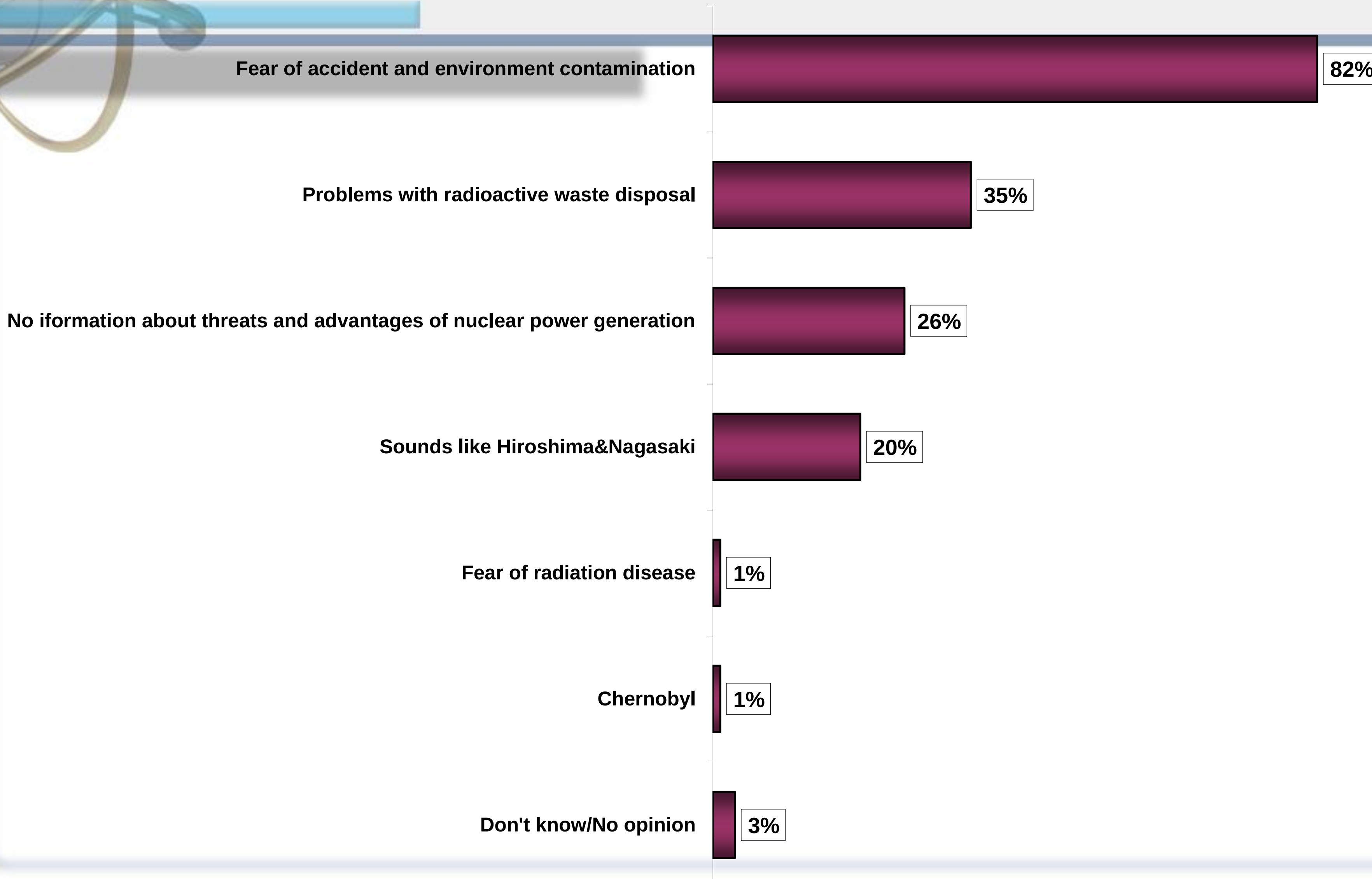
Nuclear safety issues

Adam Jerzy Rajewski
Division of Thermodynamics
Institute of Heat Engineering
Politechnika Warszawska

Reasons the people oppose construction of a NPP in Poland



Find a difference...

Kraftwerk Schwarze Pumpe
Spremberg, Germany
2 × 800 MW, lignite

Once-through steam generator
Complex regeneration system
Supercritical steam, 260 bar, 550˚C

Kernkraftwerk Krümmel
Geesthacht, Germany
1 × 1400 MW, BWR

Boiling water reactor, single circuit
Simpler regeneration system
Wet steam, 70 bar, 280˚C

Key difference: Attitude

WHAT'S SO SPECIAL?

Other businesses with the same approach:

Civilian aviation

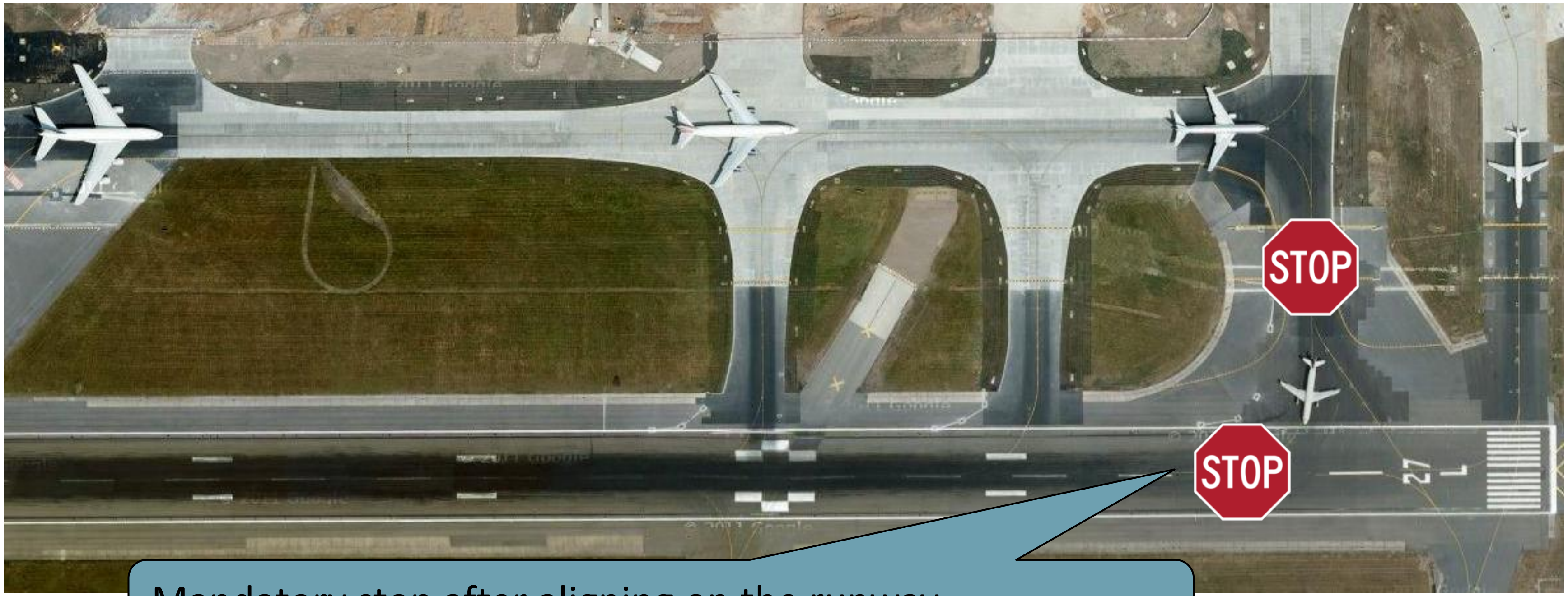
Military

Healthcare

…or is it REALLY the same?

AVIATION, "REGULATIONS WRITTEN WITH BLOOD"

Departure "by the book"



Mandatory stop after aligning on the runway

Is it ALWAYS done this way?

"YOUR SAFETY IS OUR FIRST PRIORITY"

"Please make sure all your electronic devices are switched off at this time"

"Please find your way to the nearest emergency exit"

"Please remain seated and do not switch your phone on until the aircraft has stopped completely and the seat belt sign has been switched off"

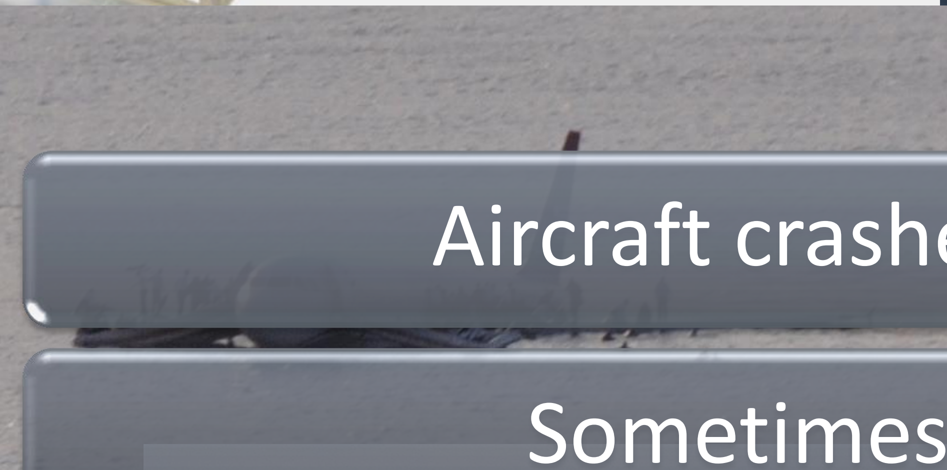
Do you REALLY do as instructed?

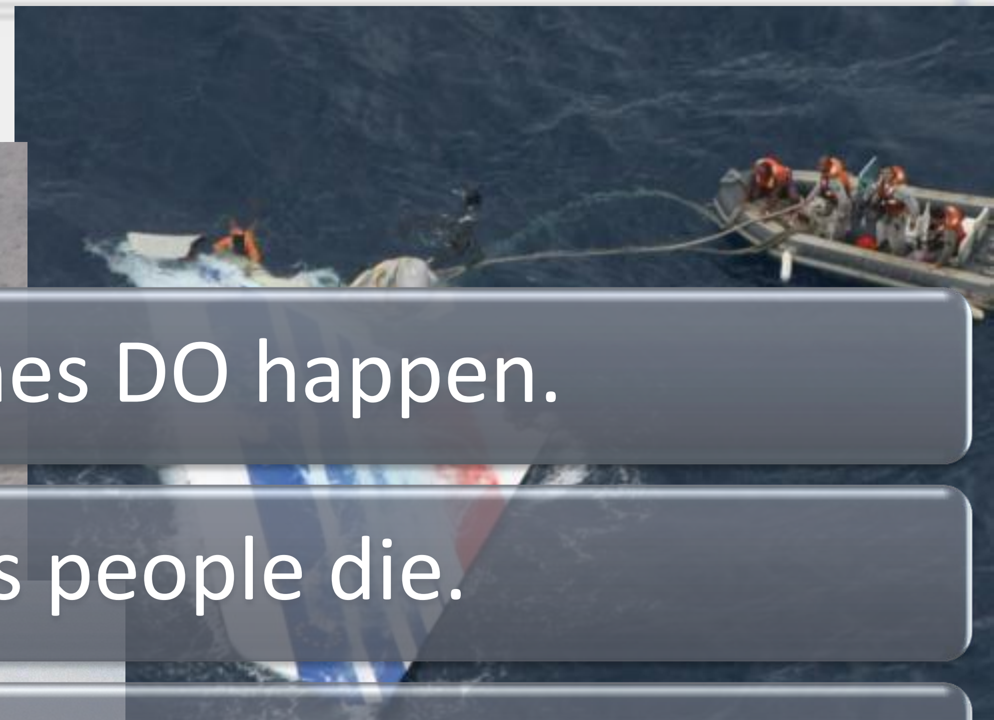
Does ANYONE check it?

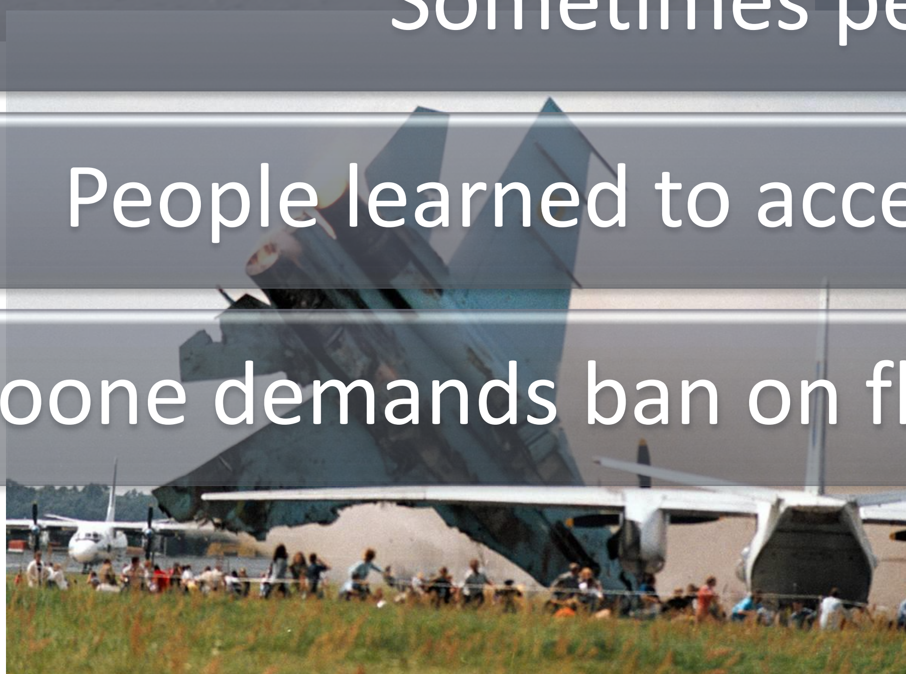
Are there any penalties?

Other kinds of safety rules…

…BUT…







Aircraft crashes DO happen.

Sometimes people die.

People learned to accept this possibility.

Noone demands ban on flying because of that!

SMALLER SCALE INCIDENTS AND ACCIDENTS – EVER HEARD OF THEM?

Monday Oct 22nd 2012

- (I) Chautauqua E145 near New York on Oct 22nd 2012, unidentified noises in flight

Sunday Oct 21st 2012

- (I) Emirates A388 at Tokyo on Oct 21st 2012, asymmetric flaps
- (I) Lufthansa A321 at London on Oct 21st 2012, fumes in cabin
- (I) Emirates A332 at Lusaka on Oct 21st 2012, uncontained engine failure
- (I) Arann AT42 near Shannon on Oct 21st 2012, engine shut down in flight

Saturday Oct 20th 2012

- (I) Air Berlin A320 at Zweibrucken on Oct 20th 2012, near collision with ultralight
- (I) OLT F100 at Saarbruecken on Oct 20th 2012, could not retract gear
- (I) Transavia B738 near Zagreb on Oct 20th 2012, odour in cabin

Friday Oct 19th 2012

- (I) Swiss RJ1H at Basel on Oct 19th 2012, slanting nose wheel
- (I) Sriwijaya B734 at Pontianak on Oct 19th 2012, overran runway on landing
- (I) Mount Cook AT72 near Invercargill on Oct 19th 2012, engine shut down in flight
- (I) Thomas Cook B763 near Dublin on Oct 19th 2012, smoke in cockpit
- (I) Norwegian B738 at Oslo on Oct 19th 2012, rejected takeoff
- (A) jet2 B738 at Glasgow on Oct 19th 2012, rejected takeoff

Thursday Oct 18th 2012

- (I) Westjet B737 near Calgary on Oct 18th 2012, burning odour in cabin
- (I) Skywest CRJ9 near Los Angeles on Oct 18th 2012, engine shut down in flight
- (I) American Eagle CRJ7 at Los Angeles on Oct 18th 2012, hydraulic failure
- (I) Jetblue E190 at Orlando on Oct 18th 2012, hydraulic problem

Search results for "Poland"

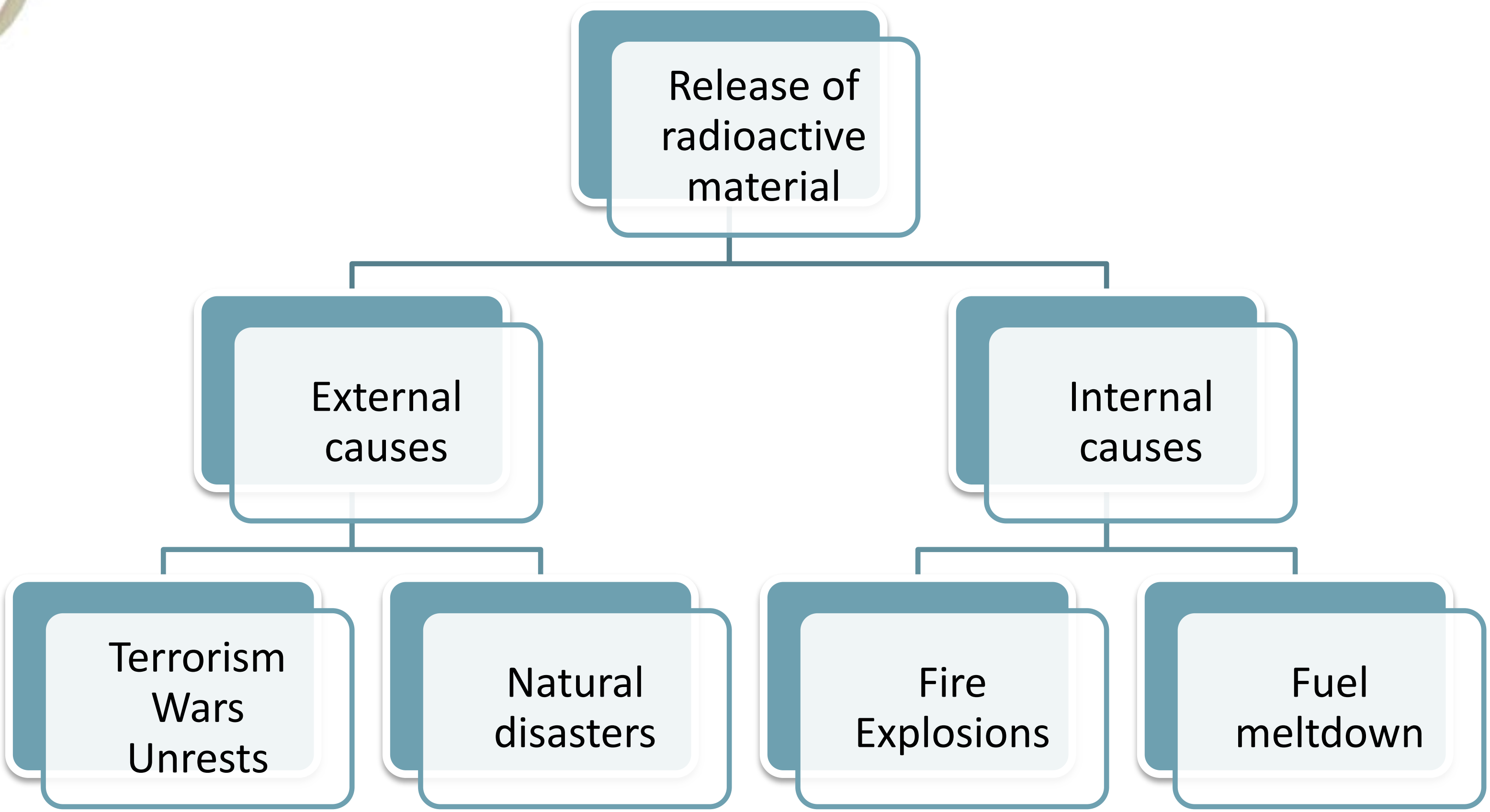
- (I) Mars RK SF34 near Warsaw on Sep 24th 2012, engine problem
- (I) Easyjet A319 at Krakow on Sep 12th 2012, nose gear steering fault
- (I) Air France A319 at Prague on Sep 7th 2012, loss of separation
- (I) Bingo A320 near Warsaw on Sep 2nd 2012, hydraulic fault
- (I) Wizz A320 at Gdansk on Aug 29th 2012, bird strike
- (I) Finnair B752 over Poland on Aug 16th 2012, cracked windshield
- (I) Travel Service B738 near Warsaw and Prague on Aug 5th 2012, cabin pressure problems
- (I) Ryanair B738 near Berlin on Jul 11th 2012, medical emergency
- (I) LOT B734 near Geneva on Jul 5th 2012, cabin pressure problems
- (I) Swiftair AT72 near Poznan on Jun 26th 2012, engine shut down in flight
- (I) Lufthansa E190 at Munich on Jun 2nd 2012, burst tyre on takeoff
- (I) OLT Express A320 near Sofia on May 17th 2012, loss of cabin pressure, fire in cabin
- (I) Ryanair B738 near London on May 10th 2012, pitot failure
- (I) LOT B763 over Atlantic on Feb 24th 2012, unruly passenger
- (I) CSA AT42 near Prague on Feb 15th 2012, captain incapacitated and died
- (I) Sprint SF34 at Kiev on Feb 2nd 2012, rejected takeoff
- (I) Austrian DH8D near Krakow on Jan 28th 2012, engine shut down in flight
- (I) Eurolot AT42 at Wroclaw on Nov 15th 2011, took off from taxiway
- (I) LOT B734 at Warsaw on Nov 3rd 2011, window opened on takeoff
- (A) LOT B763 at Warsaw on Nov 1st 2011, forced gear up landing
- (I) Brussels RJ1H near Berlin on Oct 20th 2011, fuel system problem
- (I) Air France A320 and Emirates A388 near Frankfurt on Oct 14th 2011, wake turbulence
- (I) Air Baltic B735 near Krakow on Oct 11th 2011, cracked passenger window
- (I) TNT B733 near Berlin on Sep 14th 2011, loss of cabin pressure

NPP ACCIDENTS

Safety of nuclear reactor operation

- Fission is carried out within the fuel pellets ONLY!
- Radioactive fission products are contained within the fuel elements
- Safety barriers:
  - Pellet structure (for solids)
  - Fuel element cladding
  - Integral coolant (primary) circuit
  - Biological shield (concrete, water)
  - Containment (concrete)
- Heat is transferred through the cladding into coolant

What can go wrong?



External threats

Proper civil design

- Building designed to withstand possible earthquakes, wind, tsunami waves…
- Building designed to withstand bomb/aircraft impact

Security measures

- Good access control measures
- Counterintelligence protection
- Thought-through location of nuclear power plants

INTERNAL THREATS

Nuclear fuel meltdown

- Caused by lack of proper cooling (Decay heat removal)
  - Loss-of-coolant-accidents (LOCAs)
  - Damage/failure of external heat removal systems (connection with heat sinks)
- Prevented by multiple independent safety systems ensuring emergency cooling
- In case of actual meltdown results contained by core-cather systems (modern reactors only!)

Internal explosions

- Hydrogen explosion threat (in case of core overheating) – possible spread of radiactive material
- Prevented by hydrogen recombination systems
- Proper building design helps to contain potential explosion in some cases (TMI)

Safety systems

Dealing with emergencies

- Full separation from normal control
- Designed for containing emergencies ONLY!

Examples of safety systems:

- Emergency coolant supply (multiple components)
- Pressure relief systems
- Hydrogen recombination systems
- Core catchers

Safety systems

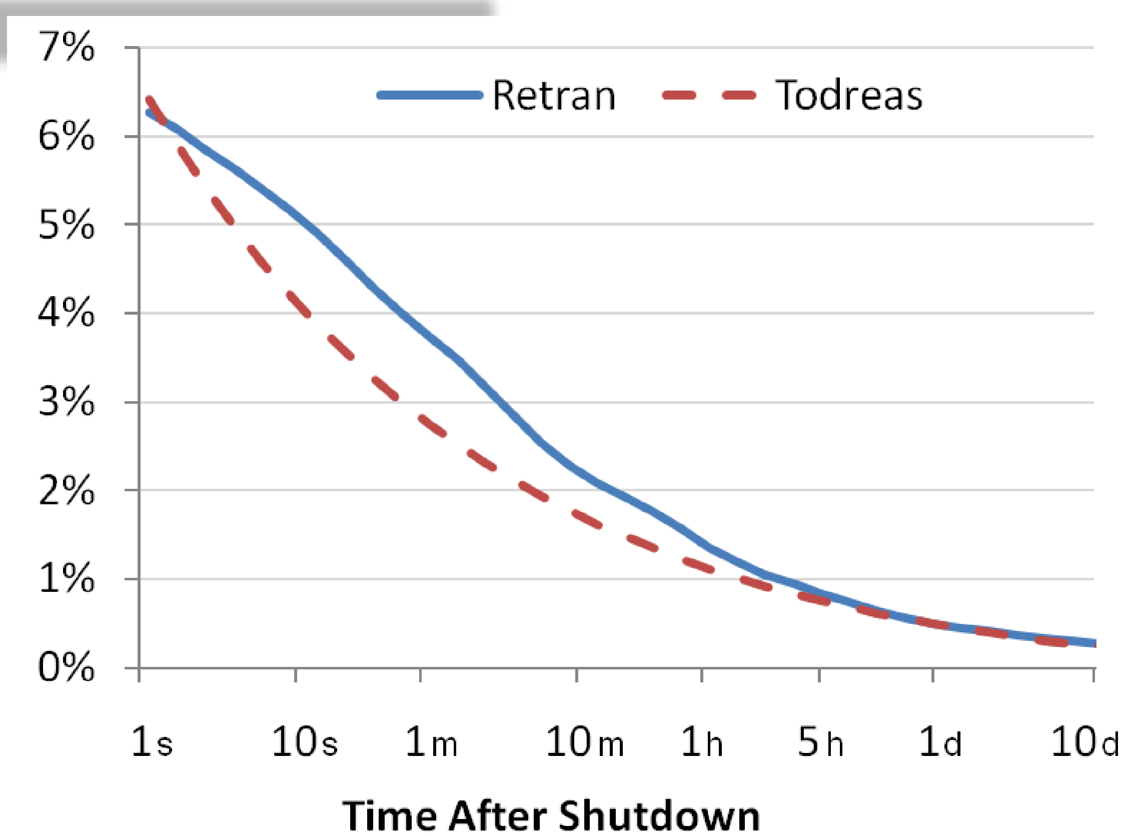
Active

- Need external power supply
- Divided into several absolutely independent divisions (absolute mechanical and electrical separation)
- Controlled independently from normal control systems

Passive

- No external power supply needed
- No operator's input needed
- No automation needed
- Based on physical phenomena (like natural convection, pressure differences etc.)
- Present in all modern reactor designs, although on different levels (e.g. core meltdown prevention or containment of already damaged core)

Decay heat



After 1 year 1 tonne of spent nuclear fuel typically generates 10 kW of heat. After 10 years it drops to 1 kW.

International Nuclear Event Scale

- 0 – Deviation (below scale)
- 1 - Anomaly
- 2 - Incident
- 3 – Serious Incident
- 4 – Accident With Local Consequences
- 5 – Accident With Wider Consequences
- 6 – Serious Accident
- 7 – Major Accident

INES 7 – Major Accident

Chernobyl 1986

- Reactor fire

Fukushima Dai-ichi 2011

- Reactor explosions following tsunami flooding

INES 6 – Serious Accident

Kyshtym 1957

- Explosion of a tank with liquid radioactive waste

INES 5 – Accident With Wider Consequences

Windscale 1957

- Fire in a nuclear pile

Three Mile Island 1979

- Partial meltdown of a PWR core

INES 4 – Accident With Local Consequences

Jaslovské Bohunice (A1), 1977

- Overheating and damage to fuel elements of KS-150 reactor

Saint-Laurant 1969, 1980

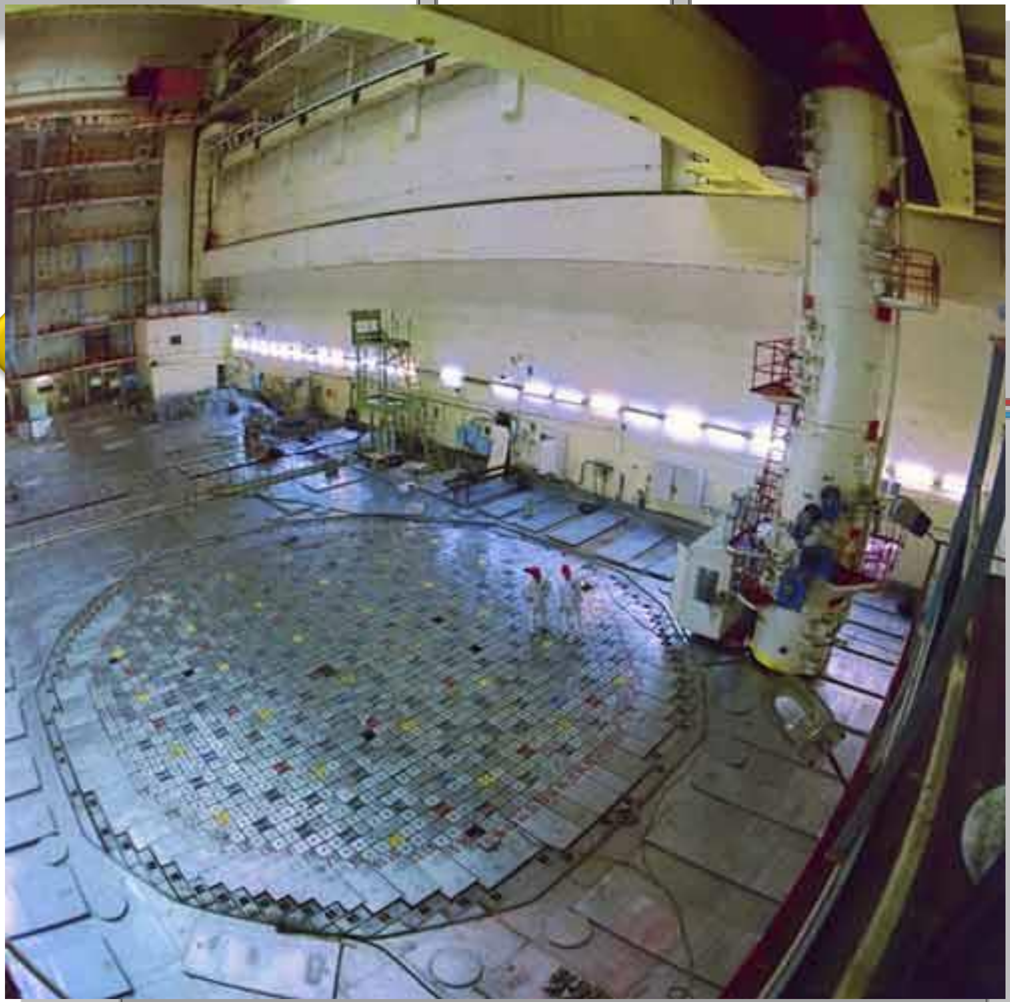
- Meltdown of small amount of uranium(1969)
- Uncontrolled power leap(1980)

Tokaimura 1999

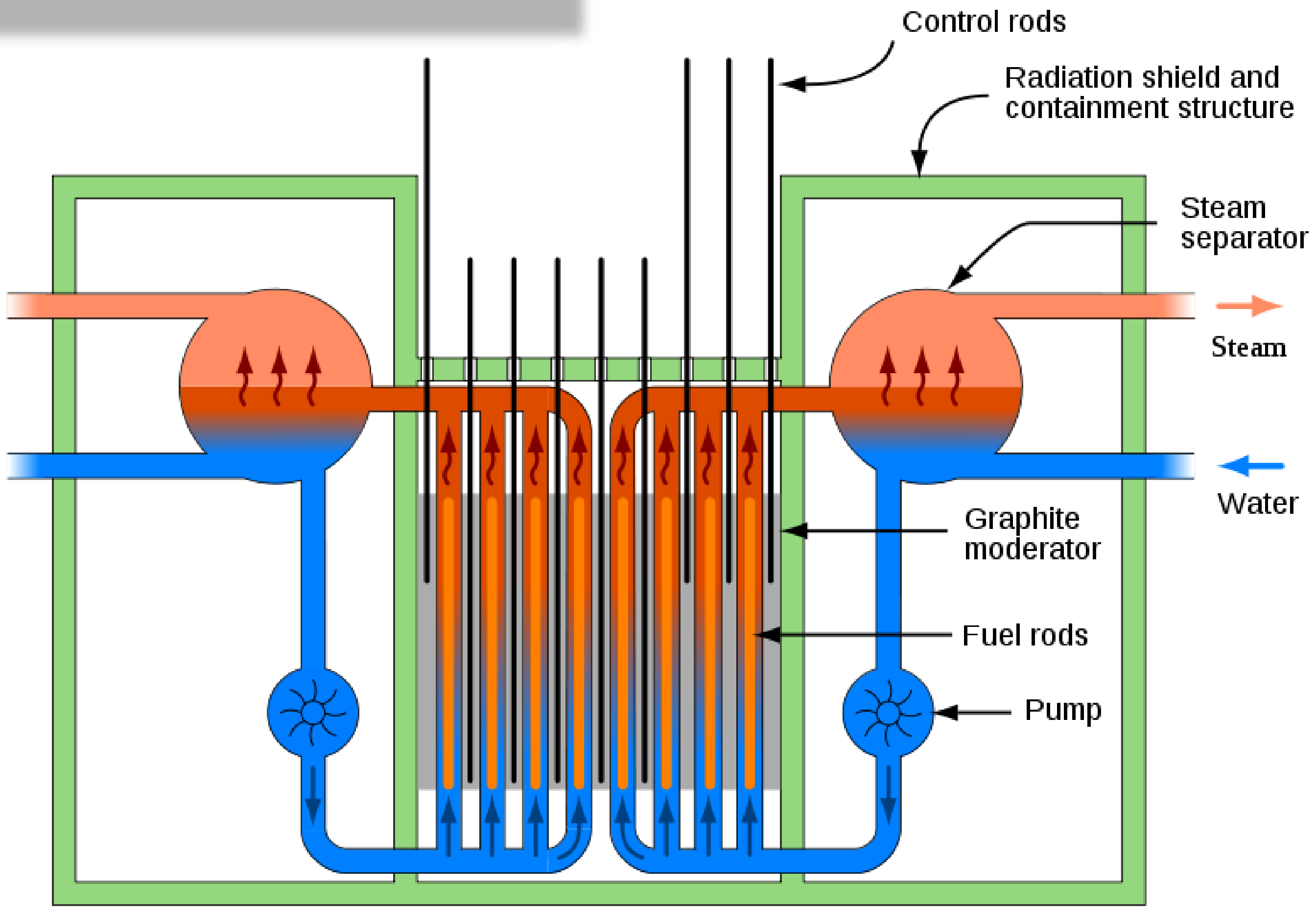
- Criticality accident at uranium reprocessing faciltiy

26.04.1986 Chernobyl USSR

RBMK-1000 Reactor



RBMK-1000 Reactor



CHERNOBYL 4 DISASTER

- Test of own consumption being fed from the T/G set rundown after sudden turbine trip
- Test to be conducted at decreased power

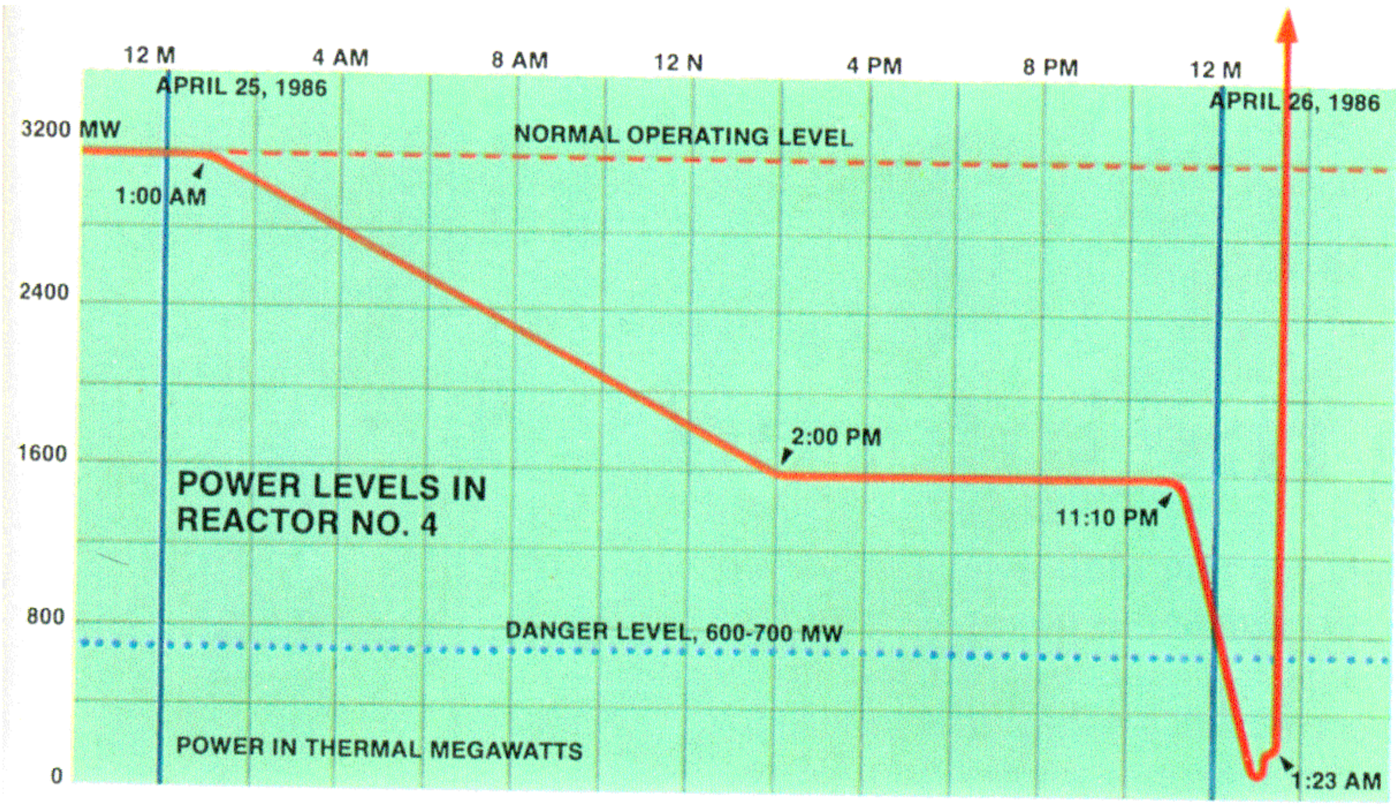
Chernobyl 4 – 25 April 1986

- 01:06 – Power decrease commenced
- 03:47 – Power stabilized at 1600 MWth, one turbine shut down
- 14:00 – Emergency cooling system disconnected for experiment
- 14:00 – Power dispatcher from Kiev opposes disconnection of another turbine, test delayed
- 23:10 – Power decrease commenced
- 00:28 – Power decreased to 500 MWt, then sudden unexpected drop to 30 MWt
- 00:32 – Power increased again with control rods withdrawal
- 01:00 – Power increased to 200 MWt
- 01:03 – Extra coolant pump engaged
- 01:07 – One more extra coolant pump engaged
- 01:19 – Further control rods withdrawn to stabilize steam drum operation
- 01:22 – Operator decides that the power is stable, reactor ready for test

Chernobyl 4 – 26 April 1986

- 01:23:04 – Steam valves shut
- 01:23:10 – Automatic control rods withdraw for some 10 seconds
- 01:23:21 – Increased steam generation results with power increase
- 01:23:44 – Power exceeds design level 100 times
- 01:24:00 – Two explosions, roof of reactor hall is blown off

CHERNOBYL 4 – POWER LEVELS



Main reasons of the disaster

- Experiment plan violated NPP safety regulations on twelve issues
- Positive void coefficient of RBMK reactor – power increases with temperature
- Graphite moderator – water gas generation above 1000˚C
- Zirconium fuel channels – reaction with water and hydrogen generation
- No reactor containment
- Combustible moderator/structural elements (graphite)

Chernobyl-4 after explosion

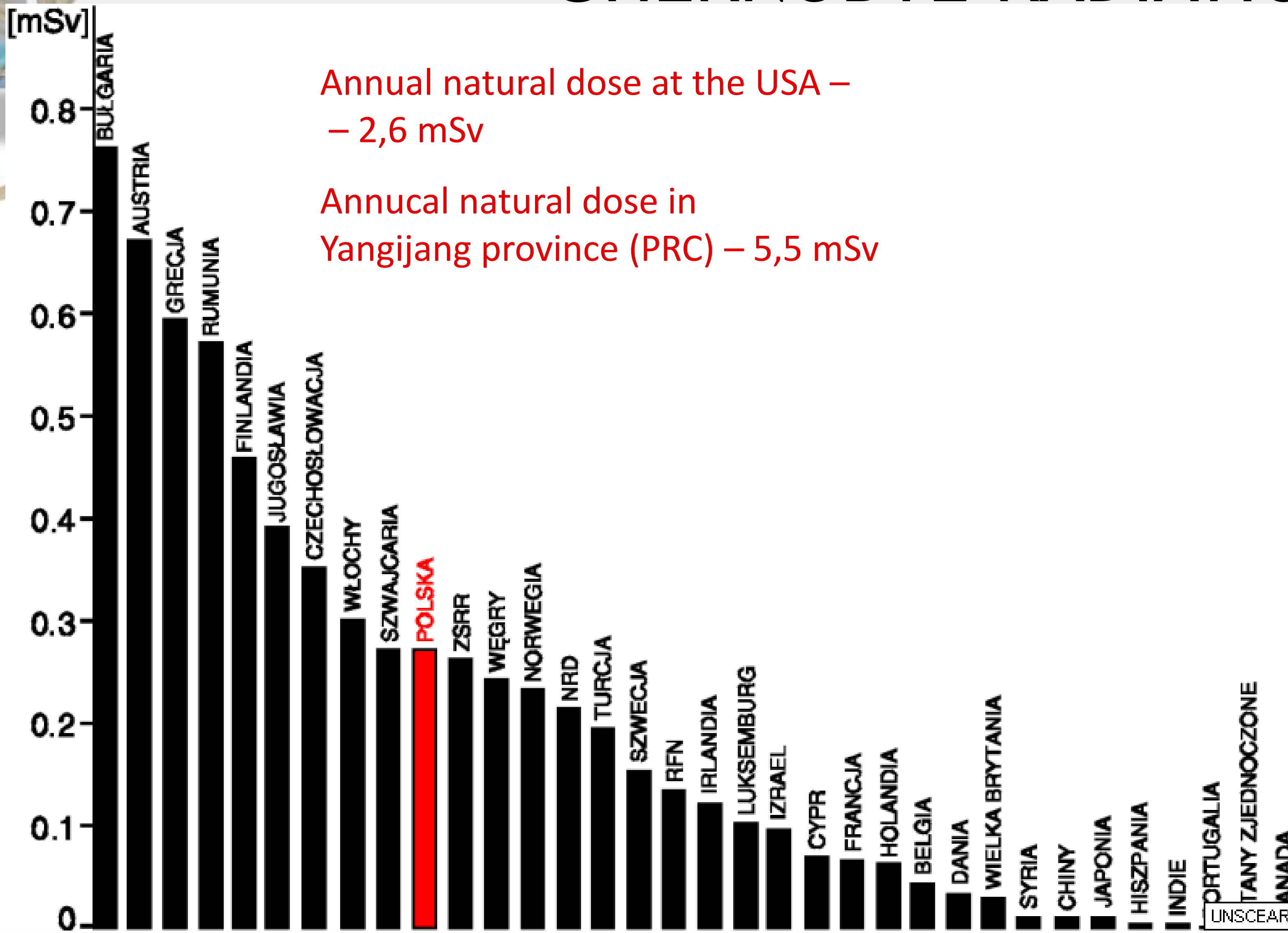
THORITIES' RESPONSE

MIASTO WIDMO: Prypeć, niegdyś ruchliwe skupisko ludzkie (45 tys. mieszkańców, w tym wielu pracowników elektrowni czarnobylskiej). Po katastrofie reaktora ewakuowano całą ludność; dziś nikt tu już nie mieszka.

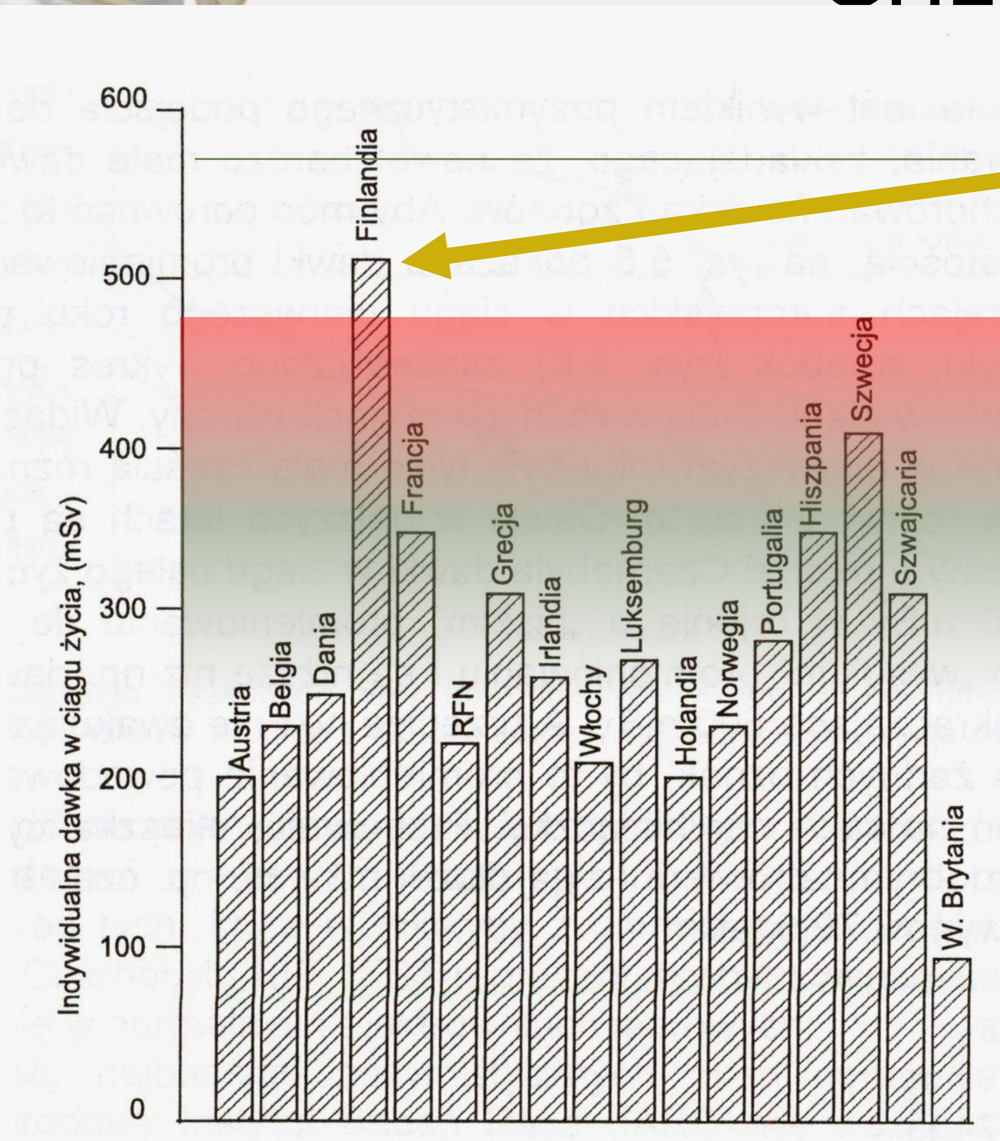
CHERNOBYL RADIATION

Annual natural dose at the USA –
– 2,6 mSv

Annucal natural dose in
Yangijang province (PRC) – 5,5 mSv



CHERNOBYL RADIATION



Finland – lifetime dose OVER 500 mSv

Lifetime doses for people living around Chernobyl up to 480 mSv

Chernobyl - Health Impact

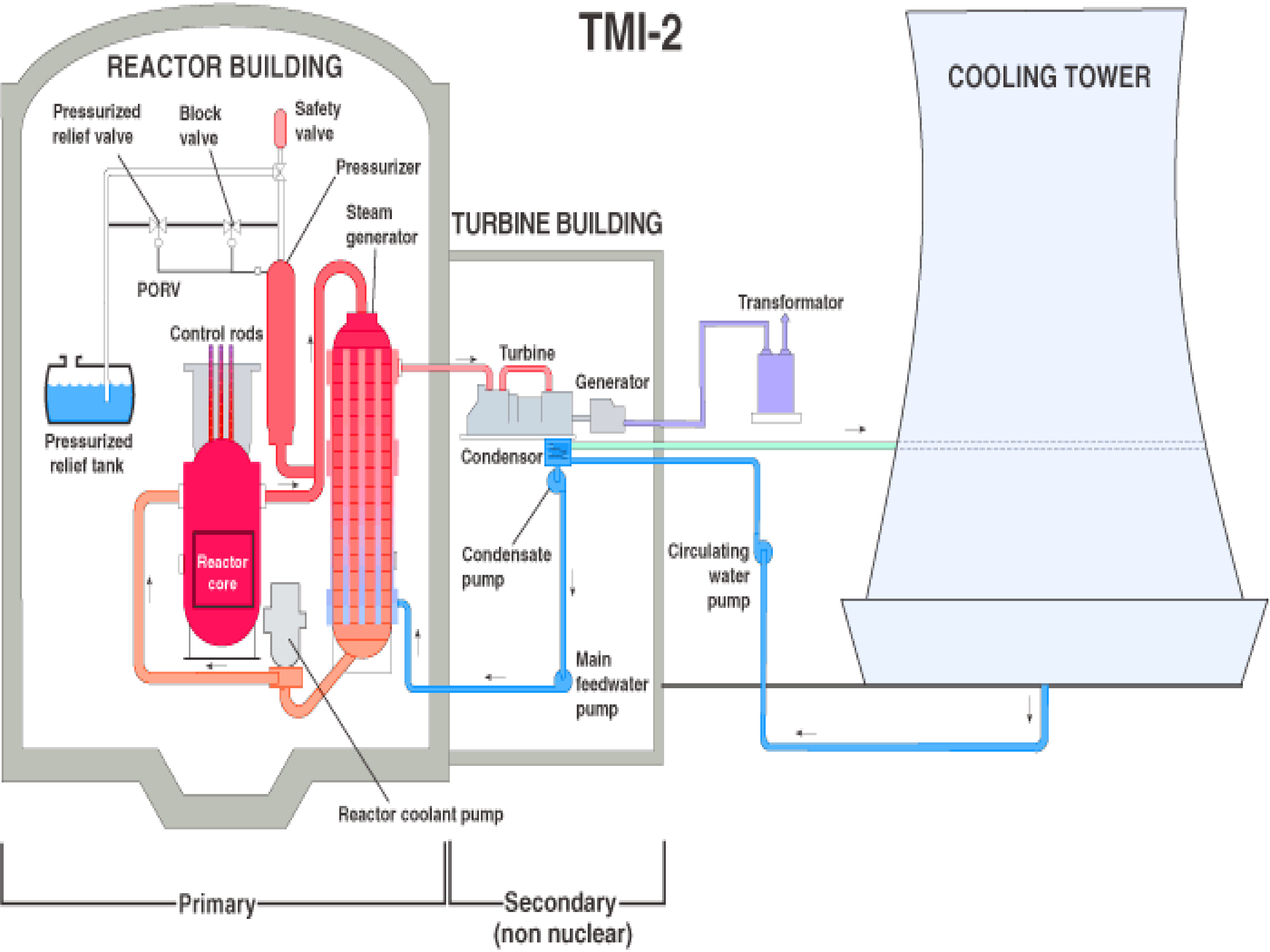
31 direct casualties (28 – radiation sickness + 3 other)

19 further heavily irradiated rescuers died so far
(but probably only 3 of them due to radiation)

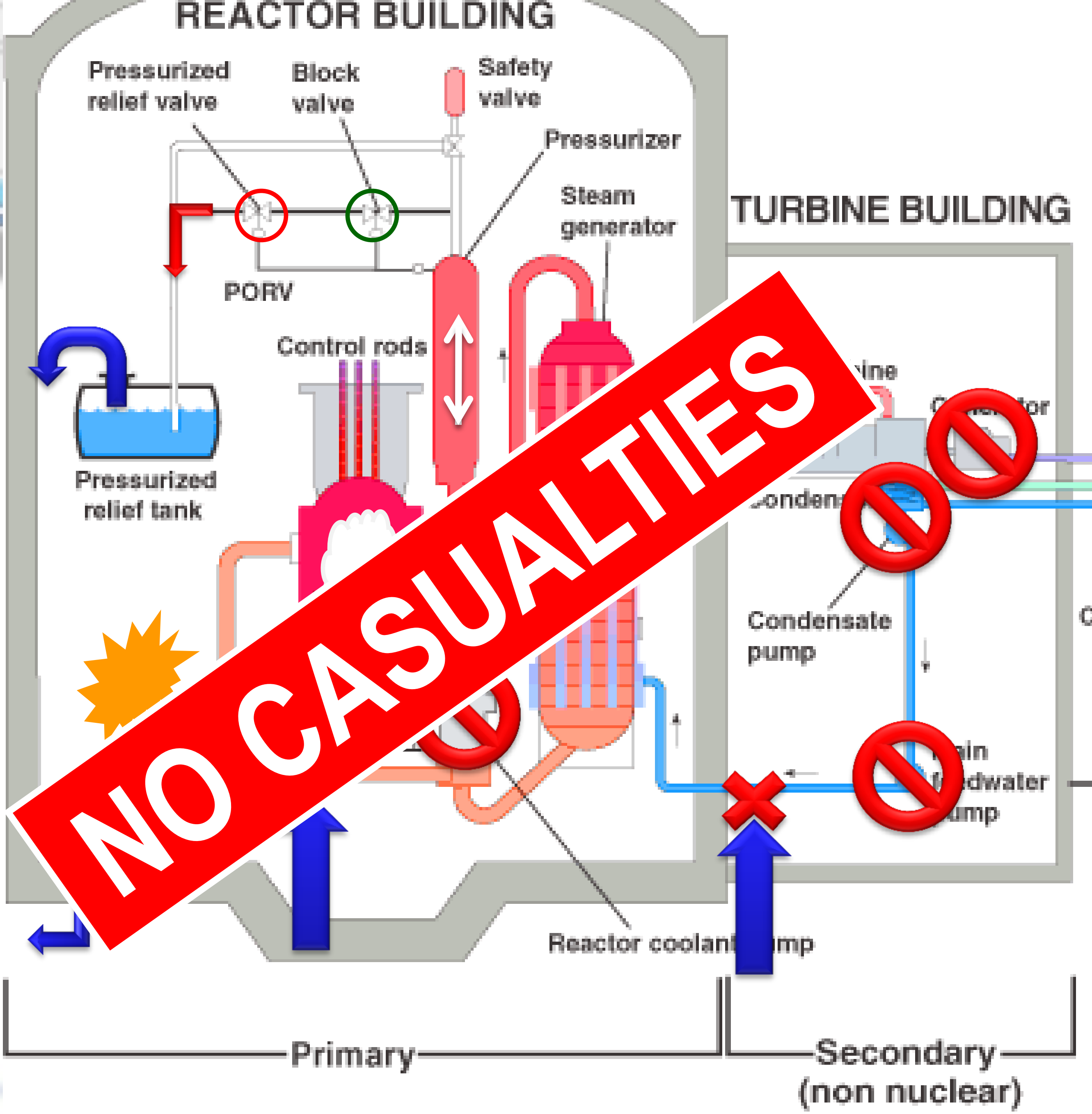
Ca. 6.5 thosuand of thyroid cancer cases – but only 15 fatal

Estimations (arguable): depend on source, recent Chernobyl Forum and UNSCEAR – max 60 more. Other claim 4000.

Three Mile Island, Harrisburg, Pennsylvania, USA, 28.03.1979.


TMI-2
REACTOR BUILDING
Pressurized relief valve
Block valve
Safety valve
Pressurizer
Steam generator
PORV
Control rods
Pressurized relief tank
Reactor core
Reactor coolant pump
TURBINE BUILDING
Turbine
Generator
Condensor
Condensate pump
Main feedwater pump
Transformator
Circulating water pump
COOLING TOWER
Primary
Secondary (non nuclear)

TMI-2


REACTOR BUILDING
Pressurized relief valve
Block valve
Safety valve
Pressurizer
Steam generator
PORV
Control rods
Pressurized relief tank
TURBINE BUILDING
Condensate pump
Reactor coolant
Primary
Secondary (non nuclear)
NO CASUALTIES

KRŠKO, 4 JUNE2008

KRŠKO CHAIN OF EVENTS

15:07 – Loss of coolant, 3 m³/h

15:56 – Lowest level alarm

16:30 – Preparations to shut down

16:38 ECURIE Notification

European Community
Urgent Radiological Information Exchange

19:30 – Generator breaker open

19:50 – Reactor subcritical

INES 0

Fukushima Dai-ichi
11 March 2011

Tōhoku earthquake

14:46 JST

- Units 1, 2, 3 SCRAM
- Loss of off-site power
- EDG startup

Tsunami wave

15:46 JST

- Site flooding
- Failure of all EDGs
- Loss of power for core cooling

Fukushima Dai-ichi timeline 11 March

- 14:46 – Earthquake, Units 1, 2 3 SCRAM
- 15:27 – First tsunami wave
- 15:30 – Unit 1, Isolation Condenser failure
- 15:46 – Main tsunami wave, site flooding, Loss of EDG power
- 16:00 – Emergency declared by NISA
- 18:00 – Unit 1, water level drops to the top of fuel
- 19:30 – Unit 1, fuel exposed
- 21:00 – Evacuation order, 3 km radius

Fukushima Dai-ichi timeline 12 March

- 02:44 – Unit 3, batteries for core flooding run out
- 04:15 – Unit 3, fuel exposed
- 05:30 – Unit 1, steam venting initiated
- 05:50 – Unit 1, fresh water injection initiated
- 06:50 – Unit 1, core melted completely
- 14:50 – Unit 1, water injection stopped
- 15:30 – Evacuation radius increased to 10 km
- 15:36 – Unit 1, reactor building explosion
- 19:00 – Unit 1, sea water injection initiated
- 21:40 – Evacuation zone extended to 20 km

Fukushima Dai-ichi timeline Further events

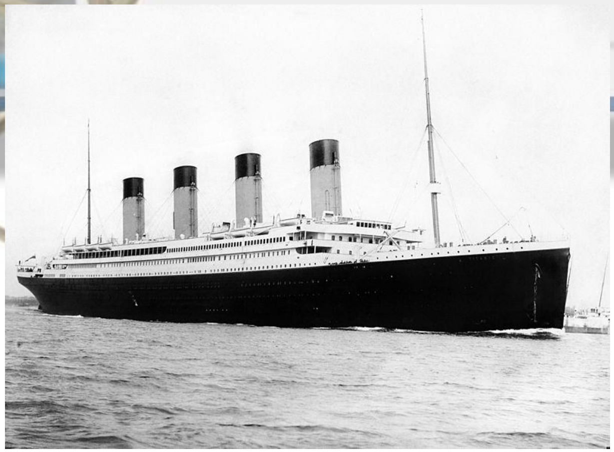
- 13 March
  - 02:42 – Unit 3, HP coolant injection stops
  - 07:00 – Unit 3, water level at top of the fuel
  - 09:00 – Unit 3, core damage
- 14 March
  - 11:01 – Unit 3, reactor building explosion
  - 13:15 – Unit 2, core isolation cooling stops
  - 15:00 – Unit 3, part of fuel drops in RPV
  - 18:00 – Unit 2, water level at top of the fuel
  - 20:00 – Unit 2, core damage
- 15 March
  - 11:00 – Unit 3, second explosion
  - 20:00 – Unit 2, fuel drops to the RPV bottom

8 April status

	Unit 1	Unit 2	Unit 3	Unit 4	Unit 5	Unit 6
Fuel integrity	Damaged (70% estimated)	Damaged (30% estimated)	Damaged (25% estimated)	Spent fuel possibly damaged	Not damaged	Not damaged
Reactor pressure vessel integrity	Unknown	Unknown	Unknown	Not damaged (defueled)	Not damaged	Not damaged
Containment integrity	Not damaged (estimation)	Damage and leakage suspected	Not damaged (estimation)	Not damaged	Not damaged	Not damaged
Core cooling system 1 (ECCS/RHR)	Not functional	Not functional	Not functional	Not necessary (defueled)	Functional	Functional
Core cooling system 2 (RCIC/MUWC)	Not functional	Not functional	Not functional	Not necessary (defueled)	Functional (in cold shutdown)	Functional (in cold shutdown)
Building integrity	Severely damaged due to hydrogen explosion	Slightly damaged, also panel removed to prevent hydrogen explosion	Severely damaged due to hydrogen explosion	Severely damaged due to hydrogen explosion	Panel removed to prevent hydrogen explosion	Panel removed to prevent hydrogen explosion
Pressure vessel, water level	Fuel exposed partially or fully	Fuel exposed partially or fully	Fuel exposed partially or fully	Safe (defueled)	Safe (in cold shutdown)	Safe (in cold shutdown)

Accidents in technology

Accidents did happen, do happen and will keep happening



Titanic, 1912
1517 killed

Estonia, 1994
852 killed

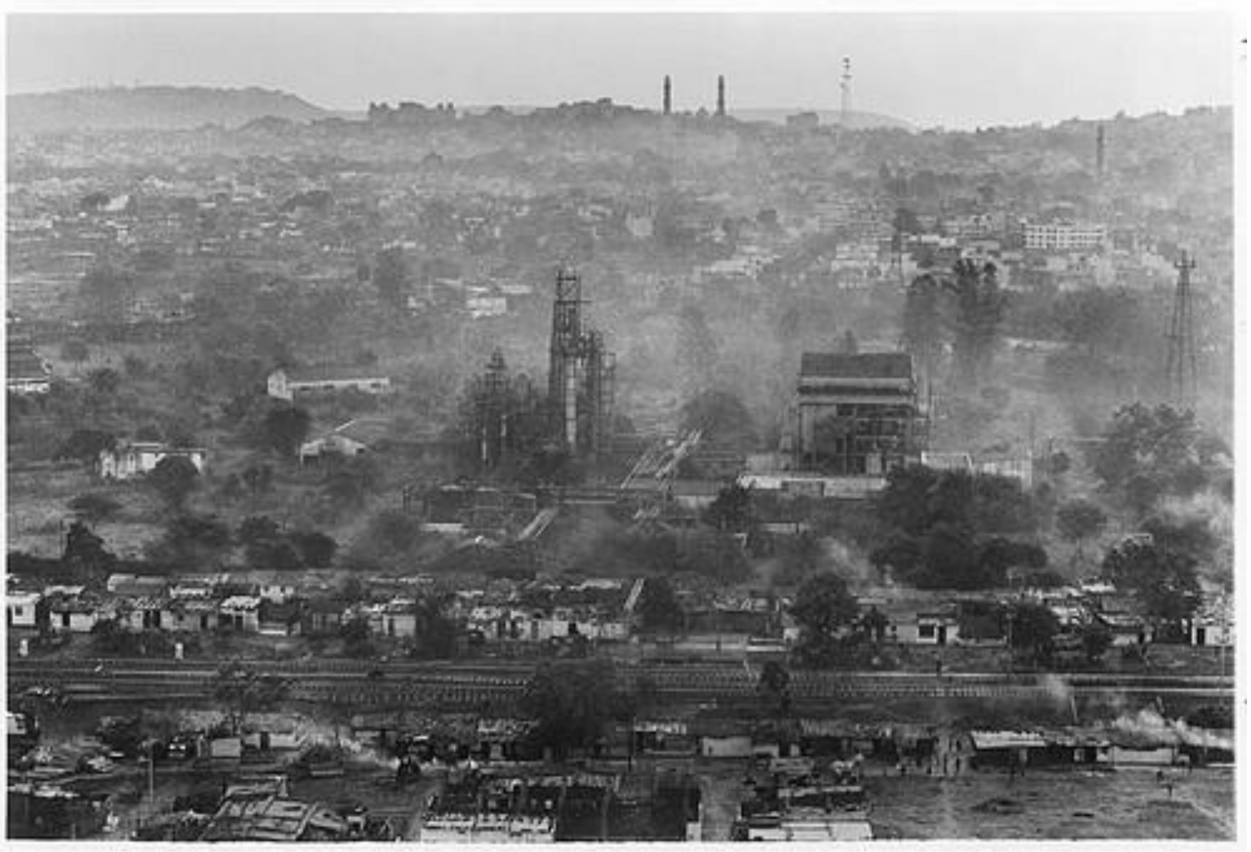
Le Joola, 2002
1853 killed

Mining accidents

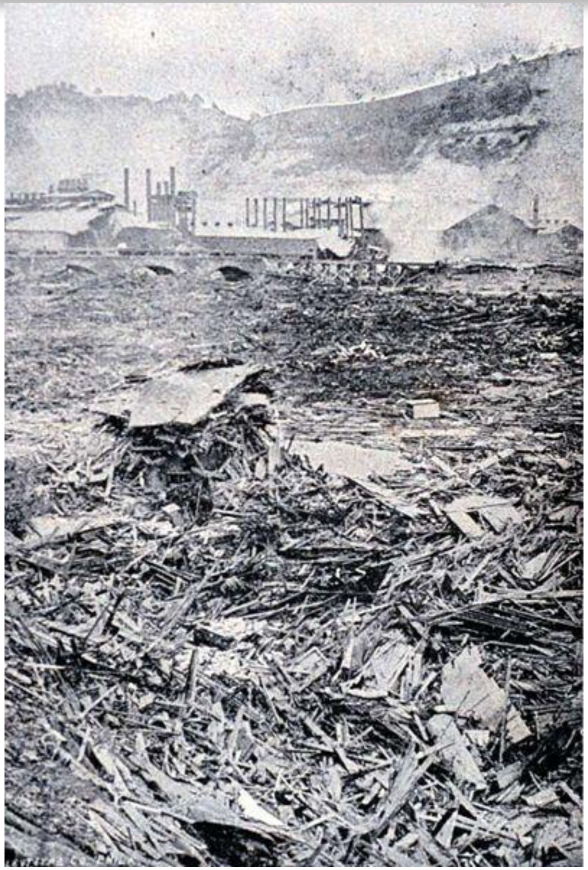
- 10.03.1906. – Courrieres, Pas de Calais, France, coal dust explosion, 1099 killed
- 12.02.1931. – Fushun, Manchuria, 3000 killed
- 26.04.1942. – Honkeiko, Manchuria, CO poisoning, coal dust and methane fire, 1527 killed
- 07.02.1962. – Luisenthal, Saar, FRG, methane ignition, 299 killed
- 09.11.1963. – Mikawa, Japan, CO poisoning, coal dust fire, 458 killed
- 06.06.1972. – Wankie Colliery, Rodesia, three gas explosions, 427 killed
- 16.07.1984. – Mei Shan, Taiwan, fire, 121 killed
- 03.03.1992. – Incirharman, Turkey, methane blast, 265 killed

In 2004 r. according to official statistics
6 thousand miners were killed in China.
NGOs mentioned 20 thousand!

Bhopal, India, 1984
At least 3000 killed instantly

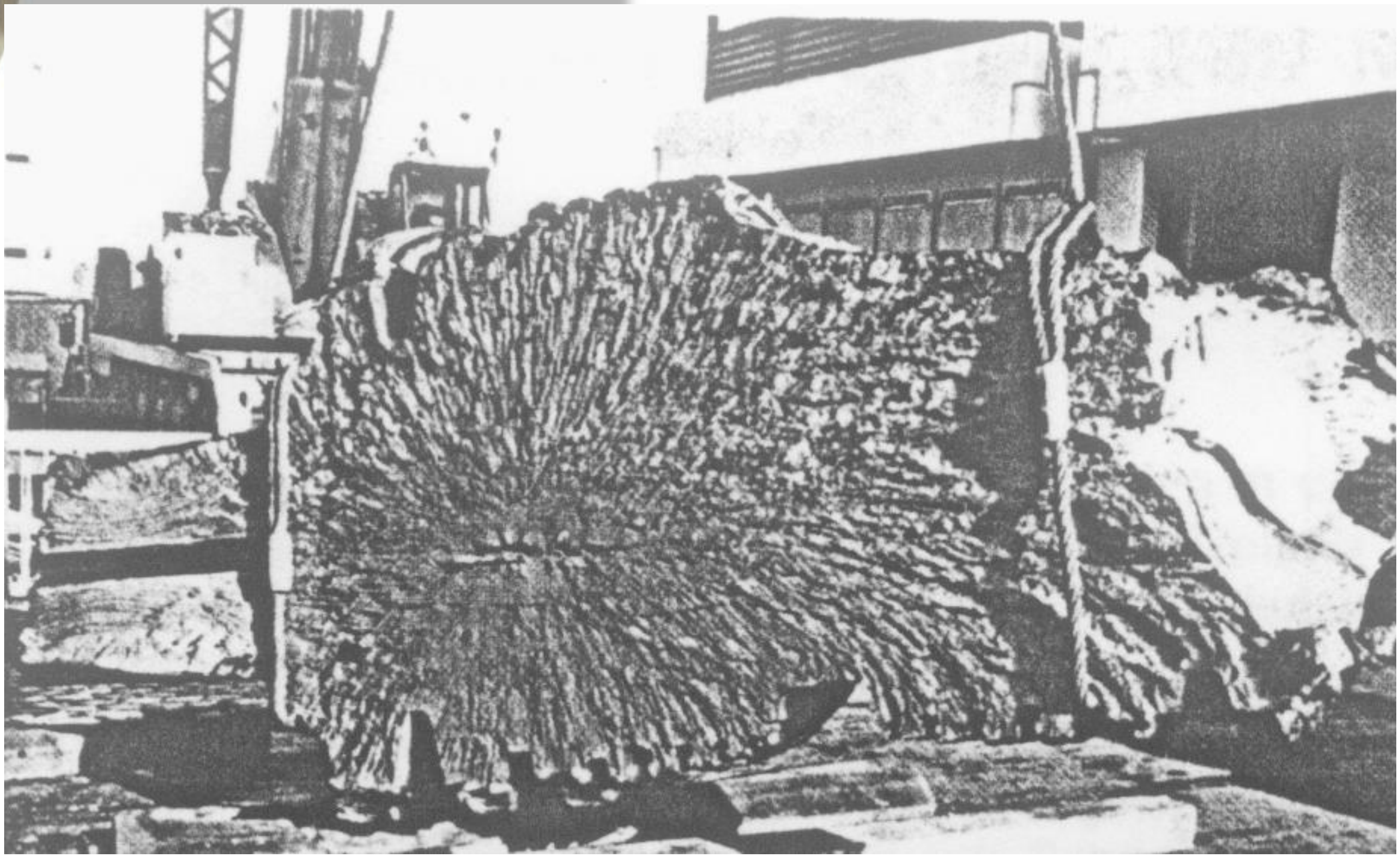


South Fork Dam, USA, 1889
2200 killed



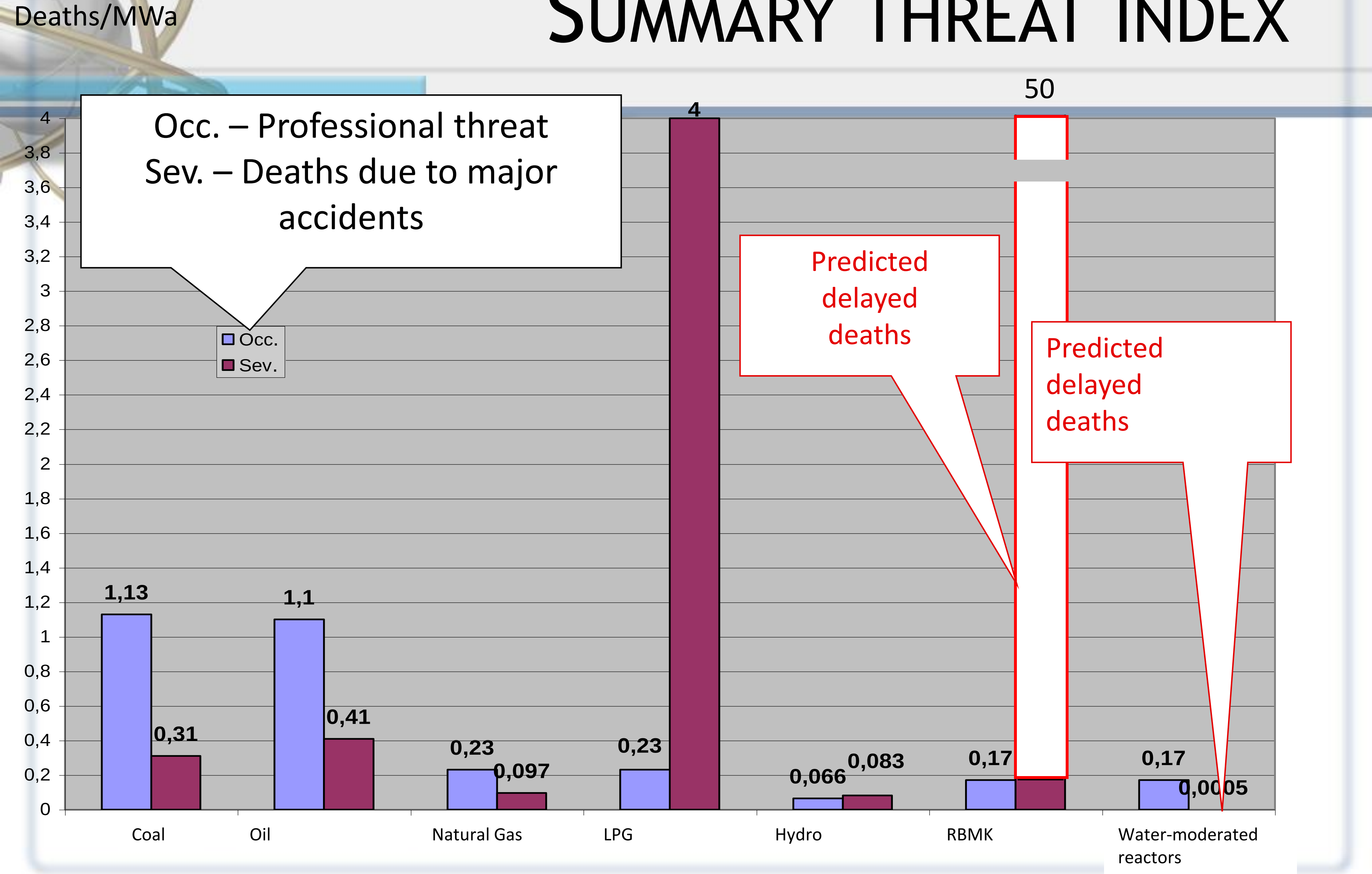
M/S PRESTIGE, 2002
77 000 MG OF HEAVY OIL

1978 – Kraftwerk Irsching



Roads of the Republic of Poland 2007 – 5583 killed

SUMMARY THREAT INDEX



Safety features of new designs

AREVA EPR

EPR Main Features

Evolutionary concept

- Development of Framatome N4 and Siemens KONVOI

High output

- 4590 MW_{th}
- Up to 1700 MW_{el} possible, highest available
- Big and heavy components (up to 550 Mg)

High performance

- Up to 37% efficiency at seawater cooling
- 24-month fuel cycles
- >92% availability

EPR Safety design In-depth defence

Lvl 1
- Preventing deviations
- Conservative design, redundancy

Lvl 2
- Detecting and intercepting deviations
- Preventing escalation into accidents

Lvl 3
- Mitigating accidents
- Maintaining at least one barrier intact

Lvl 4
- Lowering radioactivity releases

Lvl 5
- Mitigation of radiactive releases impact
- External actions

EPR Safety systems (1) Safety Injection Systems

Task

- Providing water to the reactor in case of LOCA or main steam line rupture

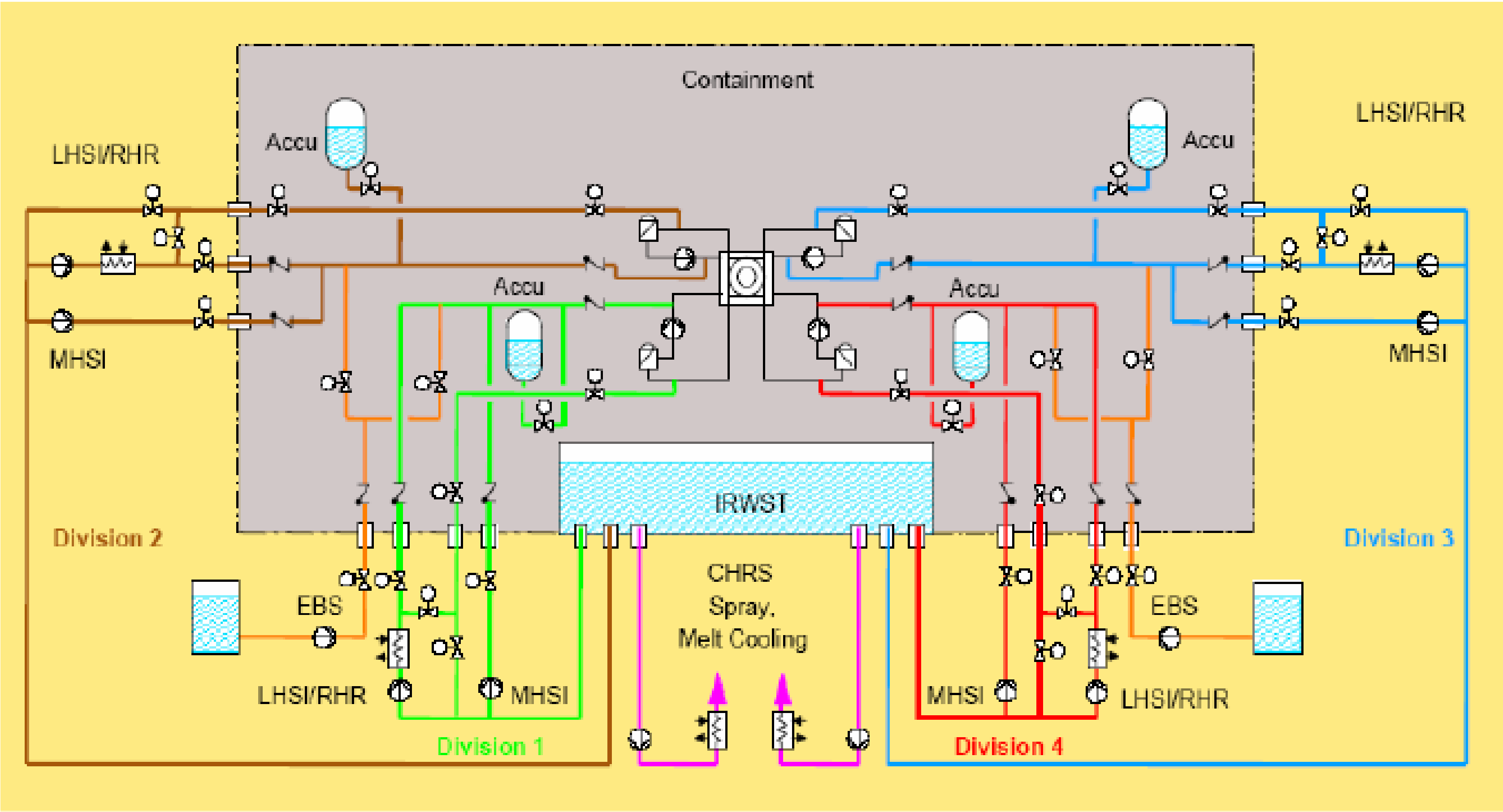
Sources of water

- In-containment Refuelling Water Tank (IRWT)
- Passive accumulators (4 pcs)

Heat sinks

- For Medium-Head sub-system: secondary circuit
- For Low-Head sub-system: secondary circuit and dedicated heat exchangers: Residual Heat Removal System (outside containment)

EPR Safety Injection Systems



EPR Safety Systems (2)

Emergency Feed Water System

- Used in case of loss of working agent from secondary circuit
- Not used in normal operating conditions
- 24 h of decay heat removal via steam generators

Residual Heat Removal System

- RH removal in combination with low-head injection
- Heat exchangers allowing to bypass steam generators

Extra Borating System

- Two trains
- Stopping reaction from any operating condition

EPR Safety for Severe Accidents

Core catching

- Preventing interaction between molten core and concrete

High-pressure core melting prevention

- Primary circuit depressurization

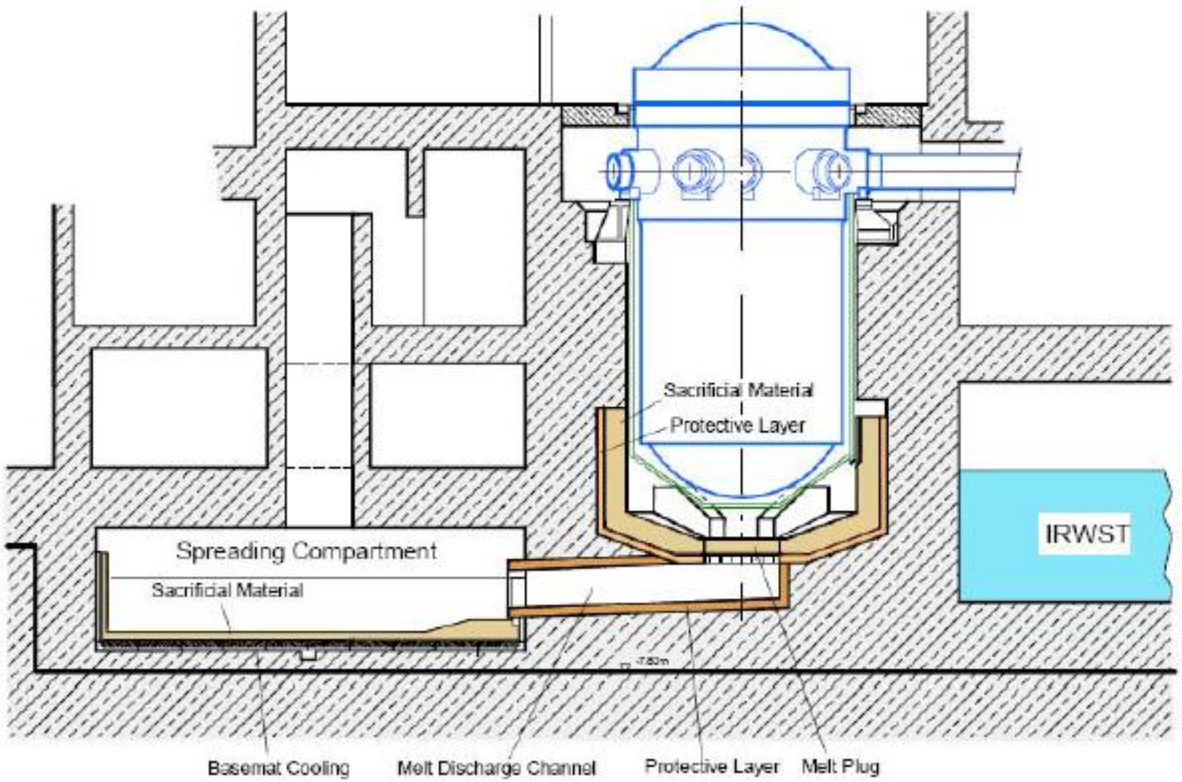
Hydrogen explosion prevention

- Passive recombination systems

Steam explosion prevention

- Minimization of water presence in corium spreading area

EPR Core Catcher



EPR Power Supply

Power Supply System

- 4 trains, 4 divisions distribution system
- After load rejection the plant stays in operation

Emergency Power Supply System

- Normally powered from turbine island system
- 4 Emergency Diesel Generators (one per division), 2 DG buildings
- 24 h autonomy required
- 2 additional DGs for Station Blackout needs (if all other 4 fail)
- 4 × 2 h UPS systems + 2 × 12 h UPS systems (for divs 1 & 4)

EPR Deployment

Olkiluoto 3, TVO, Finland

- Under construction since 2005, delayed at least until 2014

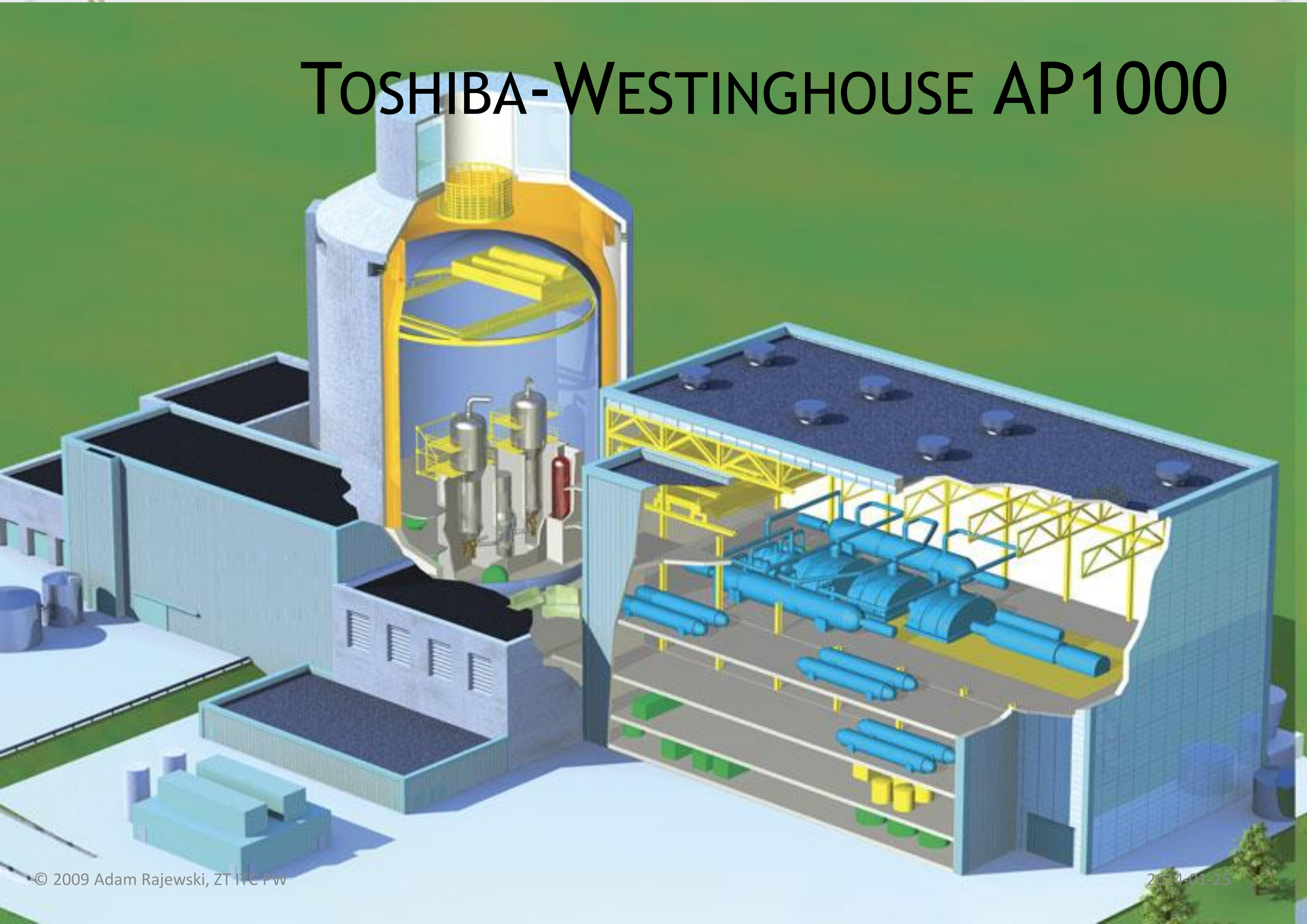
Flammanville 3, EDF, France

- Under construction since 2007, delayed at least until 2014

Taishan 1-4, Guangdong NPC, PRC

- Units 1&2 under construction since 2009/2010
- Units 3&4 under planning

Toshiba-Westinghouse AP1000



AP1000 Main Features

Focus on passive safety systems

- Passive heat removal in design-basis accidents
- No operator input required during 72 h of accident

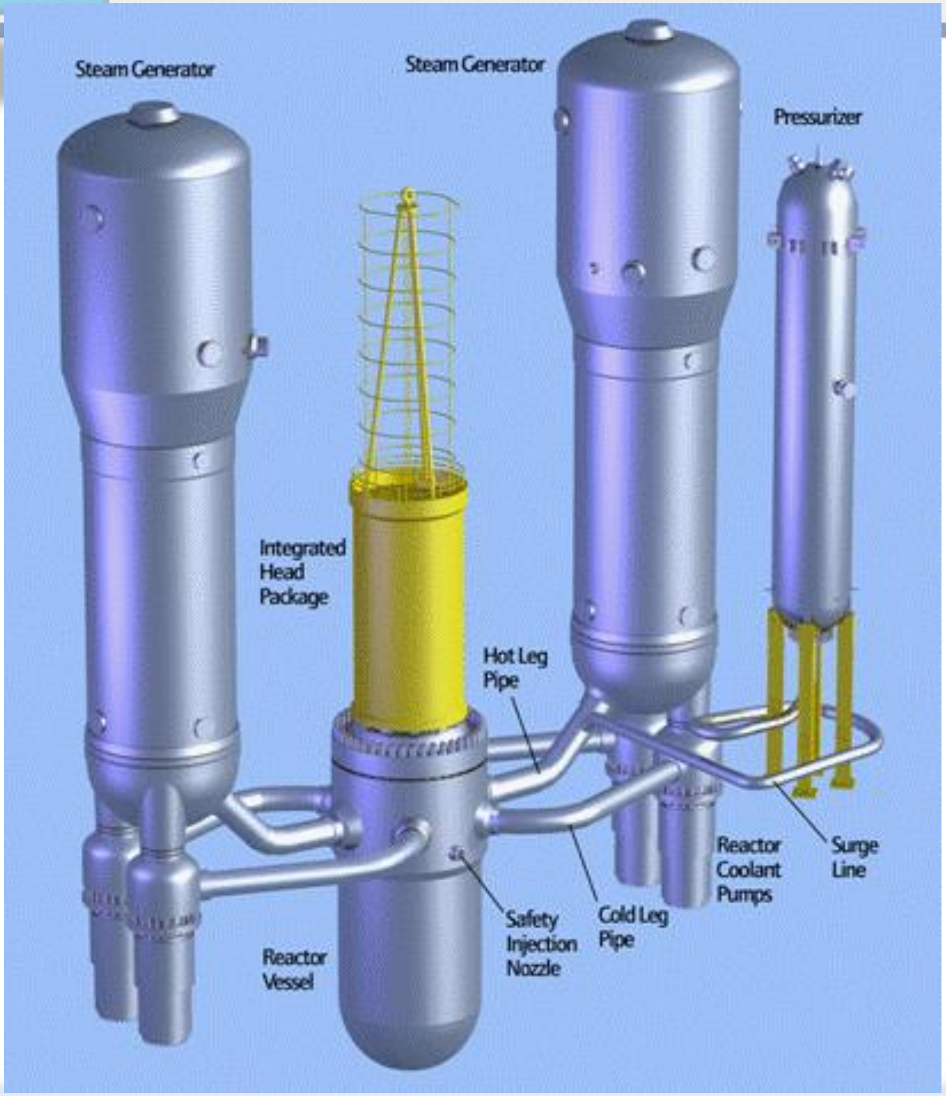
Simplification

- 2-loop primary circuit
- More modular approach

Medium output

- 3400 MWth
- Around 1200 MWel

AP1000 Primary Circuit



Passive Core Cooling System

Tasks

- Depressurization
- Heat removal
- Water injection
- Boration

Sources of water

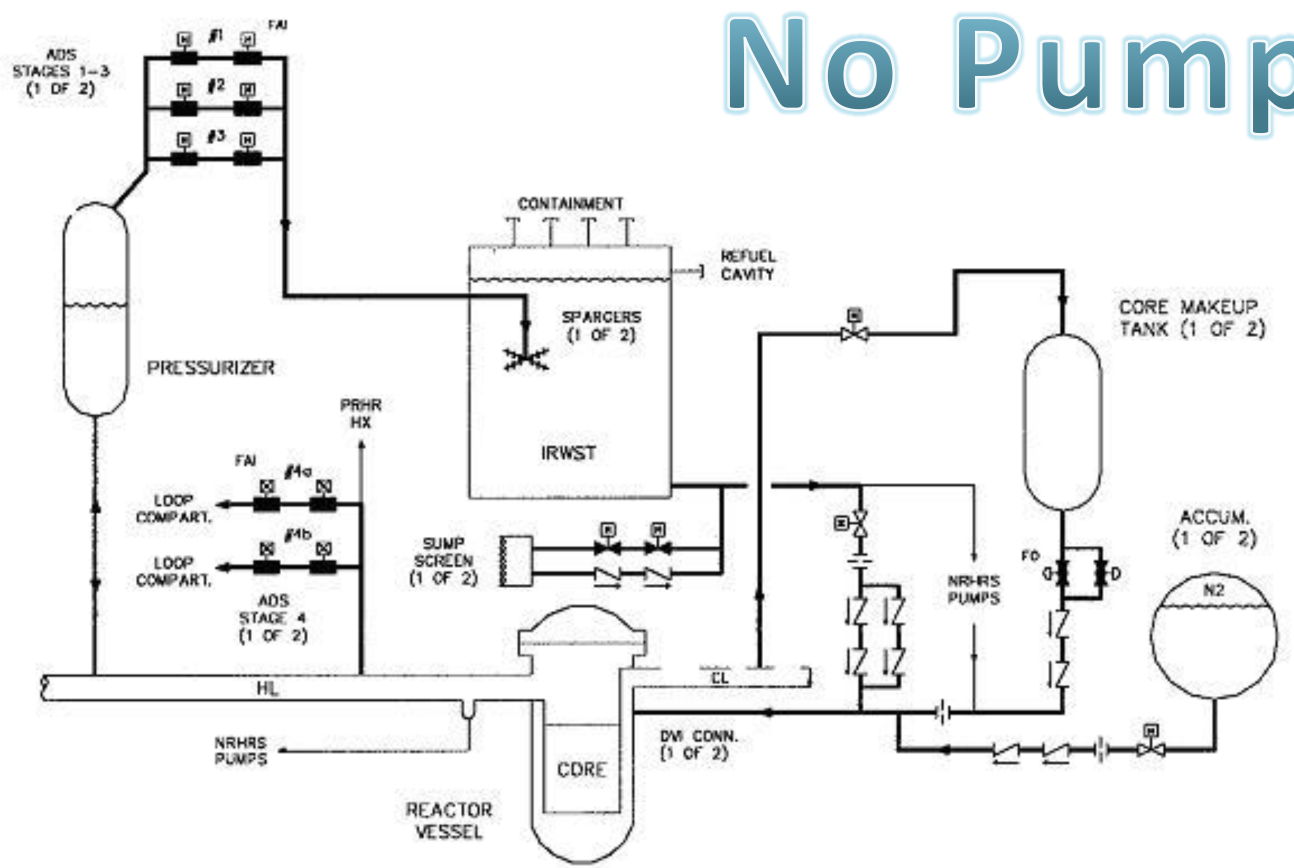
- Core Makeup Tanks
- Water accumulators
- In-Containment Refuelling Water Tank (IRWT) – preventing boiling for 1 hour

Heat sinks

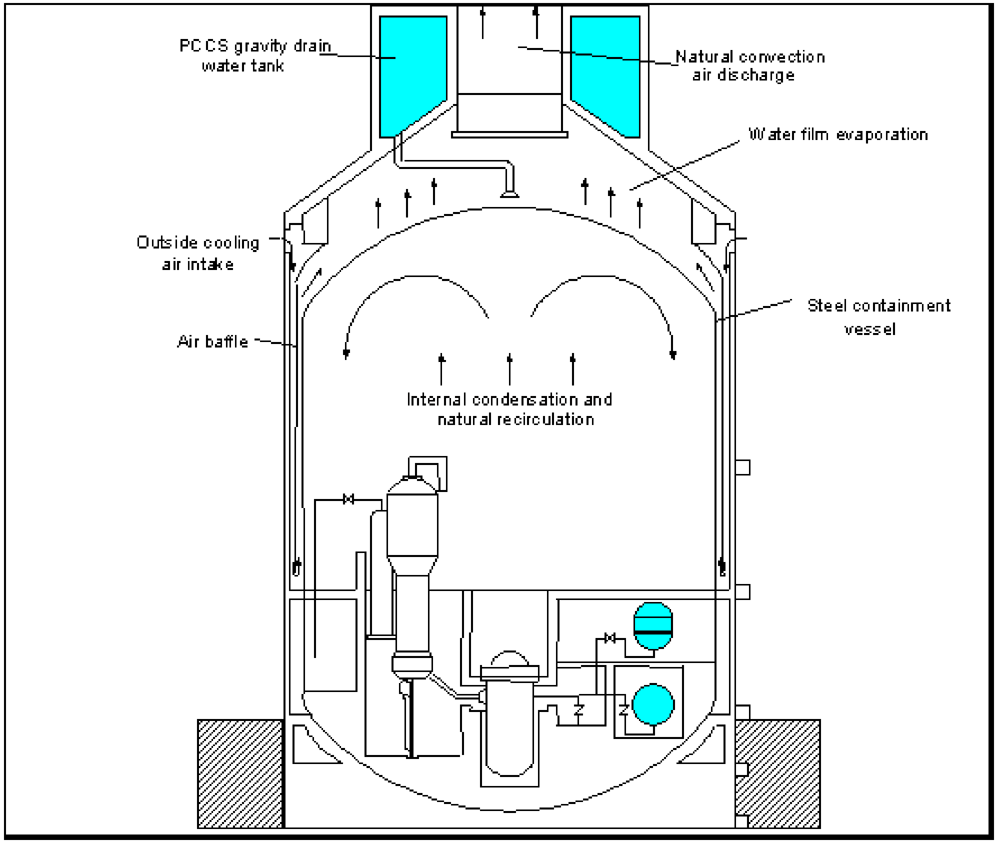
- IRWT via heat exchangers ➔ Passive Containment Cooling System
  Dimensioned for redisual heat 15 minutes after shutdown

Passive Core Cooling System

No Pumps!



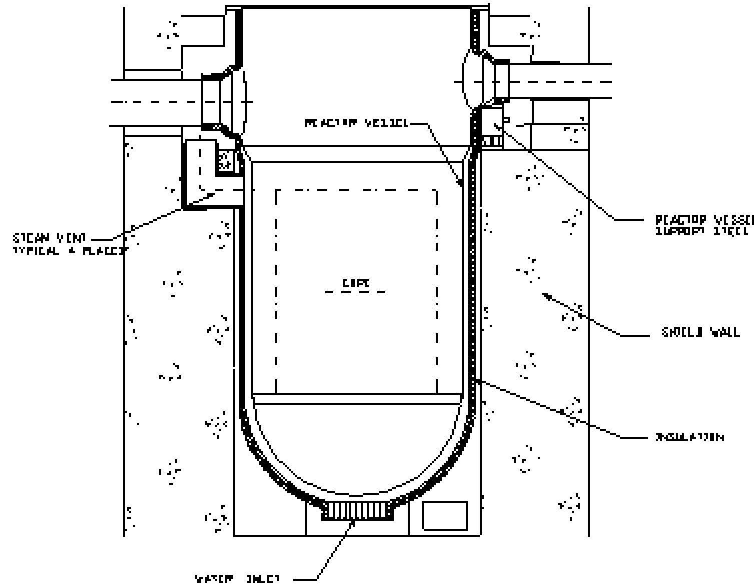
Passive Containment Cooling System



AP1000 Severe Accidents Mitigation

Core catching

- In-vessel retention of core debris
- Design of reactor well without penetrations
- Reactor well may be flooded



AP1000 Power Supply

Power Supply System

- 2 divisions for non-safety power supply
- After load rejection the plant stays in operation
- 2 standby (not emergency) DG units, separate DG building
  Three-hour firewall between the DGs

Emergency Power Supply System

- 4 independent battery systems, one of them sufficient for 72 hours
- Connections for external Class 1E emergency DGs to divisions B&C
  Covering HVAC, automation (Divs B&C), lighting

AP1000 Deployment

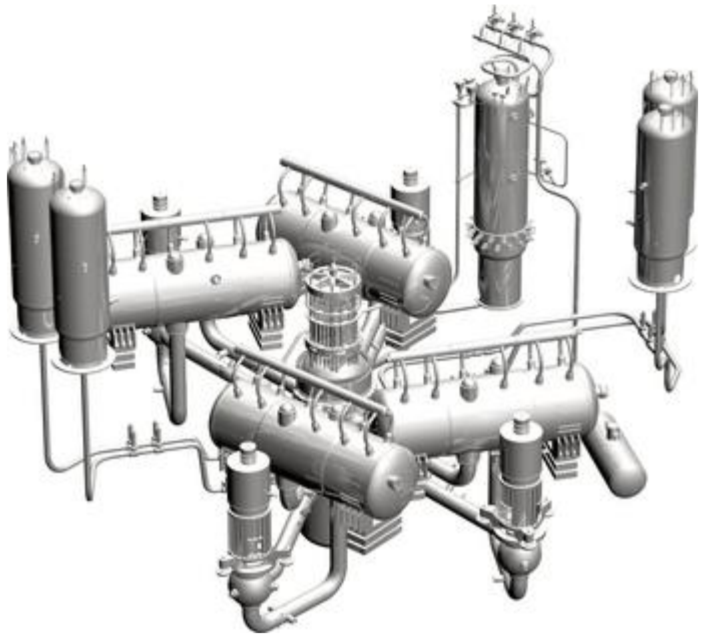
Sanmen NPP, CNNC, PRC

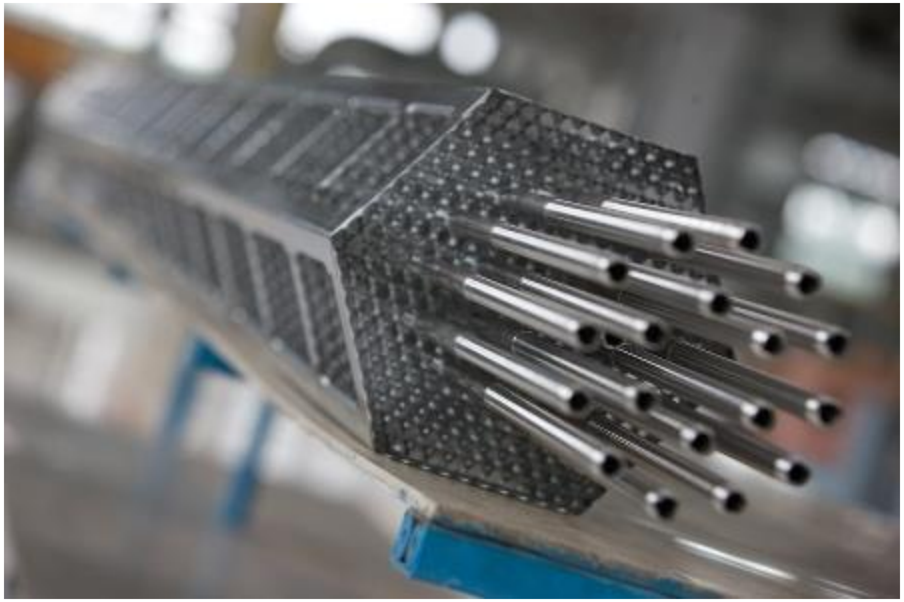
- Units 1&2, under construction since 2009
  Completion scheduled for 2013/2014
- Units 3-6 under planning (Phase II)

Haiyang NPP,

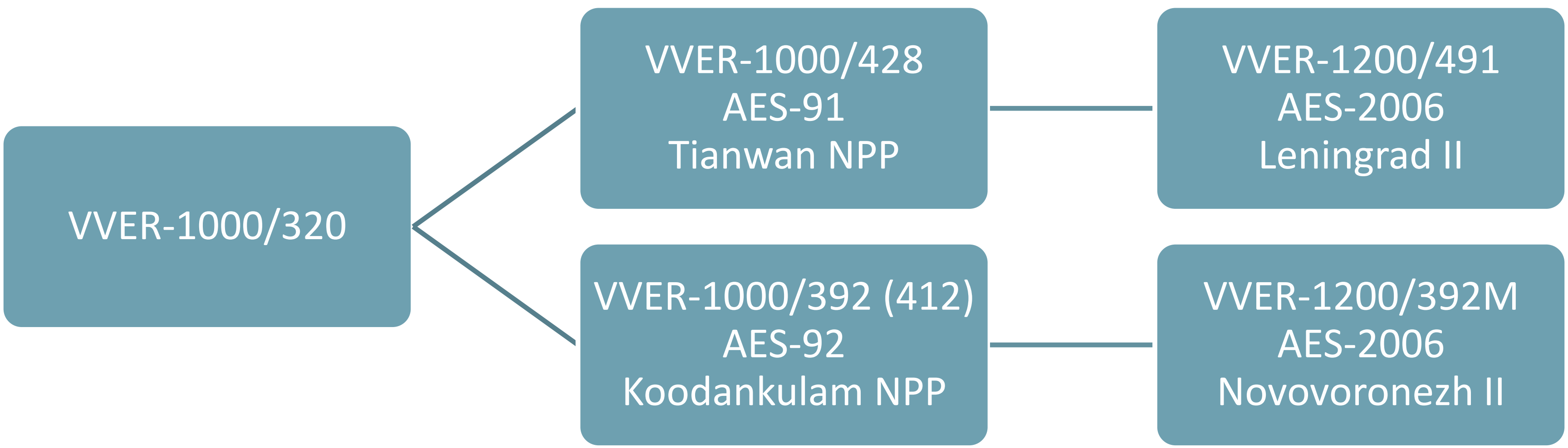
- Units 1&2 under construction since 2009/2010
  Completion scheduled for 2014/2015
- Units 3&4 under planning (Phase II)
- Units 5-8 under planning (Phase III)

VVER Reactors (1000/1200)





VVER EVOLUTION



VVER Reactor Features

Evolutionary development

- Multiple versions over 1980s, 1990s and 2000s
- Similar basic reactor design, but different external systems, including safety

Medium output

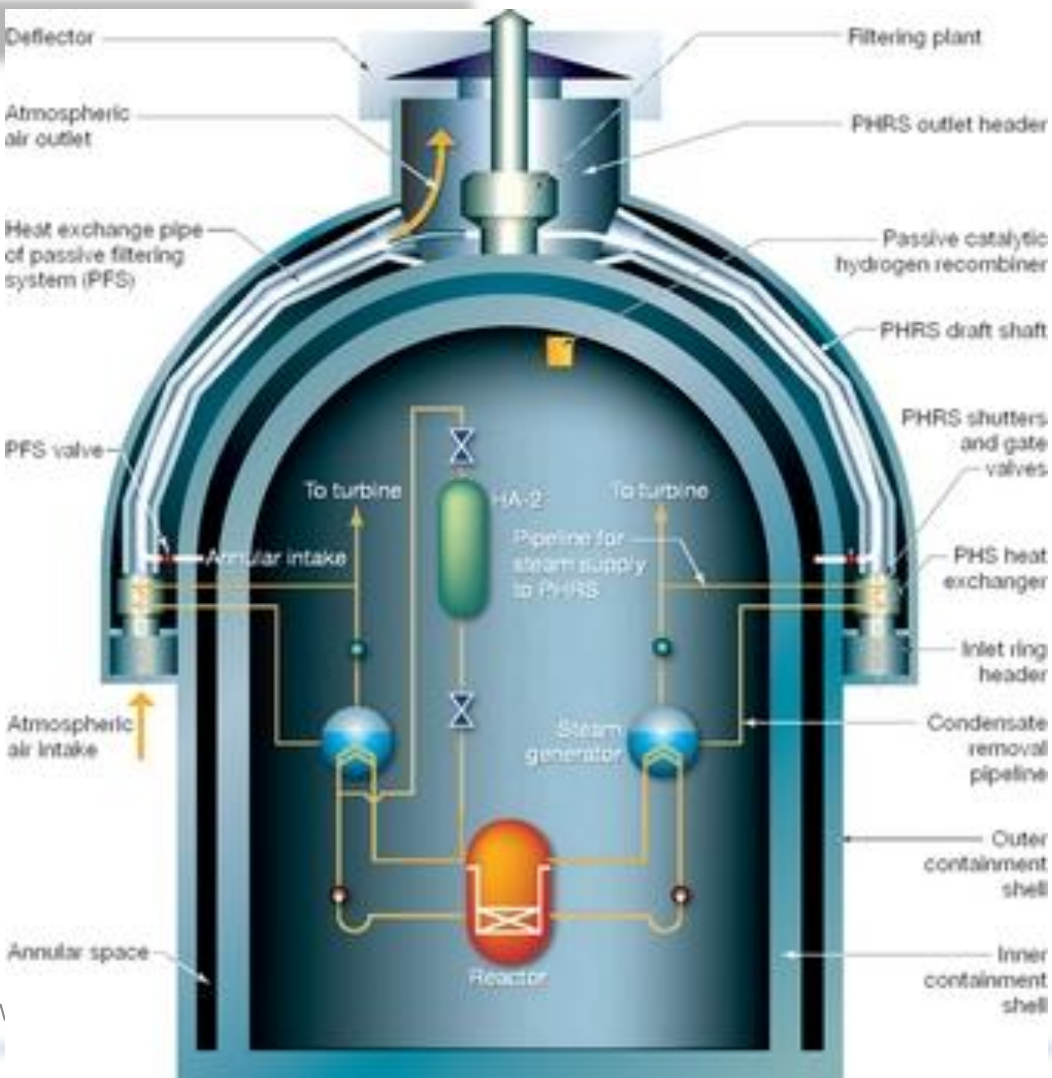
- 3200 MWth (VVER-1200)
- Around 1200 MWel (VVER-1200)

Different geometry

- Horizontal steam generators
- Hexagonal fuel

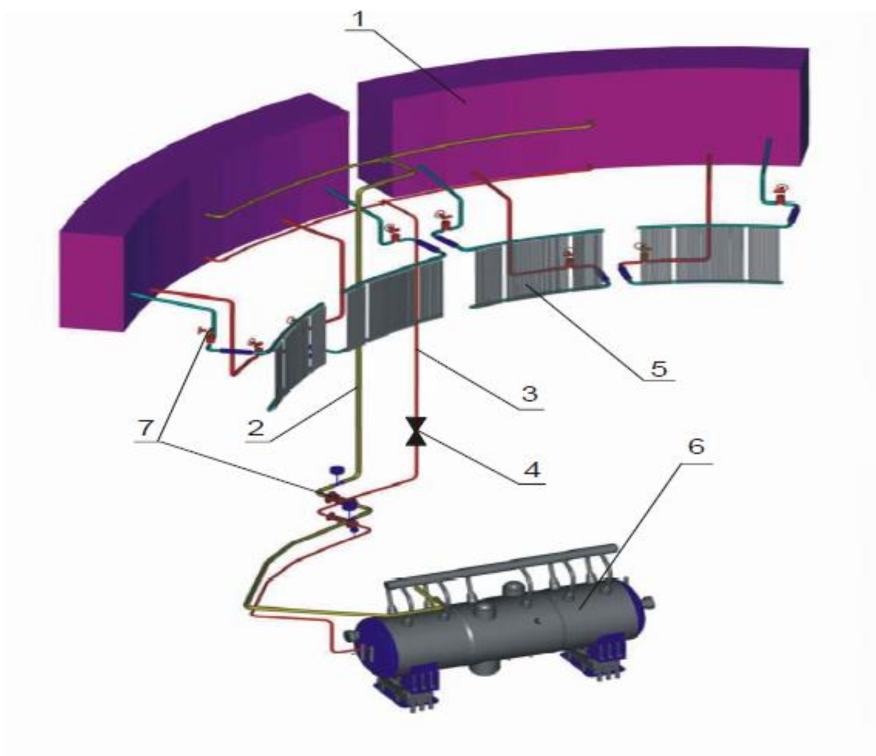
	Novovoronezh NPP-2	Leningrad NPP-2
ECCS active part	High and low pressure combined two-channel system with ejector pumps with internal redundancy of main safety functions	High and low pressure separate four-channel systems with channel redundancy 4 x 100 %, each
Emergency boron injection system	Two-channel system with channel redundancy 2 x 100 % and internal channel redundancy 2 x 50 %	Four-channel system with channel redundancy 4 x 50 %
Emergency feedwater system	Not available	Four-channel system with channel redundancy 4 x 100 % with emergency feedwater storage tanks
SG emergency cooldown system	Closed two-channel system with redundancy 2 x 100 %	Not available
Core passive flooding system (HA-2)	Passive four-channel system with channel redundancy 4 x 33 % with two accumulators in each channel	Not available
Passive heat removal system (PHRS)	Passive four-channel system with channel redundancy 4 x 25 % with two heat exchangers, cooled by air, in each channel	Passive four-channel system with channel redundancy 4 x 33 % with 18 heat exchangers, cooled by water, in each channel

VVER-1200/392M NVNPP II
Passive Decay Heat Removal

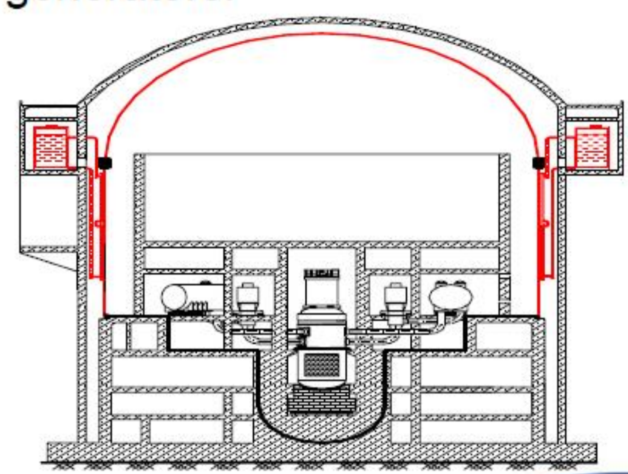


Passive Containment Heat Removal Leningrad II NPP

Passive containment cooling system in LNPP-2 design is intended for long-term condensation of steam from containment atmosphere.



This system shares the off-containment water storage tanks with passive decay heat removal system via steam generators.



1 – tank; 2 – steam line; 3 – condensate line; 4 – SG PHRS valve;
5 – HX of containment PHRS; 6 – steam generator; 7 – cut-off valve

VVER-1200 Deployment

Akkuyu, Turkey

- 4 × VVER-1200/491 AES-2006 planned

Leningrad II (LNPP II), Russia

- 2 × VVER-1200/491 AES-2006 under construction since 2008 & 2010
- 2 × VVER-1200/491 AES-2006 planned

Novovoronezh II (NVNPP II), Russia

- 2 × VVER-1200/392M AES-2006 under construction since 2008 & 2009
- 2 × VVER-1200/392M AES-2006 planned

Other VVER-related projects

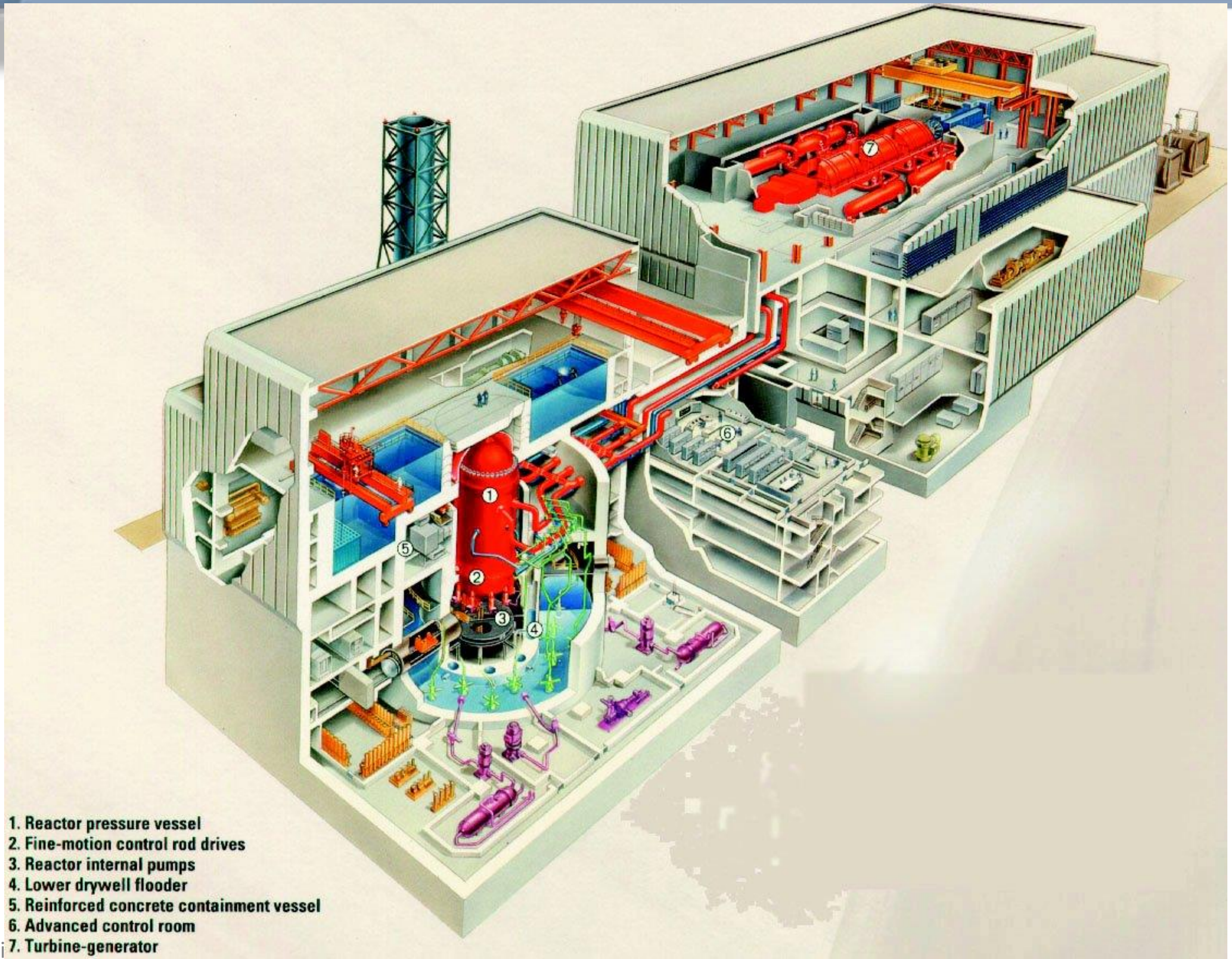
Belene NPP, Bulgaria

- 2 × VVER-1000/446 AES-92 “under construction” since 1987

MIR-2006

- Offered for extension of Temelin NPP, Czech Republic
- Design similar to AES-2006

GE-Hitachi ABWR



ABWR Main Features

Increased safety

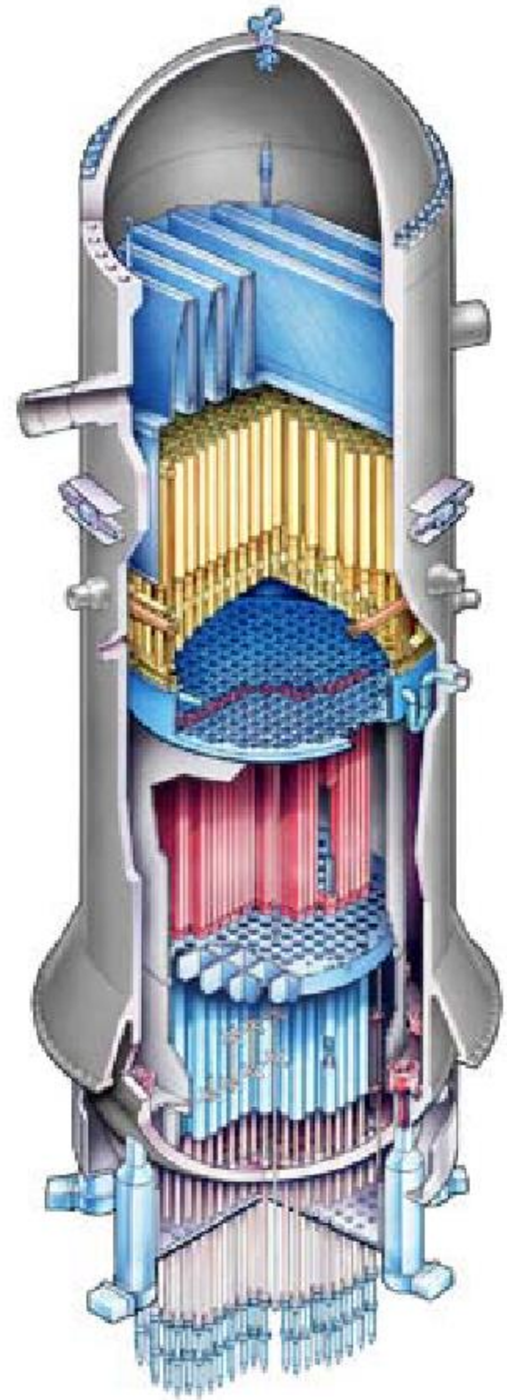
- Internal reactor pumps
- Core always covered during design-basis accident

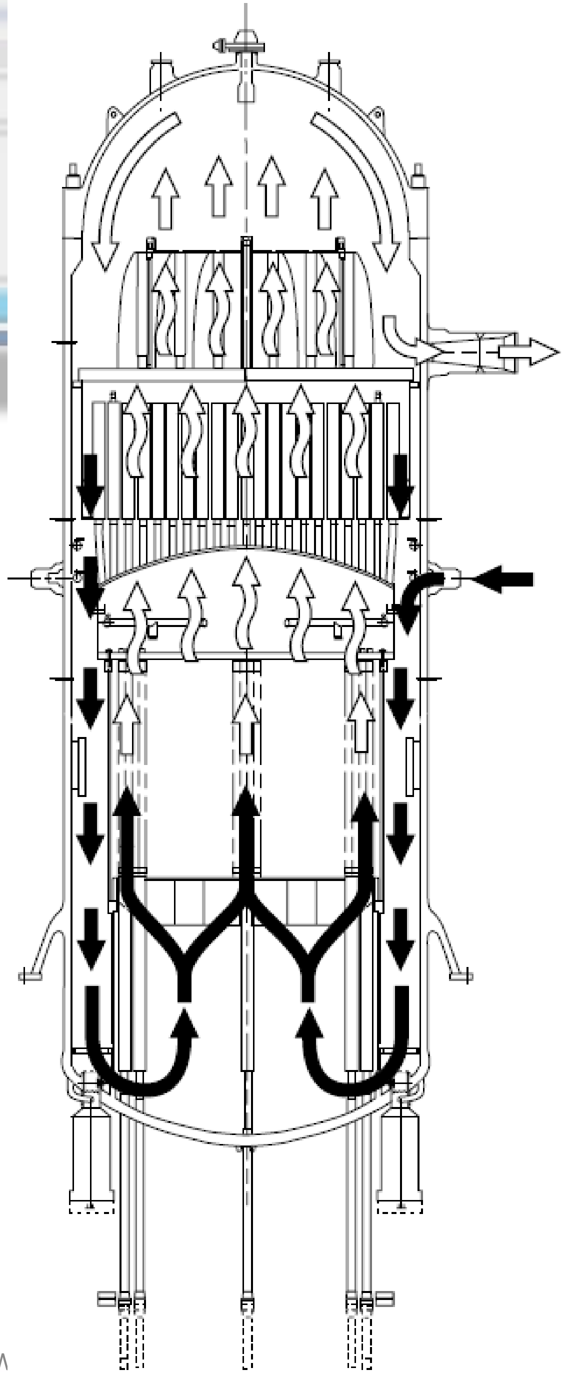
Good operating characteristics

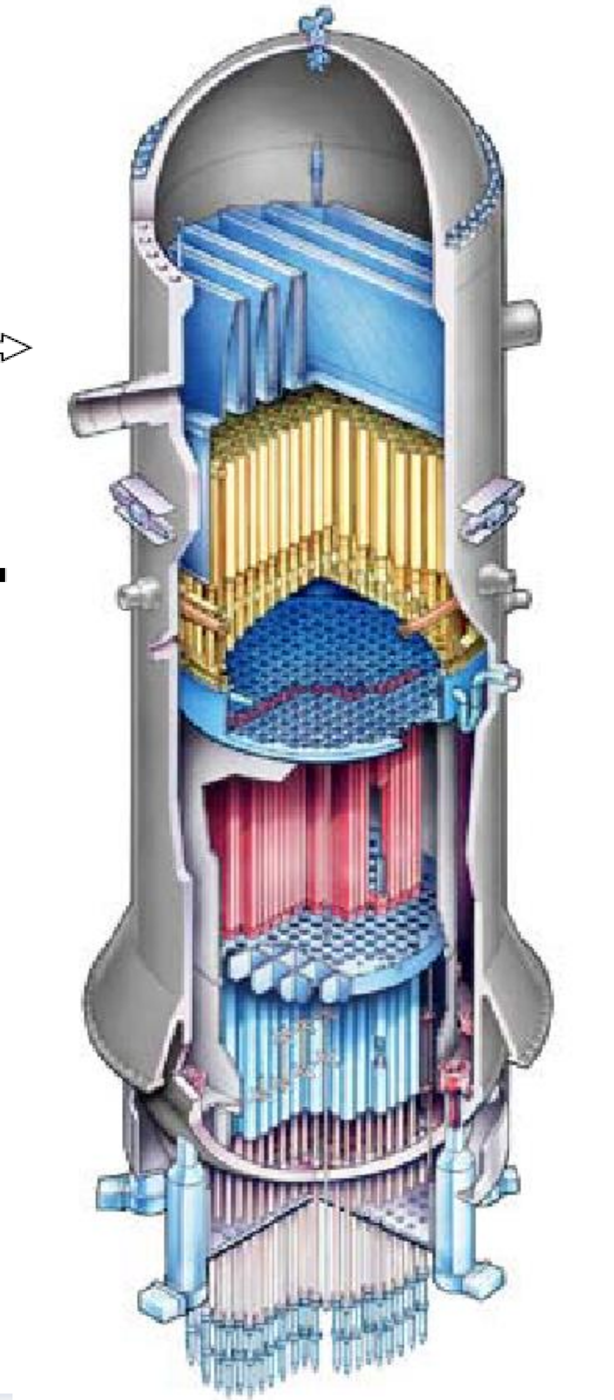
- Load following operation
- Good reliability

Medium-high output

- 3926 MWth
- Around 1400 MWel







ABWR Safety
Emergency Core Cooling Systems

High-Pressure Core Flooding – HPCF (2 divisions)

- Coolant supply in small LOCA
- Water source: makeup water tanks or suppresion pool
- Electric pumps, emergency power supply

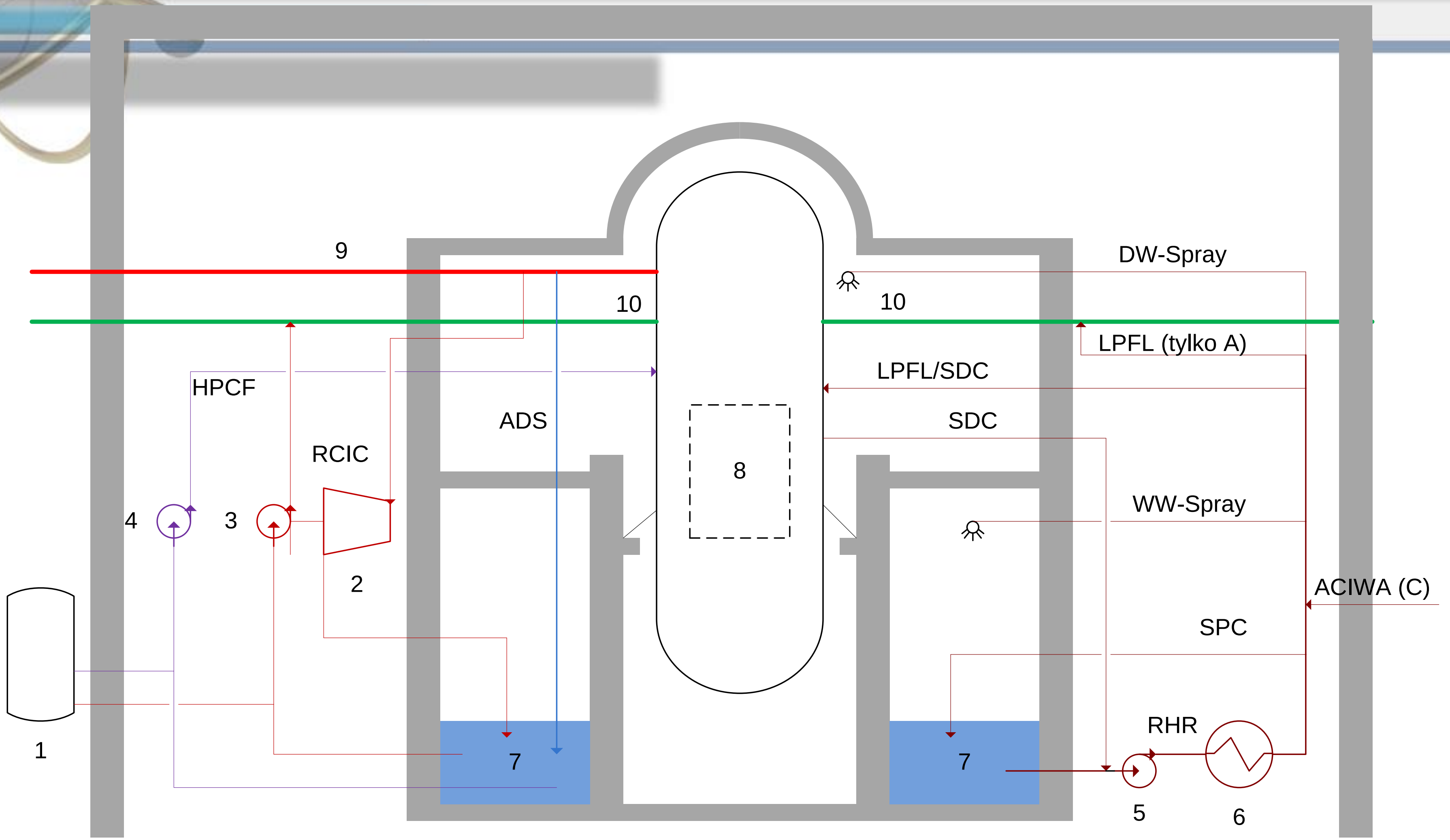
Reactor Core Isolation Cooling – RCIC (single)

- Ensuring coolant circulation when reactor is isolated
- Water source: makeup water tanks or suppresion pool
- Heat sink: suppresion pool
- Steam-driven pump

Automatic Depressurization System – ADS

- Ensuring release of excessive pressure in case of heat removal distrubances
- Steam discharged to the suppression pool

ABWR ECCS

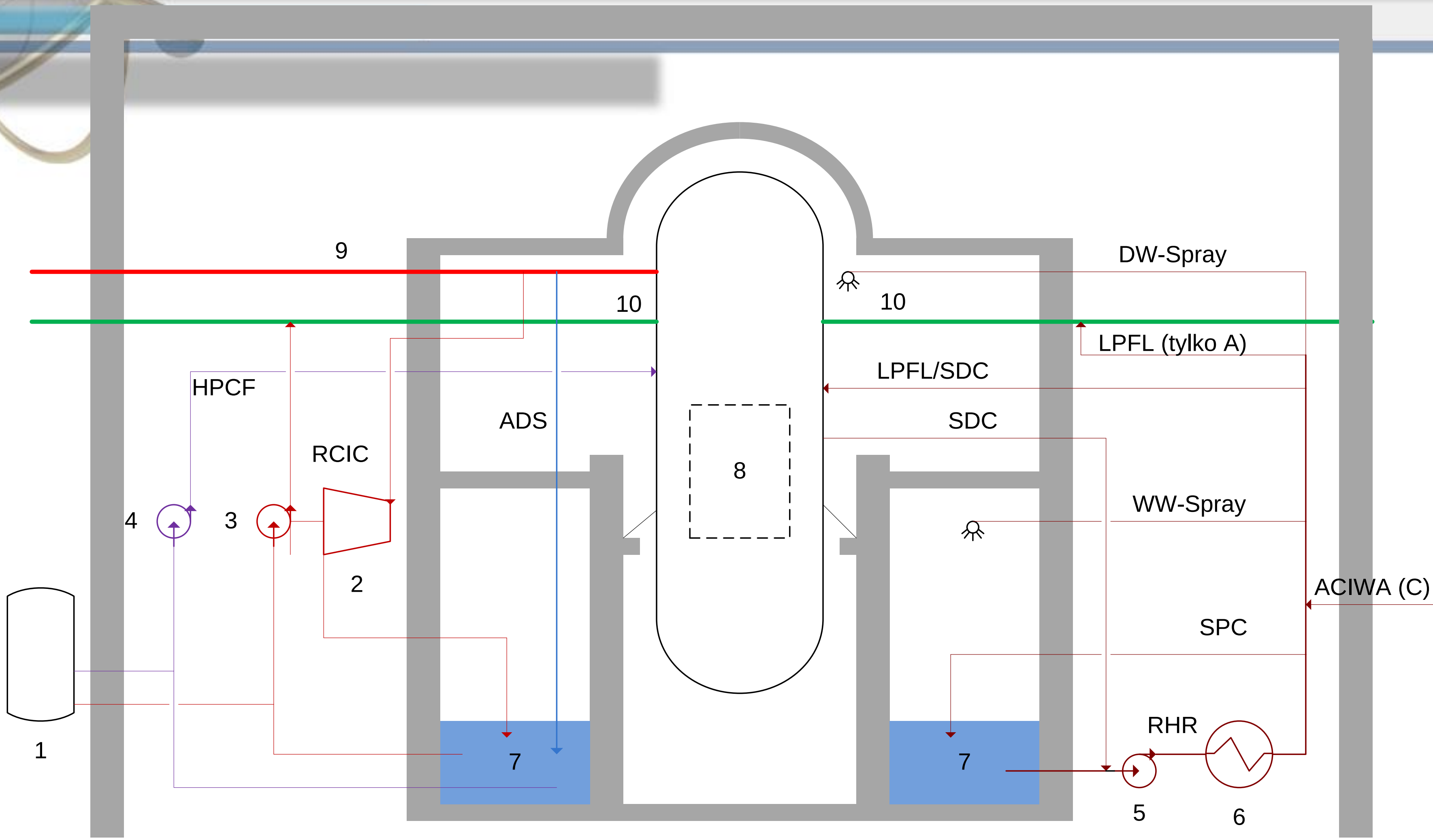

9
10
10
DW-Spray
LPFL (tylko A)
HPCF
LPFL/SDC
ADS
SDC
RCIC
8
4
3
WW-Spray
2
ACIWA (C)
SPC
1
RHR
7
7
5
6

ABWR Safety
Emergency Core Cooling Systems

Residual Heat Removal System – 3 Divisions

- Water source: suppression pool
- Heat sink: external plant cooling water system (via heat exchanger)
- Six different operating modes:
  - Low Pressure Flooding (LPFL)
  - Suppression Pool Cooling (SPC)
  - Shut-Down Cooling (SDC, non-safety function!)
  - Drywell/Wetwell spray (DW/WW spray)
  - Fuel Pool Cooling (FPC)
  - AC Independent Water Addition (ACIWA) – 1 division only

ABWR ECCS


9
10
10
DW-Spray
LPFL (tylko A)
HPCF
LPFL/SDC
ADS
SDC
RCIC
8
4
3
WW-Spray
2
ACIWA (C)
SPC
1
RHR
7
7
5
6

ABWR Electrical System

3 load groups

- Power Generation consumers
- Plant Investment Protection consumers
- Safety systems (Class 1E)

Emergency power supply (for safety systems only)

- 3 × Class 1E Diesel Generator
- 3 × 4.16 kV bus

Standby power for other systems

- Combustion turbine generator (non-Class 1E)
- May be connected to supply power for safety systems

ABWR Deployment

Kashiwazaki-Kariwa, TEPCO, Japan

- KK6&7 built 1992-1996 & 1993-1997

Hamaoka, Chubu Electric, Japan

- Hamaoka 5, built 2000-2005, shut down in May 2011, awaiting upgrades

Shika, Hokuriku Electric, Japan

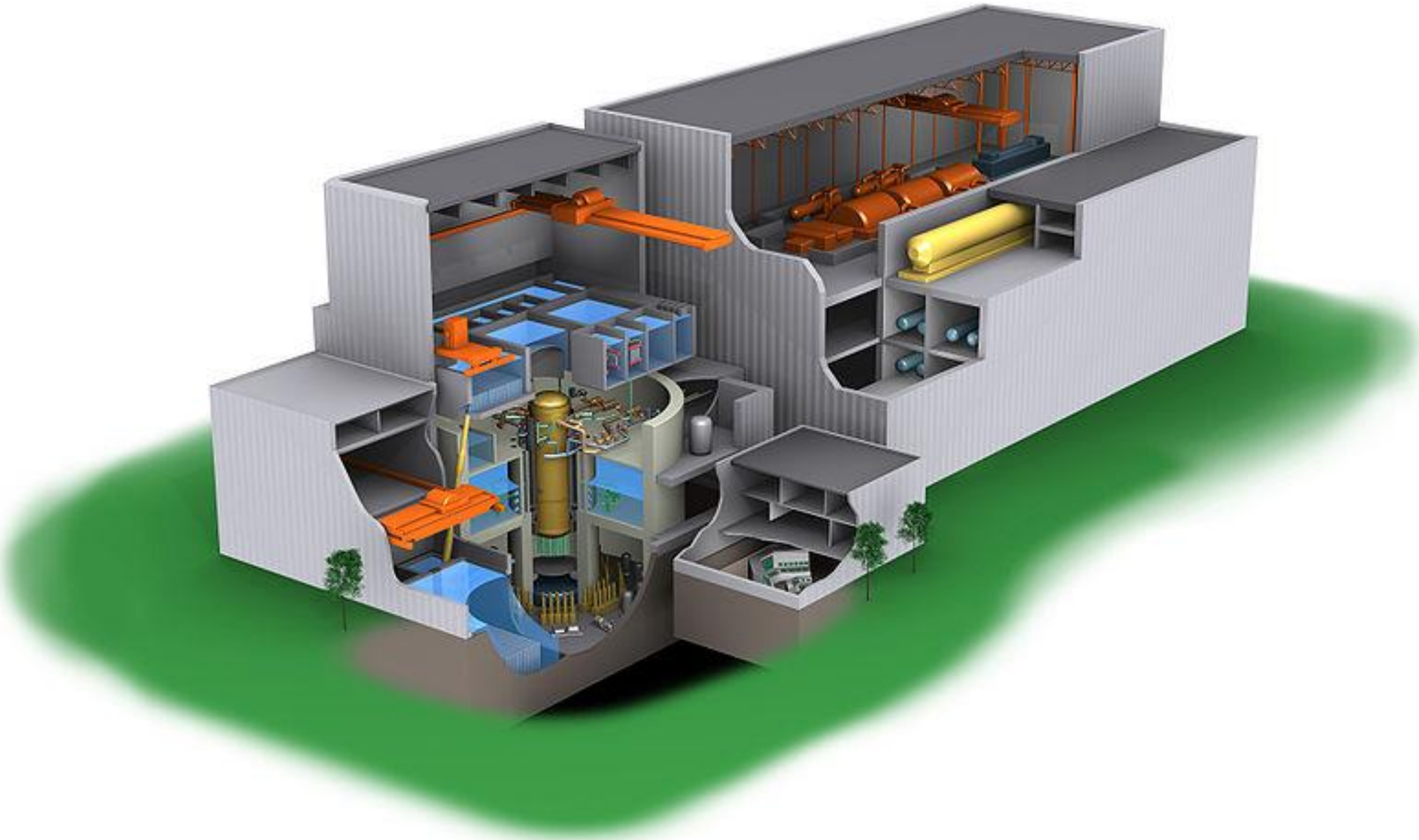
- Shika-2, built 2001-2005

Lungmen, Taiwan

- 2 × ABWR under construction since 1997

4 more units under construction in Japan (Higashidori & Oma NPPs)

GE-Hitachi ESBWR



ESBWR Main Features

Passive cooling

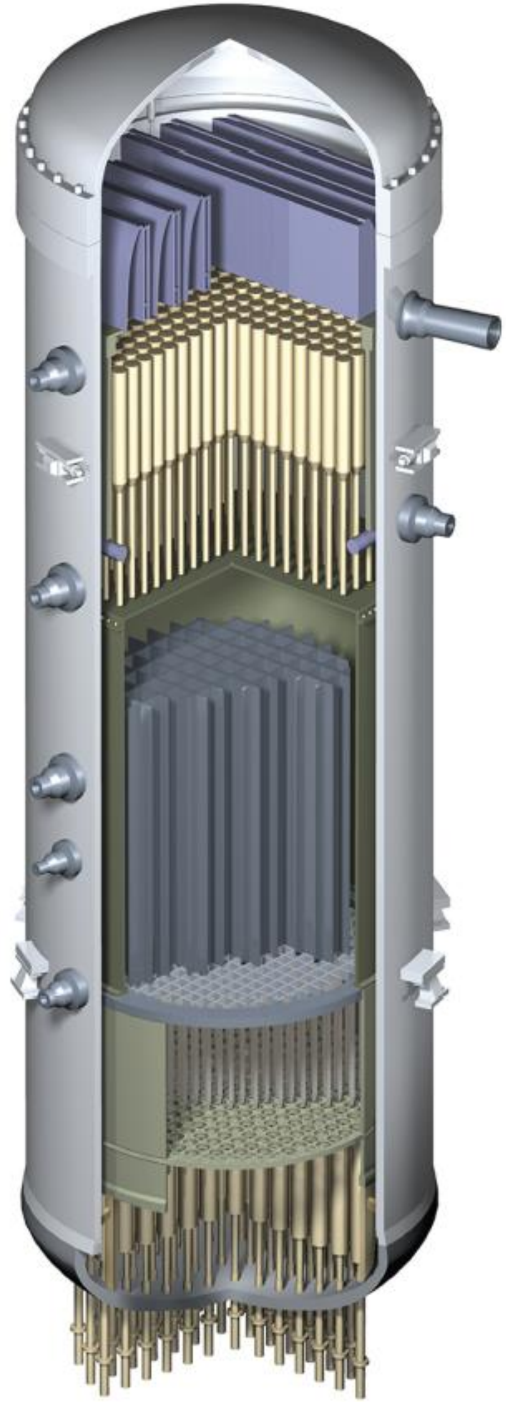
- Natural circulation during normal operation
- Passive decay heat removal
- 72 h without operator’s input or AC supply

Simplification

- Less mechanical equipment

High output

- 4500 MWth
- Around 1600 MWel



ESBWR – Core cooling

Isolation Condensers System

- Isolated reactor cooling
- Normal operation (post-shut down) and emergency
- Driven by natural convection

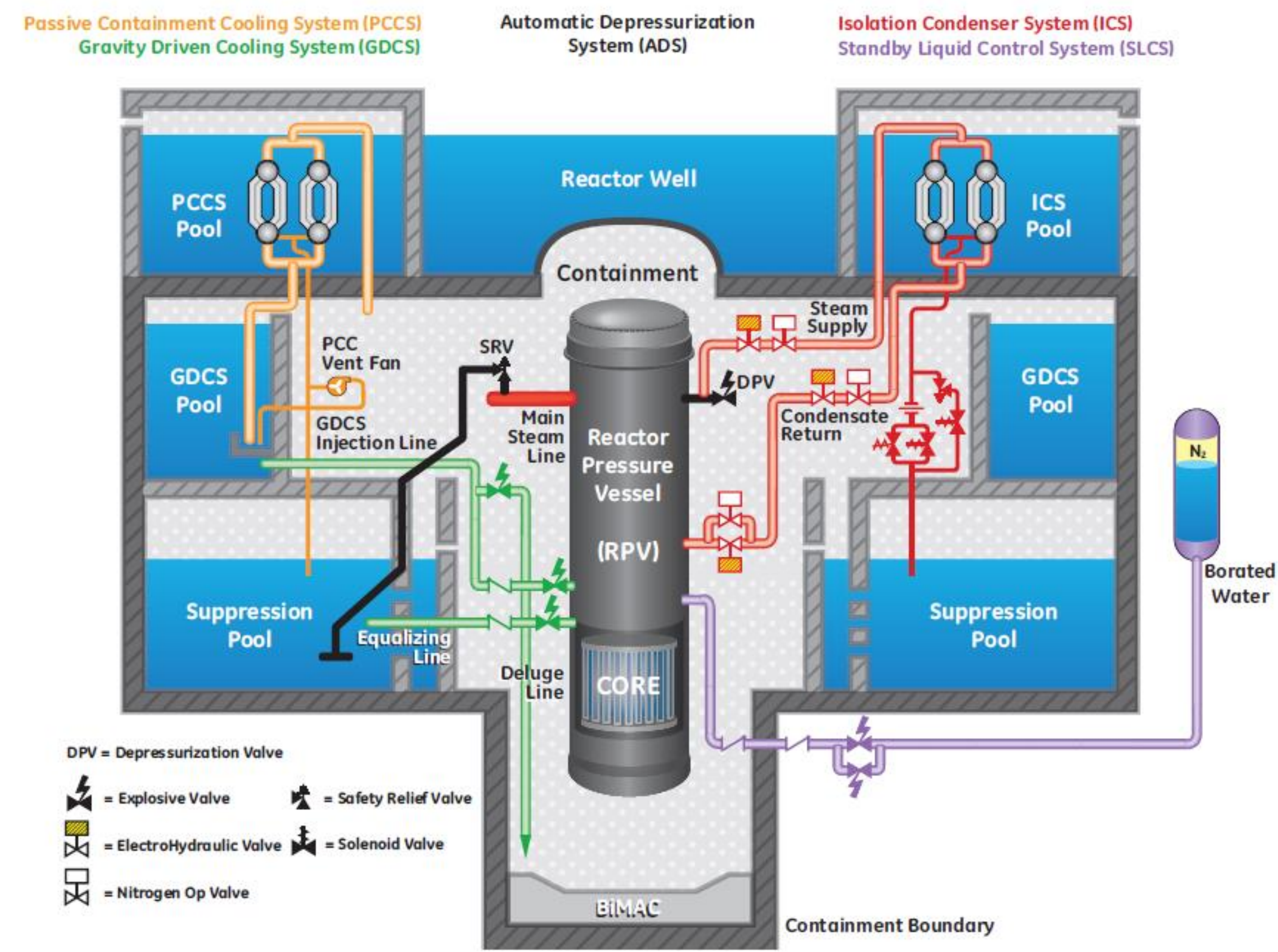
Gravity-Driven Cooling System

- Providing water supply in case of LOCA
- 4 Divisions

Passive Containment Cooling System

- Preventing pressure buildup in primary containment
- Six independent loops

Automatic Depressurization System


Passive Containment Cooling System (PCCS)
Gravity Driven Cooling System (GDCS)
Automatic Depressurization System (ADS)
Isolation Condenser System (ICS)
Standby Liquid Control System (SLCS)
PCCS Pool
Reactor Well
ICS Pool
Containment
Steam Supply
PCC Vent Fan
SRV
GDCS Pool
DPV
GDCS Pool
GDCS Injection Line
Main Steam Line
Reactor Pressure Vessel
(RPV)
Condensate Return
N2
Borated Water
Suppression Pool
Equalizing Line
Deluge Line
CORE
Suppression Pool
DPV = Depressurization Valve
= Explosive Valve
= Safety Relief Valve
= ElectroHydraulic Valve
= Solenoid Valve
= Nitrogen Op Valve
BiMAC
Containment Boundary

ESBWR Power Supply

ECCS don't need power supply

- No Class 1E generators required
- Safety-related systems only have batteries

Standby power

- 2 non-Class 1E Diesel Generators, 6.9 kV
- Requied start-up time around 2 minutes
- DGs installed in electrical auxiliary building

Further reading

- ARIS – Advanced Reactors Information System
  International Atomic Energy Agency
  http://aris.iaea.org/ARIS/reactors.cgi
- PRIS – Power Reactor Information System
  International Atomic Energy Agency
  http://www.iaea.org/programmes/a2/
- AP1000 Safety Report (UK applications)
  https://www.ukap1000application.com/
- Status and perspectives of VVER nuclear power plants
  http://www.iaea.org/NuclearPower/Downloads/Technology/meetings/2011-Jul-26-28-TWG-LWR-HWR/Session-I/21.TWG-LWR-Russia.pdf
- ESBWR Plant General Description
  http://www.ne.doe.gov/np2010/pdfs/esbwrGenera%20DescriptionR4.pdf
- ABWR Plant General Description
  http://www.foronuclear.org/images/stories/recursos/zona-descarga/Descripcion_general_ABWR_GE.pdf (might be also found elsewhere)

CONCLUSIONS

No industrial object can be totally accident-free

Nuclear power plants are extremely safe industrial objects

Change of public attitude is only possible as an effect of extensive education

Thank you.