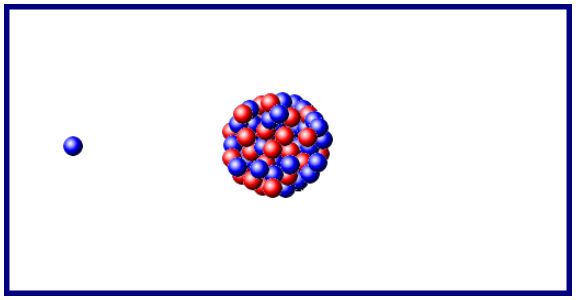
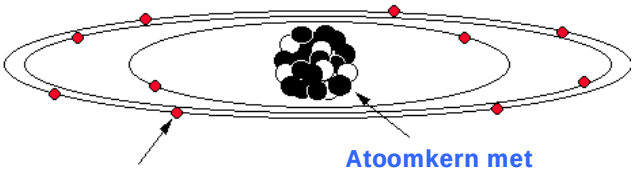
Werking van moderne kerncentrales

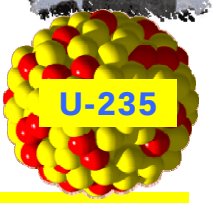


www.JanLeenKloosterman.nl

TU Delft
Delft University of Technology

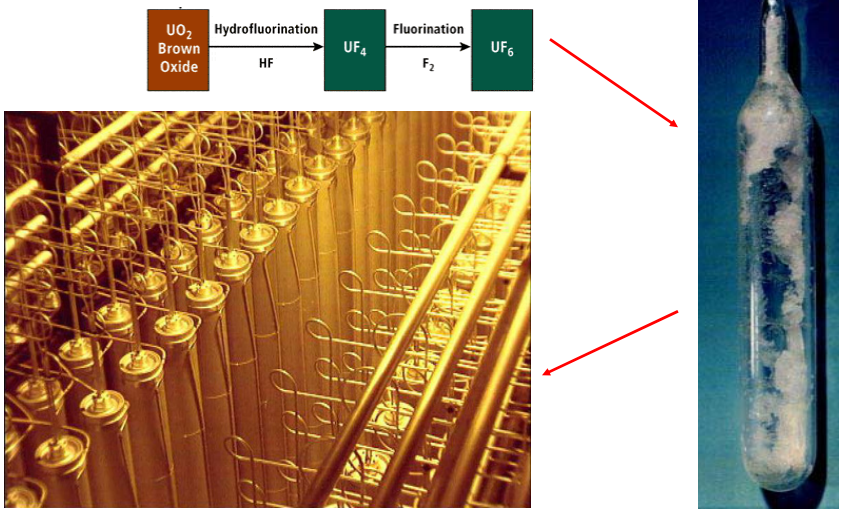
Uranium



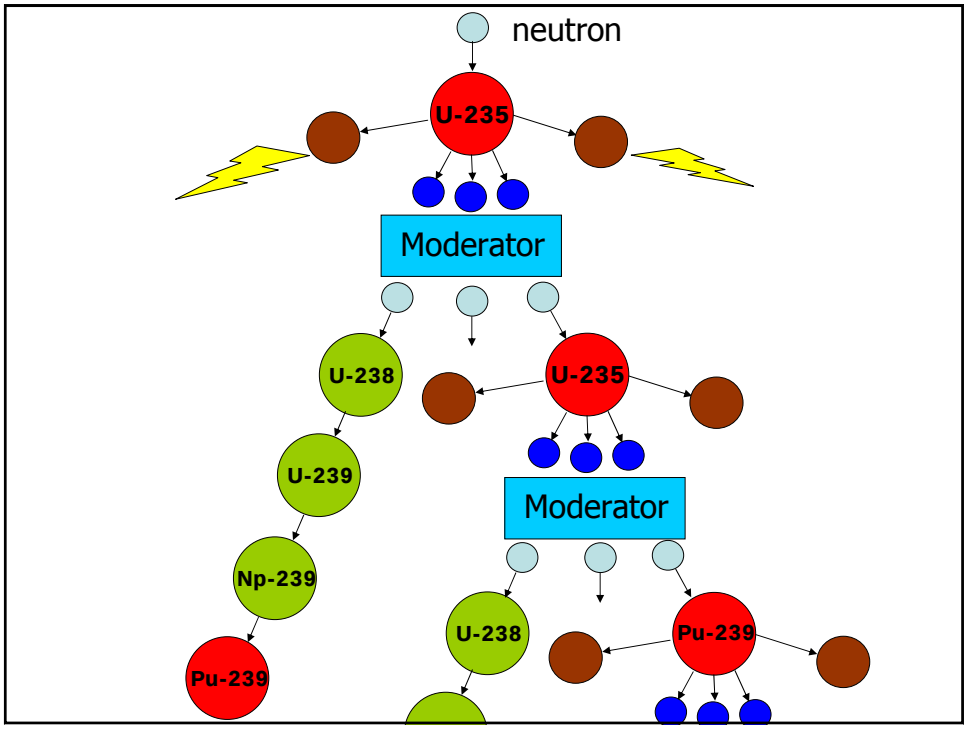


U-238	U-235
92 p en 146 n	92 p en 143 n
Niet splijtbaar	Goed splijtbaar
99,3 % voorkomen	0,7 % voorkomen

Uraniumverrijking



TU Delft



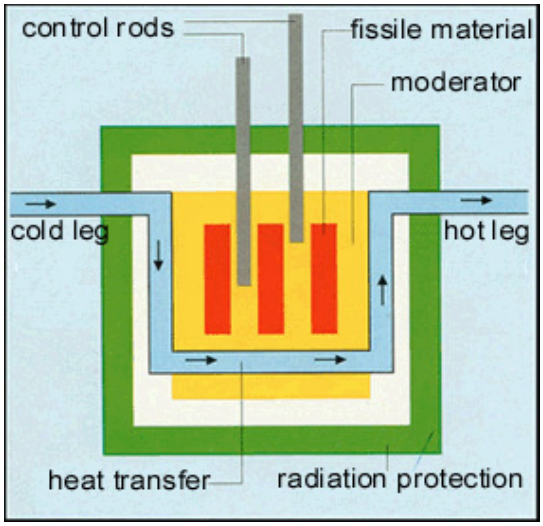
Energie dichtheid: equivalent van 1 gram

2500 liter

3000 kg

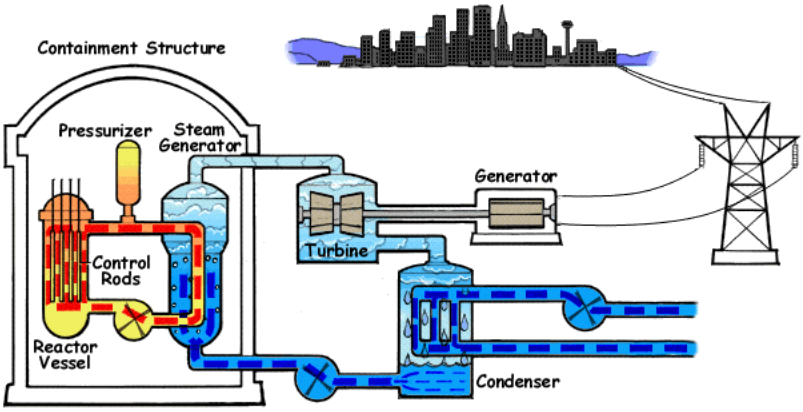
TU Delft

Componenten in reactorkern



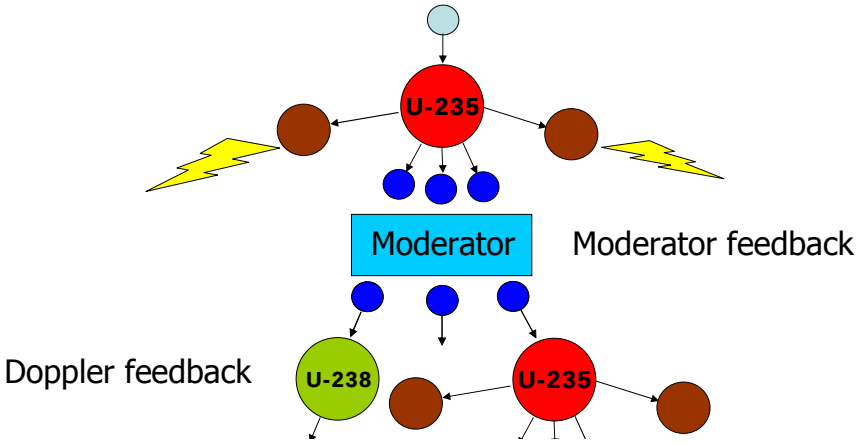
TU Delft

Werking van een drukwaterreactor (PWR)



TU Delft

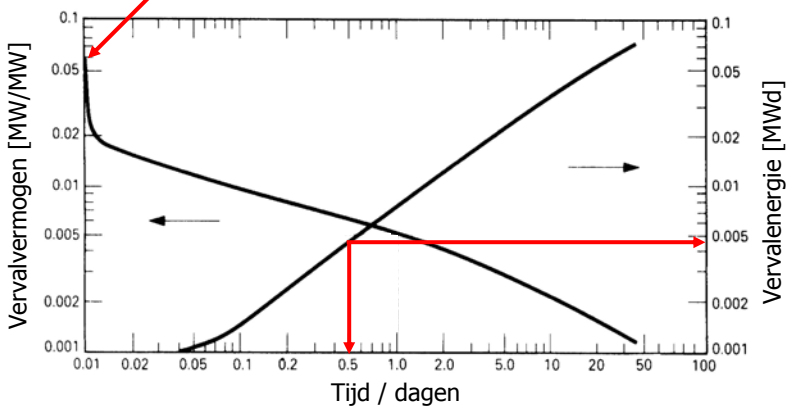
Veiligheid van lichtwaterreactoren (LWR)



1) stabiel systeem (zelfregeling)
2) verlies van koelcapaciteit schakelt de reactor af
3) verlies van moderatie schakelt de reactor af

Nawarmte: verval splijtingsproducten

KCB: 50.000 straalkachels



koeling blijft noodzakelijk na afschakeling

TU Delft

Nawarmte: verval splijtingsproducten

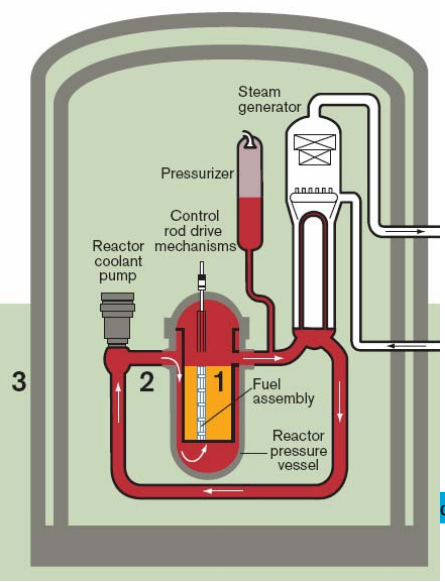
Geproduceerde warmte na 0.5 dag bedraagt:

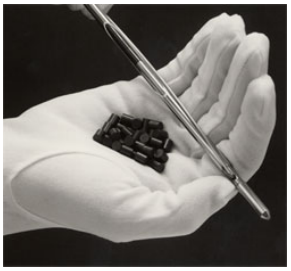
$0.0047\ \text{MWd} \approx 400\ \text{MWs} = 400\ \text{fps}$

Omschrijving	Energie (fps)
Splijtstof van $100^{o}C$ naar bedrijfstemp	9
Koelmiddel van $100^{o}C$ naar $286^{o}C$	112
Reactorvat en constructiematerialen	43

TU Delft

Principe van meerdere barrieres

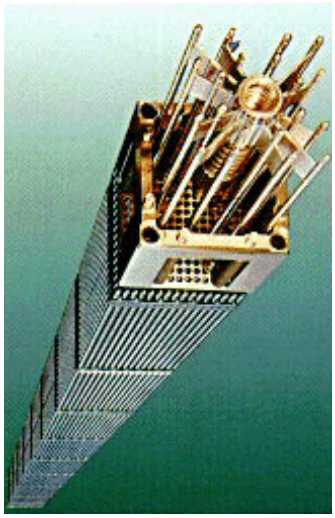


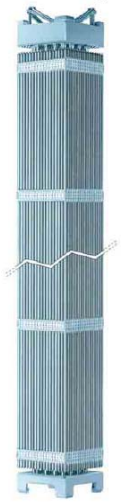


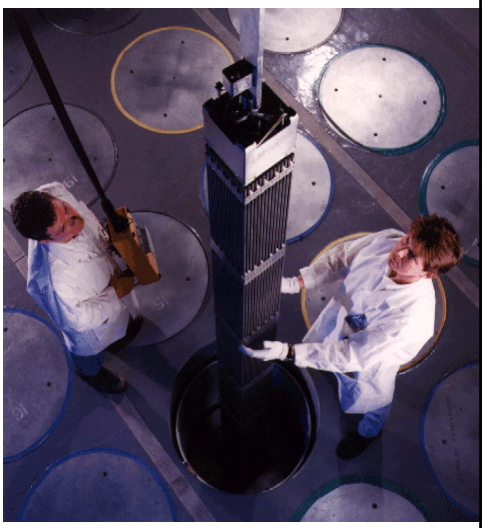
1 Splijtstof (tablet en bekleding)
2 Primair systeem (staal)
3 Veiligheidsomhulling (2x beton + staal)

TU Delft

Splijtstofelement van een PWR

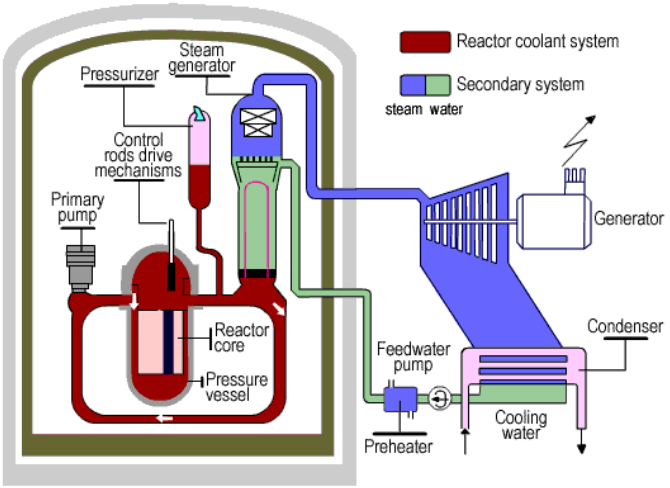






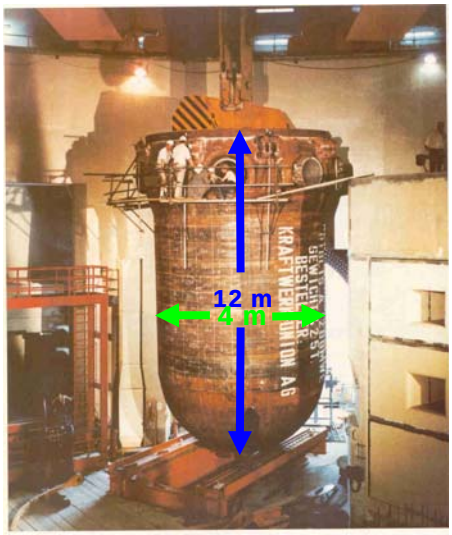
TU Delft

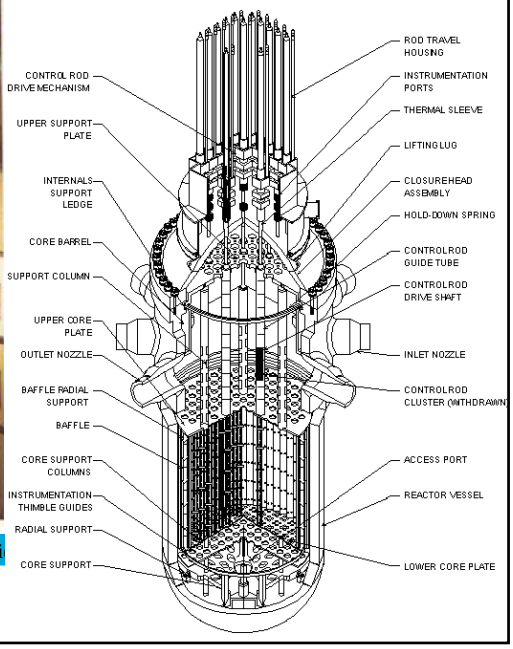
Belangrijke componenten in een PWR



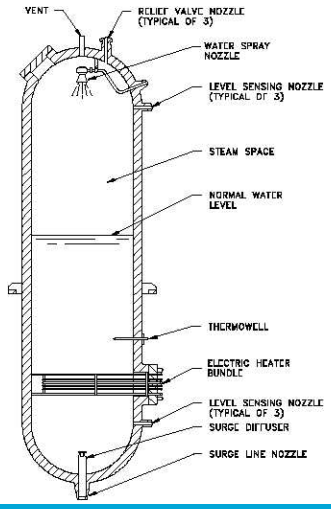
TU Delft

Reactorvat PWR



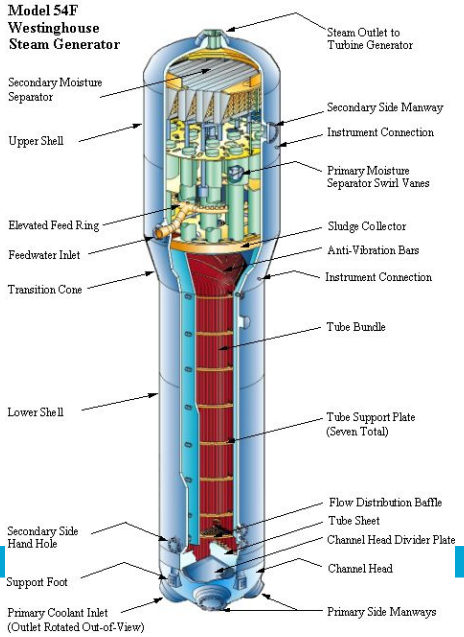


Drukhouder PWR



TU Delft

Stoomgenerator PWR



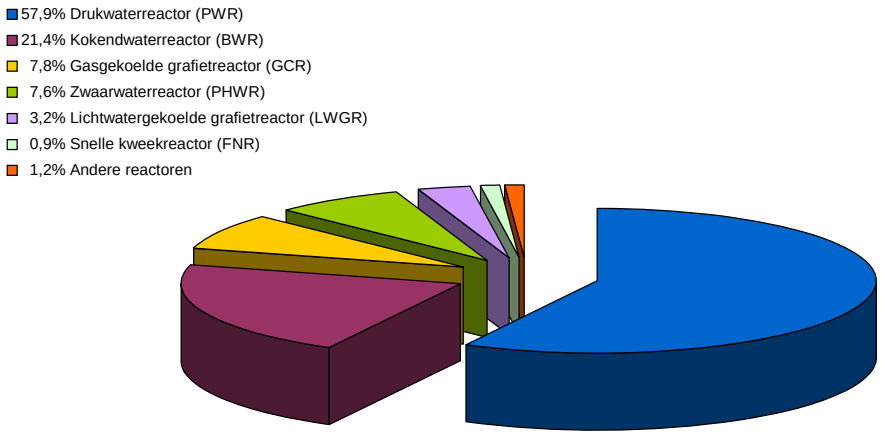
TU Delft

Vervanging stoomgenerator

TU Delft

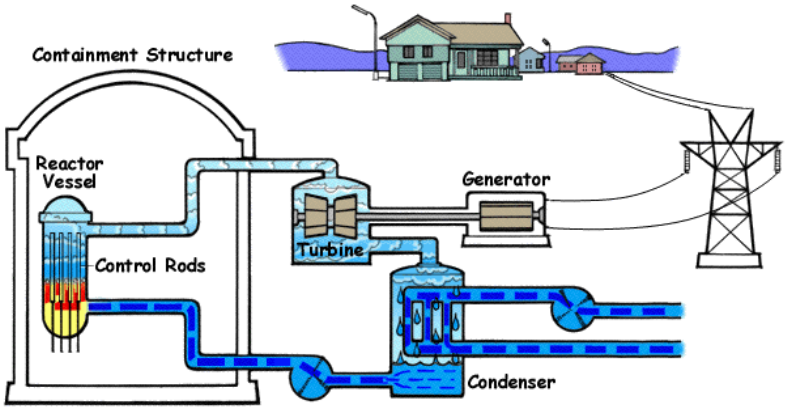
In bedrijf zijnde commerciële vermogensreactoren in 2000

(bron: Nuclear Engineering International Handbook 2000)
Totaal vermogen: 364 GWe



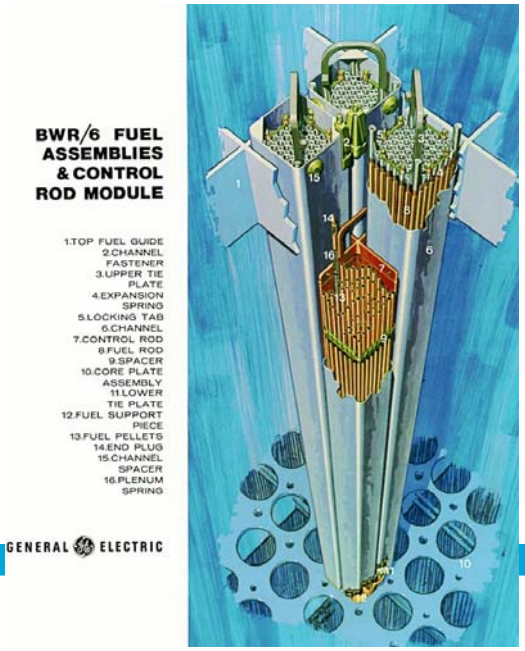
TU Delft

Werking van een BWR



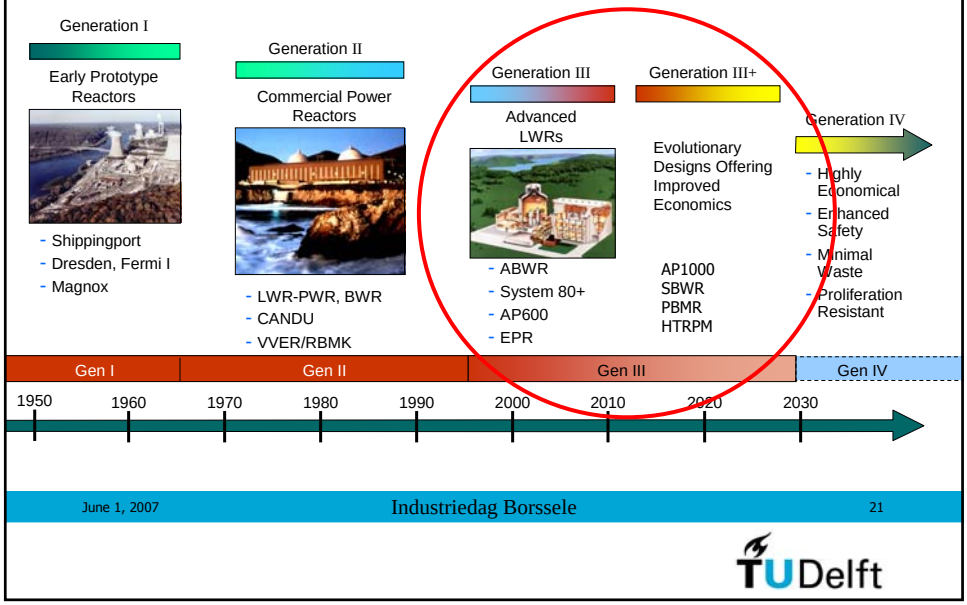
TU Delft

Splijtstofelement BWR



TU Delft

Generaties kernreactoren



TU Delft

Defense in depth

1. Design to prevent the occurrence of events (transients) that can result in damage to the fuel or reactor system
   - Negative feedback coefficients
   - Large safety margins
   - Reliable components and well-known materials
2. Protective systems to halt transients
   - Reactor SCRAM systems
   - Pressure relief valves
3. Mitigation systems to limit the consequences of transients
   - Emergency core cooling
   - Emergency secondary feed water systems
   - Emergency electrical systems
   - Multiple barriers to the biosphere

Defense in depth generation II

1. Design to prevent the occurrence of events (transients) that can result in damage to the fuel or reactor system
   - Negative feedback coefficients
   - Large safety margins
   - Reliable components and well-known materials
2. Protective systems to halt transients
   - Reactor SCRAM systems
   - Pressure relief valves
3. Mitigation systems to limit the consequences of transients
   - Emergency core cooling
   - Emergency secondary feed water systems
   - Emergency electrical systems
   - Multiple barriers to the biosphere

Defense in depth generation III

1. Design to prevent the occurrence of events (transients) that can result in damage to the fuel or reactor system
   - Negative feedback coefficients
   - Large safety margins
   - Reliable components and well-known materials
2. Protective systems to halt transients
   - Reactor SCRAM systems
   - Pressure relief valves
3. Mitigation systems to limit the consequences of transients
   - Emergency core cooling
   - Emergency secondary feed water systems
   - Emergency electrical systems
   - Multiple barriers to the biosphere

Defense in depth generation III+

1. Design to prevent the occurrence of events (transients) that can result in damage to the fuel or reactor system
   - Negative feedback coefficients
   - Large safety margins
   - Reliable components and well-known materials
2. Protective systems to halt transients
   - Reactor SCRAM systems
   - Pressure relief valves
3. Mitigation systems to limit the consequences of transients
   - Emergency core cooling
   - Emergency secondary feed water systems
   - Emergency electrical systems
   - Multiple barriers to the biosphere

European Pressurized-water Reactor

TU Delft

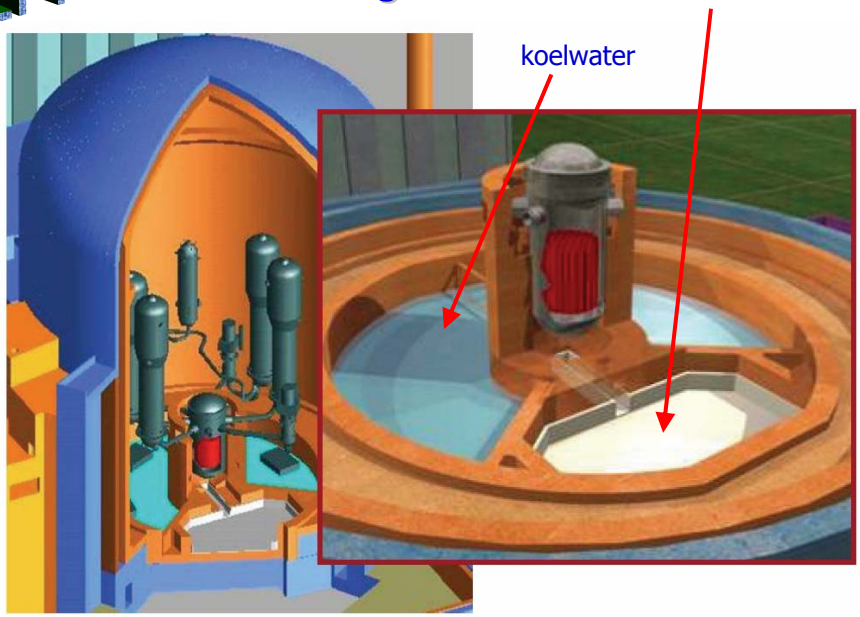
Dubbele veiligheidsomhulling

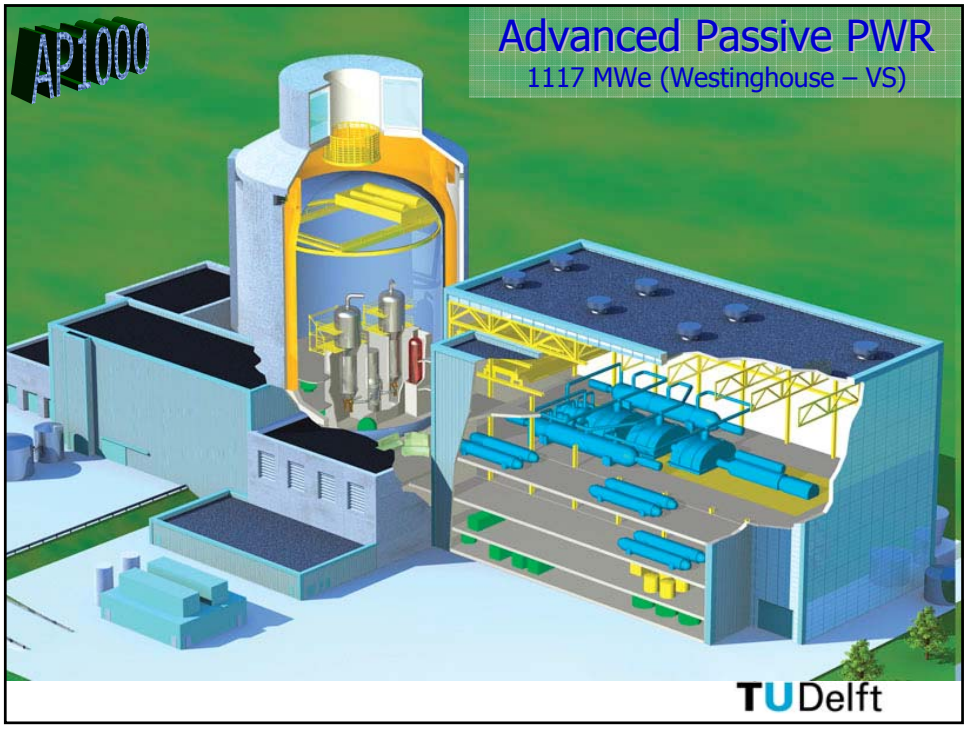
– beton –
– staal –
– beton –

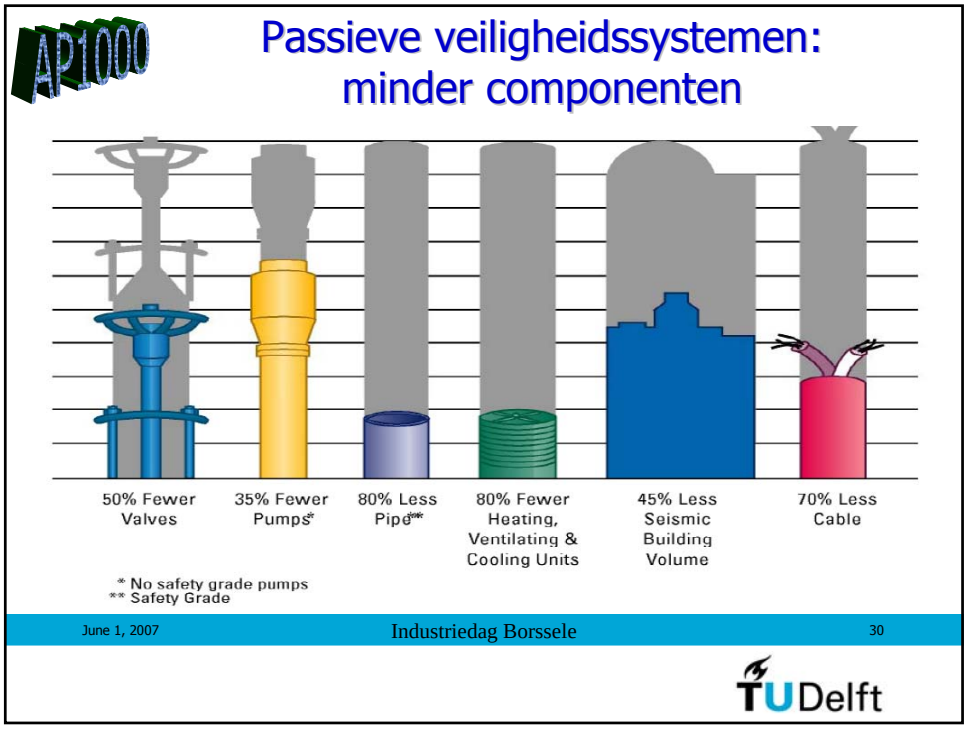
bestand tegen de inslag van een groot verkeersvliegtuig

TU Delft

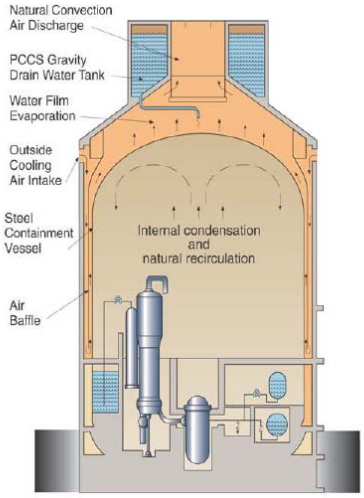
Passief gekoelde 'Core catcher'




AP1000
Advanced Passive PWR
1117 MWe (Westinghouse – VS)
TU Delft


AP1000
Passieve veiligheidssystemen:
minder componenten
50% Fewer Valves
35% Fewer Pumps*
80% Less Pipe**
80% Fewer Heating, Ventilating & Cooling Units
45% Less Seismic Building Volume
70% Less Cable
* No safety grade pumps
** Safety Grade
June 1, 2007
Industriedag Borssele
30
TU Delft

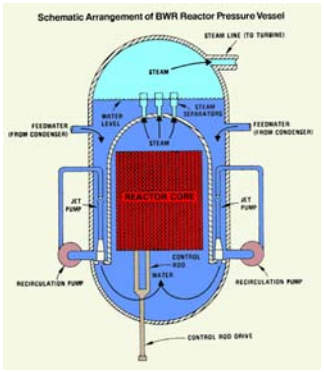
Passieve noodkoeling van veiligheidsomhulling



TU Delft

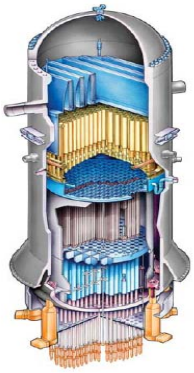
Generaties BWR

gen II



gen III

ABWR

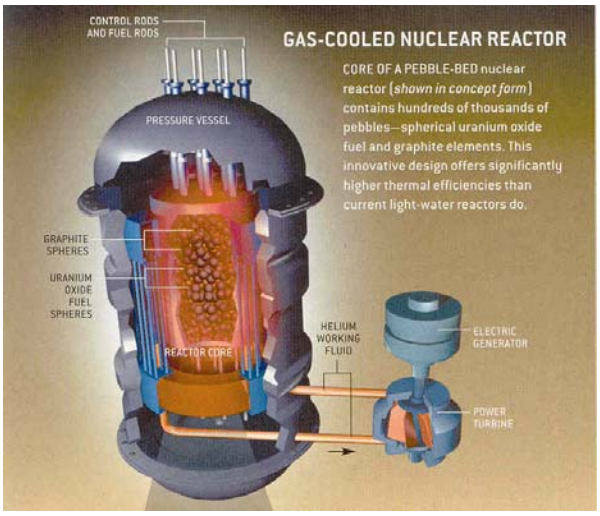


gen III+

ESBWR

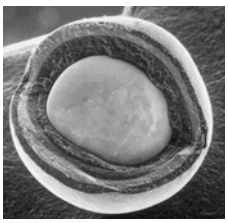
TU Delft

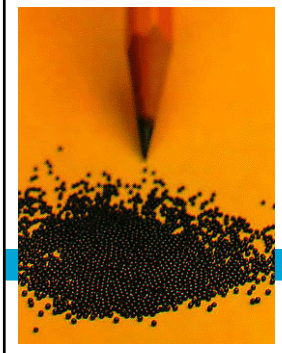
High Temperature Reactor (HTR)

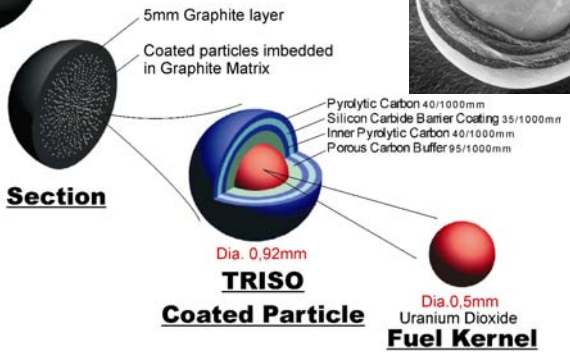


TU Delft

TRISO splijtstof

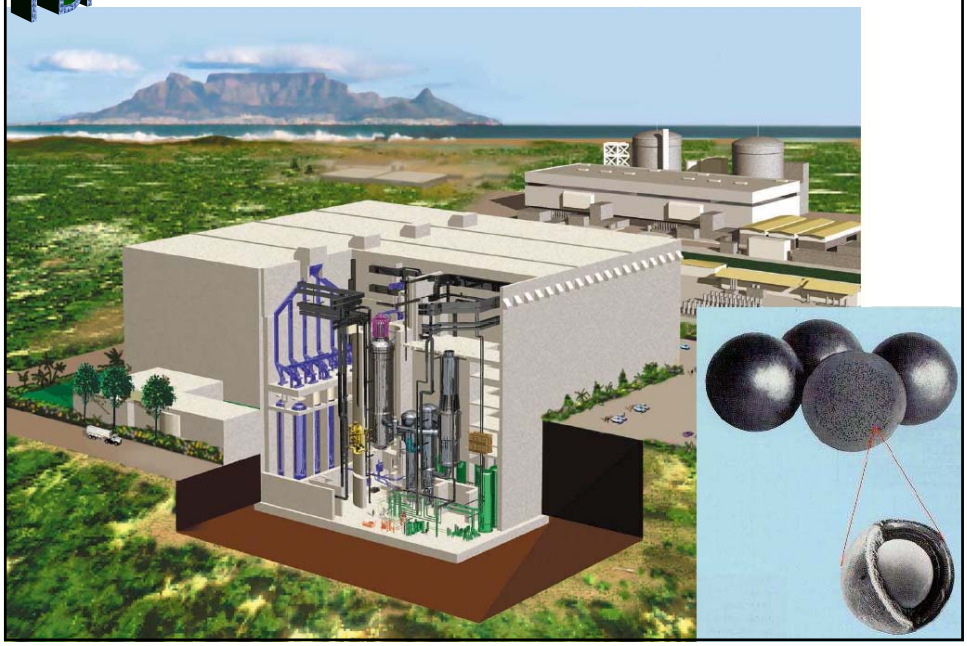






TU Delft

Pebble-Bed Modular Reactor



Overzicht van moderne kerncentrales

	Generatie III		Generatie III+			
	ABWR	**EPR**	**AP1000**	**ESBWR**	**PBMR**	**HTR-PM**
Type	BWR	PWR	PWR	BWR	HTR	HTR
Generatie	III	III	III+	III+	III+	III+
Vermogen	1350	1600	1150	1550	165	190
VS certificatie	ja	2007	ja	2010	nee	nee
In gebruik	3	0	0	0	0	0
In aanbouw	3	1	0	0	0	0
Respijtperiode	72 uur	30 min.	72 uur	24 uur	∞	∞
Kernsmeltfrequentie (1/jaar)	$2 \cdot 10^{-7}$	$1.3 \cdot 10^{-6}$	$4 \cdot 10^{-7}$	$3 \cdot 10^{-8}$	0	0
'core catcher'	nee	ja	<24 uur	<24 uur	onnodig	onnodig
Constructietijd (jr)	4	4	3	3	2	?
Technische levensduur (jr)	60	60	60	60	?	?