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Department of Mechanical & Nuclear Engineering

Nuclear Events and Lessons Learned

April 25, 2012

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Osher Lifelong Learning Institute
Spring 2012

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Content

- Three Mile Island
- Chernobyl
- Fukushima Daiichi

Objectives

- General knowledge of incident progression
- Understanding of the root cause of each incident
- Understanding of radiological effects of the releases from each incident
- General knowledge of lessons learned from each event
- Most importantly: How those lessons have been applied to make the industry safer

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Contents

- For each incident we will cover:
  - Reactor Type
  - The Accident
  - Consequences
  - Lessons Learned

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THREE MILE ISLAND

THREE MILE ISLAND UNIT 2 (TMI-2)

THE REACTOR

THE ACCIDENT

THE CONSEQUENCES

THE LESSONS LEARNED

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Three Mile Island Nuclear Station

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Three Mile Island Nuclear Station

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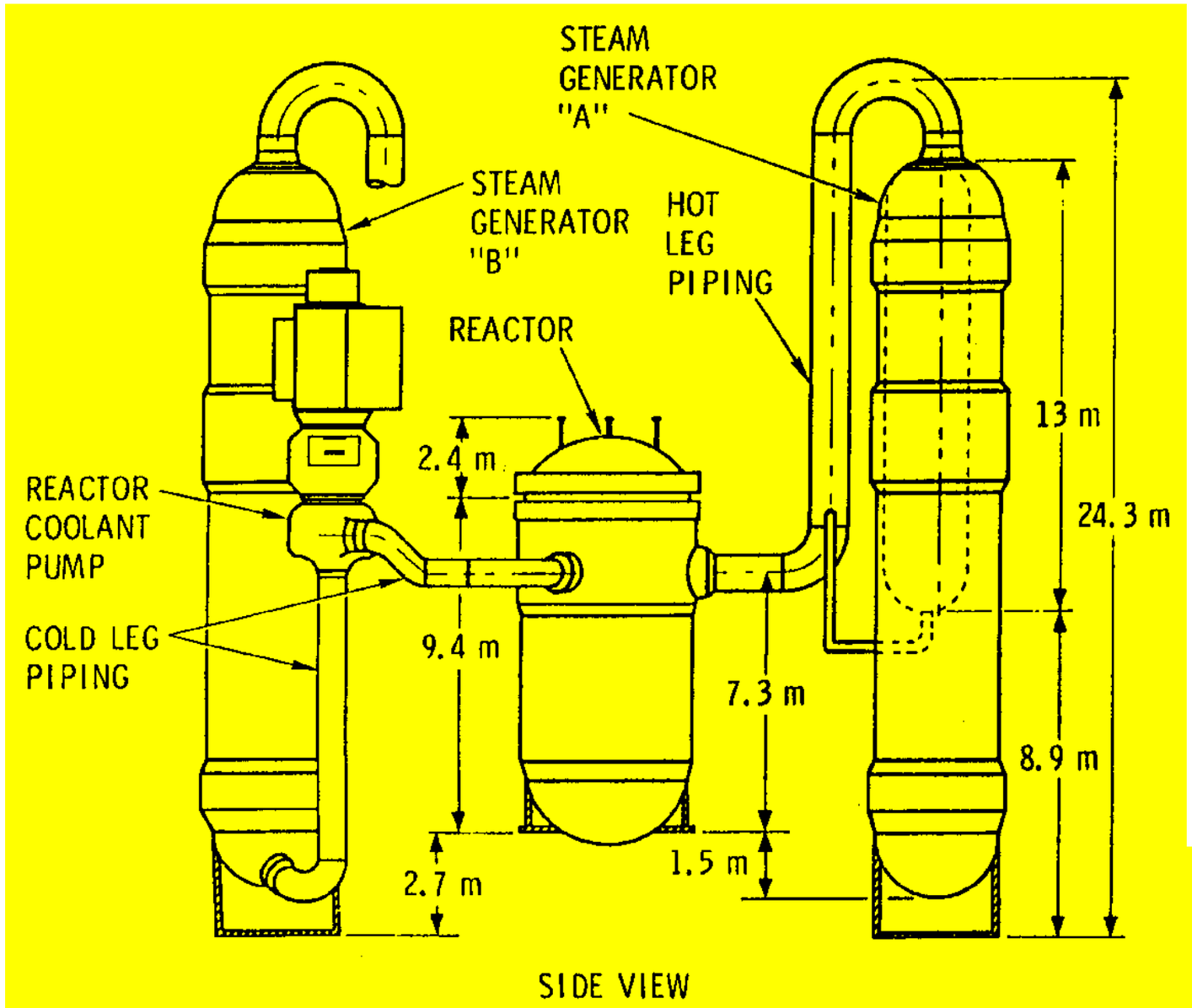
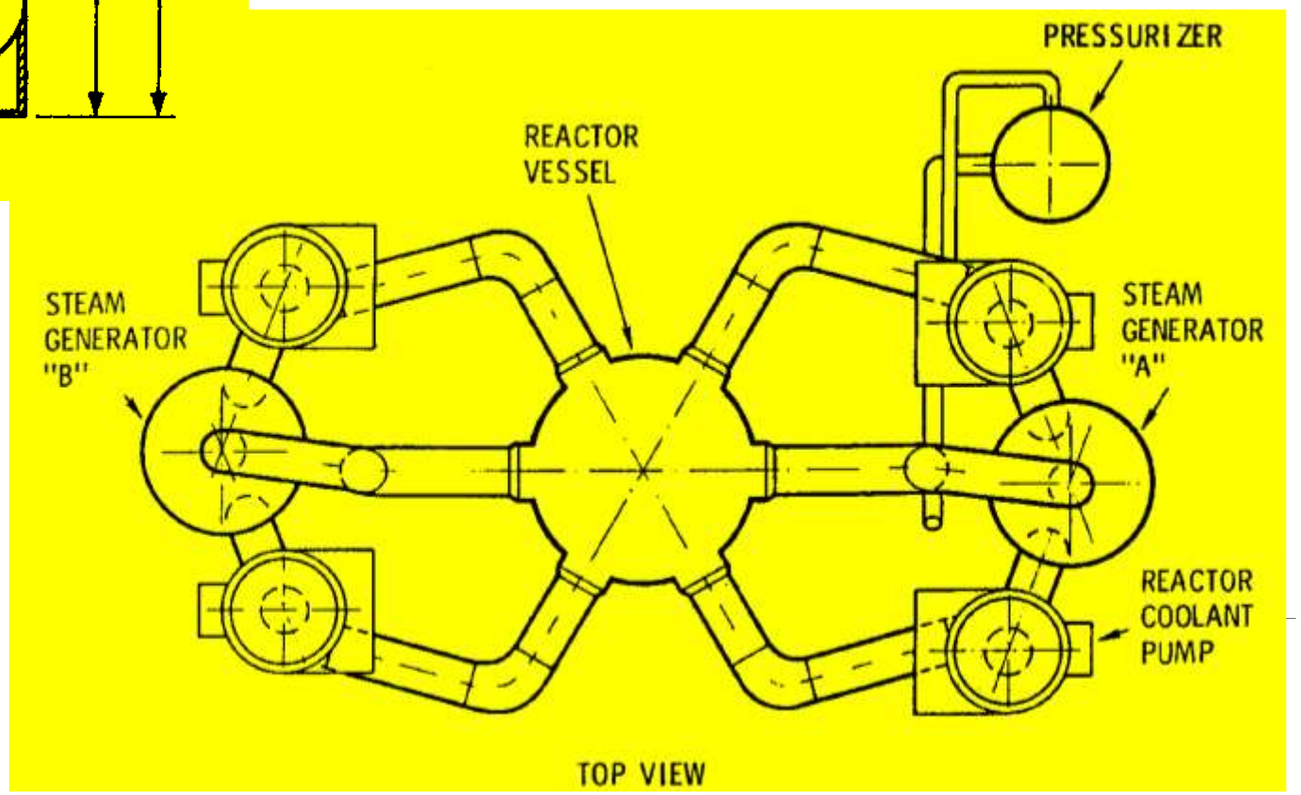
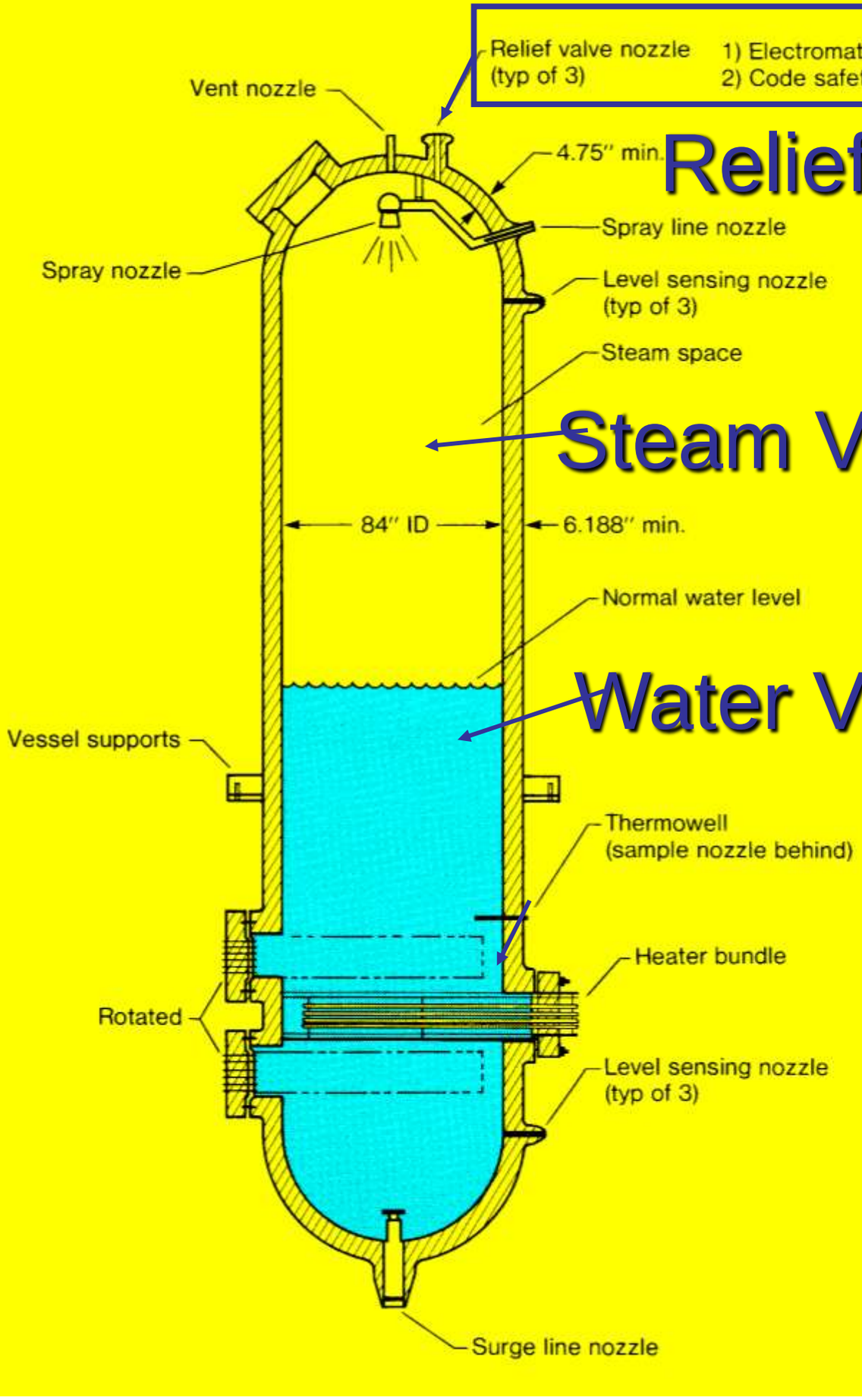
TMI-2 Reactor Coolant System



SIDE VIEW



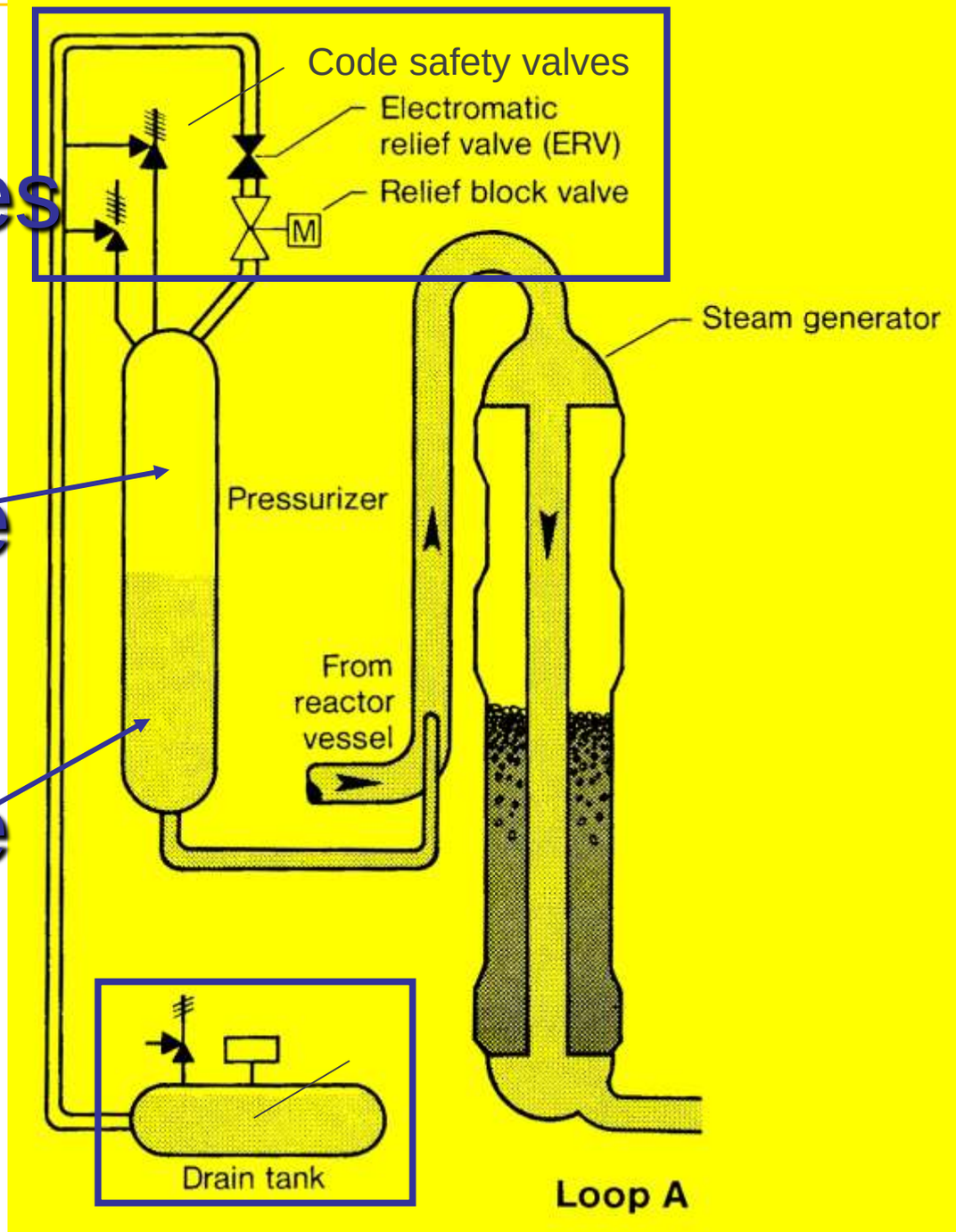
TOP VIEW



Relief Valves

Steam Volume

Water Volume



TMI-2 Pressurizer

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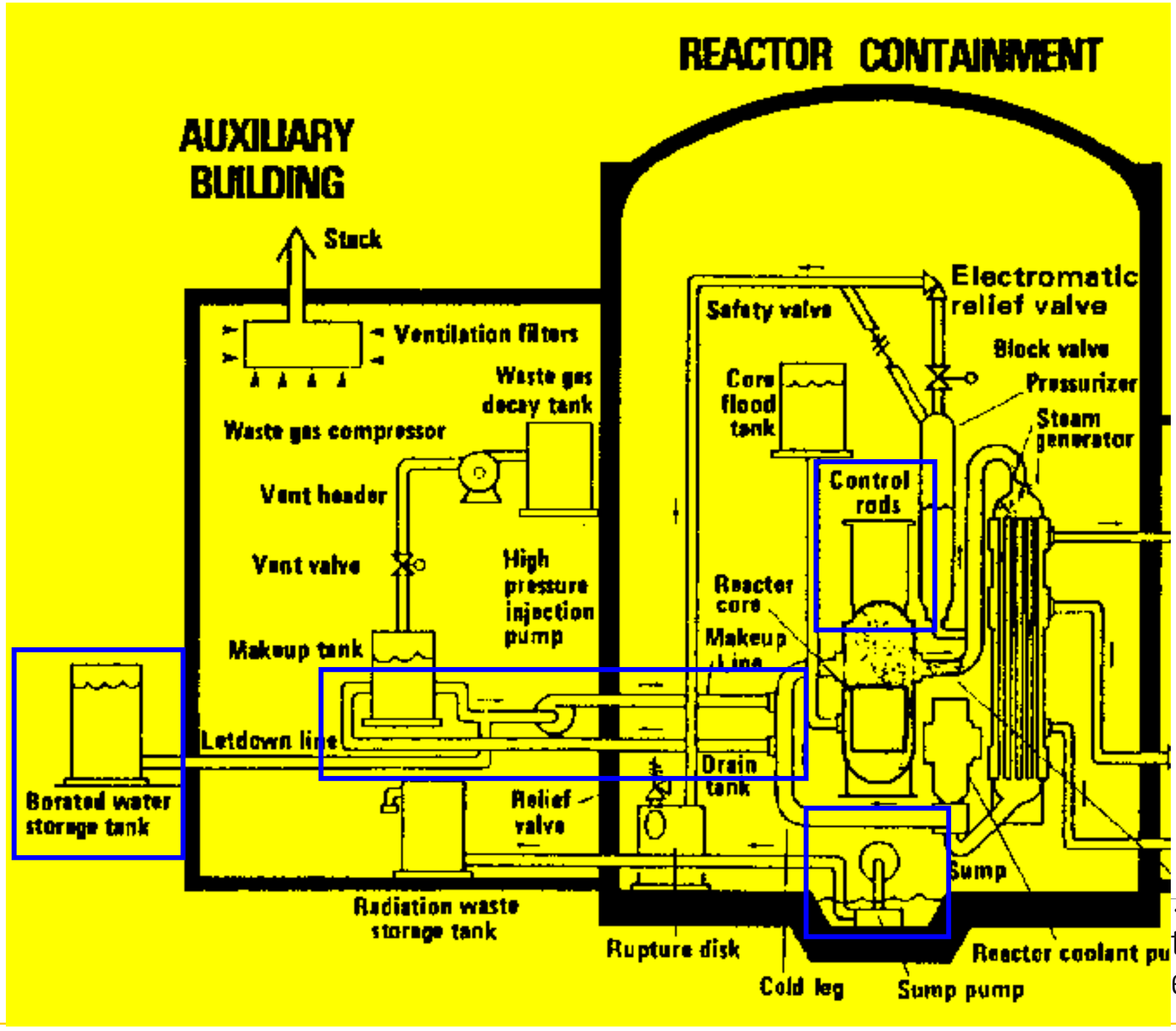
TMI-2 Station Schematic



THREE MILE ISLAND UNIT 2 (TMI-2)

THE REACTOR

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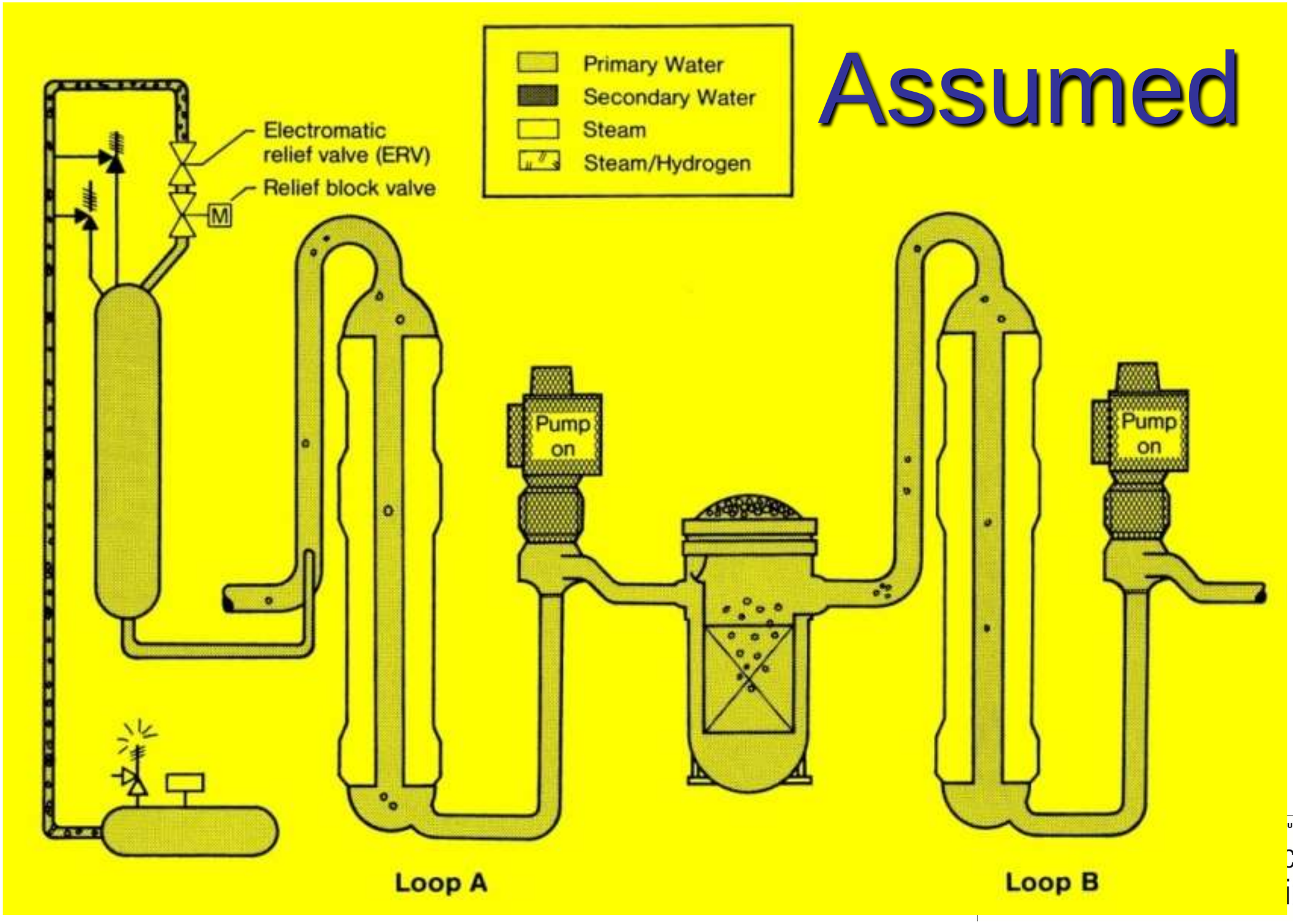
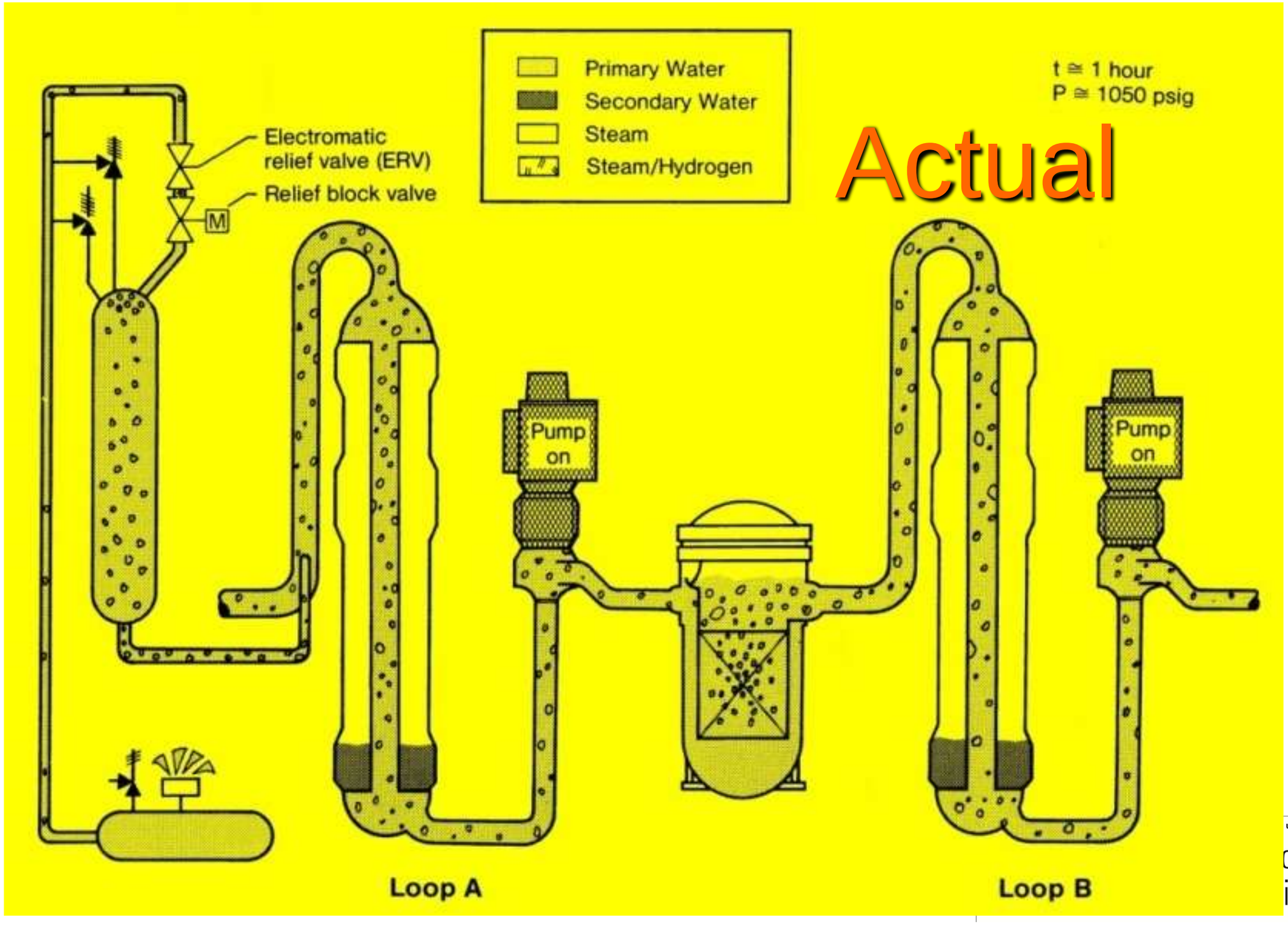
TMI-2 Control Room

Accident Progression

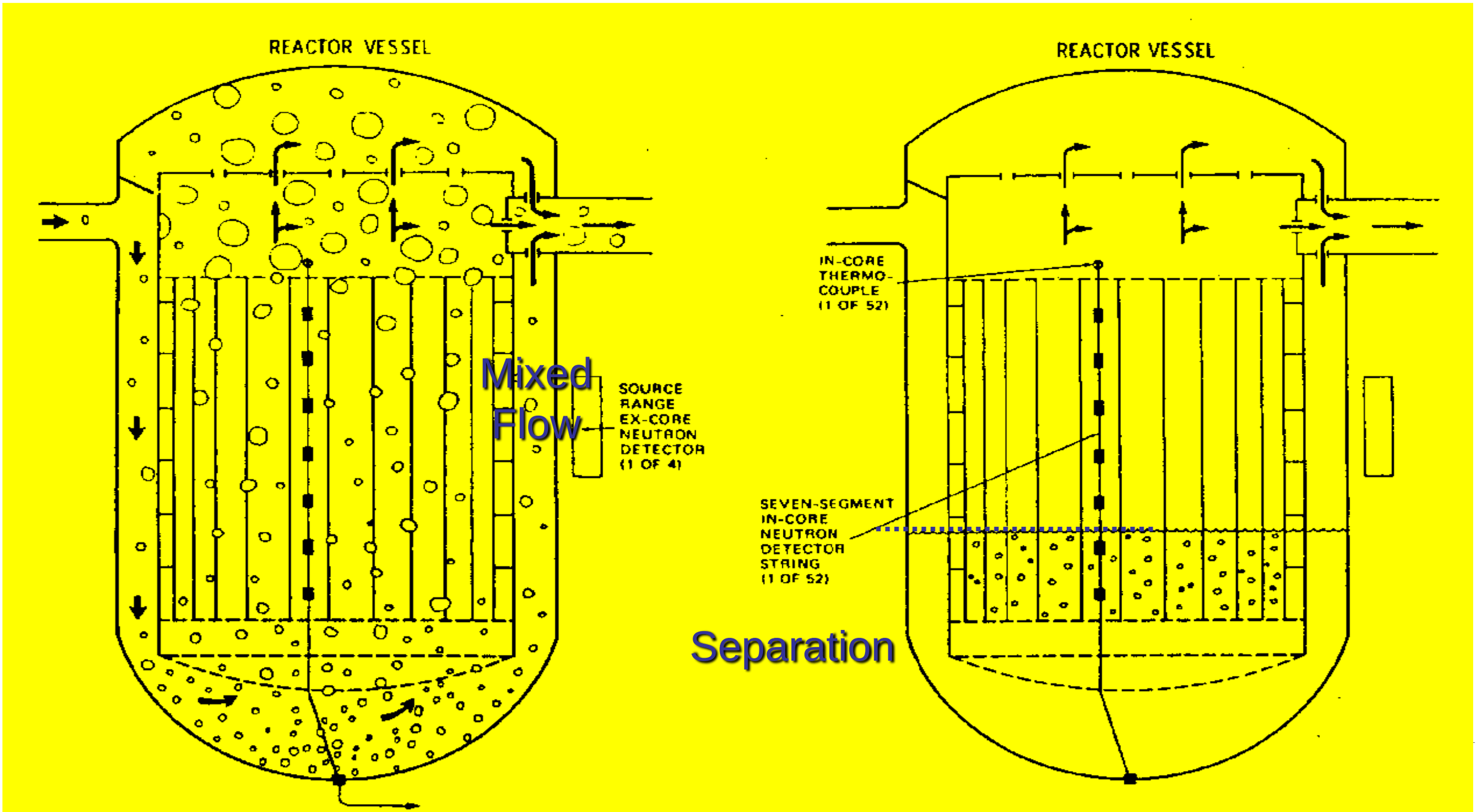
Accident Progression



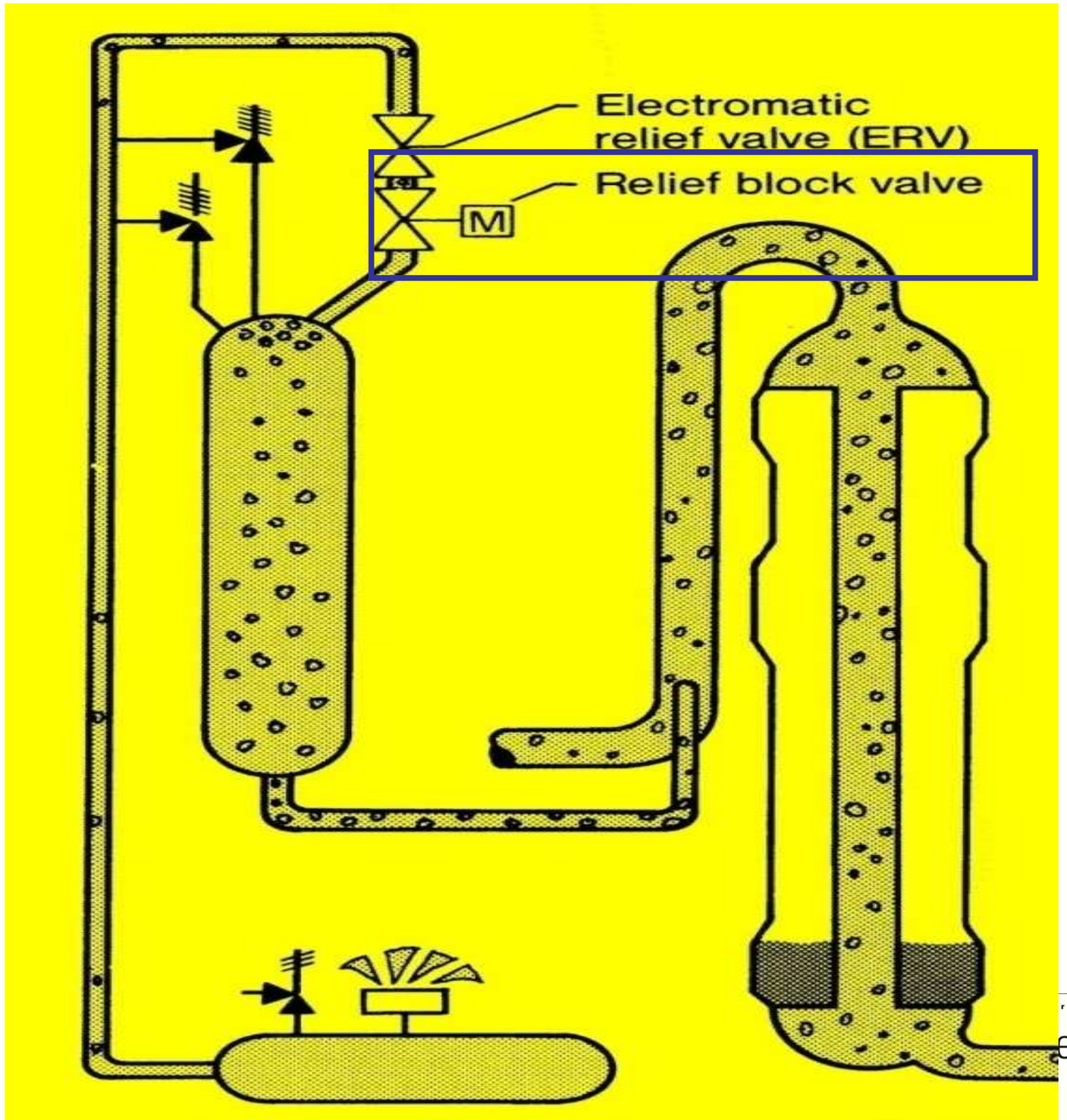
Accident Progression



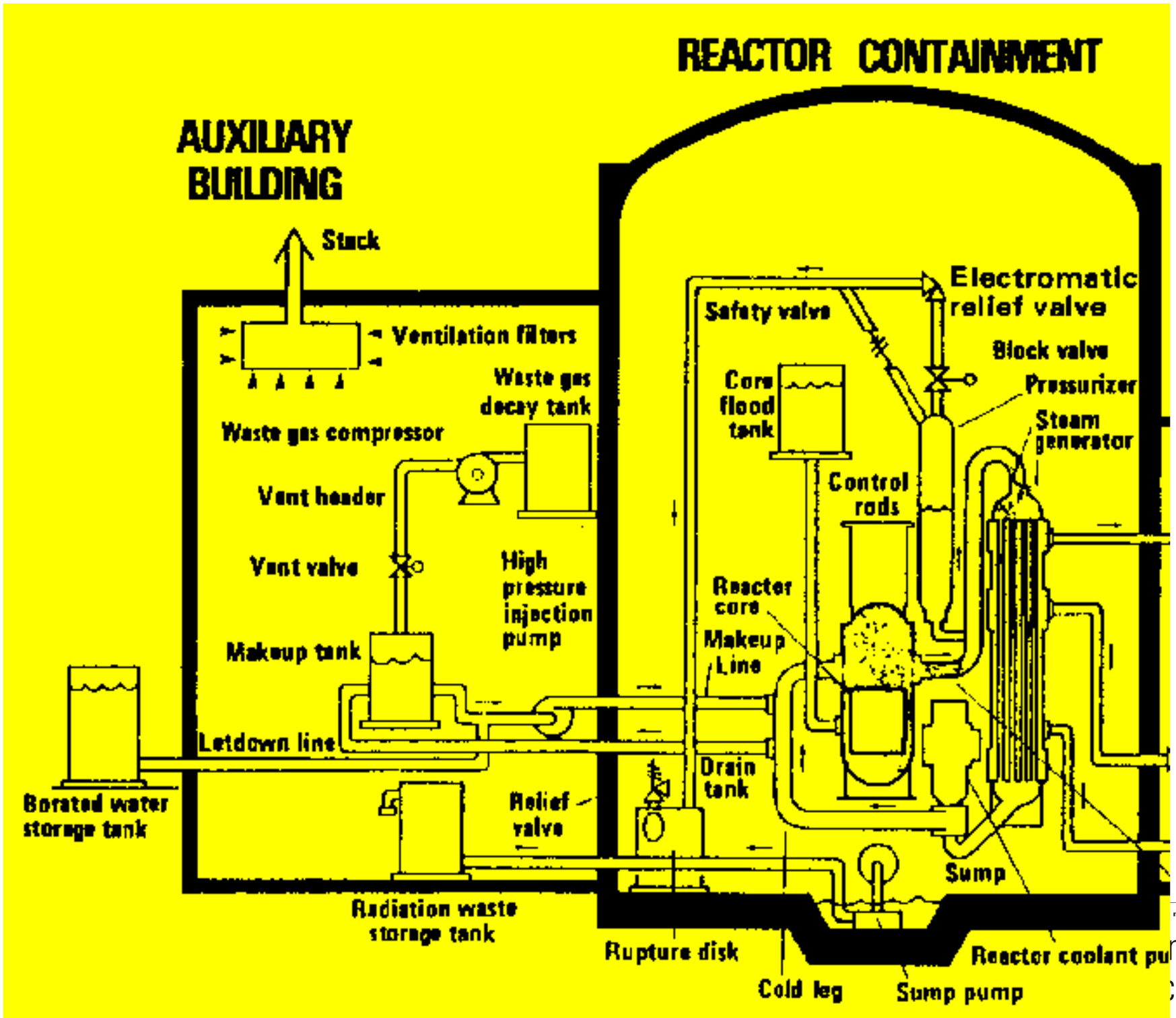
Accident Progression



Accident Progression



Accident Progression



THREE MILE ISLAND UNIT 2 (TMI-2)

THE REACTOR

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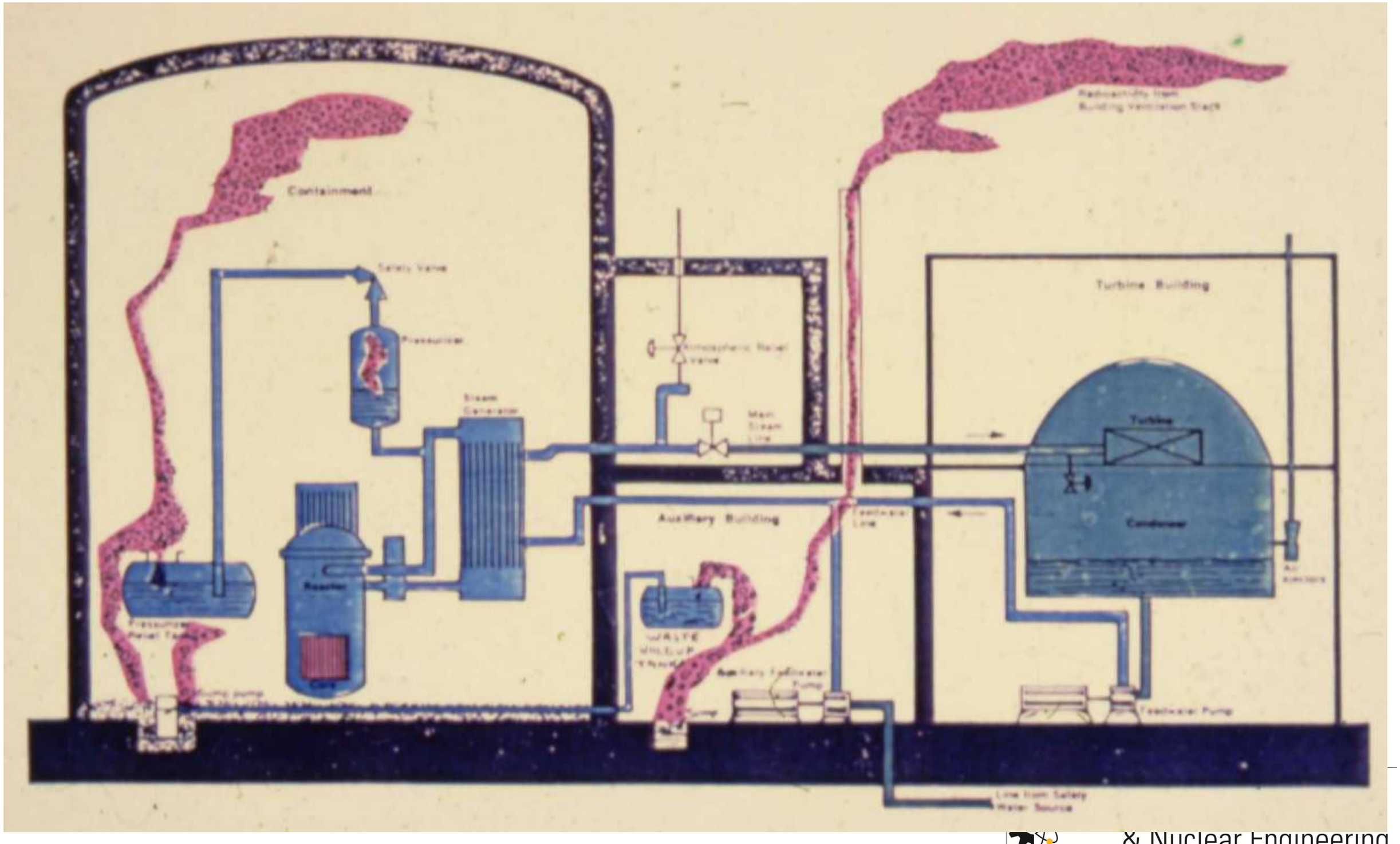
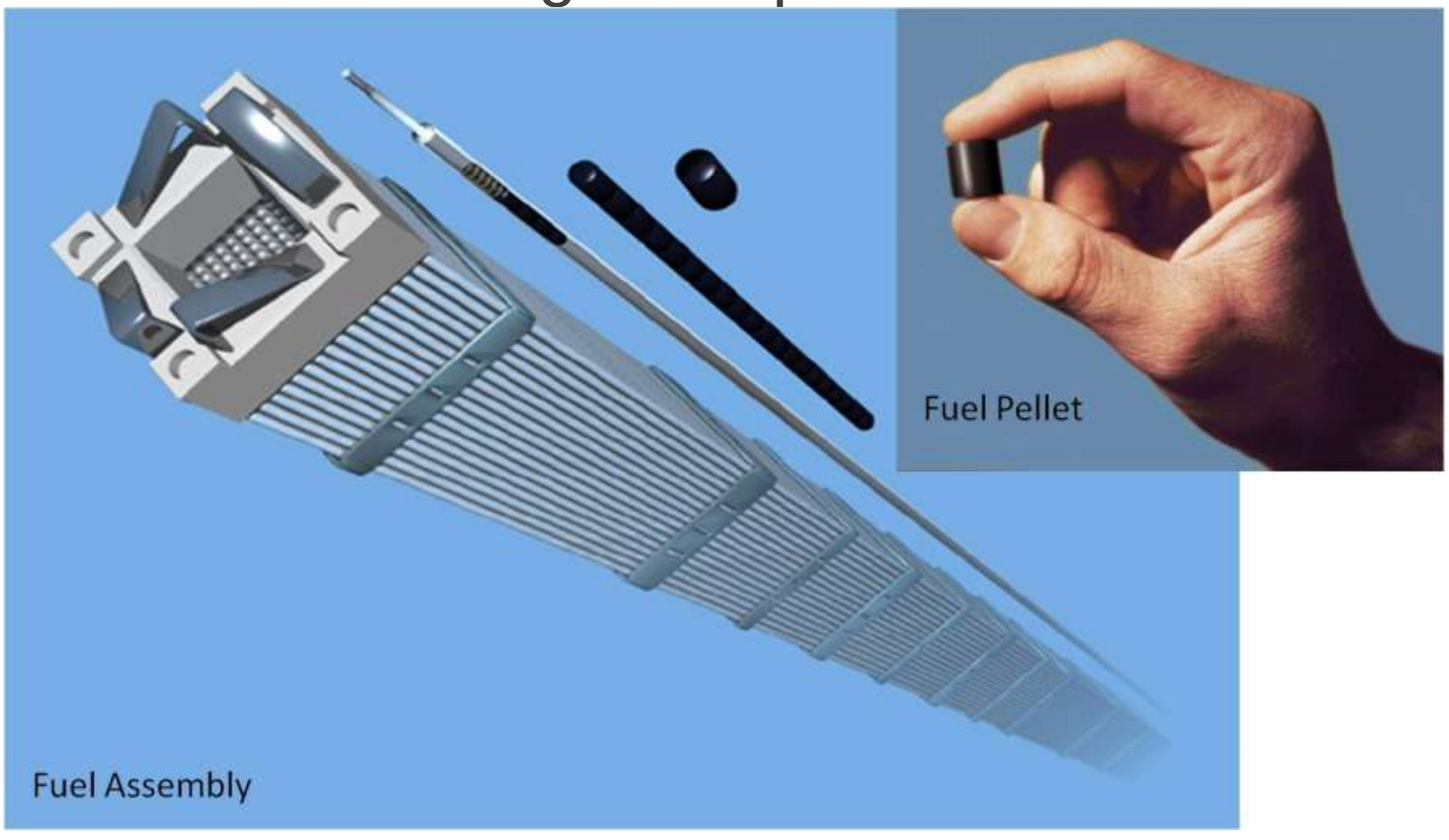
Radioactivity



Hydrogen

$$Zr + 2H_20 \rightarrow ZrO_2 + 2H_2$$

At High Temperatures



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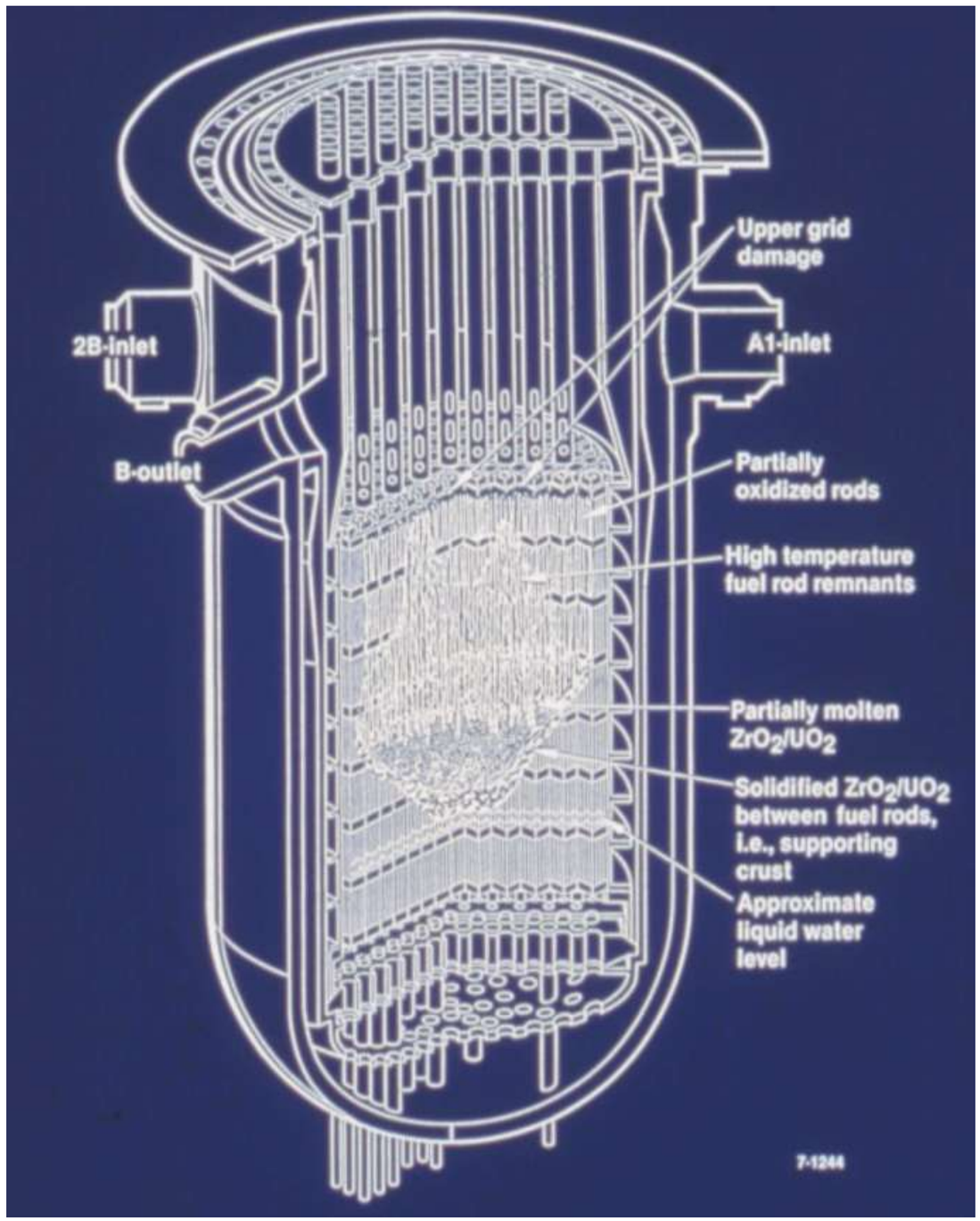
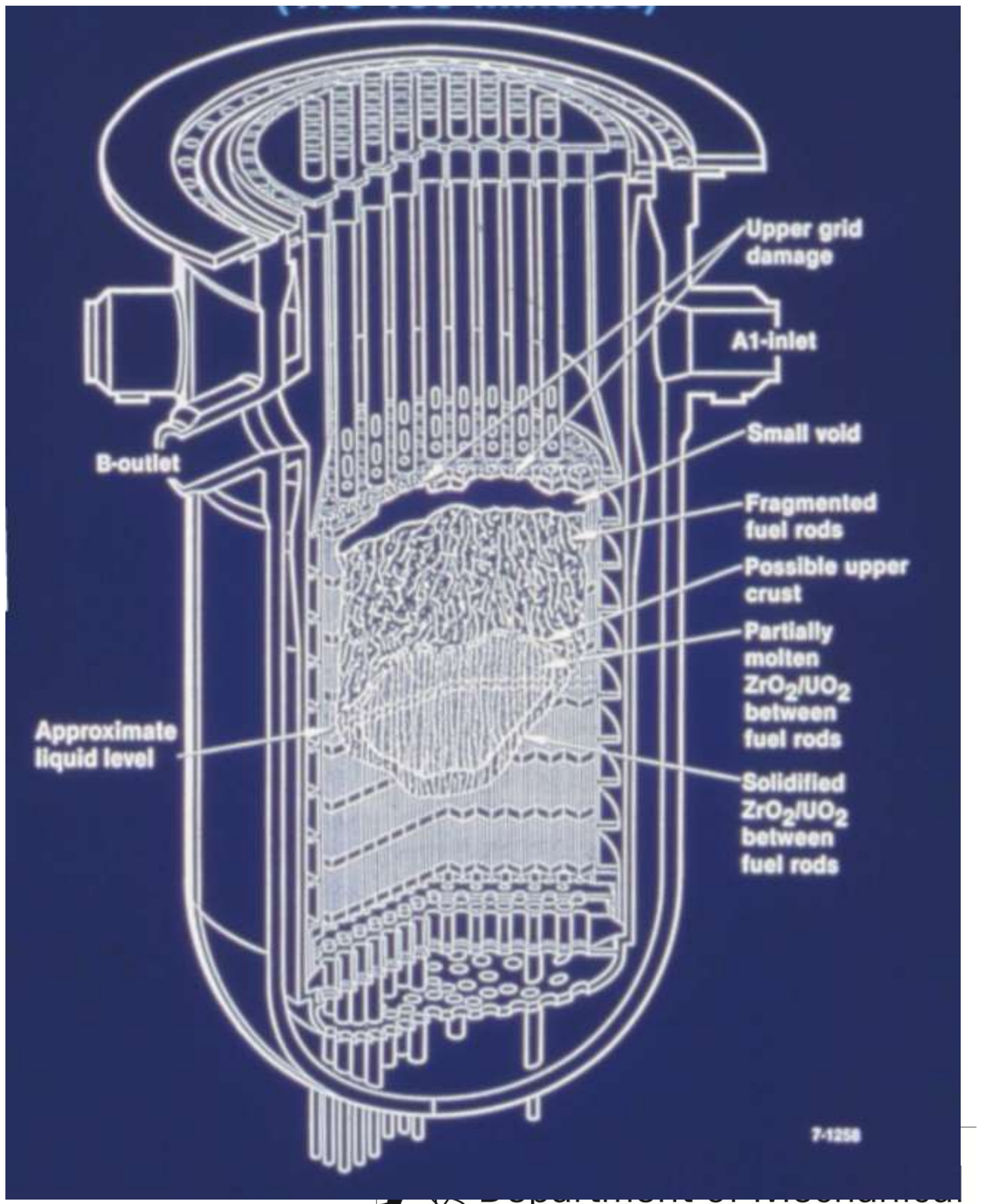
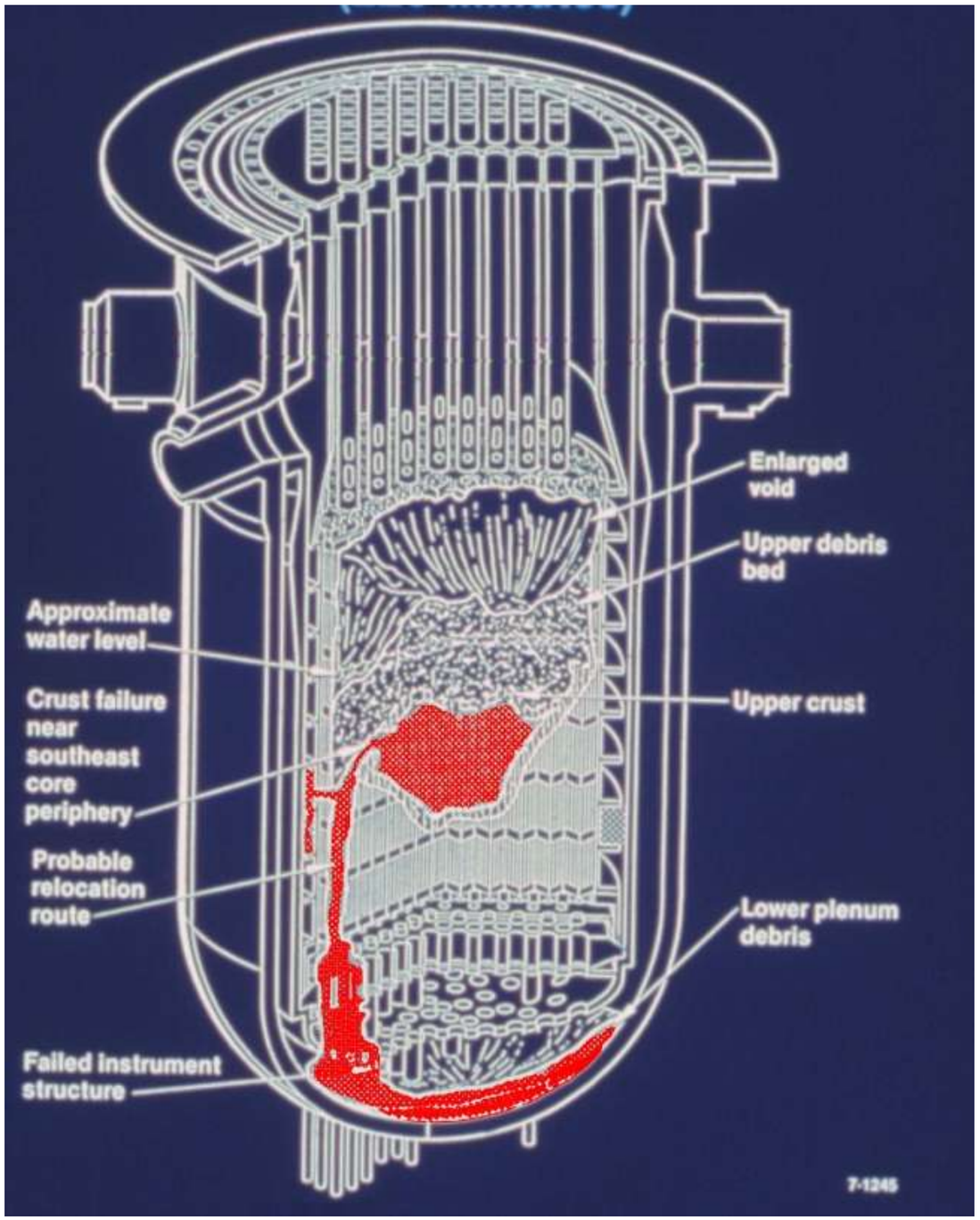
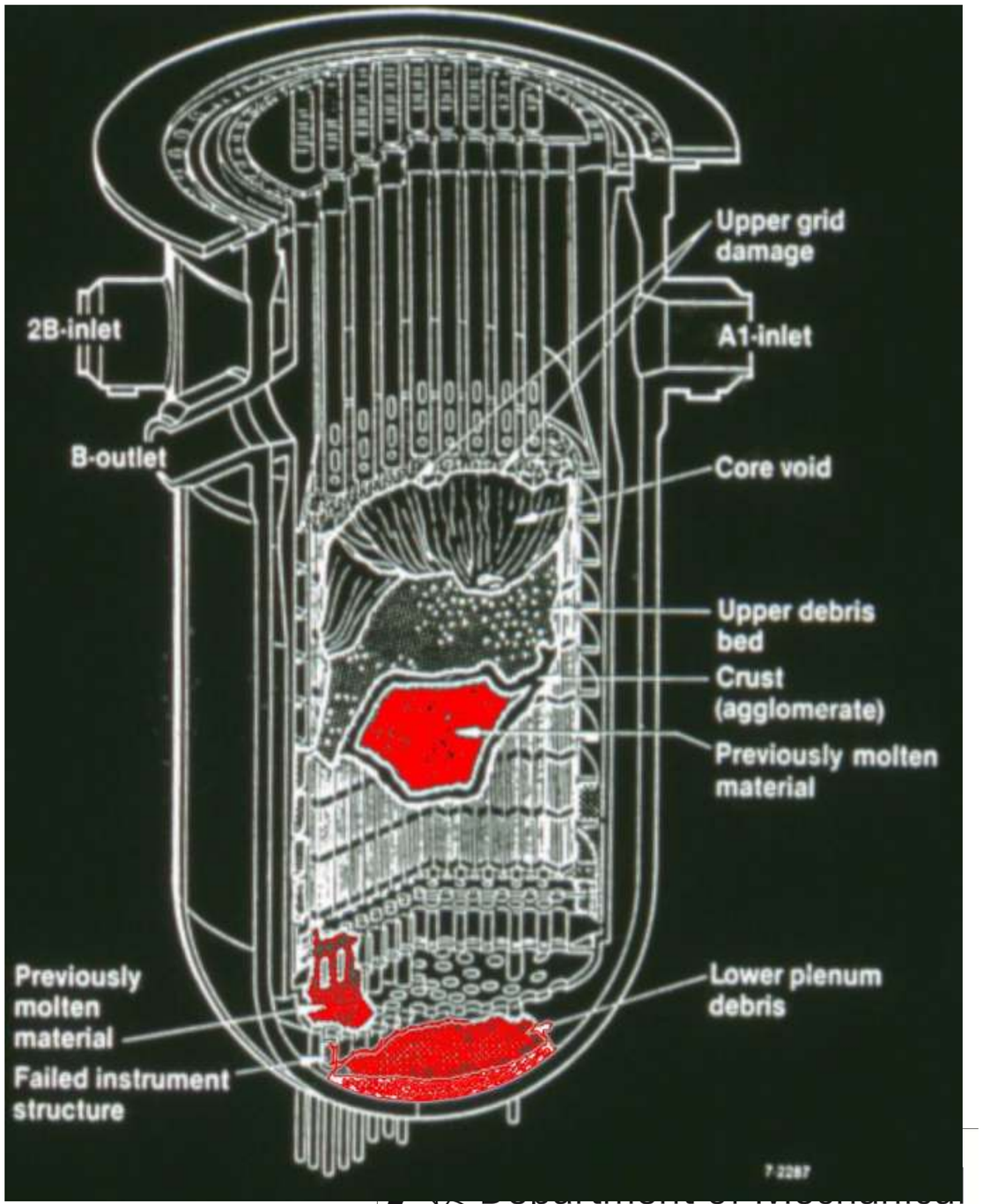
Core Status


Upper grid damage
2B-inlet
A1-inlet
B-outlet
Partially oxidized rods
High temperature fuel rod remnants
Partially molten ZrO_2/UO_2
Solidified ZrO_2/UO_2 between fuel rods, i.e., supporting crust
Approximate liquid water level
7-1244


Upper grid damage
A1-inlet
Small void
B-outlet
Fragmented fuel rods
Possible upper crust
Partially molten ZrO_2/UO_2 between fuel rods
Approximate liquid level
Solidified ZrO_2/UO_2 between fuel rods
7-1258

Core Status





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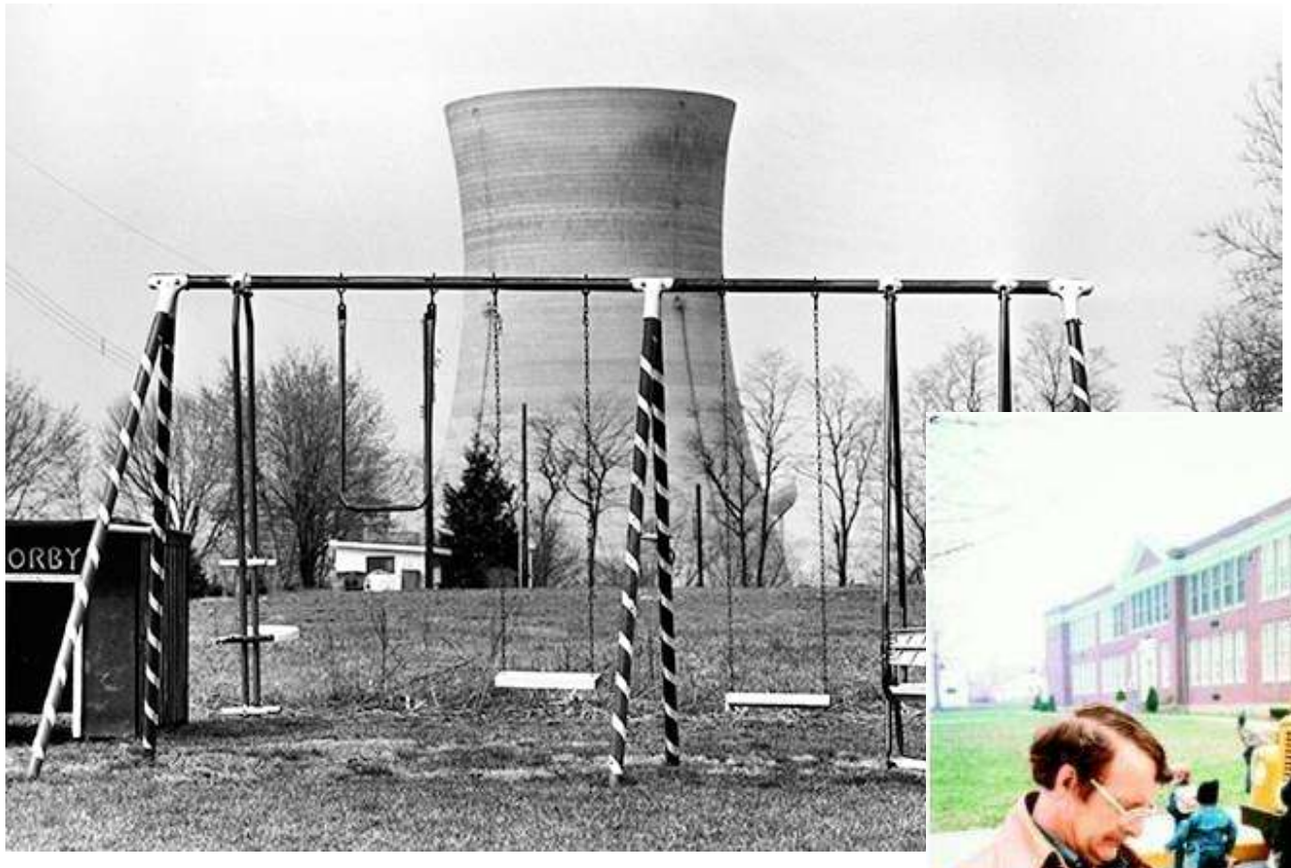
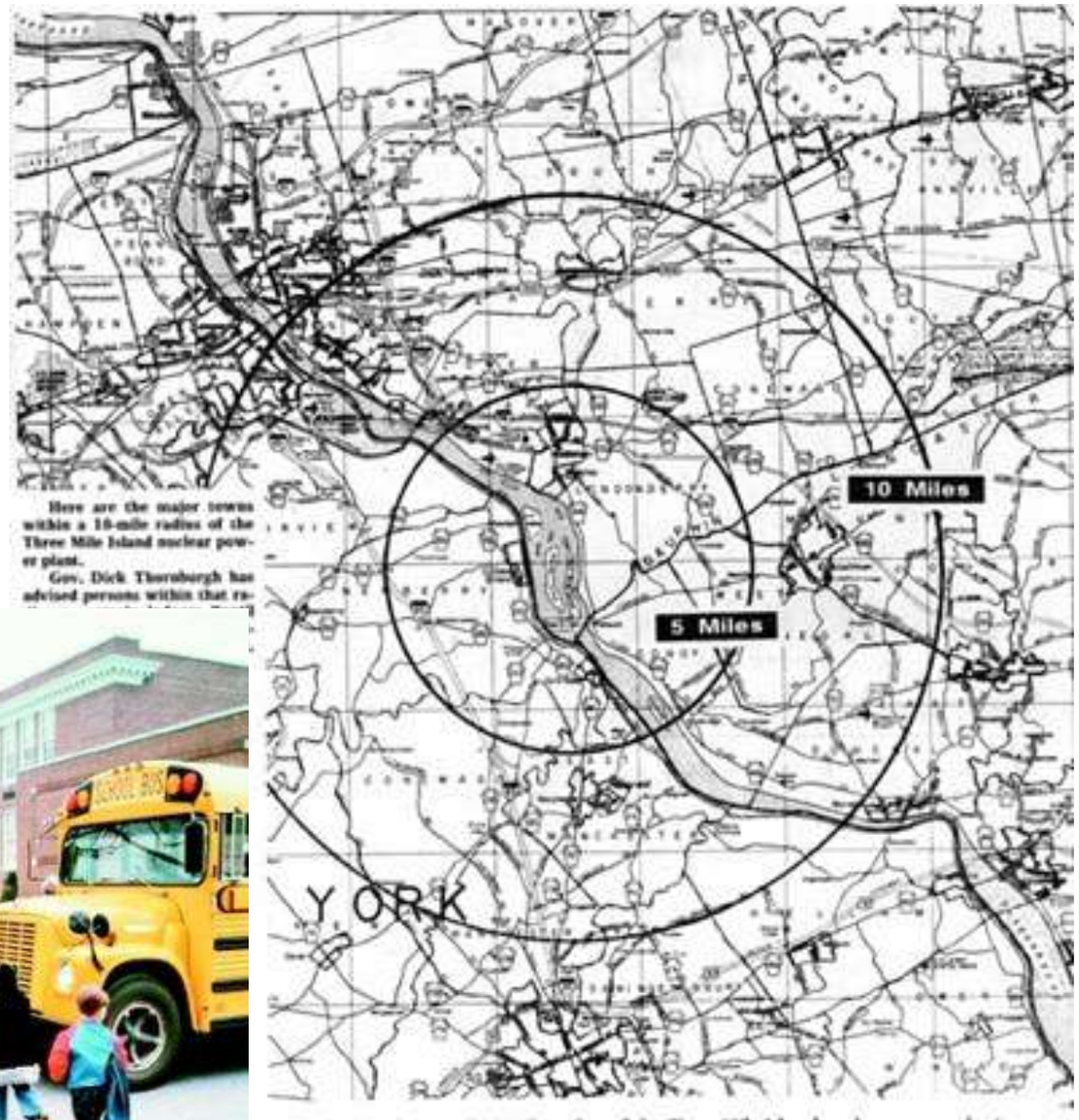
Emergency Response





Here are the major towns within a 10-mile radius of the Three Mile Island nuclear power plant.

Gov. Dick Thornburgh has advised persons within that ra-

ws areas within five- and 10-mile radius of the Three Mile Island nuclear power plant.

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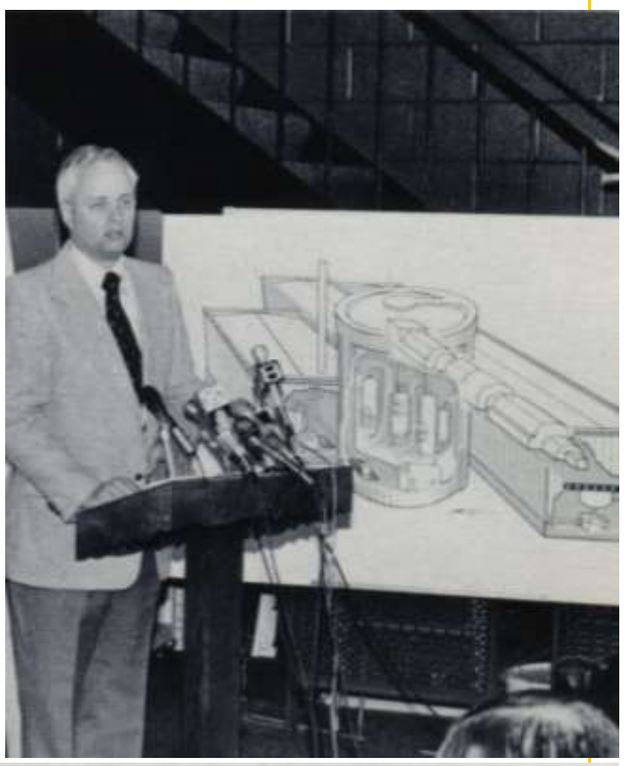
Dignitaries, Briefings & Media



Technical Support

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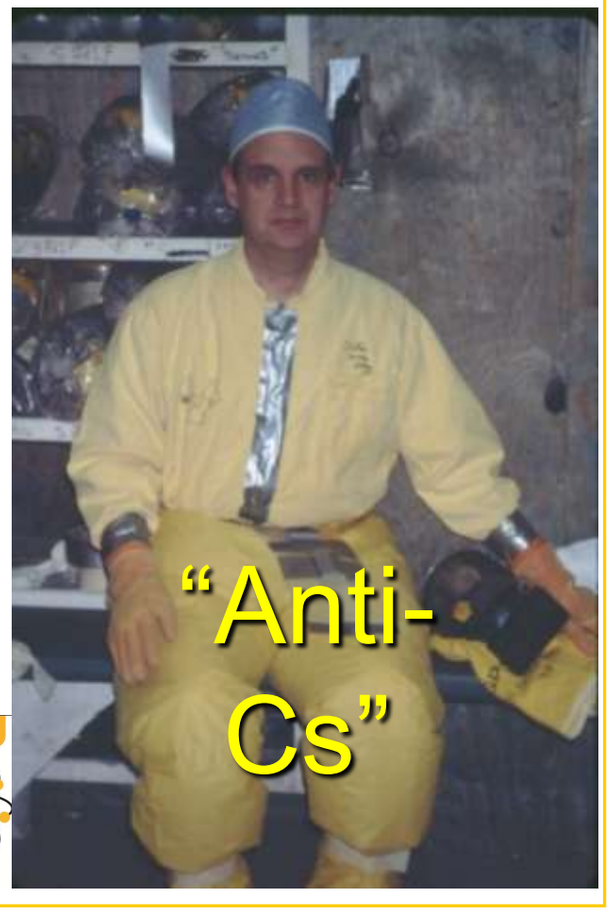
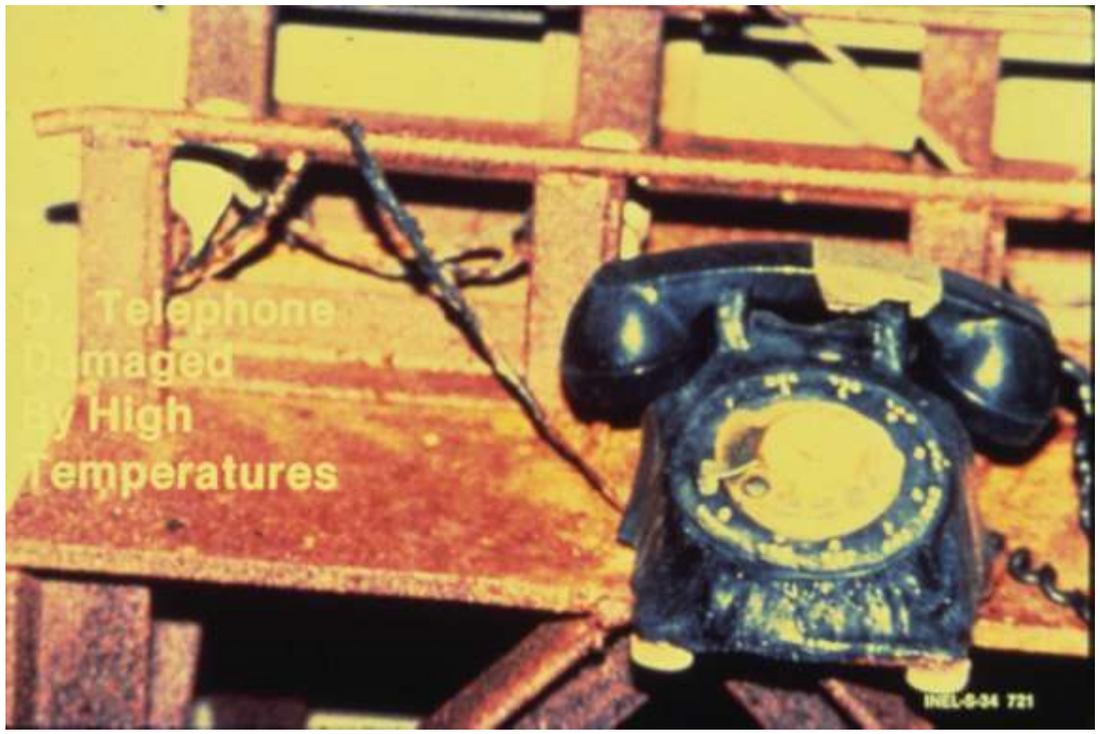
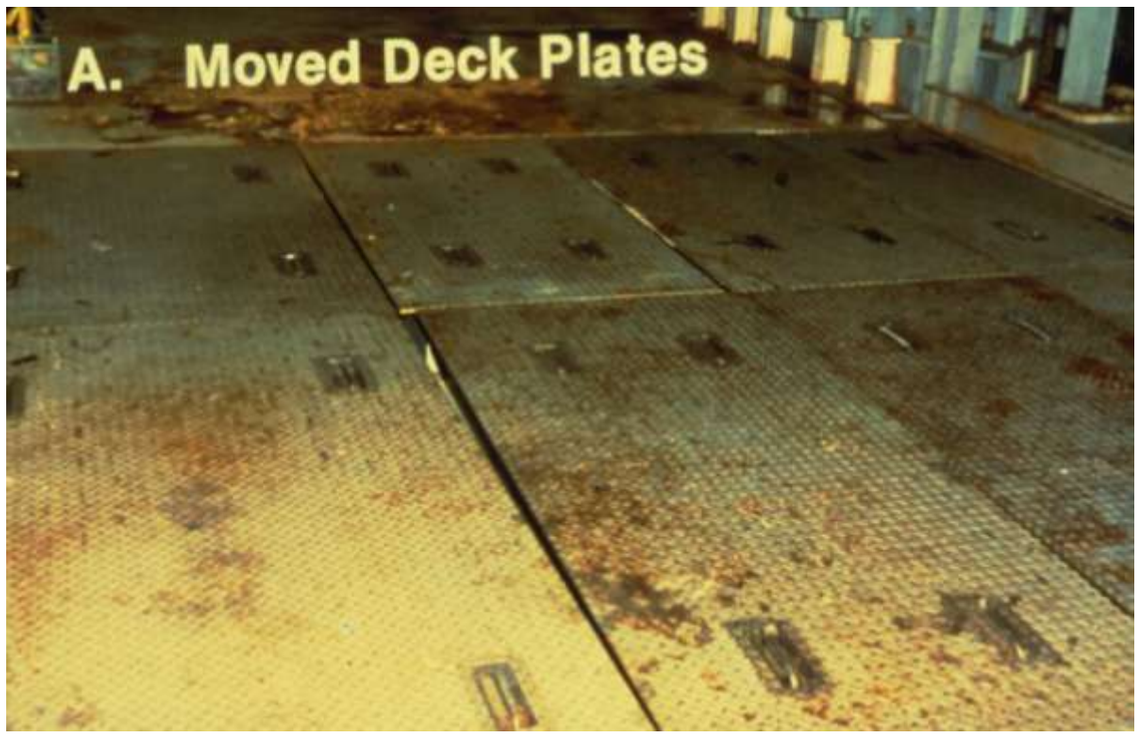
Radiation Safety

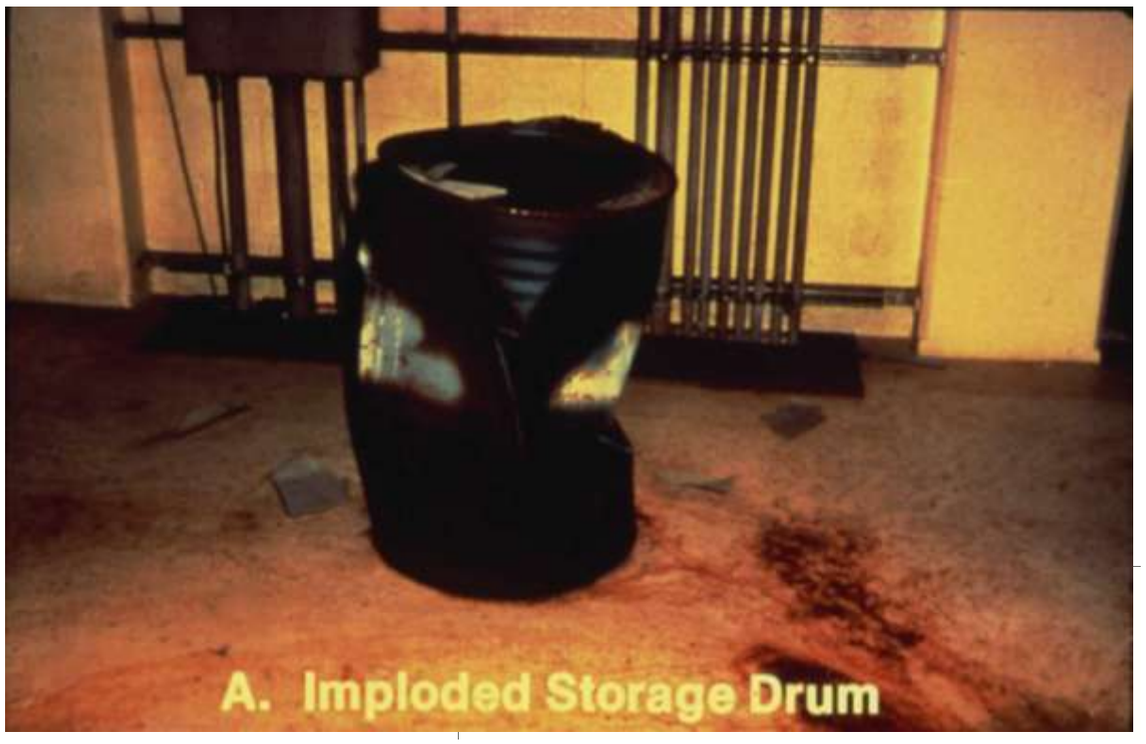


First Manned Entry

Damage from Hydrogen







Stairwell to Basement – Flooded w/ 8-ft of Water

Containment Decontamination

Strippable Coatings

Scabbling

Hydro Lasing

Manual

Robotic

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Other Consequences

- Direct Costs of Recovery – $1 Billion
- TMI-1 6½-Years Before Restart
- Nuclear Industry
  - Backfit & License-Related Costs
  - Many Reactor Orders Cancelled
  - No New Reactor Orders Post-Accident

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THREE MILE ISLAND UNIT 2 (TMI-2)

THE REACTOR

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Accident Summary

- Most Serious Accident in U.S. Commercial Nuclear Power History
- Reactor Core Melted (Not Known at Time)
- Large Releases to Containment Building
- Only Minor Environmental Releases & Consequences
- Profound Effects
  - Utility
  - Nuclear Industry
  - Regulatory Authorities

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TMI-2 Lessons Learned

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TMI-2 Lessons Learned

- Technical Assessment
  - Control Room Redesign
    - Annunciator Prioritization
    - Direct Indication
  - Symptom-Based Procedures
- Worker and Public Health and Safety
- Emergency Planning and Response
  - Off-Site Emergency Operation Center
  - Full Scope Drills/Exercises
- The Public Right to Information

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CHERNOBYL

CHERNOBYL UNIT 4

THE REACTOR

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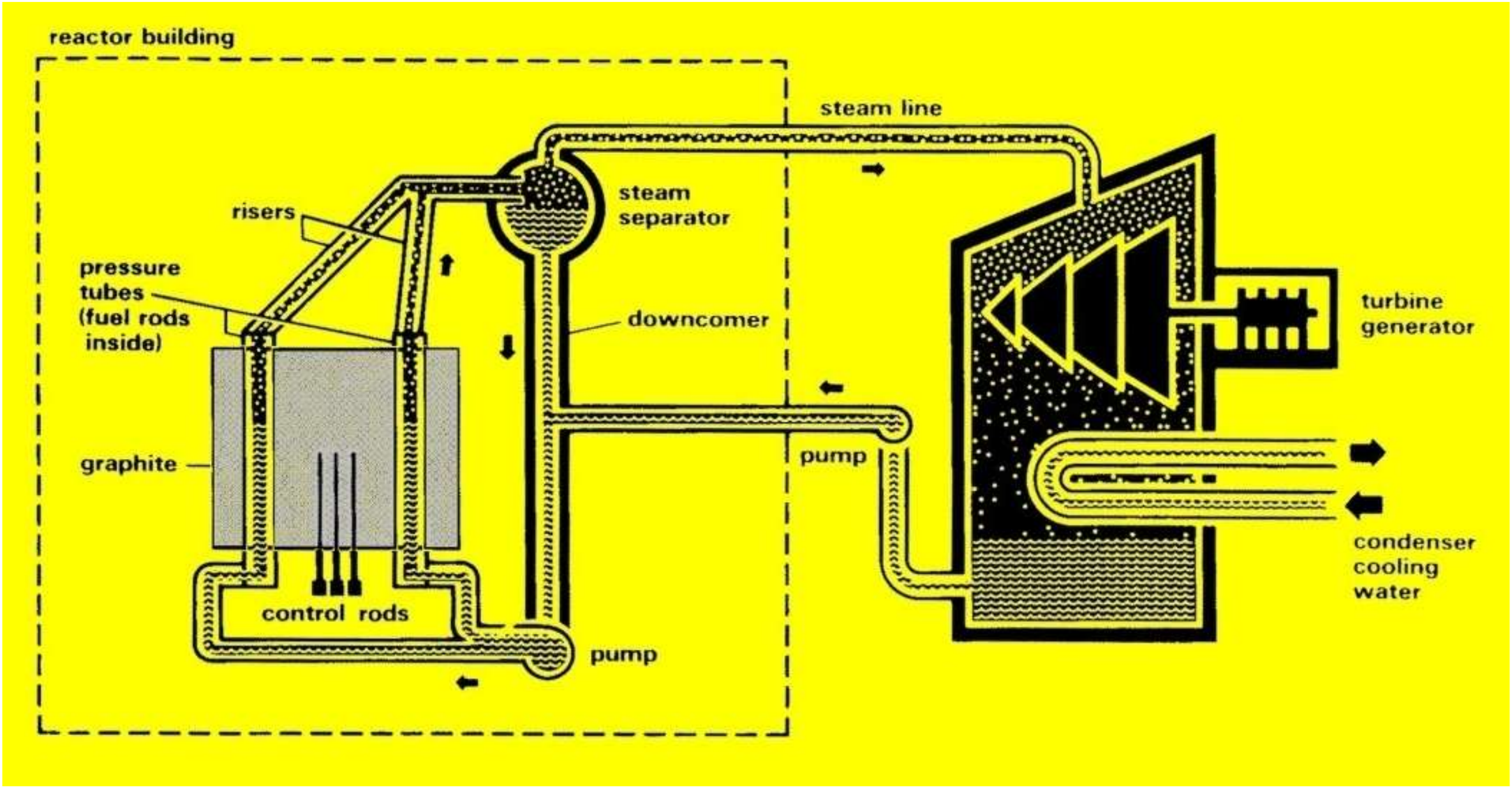
RBMK Reactor



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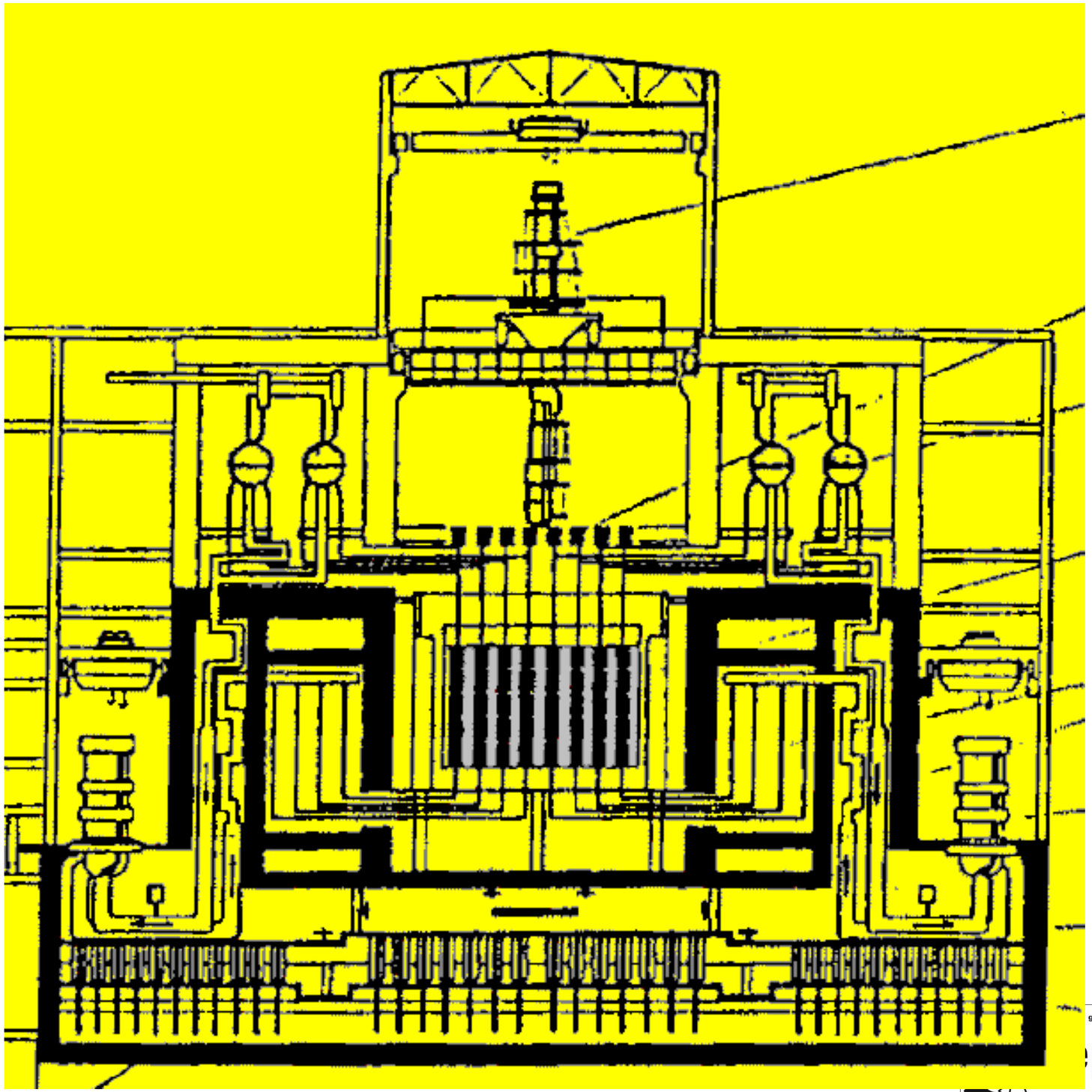
RBMK Reactor



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CHERNOBYL UNIT 4

THE REACTOR

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Background

- Test to be Conducted
  - Provide Emergency Electrical Power
  - Use Turbine “Coast-Down” Power
  - Difficulty / Timing
- Test Plan
  - Preparer Not Familiar w/ RBMK-1000
  - Review Requirements Not in Place

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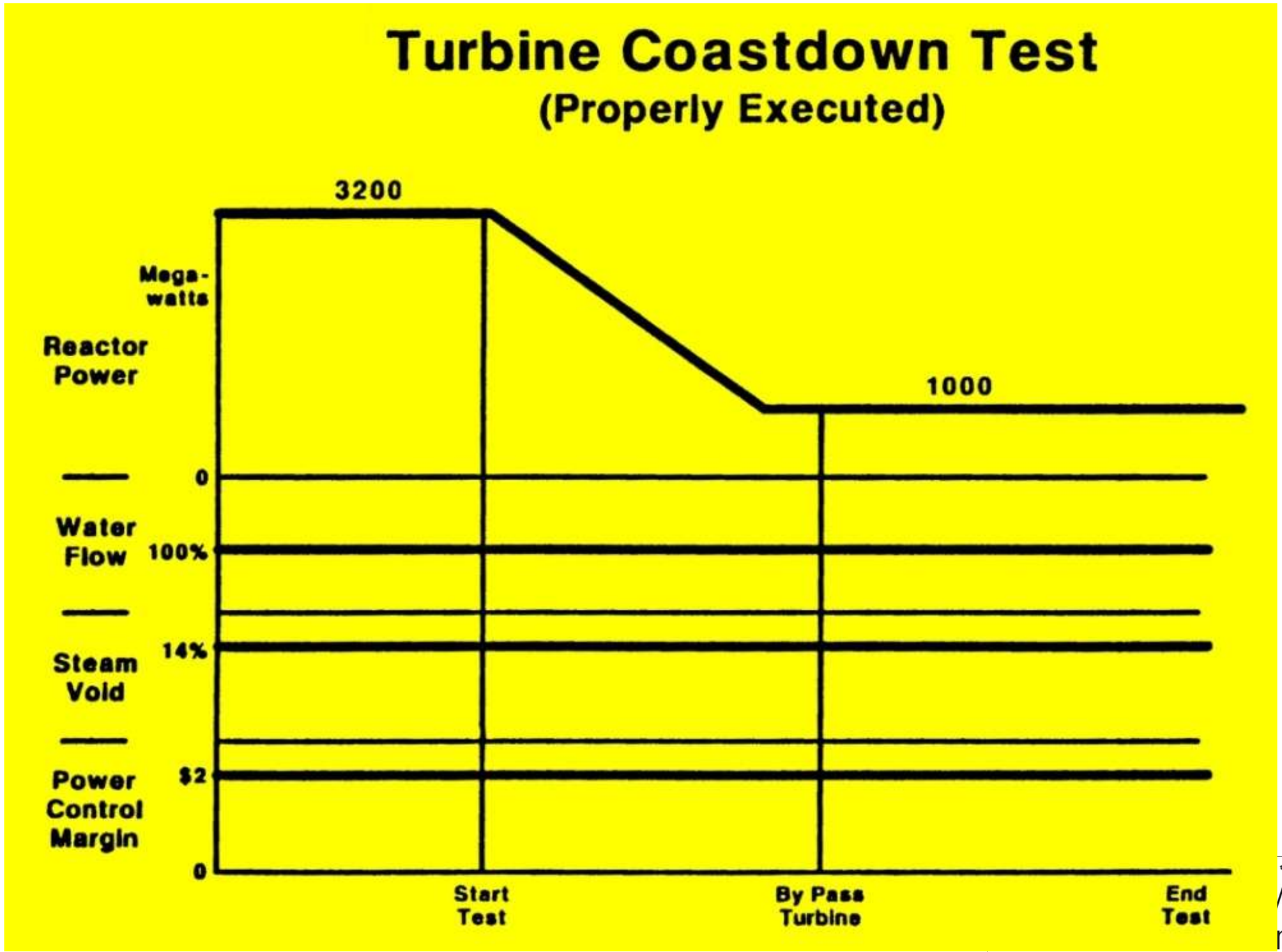
Test Plan



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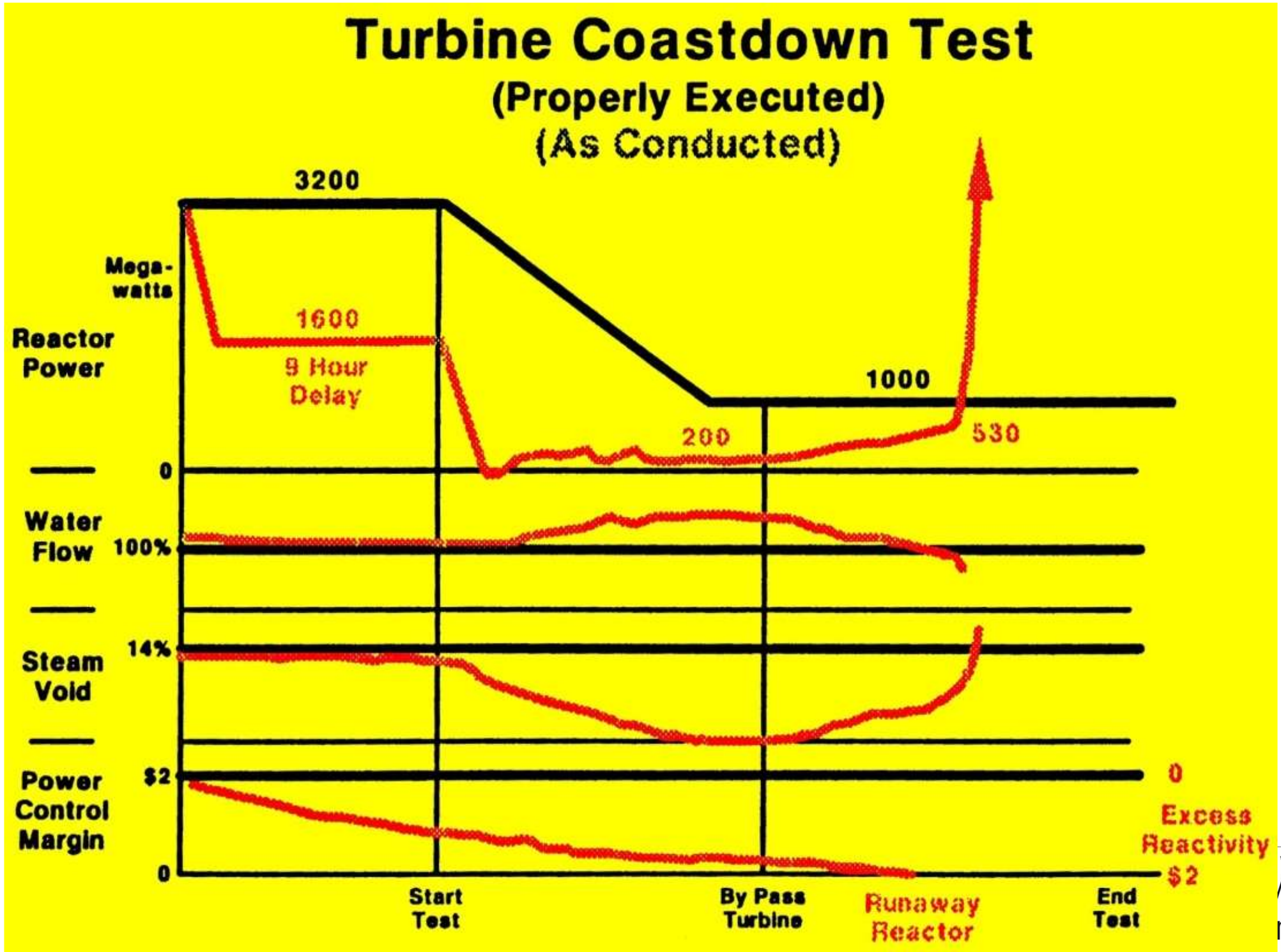
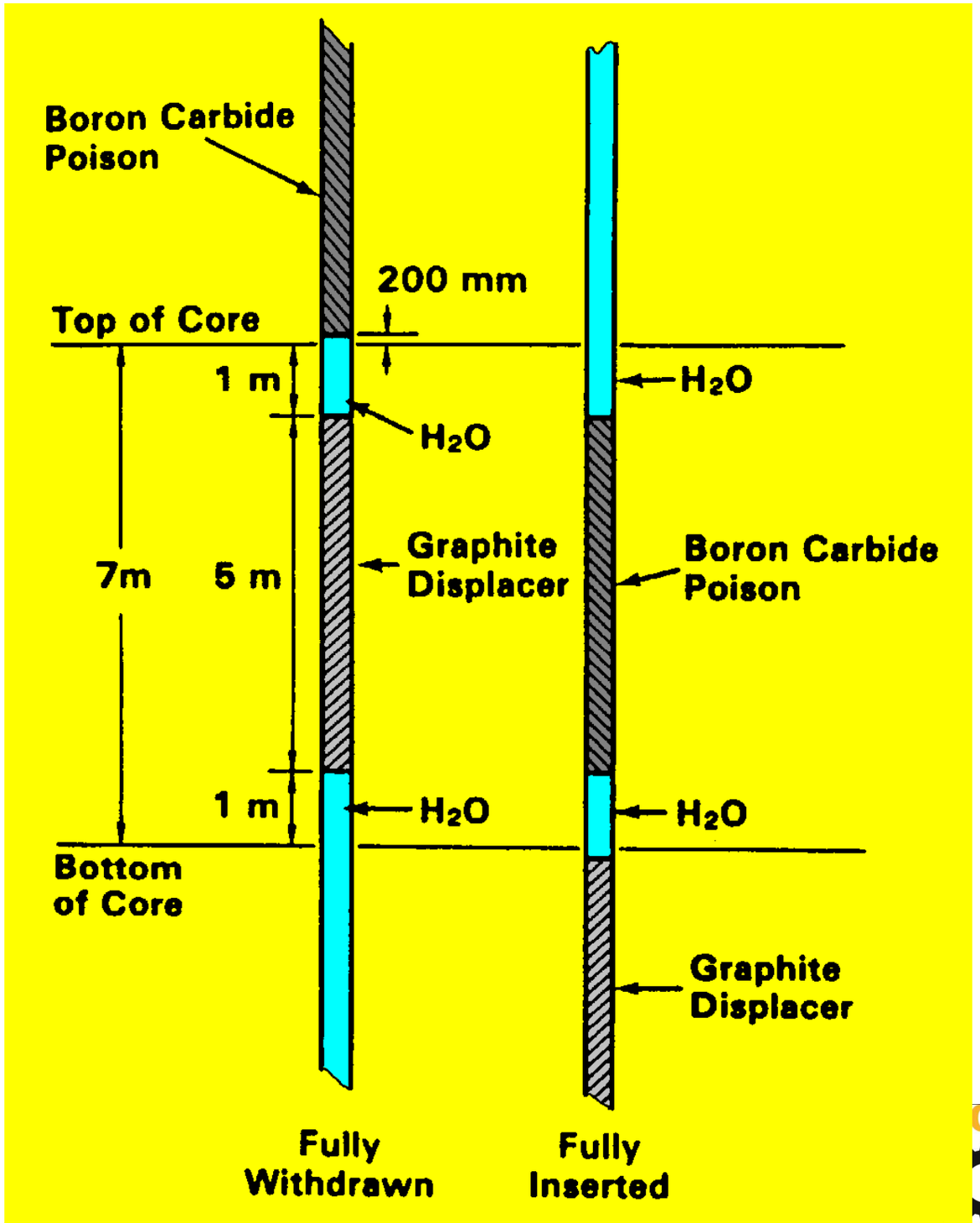
The Accident



th University
Mechanical
ngineering

The Accident



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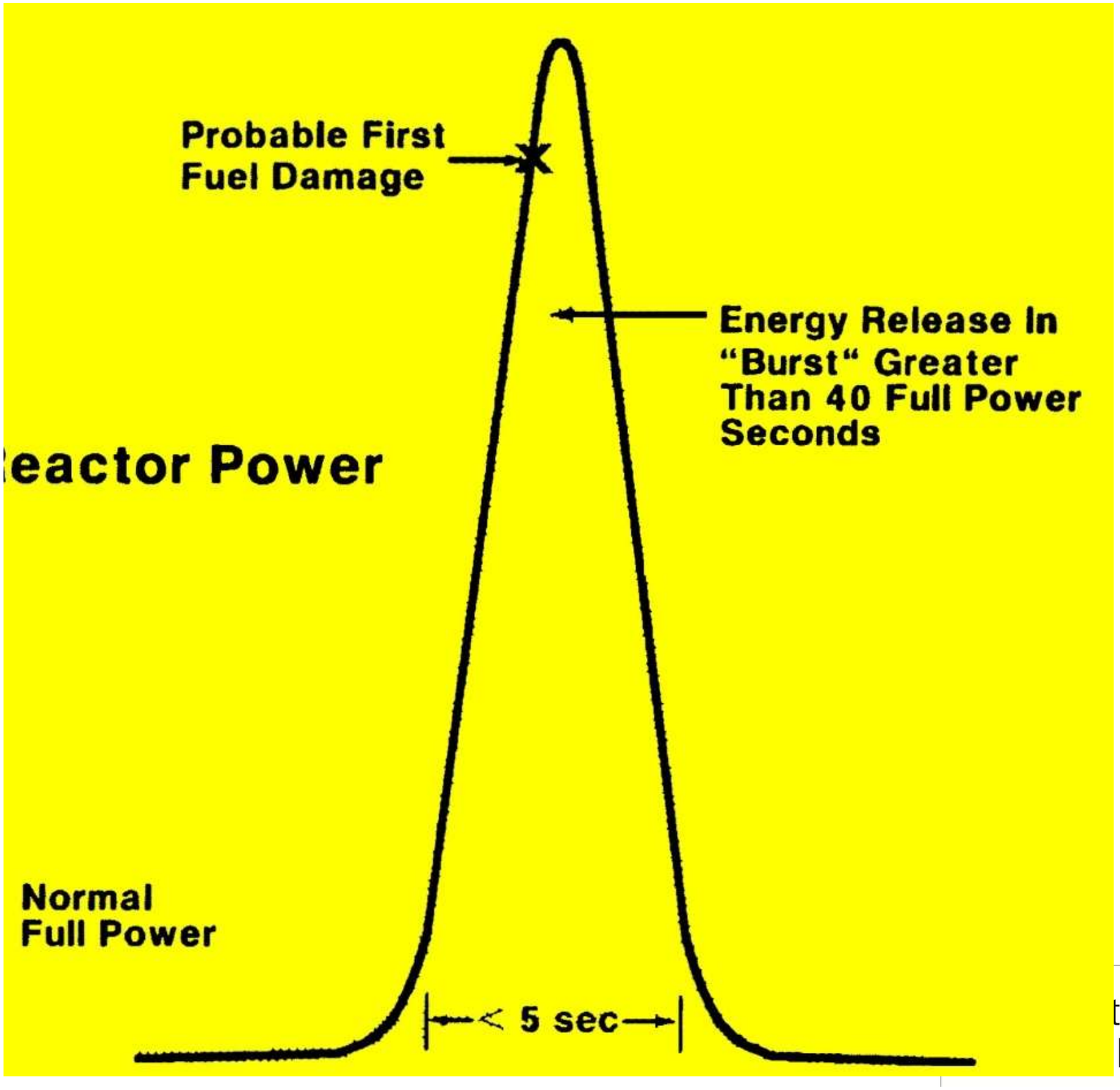

The Accident

CHERNOBYL UNIT 4

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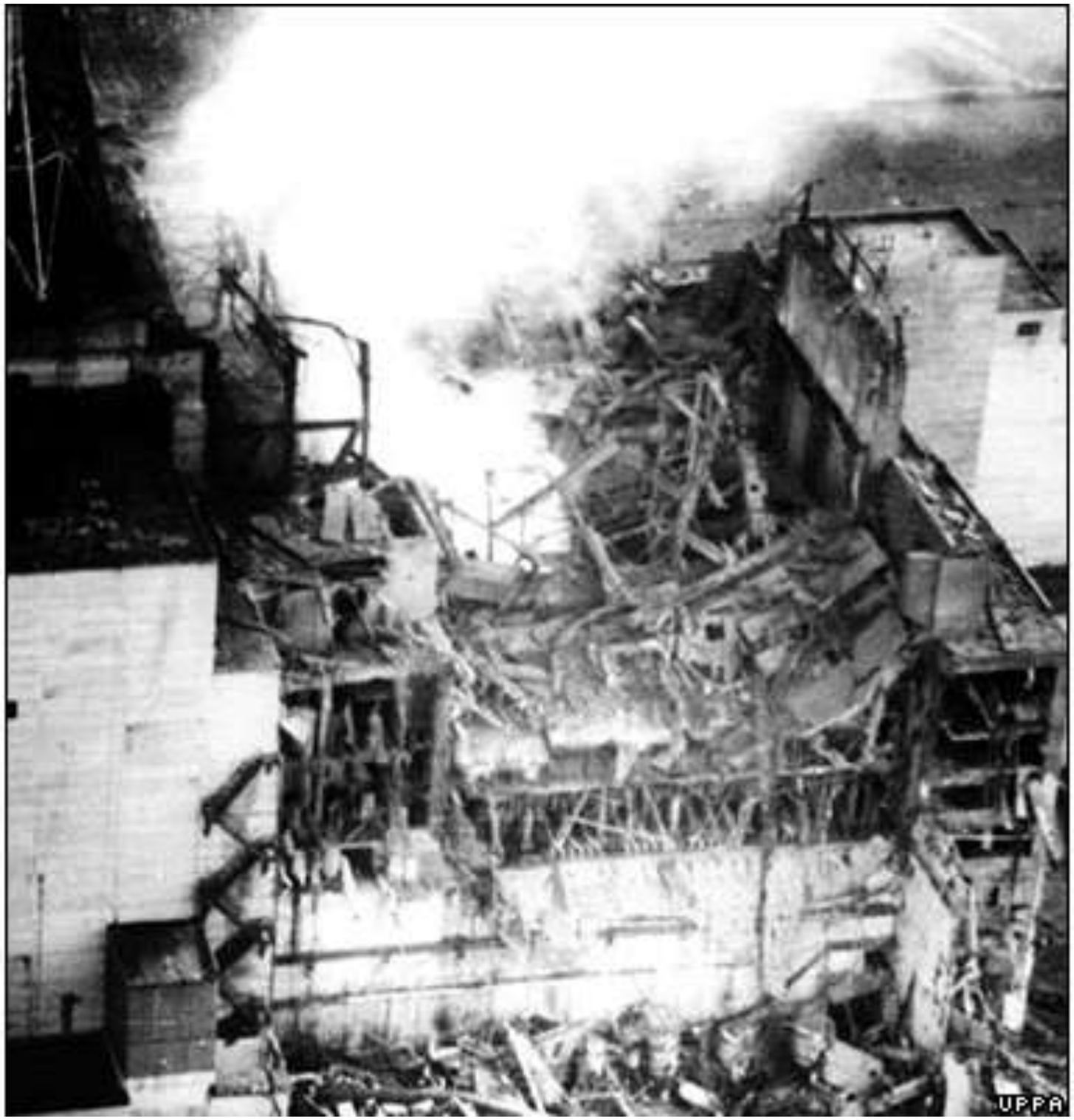
The Consequences



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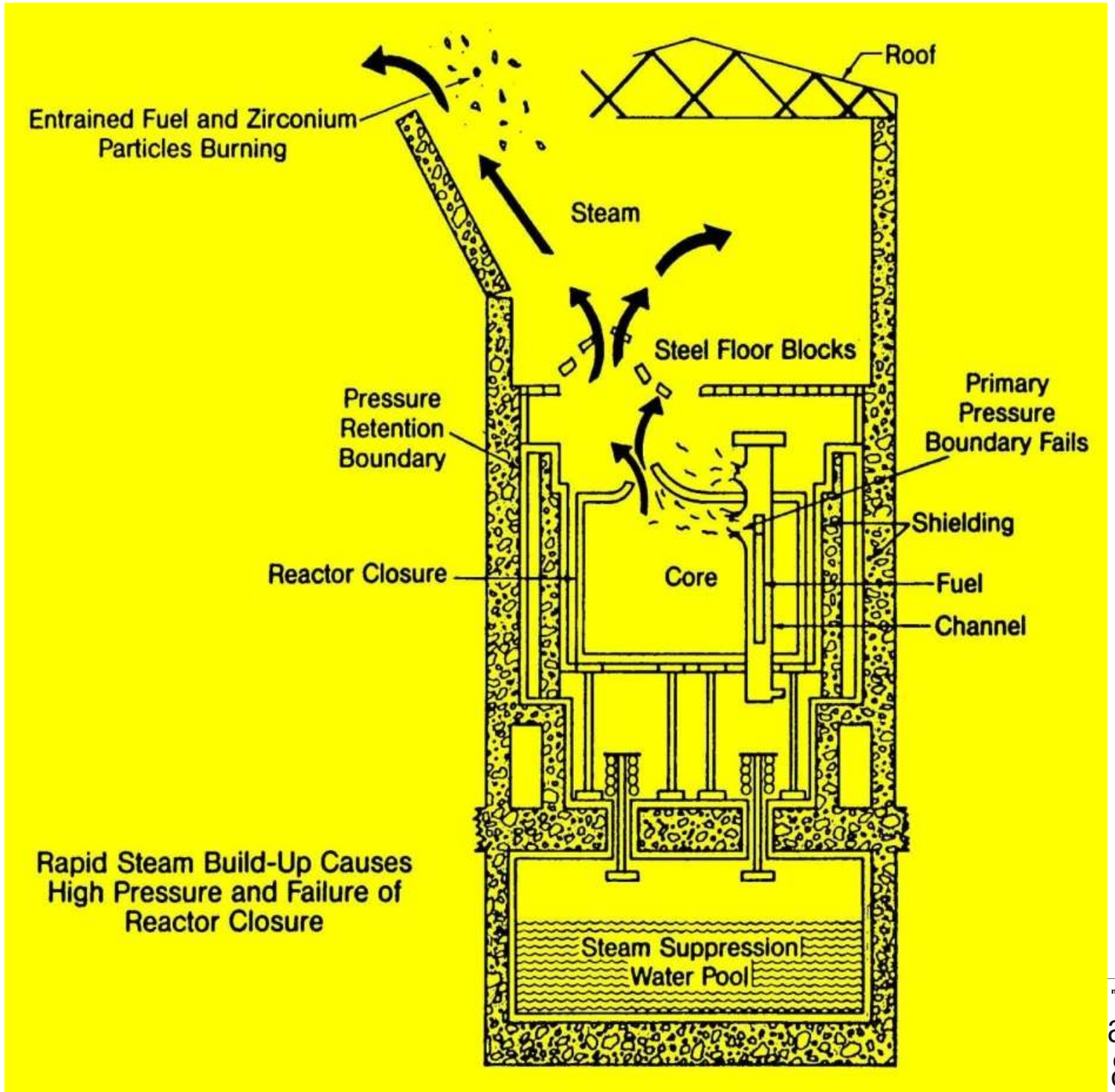
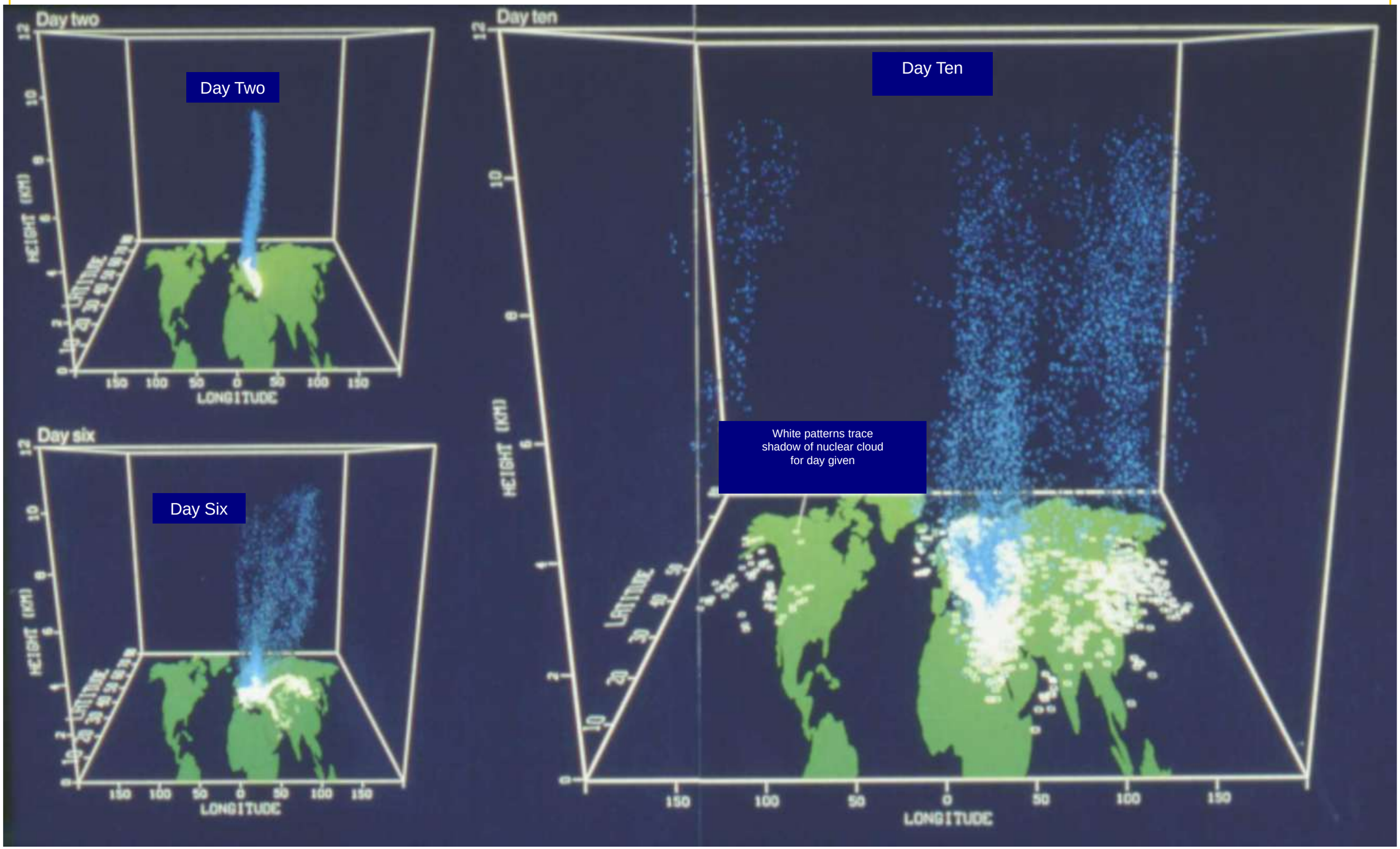
The Consequences



Evacuation

Radiological Release



Radiological Release

Comparison of Chernobyl & TMI-2
Accident Source Terms

Constituent	Chernobyl	TMI-2
Noble Gases	100%	< 8 %
Iodine	40% (20 MCi)	$< 2x10^{-5}$ % (18 Ci)
Cs	25%	--
Te	>10%	--
Particulate	3-6%	--

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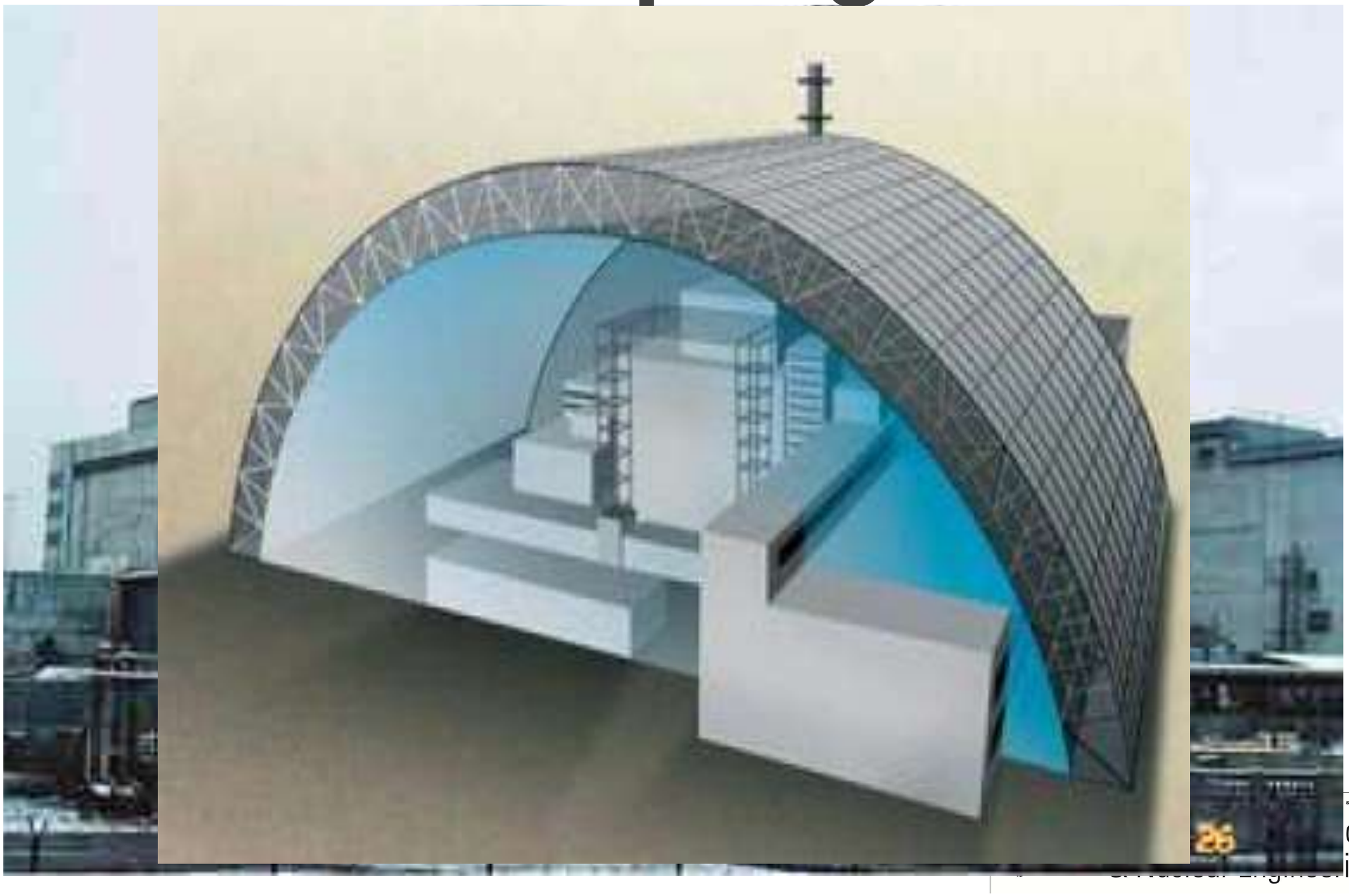
Fire Fighter Memorial

Molten Fuel
“Elephant’s Foot”

niversity
hanical
neering

Sarcophagus



CHERNOBYL UNIT 4

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Lessons Learned

- Most Significant Lesson →
  - Importance of Learning from Experience
  - Soviet Precursors at Kursk (1980) & Perhaps Leningrad
  - *Failure to Evaluate TMI-2 Lessons Learned*
- Initial Soviet Evaluation →
  - Operator Error
- World Evaluation Added →
  - **Design Management Systems**

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Lessons Learned

- Operator Error
- Design Deficiencies
- Management System Deficiencies
- Inadequate Safety Culture
- International Perspective

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TRAGEY HAS
INDUCED
CAUTION

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Fukushima - Daiichi

Fukushima - Daiichi

THE REACTORS

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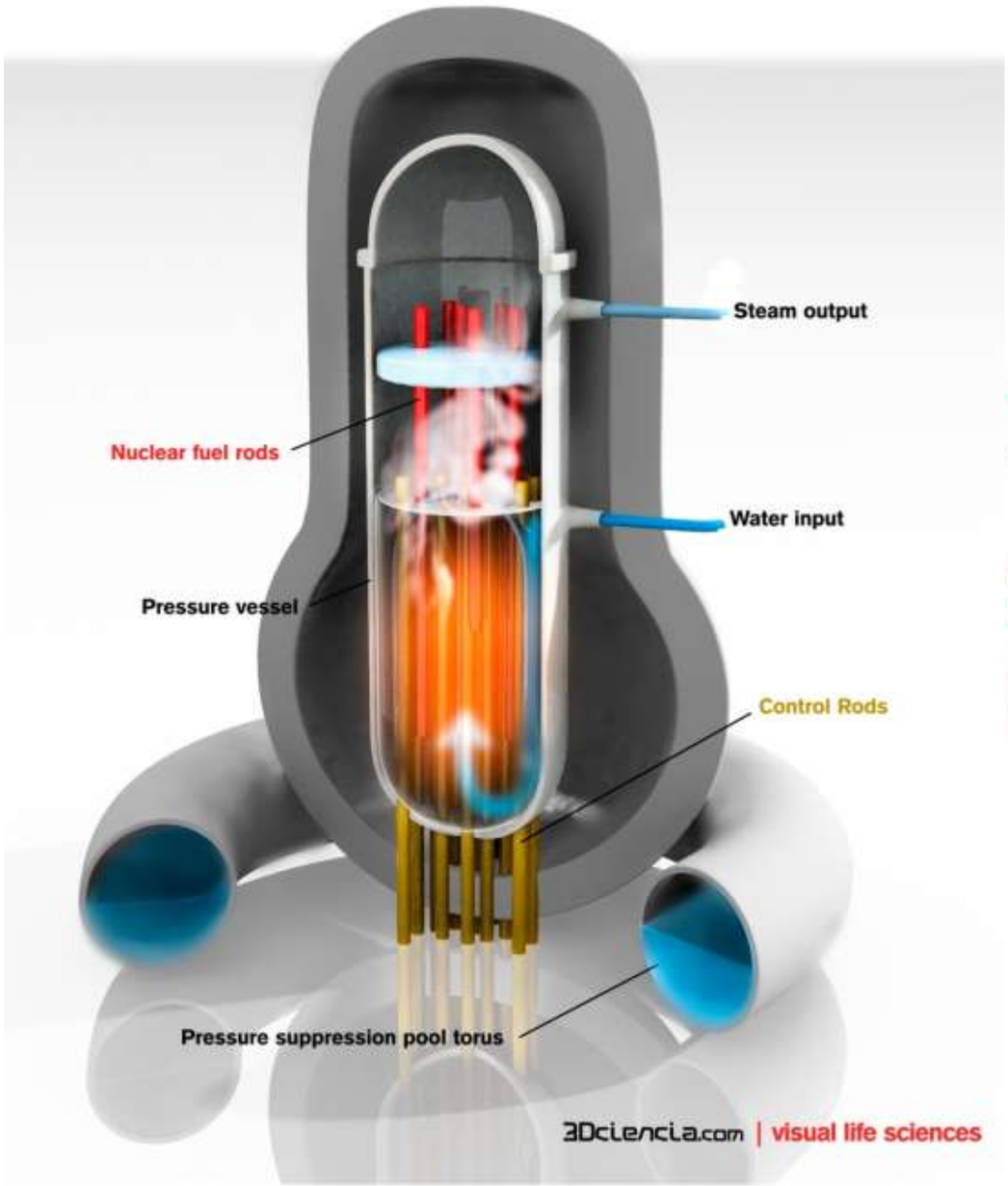
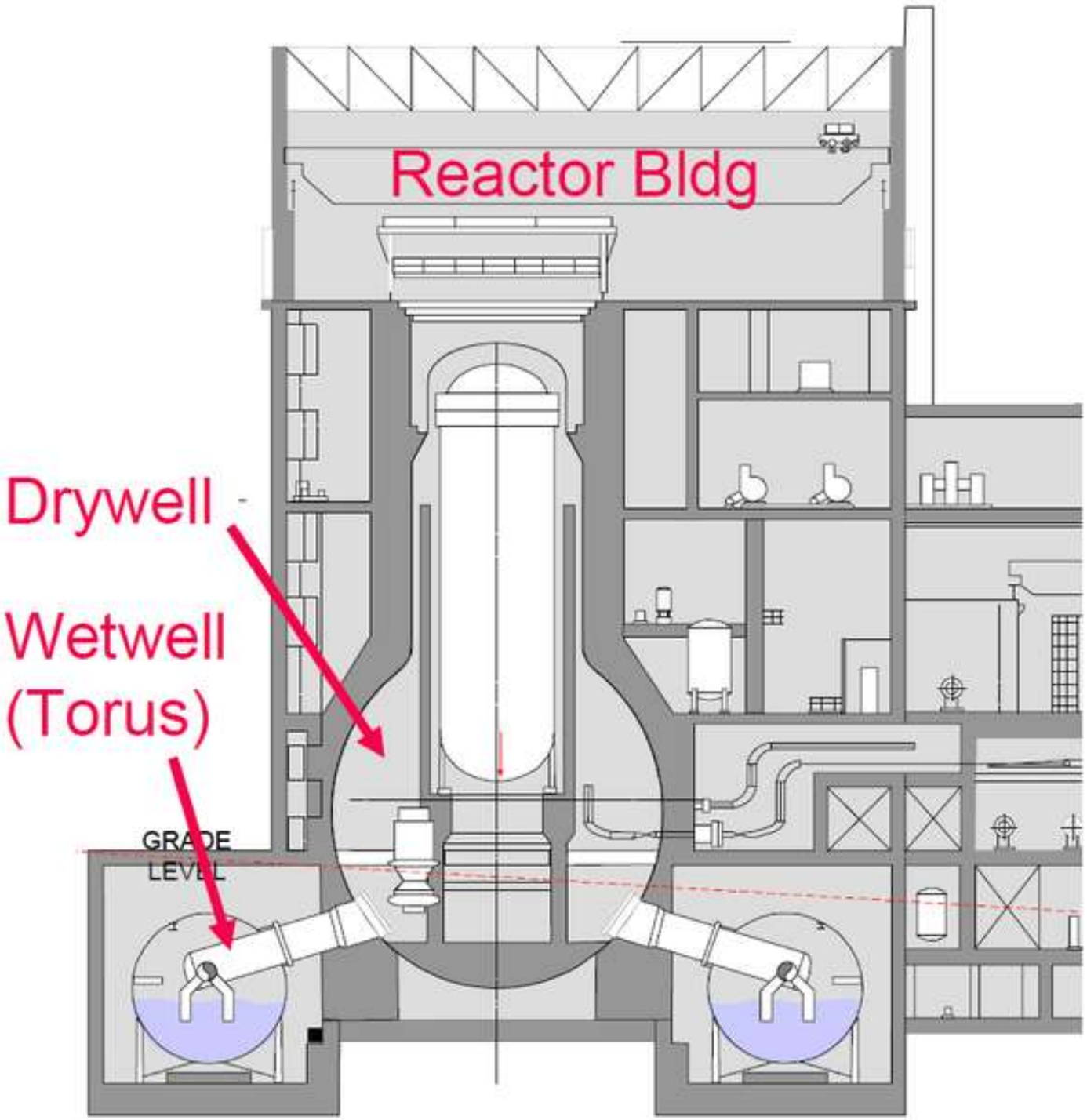
Reactor: BWR


Steam output
Nuclear fuel rods
Water input
Pressure vessel
Control Rods
Pressure suppression pool torus
3Dciencia.com | visual life sciences


Reactor Bldg
Drywell
Wetwell
(Torus)
GRADE
LEVEL

Fukushima - Daiichi

THE REACTOR

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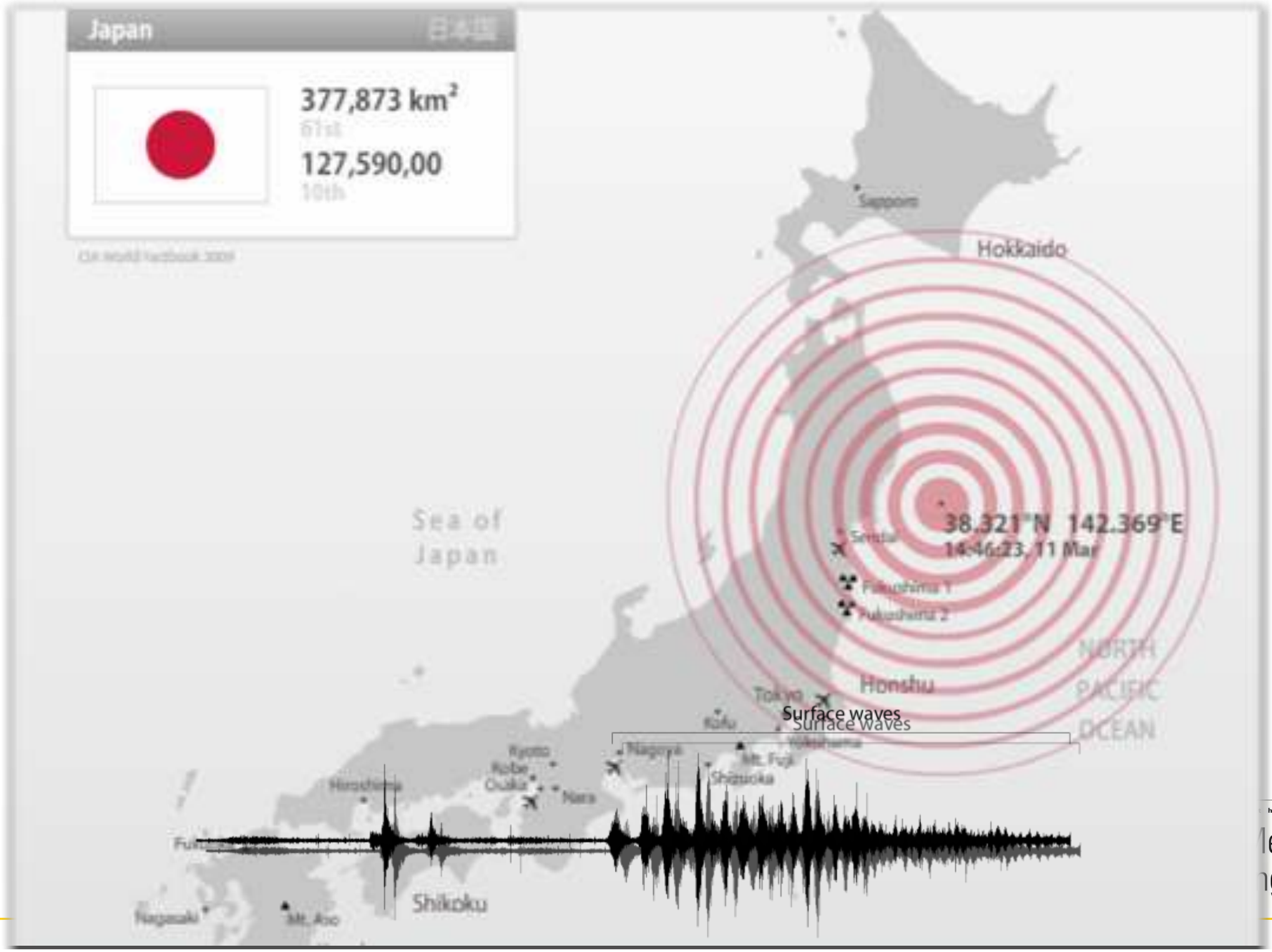
Tohoku Earthquake

Tohoku Earthquake

Tohoku Earthquake

11 March 2011 – 14:46



Ground Acceleration

Nr.	MWe	3.11 Observed (max. gal)			Design (Ss) (max. gal)		
		N-S	E-W	Vertical	N-S	E-W	Vertical
1Fuku1	460	460	447	258	487	489	412
1Fuku2	784	346	550	302	441	438	420
1Fuku3	784	322	507	231	449	441	429
1Fuku4	784	281	319	200	447	445	422
1Fuku5	784	311	548	256	452	452	427
1Fuku6	1100	298	444	244	445	448	415

GAL = galileos

gal to g's

100 gal = 0.102 g's

VA Earthquake
Highest Acceleration:
≈ 120 gal

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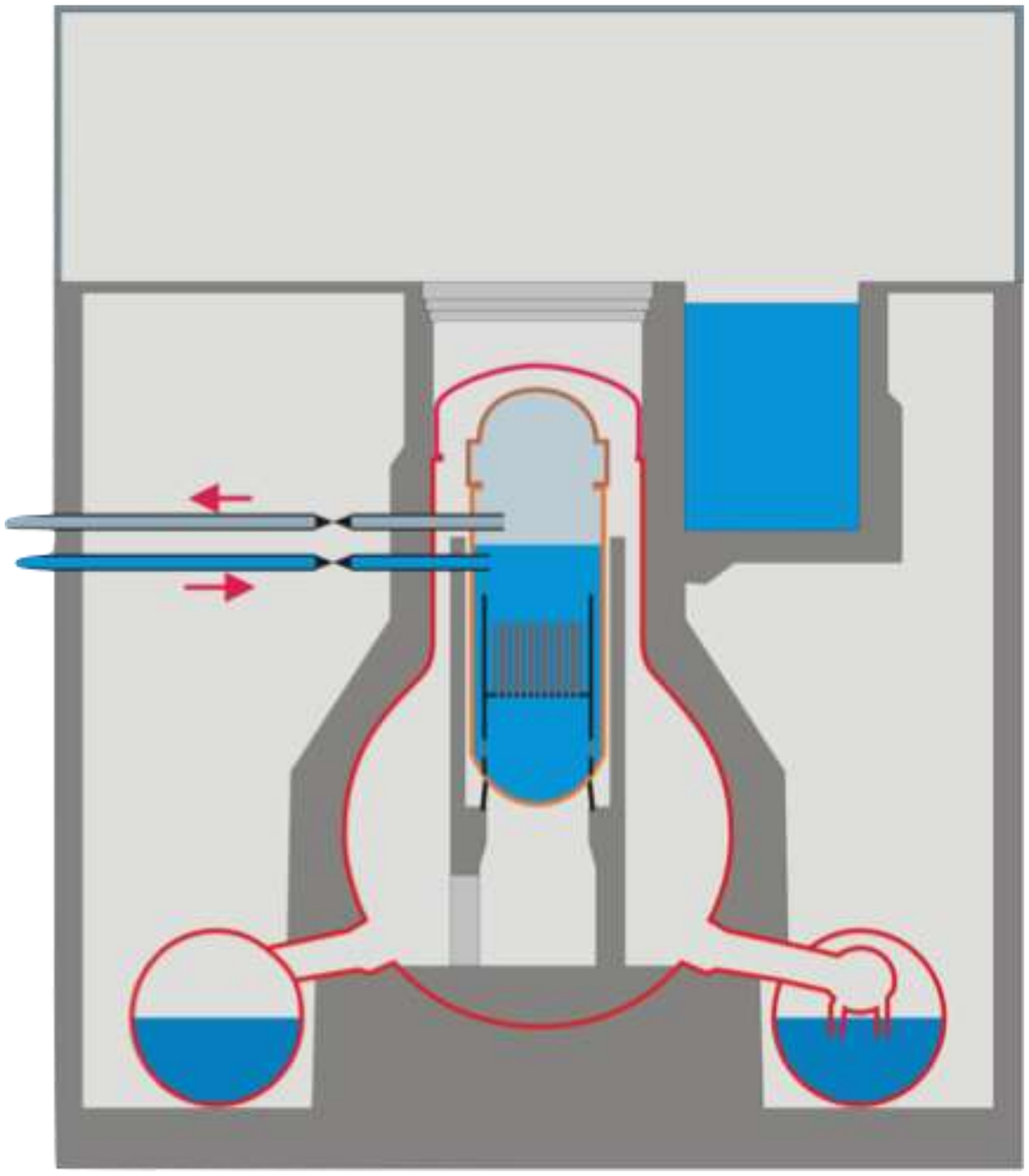
Acceleration Damage

SHUTDOWN / TRIP

- Cuts off turbine building
- Diesel generators start
- Emergency core cooling systems are supplied
- Plant is in a stable safe state



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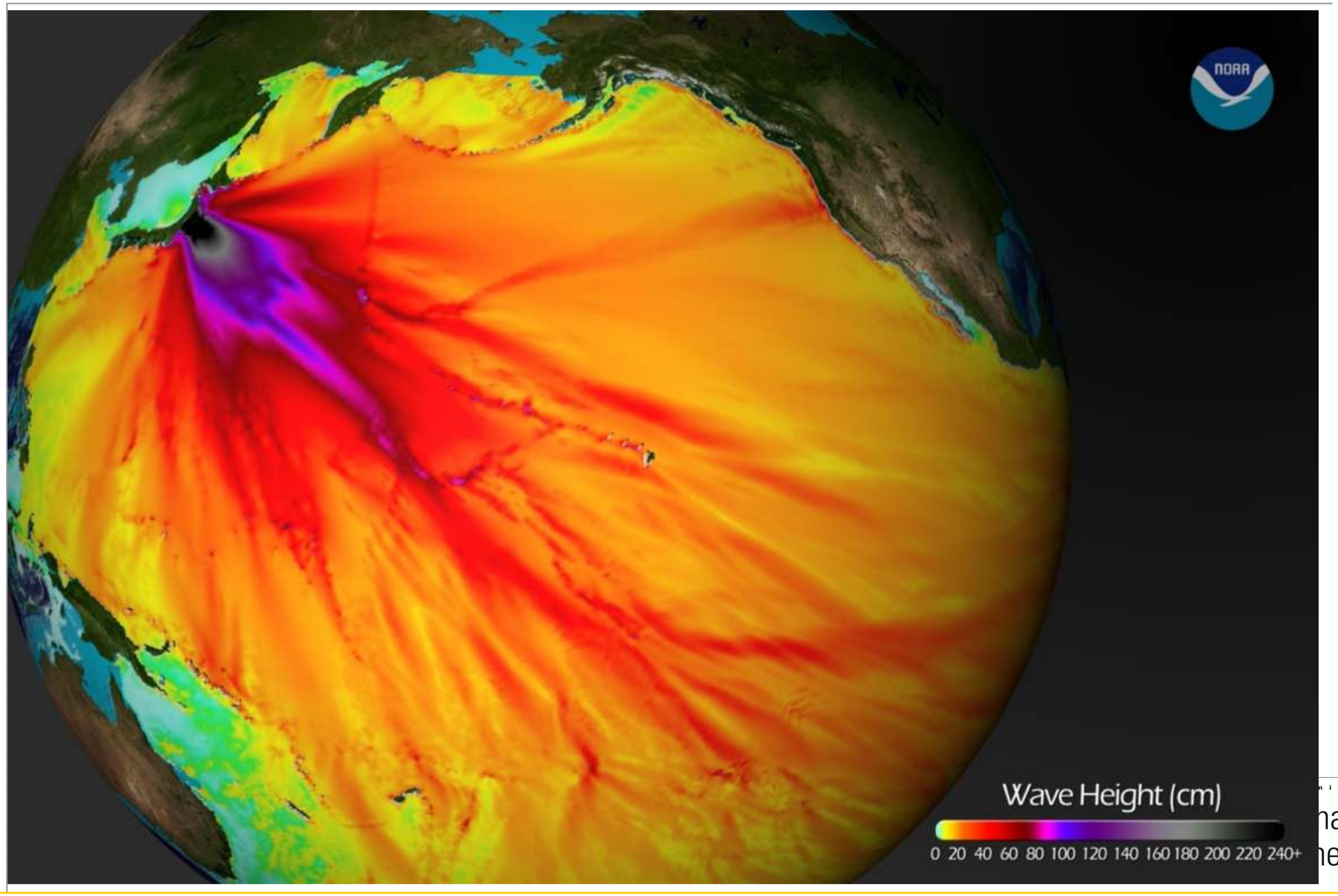
Tsunami



Tsunami

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Tsunami

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Tsunami

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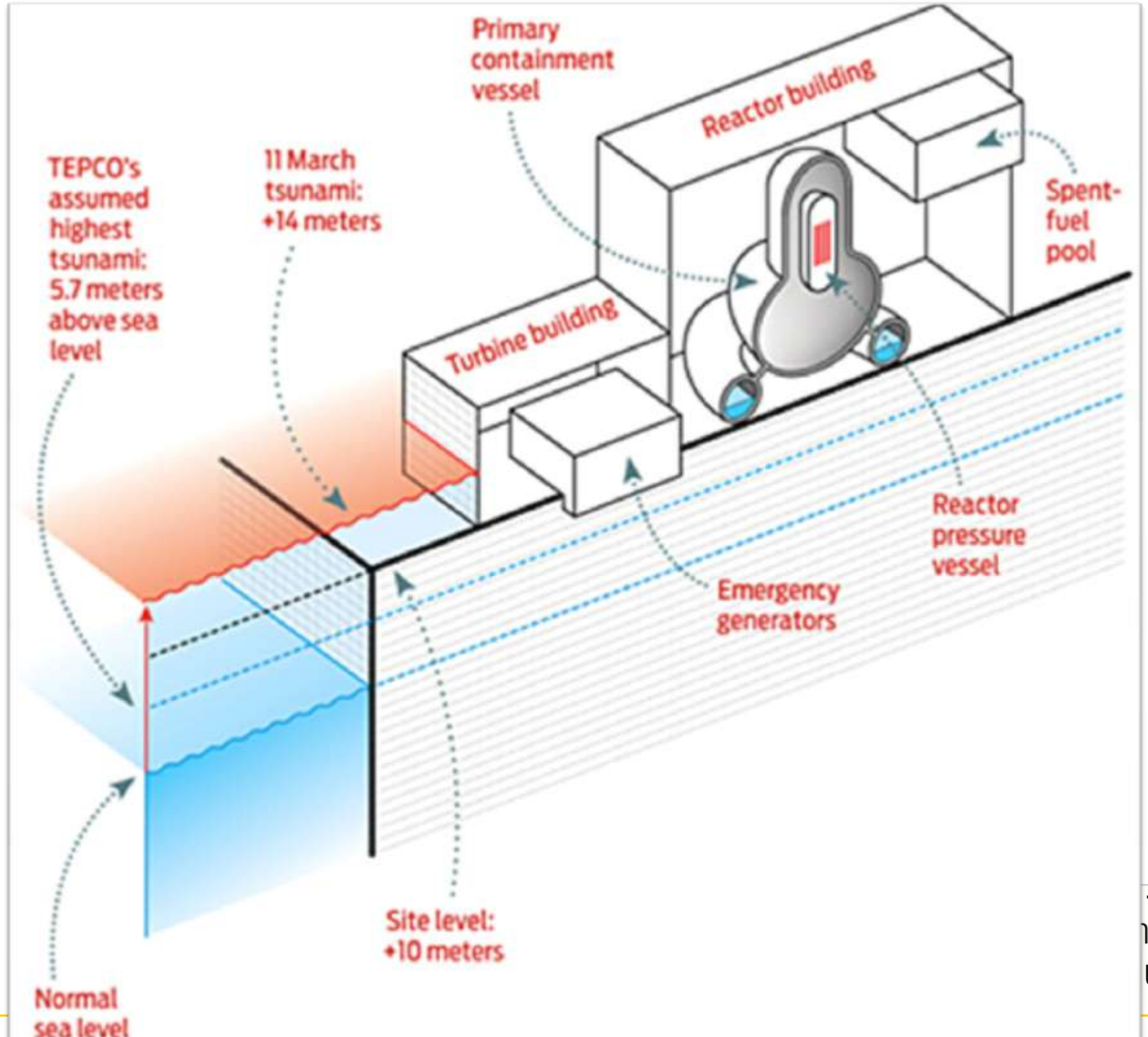
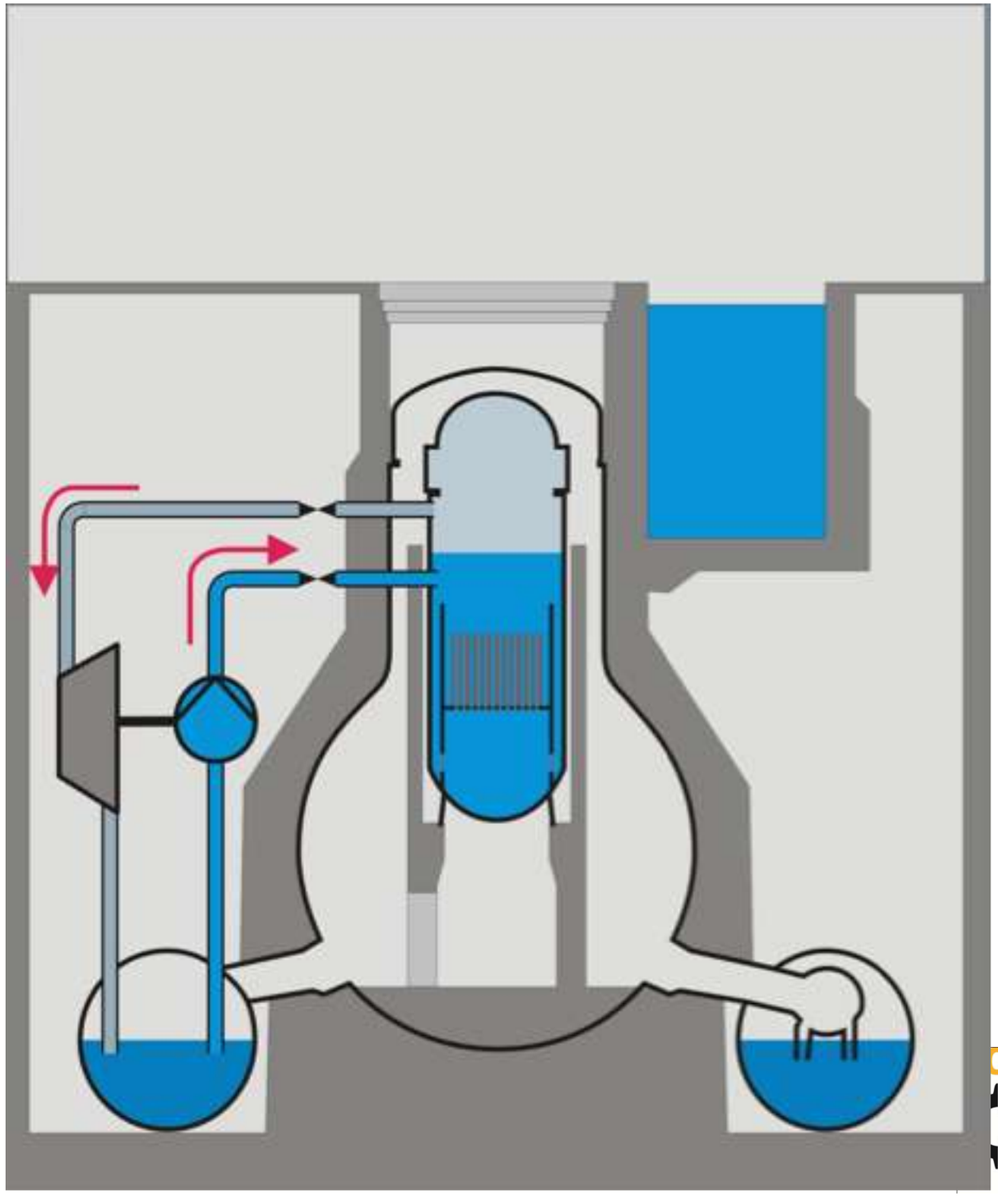

Primary containment vessel
Reactor building
TEPCO's assumed highest tsunami: 5.7 meters above sea level
11 March tsunami: +14 meters
Turbine building
Spent-fuel pool
Reactor pressure vessel
Emergency generators
Site level: +10 meters
Normal sea level

Accident Progression

- Pla
  - up
- Act
  m
- Flo
- Ess
  Bui
- Sta
- Fai
  em
  sys

Accident Progression



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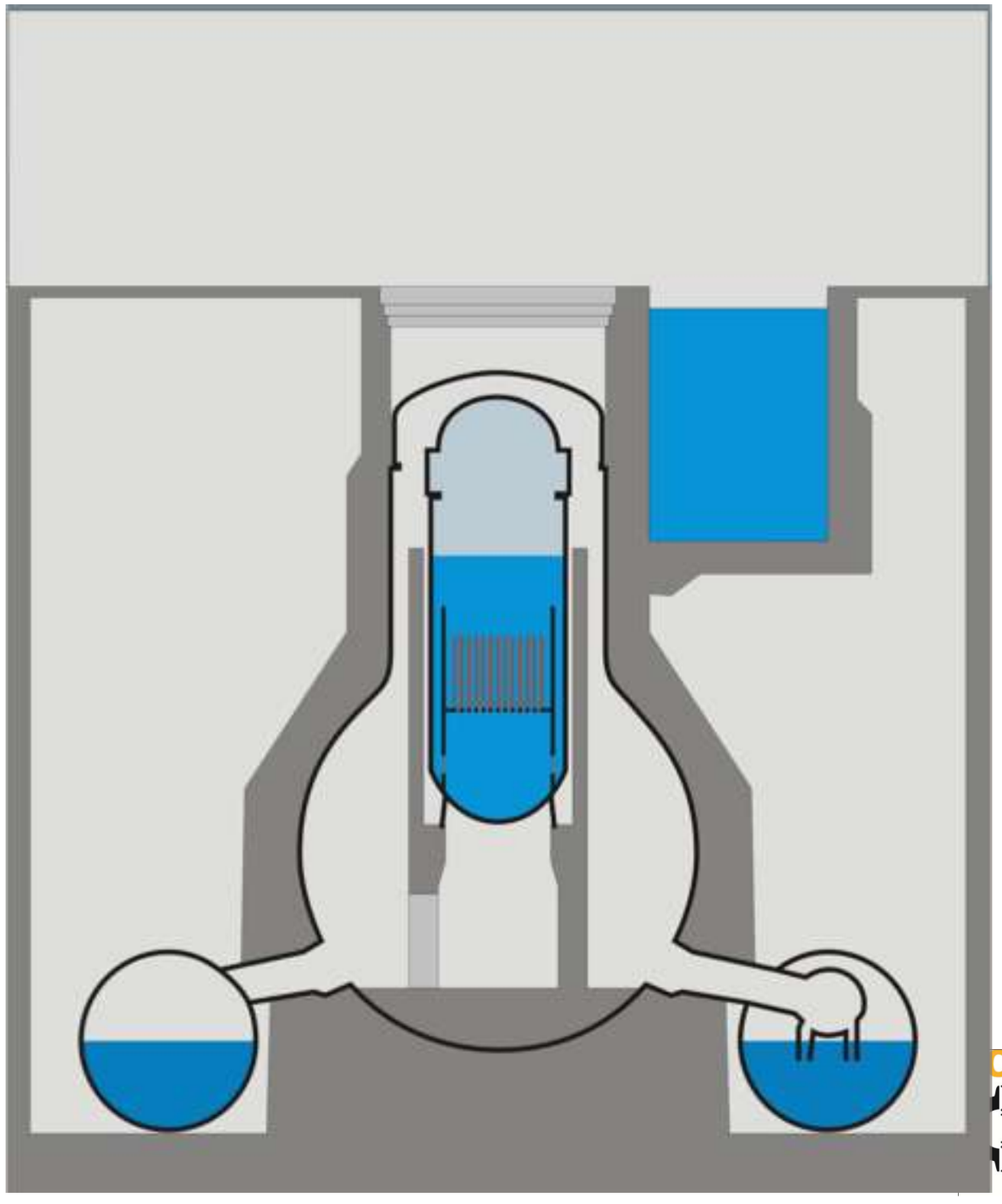
Accident Progression



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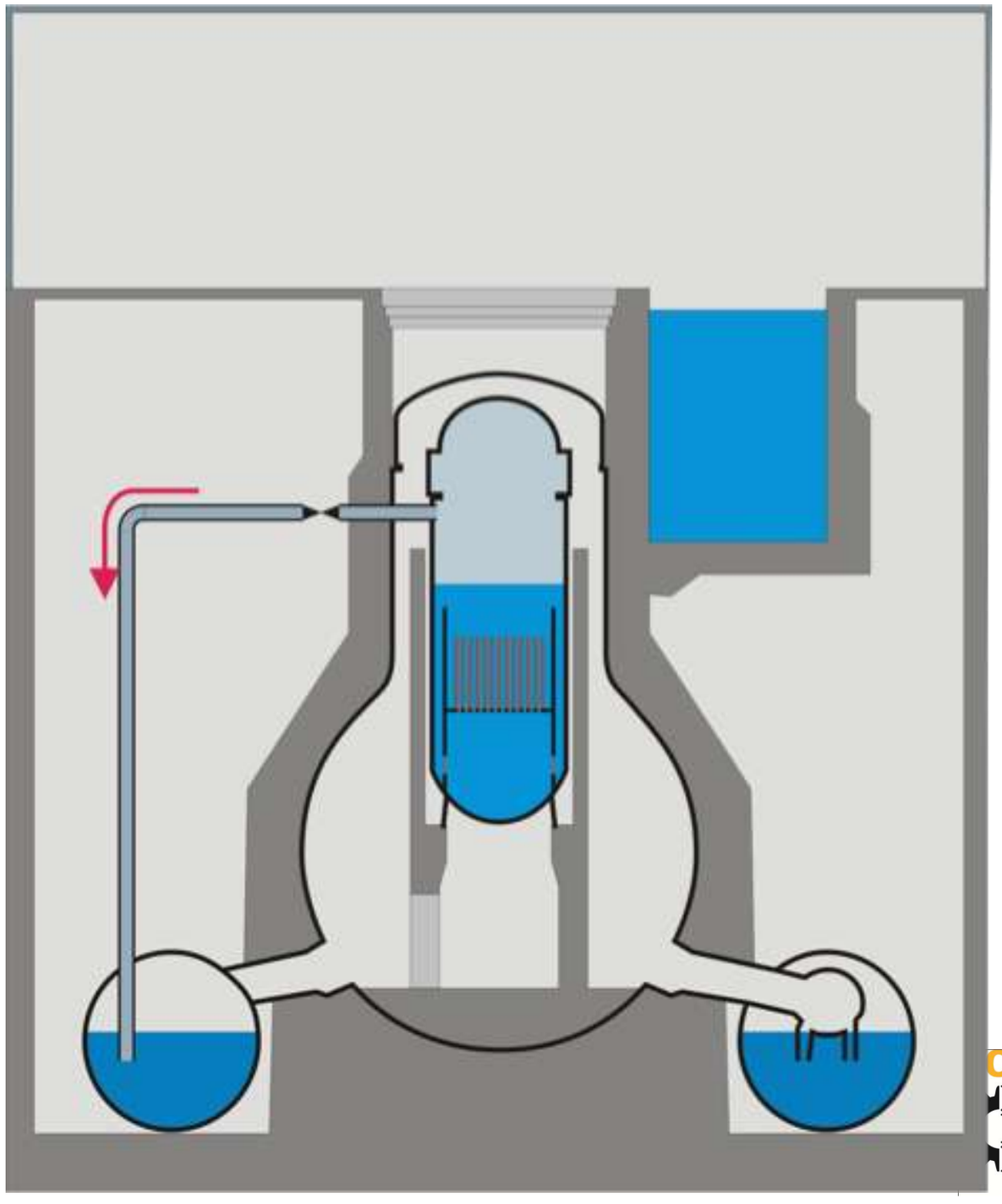
Accident Progression



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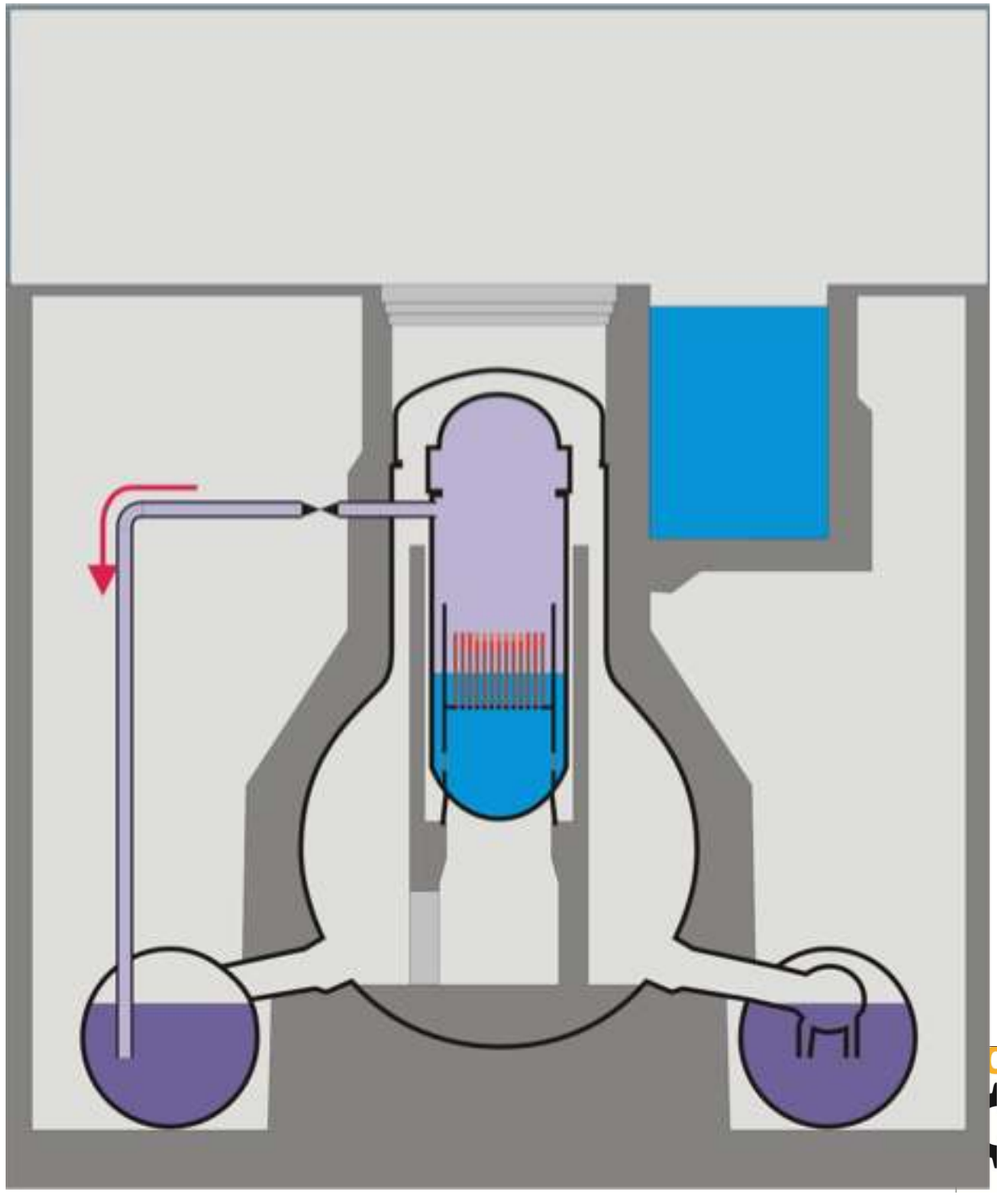
Accident Progression



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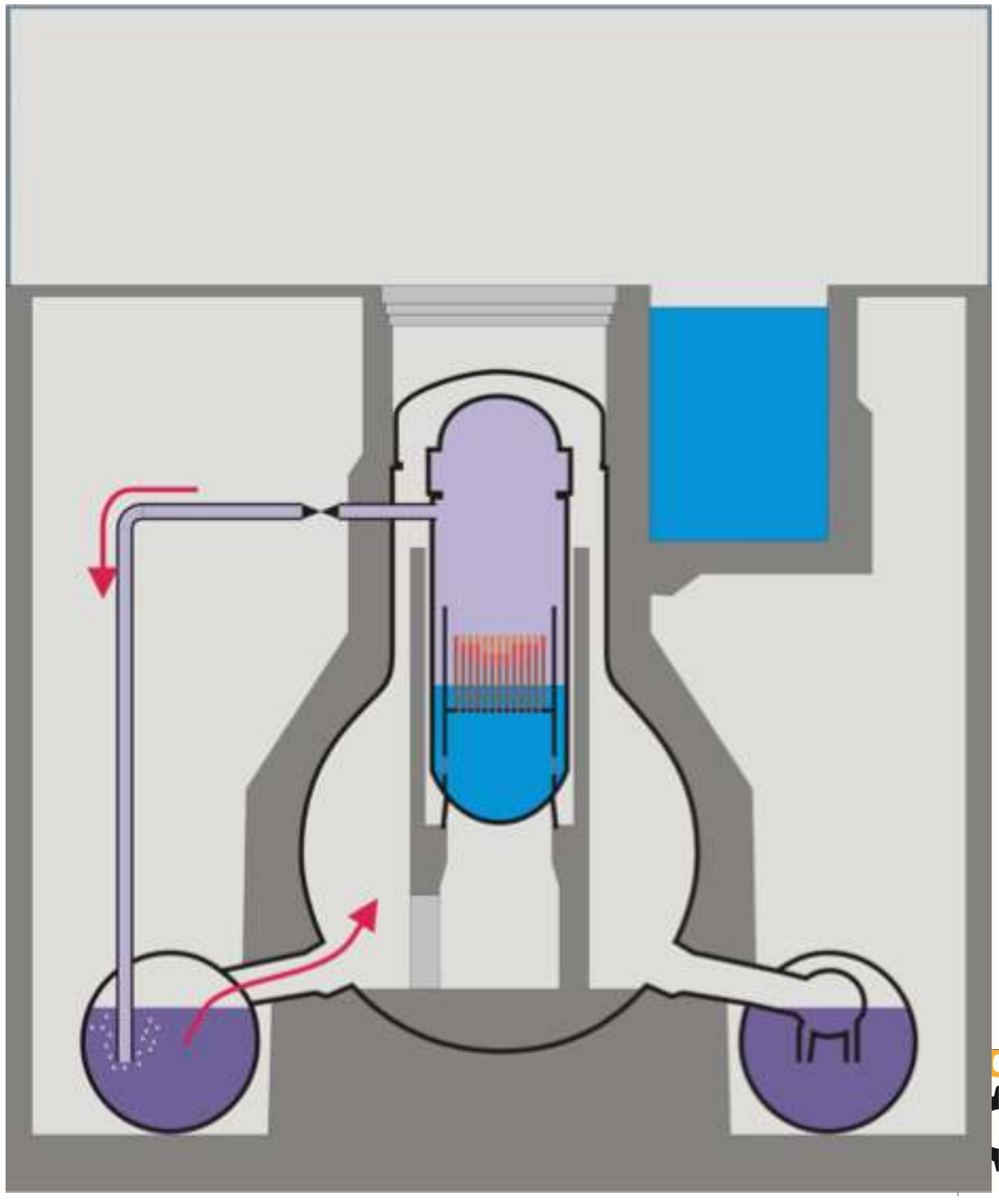
Accident Progression



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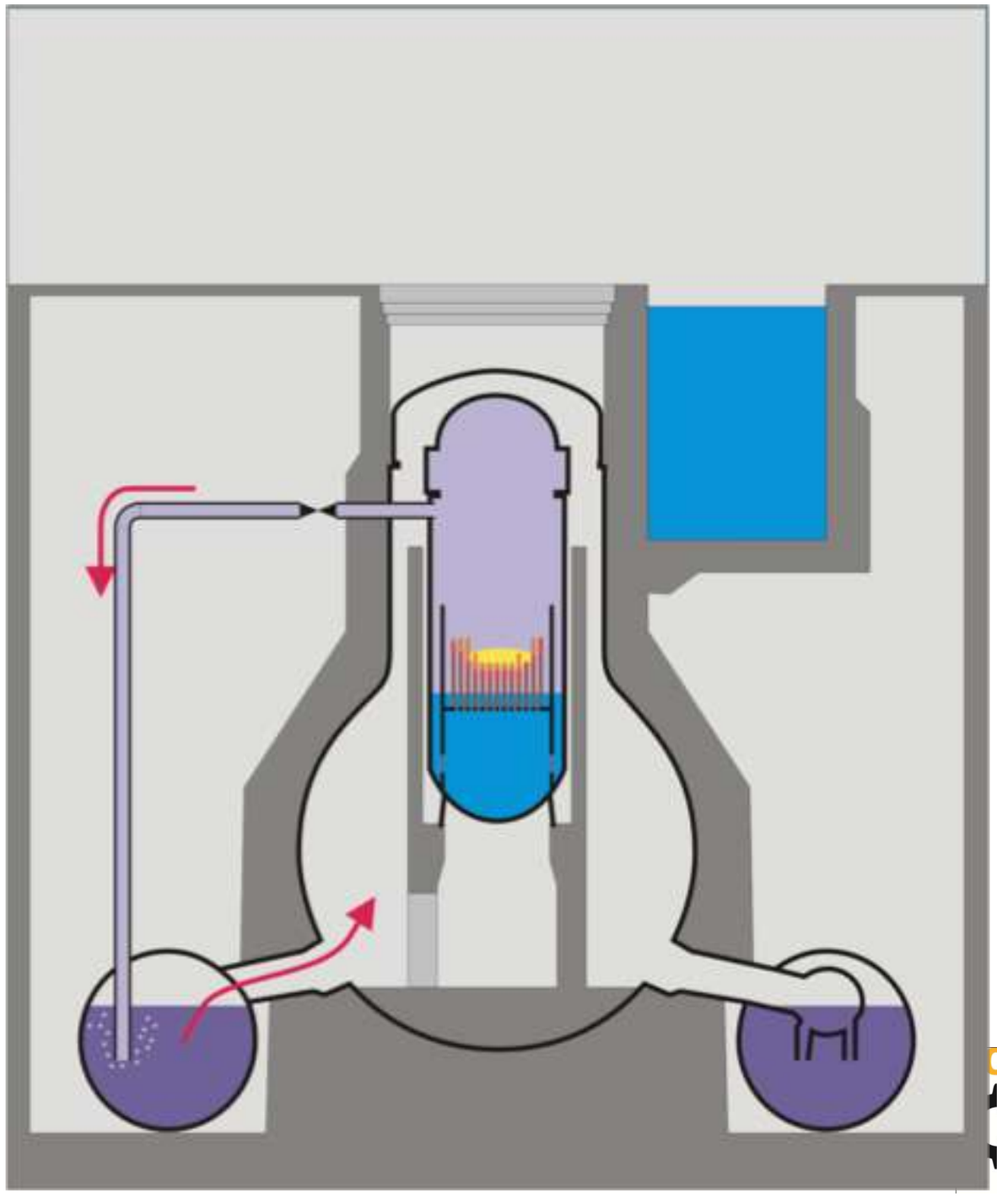
Accident Progression



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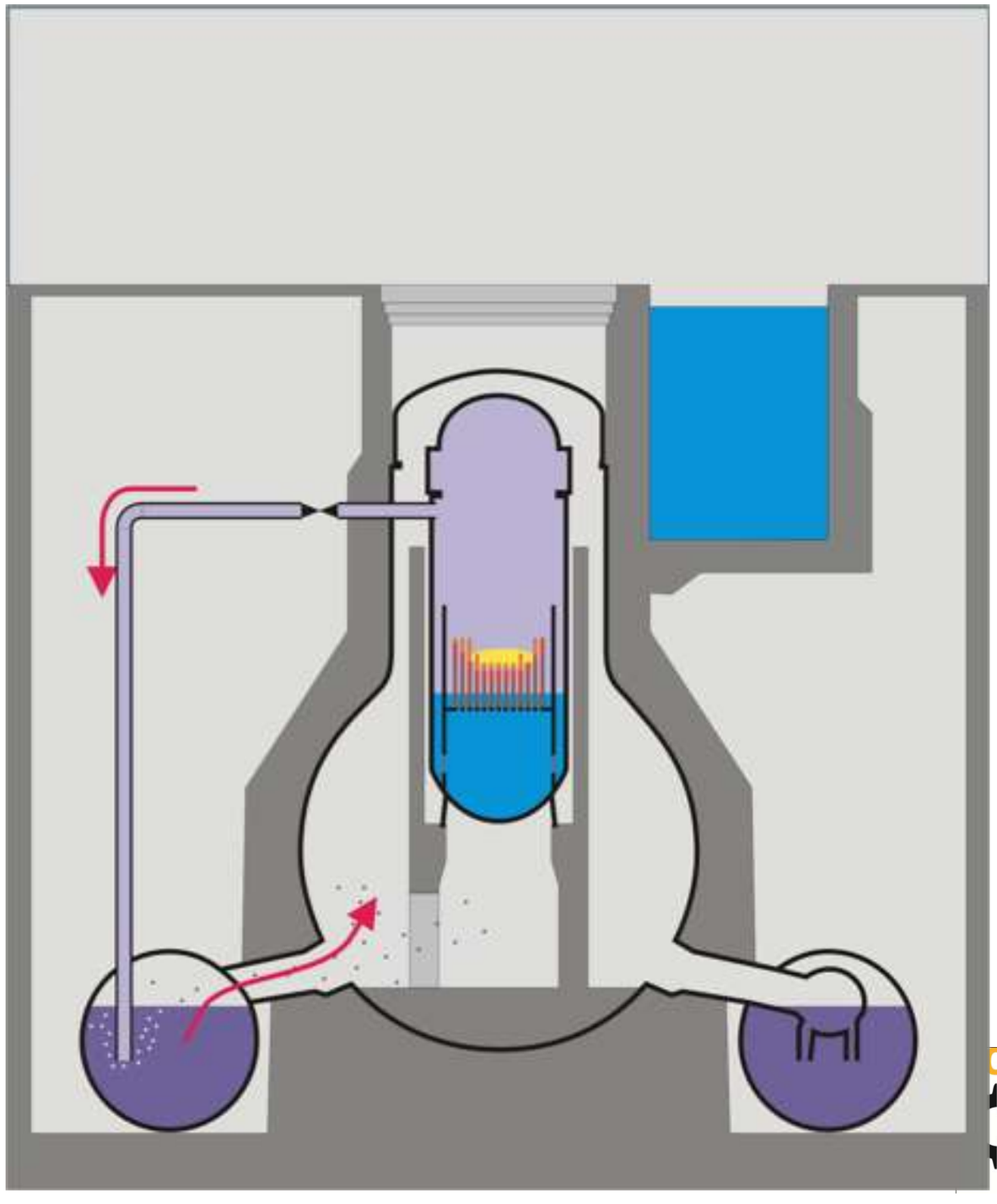
Accident Progression



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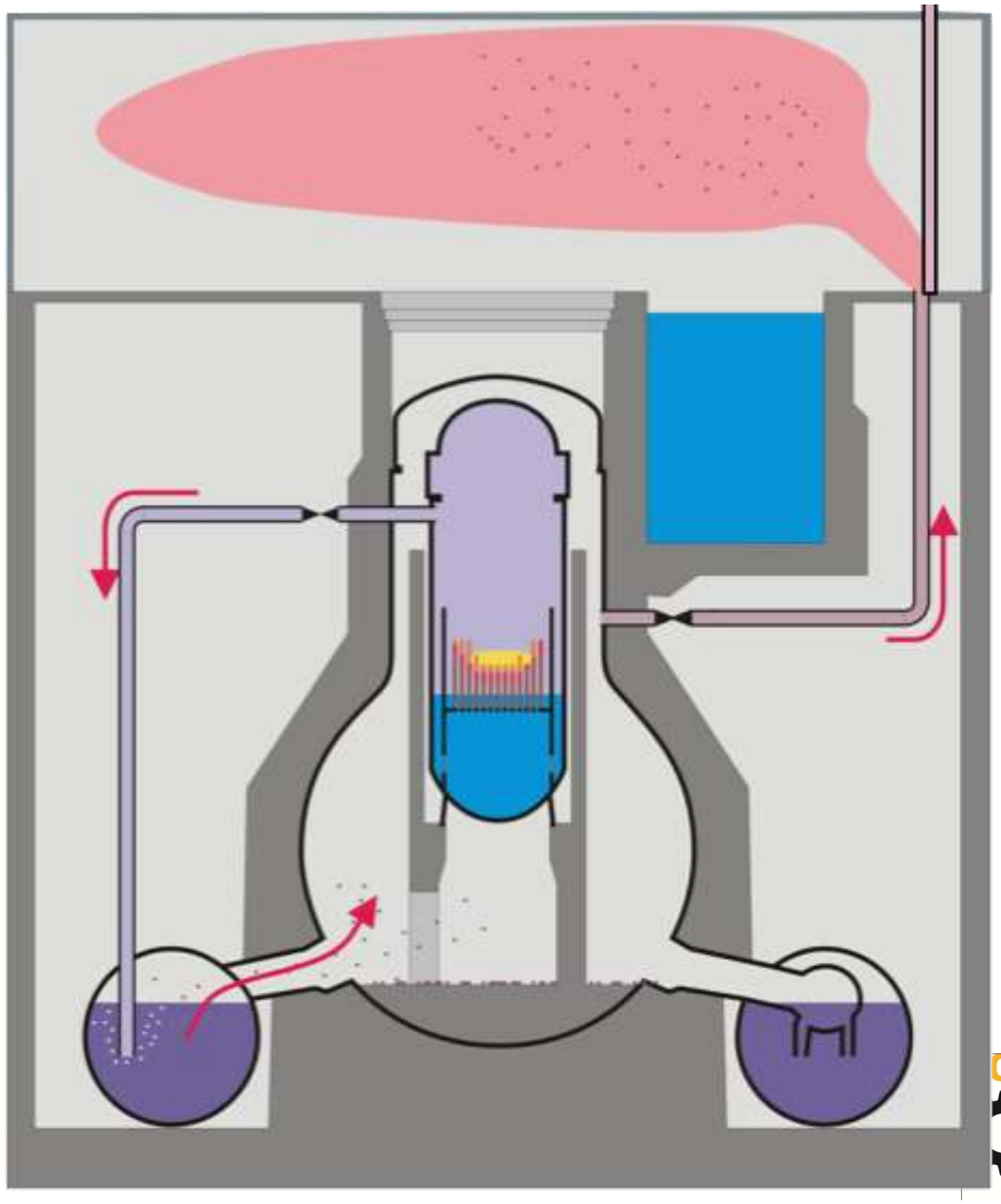
Accident Progression



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Accident Progression
Unit 1 & 3

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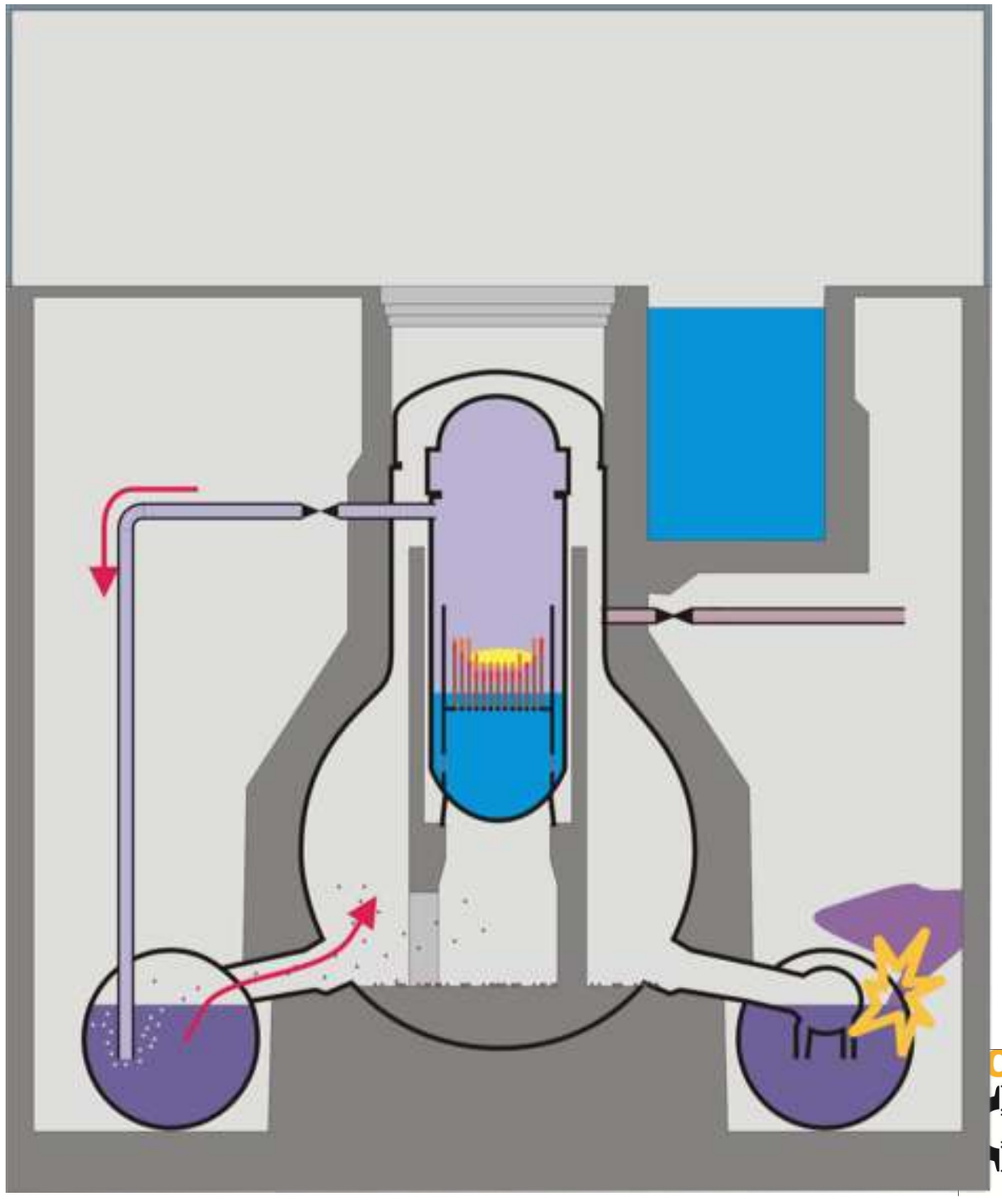
Accident Progression
Unit 2



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Accident Progression

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Accident Progression
Unit 4

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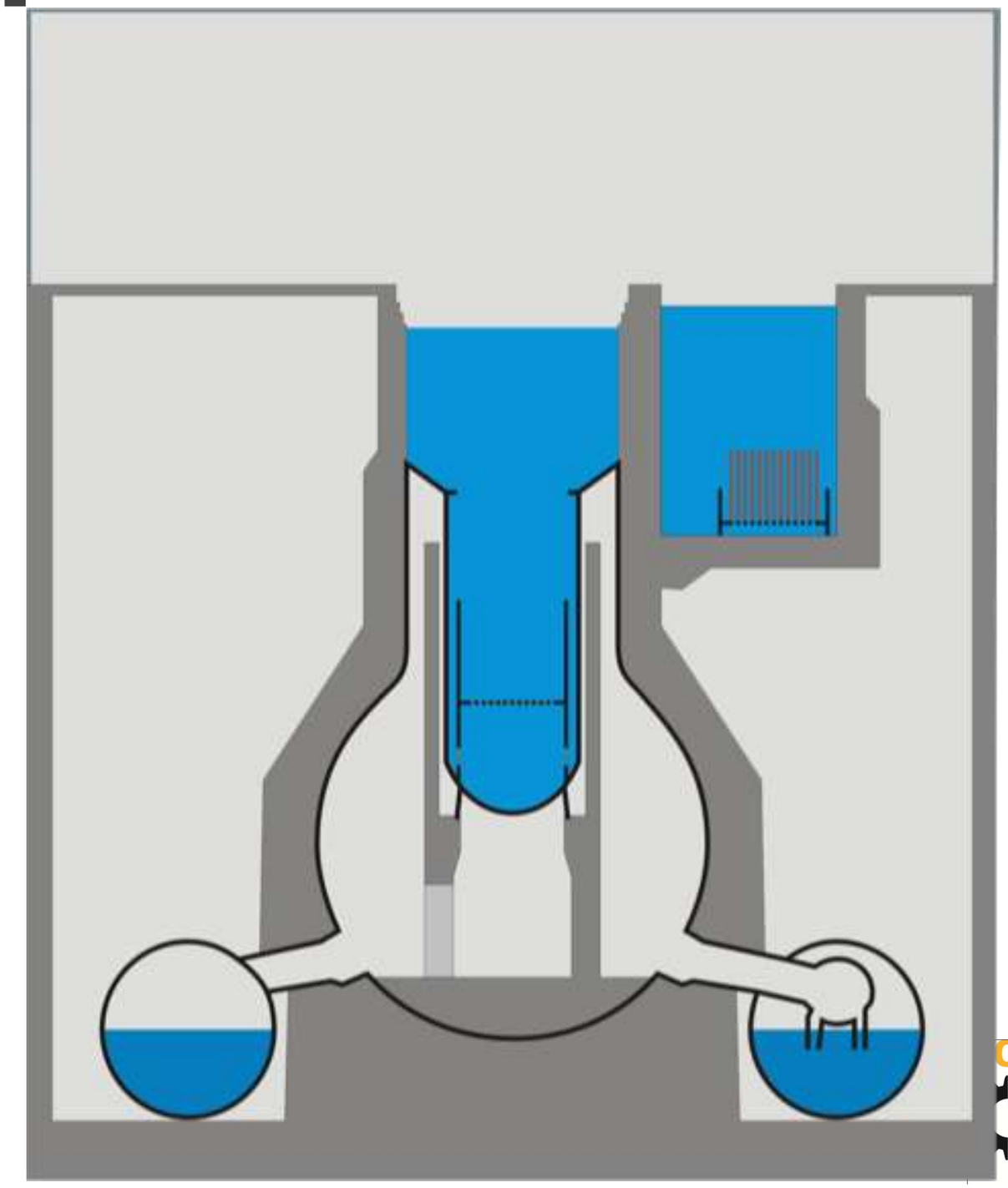
Accident Progression Spent Fuel Pools



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Fukushima - Daiichi

THE REACTOR

THE ACCIDENT

THE RECOVERY

THE LESSONS LEARNED

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Radiation Release

- CT Scan: 6 -18 mSv

- Monitoring underway for 2 million residents of Fukushima
  - 40% received less than 1 mSv;
  - <1% received more than 20 mSv
  - Remainder were between 1 and 20 mSv
- Significant doses occurred to some workers in the first few weeks
  - 167 workers received >100 mSv
  - Emergency dose limit was raised to 250 mSv until December 2011, now set at 100 mSv

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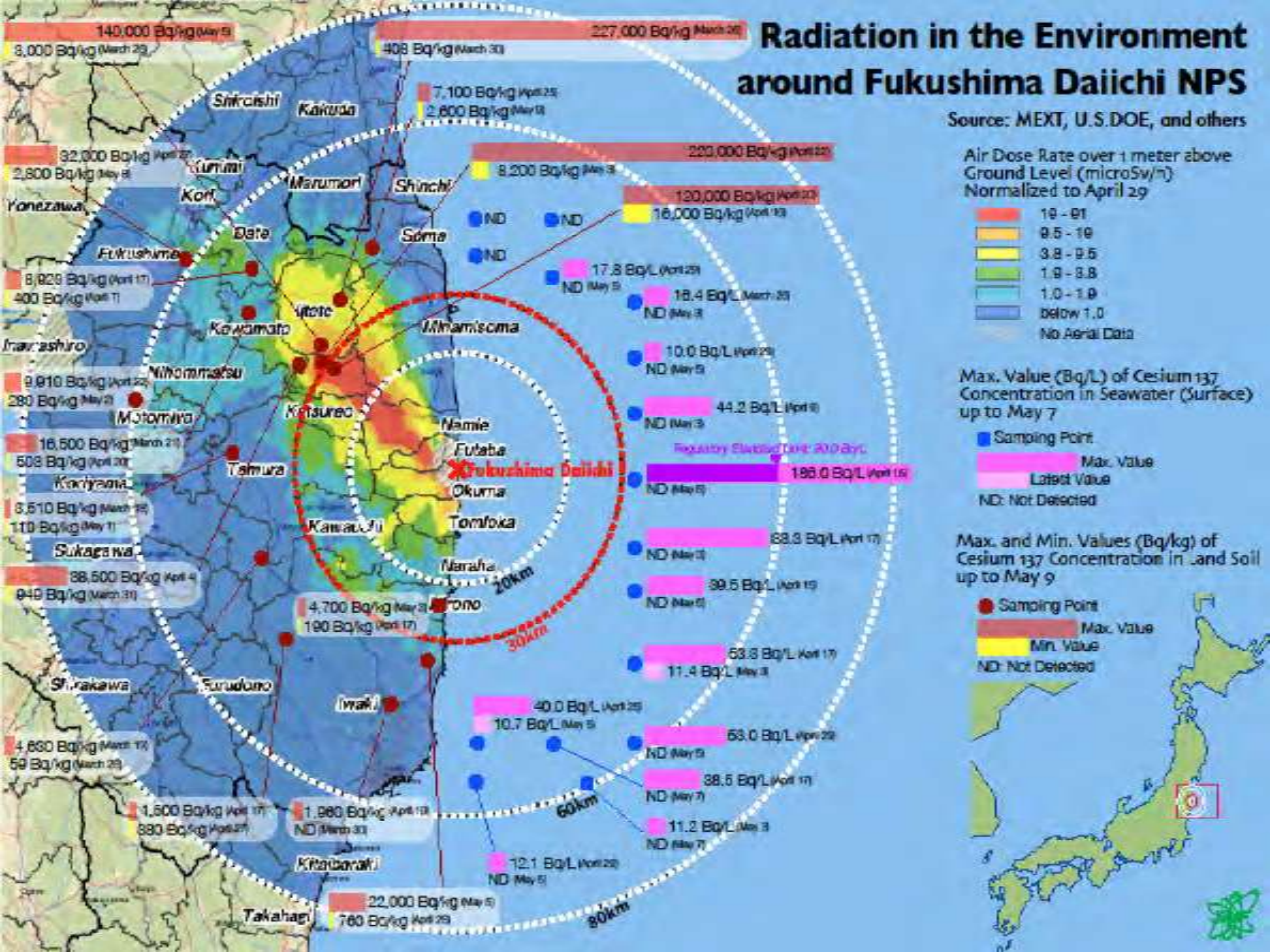

Radiation in the Environment around Fukushima Daiichi NPS
Source: MEXT, U.S.DOE, and others
Air Dose Rate over 1 meter above Ground Level (microSv/h) Normalized to April 29
19 - 91
9.5 - 19
3.8 - 9.5
1.9 - 3.8
1.0 - 1.9
below 1.0
No Aerial Data
Max. Value (Bq/L) of Cesium 137 Concentration in Seawater (Surface) up to May 7
Samping Point
Max. Value
Latest Value
ND: Not Detected
Max. and Min. Values (Bq/kg) of Cesium 137 Concentration in Land Soil up to May 9
Samping Point
Max. Value
Min. Value
ND: Not Detected
140,000 Bq/kg
227,000 Bq/kg
408 Bq/kg
7,100 Bq/kg
2,600 Bq/kg
32,000 Bq/kg
2,800 Bq/kg
220,000 Bq/kg
8,200 Bq/kg
120,000 Bq/kg
16,000 Bq/kg
8,929 Bq/kg
400 Bq/kg
17.8 Bq/L
18.4 Bq/L
10.0 Bq/L
9,910 Bq/kg
280 Bq/kg
44.2 Bq/L
16,500 Bq/kg
508 Bq/kg
186.0 Bq/L
6,610 Bq/kg
110 Bq/kg
88.3 Bq/L
38,500 Bq/kg
949 Bq/kg
39.5 Bq/L
4,700 Bq/kg
190 Bq/kg
53.3 Bq/L
11.4 Bq/L
40.0 Bq/L
10.7 Bq/L
53.0 Bq/L
4,630 Bq/kg
59 Bq/kg
38.5 Bq/L
1,500 Bq/kg
380 Bq/kg
1,980 Bq/kg
11.2 Bq/L
12.1 Bq/L
22,000 Bq/kg
760 Bq/kg
ND
Shiroishi
Kakuda
Marumori
Shinchi
Koori
Yonezawa
Date
Soma
Fukushima
Kawamata
Minamisoma
Inawashiro
Nihonmatsu
Motomiya
Katsurao
Namie
Futaba
Fukushima Daiichi
Okuma
Tamura
Koriyama
Tomioka
Kawauchi
Sukagawa
Naraha
Shirakawa
Iwaki
Kitaibaraki
Takahagi
20km
30km
60km
80km

Recovery

- March 12: Sea Water continued to be used for cooling Reactors
- March 15: Units 1 & 3 Stable
- March 17: Unit 2 Stable
- March 20: Units 5 & 6 in cold shutdown
- March 22: Power restored on site
- March 25: Switch to fresh water for core cooling

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Recovery

- May 6: Enter Unit 1 building for the first time
- June 15: Sea Water Filtering system begins operation
- August 10: Circulating cooling water restored for all units
- Sept. 30: Units 1-3 are below boiling
- October 3: Japanese Government to assist with clean up efforts

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Recovery

- Dec 19: All Units in cold shutdown
- Dec 26: Cancellation of Nuclear Emergency Situation was declared
- Feb 13, 2012: Japan establishes INPO style organization
- Feb 27: TEPCO announces plans to seal sea bed around site

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Fukushima - Daiichi

THE REACTOR

THE ACCIDENT

THE CONSEQUENCES

THE LESSONS LEARNED

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Lessons Learned Japan

- Severe Accident Management procedures implemented
- Nuclear safety regulation organization formed
  - Nuclear Safety and Security Agency (NSSA)
- Improved training and capability of Nuclear personnel

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Lessons Learned
USA

- Review of long term loss of off site power regulations
- Review of standards and criteria for design basis
- Hydrogen Management
- Stress test designs

- Be humble, especially toward natural phenomena

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Acknowledgements

Dr. Sama Bilbao y Leon

Dr. Ronald Allen Knief

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