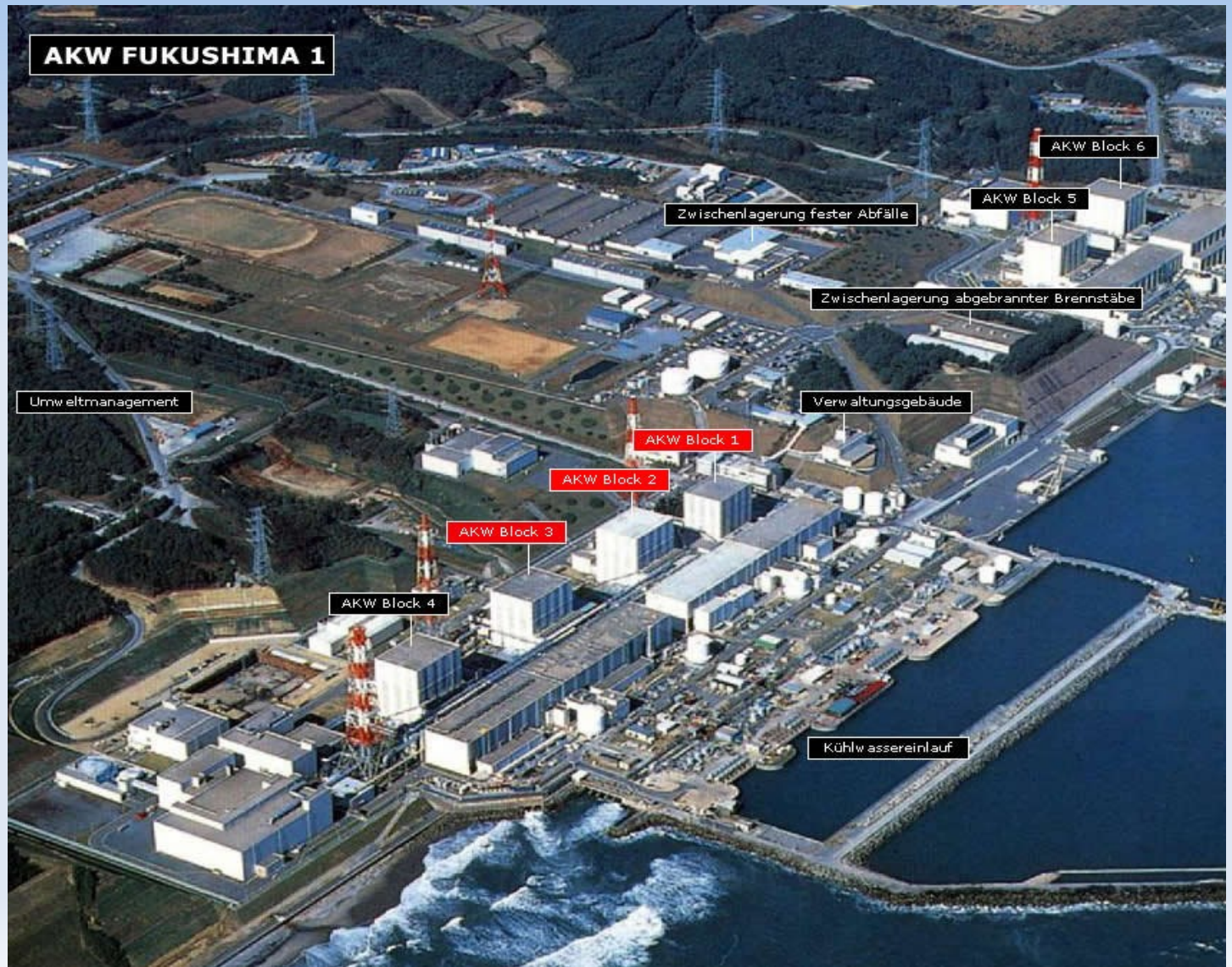
# Fukushima, Chronologie eines Unfalls

- Struktur des Vortrags
  - Ablauf des Reaktorunfalls
  - Technische Maßnahmen für die Zukunft
  - Radiologie
    - An Land
    - Zu Wasser

# Reaktordesign



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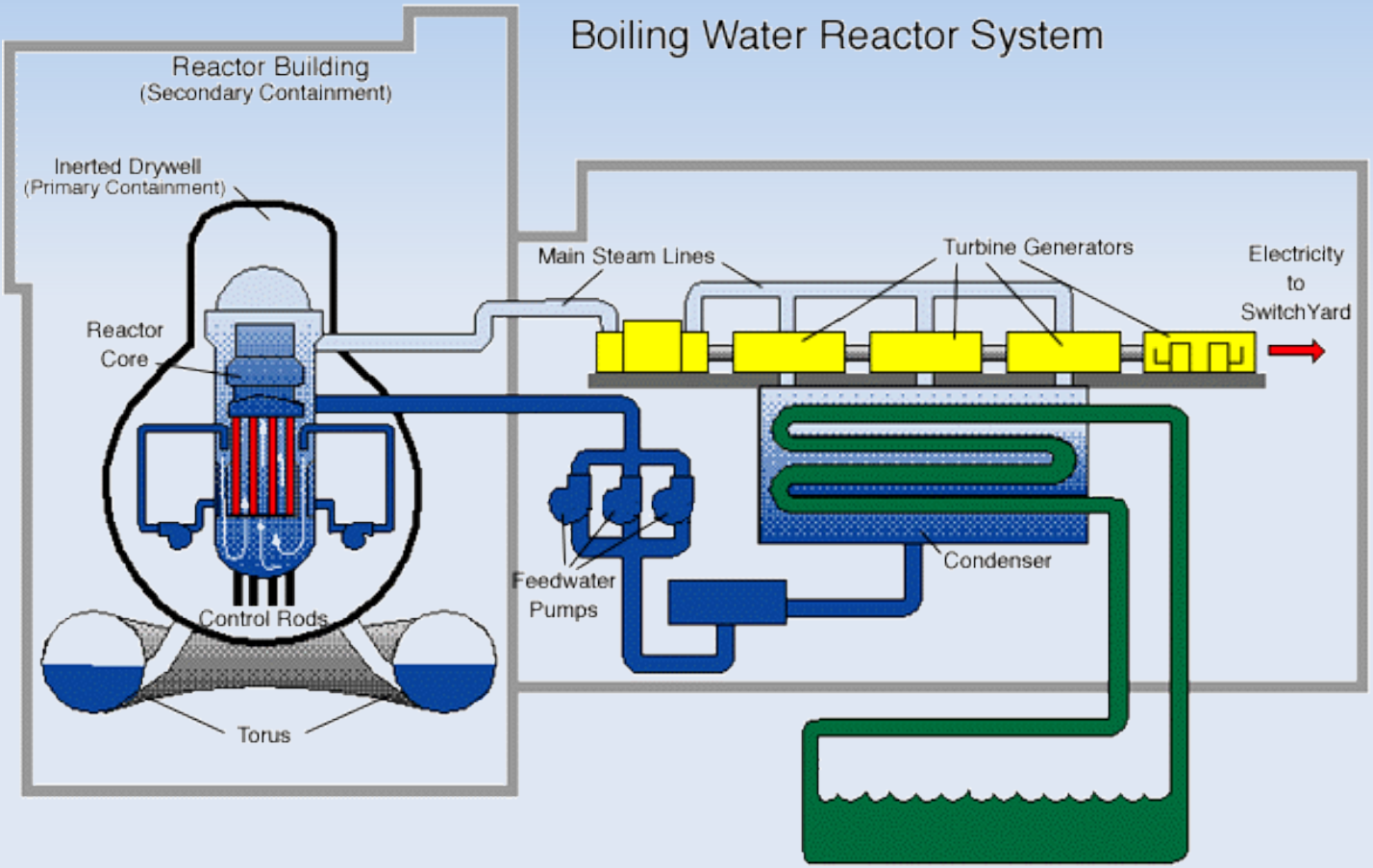

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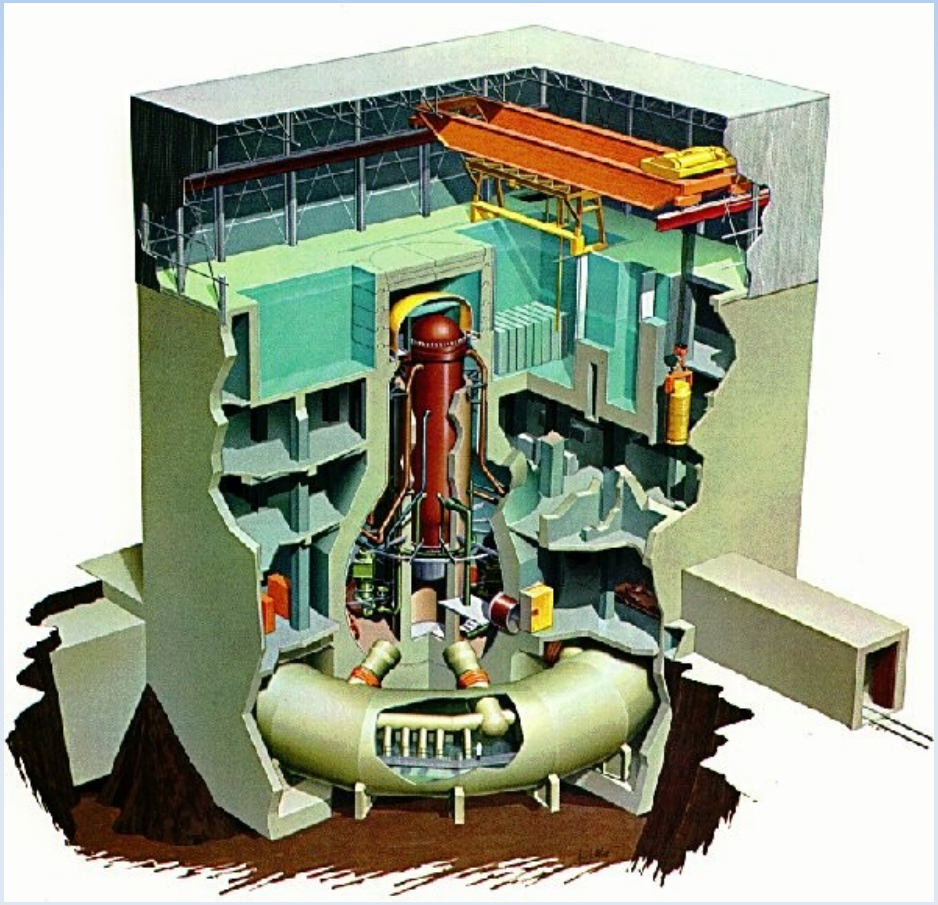

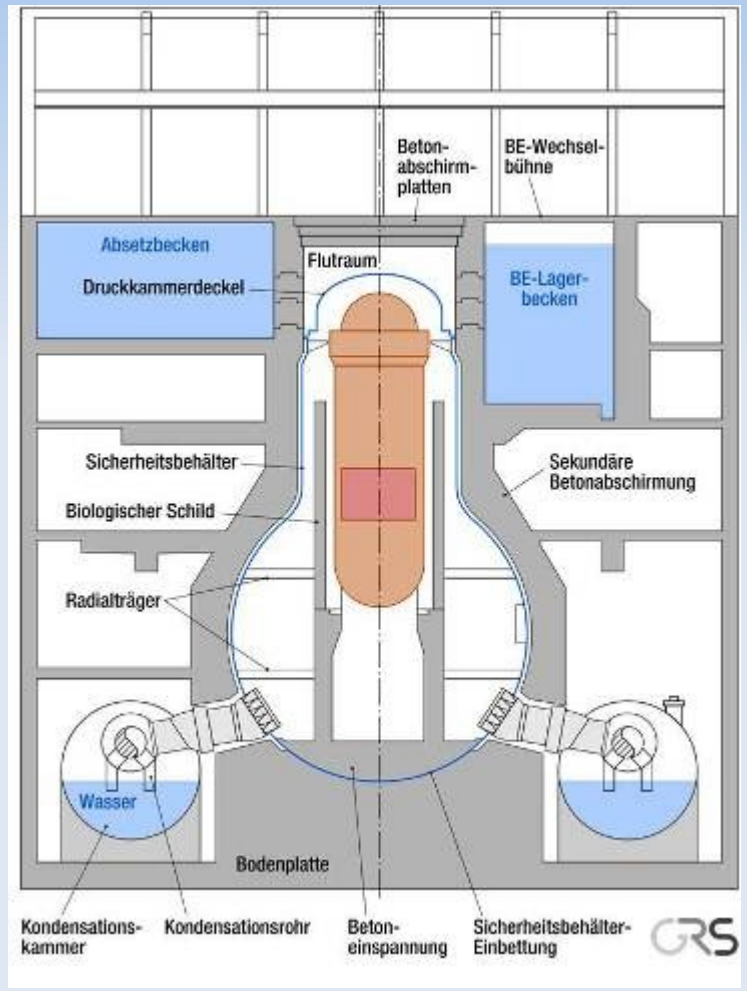

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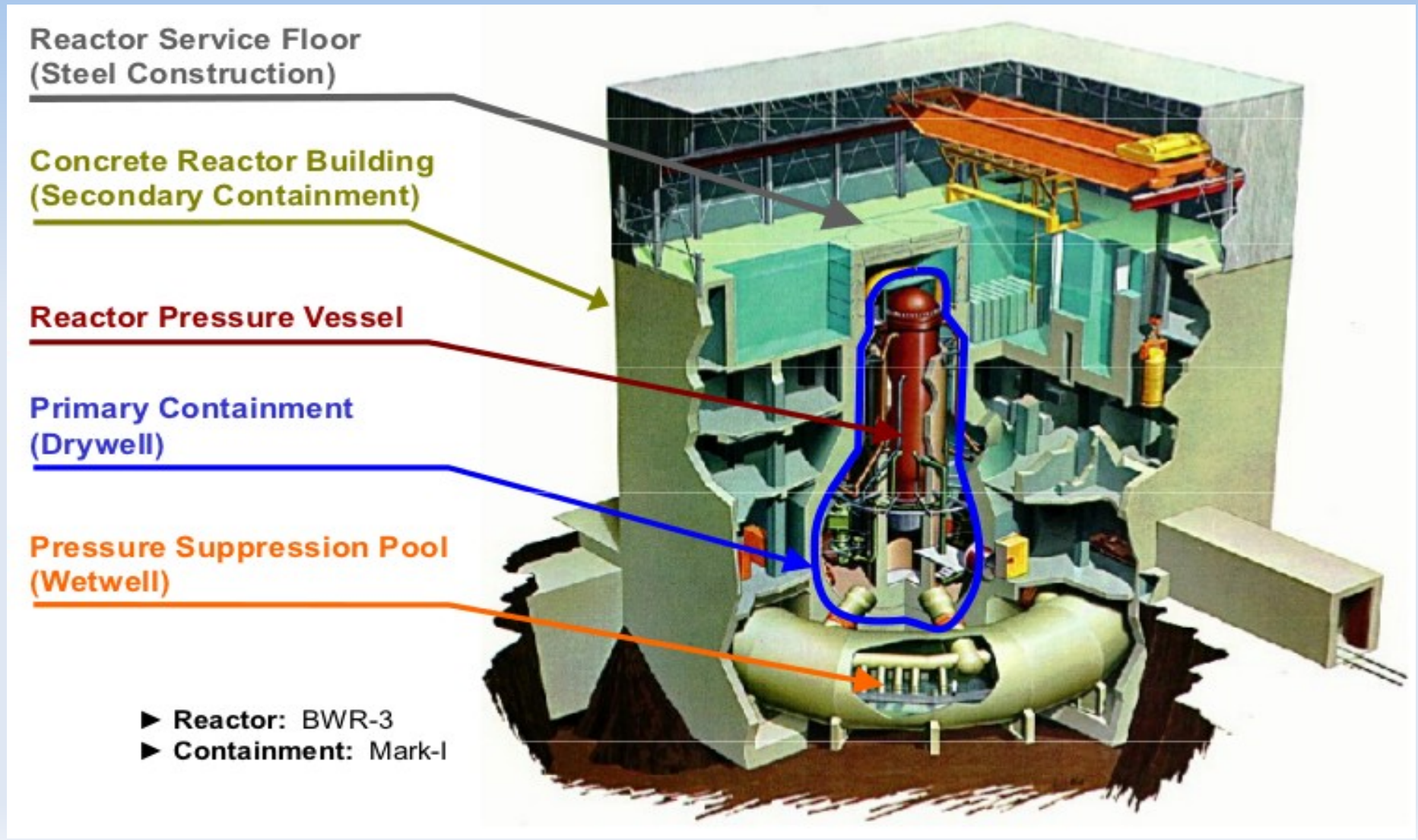
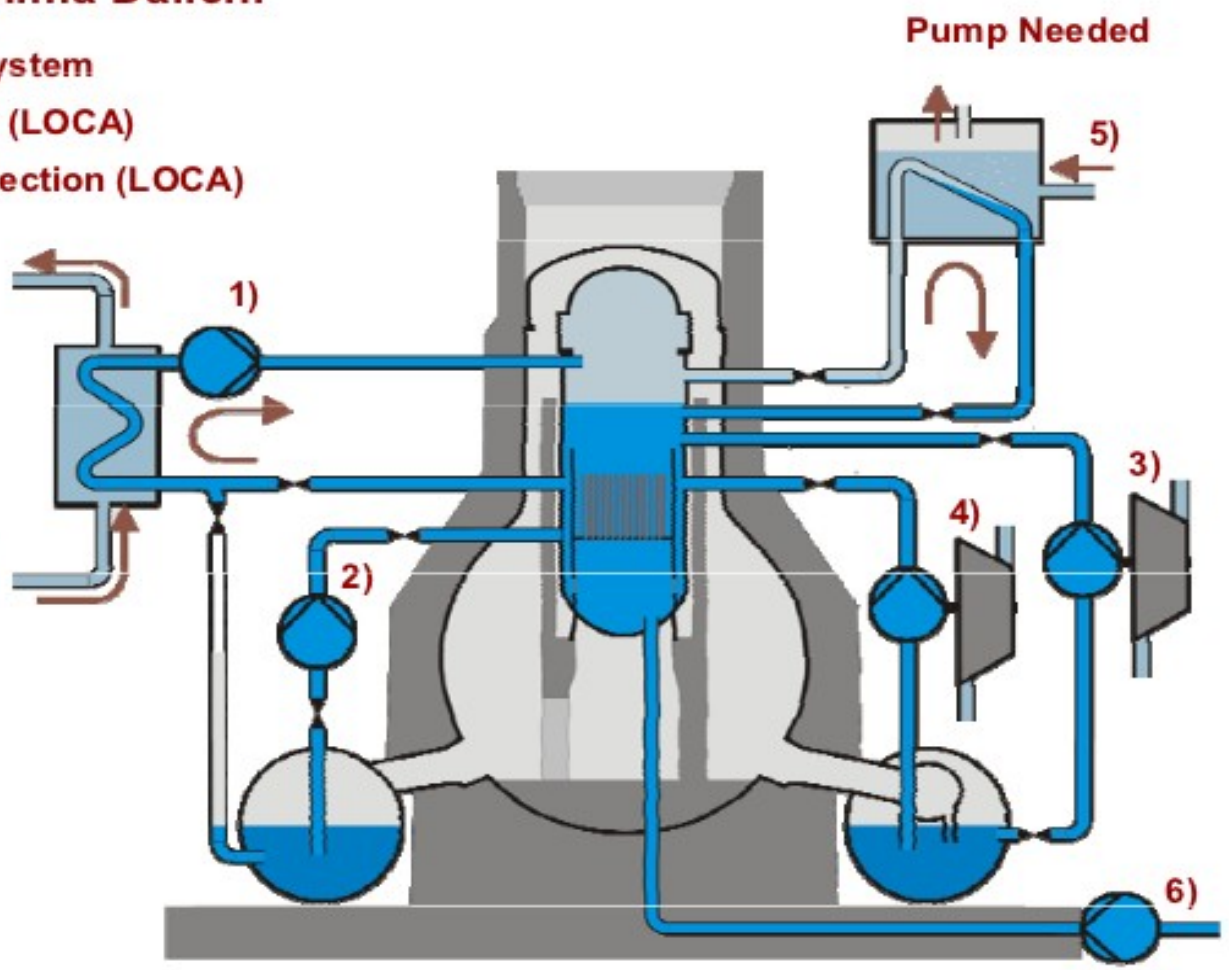


# Reaktordesign

## Emergency Core Cooling Systems of Different Units at Fukushima Daiichi

1) Residual Heat Removal System
2) Low-Pressure Core Spray (LOCA)
3) High-Pressure Coolant Injection (LOCA)
4) Reactor Core Isolation Cooling (Unit 2/3: BWR-4)
5) Isolation Condenser (Unit 1: BWR-3)
6) Borating System



# Reaktortypen

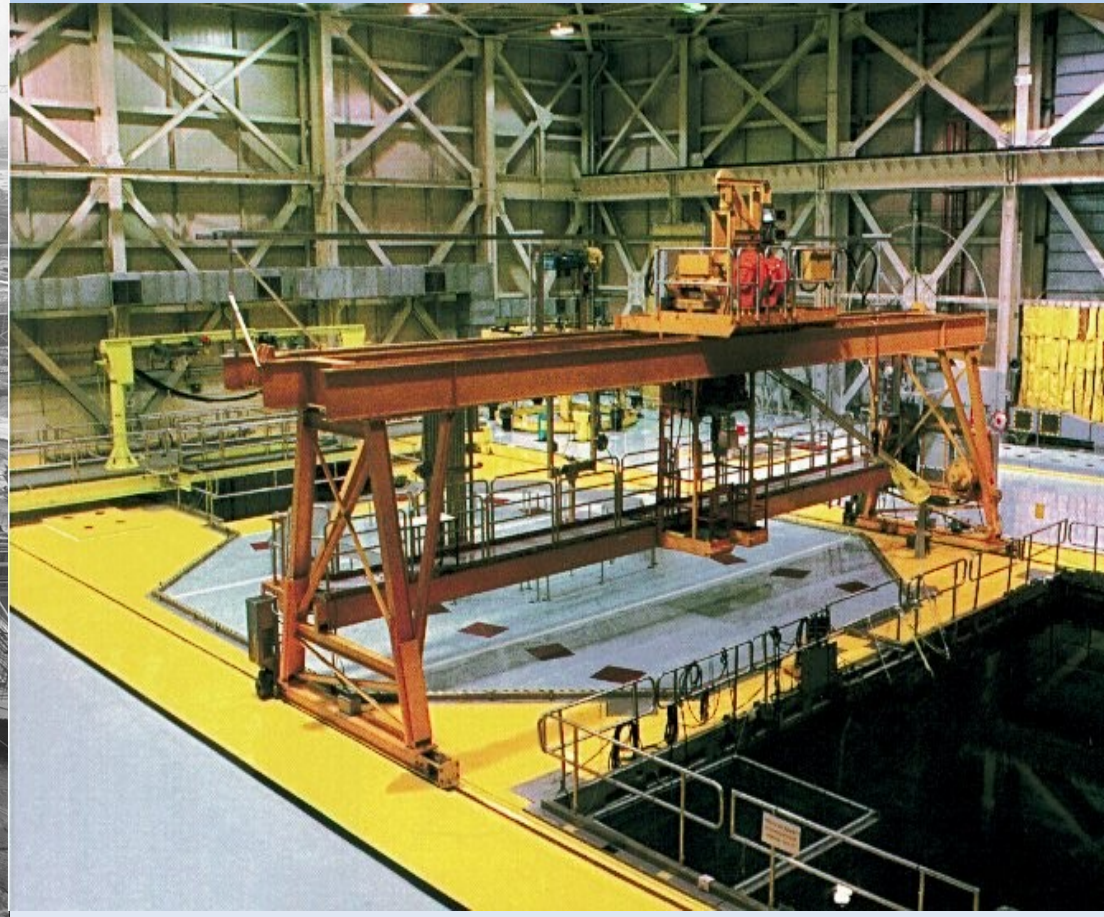
| | Unit 1 | Unit 2 | Unit 3 | Unit 4 | Unit 5 | Unit 6 |
|---|---|---|---|---|---|---|
| | BWR-3 | BWR-4 | BWR-4 | BWR-4 | BWR-4 | BWR-5 |
| PCV Model | Mark-1 | Mark-1 | Mark-1 | Mark-1 | Mark-1 | Mark-2 |
| Electric Output (MWe) | 460 | 784 | 784 | 784 | 784 | 1100 |
| Max. pressure of RPV | 8.24MPa | 8.24MPa | 8.24MPa | 8.24MPa | 8.62MPa | 8.62MPa |
| Max. Temp of the RPV | 300℃ | 300℃ | 300℃ | 300℃ | 302℃ | 302℃ |
| Max. Pressure of the CV | 0.43MPa | 0.38MPa | 0.38MPa | 0.38MPa | 0.38MPa | 0.28MPa |
| Max. Temp of the CV | 140℃ | 140℃ | 140℃ | 140℃ | 138℃ | 171℃(D/W)<br>105℃(S/C) |
| Commercial Operation | 1971,3 | 1974,7 | 1976,3 | 1978,10 | 1978,4 | 1979,10 |
| Emergency DG | 2 | 2 | 2 | 2 | 2 | 3* |
| Electric Grid | 275kV × 4 | | | | 500kV × 2 | |
| Plant Status on Mar. 11 | In Operation | In Operation | In Operation | Refueling Outage | Refueling Outage | Refueling Outage |

* One Emergency DG is Air-Cooled

# Reaktordesign

| Unit | 1 | 2 | 3 | 4 | 5 | 6 |
|---|---|---|---|---|---|---|
| Number of Fuel Assembly in the Core | 400 | 548 | 548 | - | 548 | 764 |
| Number of Spent Fuel Assembly in the Spent Fuel Pool | 292 | 587 | 514 | 1,331 | 946 | 876 |
| Number of New Fuel Assembly in the Spent Fuel Pool | 100 | 28 | 52 | 204 | 48 | 64 |
| Water Volume ($m^3$) | 1,020 | 1,425 | 1,425 | 1,425 | 1,425 | 1,497 |

# Reaktordesign



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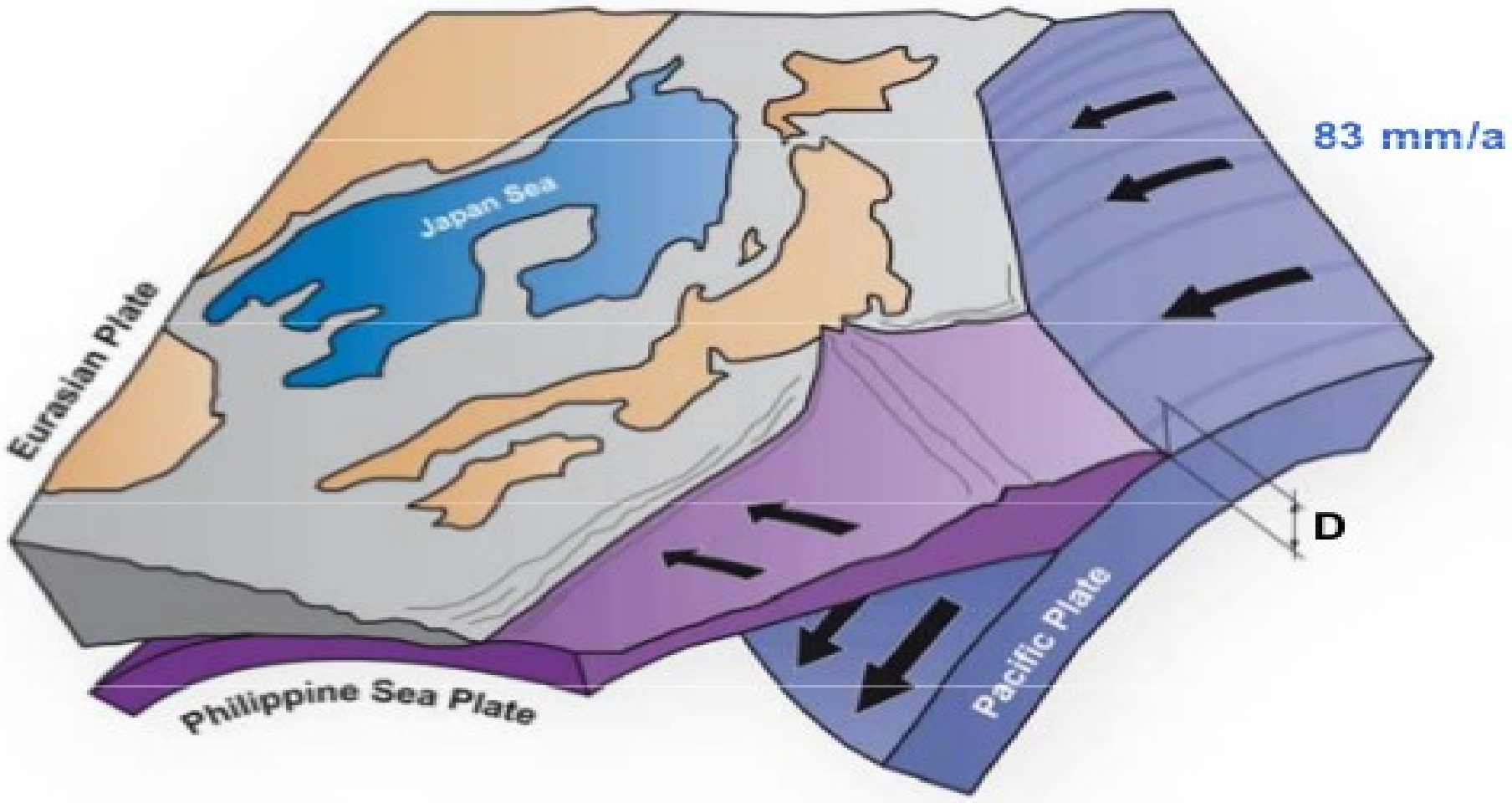

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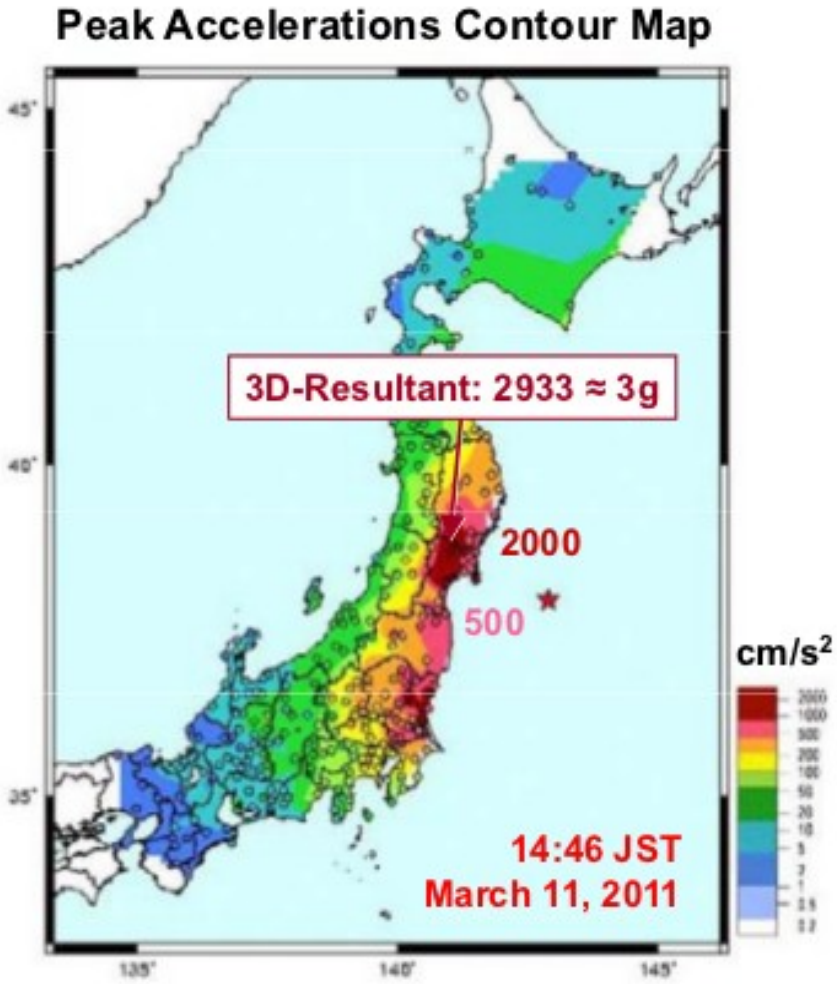


| Fukushima | Acceleration [1] in cm/s² | | |
|---|---|---|---|
| | Horizontal | | Vertical |
| | N-S | E-W | |
| Daiichi-1 | 460 | 447 | 258 |
| Daiichi-2 | 348 | 550 | 302 |
| Daiichi-3 | 322 | 507 | 231 |
| Daiichi-4 | 281 | 319 | 200 |
| Daiichi-5 | 311 | 548 | 256 |
| Daiichi-6 | 298 | 444 | 244 |
| Design Basis | 441 | 438 | 412 |
| Daini-1 | 254 | 230 | 305 |
| Daini-2 | 243 | 196 | 232 |
| Daini-3 | 277 | 216 | 208 |
| Daini-4 | 210 | 205 | 288 |
| Design Basis | 415 | 415 | 504 |
| Shutdown [2] | 135 to 150 | | 100 |

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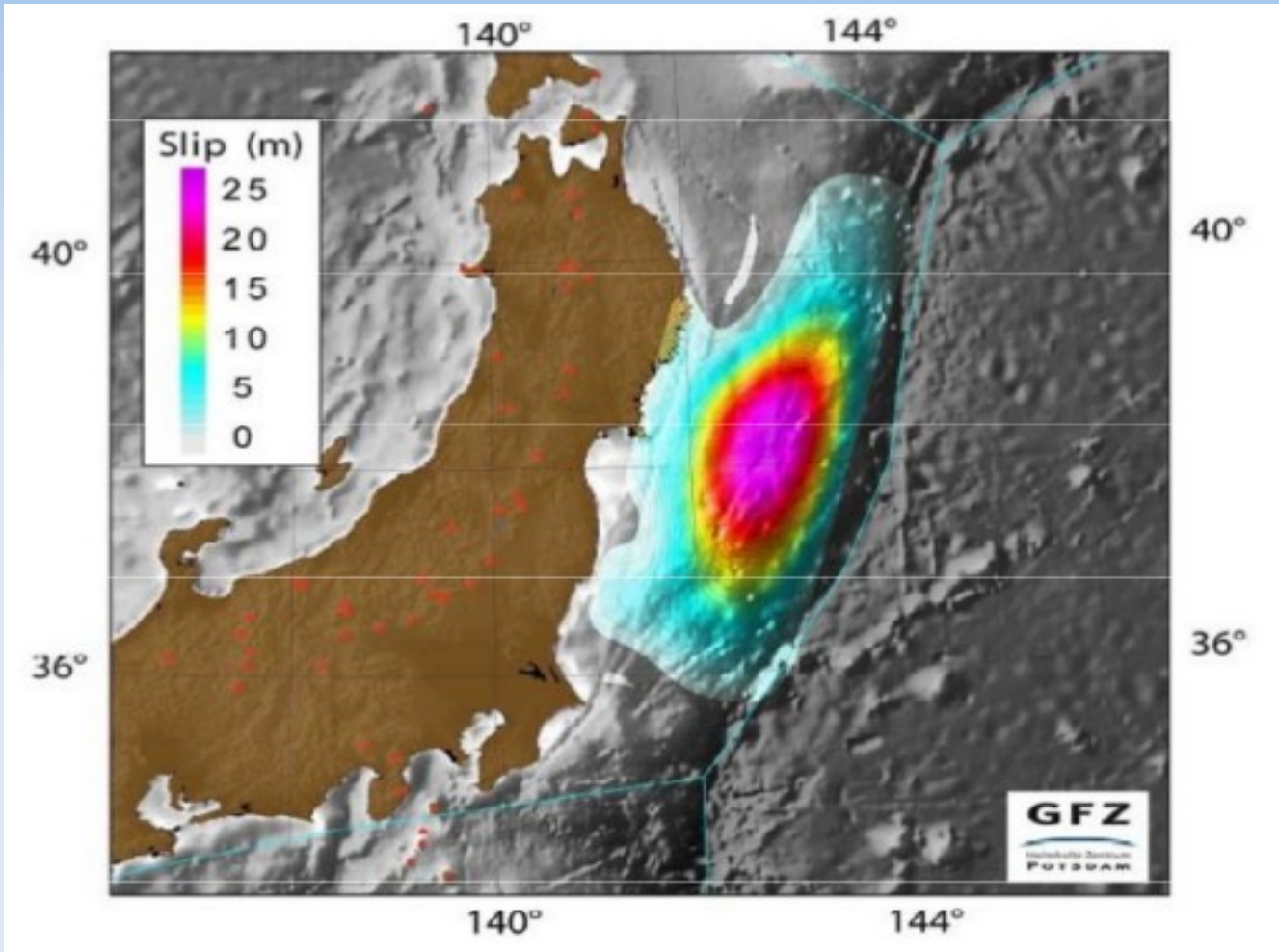
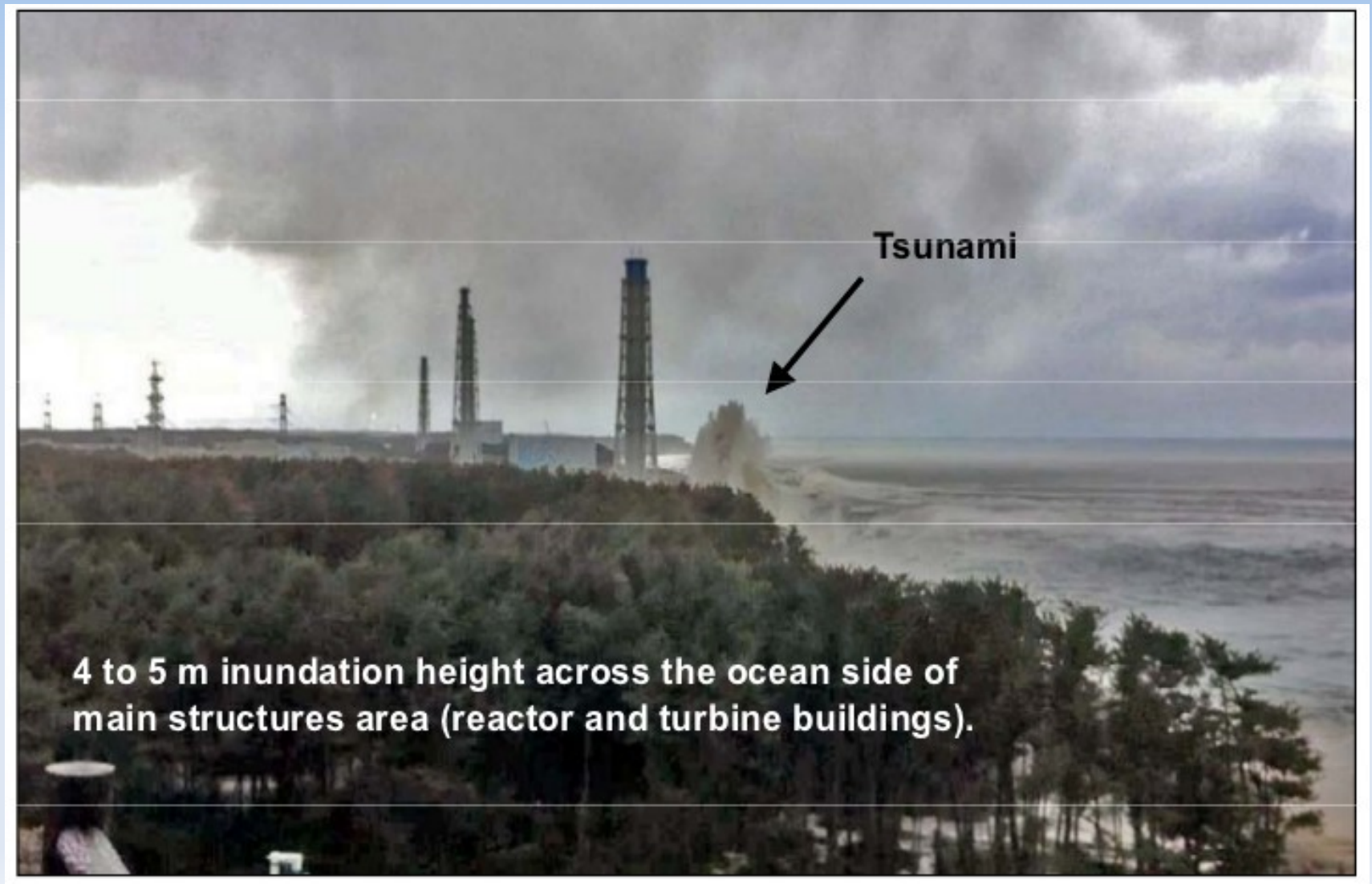


| Unit | 1 | 2 | 3 | 4 |
|---|---|---|---|---|
| Power (MWe /MWth) | 460/1380 | 784/2381 | 784/2381 | 784/2381 |
| Type of Reactor | BWR-3 | BWR-4 | BWR-4 | BWR-4 |
| Status at time of EQ | In service – auto shutdown | In service – auto shutdown | In service – auto shutdown | Outage |

# Chronologie eines Unfalls



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| Type of Reactor | BWR-3 | BWR-4 | BWR-4 | BWR-4 |
| Status at time of EQ | In service – auto shutdown | In service – auto shutdown | In service – auto shutdown | Outage |
| Core and fuel integrity | Damaged | Damaged | Damaged | No fuel in the Reactor |
| RPV & RCS integrity | RPV temperature decreasing | RPV temperature stable | RPV temperature stable | Not applicable due to outage plant status |
| Containment integrity | No information | Damage suspected | Damage suspected | |
| AC Power | AC power available - power to instrumentation – Lighting to Central Control Room | AC power available – power to instrumentation – Lighting to Central Control Room | AC power available – power to instrumentation – Lighting to Central Control Room | AC power available – power to instrumentation – Lighting to Central Control Room |
| Building | Severe damage | Slight damage | Severe damage | Severe damage |
| Water level of RPV | Around half of Fuel is uncovered | Around half of Fuel is uncovered | Around half of Fuel is uncovered | Not applicable due to outage plant status |
| Pressure of RPV | Slowly increasing | Stable | Stable | |
| CV Pressure Drywell | Stable | Stable | Stable | |
| Water injection to RPV | Injection of freshwater – via mobile electric pump with off-site power | Injection of freshwater – via mobile electric pump with off-site power | Injection of freshwater – via mobile electric pump with off-site power | |
| Water injection to CV | No information | No information | No information | |
| Spent Fuel Pool Status | Fresh water injection by concrete pump truck | Freshwater injection to the Fuel Pool Cooling Line | Freshwater injection via Fuel Pool Cooling Line and Periodic spraying | Fresh water injection by concrete pump truck |

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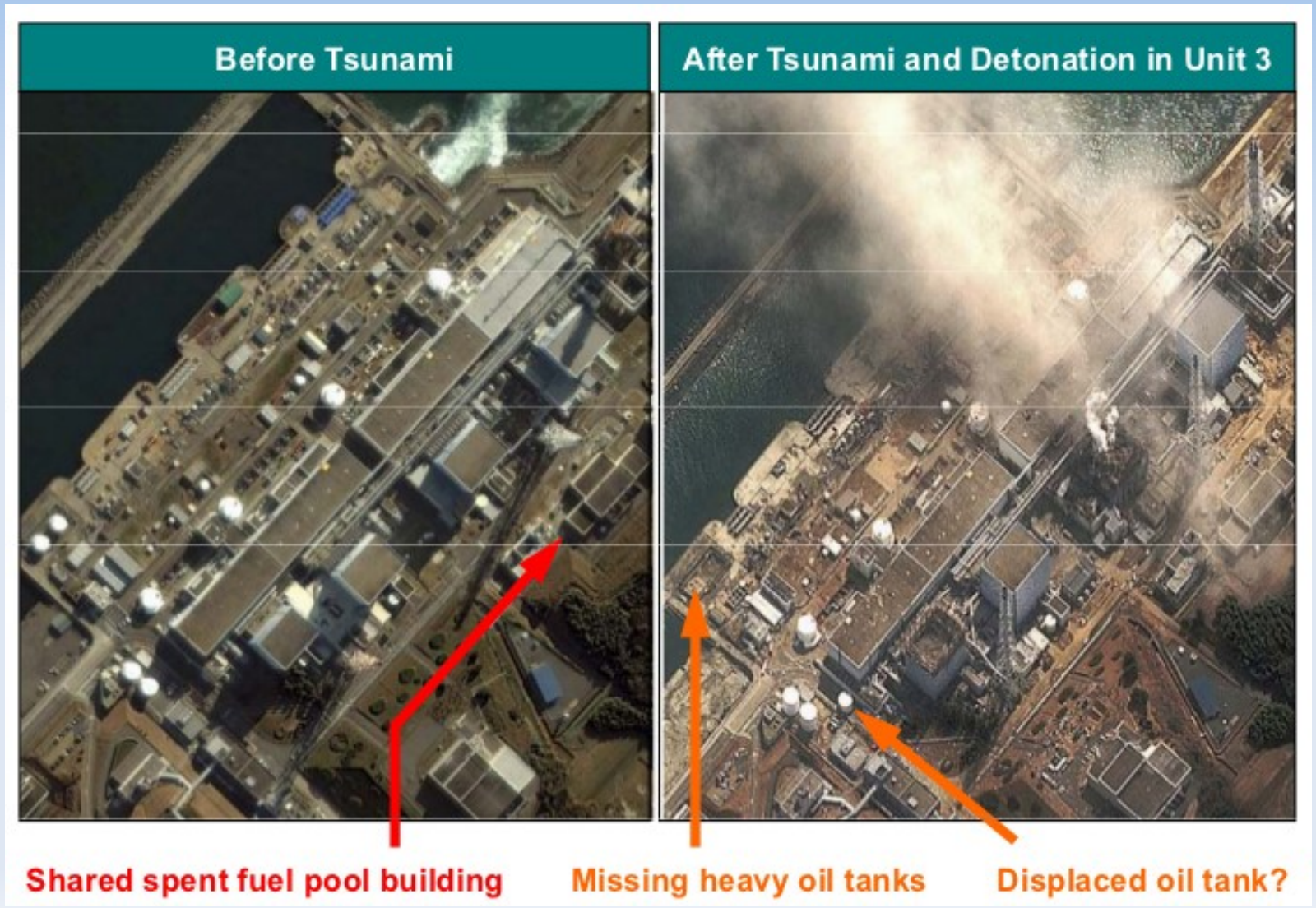

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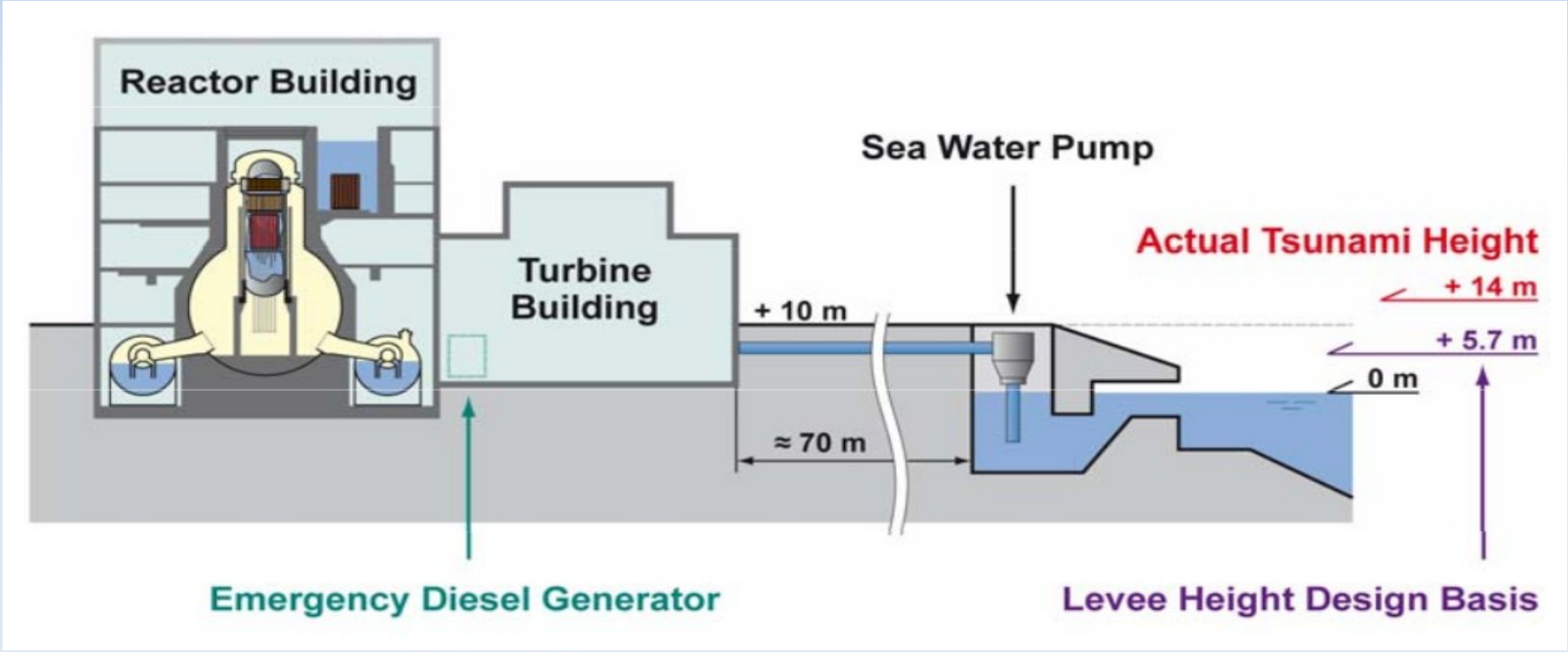

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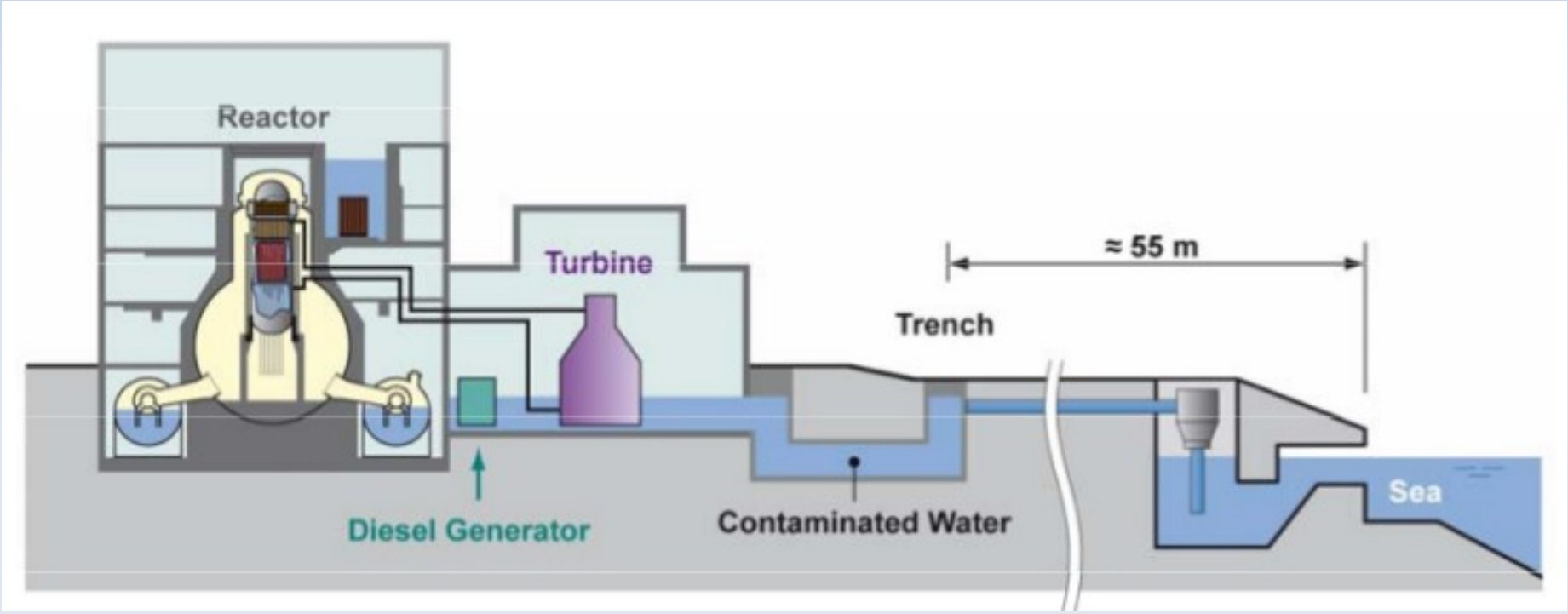

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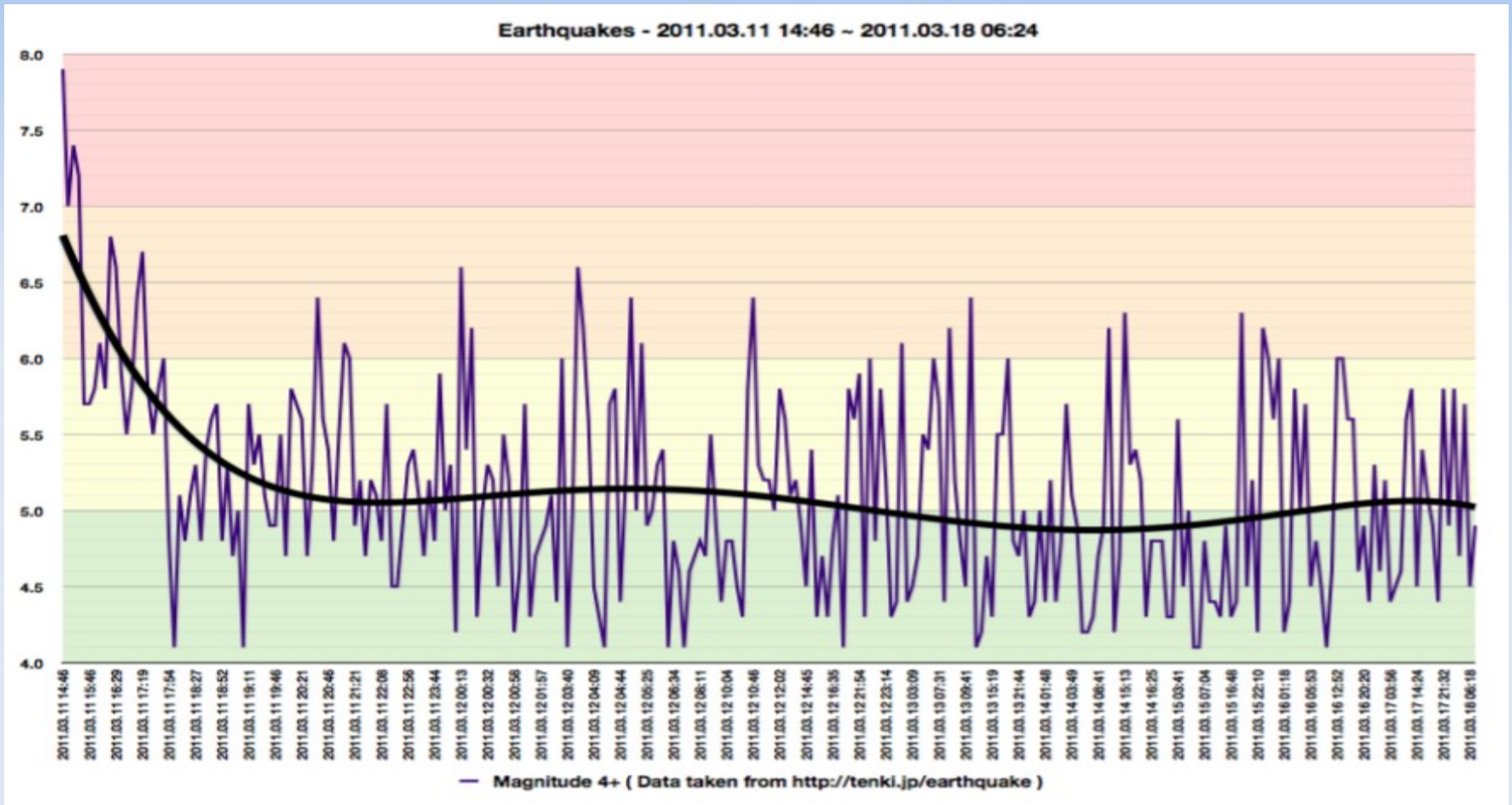
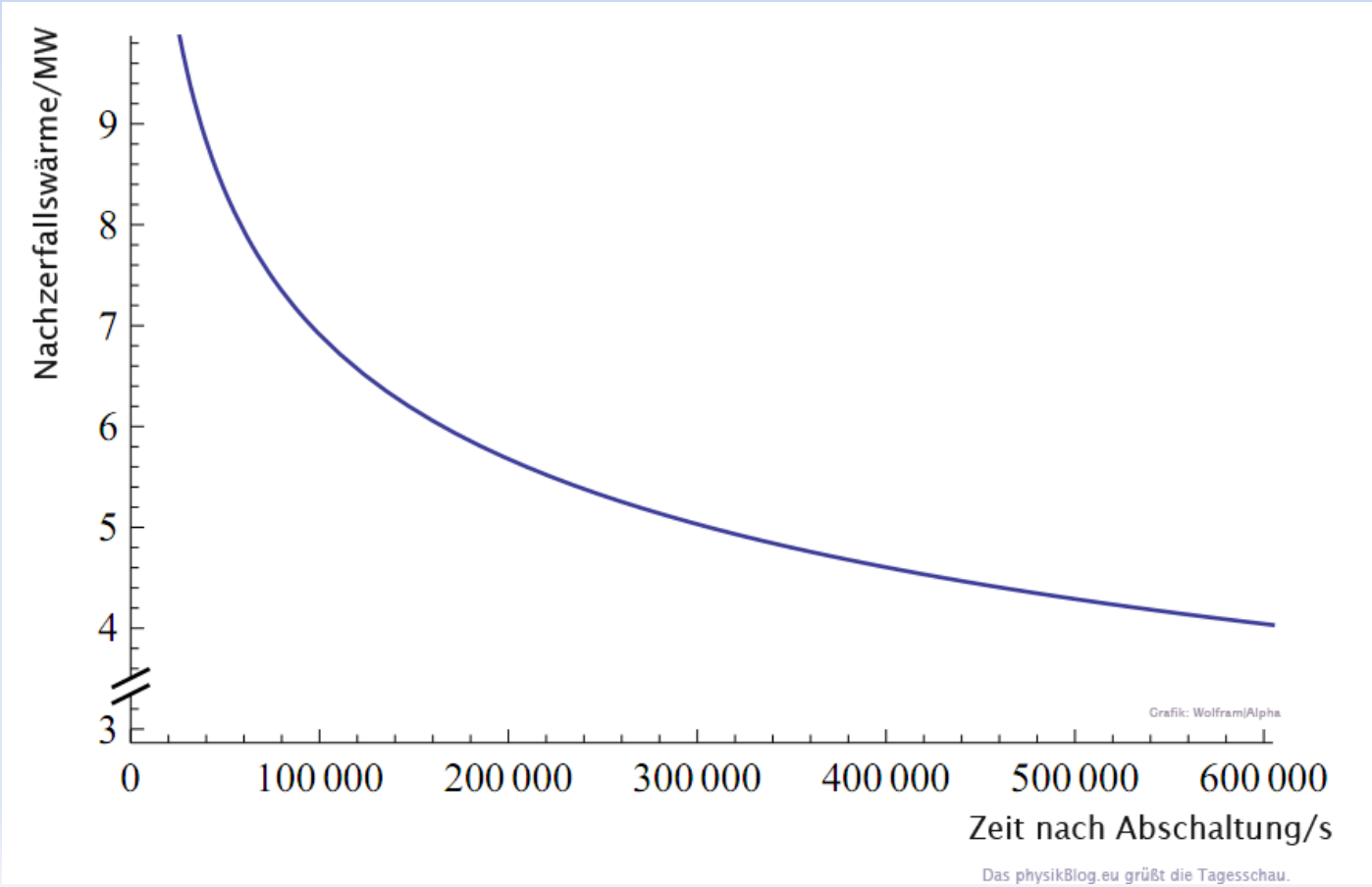


# Chronologie eines Unfalls

$$\frac{P}{P_0} = 6,22 \cdot 10^{-2} \cdot \left[ t^{-0,2} - \left( T_0 + t \right)^{-0,2} \right]$$



# Chronologie eines Unfalls

| Temp. [K] | Ereignis |
|---|---|
| **3120** | **Schmelzpunkt von $UO_2$** |
| **2960** | **Schmelzpunkt von $ZrO_2$** |
| 2620 | Schmelzpunkt von $B_4C$ |
| **2400 - 2600** | **Zerstörung der Brennstäbe** |
| 2100 | Beg. Verflüssigung $UO_2$ - Zry |
| **2030** | **Schmelzpunkt von Zry** |
| *1850* | *Eskalation der Zry-Oxidation* |
| 1700 | Schmelzpunkt von Edelstahl |
| 1450 | Eutektika Zry - Ag, Zerstörung DWR-Steuerstäbe |
| 1420 | Eutektika Stahl - $B_4C$, Zerstörung SWR-Steuerstäbe |
| *1270* | *verstärkte Zry-Oxidation* |
| 1210 | Eutektika Stahl - Zr, relevant für DWR-Steuerstäbe |
| 1170 | Bersten von Brennstäben, Beginn Spaltproduktfreisetzung |
| 1100 | Schmelzpunkt von Ag-In-Cd |

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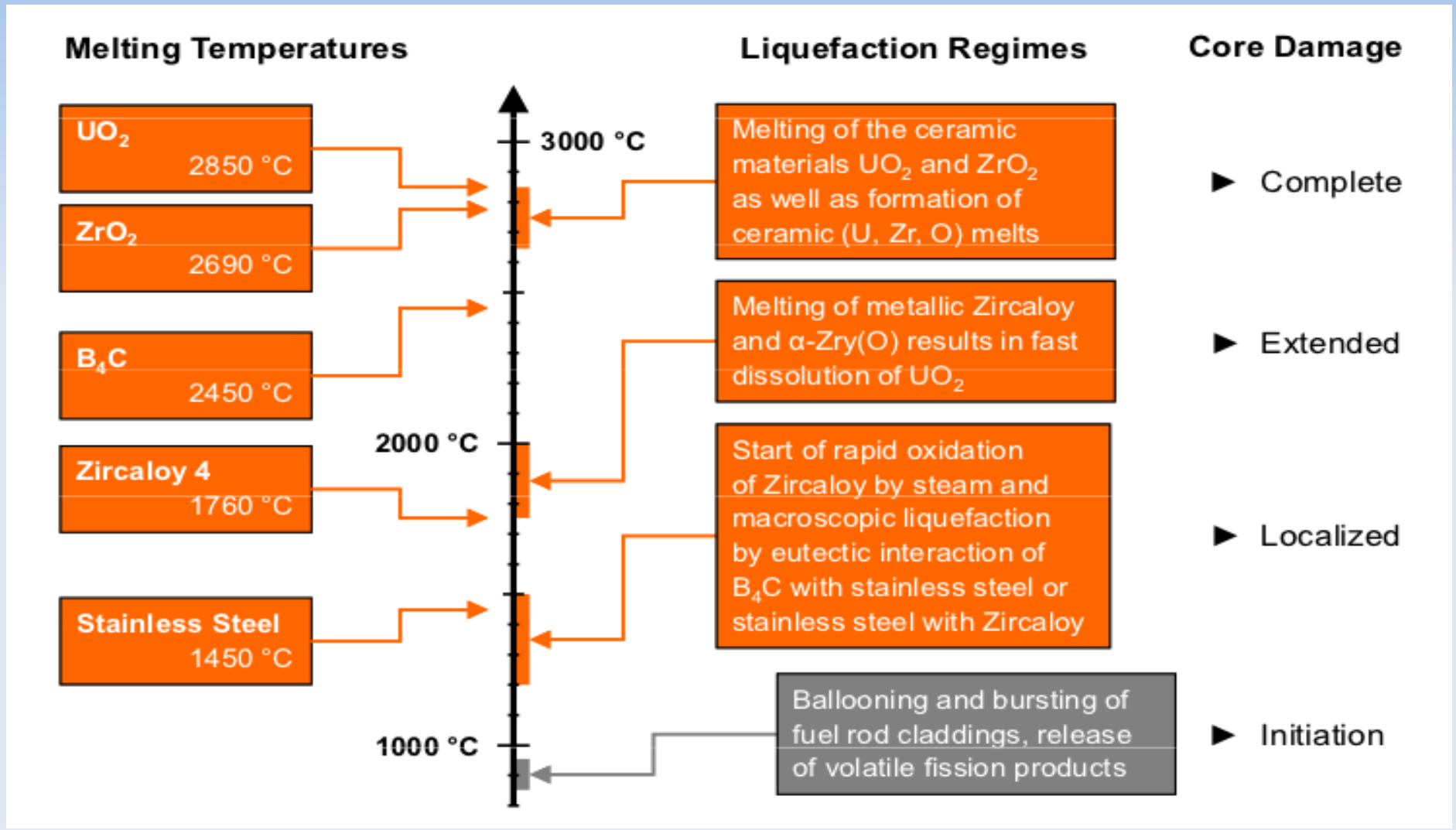

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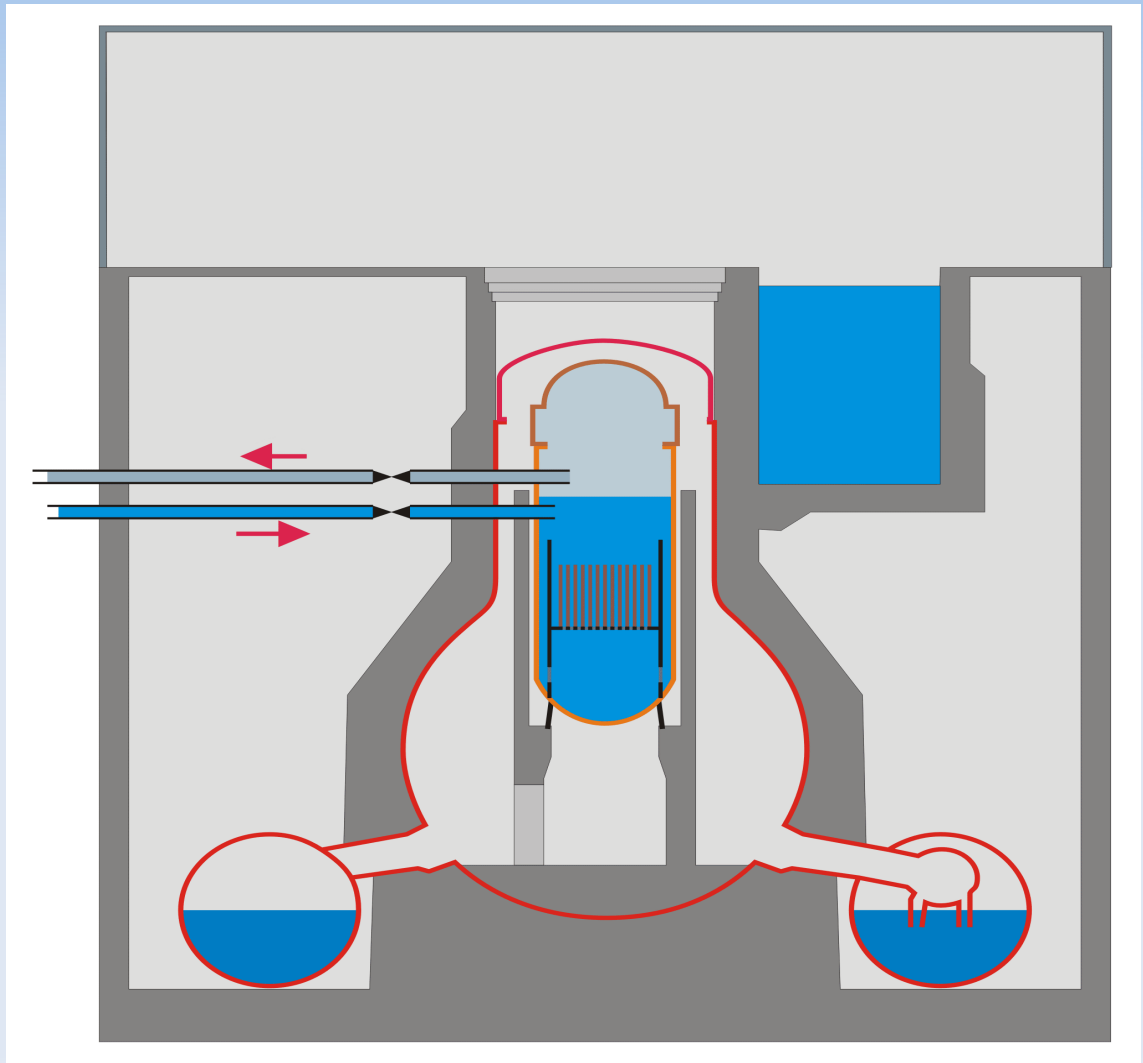

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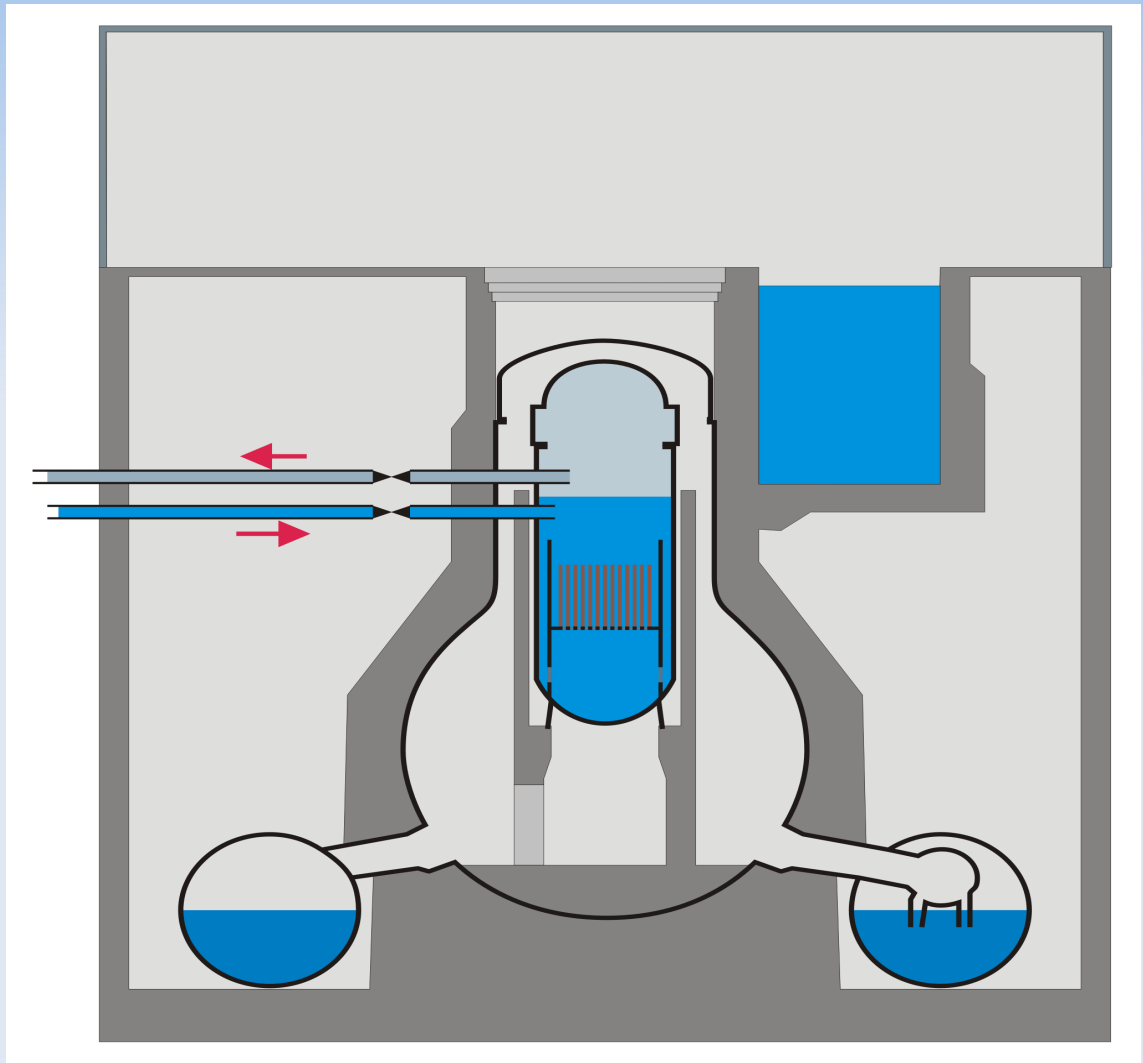

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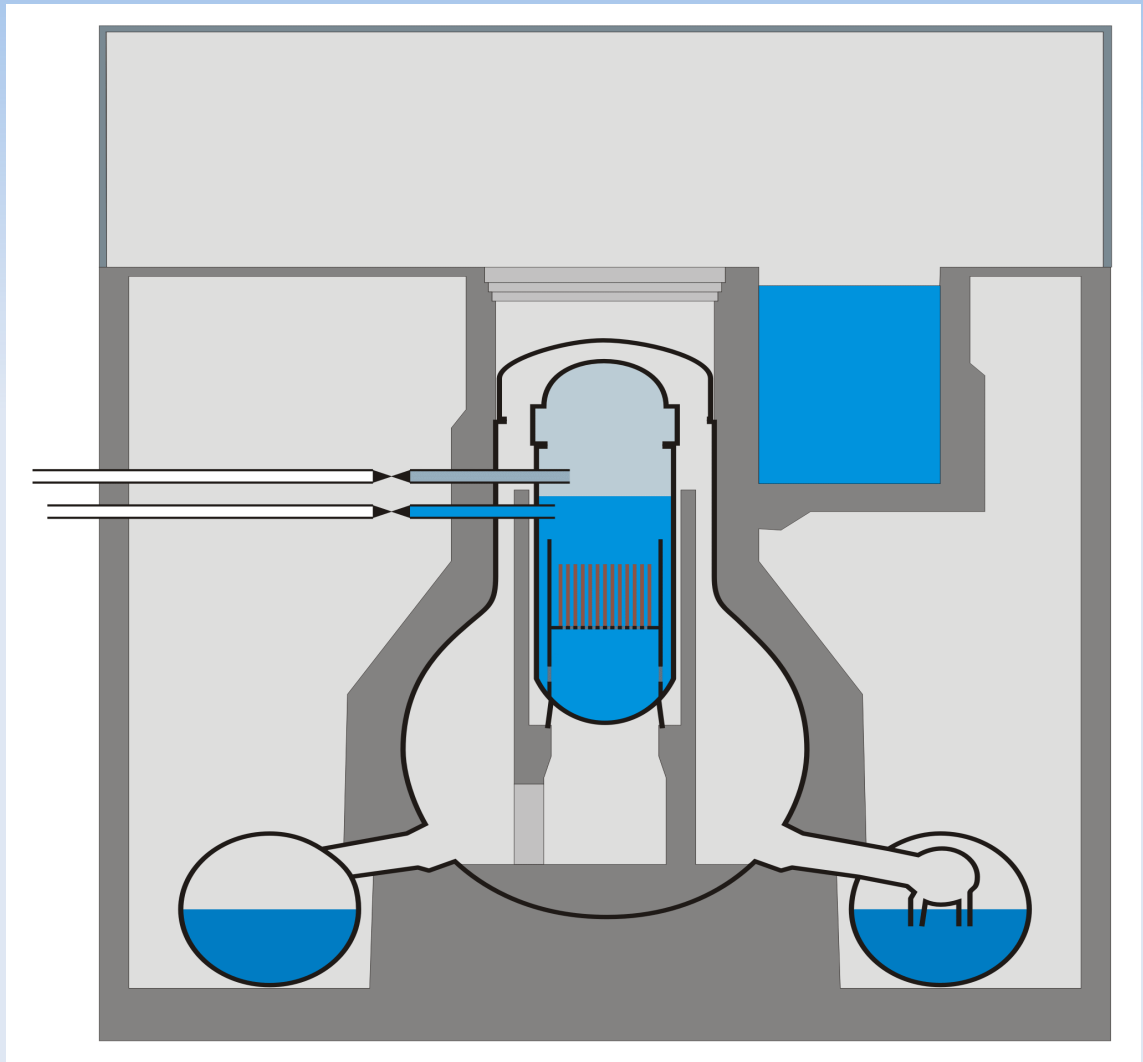

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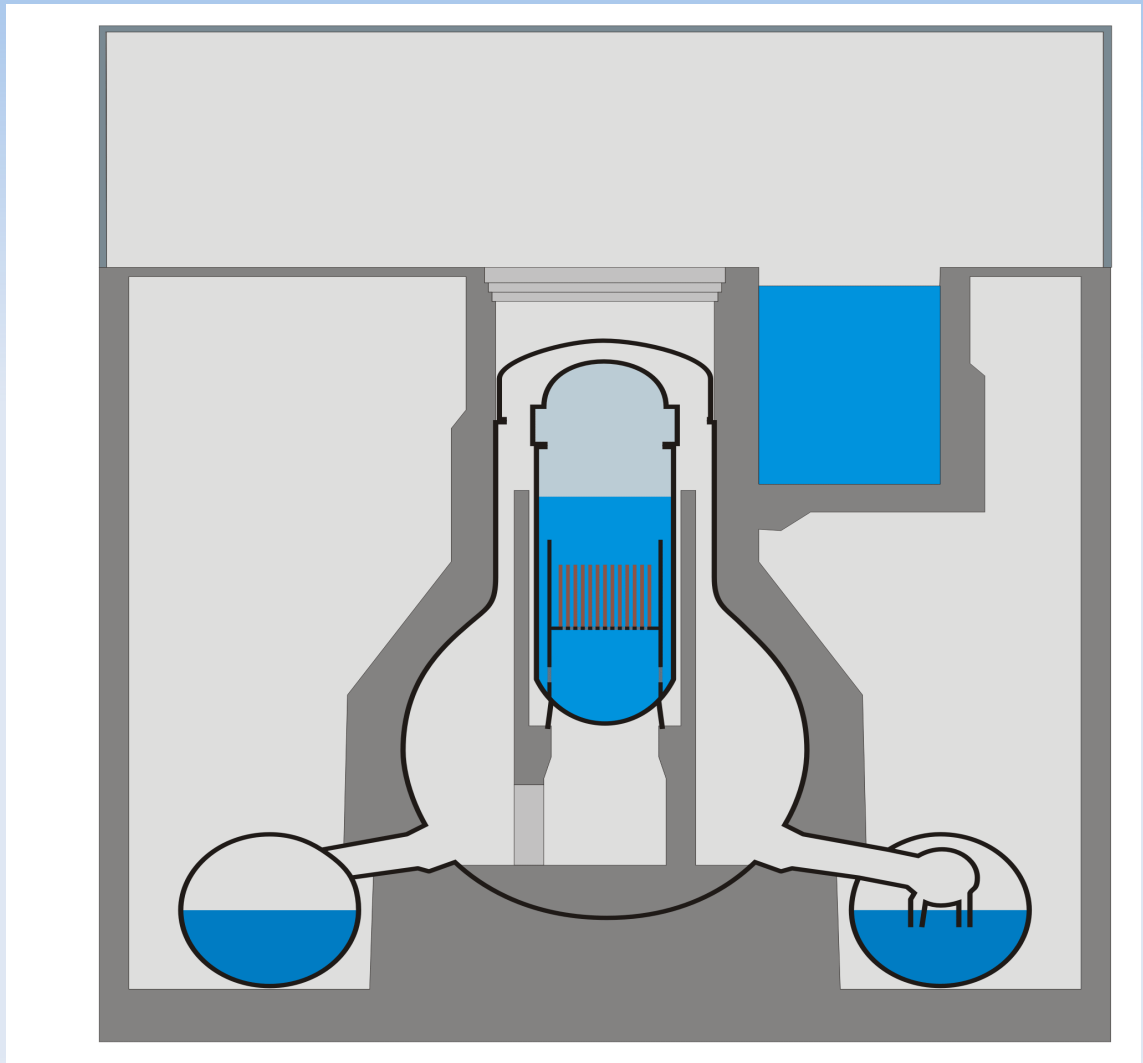

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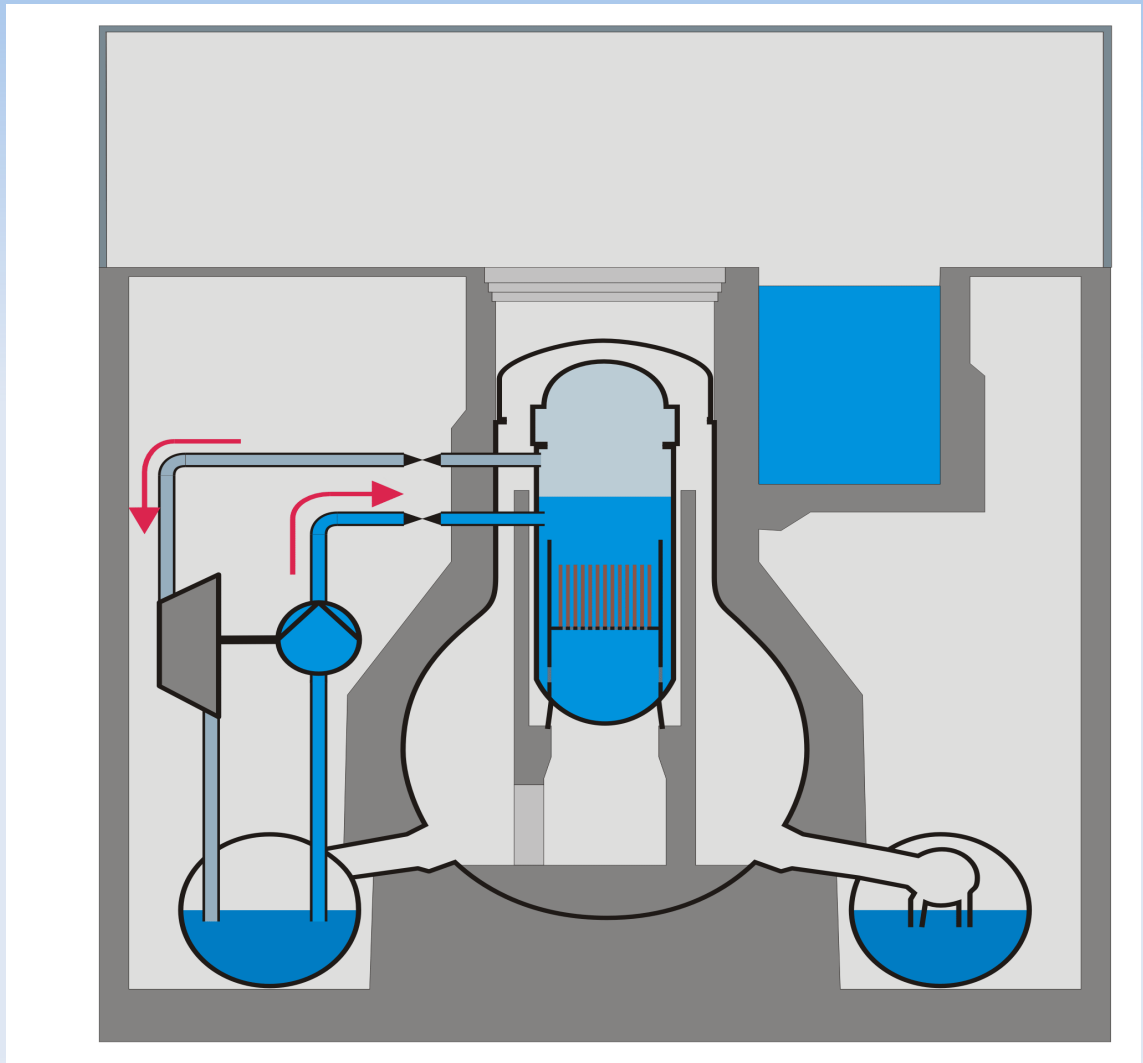

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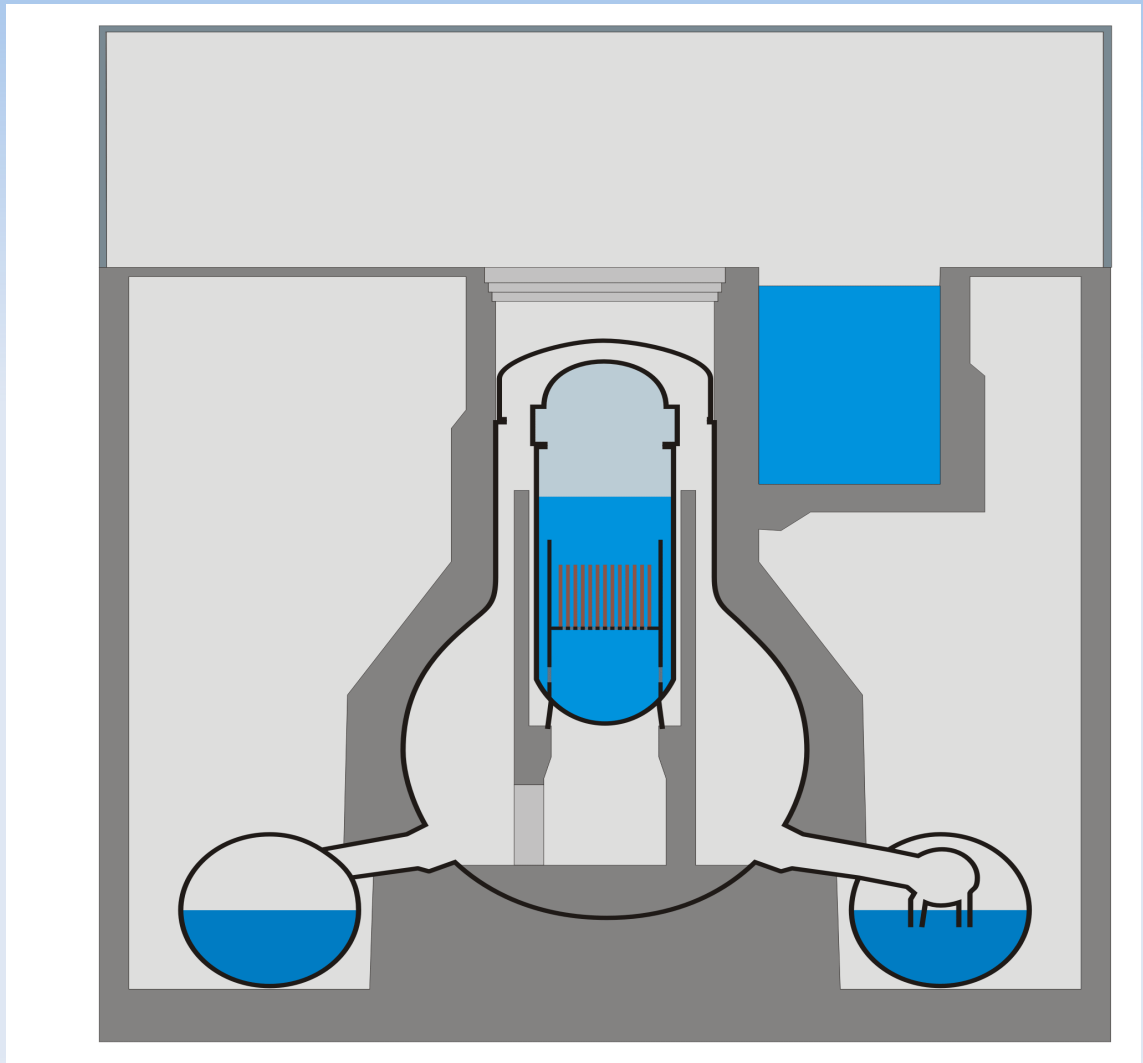

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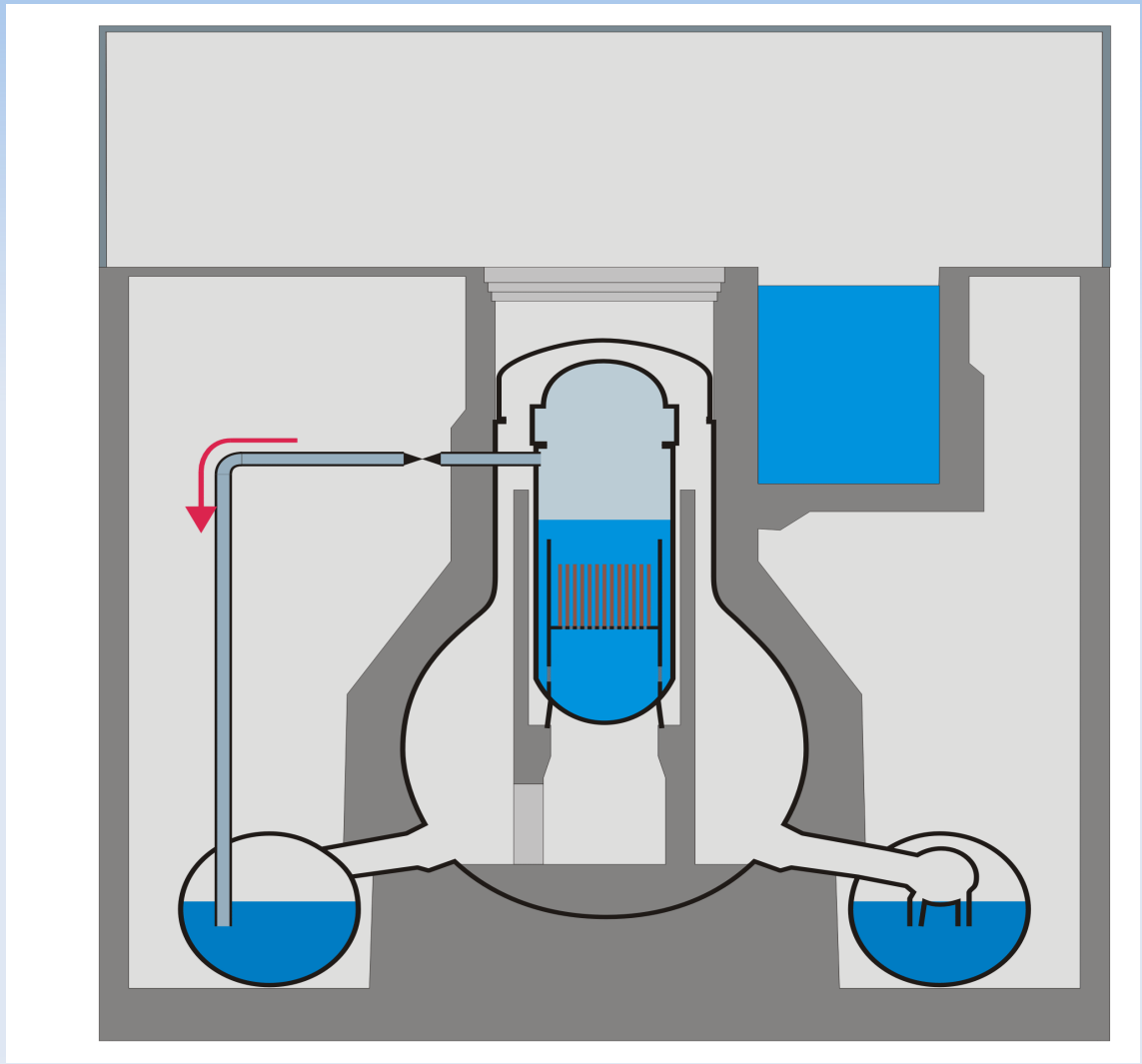

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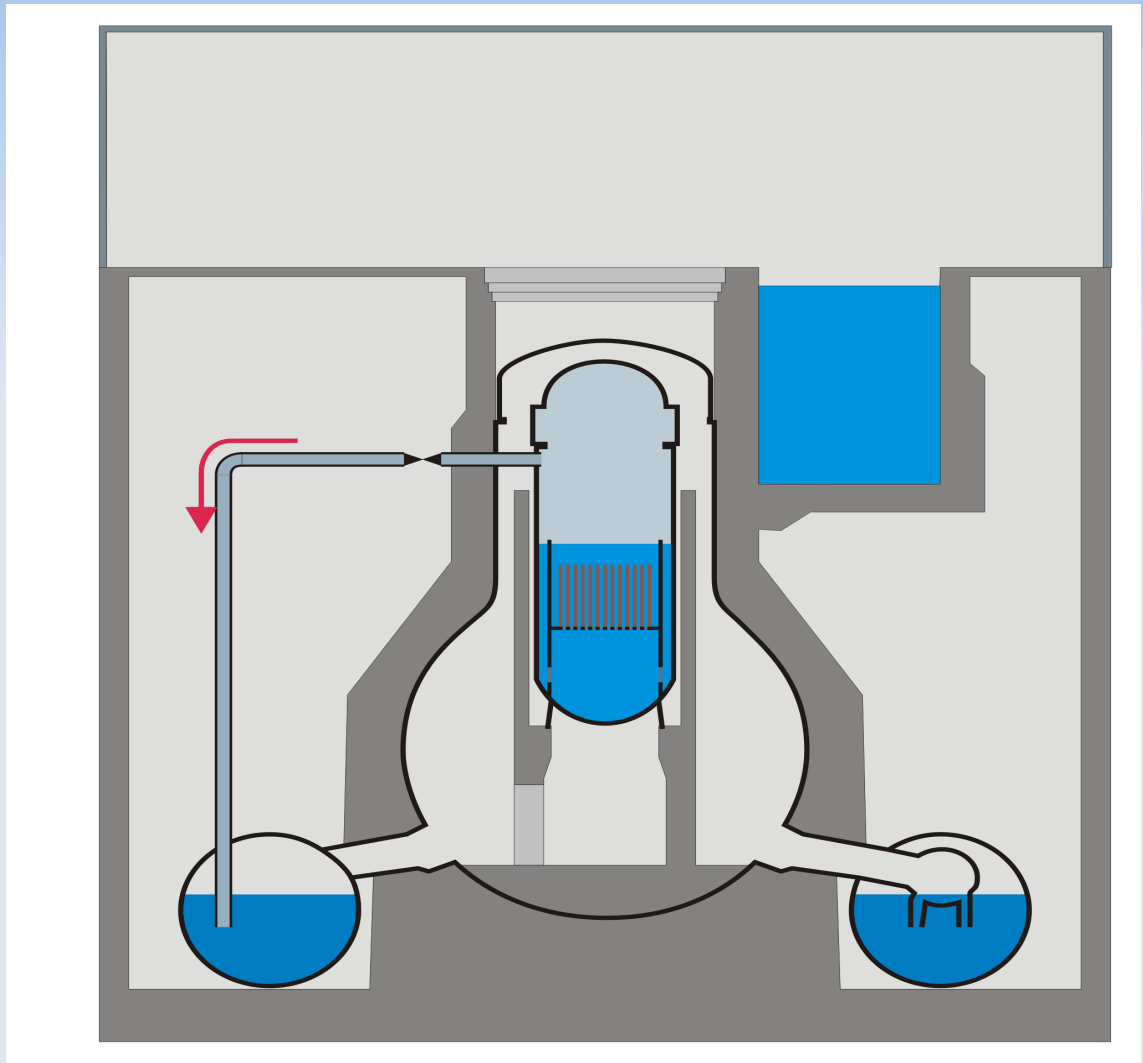

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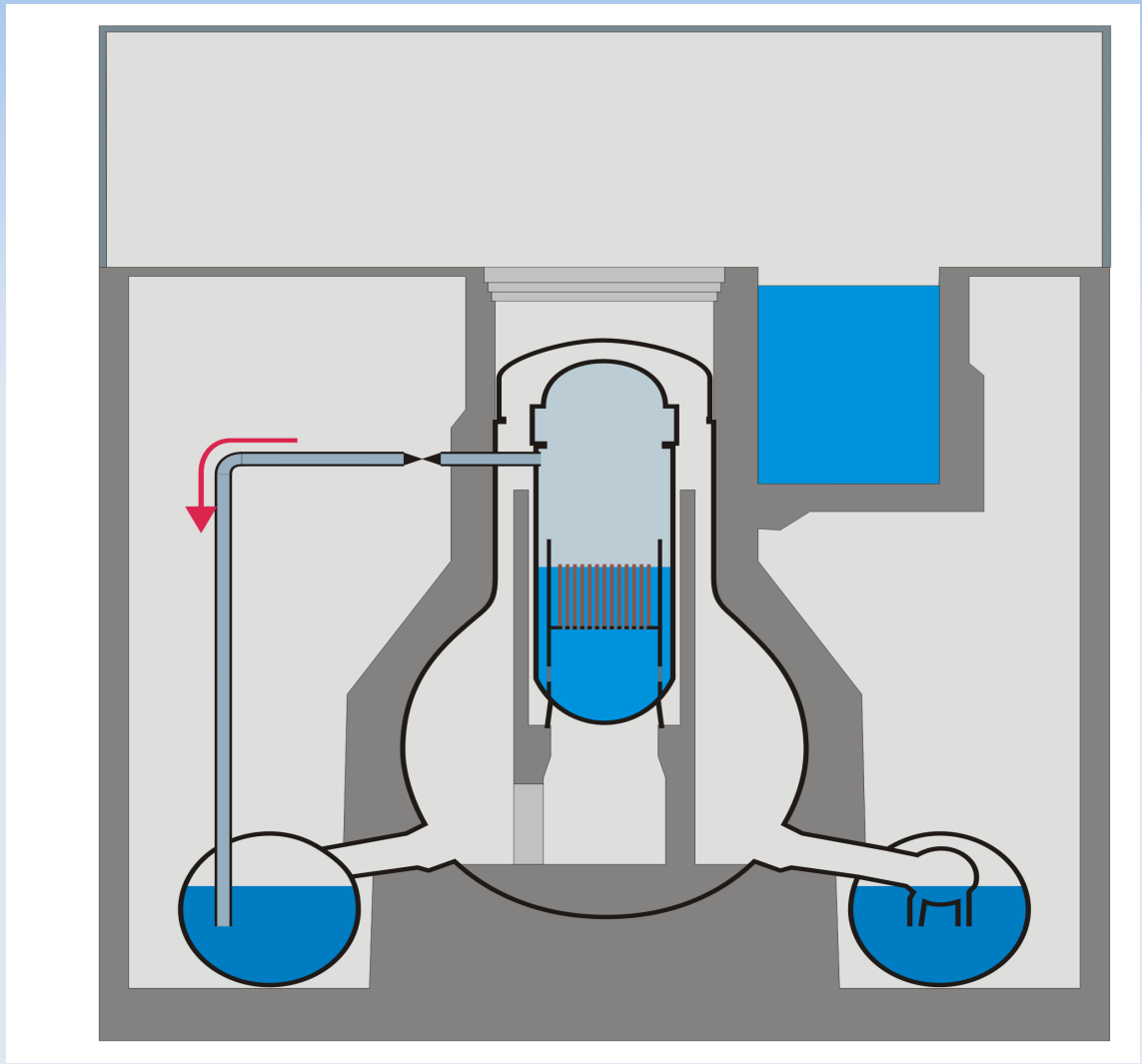

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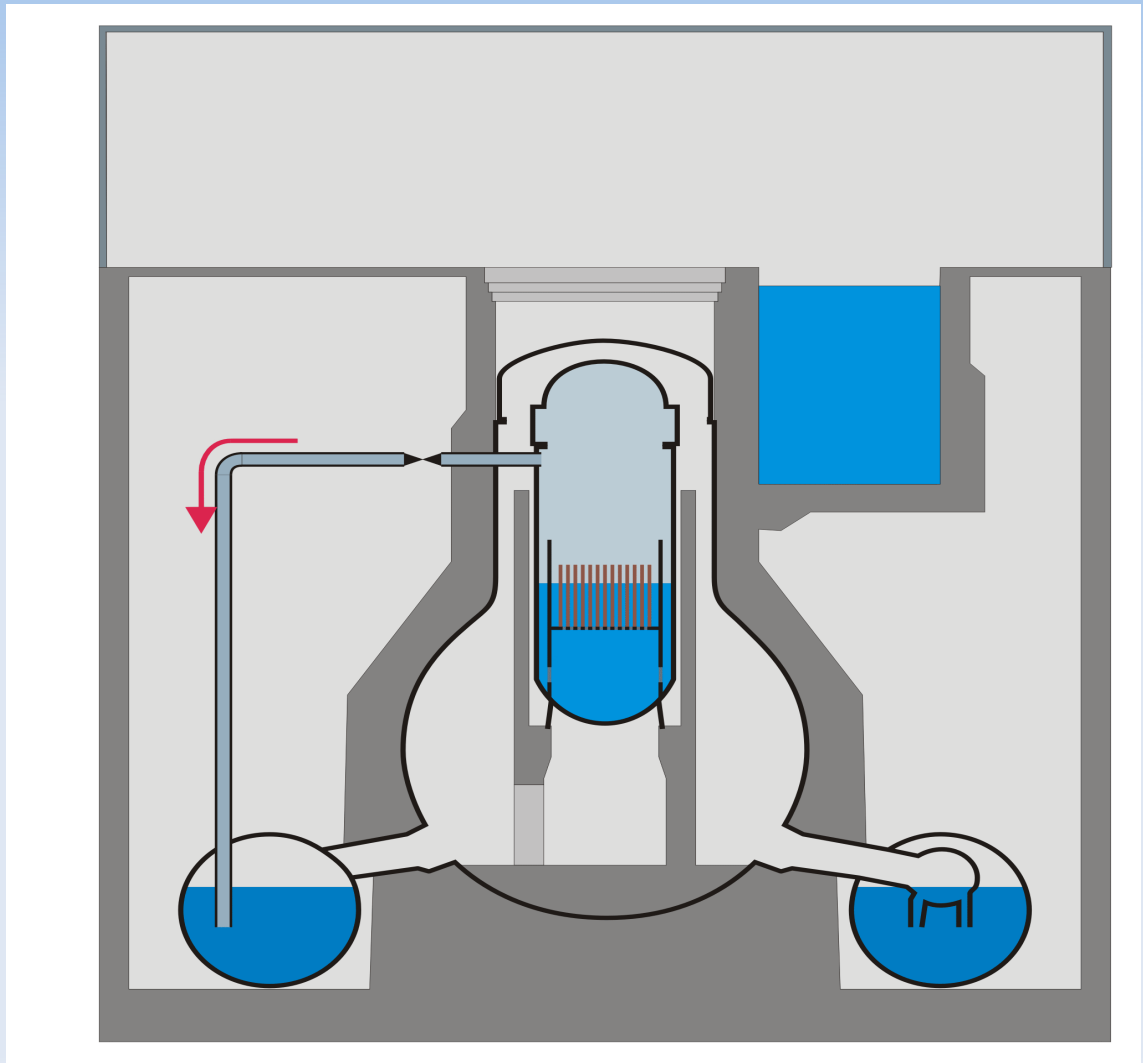

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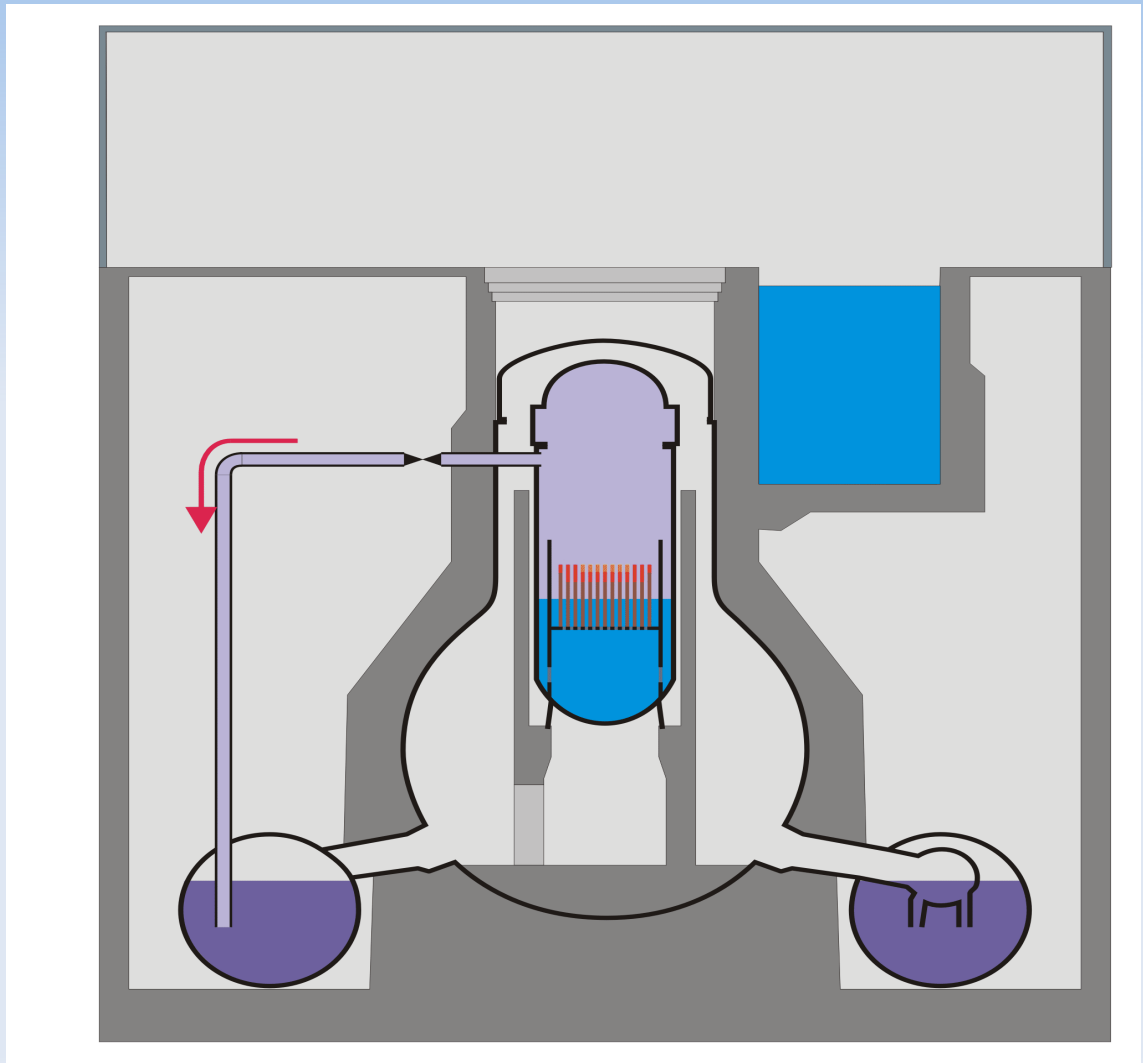

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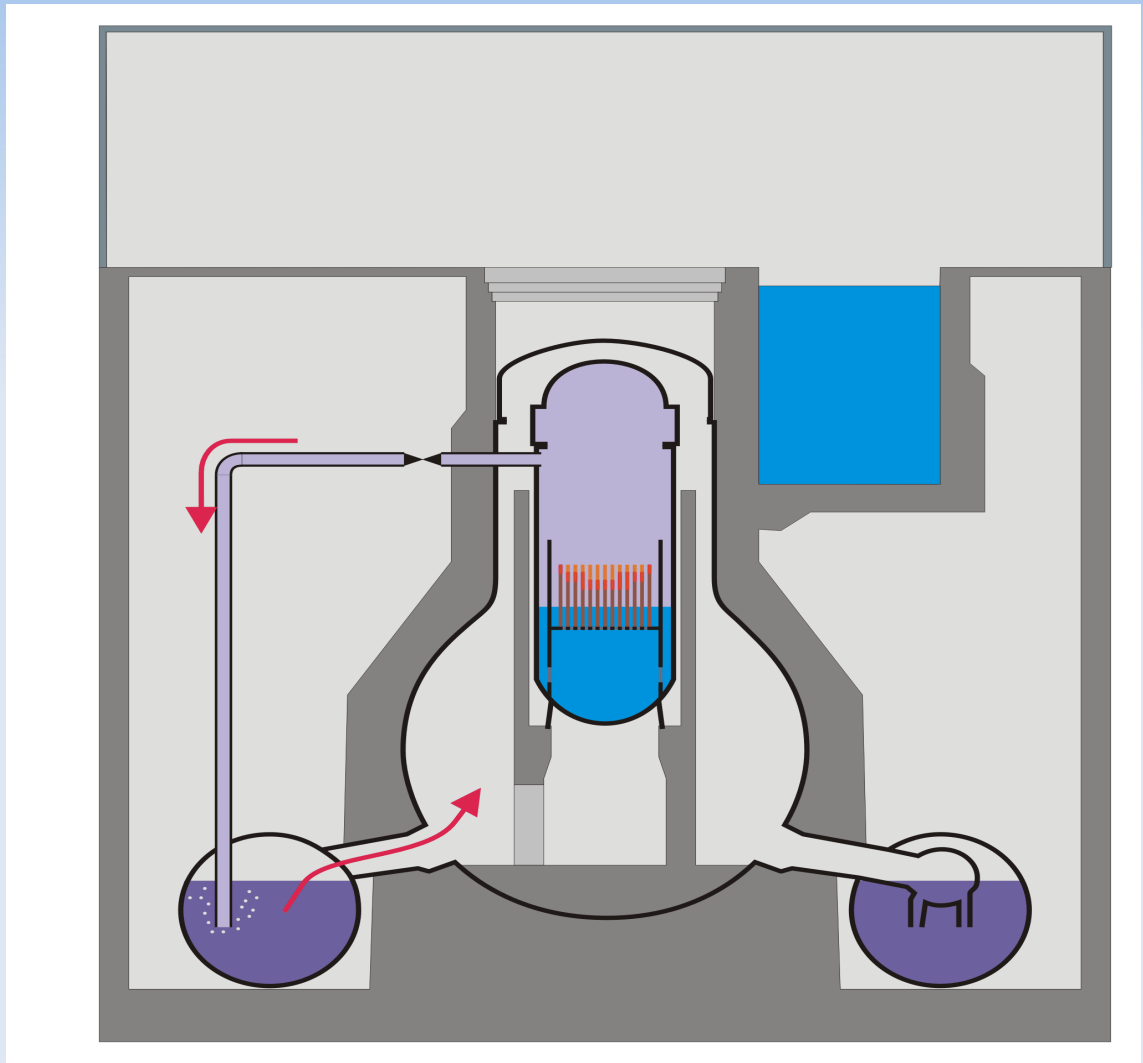

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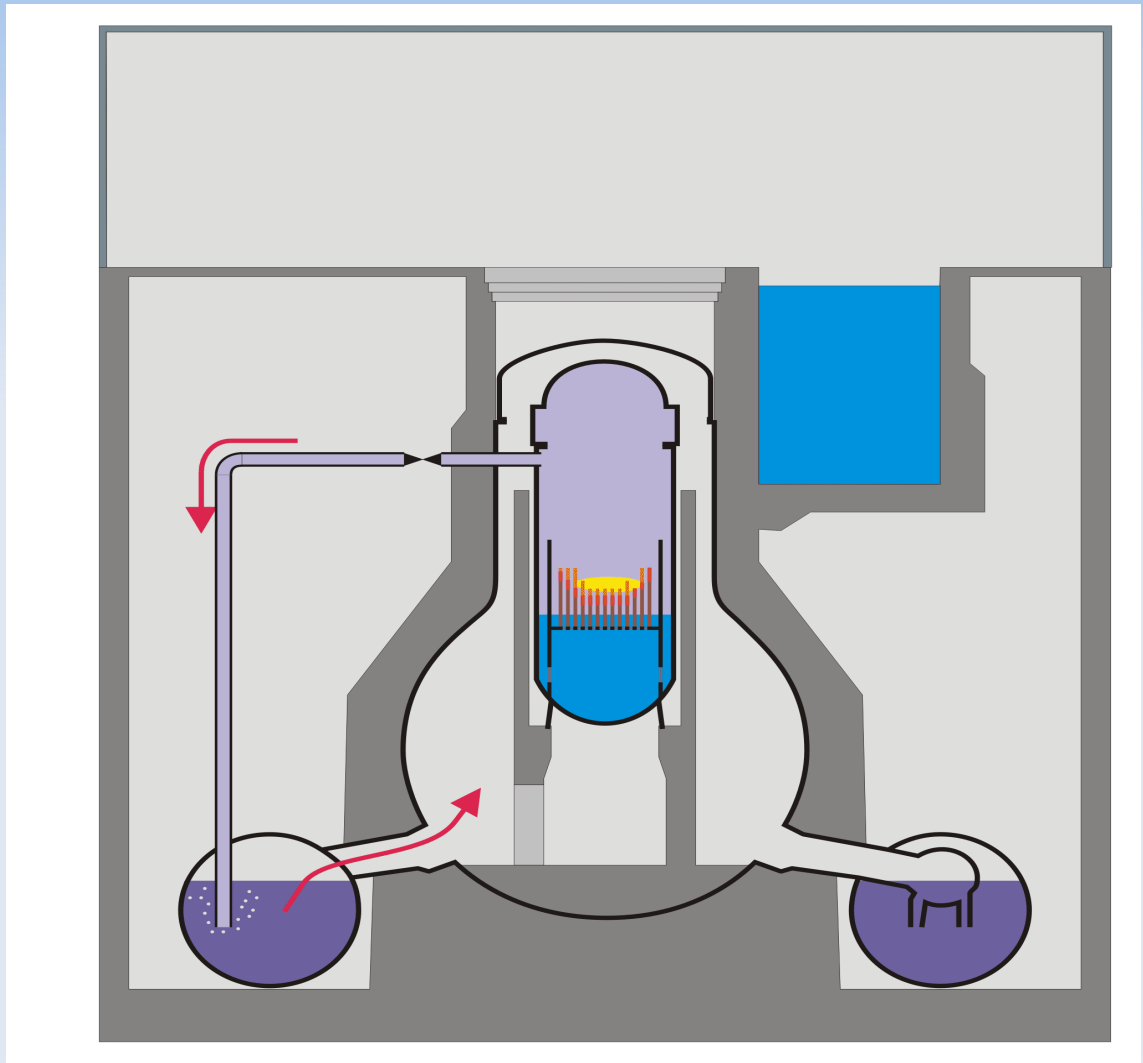

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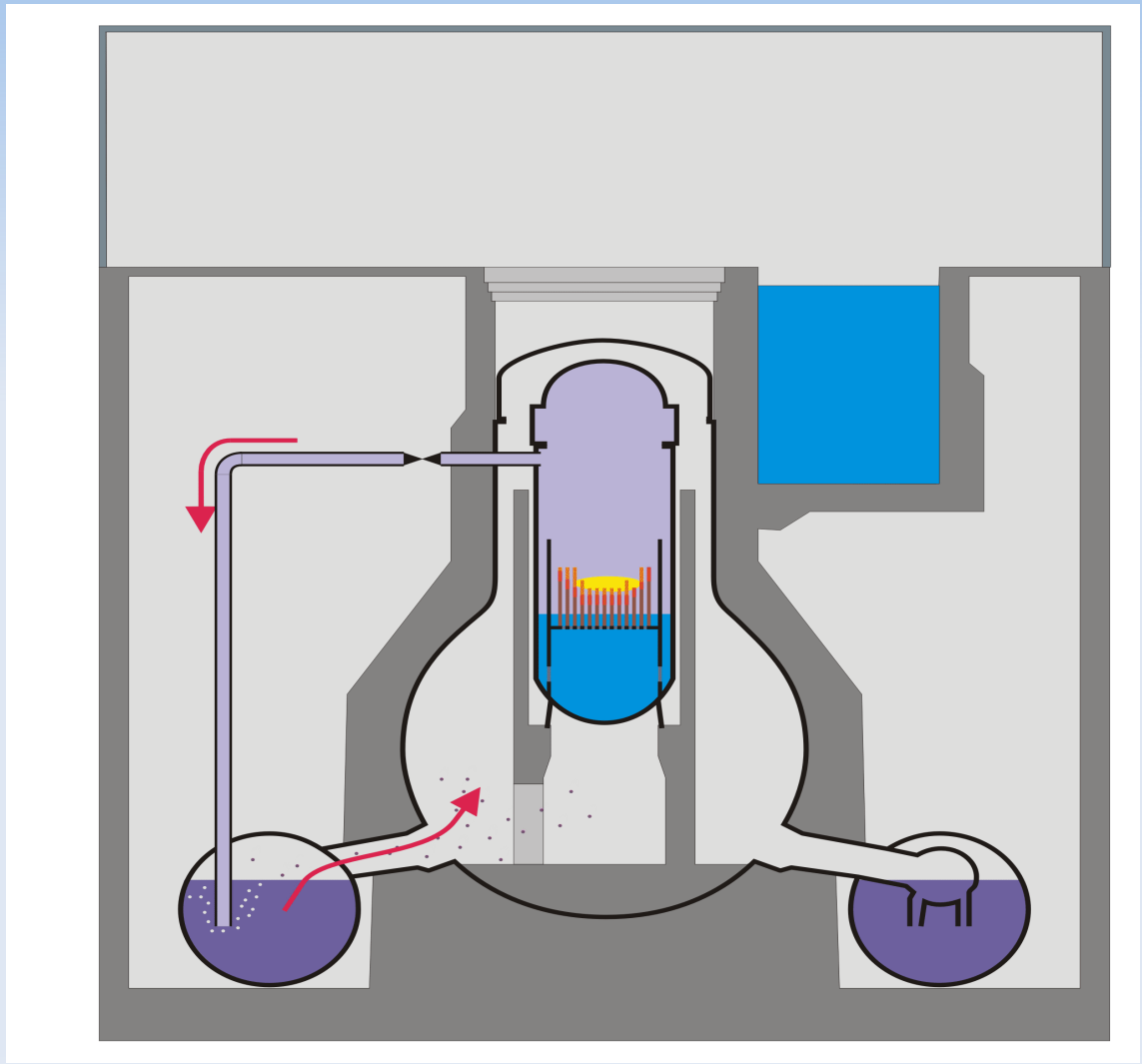

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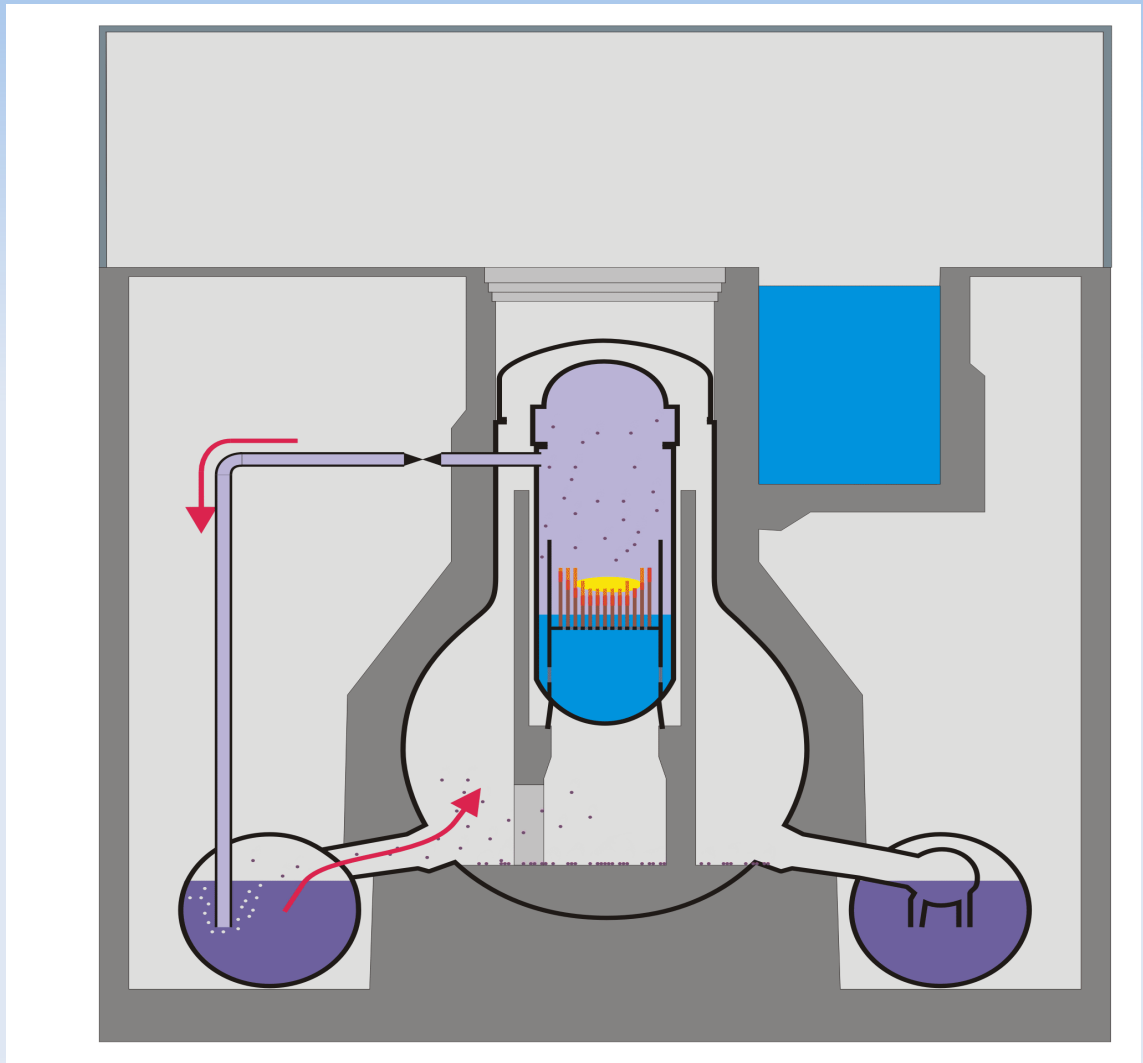

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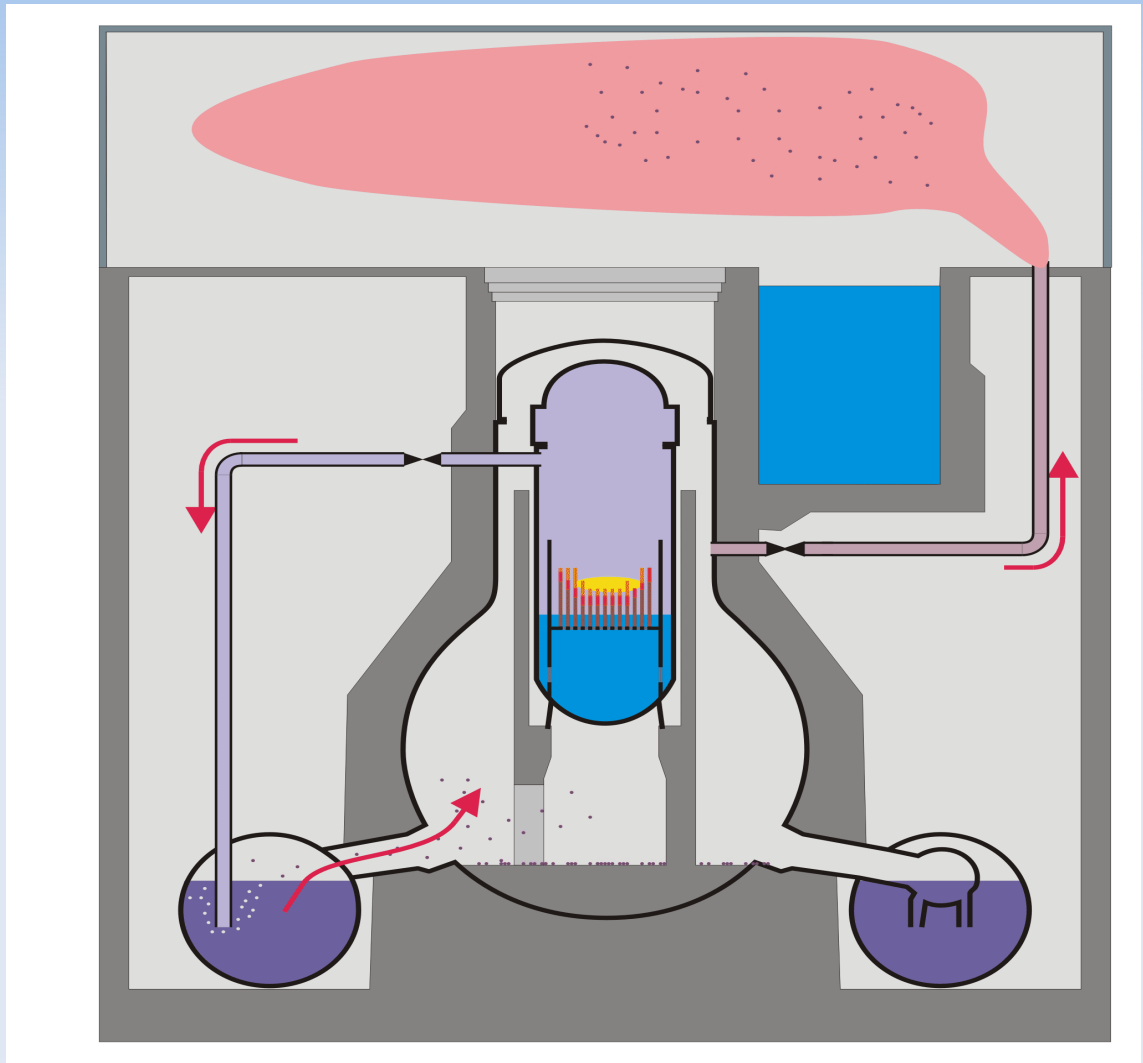

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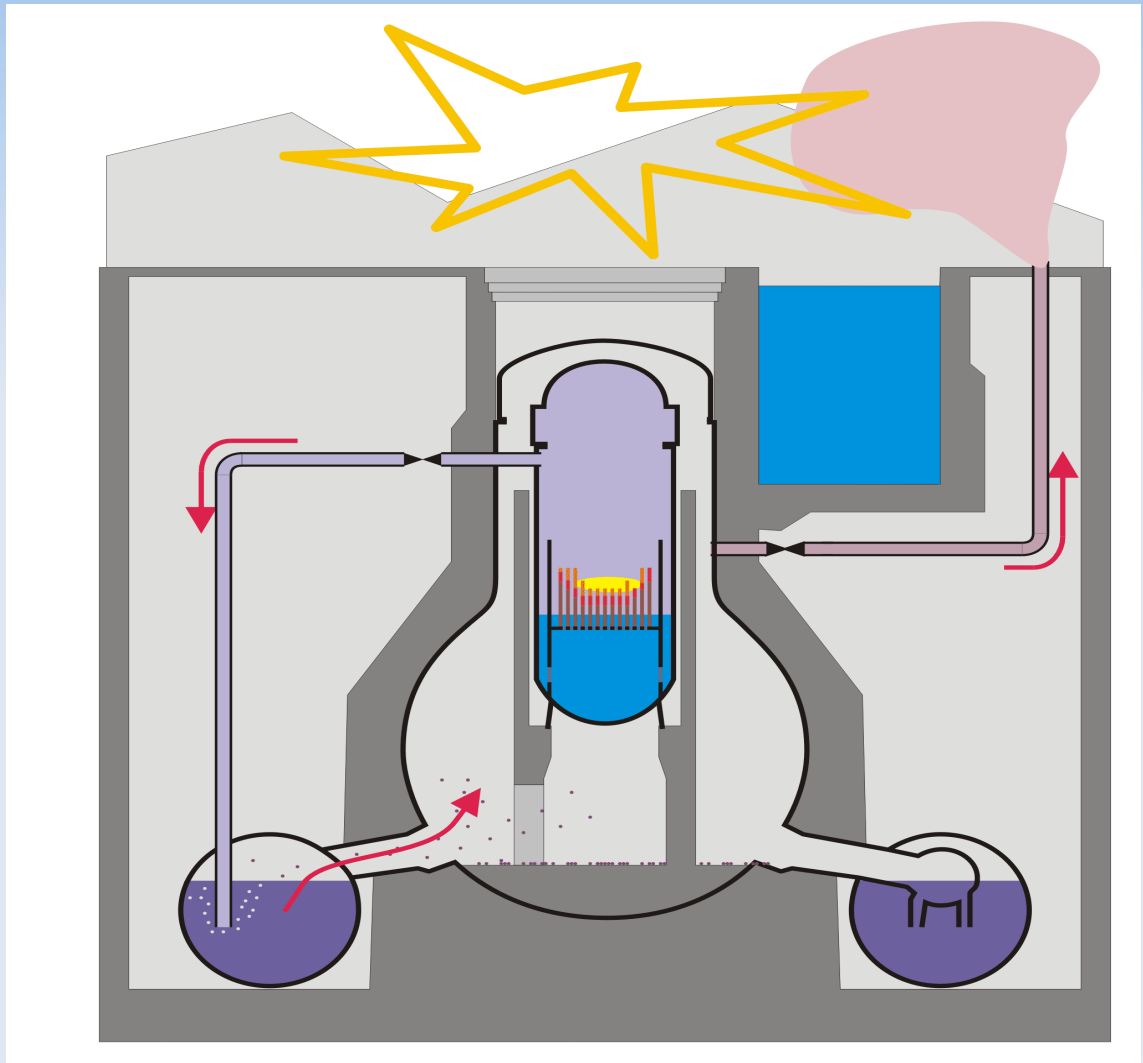

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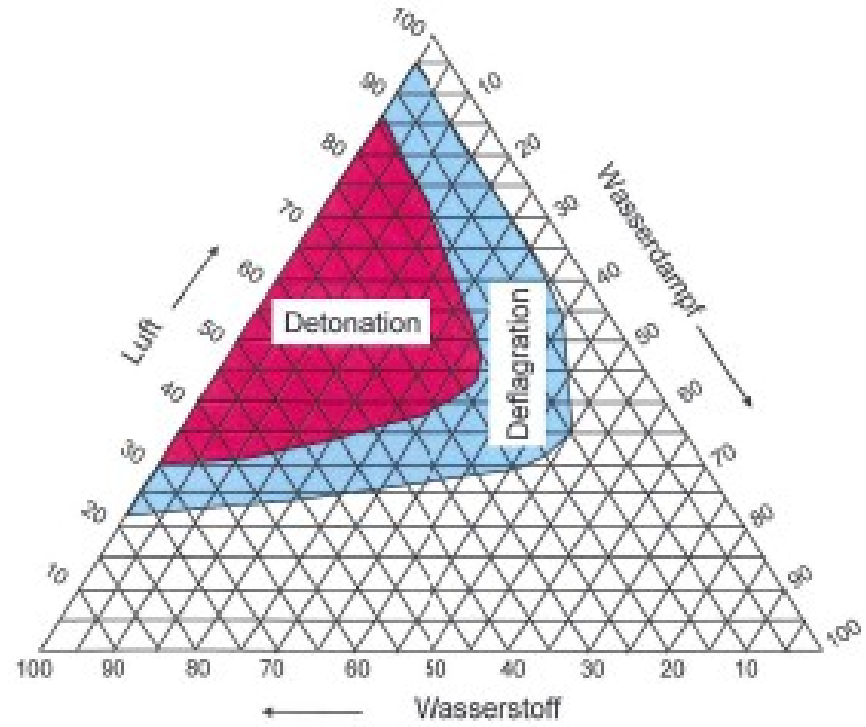


Abb. 23: Deflagrations- bzw. Detonationsbereich eines Wasserstoff-Luft-Wasserdampfgemischs

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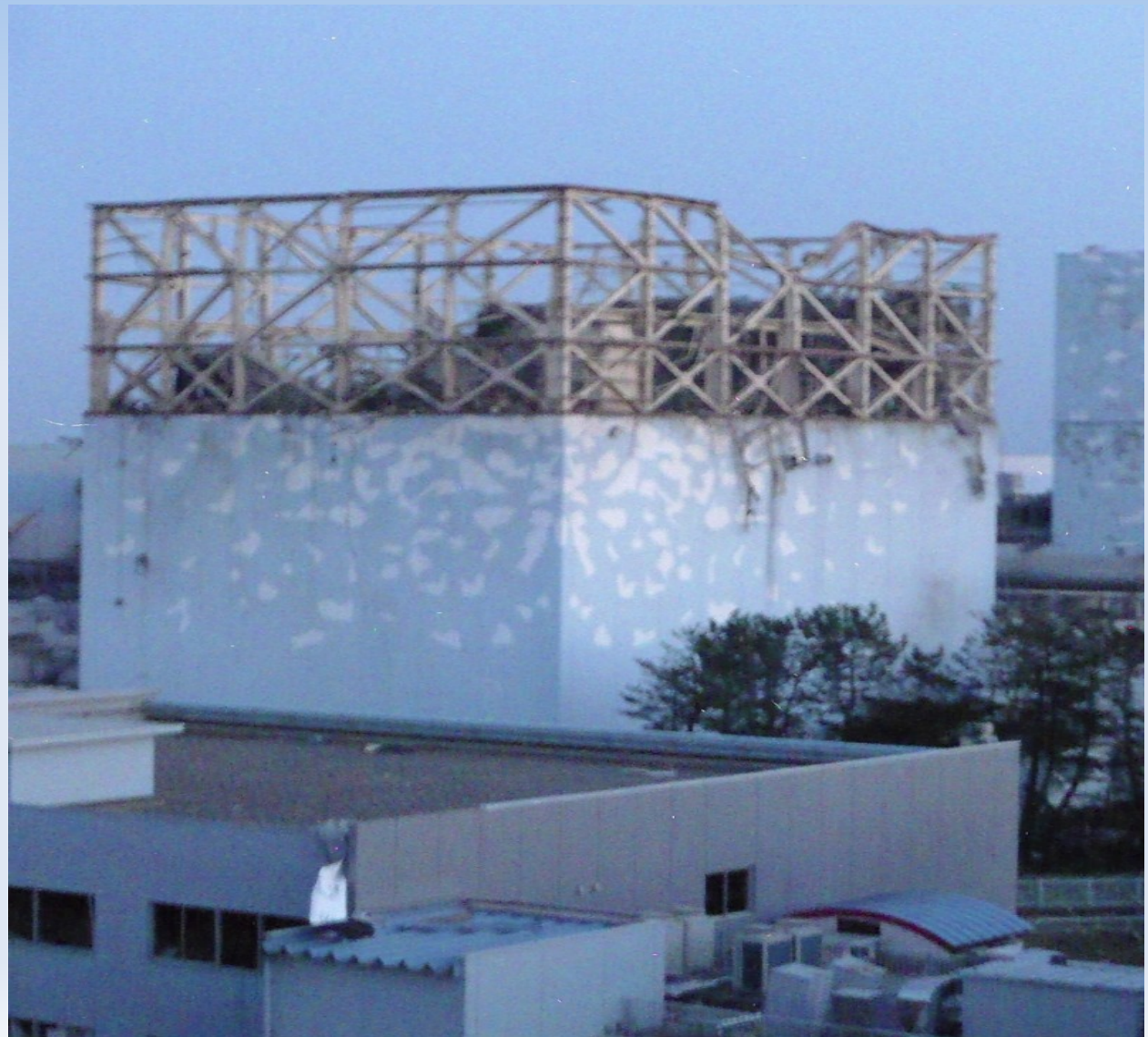

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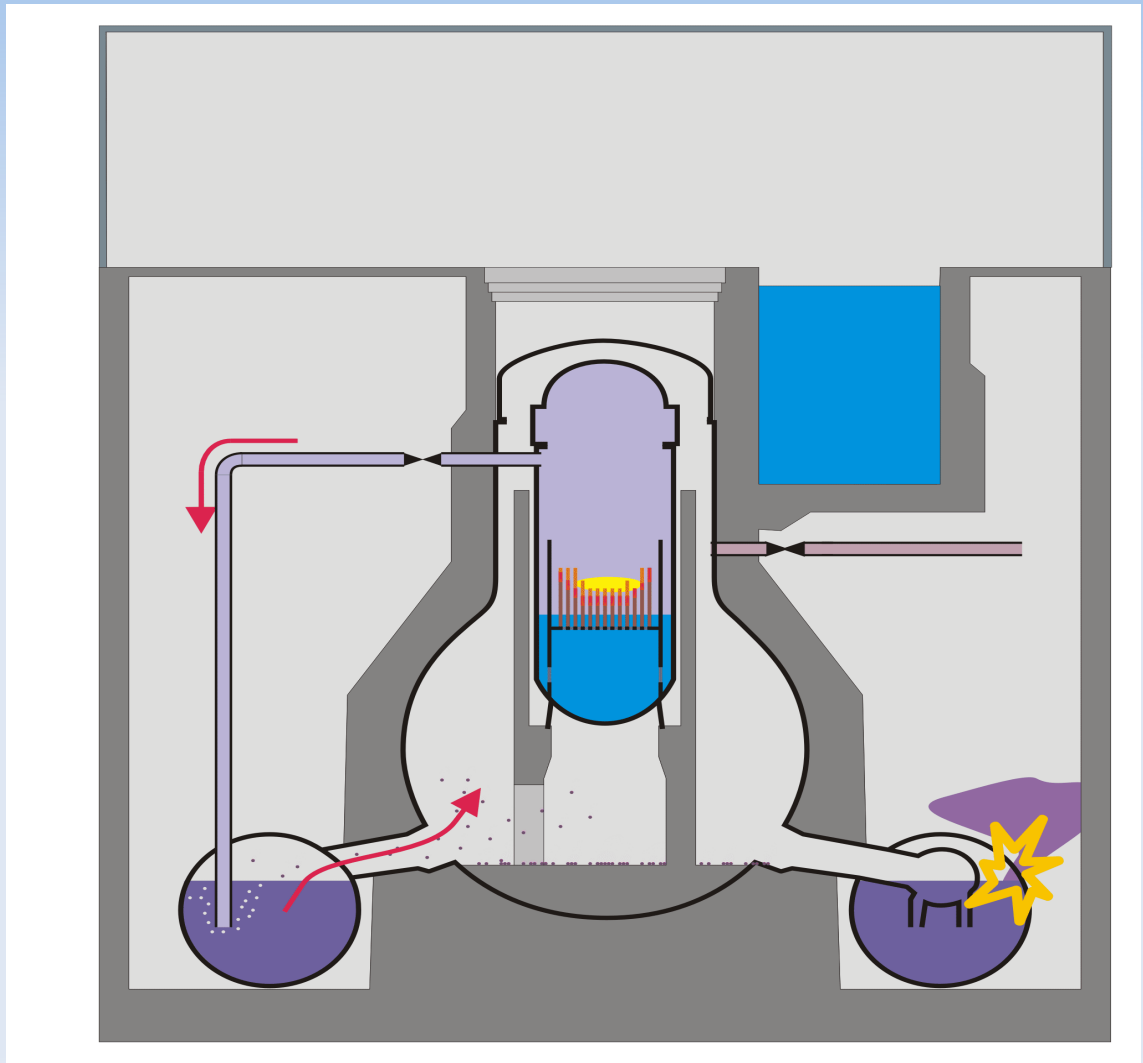

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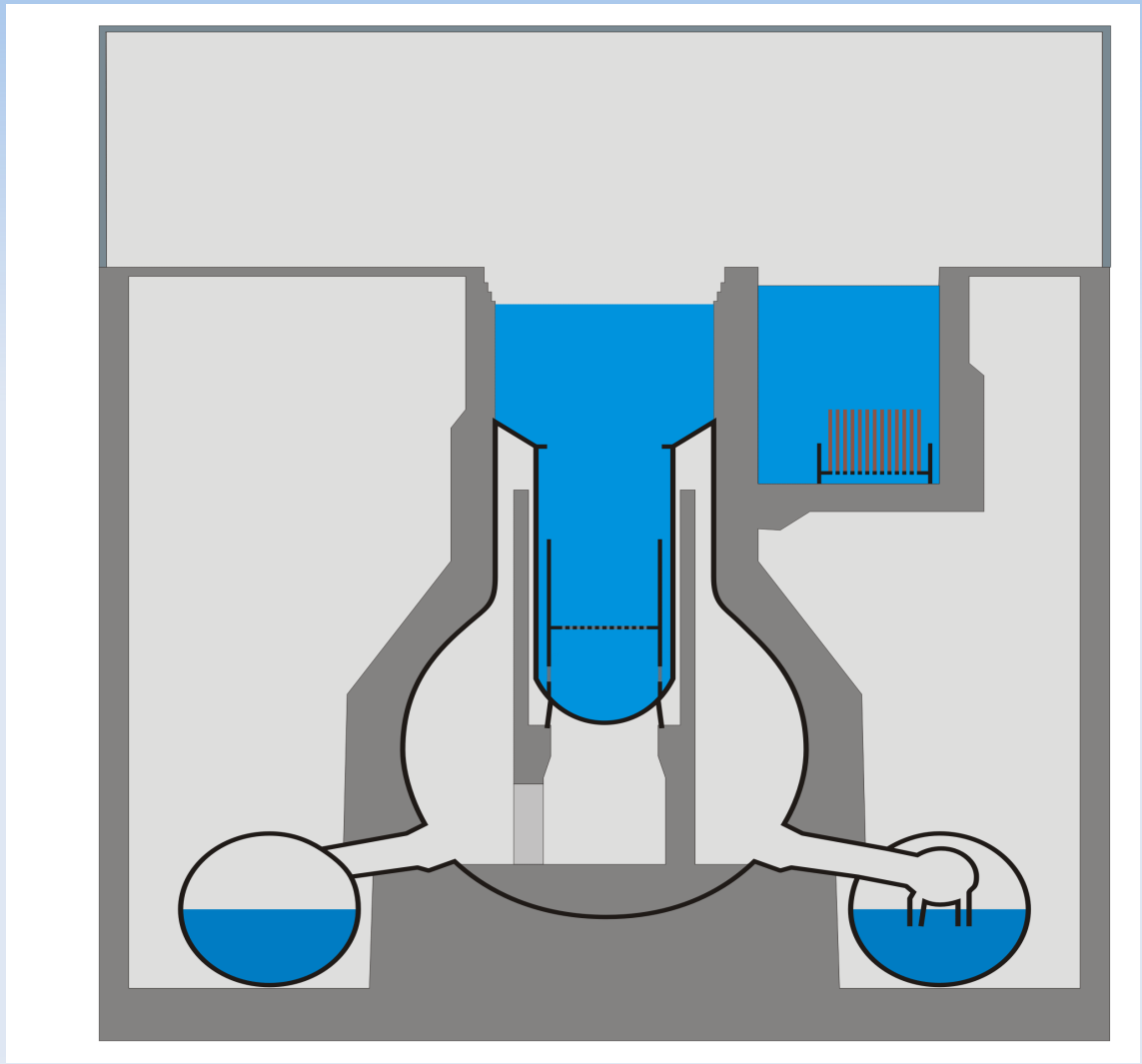

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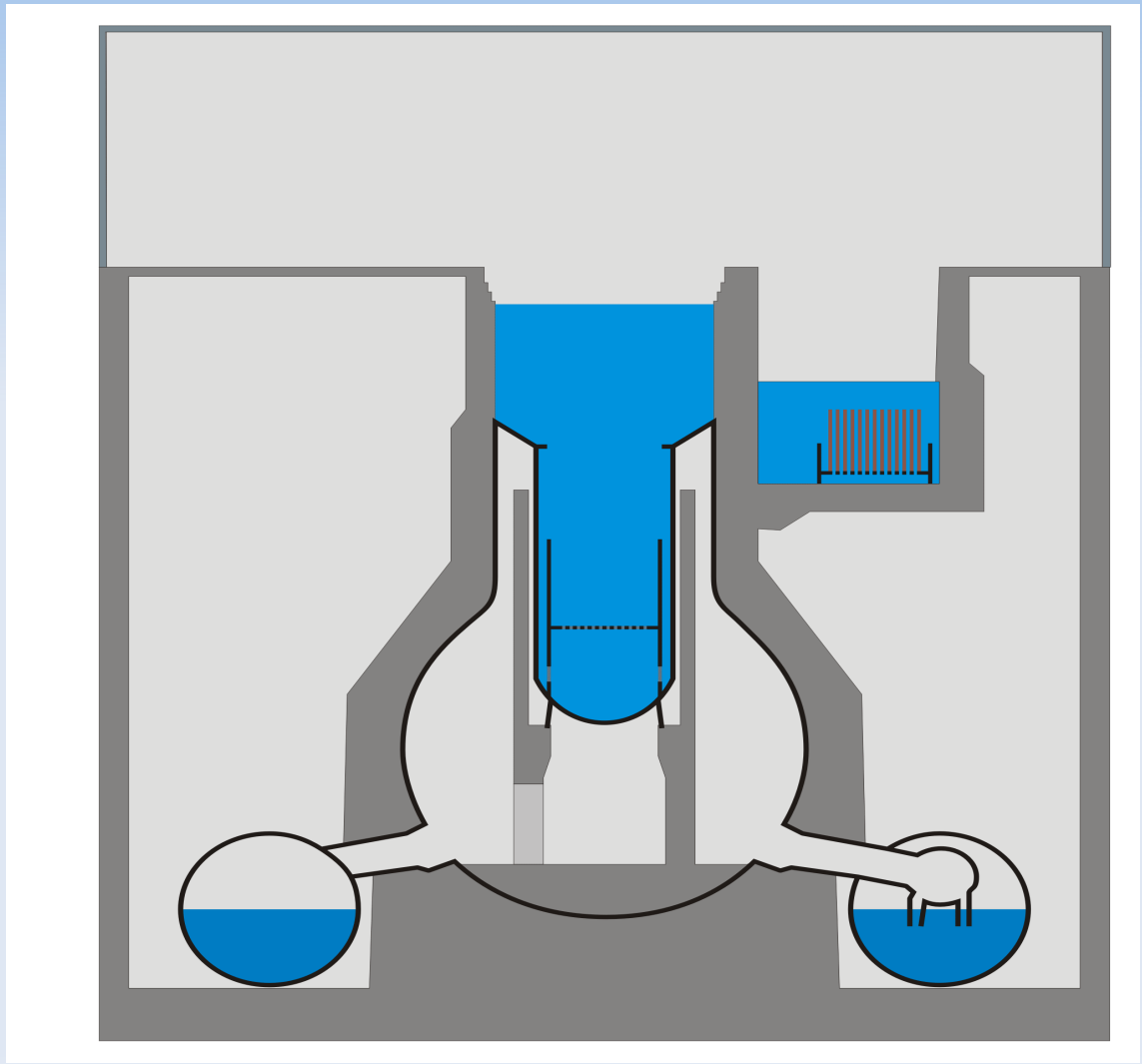

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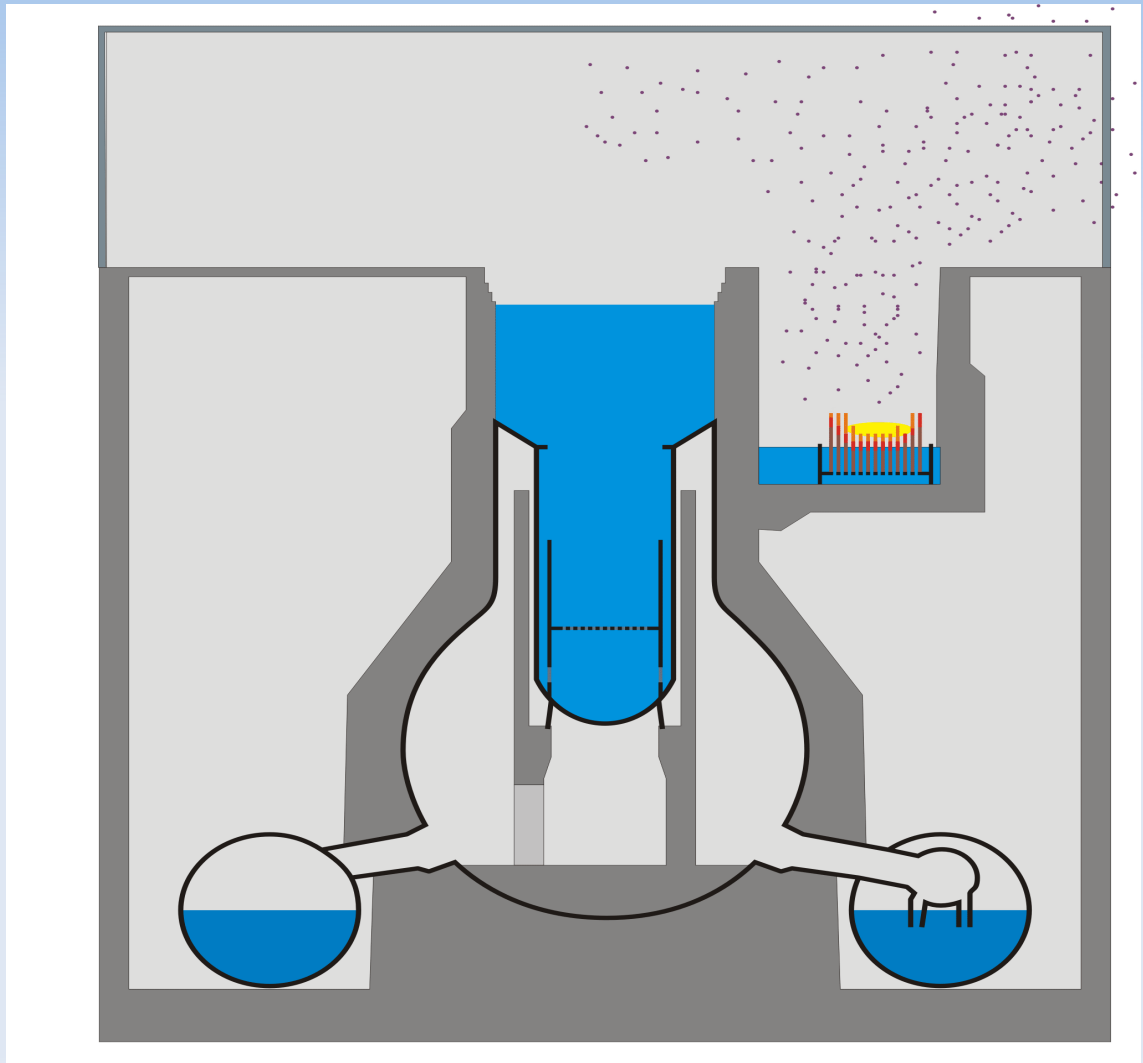

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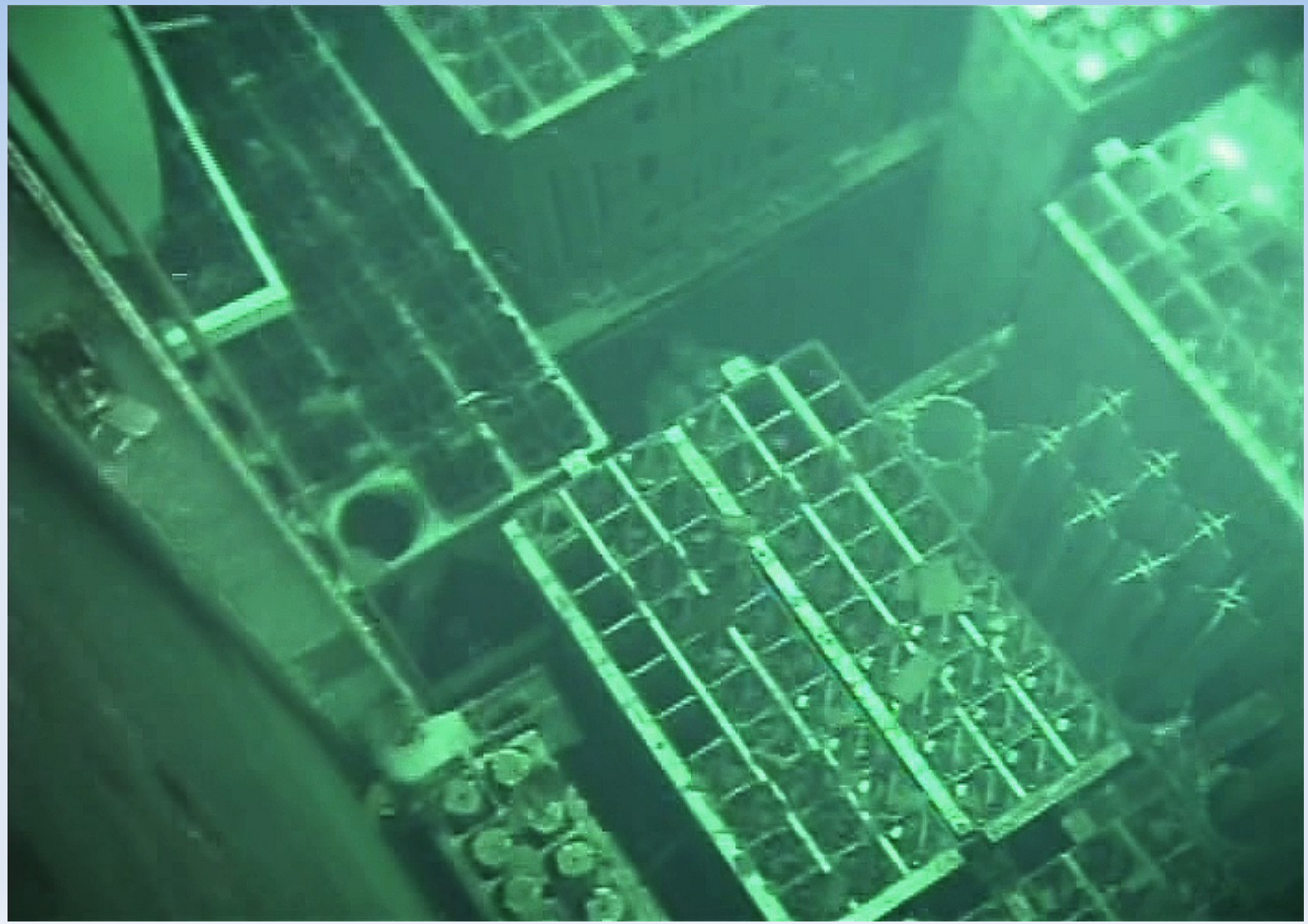
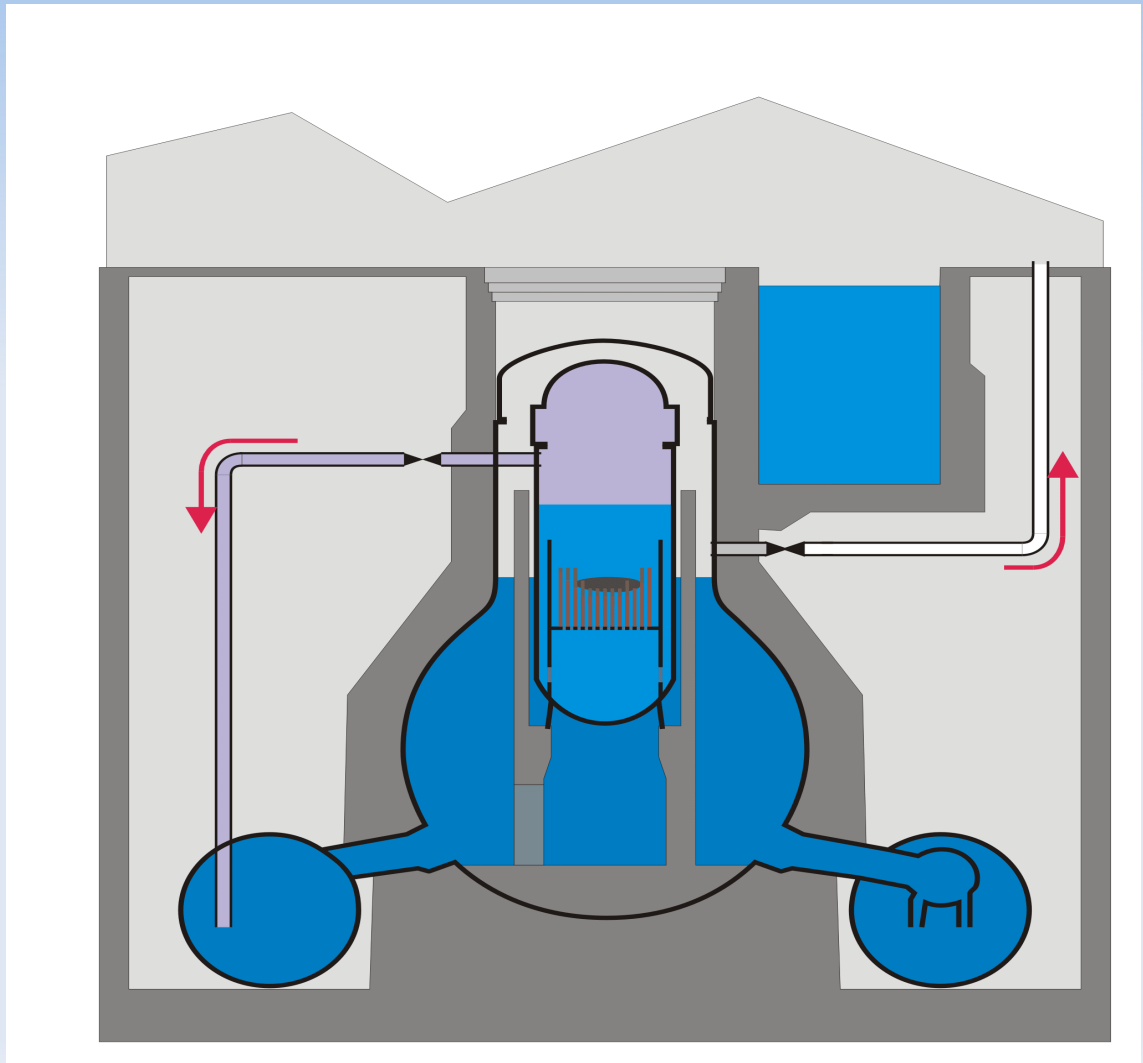


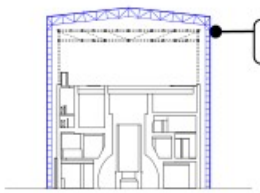
# Chronologie eines Unfalls



| Unit | 1 | 2 | 3 | 4 |
|---|---|---|---|---|
| Power (MWe /MWth) | 460/1380 | 784/2381 | 784/2381 | 784/2381 |
| Type of Reactor | BWR-3 | BWR-4 | BWR-4 | BWR-4 |
| Status at time of EQ | In service – auto shutdown | In service – auto shutdown | In service – auto shutdown | Outage |
| Core and fuel integrity | Damaged | Damaged | Damaged | No fuel in the Reactor |
| RPV & RCS integrity | RPV temperature decreasing | RPV temperature stable | RPV temperature stable | Not applicable due to outage plant status |
| Containment integrity | No information | Damage suspected | Damage suspected | |
| AC Power | AC power available - power to instrumentation – Lighting to Central Control Room | AC power available – power to instrumentation – Lighting to Central Control Room | AC power available – power to instrumentation – Lighting to Central Control Room | AC power available – power to instrumentation – Lighting to Central Control Room |
| Building | Severe damage | Slight damage | Severe damage | Severe damage |
| Water level of RPV | Around half of Fuel is uncovered | Around half of Fuel is uncovered | Around half of Fuel is uncovered | Not applicable due to outage plant status |
| Pressure of RPV | Slowly increasing | Stable | Stable | |
| CV Pressure Drywell | Stable | Stable | Stable | |
| Water injection to RPV | Injection of freshwater – via mobile electric pump with off-site power | Injection of freshwater – via mobile electric pump with off-site power | Injection of freshwater – via mobile electric pump with off-site power | |
| Water injection to CV | No information | No information | No information | |
| Spent Fuel Pool Status | Fresh water injection by concrete pump truck | Freshwater injection to the Fuel Pool Cooling Line | Freshwater injection via Fuel Pool Cooling Line and Periodic spraying | Fresh water injection by concrete pump truck |

Reference 2

# Overview of Major Countermeasures in the Power Station



Reactor building cover (countermeasures 5, 50, 54, 55)

Cooling of spent fuel pool by external water injection (countermeasures 18, 22, 28)

Sampling of steam/pool water and measurement of radioactive materials (countermeasure 19)

Storage of low radiation-level water (countermeasures 33, 35, 40)

Tanks, Megafloats, Barges, Reservoir

Nitrogen gas injection (countermeasures 2, 11, 15)

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Circulation cooling of spent fuel pool (countermeasures 23, 24, 25, 27)

Tank

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Tank Lorry

Reuse of processed water (Countermeasure 45)

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Flooding up to top of active fuel (countermeasures 3, 9)

Reactor Pressure Vessel (RPV)

Turbine Building

Steam Turbine

Heat Exchanger

Additionally-installed Tank

Centralized Waste Treatment Building

Installation of heat exchangers (countermeasure 13)

Condenser

Injection of fresh water with pumps (countermeasure 1)

Suppression Chamber

(Unit 2) Sealing the damaged location (countermeasures 6, 16)

Dispersion of inhibitor (countermeasures 47, 48, 52)
Removal of debris (countermeasures 49, 53)
Consideration of countermeasures for contaminated soil (countermeasure 51)

Preventive measures against leakage of high radiation-level water (countermeasure 29)

Treatment of sub-drainage water after being pumped up (countermeasure 36)

Seismic assessment (countermeasure 20),
Continued monitoring (countermeasure 21),
(Unit 4) Installation of supporting structure under the bottom of spent fuel pool (countermeasure 26)

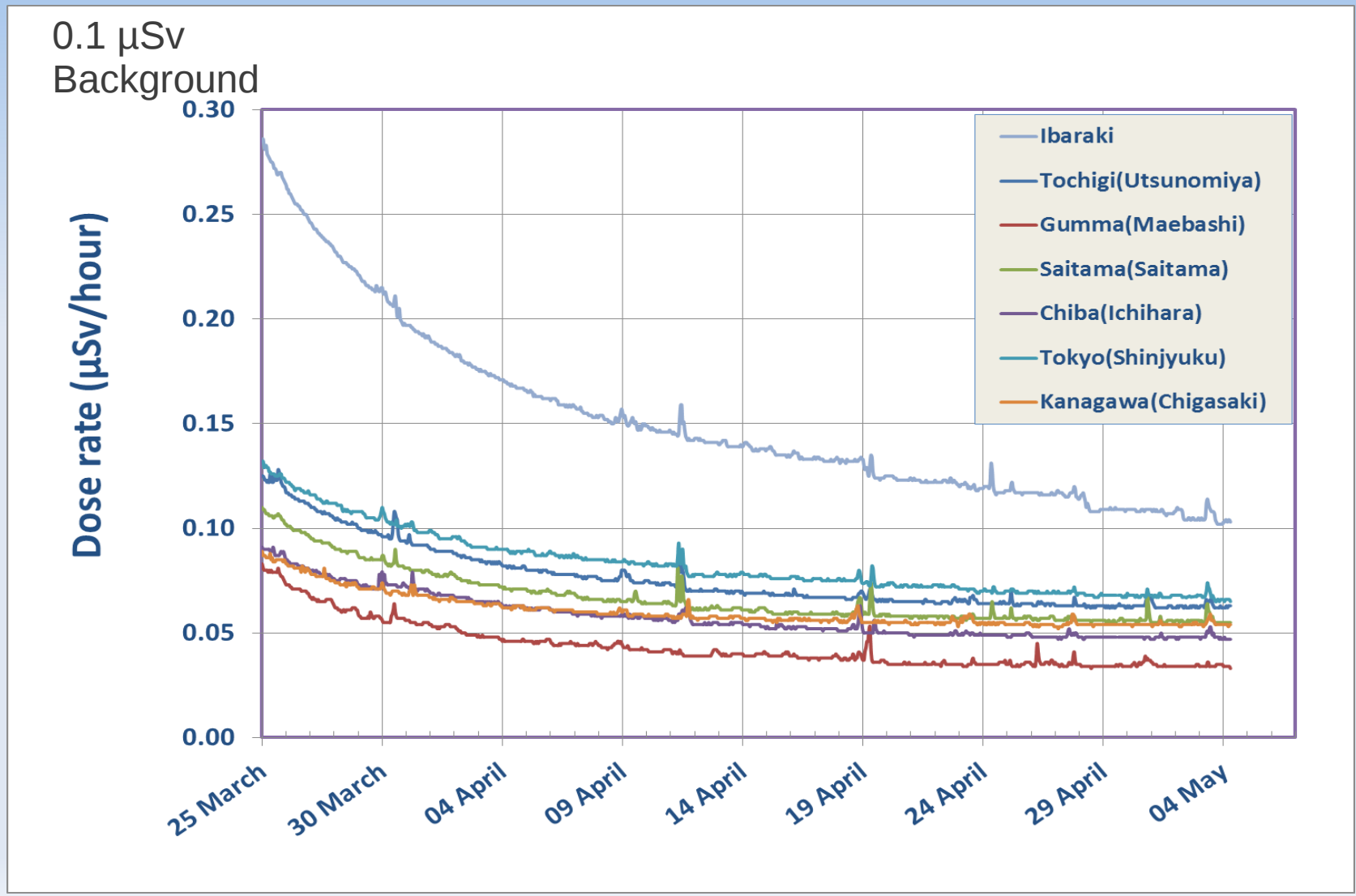
piping

pumps

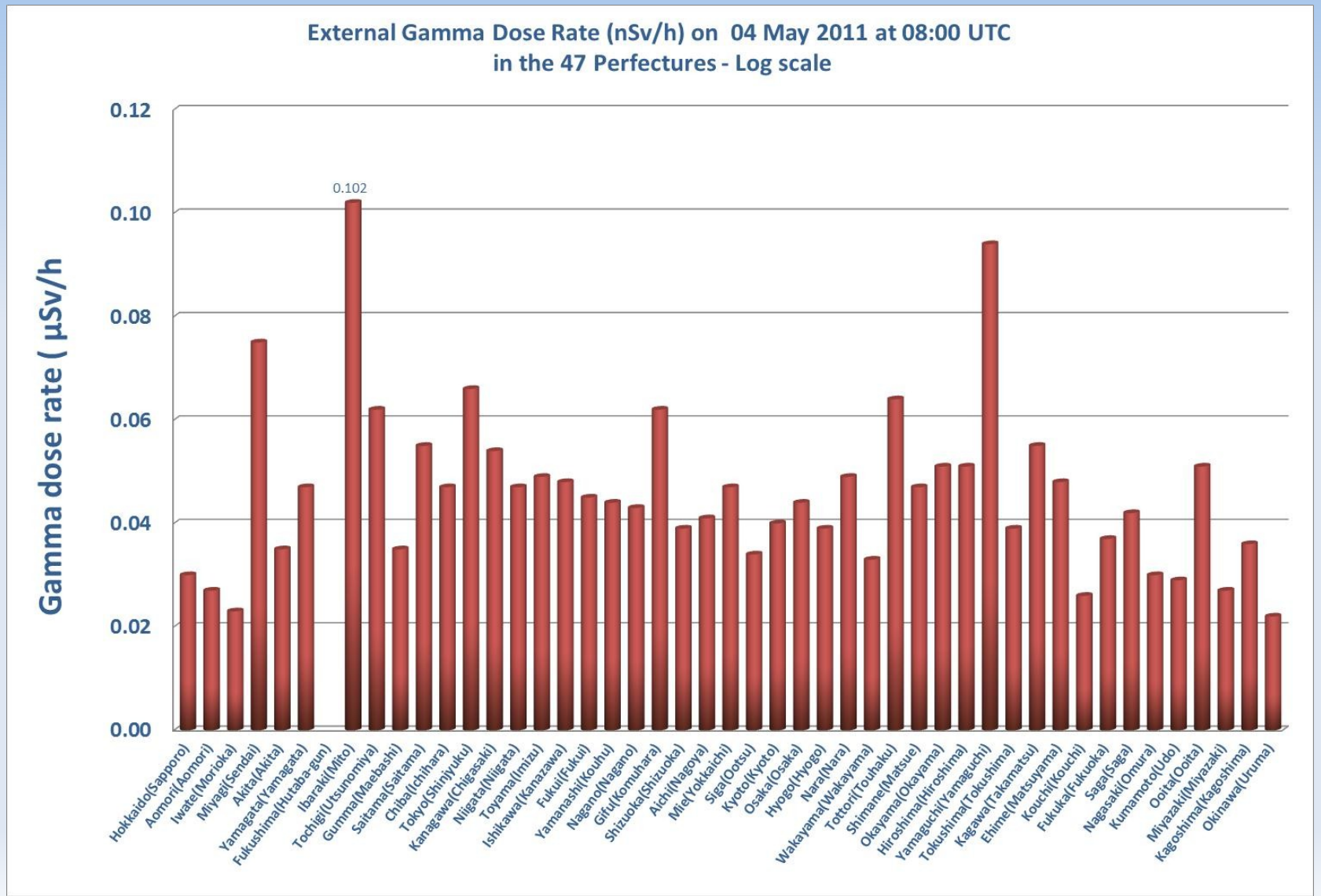
heat exchangers, water processing facilities

# Maßnahmen

# Radiologie

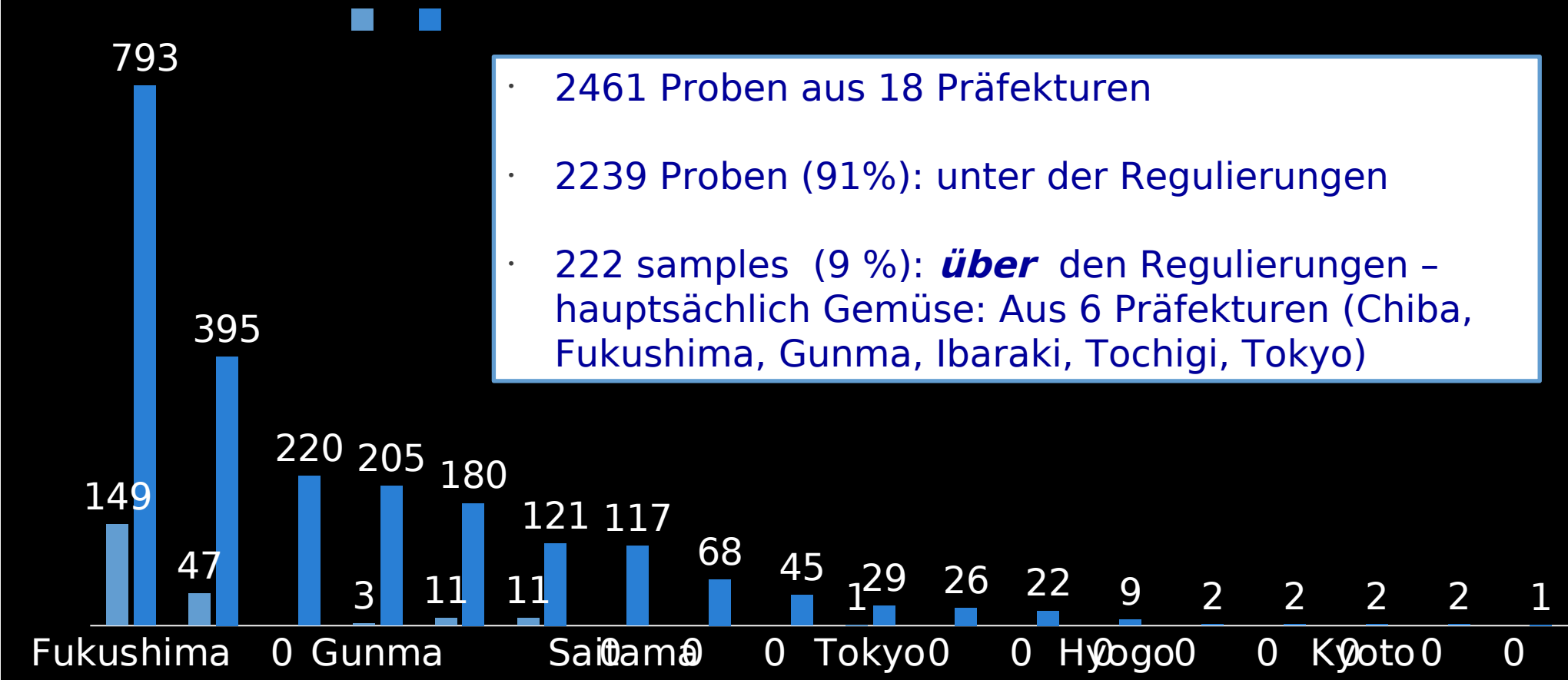

0.1 µSv
Background
Dose rate (µSv/hour)
0.30
0.25
0.20
0.15
0.10
0.05
0.00
25 March
30 March
04 April
09 April
14 April
19 April
24 April
29 April
04 May
Ibaraki
Tochigi(Utsunomiya)
Gumma(Maebashi)
Saitama(Saitama)
Chiba(Ichihara)
Tokyo(Shinjyuku)
Kanagawa(Chigasaki)

# Radiologie


External Gamma Dose Rate (nSv/h) on 04 May 2011 at 08:00 UTC
in the 47 Perfectures - Log scale
Gamma dose rate ( µSv/h
0.12
0.10
0.08
0.06
0.04
0.02
0.00
0.102
Hokkaido(Sapporo)
Aomori(Aomori)
Iwate(Morioka)
Miyagi(Sendai)
Akita(Akita)
Yamagata(Yamagata)
Fukushima(Hutaba-gun)
Ibaraki(Mito)
Tochigi(Utsunomiya)
Gumma(Maebashi)
Saitama(Saitama)
Chiba(Ichihara)
Tokyo(Shinjyuku)
Kanagawa(Chigasaki)
Niigata(Niigata)
Toyama(Imizu)
Ishikawa(Kanazawa)
Fukui(Fukui)
Yamanashi(Kouhu)
Nagano(Nagano)
Gifu(Komuhara)
Shizuoka(Shizuoka)
Aichi(Nagoya)
Mie(Yokkaichi)
Siga(Ootsu)
Kyoto(Kyoto)
Osaka(Osaka)
Hyogo(Hyogo)
Nara(Nara)
Wakayama(Wakayama)
Tottori(Touhaku)
Shimane(Matsue)
Okayama(Okayama)
Hiroshima(Hiroshima)
Yamaguchi(Yamaguchi)
Tokushima(Tokushima)
Kagawa(Takamatsu)
Ehime(Matsuyama)
Kouchi(Kouchi)
Fukuka(Fukuoka)
Saga(Saga)
Nagasaki(Omura)
Kumamot o(Udo)
Ooita(Ooita)
Miyazaki(Miyazaki)
Kagoshima(Kagoshima)
Okinawa(Uruma)

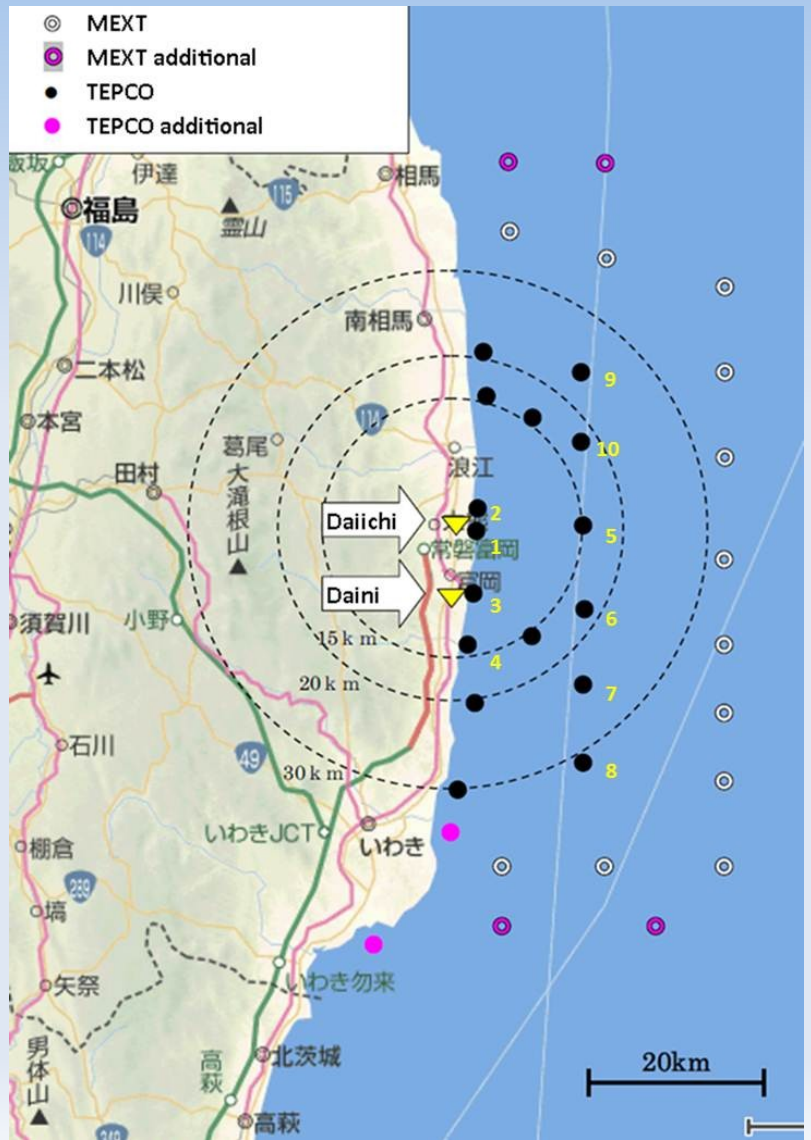
# Radiologie

## Food Monitoring 19 March to 3 May, MHLW



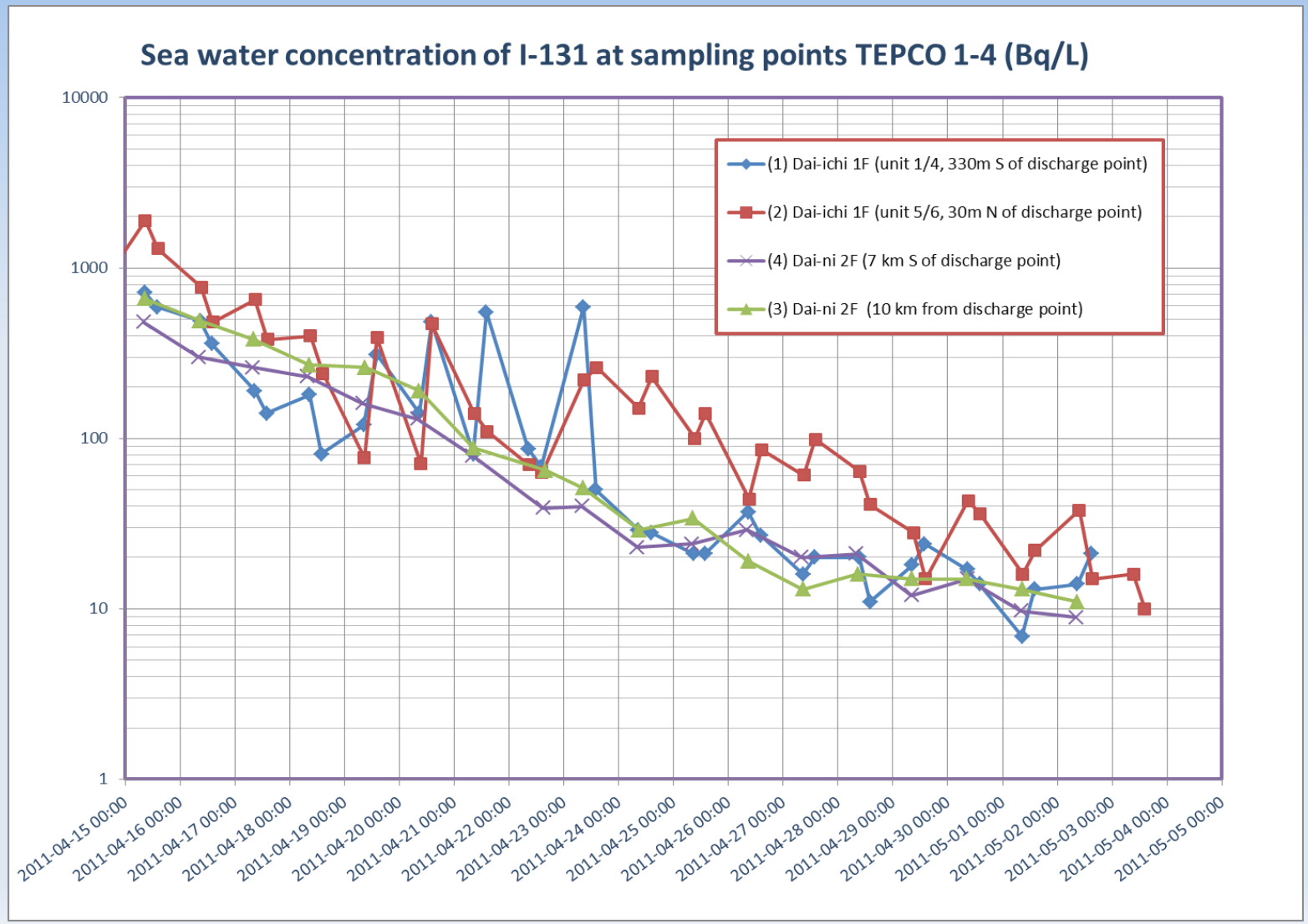

- 2461 Proben aus 18 Präfekturen
- 2239 Proben (91%): unter der Regulierungen
- 222 samples (9 %): ***über*** den Regulierungen – hauptsächlich Gemüse: Aus 6 Präfekturen (Chiba, Fukushima, Gunma, Ibaraki, Tochigi, Tokyo)

# Radiologie

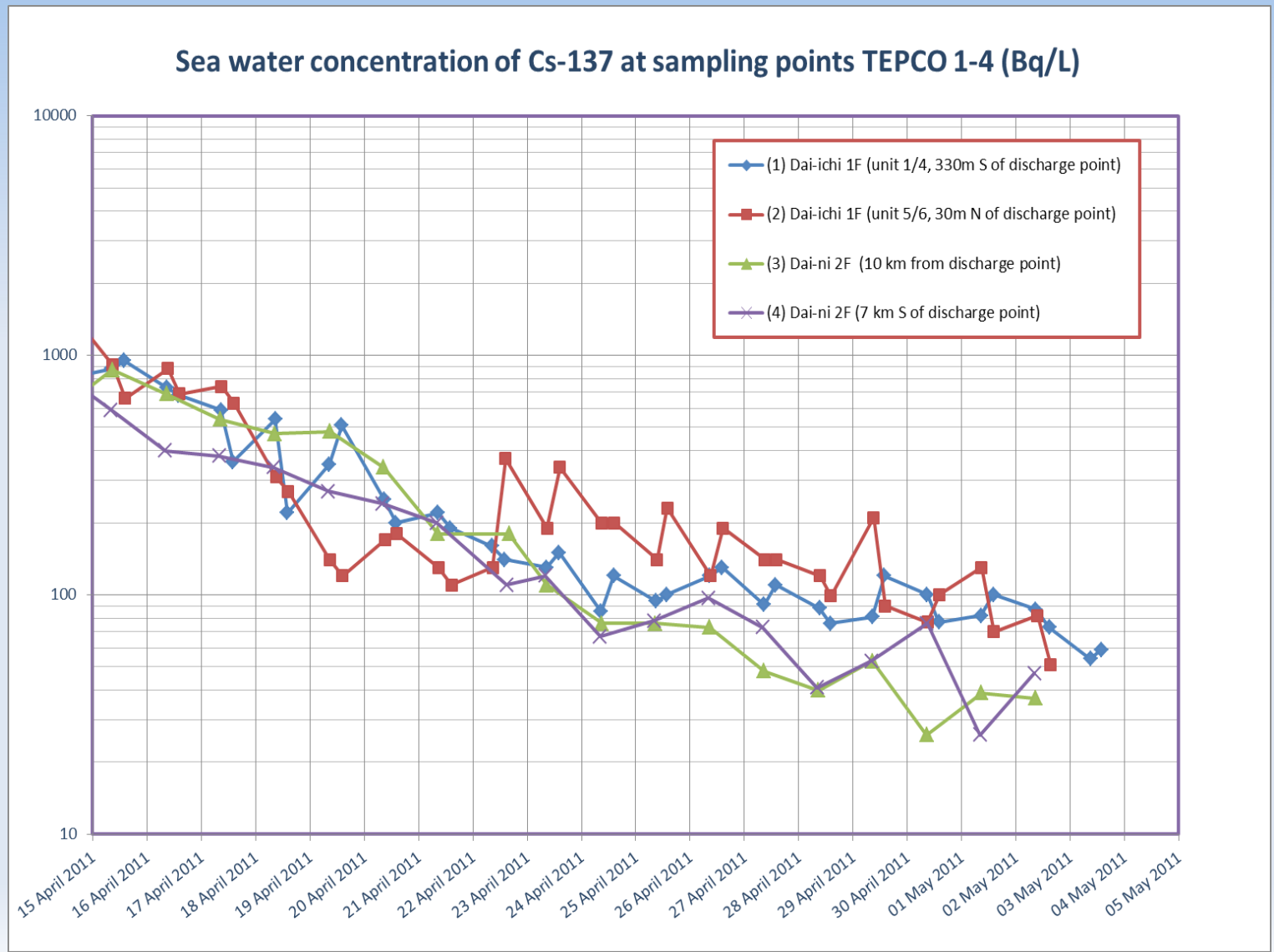

MEXT
MEXT additional
TEPCO
TEPCO additional
Daiichi
Daini
15 k m
20 k m
30 k m
20km
福島
伊達
相馬
霊山
川俣
南相馬
二本松
本宮
田村
葛尾
大滝根山
浪江
須賀川
小野
石川
棚倉
塙
矢祭
いわきJCT
いわき
いわき勿来
高萩
北茨城
男体山


沖合予定地点
塙
矢祭
男体山
いわき勿来
高萩
北茨城
日立中央
日立
常陸太田
水戸
友部JCT
水戸南
茨城町JCT
茨城空港北
小美玉
石岡
千代田石岡
霞ケ浦
土浦
茨城県
行方
鹿嶋
潮来
龍ヶ崎
香取
神栖
成田
新空港
佐倉
旭
銚子
九十九里浜
犬吠埼
利根川
鹿島灘
20km

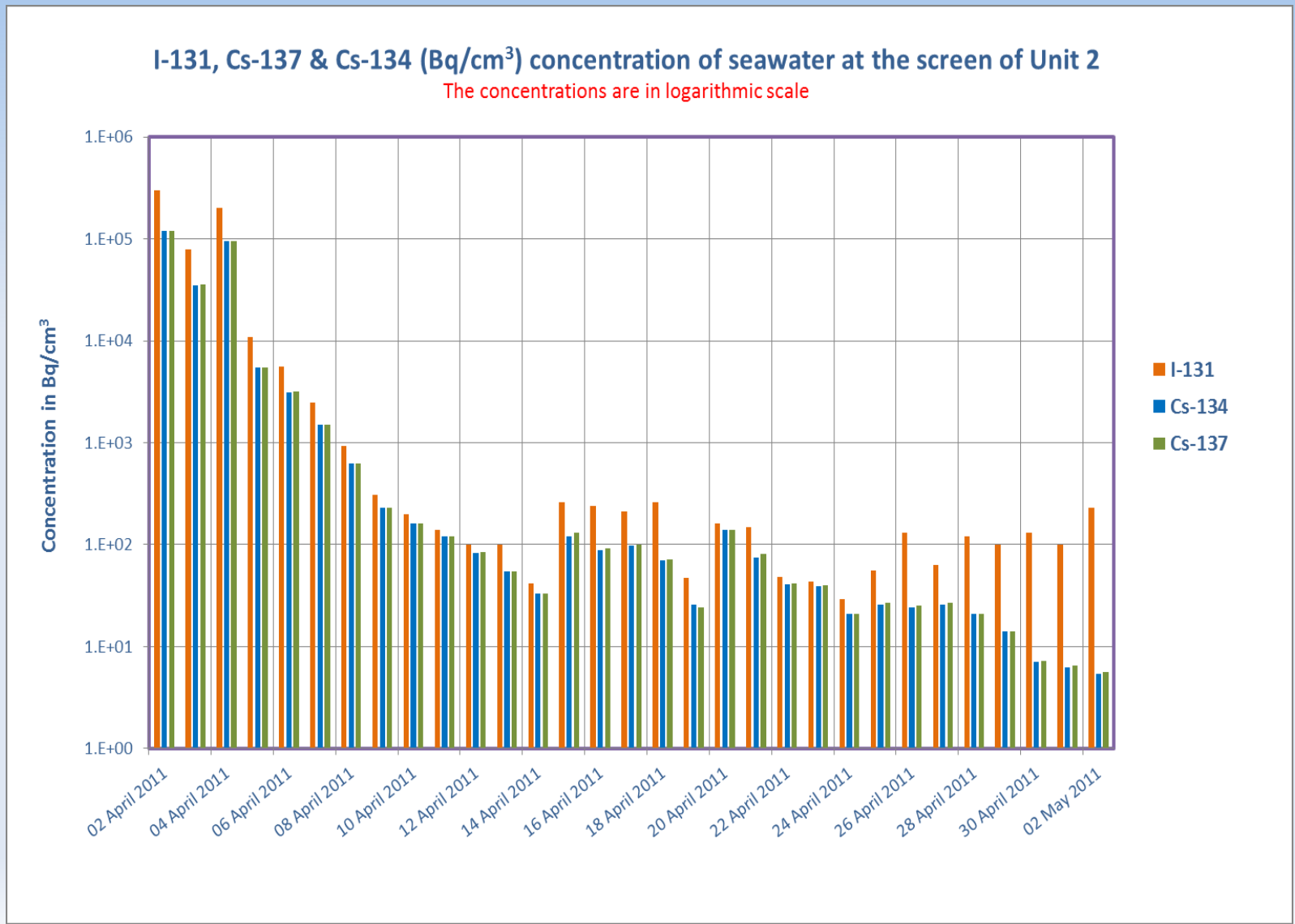
# Radiologie


Sea water concentration of I-131 at sampling points TEPCO 1-4 (Bq/L)
10000
1000
100
10
1
(1) Dai-ichi 1F (unit 1/4, 330m S of discharge point)
(2) Dai-ichi 1F (unit 5/6, 30m N of discharge point)
(4) Dai-ni 2F (7 km S of discharge point)
(3) Dai-ni 2F (10 km from discharge point)
2011-04-15 00:00
2011-04-16 00:00
2011-04-17 00:00
2011-04-18 00:00
2011-04-19 00:00
2011-04-20 00:00
2011-04-21 00:00
2011-04-22 00:00
2011-04-23 00:00
2011-04-24 00:00
2011-04-25 00:00
2011-04-26 00:00
2011-04-27 00:00
2011-04-28 00:00
2011-04-29 00:00
2011-04-30 00:00
2011-05-01 00:00
2011-05-02 00:00
2011-05-03 00:00
2011-05-04 00:00
2011-05-05 00:00

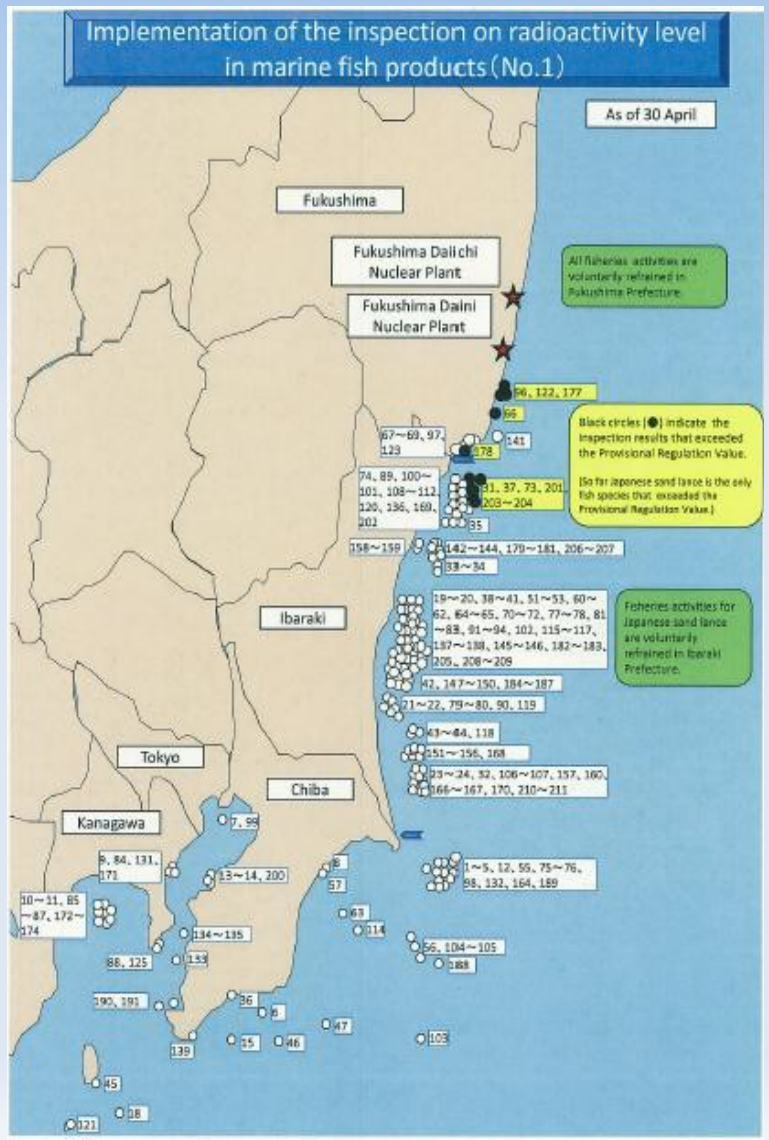
# Radiologie


Sea water concentration of Cs-137 at sampling points TEPCO 1-4 (Bq/L)
10000
1000
100
10
(1) Dai-ichi 1F (unit 1/4, 330m S of discharge point)
(2) Dai-ichi 1F (unit 5/6, 30m N of discharge point)
(3) Dai-ni 2F (10 km from discharge point)
(4) Dai-ni 2F (7 km S of discharge point)
15 April 2011
16 April 2011
17 April 2011
18 April 2011
19 April 2011
20 April 2011
21 April 2011
22 April 2011
23 April 2011
24 April 2011
25 April 2011
26 April 2011
27 April 2011
28 April 2011
29 April 2011
30 April 2011
01 May 2011
02 May 2011
03 May 2011
04 May 2011
05 May 2011

# Radiologie

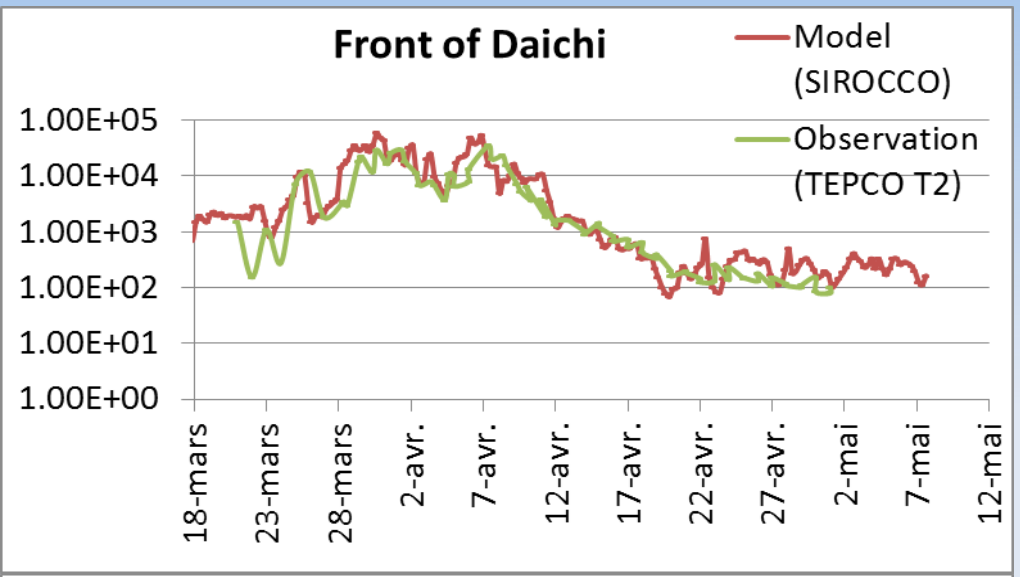

I-131, Cs-137 & Cs-134 (Bq/cm3) concentration of seawater at the screen of Unit 2
The concentrations are in logarithmic scale
Concentration in Bq/cm3
1.E+06
1.E+05
1.E+04
1.E+03
1.E+02
1.E+01
1.E+00
02 April 2011
04 April 2011
06 April 2011
08 April 2011
10 April 2011
12 April 2011
14 April 2011
16 April 2011
18 April 2011
20 April 2011
22 April 2011
24 April 2011
26 April 2011
28 April 2011
30 April 2011
02 May 2011
I-131
Cs-134
Cs-137

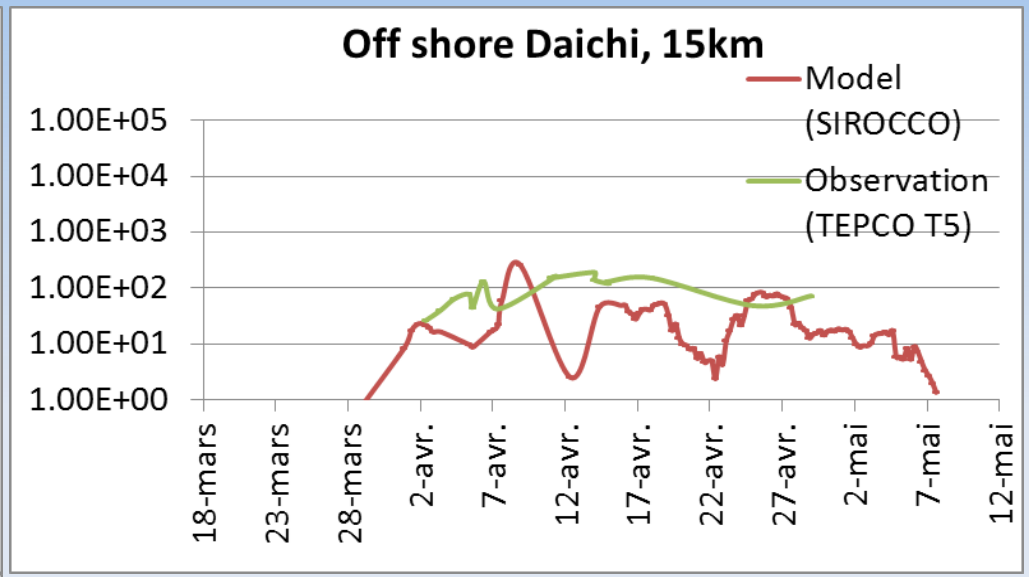
# Radiologie

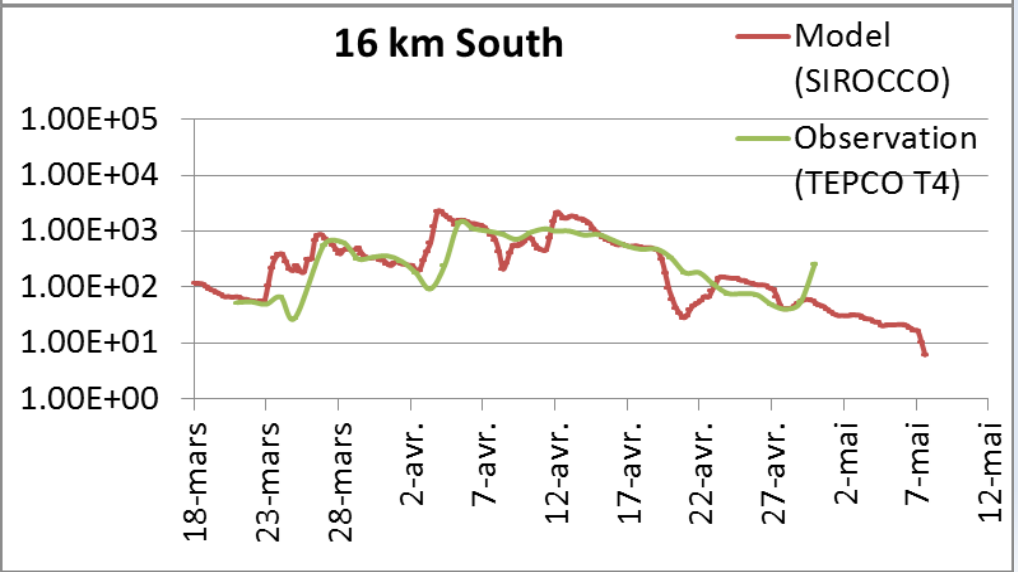



Nur 3 Proben liegen über den festgelegten Werten für Cs-134 und Cs-137.
Nur Sandaale

# Radiologie

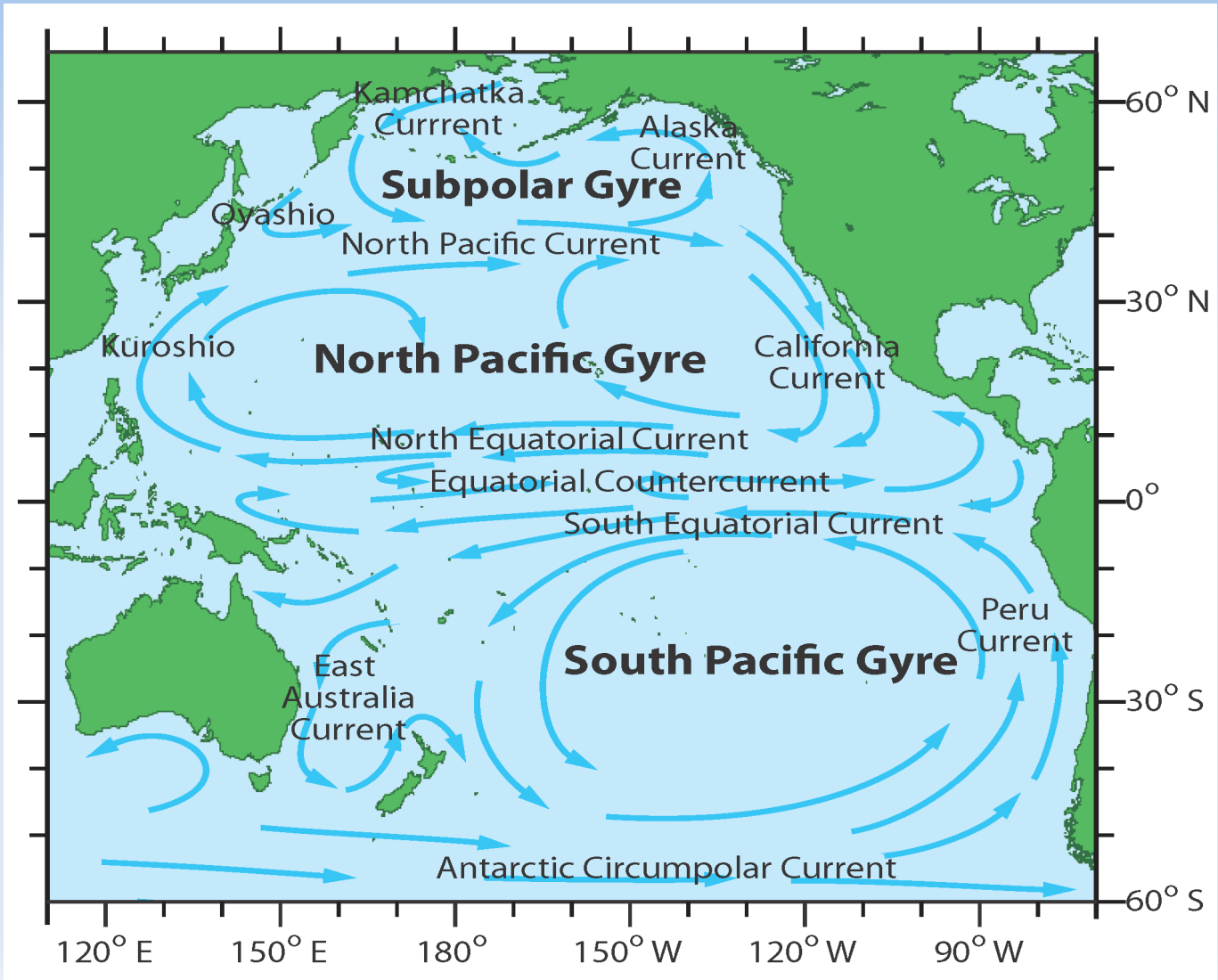


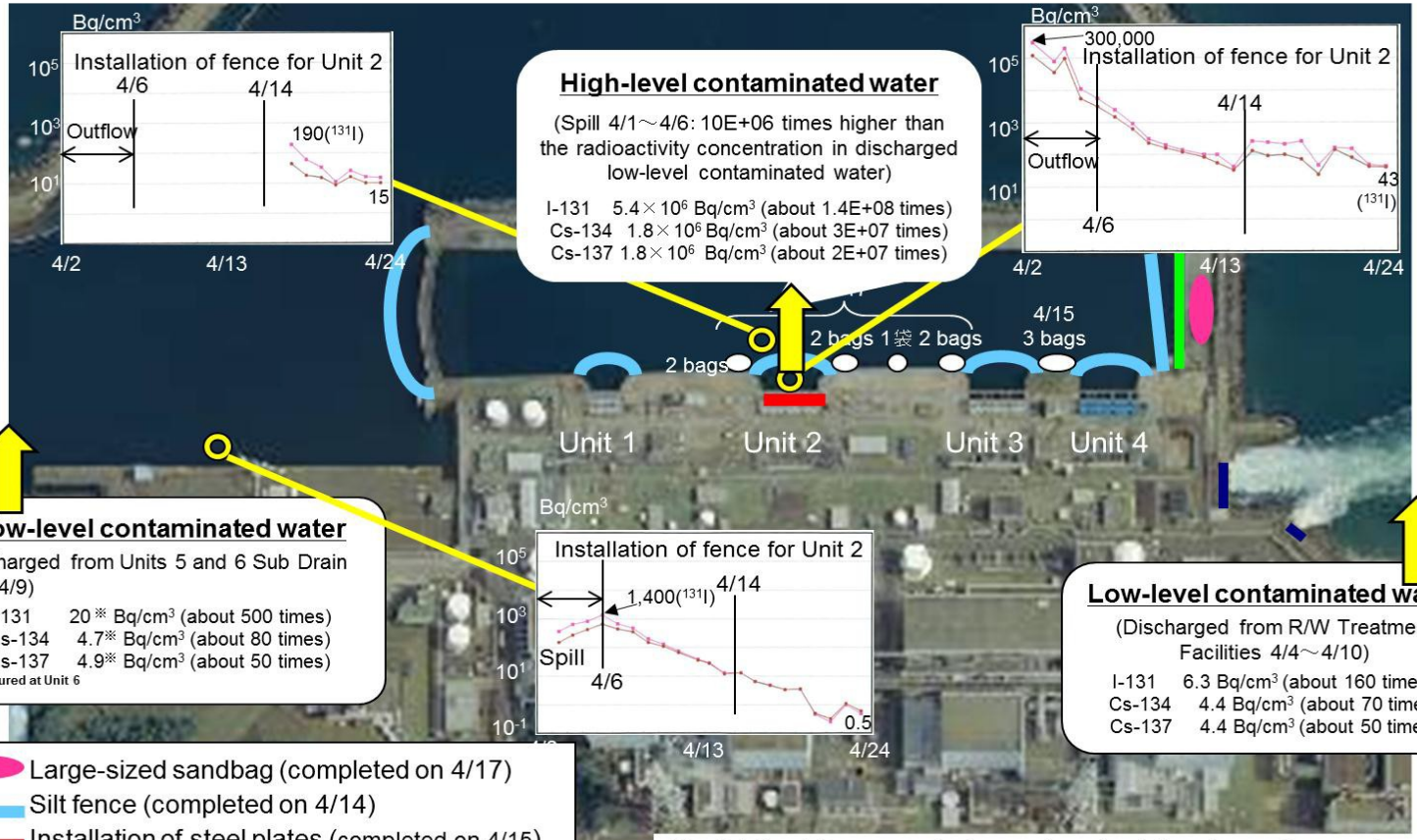

http://sirocco.omp.obs-mip.fr/outils/Symphonie/

# Radiologie


Kamchatka Currrent
Alaska Current
Subpolar Gyre
Oyashio
North Pacific Current
Kuroshio
North Pacific Gyre
California Current
North Equatorial Current
Equatorial Countercurrent
South Equatorial Current
Peru Current
East Australia Current
South Pacific Gyre
Antarctic Circumpolar Current
60° N
30° N
0°
30° S
60° S
120° E
150° E
180°
150° W
120° W
90° W

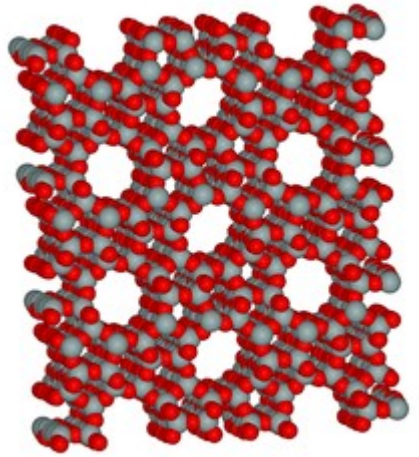
# Maßnahmen

## Measures for preventing spread of the liquid including radioactive materials




(Note) Radioactivity concentration in parentheses is relative value to reference value of concentration.
Reference value: $^{131}I$: $4\times10^{-2}$, $^{134}Cs$: $6\times10^{-2}$, $^{137}Cs$: $9\times10^{-2}$ (Bq/cm$^3$)

(Note) Red lines in graph: $^{131}I$, blue lines: $^{134}Cs$, brown lines: $^{137}Cs$



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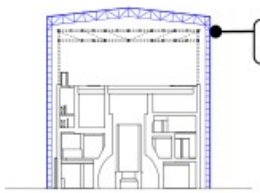

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Continued monitoring (countermeasure 21),
(Unit 4) Installation of supporting structure under the bottom of spent fuel pool (countermeasure 26)

piping

pumps

heat exchangers, water processing facilities

# Quellen

- IAEA
- JAIF
- VBG
- AREVA
- ATI
- TEPCO
- SIROCCO