1 000
Tube dimensions (in)	0 750 × 0 043	0 750 × 0 043	0 688 × 0 040	0 688 × 0 040	0 625 × 0 034	0 750 × 0 048	0 750 × 0 042
Tubing material	Alloy 600	Alloy 600	Alloy 600	Alloy 690	Alloy 600	Alloy 600	Alloy 600
Tubing heat treatment	Thermally treated	Mill-annealed or therm. treated	Thermally treated	Thermally treated	Mill-annealed	Mill-annealed	Mill-annealed
Tubesheet expansion method	Hydraulic	Full-depth rolled or hydraulic	Hydraulic	Hydraulic	Partial-depth rolled	Explosive	Explosive
Tubesheet crevice depth (in)[c]	None	None	None	None	22	None	None
Tube support type	Broached quatrefoil	Drilled	Broached quatrefoil	Broached trefoil	Broached trefoil	Eggcrate/ vertical	Eggcrate/ vertical
Tube support material	Stainless steel	Carbon or stainless	405 stainless steel	405 stainless steel	Carbon or MnMo steel	Carbon steel	Stainless steel
Preheater type	Counterflow, expanded pre-heater tubes	Counterflow, expanded preheater tubes	None	None	None	None	Axial flow
Flow distribution baffles	Yes	Yes	Yes	Broached plate	No	None	Yes

[a]For Model 51s with part-depth rolled tubes only

[b]The crevice radial gaps varied from 0 005 to 0 011 inches except in the Model 24 where they were 0 0135-0 0175 inches

[c]Some later Model 51s were equipped with alloy steel tube support plates and flow distribution baffles

[d]The row 1 and 2 tubes in most Model 51 D2/D3, D4 and E steam generators have been u-bend heat treated and shot or roxopeened for added resistance to PWSCC

Gőzfejlesztő – álló (nyugati)

(*)

TABLE II. TYPICAL MITSUBISHI HEAVY INDUSTRIES RECIRCULATING STEAM GENERATOR MODELS AND THEIR PARAMETERS

Manufacturer and Model	MHI 44	MHI 46F	MHI 51,51A	MHI 51M	MHI 51F,51FA	MHI 52F,52FA	MHI 54F,54FA
Heat transfer area (m²)	4130	4300	4785	4780	4780	4870	5055
No. of tubes	3260	3382	3388	3382	3382	3382	3382
No. of row-1 tubes	92	94	94	94	94	94	94
Tube pattern	Square	Square	Square	Square	Square	Square	Square
Tube spacing (mm)	31.35	32.54	32.54	32.54	32.54	32.54	32.54
Tube dimensions (mm)	22.23×1.27	22.23×1.27	22.23×1.27	22.23×1.27	22.23×1.27	22.23×1.27	22.23×1.27
Tubing material	Alloy 600	Alloy 690	Alloy 600	Alloy 600	Alloy 600	Alloy 690	Alloy 690
Tubing heat treatment	Mill-annealed	Thermally treated	Mill-annealed	Mill-annealed, thermally treated	Thermally treated	Thermally treated	Thermally treated
Tubesheet expansion method	Part-depth rolled	Full-depth hydraulic and one step rolled	Part-depth rolled, full-depth rolled	Full-depth rolled, full-depth hydraulic and rolled	Full-depth hydraulic and one step rolled	Full-depth hydraulic and one step rolled	Full-depth hydraulic and one step rolled
Tubesheet crevice depth (mm)	497[a] (original design)	None	488[a], None	None	None	None	None
Tube support type	Drilled	Broached eggcrate	Drilled	Drilled, drilled chamfer	Broached eggcrate	Broached eggcrate	Broached eggcrate
Tube support material	Carbon Steel	405 stainless steel	Carbon steel	Carbon steel, 405 stainless steel	405 stainless steel	405 stainless steel	405 stainless steel
Preheater type	None	None	None	None	None	None	None
Flow distribution baffles	None	Yes	None	Yes	Yes	Yes	Yes

[a]Tubesheet radial gap of 0.185 mm

Gőzfejlesztő – álló (nyugati)

(*)

TABLE III TYPICAL SIEMENS/KWU RECIRCULATING STEAM GENERATORS AND THEIR PARAMETERS

Manufacturer and model	MAN-GHH Obrigheim (Orig.)	MAN-GHH Obrigheim (Repl.)	Balcke Stade	Babcock Biblis A	[h] Standard with preheater	MAN-GHH Konvoi [n]	[k] Replacement SGs for 51C/51M/D3
Heat transfer area (m²)	2750	3070	2930	4510	5386	5427	5105/6103/7155 [l]
No of tubes	2605	3010	2993	4060	4086	4118	5130/5428 [m]
No of row-1 tubes	81	46	49	55	48	54	57/59 [m]
Tube pattern	Rectangular	Triangular	Triangular	Triangular	Triangular	Triangular	Triangular
Tube spacing (mm)	27 9 × 28 8	29 0	29 3	30 0	30 0	30 0	26 164
Tube dimensions (mm)	22 × 1 23 (1 5) [a]	22 × 1 23	22 × 1 23	22 × 1 23	22 × 1 23	22 × 1 23	19 05 × 1 09
Tubing material	Alloy 600	Alloy 800 M [p]	Alloy 800 M [p]	Alloy 800 M [p]	Alloy 800 M [p]	Alloy 800 M [p]	Alloy 690 [o] Alloy 800 M [p]
Tubing heat treatment	Mill annealed	[o]	[o]	[o]	[o]	[o]	Alloy 690 therm. treated Alloy 800 M [p] [o]
Tubesheet expansion method	Part-depth rolled (3 locations)	Part-depth rolled (both ends)	Part-depth rolled (both ends)	Part-depth rolled (both ends)	Part-depth rolled (both ends)	Part-depth rolled (both ends)	Full-depth hydraulic plus part-depth rolled (both ends)
TS crevice depth (mm)	None	None	None	None	None	None	None
Tube support type	Eggcrate [b]	Eggcrate [c]	Eggcrate [d]	Eggcrate [e]	Eggcrate [f]	Eggcrate [c]	Eggcrate [g]
Tube support material	Stainless steel	Stainless steel	Stainless steel	Stainless steel	Stainless steel	Stainless steel	Stainless steel
Preheater type	None	None	None	None	Split-flow design	None	None
Flow distribution baffles	None	Yes	None	None	Yes	None	Yes
U-Bend Treatment	None	None	None	None	None	None	Alloy 690 Yes [o]
Peening of the roll-transition zone	None	None	None	None	None	None	None

Notes

a) Innermost rows wall thickness = 1 5 mm
b) Bend Vertical flat bars
c) Bend Vertical and horizontal flat bars, vertical corrugated strips
d) Bend Vertical flat bars, horizontal and vertical corrugated strips
e) Bend Radial flat bars, vertical corrugated strips
f) Bend Vertical and horizontal flat bars, vertical corrugated strips, block tubing (zero gaps)
g) Similar to ASTM SB 163, UNS N05800
h) Grafenrhenfeld, Grohnde (Manuf MAN-GHH), Brokdorf (Manuf UDDCOMB), Trillo 1 (Manuf ENSA)
j) Almost identical plants Isar 2, Neckarwestheim 2, Emsland
k) Replacement steam generator for Westinghouse model 51C (Ringhals 2, Manuf MAN-GHH), 51M (Doel 3, Manuf ENSA/CMI), D3 (Asco ½ and Almaraz ½, Manuf ENSA), D3 (Ringhals 3, Manuf Framatome)
l) Replacement steam generator for Ringhals 2 5105 m², Doel 3, Asco ½ and Almaraz ½ 6103 m², Ringhals 3 7155 m²
m) Replacement steam generator for Ringhals 2, Doel 3, Asco ½ and Almaraz ½ 5130 tubes, 57 row-1 tubes, Ringhals 3 5428 tubes, 59 row-1 tubes
n) Replacement generator for Ringhals 2 and Ringhals 3 Alloy 690, Doel 3, Asco ½ and Almaraz ½ Alloy 800 M
o) *Alloy 690 Tubes with Radius <300 mm*
p) Modified according to Siemens/KWU specification

Gőzfejlesztő – álló (nyugati)

- GF cső távtartók/pozícionálók
  - lemezes kialakítás
    - furatok a GF csövek számára
    - szűk keresztmetszet a tápvíz számára
    - másodlagos furatok a tápvíz számára
  - B&W: szintén furatos lemez, de a furatok három irányban ki vannak marva, így nagyobb hely a tápvíz számára a GF cső közvetlen közelében
  - rácsos távtartók

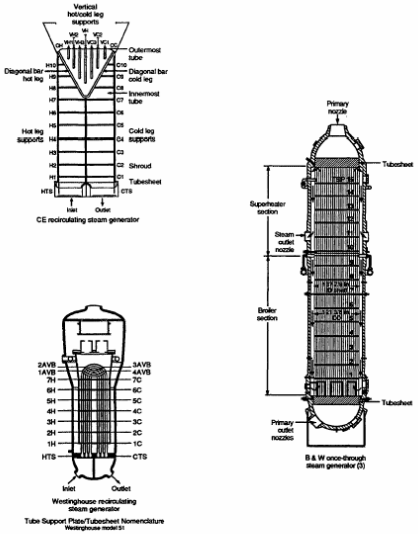


FIG. 7. Typical steam generator tube support layouts with tube support plate and tubesheet nomenclature.

Gőzfejlesztő – álló (nyugati)

- GF rezgéscsillapítók
  - lemezes vagy huzalos kialakítás az U-régióban

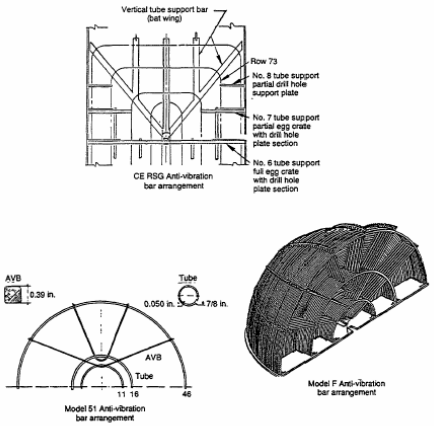


FIG. 8. Typical recirculating steam generator antivibration bar arrangement.

- GF hegesztési helyek

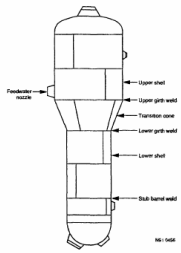


FIG. 10. PWR steam generator showing shell welds (Westinghouse 1990). Copyright Westinghouse Electric; reprinted with permission.

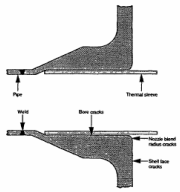


FIG. 11. Feedwater nozzle sites susceptible to high-cycle thermal fatigue damage caused by turbulent mixing of leaking feedwater and hot steam generator coolant (Westinghouse 1990). Copyright Westinghouse Electric; reprinted with permission.

Gőzfejlesztő – álló (nyugati)

- GF cső sérülési zónák
  - PWSCC: primeroldali feszültség-korróziós helyek
  - fretting: kopás
  - ODSCC: külső átmérő feszültség-korrózió
  - IGSCC: intergranular (szemcseközi) SCC
  - IGA: intergranular attack
  - fatigue: fáradás
  - iszap lerakódás (sludge pile)

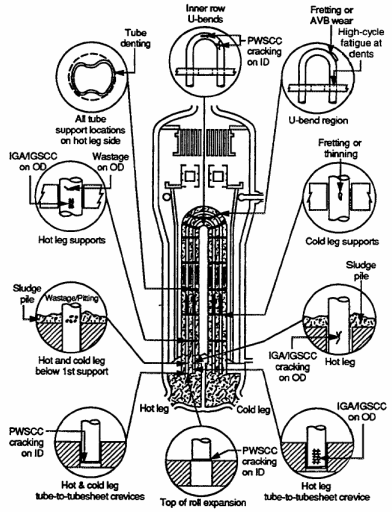


FIG. 14. Locations of known tube wall degradations in recirculating steam generators. (Courtesy of K. J. Krzywosz of the Electric Power Research Institute NDE Center; modified.)

Gőzfejlesztő – álló (nyugati)

- Sérült GF csövek kezelése
  - ledugózás
    - a ledugózott cső továbbra is károsodhat
    - viszont alacsonyabb a hőmérséklet, ami lassítja a roncsolódást
    - ledugózott csövekbe (vibráció miatt) tartóhuzalokat is helyezhetnek
    - ledugózás is okozhat károsodást

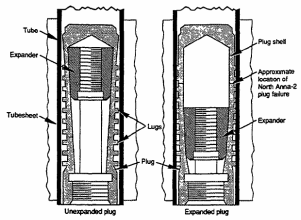


FIG. 25. Sketches of unexpanded and expanded mechanical plugs (Westinghouse 1989). Reprinted with permission.

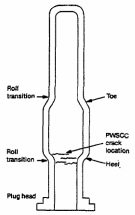


FIG. 26. PWSCC cracks in rolled plug supplied by Babcock & Wilcox (USNRC 1989b).

Gőzfejlesztő – álló (nyugati)

- Sérült GF csövek kezelése
  - hüvelyezés/szigetelőcső behúzása
    - sérült csőben a sérült zóna „kibélelése”
    - ledugózott csövek így akár újra üzembe helyezhetők

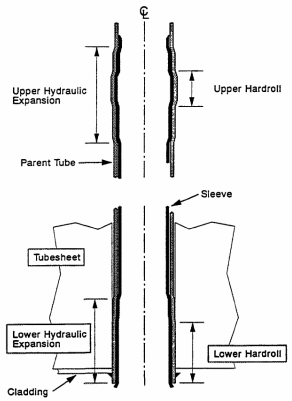
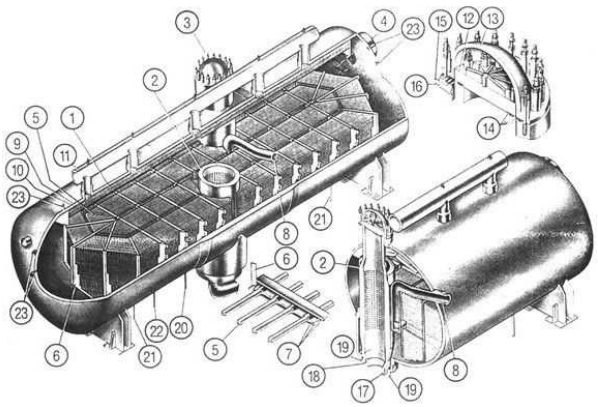


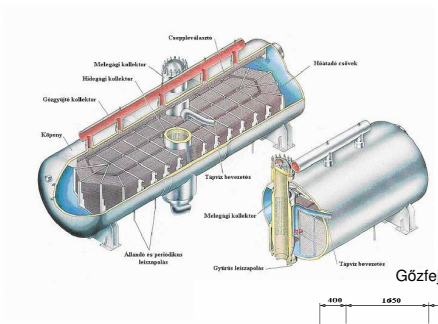
FIG. 27. Typical sleeve installation with a hybrid expanded joint (Westinghouse 1994). Copyright Westinghouse Electric Corporation; reprinted with permission.

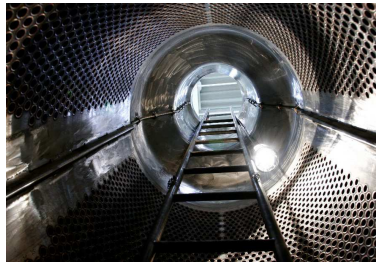
Gőzfejlesztő – fekvő, VVER-440



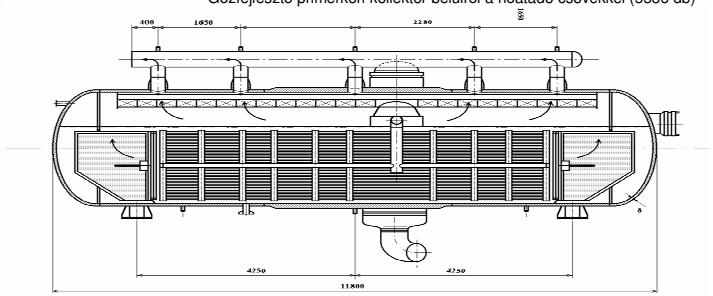
1 - köpeny, 2 - hidegági kollektor, 3 - melegági kollektor, 4 - búvónyílás, 5 - hőátadó csövek, 6 - függőleges távtartó, 7 - vízszintes távtartó, 8 - tápvízelosztó, 9 - csepleválasztó, 10 - perforált lemez, 11 - gőzgyűjtő, 12 - primerköri fedél, 13 - szekunderköri fedél, 14 - tömítő gyűrű a primer- és a szekunderkör között, 15, 16 - szekunderköri tömítés, 17 - primerköri tömítés, 18 - primerköri légtelenítés, 19 - periodikus leürítés, 20 - gőzfejlesztő periodikus leiszapolás, 21 - gőzfejlesztő folyamatos leiszapolás, 22 - csonk, 23 - vízszintjelző cső

Gőzfejlesztő – fekvő, VVER-440





Gőzfejlesztő primerköri kollektor belülről a hőátadó csövekkel (5536 db)



Gőzfejlesztő – fekvő, VVER-440 (*)

TABLE IV. WWER STEAM GENERATOR PARAMETERS

Parameters	WWER-440	WWER-1000	WWER-1000U
Thermal power, MW	229.2	750	750
Steam capacity, kg/s	125	408.33	408.33
Pressure of steam, MPa	4.61	6.27	6.27
Steam temperature, °C	258.9	278.5	278.5
Feedwater temperature, °C	164-223	164-220	164-220
Coolant temperature, °C			
- at steam generator inlet	295	320	320
- at steam generator outlet	267	290	292
Coolant flow rate, m^3/hr	7100	21 200	21 200
Coolant pressure, MPa	12.26	15.7	15.7
Coolant flow rate in tubes, m/s	2.71	4.21	4.91
Average heat transfer factor, kW/m^2K	4.7	5.4	6.1
Mean logarithmic temperature head, °C	18.7	22.9	24
Specific heat flux (average), kW/m^2	89.23	123	141
Total heat exchanging surface, m^2	2576.6	6115	5126.6
Total number of tubes	5536	11 000	9157
Diameter and thickness of tube walls, mm	16x1.4	16x1.5	16x1.5
Tube mean length, m	9.26	11.10	11.14
Pressure loss along the coolant path, MPa	0.075	0.126	0.169
Reduced outlet steam rate from the evaporation surface, m/s	0.240	0.382	0.382
Steam humidity at steam generator outlet, %	0.25	0.2	0.2
Vessel material	22K	10GN2MFA	10GN2MFA
Collector material	08X18N10T[a]	10GN2MFA with inner cladding	08X18N10T perforated area
Heat exchanging tube material	08X18N10T	08X18N10T	08X18N10T
Collector dimensions in the perforated area			
- inner diameter, mm	800	834	780
- wall thickness, mm	136	171 with cladded layer	198
Hole array in the header perforated area			
- dimensions of minimum ligament, mm	11.34	6.93[b]	9.75
- number of horizontal rows along the height	77	110	94
- number of tubes in a horizontal row	89	120	112

TABLE IV. (Cont.)

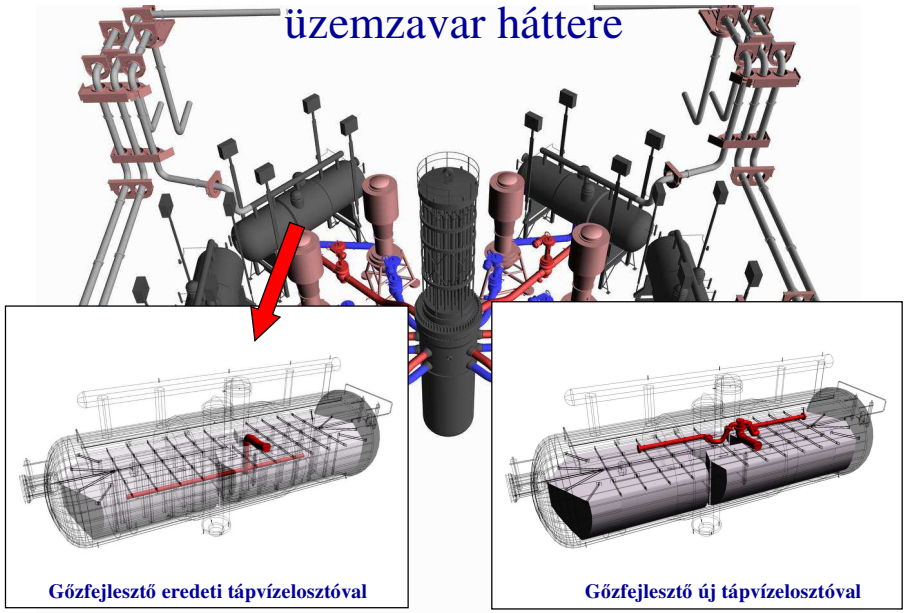
Parameters	WWER-440	WWER-1000	WWER-1000U
	square array	staggered	staggered
Tube array in tube bundle	24	19	22.1
- array pitch along the vertical axis, mm	29.5	23	25, 23[c]
- array pitch along the horizontal axis, mm			
Submerged perforated sheet	absent	installed	installed
Steam generator circulating factor (minimum)	4-6	1.5	1.9
Void fraction, %	0.32	0.493	0.485

[a]This material is also labelled 08Cr18Ni10Ti which is a titanium stabilized austenitic stainless steel with 0.08% carbon, 18% chrome, 10% nickel and less than 1% titanium

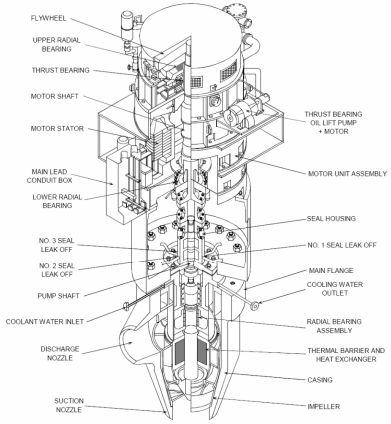
[b]Along medium surface

[c]25 mm for the central set and 23 mm for the lateral set

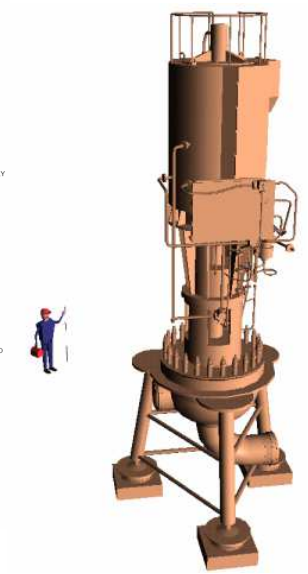
Gőzfejlesztő – fekvő, VVER-440 – 2003-as üzemzavar háttere



Főkeringető szivattyú (FKSZ)

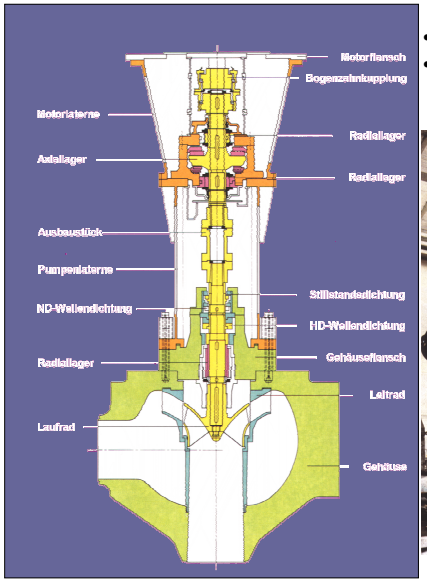


Cutaway View of a Reactor Coolant Pump



VVER-440, Paks

Főkeringtető szivattyú (FKSZ)

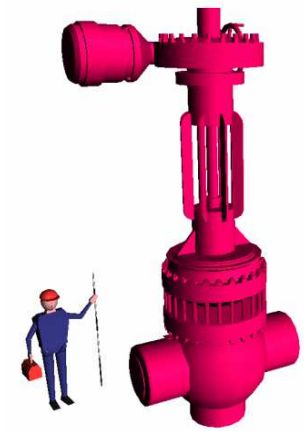


- Függőleges, egyfokozatú centrifugálszivattyú
- A tömítés nagynyomású, kisnyomású és állótömítésből áll

Műszaki adatok

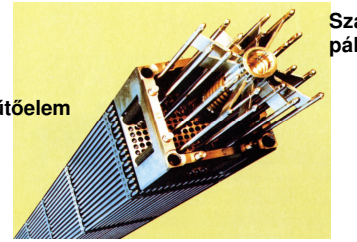
Nyomás 172,5 bar
Kapacitás 18 000 t/h
Emelőmag. 93 m folyadékoszlop
Hőmérséklet 350 °C
Csőcsonk 800 mm
Tömeg 50 t
Teljesítmény 8,5 MW
Ford.szám 1500/min
Betáp feszültség 10kV

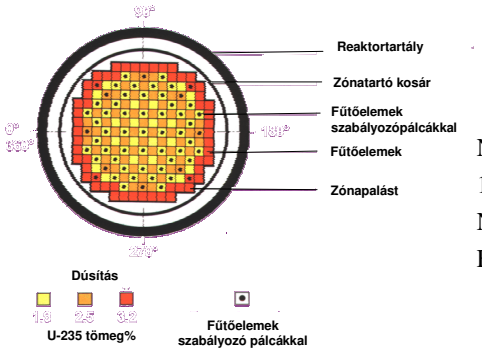
Főelzáró tolózár (FET)



Átrakógép és pihentető medence

PWR üzemanyag





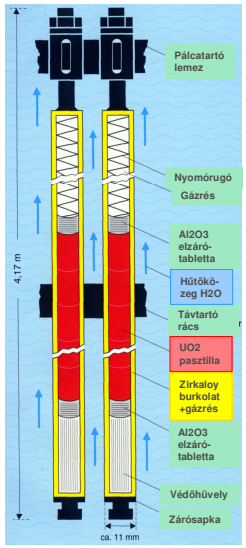
Négyzetrács

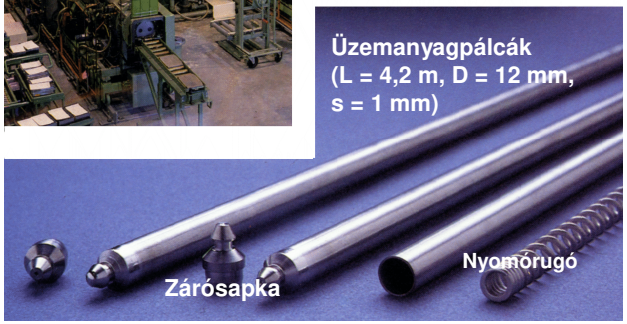
15x15, 16x16, 17x17, 18x18

Nincs kazettafal (keresztáramlás)

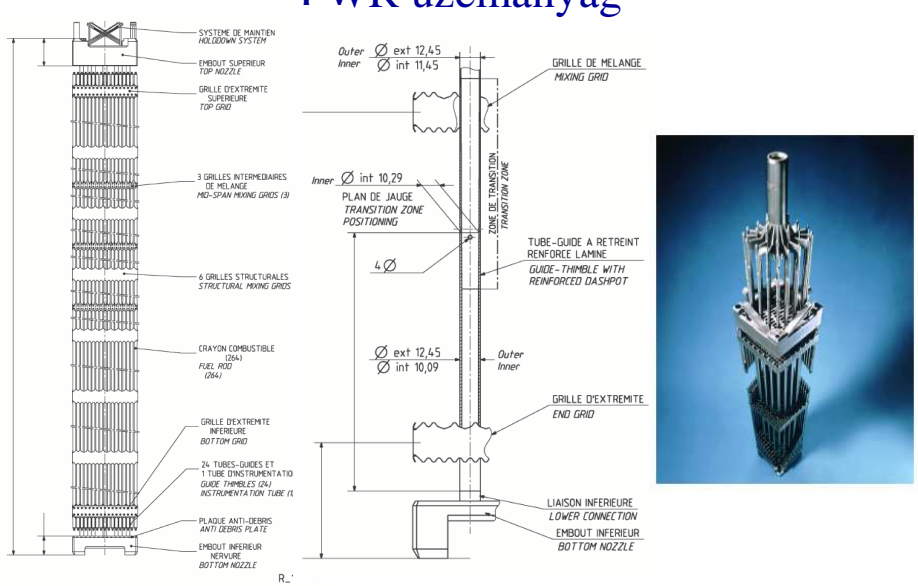
Fésű szerűen bevezetett szabályozó pálca kötegek

PWR üzemanyag



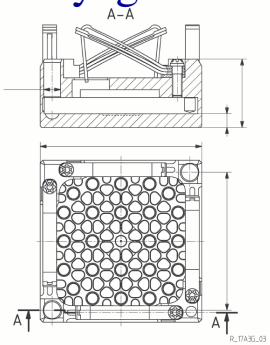


PWR üzemanyag

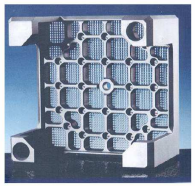


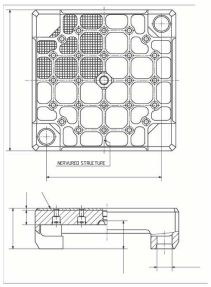
PWR üzemanyag

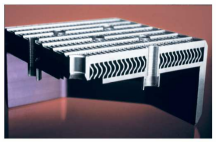
Felső leszorító

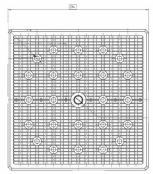


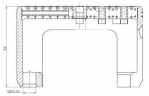
Alsó törmelékrács („Fuel guard”)



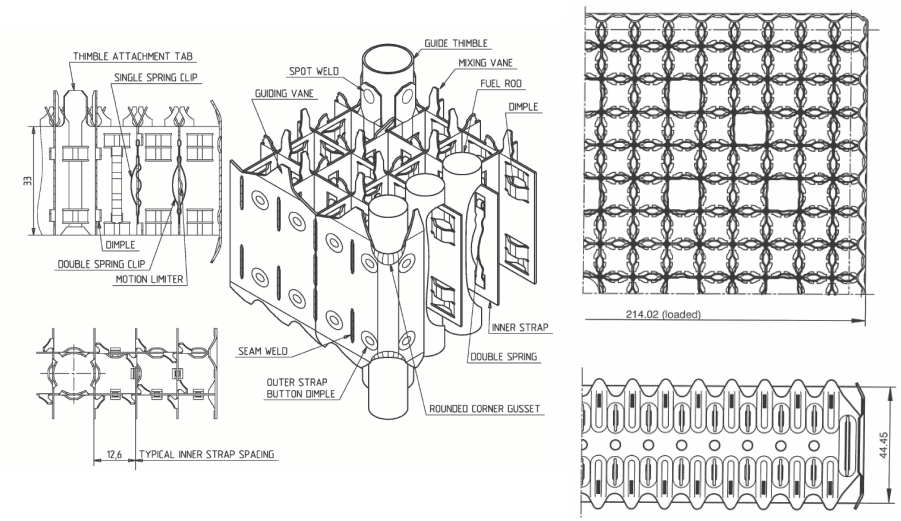




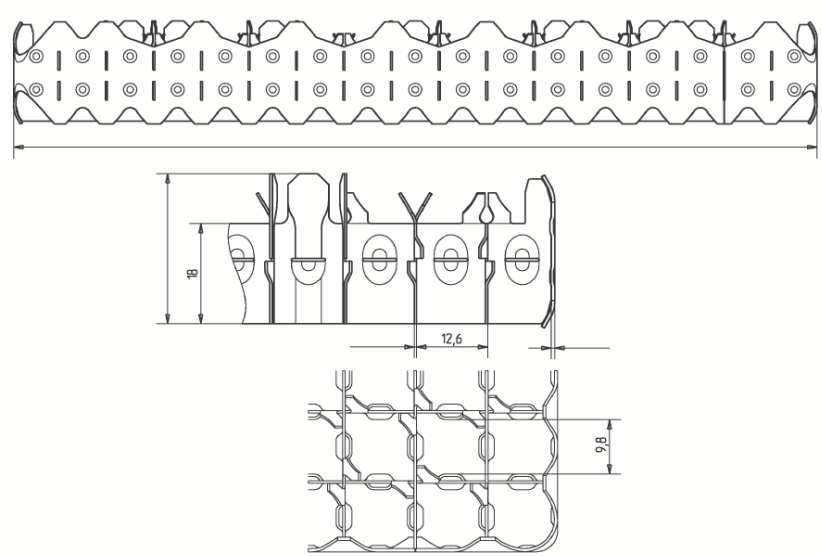




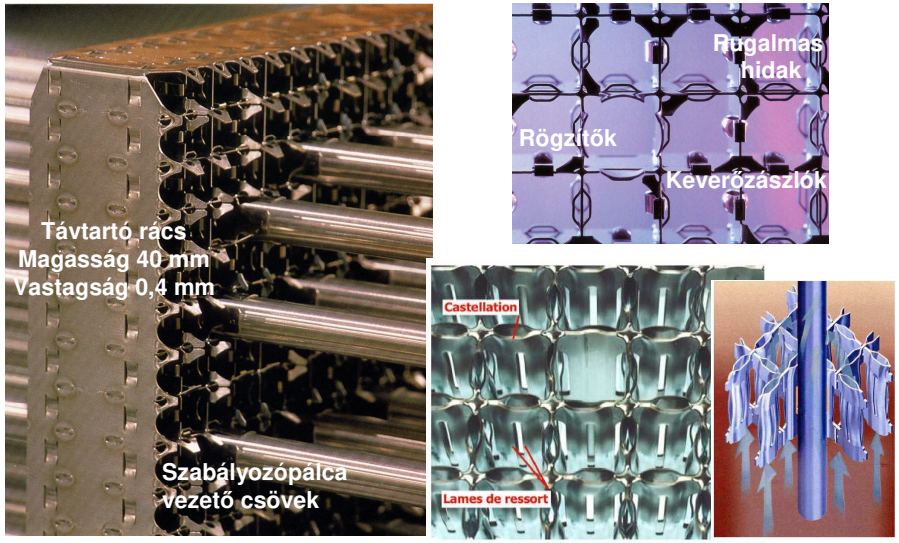
PWR üzemanyag



PWR üzemanyag

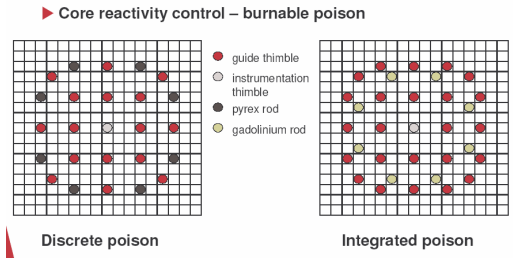


PWR üzemanyag



PWR üzemanyag

- Kiégőmérges



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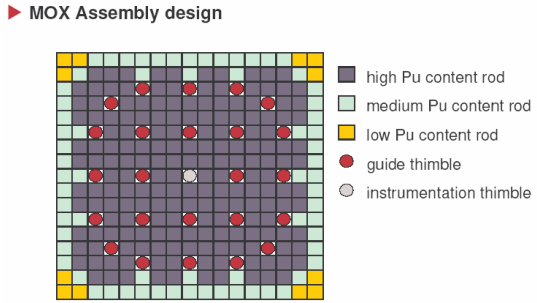

PWR üzemanyag

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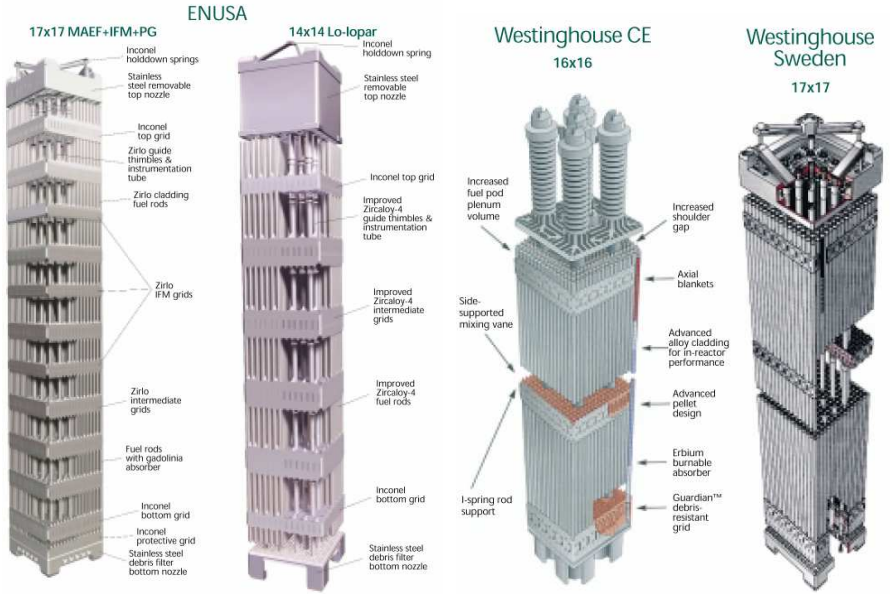

PWR üzemanyag

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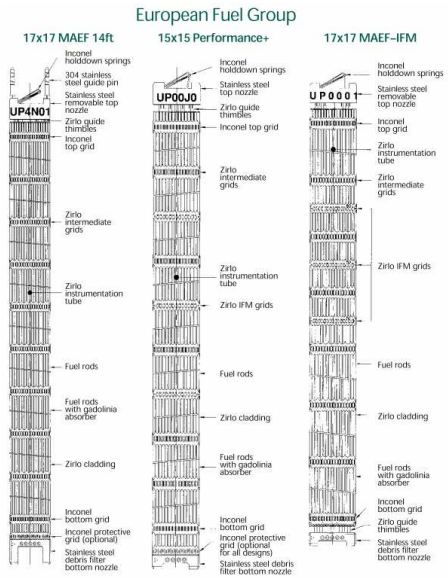

PWR üzemanyag

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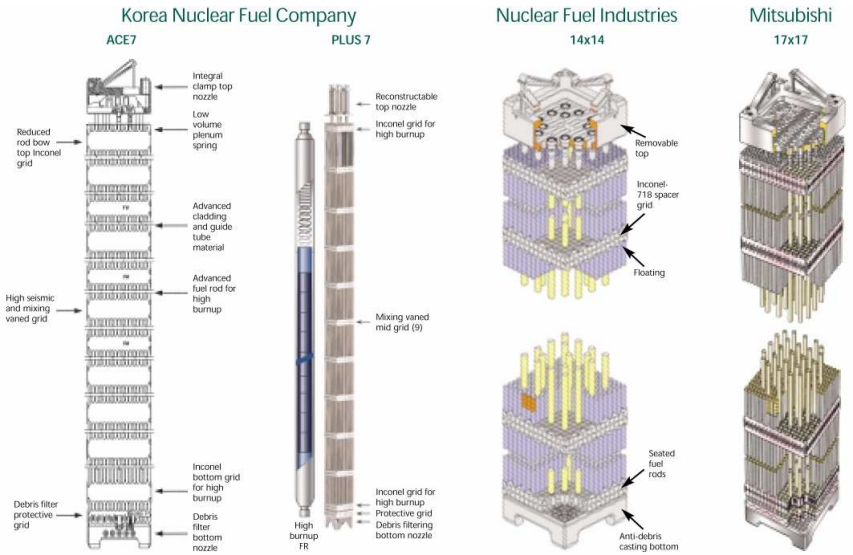

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PWR üzemanyag

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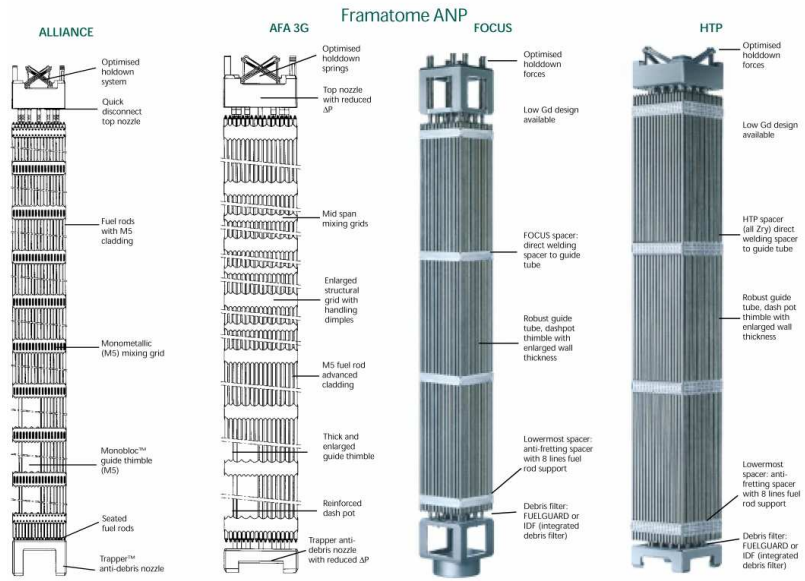

PWR üzemanyag

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PWR design data

	Korea Nuclear Fuel (KNFC)						Mitsubishi			
	OFA	ACE7	KSD	Plus7	FORTE	ACE7				
Assembly geometry	14x14	16x16	16x16	16x16	17x17	17x17	14x14[3]	15x15[6]	17x17[6]	17x17[7]
No of rods per assembly							179	204	264	264
– Fuelled	179	235	236	236	264	264				
– Unfuelled	17[1]	21[2]	5[3]	5	25[4]	25				
Overall assembly length (mm)	4063	4063	4528	4528	4063	4063	4057	4057	4058	4058
Overall assembly width (mm)	197	197	207	207	214	214	197	214	214	214
Rod length (mm)	3868	3878	4094	4094	3879	3881	3866	3866	3856	3856
Rod outside diameter (mm)	10.16	9.14	9.7	9.5	9.5	9.5	10.72	10.72	9.5	9.5
Pellet length (mm)	10.49	9.4	9.9	9.83	9.83	9.83	12.6	12.6	11.5	11.5
Pellet outside diameter (mm)	8.748	7.84	8.26	8.192	8.192	8.192	9.29	9.29	8.19	8.19
Pellet density (g/cm^3 or TD)	95%	95%	95.25%	95%	95%	95%	97%	97%	97%	97%
Average linear fuel rating (kW/m)	21.22	17.62	17.245	17.68	17.83	17.85	20.4	20.3	17.1	17.9
Peak linear fuel rating (kW/m)							–	–	–	–
Maximum fuel temperature (°C)							–	–	–	–
Clad material	Zirlo	Zirlo	Zirlo	Zirlo	Zirlo	Zirlo	Imp.Zy4	Imp.Zy4	Imp.Zy4	Imp.Zy4
Clad thickness (mm)	0.617	0.572	0.64	0.572	0.572	0.572	0.62	0.62	0.57	0.57
Average clad temperature (°C)							–	–	–	–
Maximum clad temperature (°C)							–	–	–	–
Grid material	Zirlo or Inc718	Zirlo or Inc718	Zirlo or Inc718	Zirlo or Inc718	Zirlo or Inc718	Zirlo or Inc718	Inc.	Inc.	Inc/Zy-4	Inc/Zy-4
Average discharge burnup (MWd/kgU)	42	55	43	55	48	55				
Maximum assembly burnup (MWd/kgU)	60	75	60	72	60	75	55	55	55	55

*Depends on plant requirements. **Depends on plant design. [1]Comprises 16 guide thimbles and one instrumentation rod. [2]Comprises 20 outer guides and one centre guide rod. [3]Comprises four outer guides and one centre guide rod. [4]Comprises 24 guide thimbles and one instrumentation rod. [5]Two-loop. [6]Three-loop. [7]Four-loop. [8]Usually >52 MWd/kgU; peak rod burnup is licensed up to 60MWd/kgU. [9]Other lattice sizes available. [10]For Westinghouse units. [11]For Framatome ANP units. [12]Fuel incorporating MOX and/or ORP can be supplied to individual requirements. [13]Wet lattice design option. [14]No melting criteria. [15]Advanced alloy M5 is a Framatome ANP trademark. [16]Depends on clad conditioning. [17]Higher reactor power rate. [18]No melting criteria. [19]Different designs available. [20]This design is available through ENUSA for Spanish customers. [21]Peak rod burnup is licensed up to 60 MWd/kgU. [22]ENUSA Industrias Avanzadas designs and manufactures PWR fuel to the Spanish plants.

PWR üzemanyag

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PWR design data (continued)

	Framatome ANP									
	ALLIANCE		Mk-B	Mk-BW17	AFA 3G					
Assembly geometry	17x17-12'	17x17-14'	15x15	17x17-12'	14x14	15x15	16x16	17x17-12'	17x17-14'	18x18
No of rods per assembly	264	264			179	204	236	264	264	300
– Fuelled			208	264						
– Unfuelled			17	25						
Overall assembly length (mm)	4060	4794.5	4209	4059	2899	4057	4827	4060	4795	4827
Overall assembly width (mm)	214	214	217	214	197.2	214	229.5	214	214	229.5
Rod length (mm)	3859	4492.3	3916	3865	2628.6	3874	4418	3863.4	4497.3	4429
Rod outside diameter (mm)	9.5	9.5	10.9/10.6[13]	9.5	10.72	10.72	10.75	9.5	9.5	9.5
Pellet length (mm)	13.46/10.2	13.46	11.5	10.2	15.25	15.25	11.0	13.46	13.46	9.66
Pellet outside diameter (mm)	8.19	8.19	9.4/9.8[13]	8.19	9.29	9.29	9.11	8.19	8.19	8.06
Pellet density (g/cm^3 or TD)	10.4/10.52	10.4	10.52	10.52	10.4	10.4	10.4	10.4	10.4	10.4
Average linear fuel rating (kW/m)	20	17.9	20.5	17.8	22	23.8[17]	21.1	20	17.9	16.6
Peak linear fuel rating (kW/m)	42/46.9	42	60.9	46.9	42[16]	42[16]	42[16]	42[16]	42[16]	42[16]
Maximum fuel temperature (°C)	2800	2800	2800[14]	2800[14]	2800[14]	2800[14]	2800[14]	2800[14]	2800[14]	2800[14]
Clad material	M5[15]	M5[15]	M5[15]	M5[15]	Zy4/M5[15]	Zy4/M5[15]	Zy4/M5[15]	Zy4/M5[15]	Zy4/M5[15]	Zy4/M5[15]
Clad thickness (mm)	0.57	0.57	0.635/0.6[13]	0.57	0.62	0.62	0.725	0.57	0.57	0.64
Average clad temperature (°C)	-	-	*	*						
Maximum clad temperature (°C)	400	400	420	404	400	400	400	400	400	400
Grid material	M5[15]	M5[15]	Zy4/M5[15] + Inc	Zy4/M5[15] + Inc	Zy4 + Inc	Zy4 + Inc	Zy4 + Inc	Zy4 + Inc	Zy4 + Inc	Zy4 + Inc
Average discharge burnup (MWd/kgU)	-	-	*	*						
Maximum assembly burnup (MWd/kgU)	>70	>70	>58	>67	>60	>60	>60	>60	>60	>60

PWR üzemanyag

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PWR design data (continued)

Westinghouse CE			Westinghouse[12]	Westinghouse Sweden & European Fuel Group (EFG – Westinghouse/ENUSA alliance)						ENUSA[22]	
		System 80	Robust fuel assembly	RFA900	RFA1300	Performance +				Lo-lopar	17x17 MAEF+IFM+PG
14x14	16x16	16x16	17x17[9]	17x17	17x17	15x15	17x17	16x16	18x18	14x14	17x17
176	236	236	264	264	264	204	264	236	300	179	264
				25	25	21	25	20	24	17[1]	25[4]
3994	4491	4528	4058	4058	4795	4058	4053	4827	4827	2854	4063
206	207	207	214	214	214	214	214	229.6	229.6	197	214
3733	4112	4112	3881	3865	4492	3874	3852	4399	4402	2583	3886
11.18	9.70	9.70	9.5	9.5	9.5	10.72	9.5	10.75	9.5	10.72	9.5
11.58	9.91	9.91	9.83	9.83	9.83	11.2	9	10	9	11.13	9.83
9.68	8.26	8.27	8.19	8.19	8.19	9.29	8.19	9.11	8.05	9.29	8.19
10.3-10.58	10.3-10.58	10.3-10.58		10.53	10.53		10.5	10.5	10.5	10.53	10.53
20.44	17.72	17.91		17.9	17.1		17.8	20.7	16.7	16.70	18.93
46.92	42.65	42.98		59.0	59.0					up to 68.9[18]	up to 68.9[18]
*	*	*		*	*	*	*	*	*	2800[18]	2800[18]
Zr4	Zr4	Zr4	Zirlo™	Zr4	Zr4	Zirlo™	Zr4	Duplex/Zr4	Duplex/Zr4	Improved Zr4	Zirlo
0.660	0.635	0.635	0.57	0.57	0.57	0.62	0.57	0.725	0.64	0.62	0.57
*	*	*		*	*	*	*	*	*		
*	*	*		*	*	*	*	*	*		
Zr4	Zr4	Zr4	Zirlo™	Inc/Zr4	Inc/Zr4	Inc/Zirlo™	Inc/Zr4	Inc/Zr4	Inc/Zr4	Inconel/impr Zr4	Inconel/Zirlo
+8	*	*		*	*	*	*	*	*		
*	*	*		*	*	*	*	*	*	45	57[21]

PWR üzemanyag

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PWR design data (continued)

Framatome ANP										Nuclear Fuel Industries				
FOCUS-X5					HTP-X5									
14x14-(16+1)	15x15-(20)	16x16-(20)	17x17-(24+1)	18x18-(24)	14x14-(16+1)	15x15-(20+1)	16x16-(20)	17x17-(24+1)	18x18-(24)	14x14[5]	14x14[5]	15x15[6]	17x17[6,7]	17x17[6,7]
196	225	256	289	324	196	225	256	289	324	179	179	204	264	264
179	205	236	264	300	179	204	236	264	300					
17	20	20	25	24	17	21	20	25	24					
3476	4179[19]	4827	4058	4827	2900	4058	4827	4057[19]	4827	4057	4057	4057	4058	4055
197.5	215	229.6	214	229.6	197.2	214	229.6	214	229.6	197	197	214	214	214
3210	3860[19]	4395	3847	4395	2635	3854	4405	3853[19]	4405	3856	3866	3856	3852	3862
10.75	10.75	10.75	9.5	9.5	10.77	10.75	10.75	9.55[18]	9.5	10.72	10.72	10.72	9.5	9.5
11.0	11.0	11.0	9.8	9.8	11.0	11.0	11.0	9.37[18]	9.8					
9.11	9.11	9.11	8.17	8.05	9.11	9.11	9.11	8.17[18]	8.05					
10.45	10.45	10.45	10.45	10.45	10.45	10.45	10.45	10.45[19]	10.45	95%	97%	95%	95%	97%
**	**	**	**	**	**	**	**	**	**	20.4	20.4	20.3	17.1/17.9	17.1/17.9
Up to 46[18]	Up to 46[18]	Up to 46[18]	Up to 46[18]	Up to 46[18]	Up to 46[18]	Up to 46[18]	Up to 46[18]	Up to 46[18]	Up to 46[18]	–	–	–	–	–
*	*	*	*	*	*	*	*	*	*	–	–	–	–	–
M5[15]/Optimised Zry4/Modified Zry4/Duplex					Optimised Zry4/Modified Zry4/Duplex/M5[15]					Imp.Zy-4	NDA	Imp.Zy-4	Imp.Zy-4	NDA
0.725	0.725	0.725	0.61	0.64	0.725	0.725	0.725	0.61[19]	0.64	0.66	0.66	0.66	0.57, 0.64	0.57
*	*	*	*	*	*	*	*	*	*	–	–	–	–	–
*	*	*	*	*	*	*	*	*	*	–	–	–	–	–
Optimised Zry4/Modified Zry4 + Inconel					Modified Zry4/M5[15]/HPA-4 + Inconel (bottom grid)					Inc	Inc	Inc	Inc/Zy-4	Inc/Zy-4
Up to 65	Up to 65	Up to 65	Up to 65	Up to 65	Up to 65	Up to 65	Up to 65	Up to 65	Up to 65	–	–	–	–	–
Up to 70	Up to 70	Up to 70	Up to 70	Up to 70	Up to 70	Up to 70	Up to 70	Up to 70	Up to 70	48	55	48	48	55

PWR üzemanyag

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ЭЛЕМАШ | ОТКРЫТОЕ АКЦИОНЕРНОЕ ОБЩЕСТВО «МАШИНОСТРОИТЕЛЬНЫЙ ЗАВОД» ТВЭЛ РОСАТОМ
ПРЕДПРИЯТИЕ ГОСКОРПОРАЦИИ «РОСАТОМ»

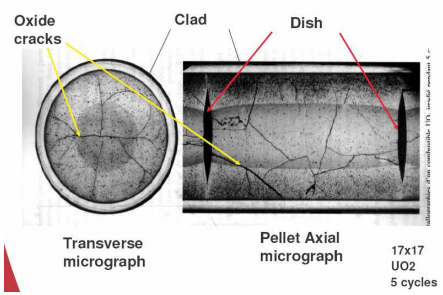
VVER design data

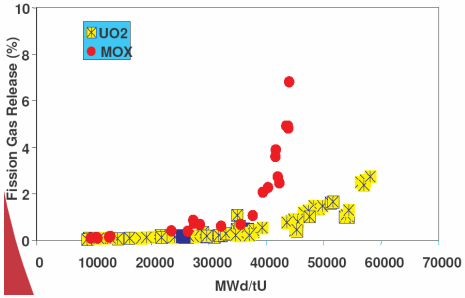
	Mashinostroitelny zavod				Westinghouse	
	VVER 440 Serial	VVER 440 Serial U-Gd Fuel	VVER 440 Advanced CFA[2]	VVER 1000A	440	Vvantage 6 1000
Assembly geometry	Hex	Hex	Hex	Hex	Hex	Hex
No of rods per assembly	127	127	127	331	127	331
– Fuelled	126	126	126	312	126	312
– Unfuelled	1	1	1	19	1	19
Overall assembly length (mm)	3217	3217	3200	4570	3188	4583
Overall assembly width (mm)	145	145	144	234.5	144	235
Rod length (mm)	2536/2546[1]	2536/2546[1]	2536	3837	2520	3889
Rod outside diameter (mm)	9.1	9.1	9.1	9.1	8.9	9.14
Pellet length (mm)	9-12	9-11	9-12	9-12	9.15	9.4
Pellet outside diameter (mm)	7.57	7.57	7.57	7.57	7.63	7.64
Pellet density (g/cm^3 or TD)	10.4-10.7	10.4-10.7	10.4-10.7	10.4-10.7		95%
Average linear fuel rating (kW/m)	12.96	12.96	12.96	16.7	15	
Peak linear fuel rating (kW/m)	32.5	32.5	32.5	44.8	35	
Maximum fuel temperature (°C)	1500	1500	1500	1667		
Clad material	Zr1%Nb	Zr1%Nb	Zr1%Nb	see note[3]	Zr4	Zy4
Clad thickness (mm)	0.63	0.63	0.63	0.63	0.55	0.57
Average clad temperature (°C)	–	–	–	–		
Maximum clad temperature (°C)	350	350	350	–	360	
Grid material	Zr1%Nb	Zr1%Nb	Zr1%Nb	Zr1%Nb	Zr4	Zr4
Average discharge burnup (MWd/kgU)	42	-	-	55	>40	
Maximum assembly burnup (MWd/kgU)	>50	53	50	60		>50

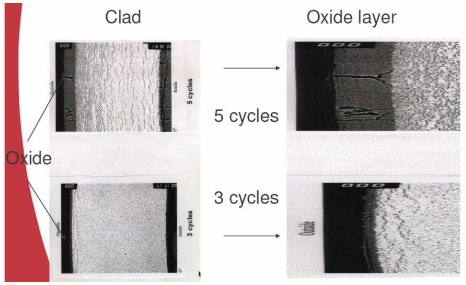
VVER 440 Serial and VVER 440 Serial U-Gd Fuel are removable for inspection purposes, whereas VVER 440 Advanced CFA is not. [1]Fuel assembly design with removable fuel rods. [2]Control fuel assembly (contains six Hf slices). [3]Zr1%Nb, Zr1%Nb1.3%Sn0.3%Fe. Hex=Hexagonal.

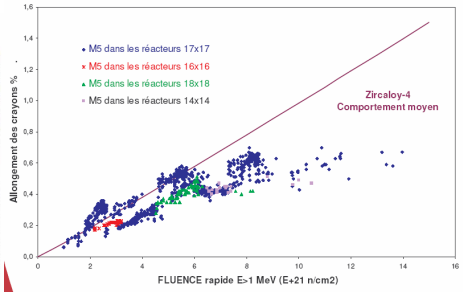
Parameters	Fuel cycle type				
	For full core			For the core containing screen assemblies	
	Advanced 3-year	4-year	5-year without U-Gd fuel/ 5-year with U-Gd fuel	Advanced 3 – year	4- year
Reactor thermal power, MW	1375	1375	1375	1375	1375
Number of fuel assemblies in the core, pcs.	349	349	349	313	313
Total uranium weight in the core, t	41,8	41,8	41,8	37,4	37,4
Time between refuellings, months	12	12	12	12	12
Number of annually replaced fuel assemblies, pcs.	117,5	90,5	78,5/66	102,5	81,5
Average enrichment of make-up fuel, %	3,28	3,62	4,01/4,21	3,59	4,01
Average discharge fuel burn up, MWd./kg U	29,37	38,29	42,66/49,89	33,08	41,95
Specific consumption of natural uranium, kg/MW day	0,247	0,212	0,211/0,193	0,242	0,215
Specific volume of separative work, swu/mwd	0,134	0,119	0,123/0,115	0,136	0,126

Üzemanyag jellemzői



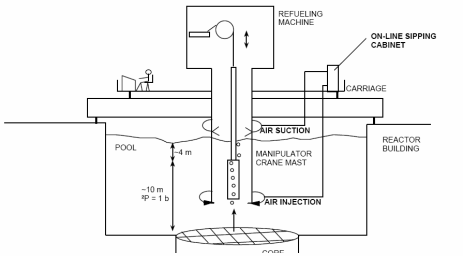


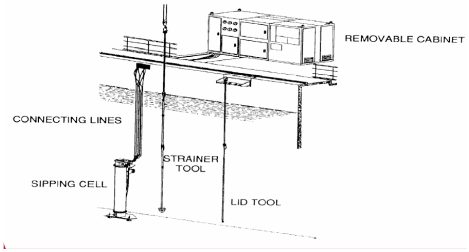


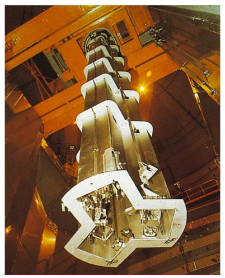


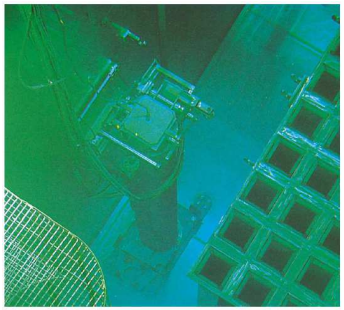
Hibás üzemanyag – hibás üa. keresése

B-2. IN MAST SIPPING SYSTEM (gas process)



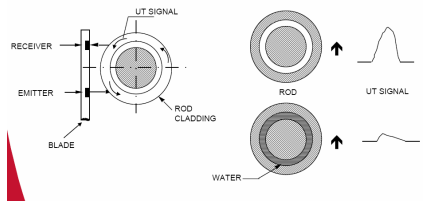


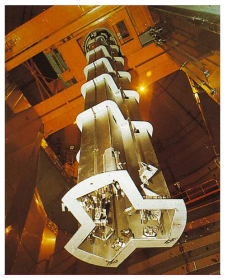


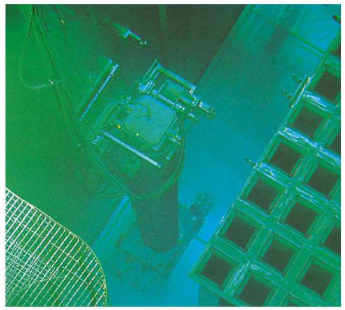


Hibás üzemanyag – hibás üa. keresése

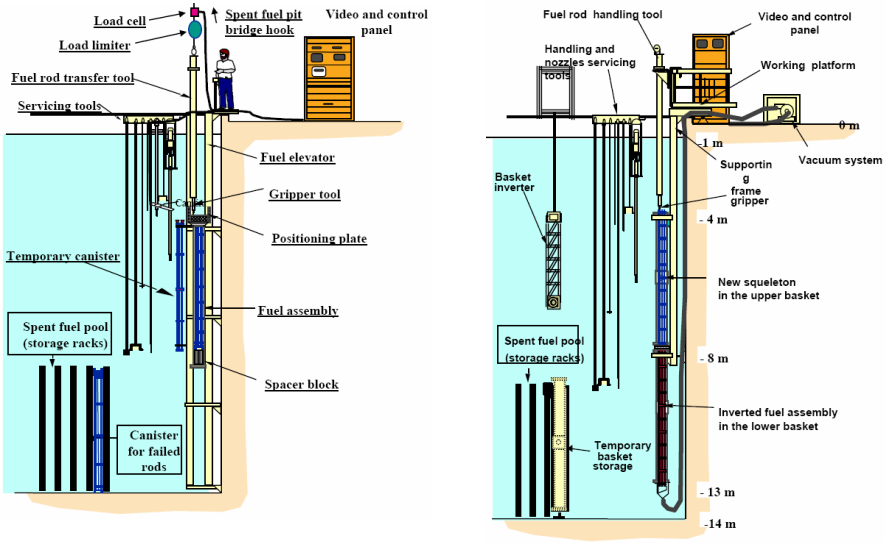
- Xe-133/Kr-85 szivárgás keresés/detektálás
- Víz mintavételezés szilárd hasadási termékek keresésére (pl. Cs-137)
- 10-30 perc/ÜA
- Hibás ÜA pálca keresése





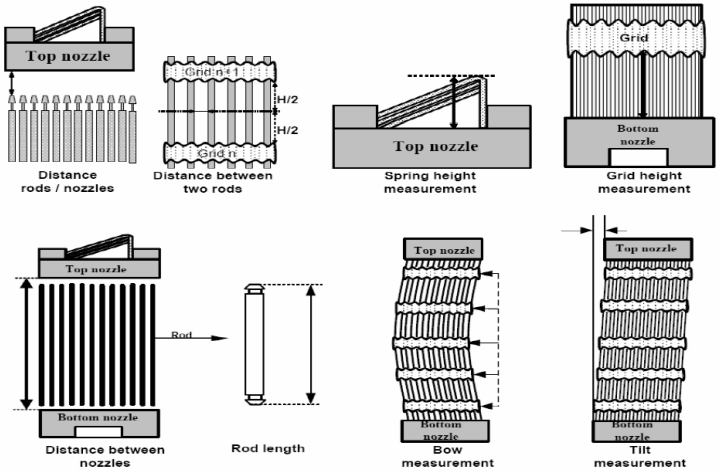


Hibás üzemanyag – sérült pálca/váz cseréje



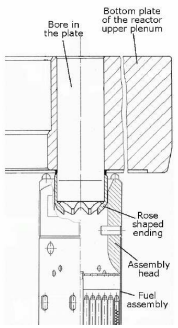
Hibás üzemanyag – hibás üa. keresése

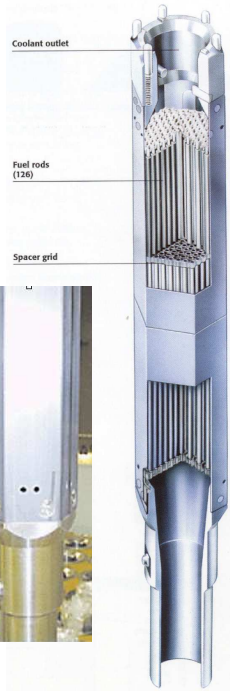
- Geometriai vizsgálatok



VVER-440 üzemanyag

- UO_2, 9 mm magas, 7,6 mm átmérőjű hengeres pasztillákban
- A pasztillákat pálcákba rendezik
- 126 pálca alkot egy fűtőelem-kazettát
- **követő- és munkakazetták**





VVER-440 üzemanyag

- Követő kazetta és abszorber köteg

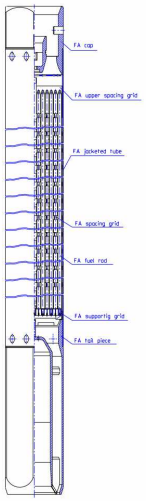


FIG. 3. Fuel assembly.

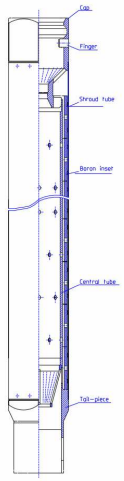


FIG. 4. Absorber.

VVER-1000 üzemanyag

- hatszögletű fűtőelemköteg
- nincs palást
- a nyugati példákhoz hasonló SZBV pálcakötegek
  - nincs követő kazetta
  - nincs fékezőcsőblokk

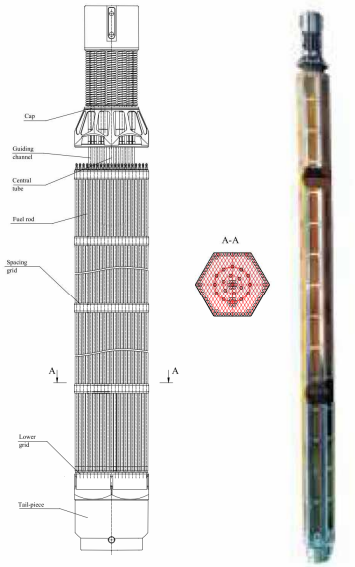
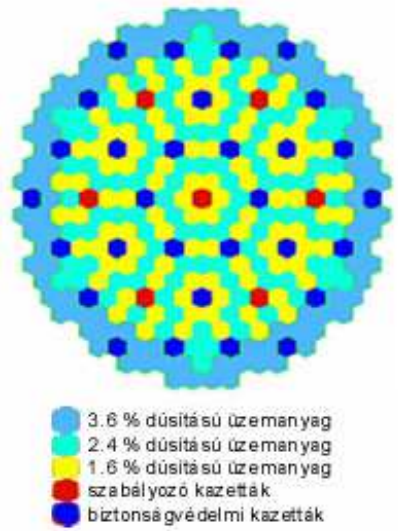


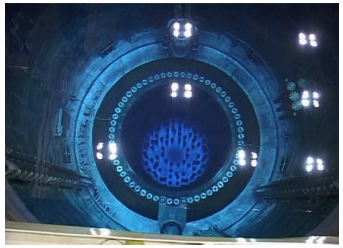
FIG. 5. WWER-1000 assembly.

A Paksi Atomerőmű - aktív zóna

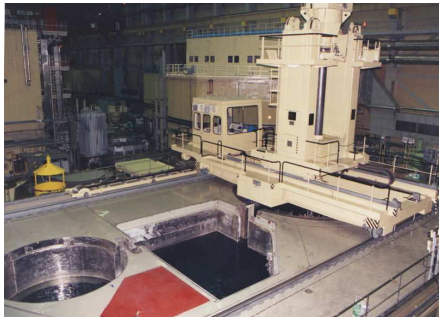
- 349 üzemanyag-kazetta
- 37 SZBV rúd (30+7)
- (dúsítás:
  4,2%, 3,6%, 2,4%, 1,6%)



Paksi atomerőmű

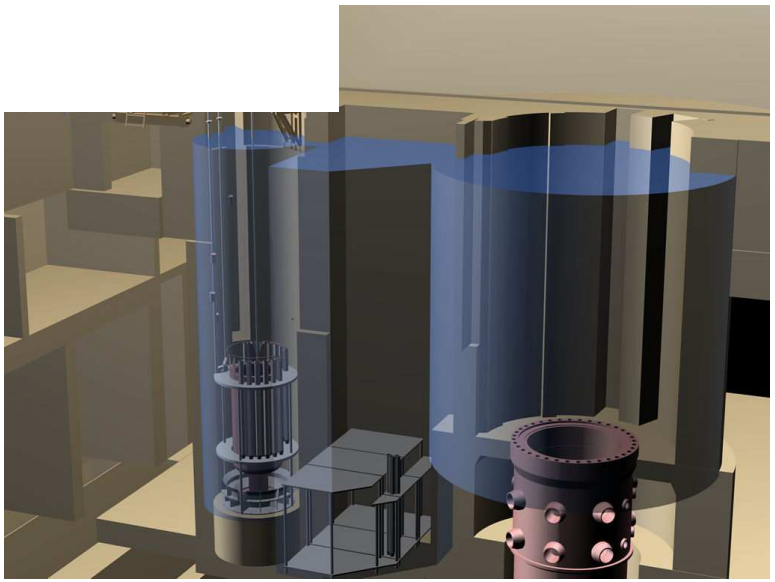


Reaktortartály (átrakomedence + üzemanyagkazetták)

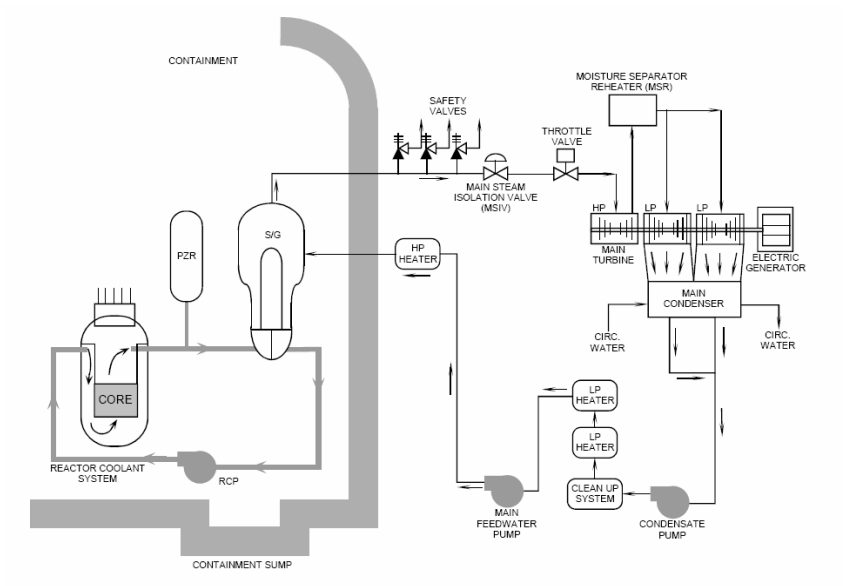


Pihentető medence és a kiégett kazetták tartó rácsa

Paksi atomerőmű

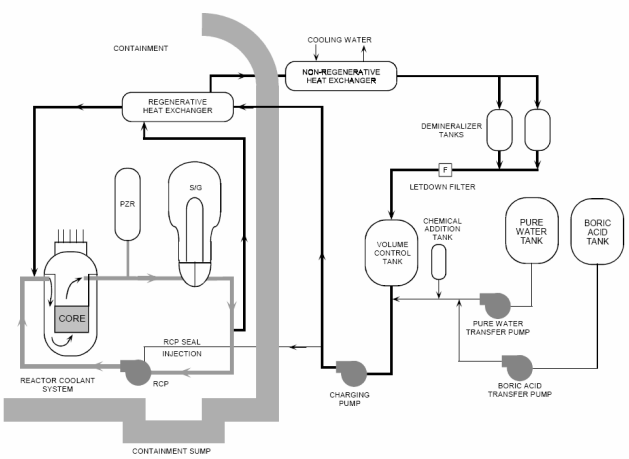


Primer kör, szekunder kör



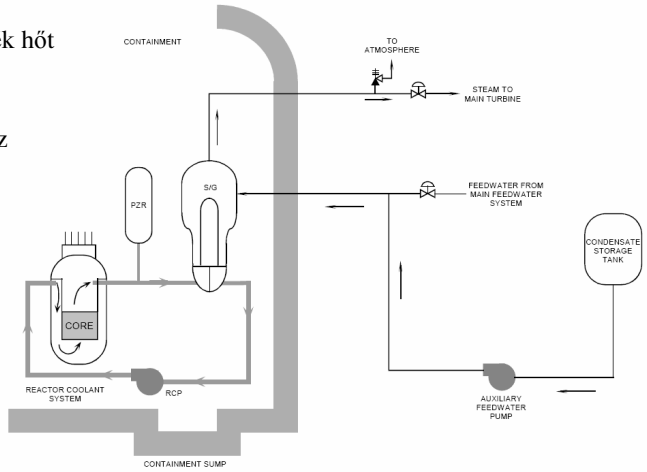
Kémiai és víztisztító rendszer

- Víztisztítás: szűrők, ioncserélők
- Bórsav-koncentráció beállítása
- Térfogatkompenzátor munkapontjának beállítása
- kis forgalmú víz-mennyiség folyamatosan ki van csatolva
- FKSZ záróvíz



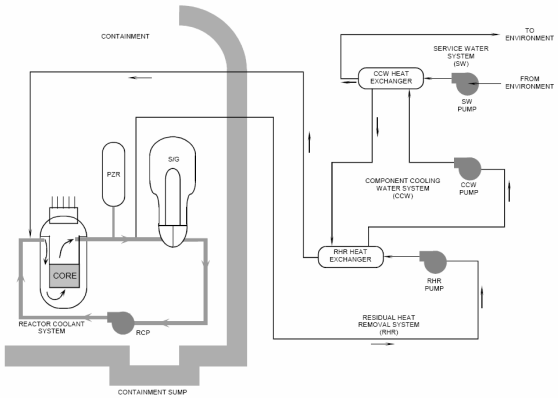
Remanenshő eltávolítása

- Reaktor leállítását követően a maradék hőt el kell távolítani
- 1. Kisegítő tápvízrendszer, gőz termelődik:
  - kondenzátorba
  - atmoszférába



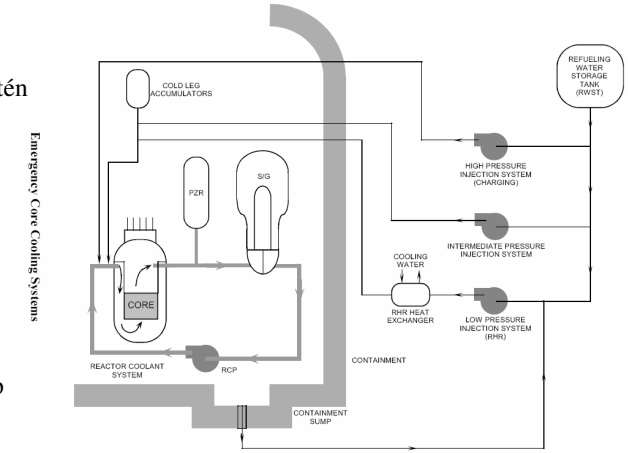
Remanenshő eltávolítása

- 2. Remanenshő eltávolító rendszer:
  - primerkör egy része a remanenshő eltávolító rendszerbe csatolva
  - a hő több hűtőrendszeren keresztül a környezetbe távozik
  - ez a rendszer olyan hőmérsékletre tudja hűteni a primer kört, hogy ott karbantartást lehessen végezni



Üzemzavari hűtőrendszer

- üzemzavar esetén, LOCA baleset esetén biztosítja a hőelvonást a reaktorból
- különböző nyomásszintek
  - magas
  - közepes
  - kis
- konténment zsomp



Konténment

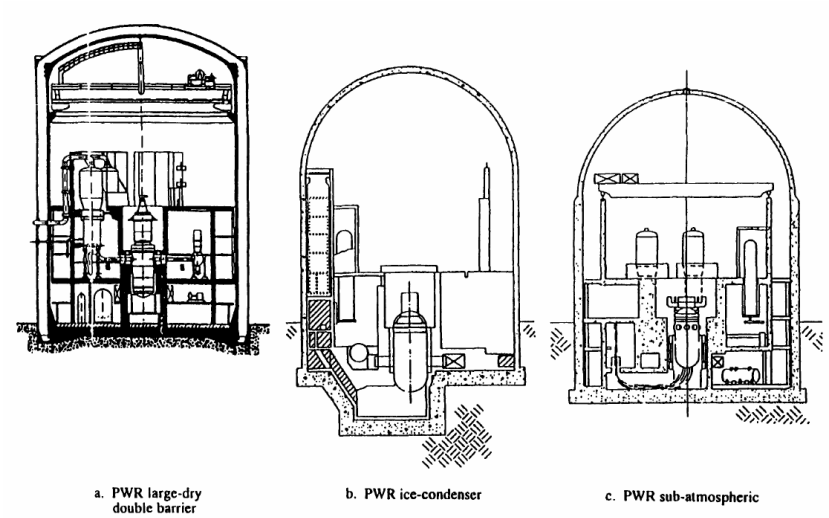


FIG. 2.1. Examples of PWR concrete containment cross-sections.

Konténment

- Száraz konténment
  - akkora a térfogata, hogy LOCA esetén a teljes primer kör energiáját vissza tudja tartani (nagy p, magas T)
  1. beton épület, 4. acél fal
  2. víz sprinkler rendszer
  3. konténment lefúvató rendszer/szűrt leeresztés

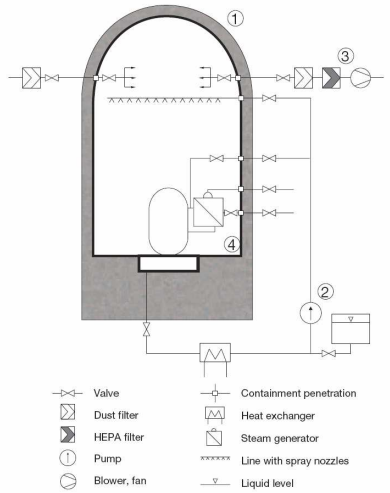


FIG. I–1. Schematic diagram of a full pressure dry containment system for a pressurized water reactor: 1, containment; 2, containment spray system; 3, filtered air discharge system; 4, liner.

Konténment

- Száraz duplafalú konténment
  - kettős fal
    1. gömb/henger belső betonból vagy acélból
    2. beton külső fal
    3. gyűrűs tér
    4. gyűrűs tér szellőztető rendszer
    5. konténment lefúvató rendszer/szűrt leeresztés

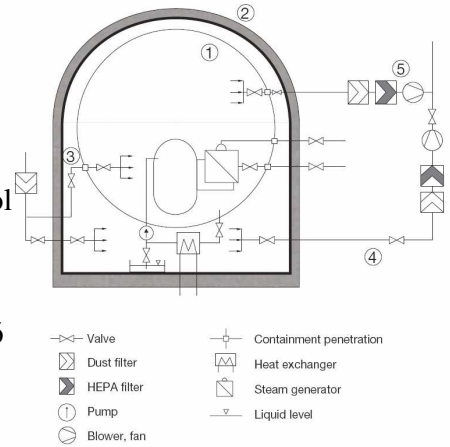


FIG. I–2. Schematic diagram of a full pressure double wall containment system for a pressurized water reactor: 1, full pressure containment; 2, secondary confinement; 3, annulus; 4, annulus evacuation system; 5, filtered air discharged system.

Konténment

- Száraz szubatmoszférikus
  - száraz konténment
  - környezethez képest depresszió (~35 kPa)
    - konténment szivárgás környezet felől befelé
    - konténment szivárgás könnyen detektálható (alacsony nyomás nehezebben tartható)
    - kis mértékben jobb tűrés DBA esetén, a tervezési p/T alacsonyabb lehet

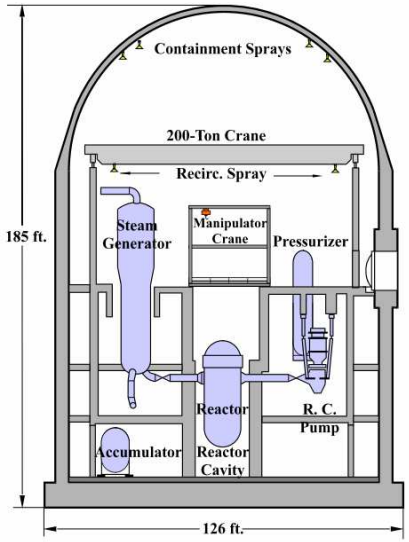


Figure 4.1-4 Typical subatmospheric containment

Konténment

- Jégkondenzációs
  - a nagynyomású víz-gőz keveréket jeget tartalmazó kosarakba vezeti
  - 4. alsó rész: reaktor, primer kör, sprinkler, stb.
  - 3. középső rész: kondenzációs rész, jégkosarak
  - 2. felső rész: nemkondenzálódó gázok ide gyűlnek
  - 5. víz sprinkler rendszer
  - 6. konténment lefúvató rendszer/szűrt leeresztés

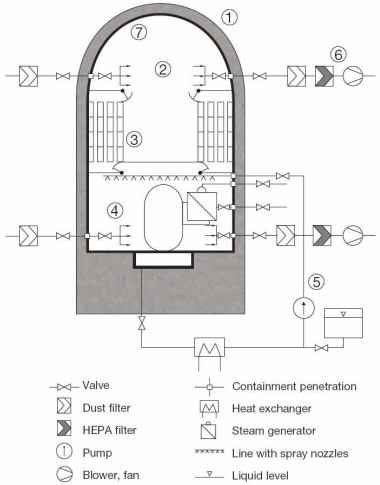


FIG. I–3. Schematic diagram of an ice condenser containment system for a pressurized water reactor; 1, containment; 2, upper containment volume; 3, ice condenser; 4, lower containment volume; 5, lower containment spray system; 6, filtered air discharge system; 7, liner.

Konténment

- Jégkondenzációs
  - beton vagy acél szerkezet
  - csak passzív nyomáscsökkentés
  - ventillátorok kényszeráramoltat(hat)ják a felső tér levegőjét vissza az alsó térbe, ezzel fokozva a kondenzációs térbe történő levegő belépést
  - Hosszú távon a jég megolvad, más módon kell biztosítani a konténment hűtését
    - konténment spray rendszer

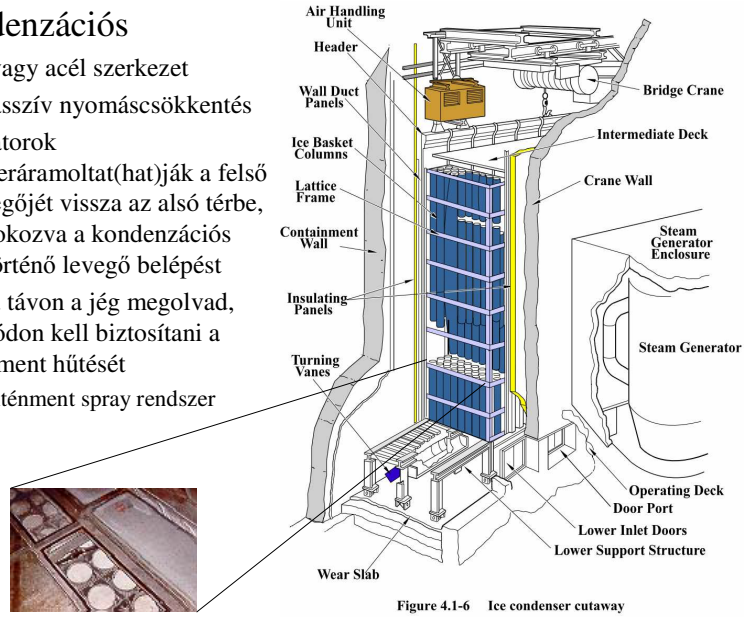


Figure 4.1-6 Ice condenser cutaway

Konténment

- Jégkondenzációs

http://ledsticklights.com/blogs/news/9721014-nuclear-plant-ice-condenser-work-lights

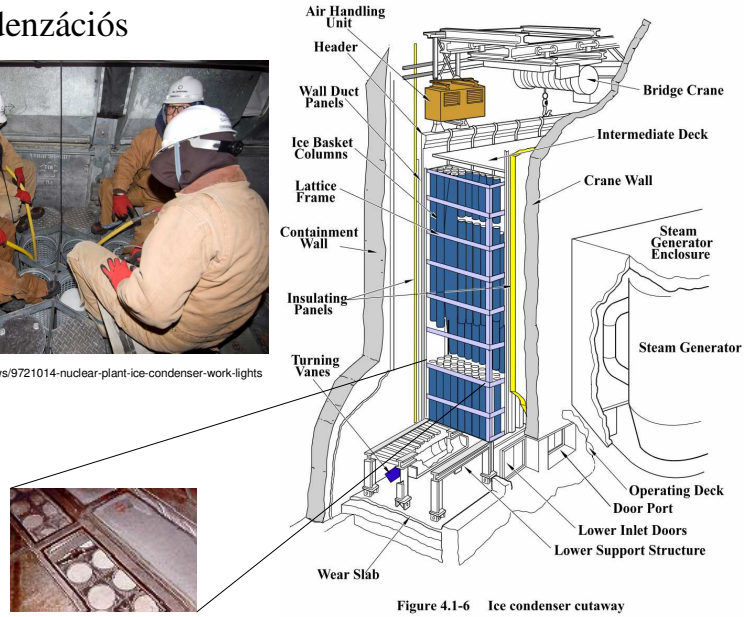


Figure 4.1-6 Ice condenser cutaway

Konténment

- Buborékoltató
  - a nagynyomású gőzt vízzel töltött nyomáscsökkentő medencékbe (4) vezeti
  - 3. alsó rész: száraz tér: primer kör, reaktor, stb.
  - középső: buborékoltatók
  - 2. felső: nedves tér

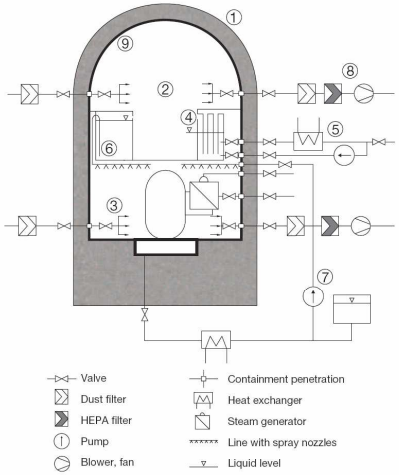
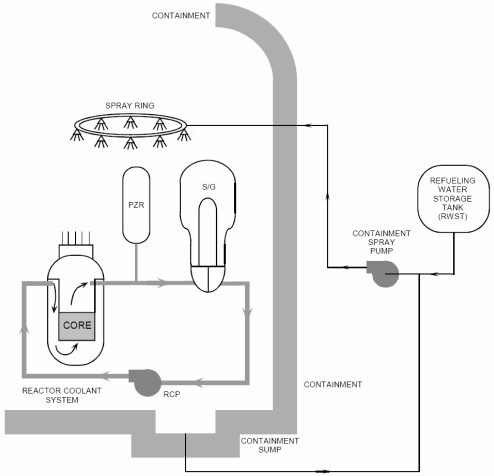
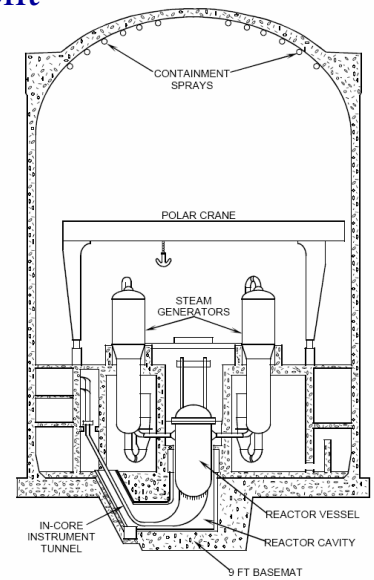


FIG. I–4. Schematic diagram of a bubbling condenser containment system for a pressurized water reactor: 1, containment; 2, upper containment volume (wet well); 3, lower containment volume (dry well); 4, bubbling condenser system (suppression pool); 5, suppression pool cooling system (not required if the heat capacity of the condenser system (4) is sufficiently large); 6, passive spray system; 7, active spray system; 8, filtered air discharge system; 9, liner.

Konténment

- Sprinkler rendszer





Konténment

Table 4.1-1 Number of U.S. containments of each type

Containment Type	Number
PWR Large Dry	59*
PWR Subatmospheric	7
PWR Ice Condenser	9
BWR Mark I	24
BWR Mark II	8
BWR Mark III	4

*Includes Big Rock Point, which is a BWR I.

Konténment

psig: relatív nyomás (túlnyomás) [psi]
(vö. psia: psi abszolút)

psi = pound per square inch

1 psi = 6,895 kPa = 0,06895 bar

12 psig = 0,82 bar
15 psig = 1,034 bar
45 psig = 3,103 bar
60 psig = 4,137 bar
62 psig = 4,275 bar

1 ft^3 = 0.02832 m^3
1,6E+06 ft^3 = 45 310 m^3
2E+06 ft^3 = 56 630 m^3

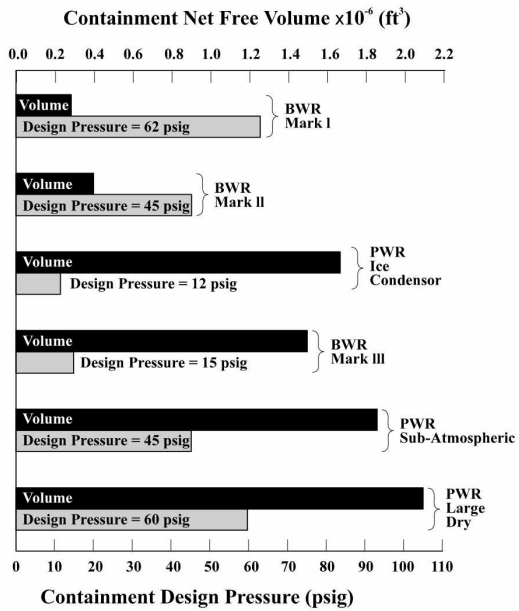


Figure 4.1-1 Typical containment volumes and design pressure (psig)

Konténment

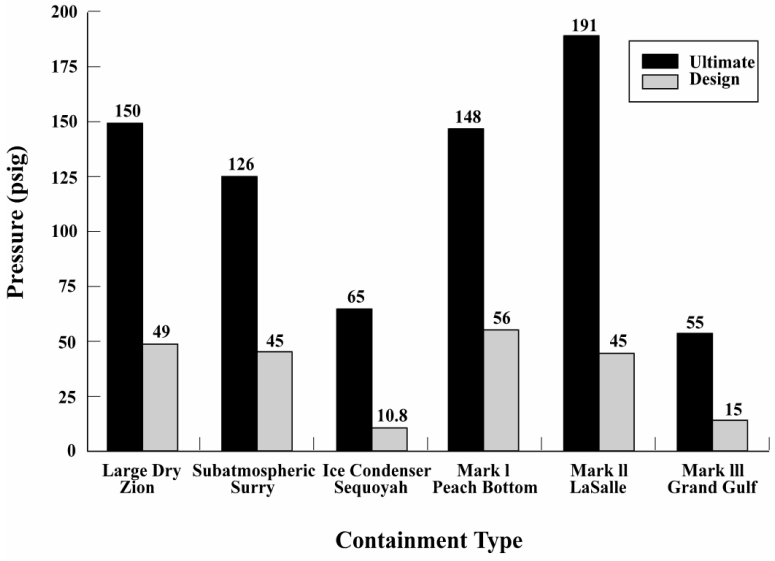
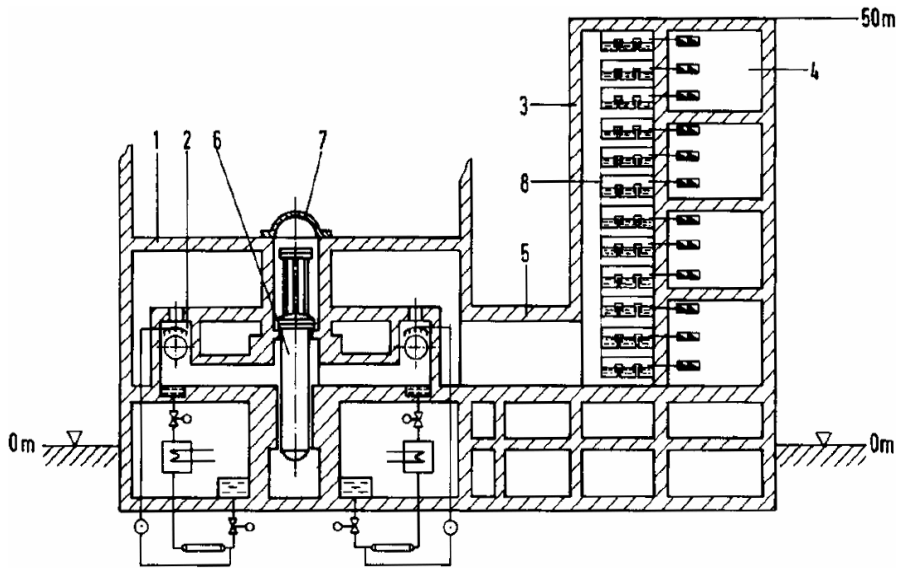
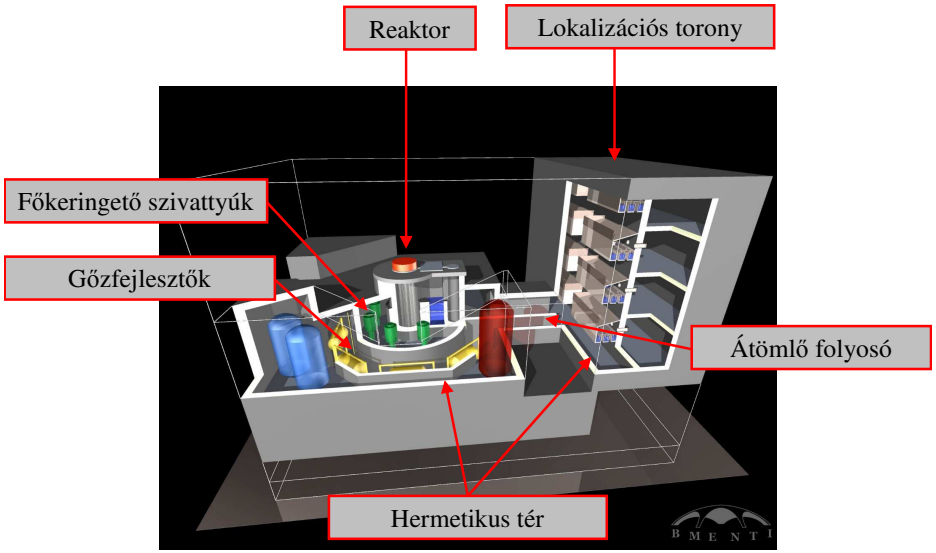


Figure 4.1-2 Comparison of design pressure and ultimate failure pressure

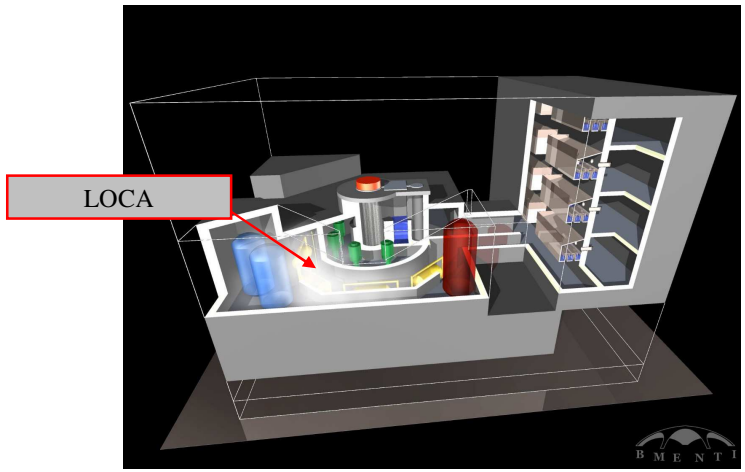
VVER-440/213 lokalizációs torony (Paks)



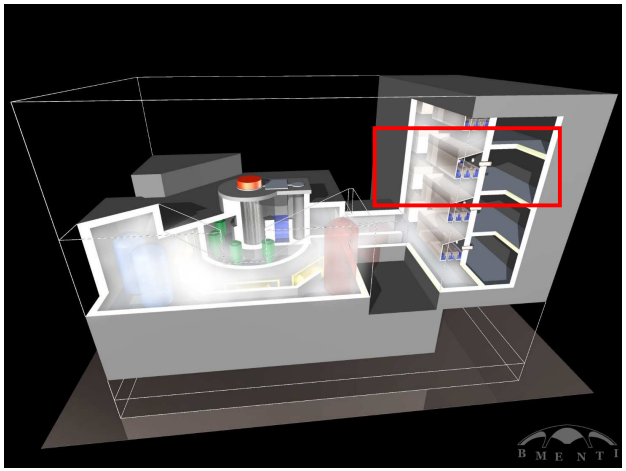
VVER-440/213 lokalizációs torony



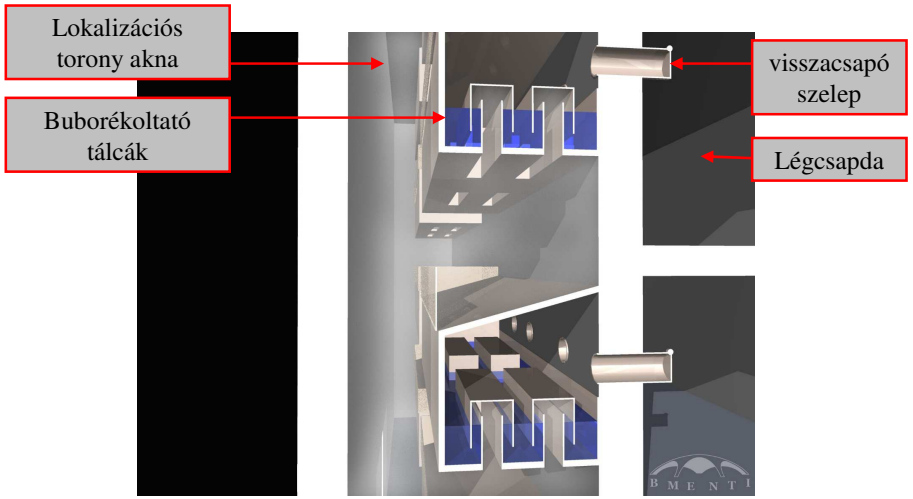
VVER-440/213 lokalizációs torony – LOCA



VVER-440/213 lokalizációs torony – LOCA



VVER-440/213 lokalizációs torony – LOCA
Lokalizációs torony



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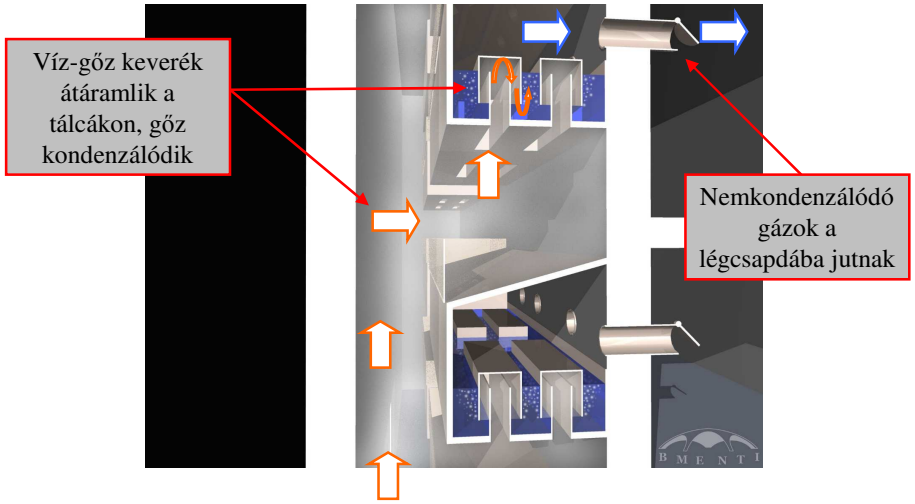
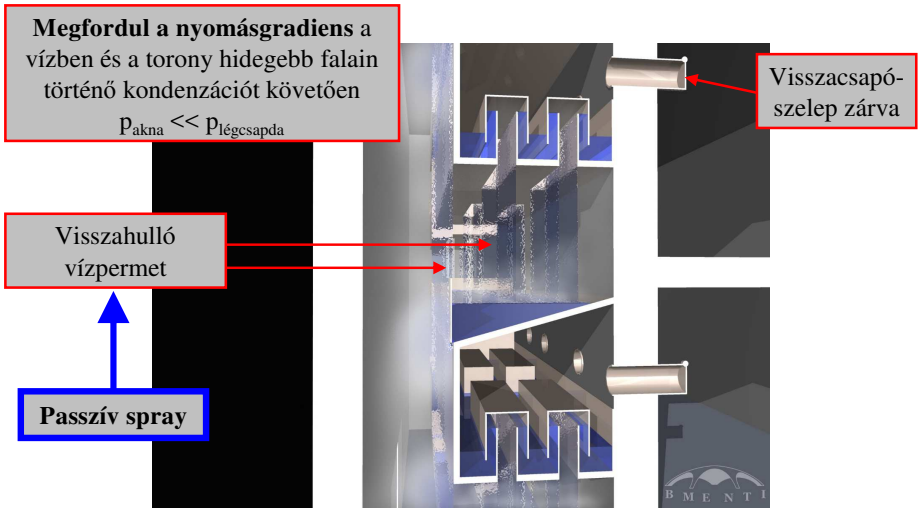
Lokalizációs torony



VVER-440/213 lokalizációs torony – LOCA
→ Passzív spray



Irodalom

- IAEA Tecdoc 1025: Assessment and management of ageing of major nuclear power plant components important to safety: Concrete containment buildings
- IAEA Tecdoc 981: Assessment and management of ageing of major nuclear power plant components important to safety: Steam generators
- IAEA Tecdoc 1556: Assessment and management of ageing of major nuclear power plant components important to safety: PWR Pressure Vessels
- IAEA Tecdoc 1557: Assessment and management of ageing of major nuclear power plant components important to safety: PWR Vessel Internals
- IAEA Tecdoc 1361: Assessment and management of ageing of major nuclear power plant components important to safety: Primary pipings in PWRs
- Fuel Design Data, Nuclear Engineering International, pp 26-35, September 2004
- ENEN/INSTN: International Seminar on Nuclear Fuel Cycle előadás anyagok
- US NRC: Reactor Concepts Manual, Pressurized Water Reactor (PWR) Systems
- US NRC: NUREG/CR-6042, Rev. 2. SAND 93-0971: Perspectives on Reactor Safety
- JNES: The Presurized Water Reactor, JNESeL-BK-003, training material
- Dr. Aszódi Attila Termohidraulika c. előadása