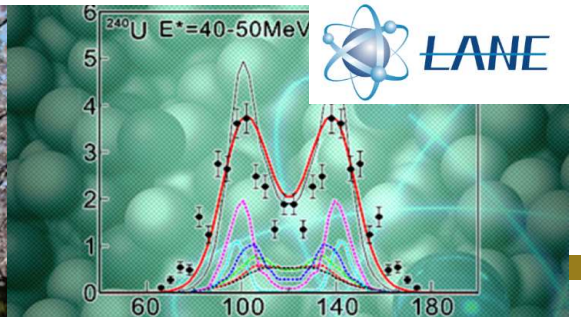
IAEA Technical Meeting on Codes and Standards, Design Engineering and Manufacturing of Components for , Small Modular Reactors, 10-13 May 2022 (Virtual Event) Ref. No. EVT2103861

Proposals that contribute to the innovation of SMR, such as LBB, Seismic Isolation Structures, Ship Hull Structures, and Application of General Industrial Products

Tokyo Tech

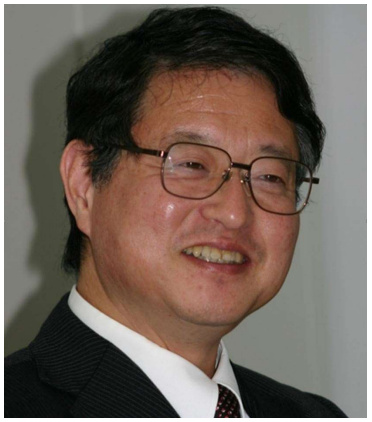


LANE

***14:50-15:20 May* 10 (Tuesday)**

Dr. Tadashi NARABAYASHI
Professor,
Laboratory for Zero-Carbon Energy,
Tokyo Institute of Technology (Tokyo Tech)

Biography: Tadashi Narabayashi



Prof. Tadashi Narabayashi , PhD
He graduated the master course of Nuclear Engineering, Tokyo Institute of Technology, 1978.
He was the Chief Specialist of Reactor Components and Two-Phase Flow in Toshiba Corp.
He was the Professor of **the Hokkaido University** from 2005 to March 2018.
He back to the **Tokyo Institute of Technology** April 2018.

He has been involved in investigating the causes of the accidents and developing countermeasures for other NPPs in Japan, as an advisory meeting member of NRA (Nuclear Regulation Authority) for Fukushima Daiichi Accident Investigation Team.

He was also Nuclear Program Advisory Panel (NPAP) members for Khalifa University, UAE from 2012 to 2015. He was also given the Outstanding Professor of the Year Award given at the ISOE (IAEA/ OECD-NEA), 2018.

Station Blackout caused by Earthquake in Hokkaido Japan

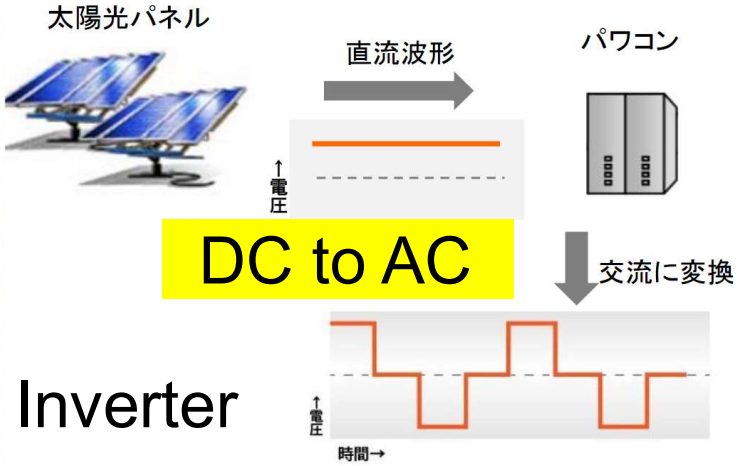
- 3:08am, Sept. 6, 2018, big earthquake caused the wide area black out in Hokkaido, Japan.
- Tomatou-Atsuma thermal power station 1,2 and 4 tripped.
- 1650MW lost (About 50% of total demand at 3:00am)

Renewable energy without inertia increases the risk of blackout

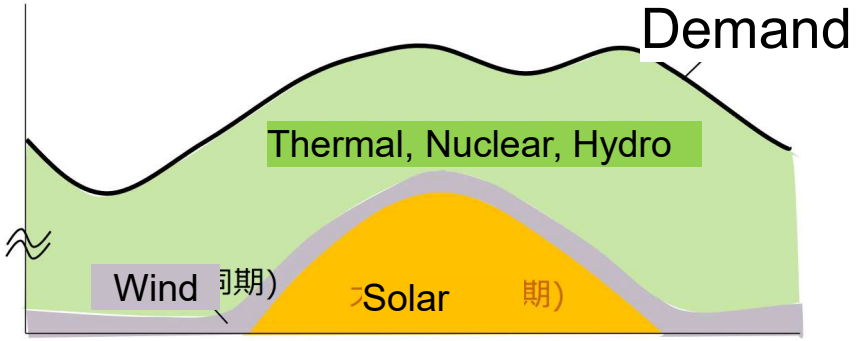
Synchronous power (thermal, nuclear, hydro power)

AC

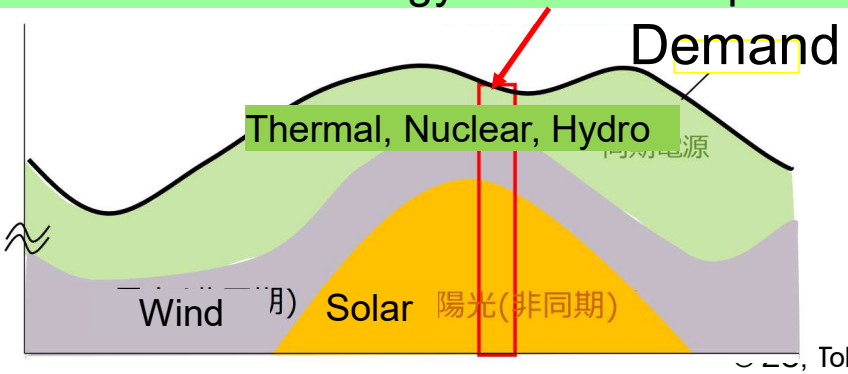
Asynchronous power (solar / wind)



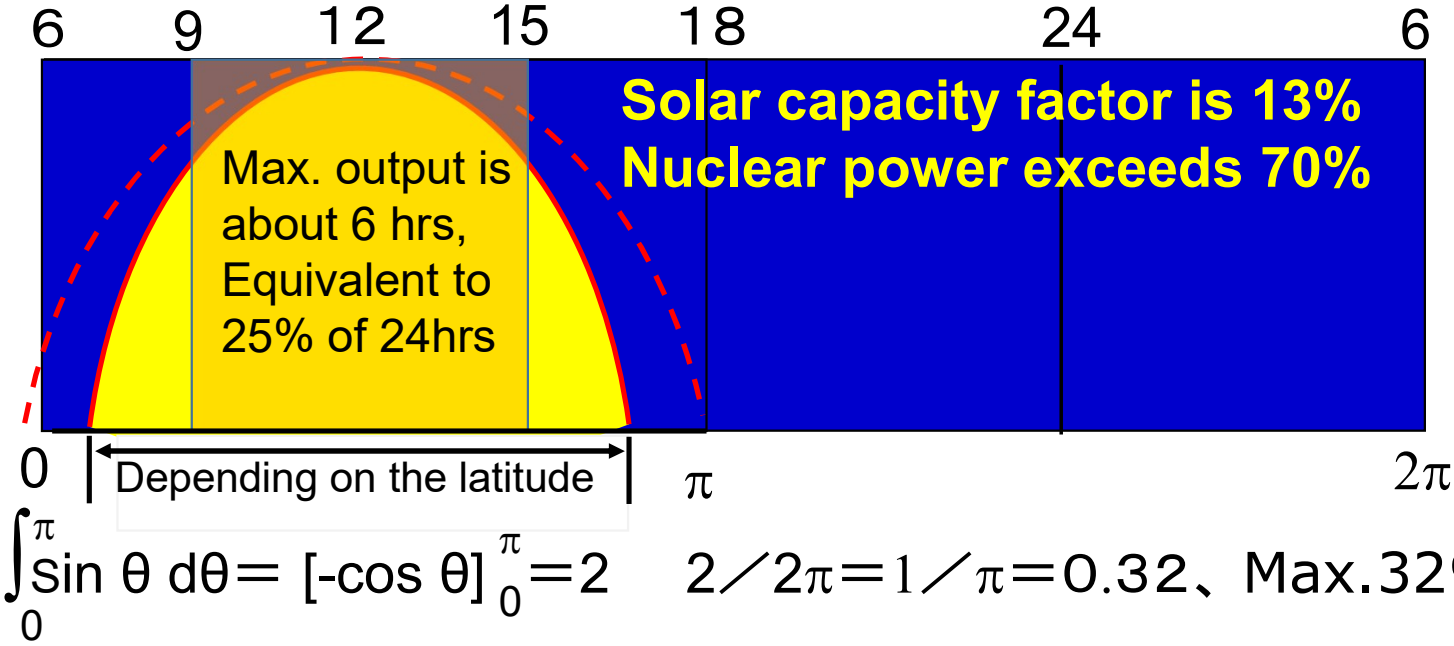
Current status



Increased renewable energy destabilizes power grid



Solar and wind power requires backup of other power sources



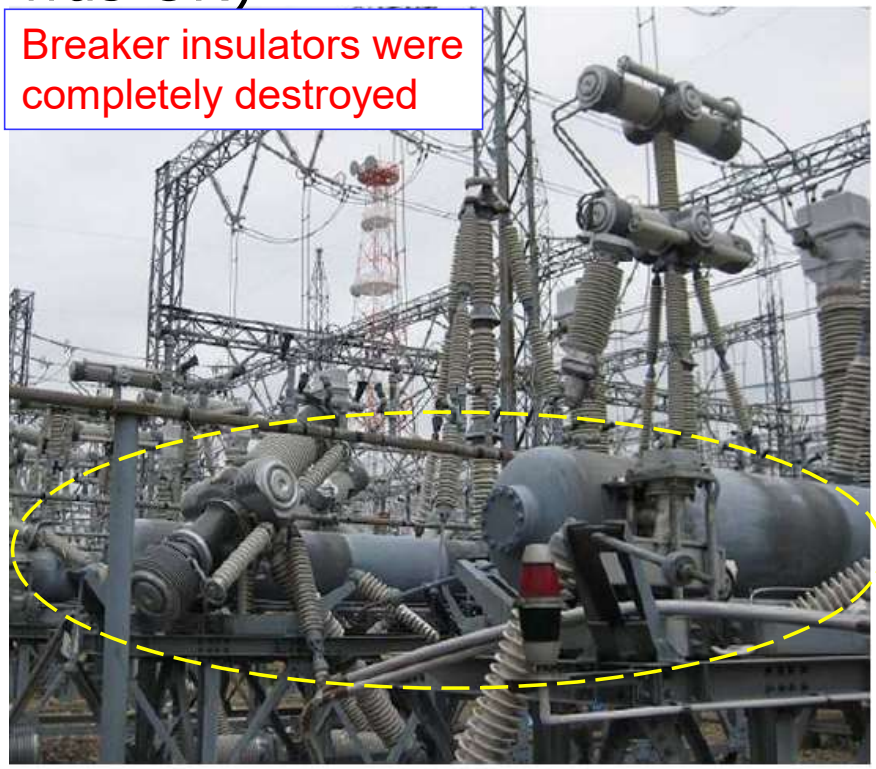
$$\int_0^{\pi} \sin\theta \, d\theta = [-\cos\theta]_0^{\pi} = 2 \qquad 2/2\pi = 1/\pi = 0.32、\text{Max.}32\%$$

- When the probability of sunny weather is multiplied by 50%, it is 16%, and when the electric circuit loss is subtracted, the capacity factor is at most 13% in Japan. Double capacity factor will be obtained at UAE.
- Equivalent full power to 6 hours a day (25%) in Japan
- The rest is supplemented with hydro, thermal, and nuclear power.
- The capacity factor of wind power generation is 30% in Japan.
- It is difficult to use renewable energy as the main power source in Japan

Loss of external power supply (Damaged insulator at switchyard)

Fukushima Daiichi:ABB was broken, Onagawa NPP:GIS was OK)

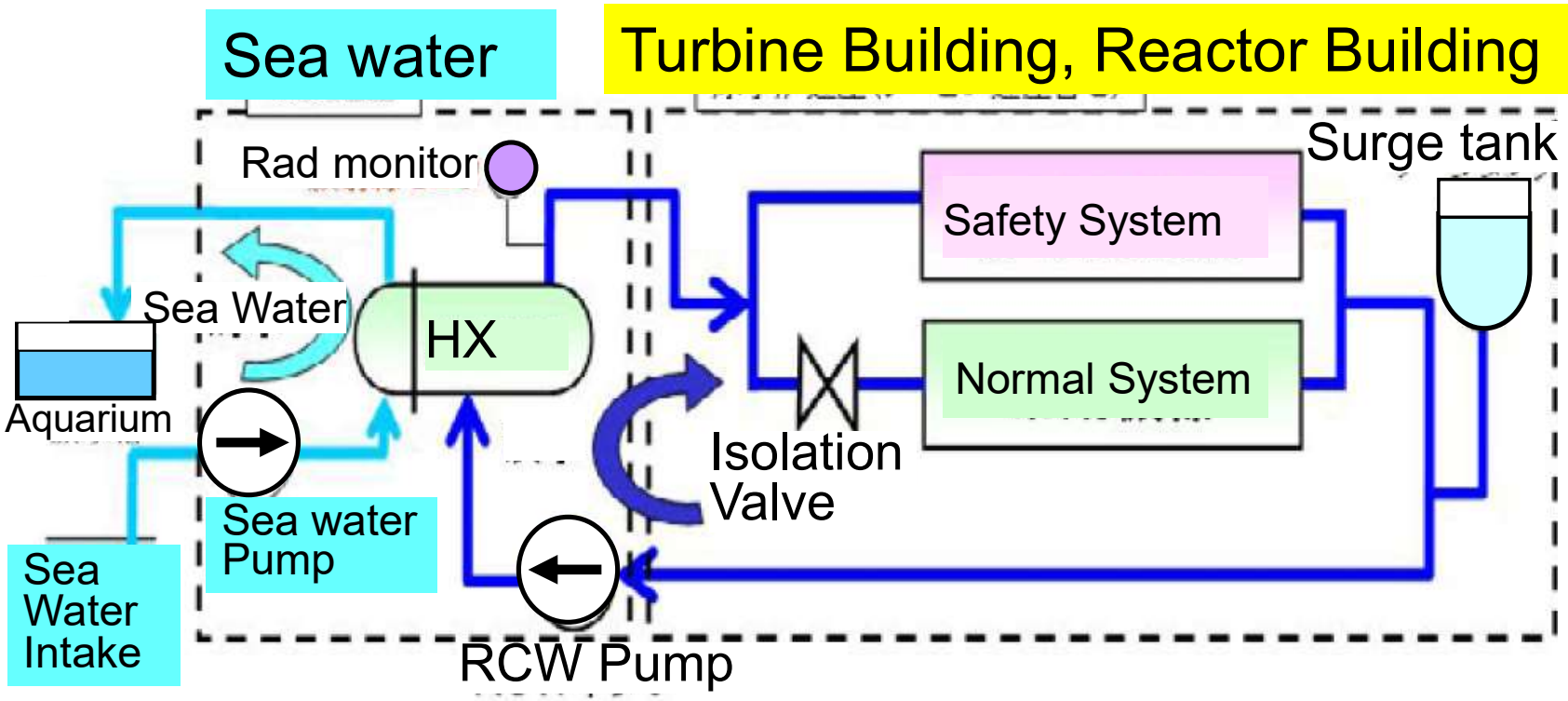
Breaker insulators were completely destroyed



Damaged ABB(Air Blast Breaker)
Fukushima Daiichi Unit 1-4

GIS：Gas Insulated Switchgear
Onagawa Unit 1-3 were OK

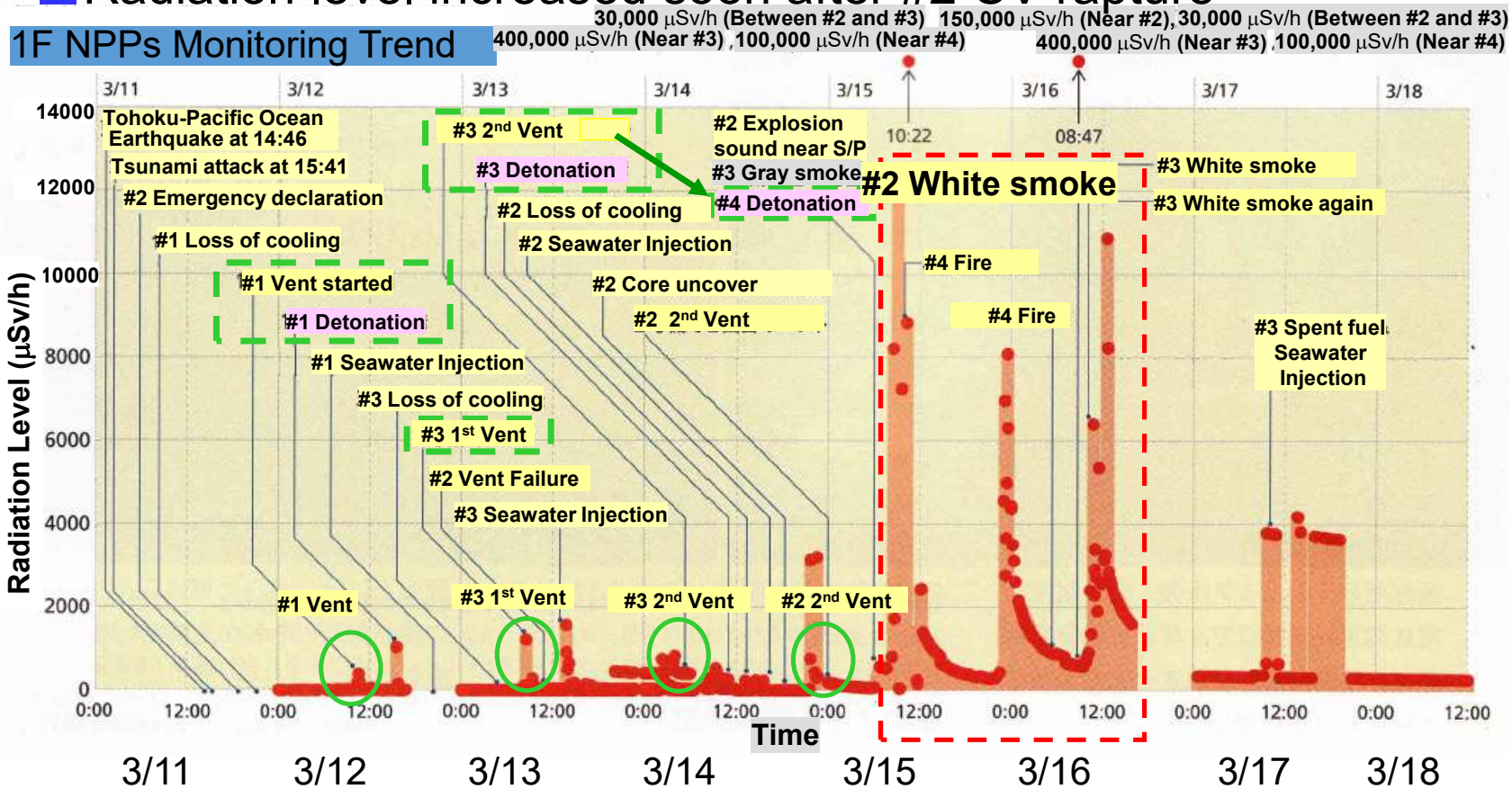
If the support system loses its function due to the tsunami, the safety system will collapse together



Safety System	Emergency DG, RHR Pump RHR HX, Spent Fuel Pool Pump etc.
Normal System	PLR Pump, CRD Pump, Feedwater Pump, Turbine Condenser, Seawater Pump etc.

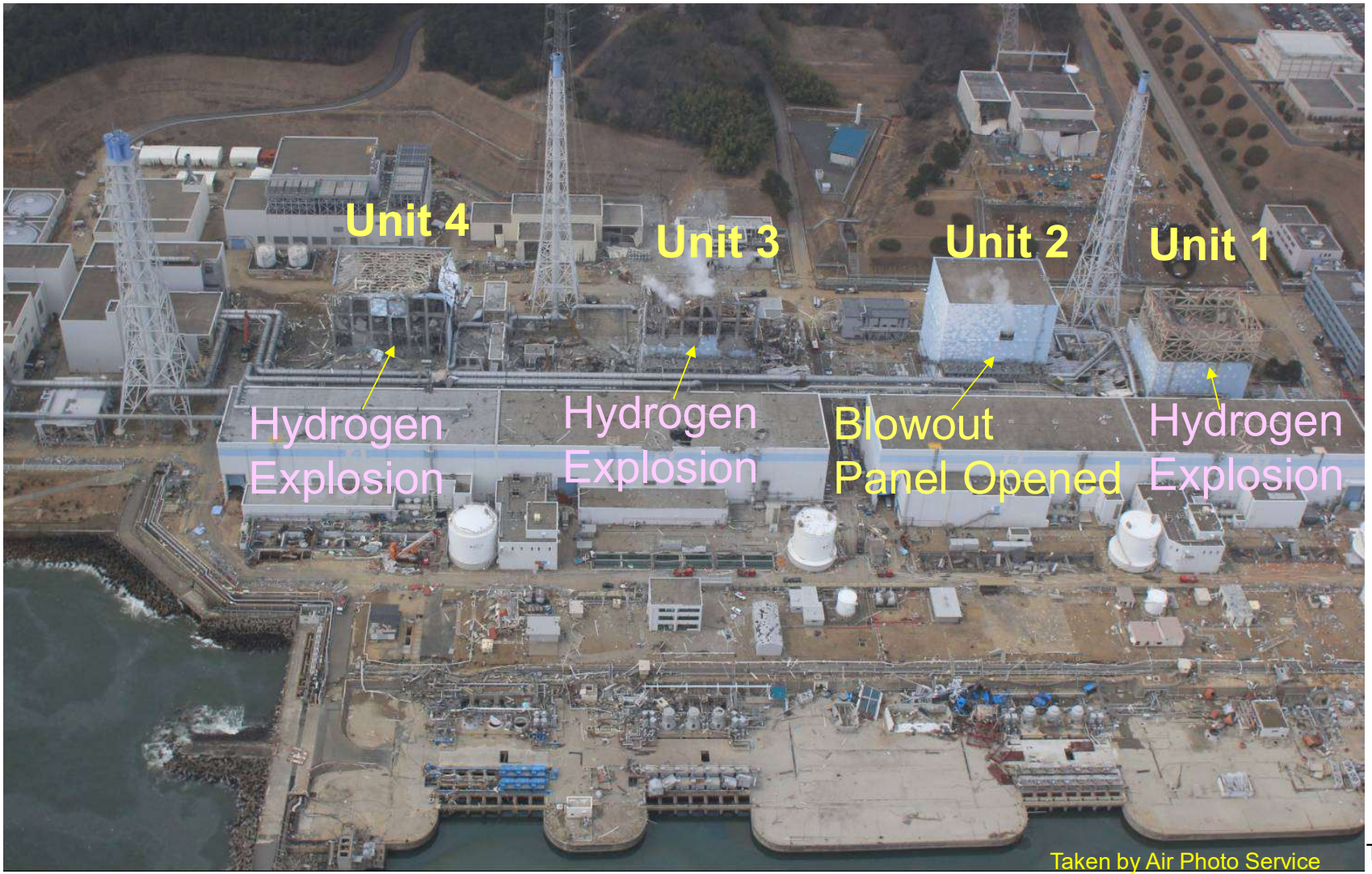
Radiation level increased after CV Leak

- H_2 detonation were occurred after vent operation (#1, #3, #4)
- Radiation level increased soon after #2 CV rapture



Nikkei Science, July 2011

Hydrogen Explosion at Fukushima Daiichi



Direct leak from PCV of 1F-2 and 1F-3

(a) 13:00, March 13

(b) 7:00, March 15

(c) 10:00, March 16

(e) Unit2, 8:58, March 15

(d) Unit3, 7:31, March 15

(e) Unit3, 9:51, March 16

Loss of air for vent valves cause the PCV direct leaks, and the cause of contamination around Fukushima-Daichi

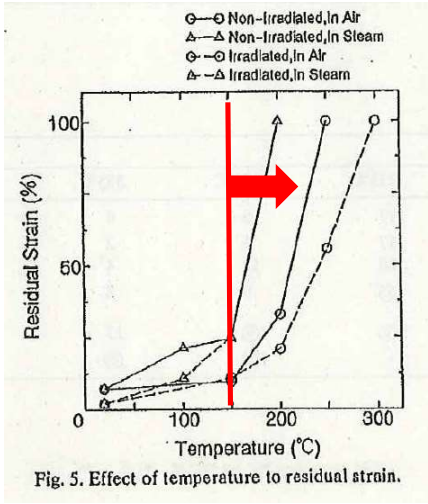
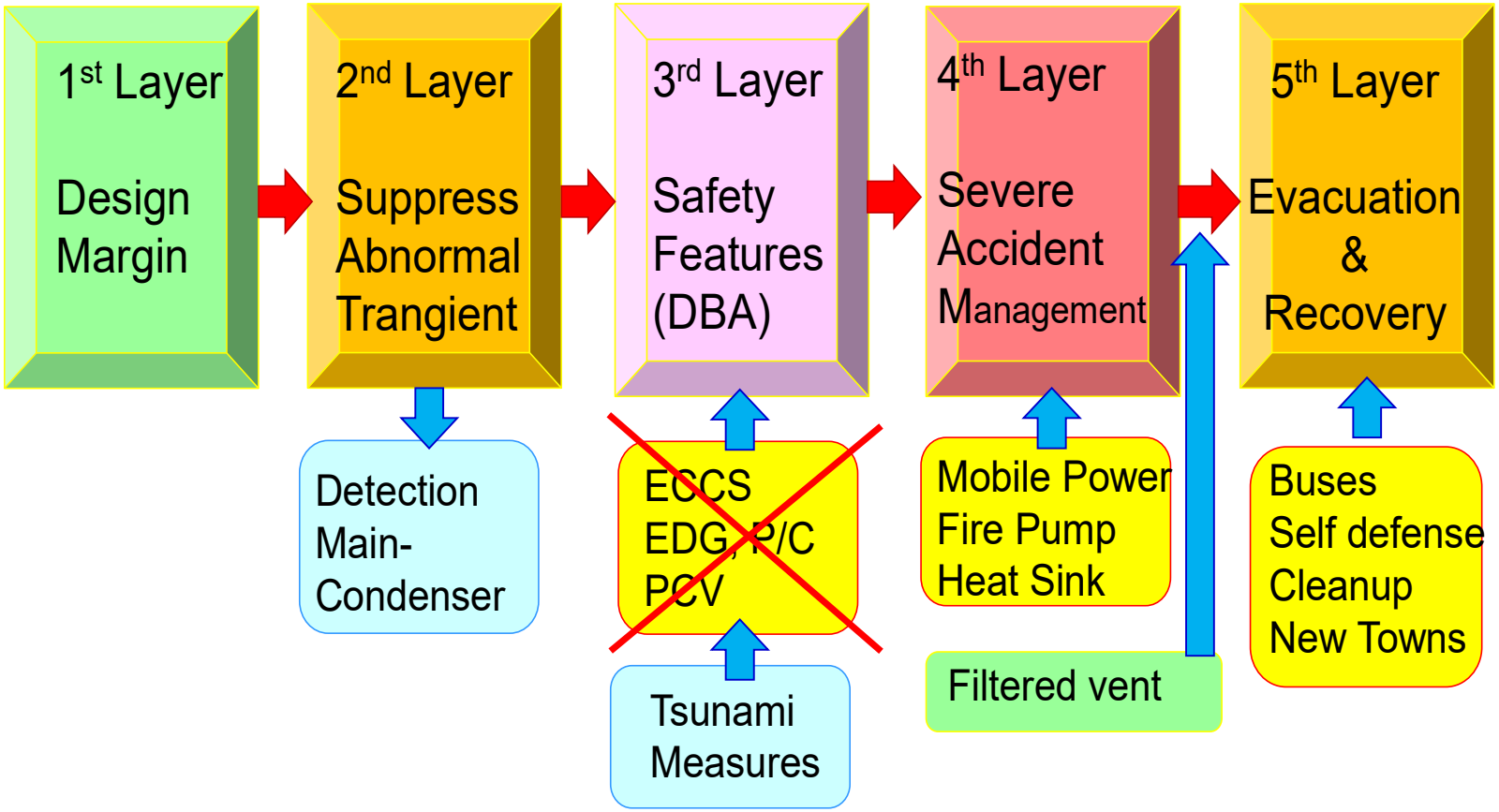
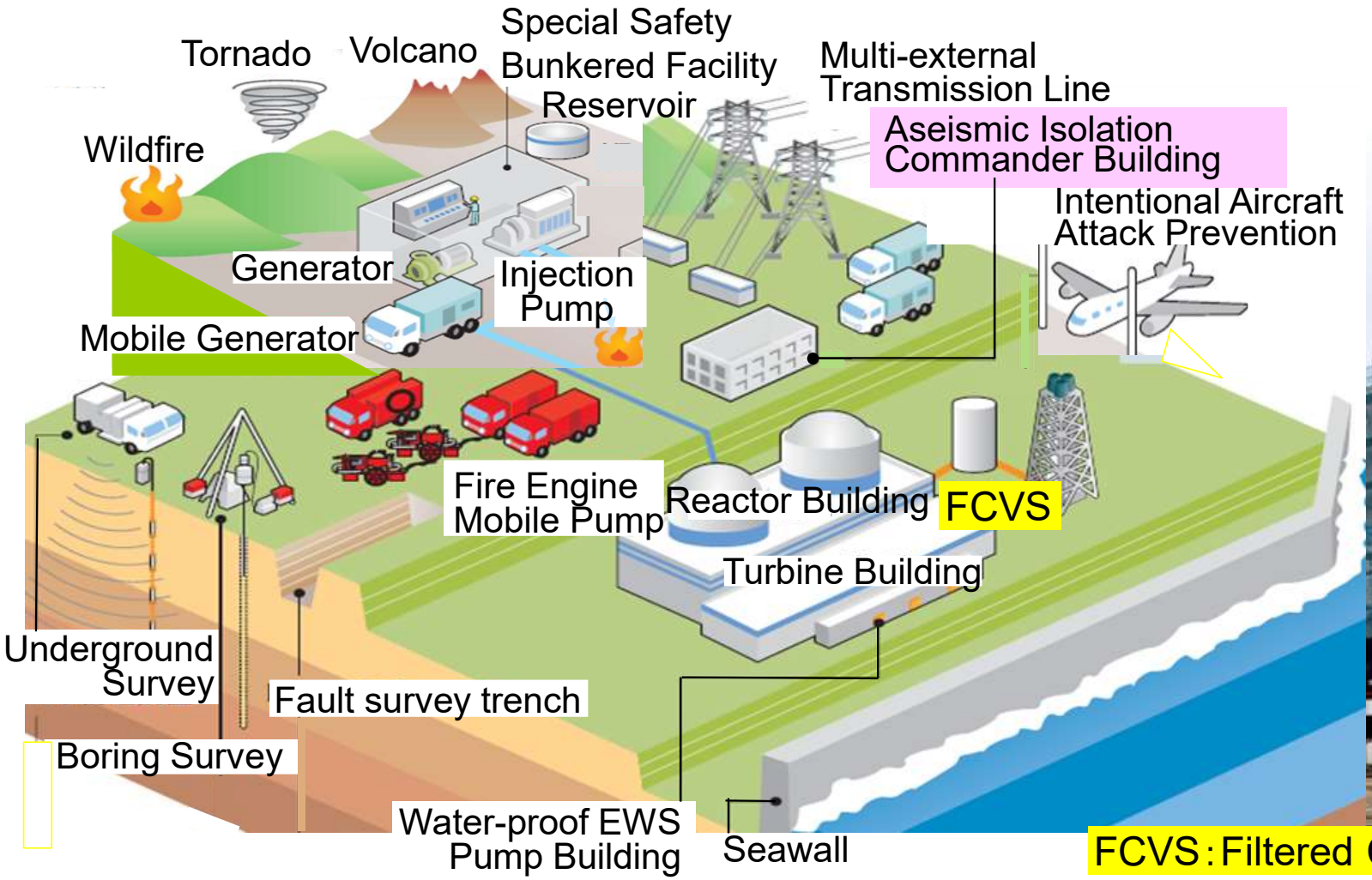


Fig. 5. Effect of temperature to residual strain.

Defense In Depth Strategy



New Regulatory Requirements in Japan



FCVS：Filtered Containment Venting System

New Regulatory Requirements by DiD

1st Layer
Design
Margin

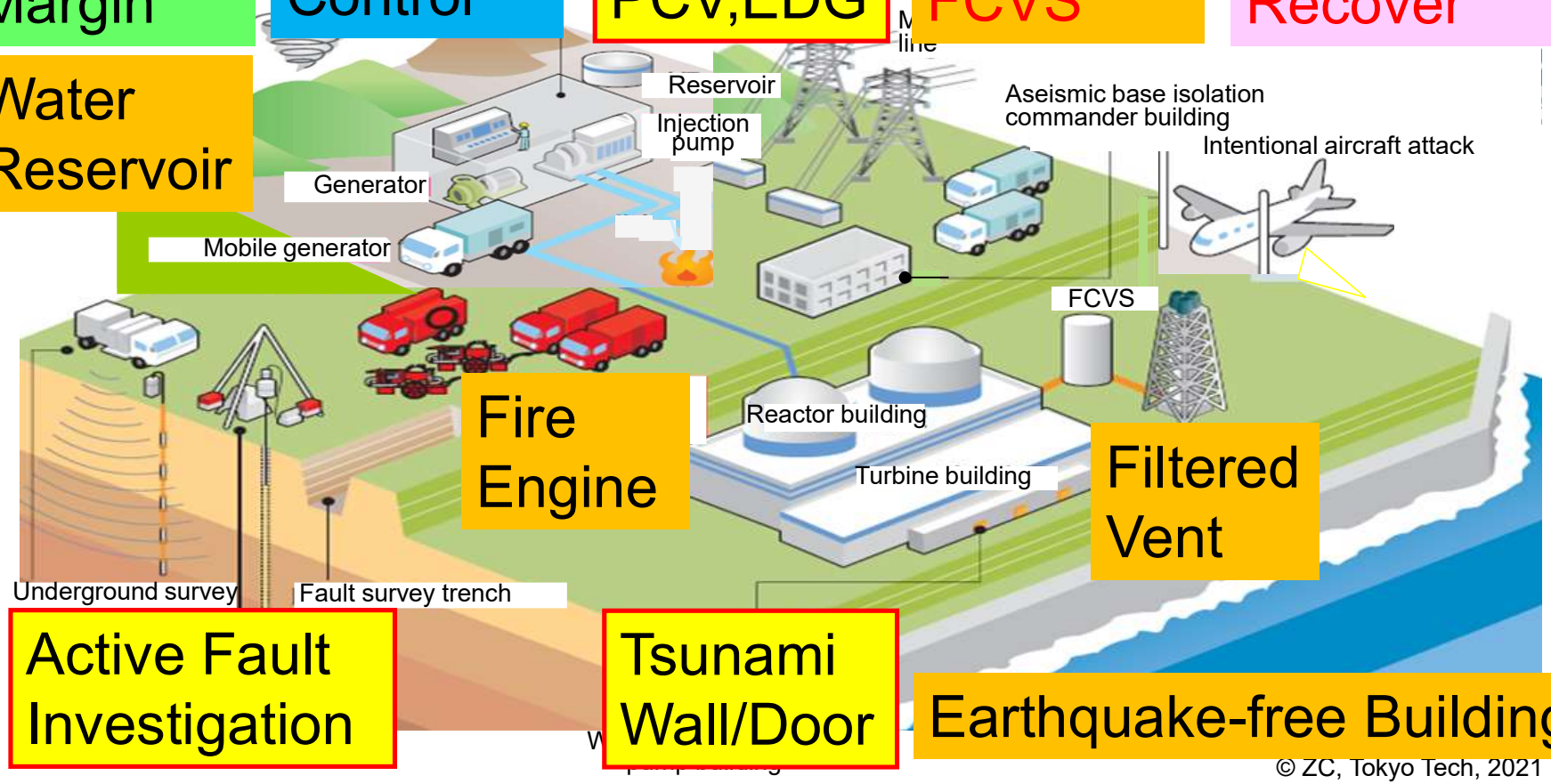
2nd Layer
Transient
Control

3rd Layer
ECCS
PCV,EDG

4th Layer
SAM
FCVS

5th Layer
Evacuation
Recover

Water
Reservoir



Fire
Engine

Filtered
Vent

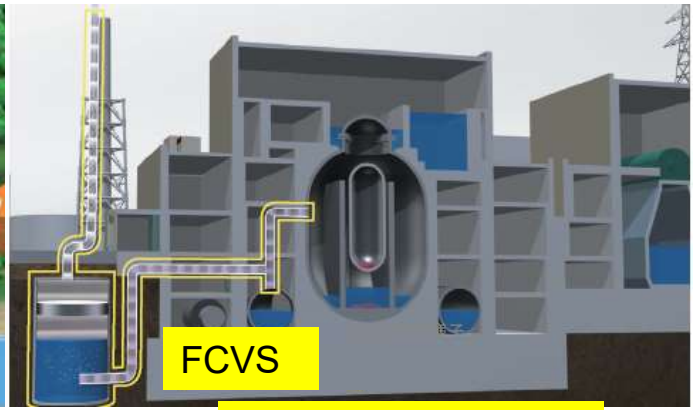
Active Fault
Investigation

Tsunami
Wall/Door

Earthquake-free Building

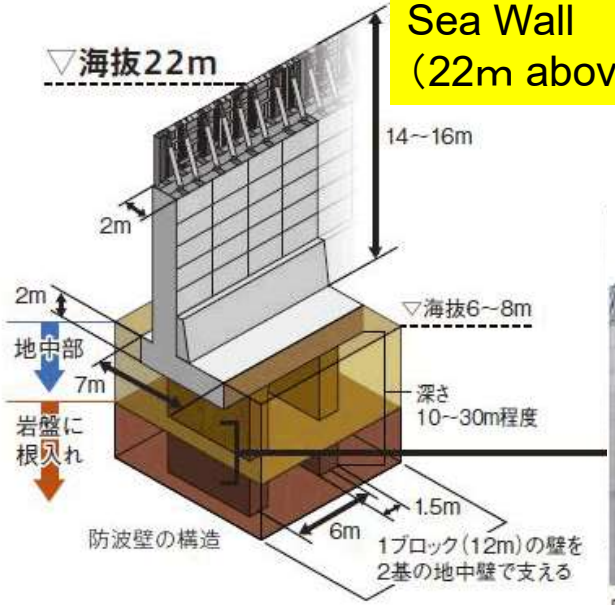
Tsunami Wall and FCVS at Hamaoka NPS

Sea Wall (1.6km length）



FCVS

Sea Wall
（22m above sea level）



防波壁

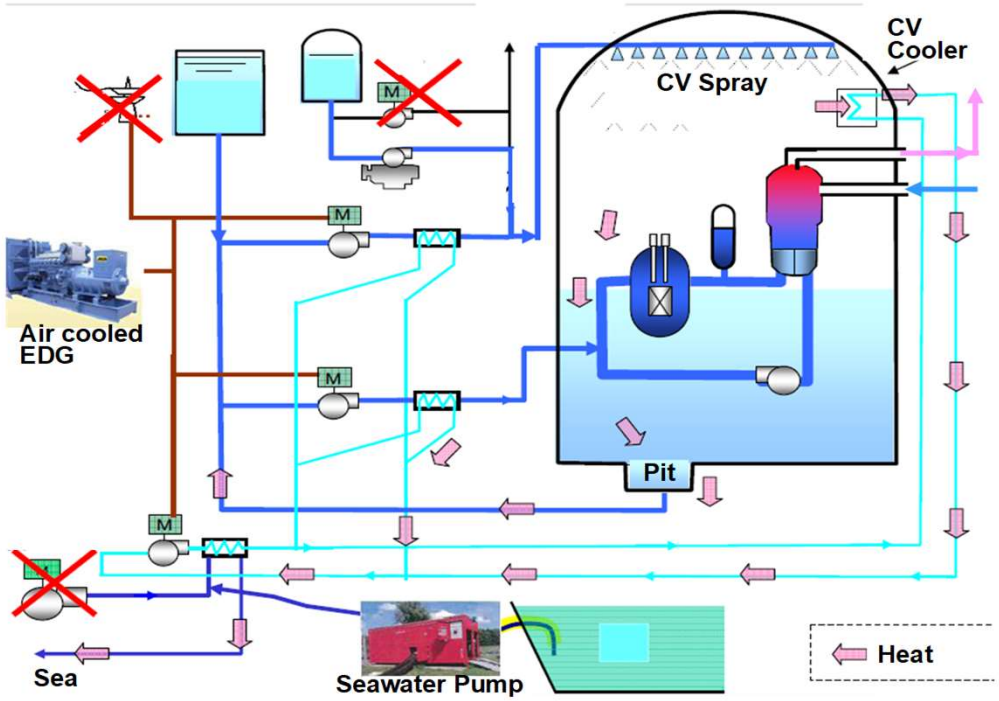
Waterproof Door

❶ 強化扉（厚さ：約1m、重さ：約40ｔ）

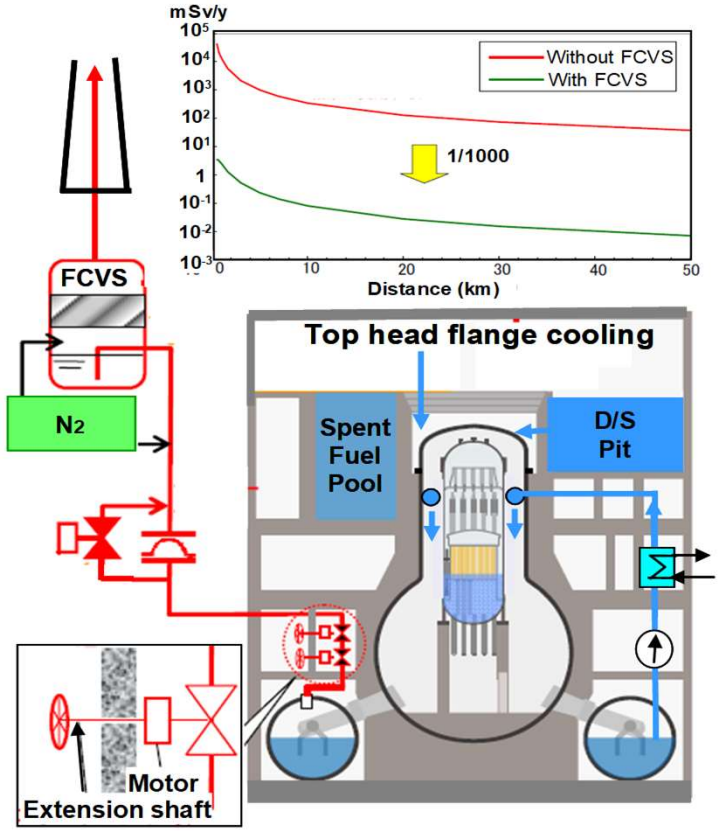
EWS Pump Building

Protect CV and PCV cooling for PWR & BWR

PWR: CV Spray, CV recirculation cooling, PAR

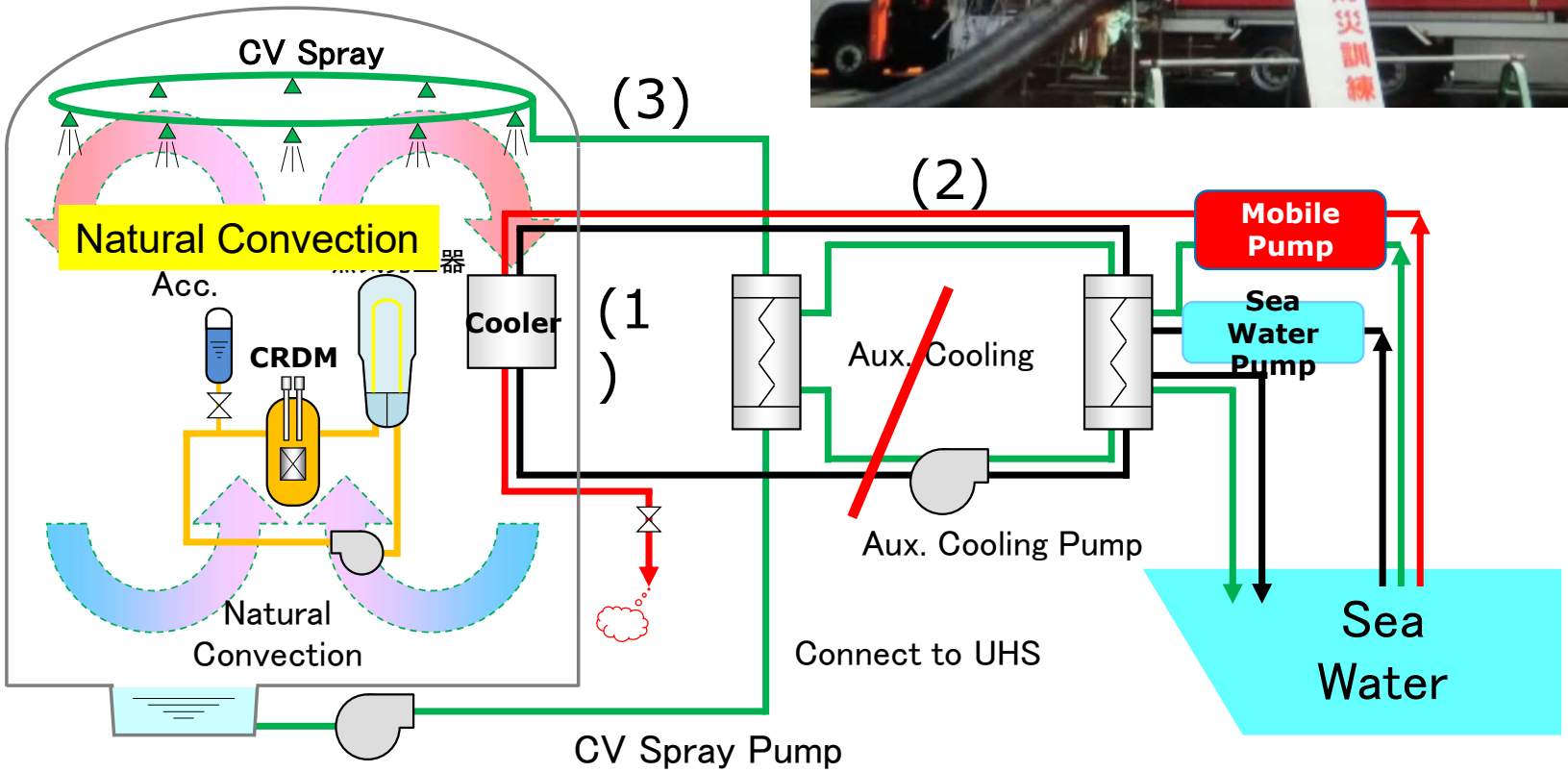


BWR: PCV Spray and RHR, FCVS



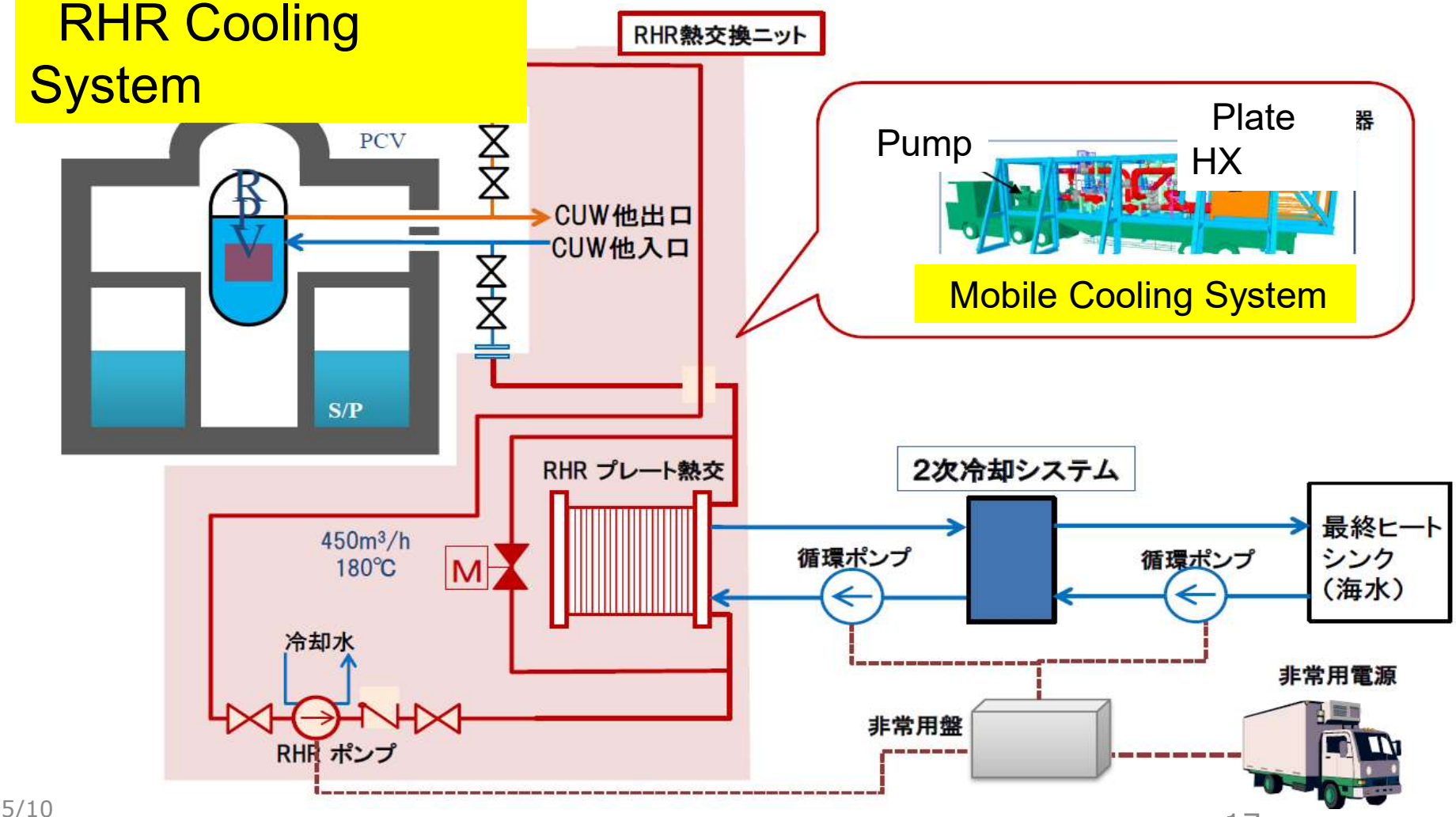
Recover of CV Cooling by Mobile System

(1)CV Cooling System
(2) Mobile Sea Water Pump
(3) CV Spray

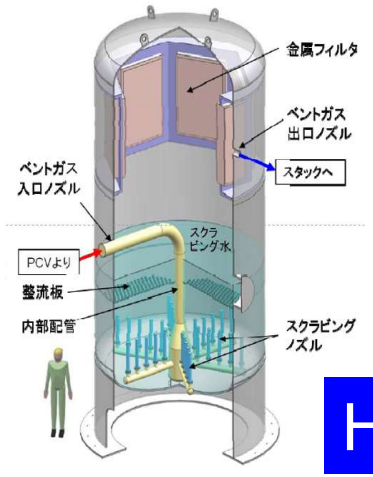


Recover of Heat Sink by Mobile System

RHR Cooling System



Filtered Containment Venting system



AgX RASA

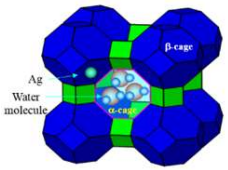
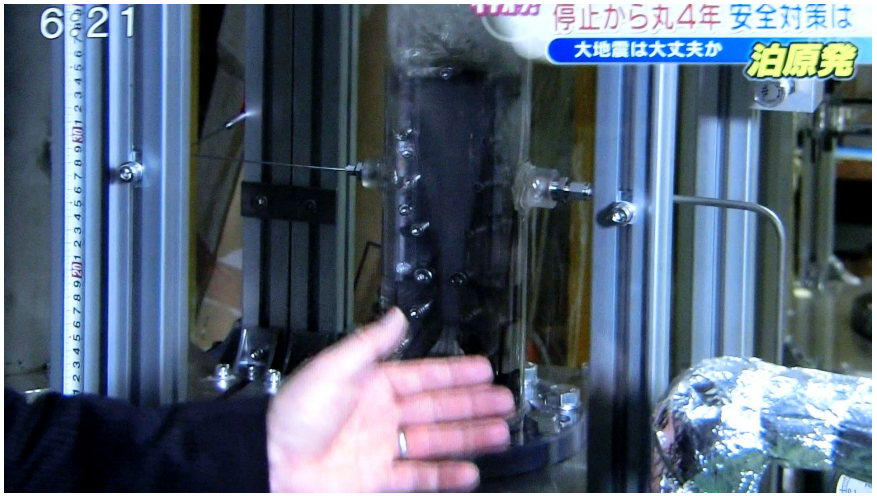


Figure 2 A-type silver-zeolite.

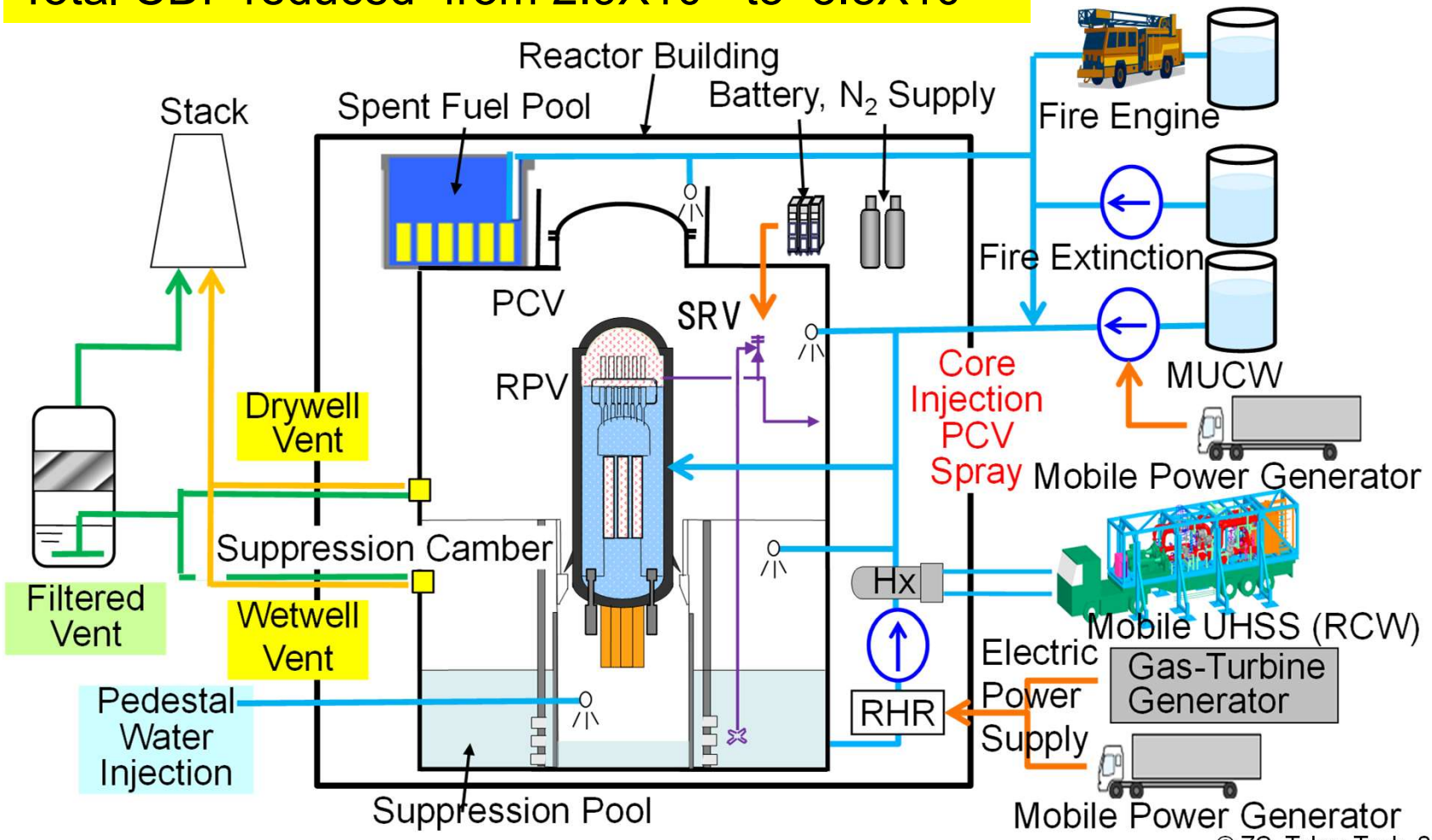
Hokkaido University



Kashiwazaki Kariwa
TEPCO

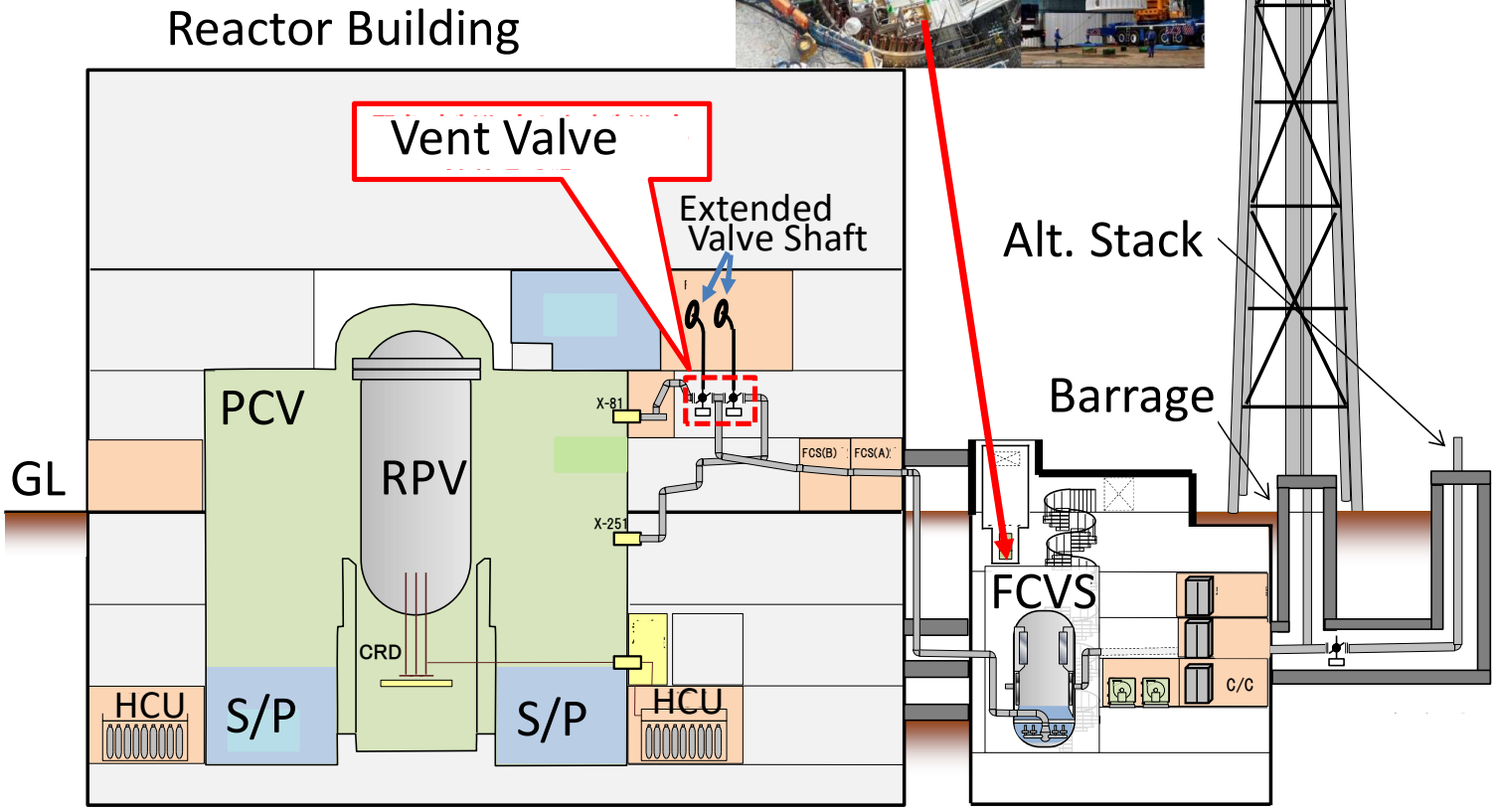
PCV Depressurization and Water Injection

Total CDF reduced from $2.9X10^{-6}$ to $3.8X10^{-9}$

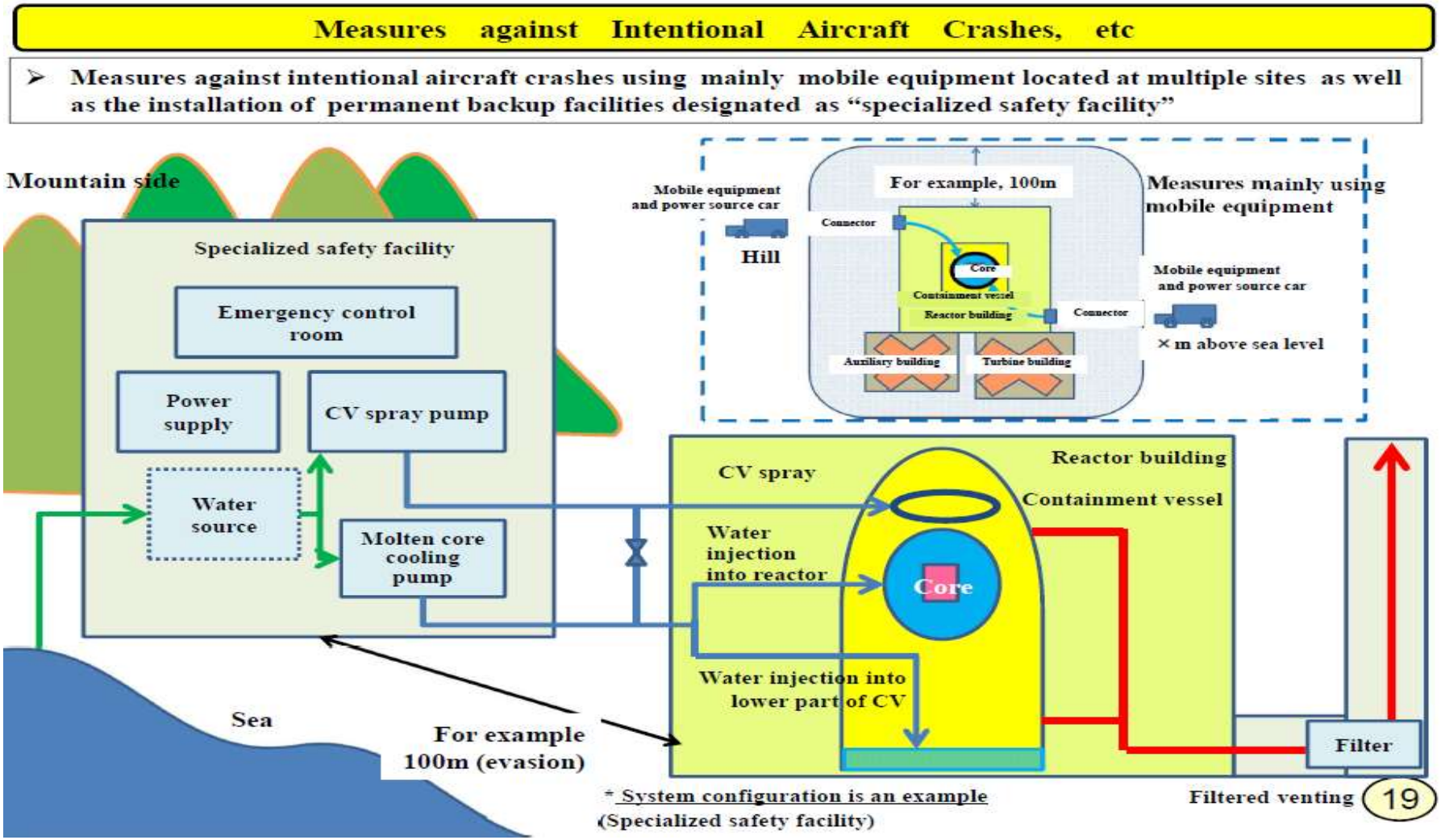


That is why I recommended FCVS

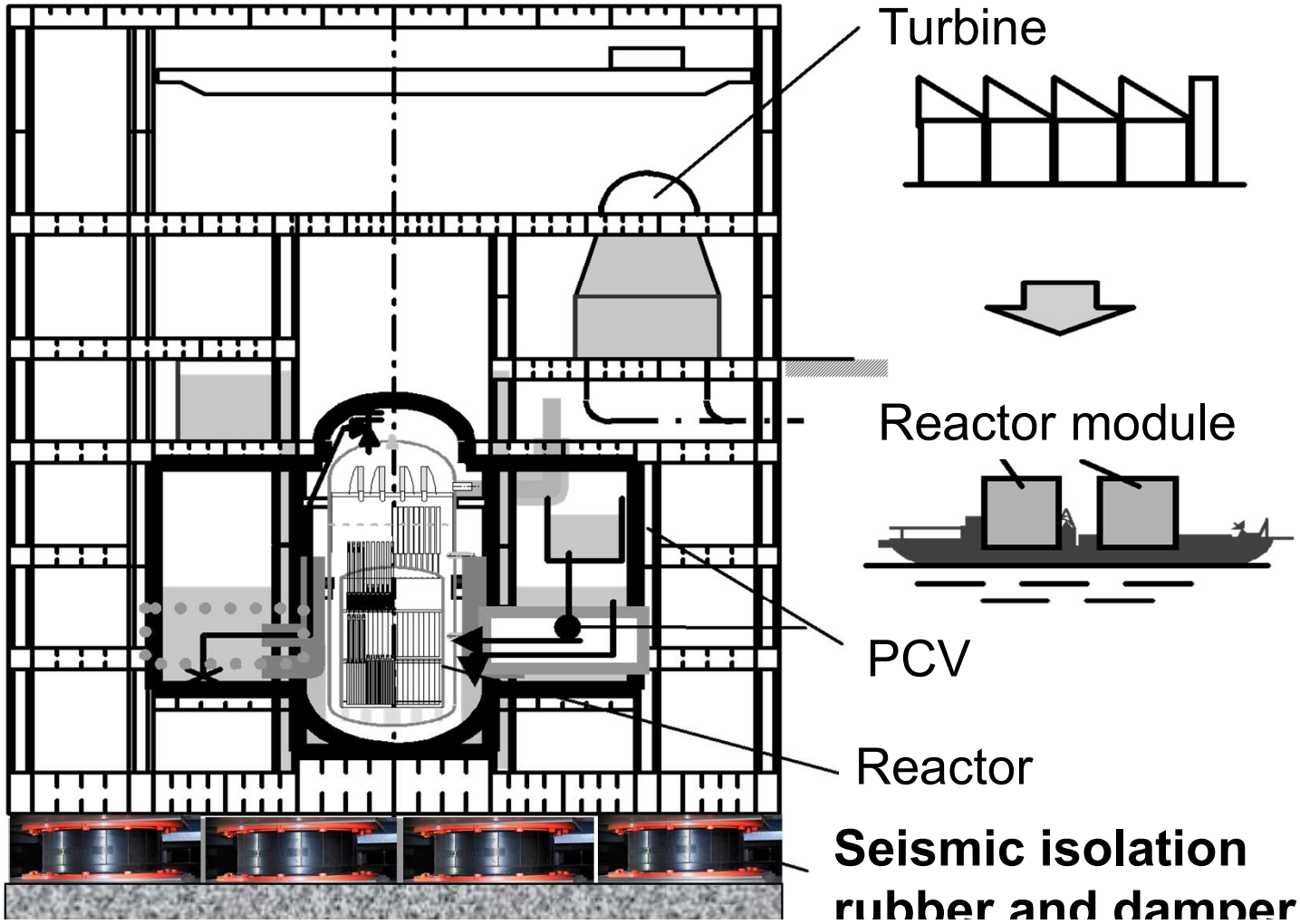
- FCVS will be installed under ground Pit (Banker)

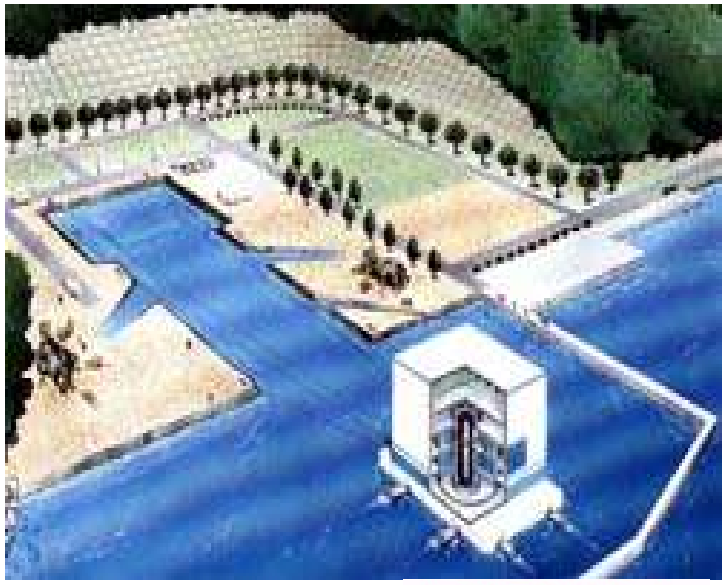


Measures against Aircraft Crash or Protect Missile



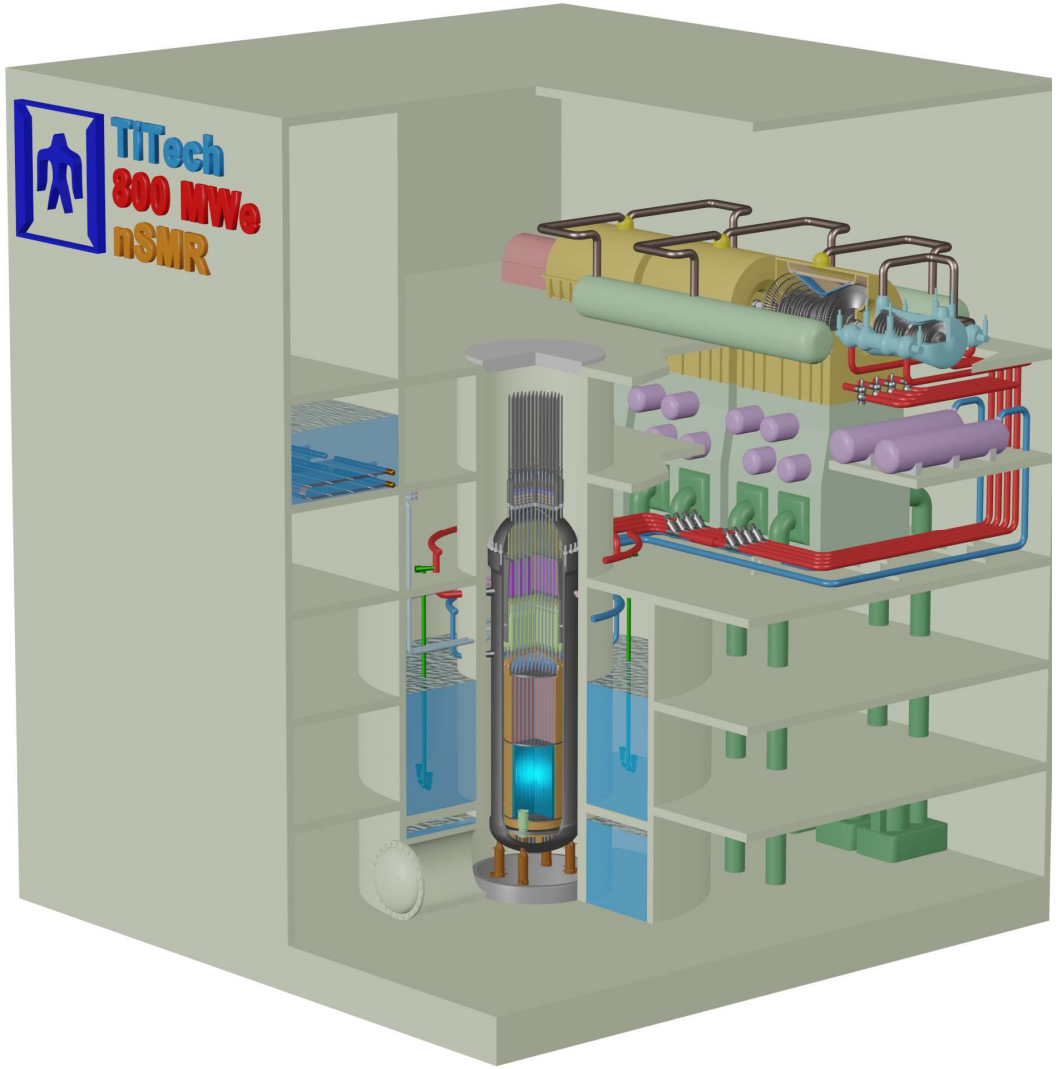
Seismic Isolation Structures, Ship Hull Structures

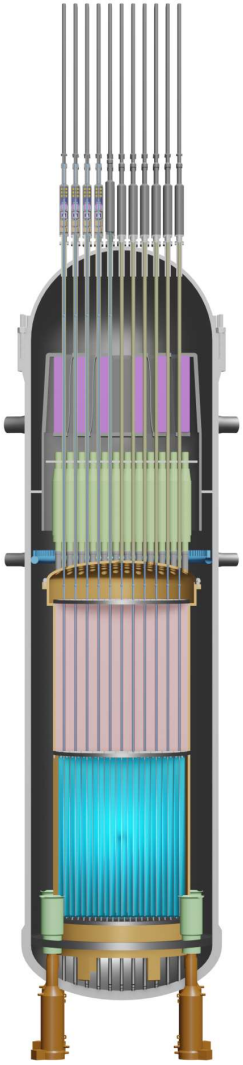


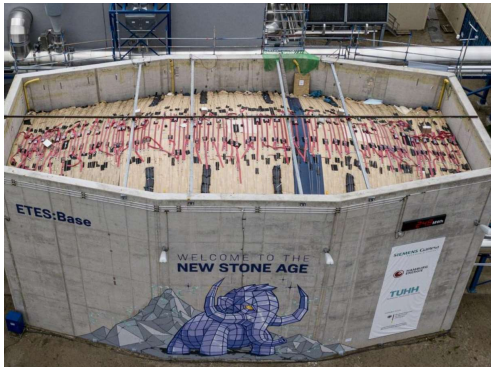


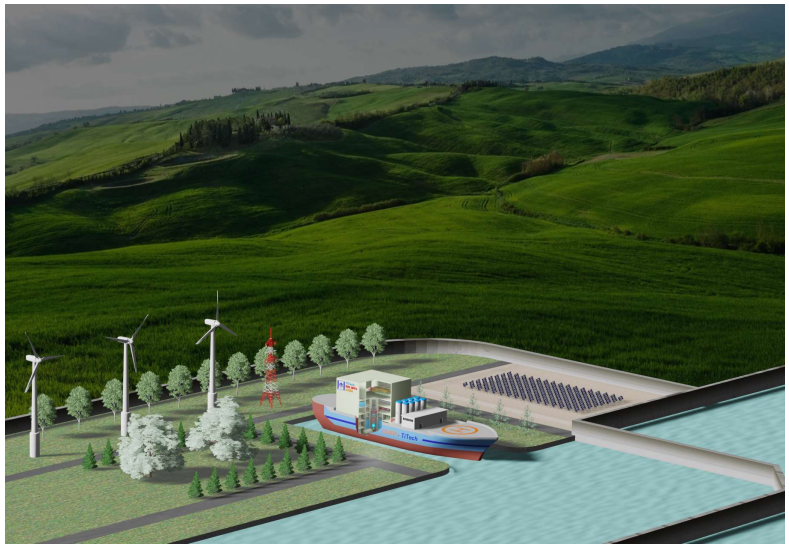
Oct. 2001 TOSHIBA

Load-following SMR with Reactor Internal Pumps and Heat storage will cooperate with renewable Energies

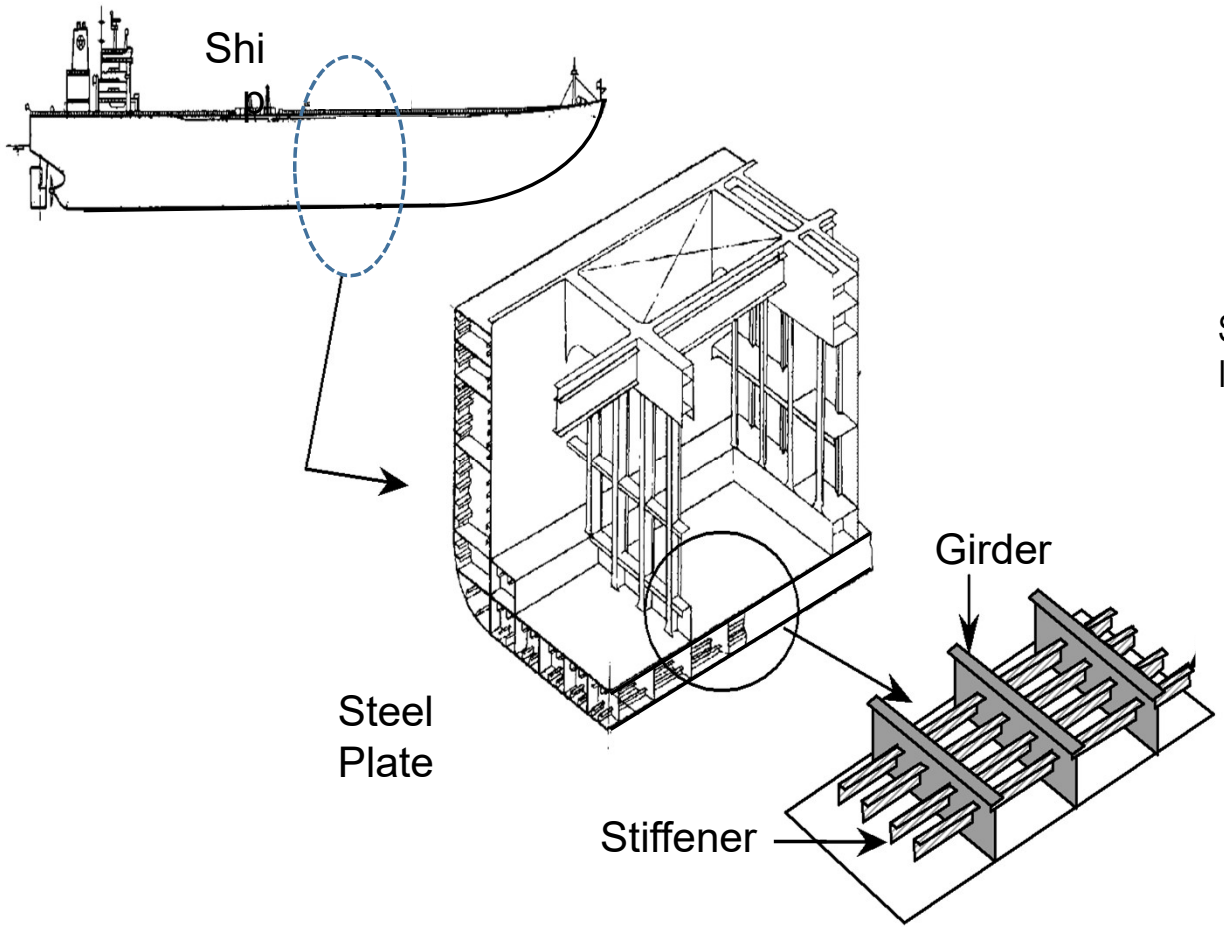


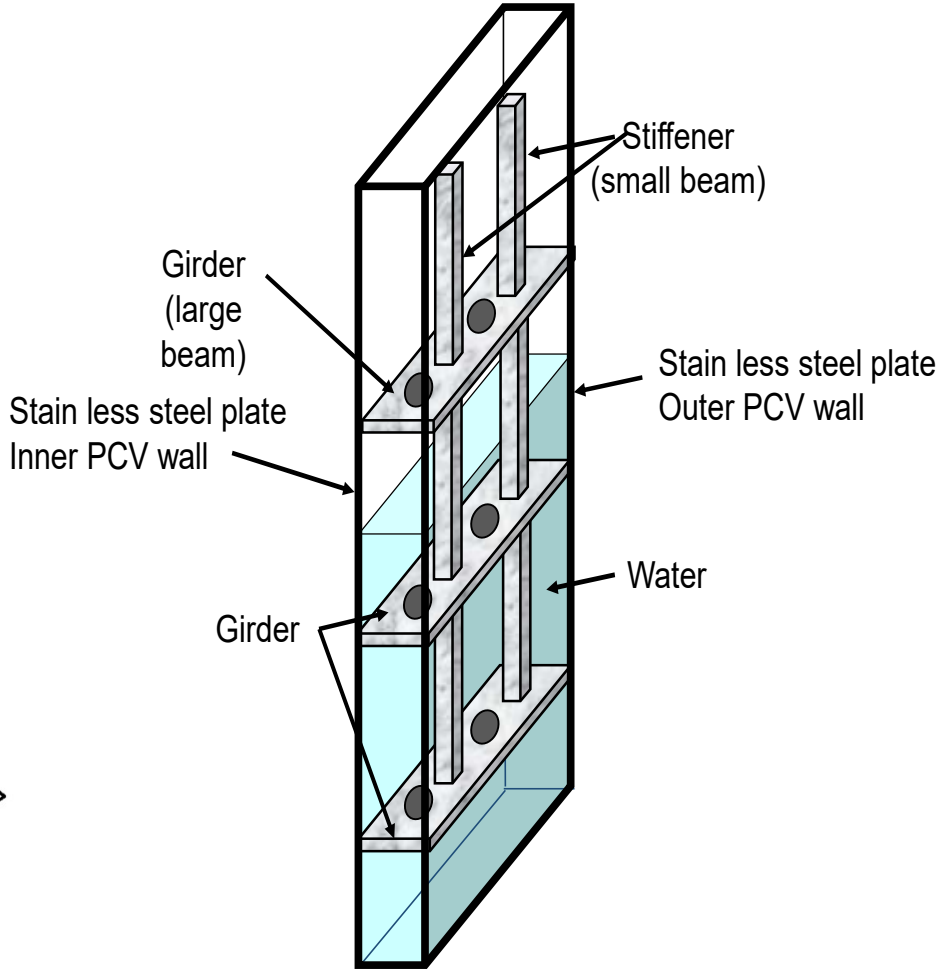






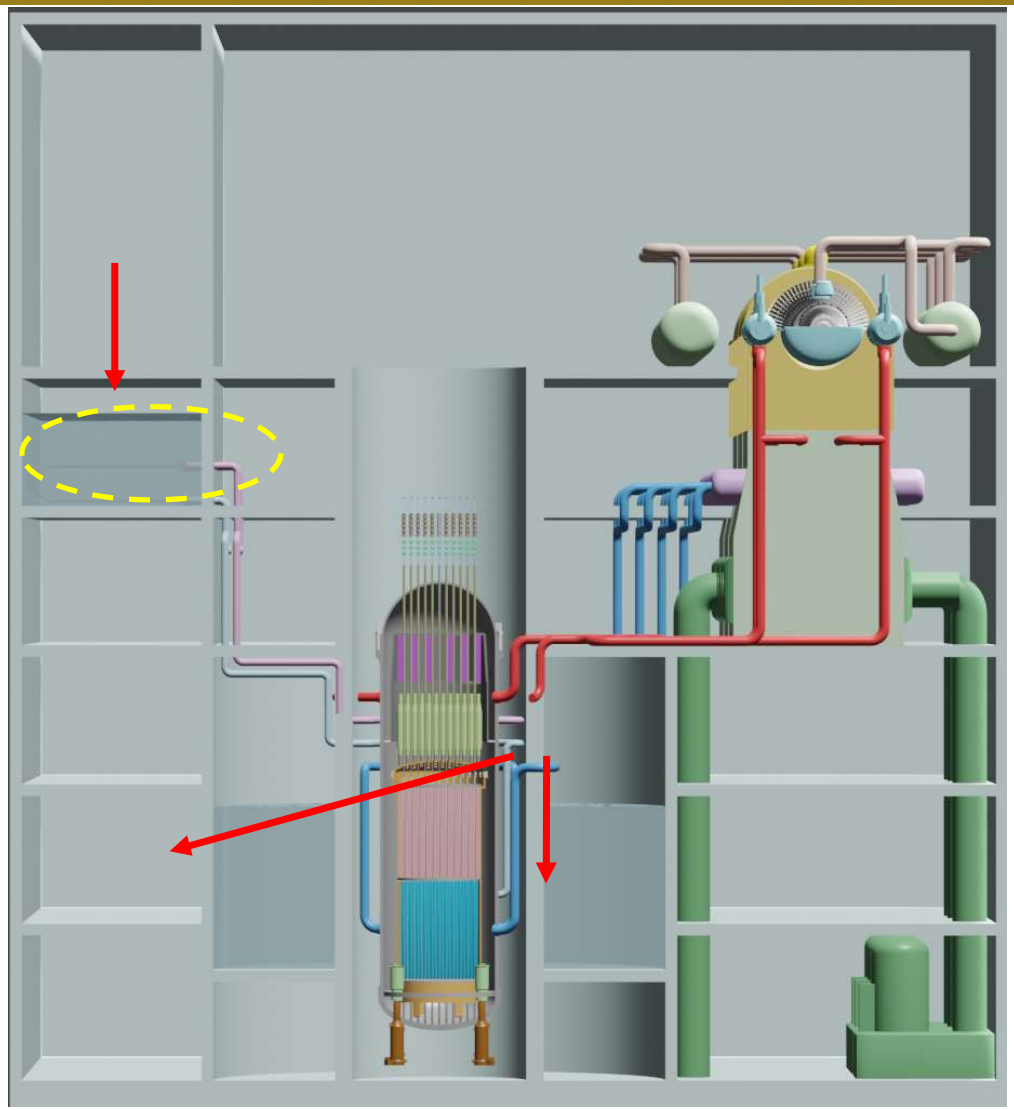
Ship Hull Structures





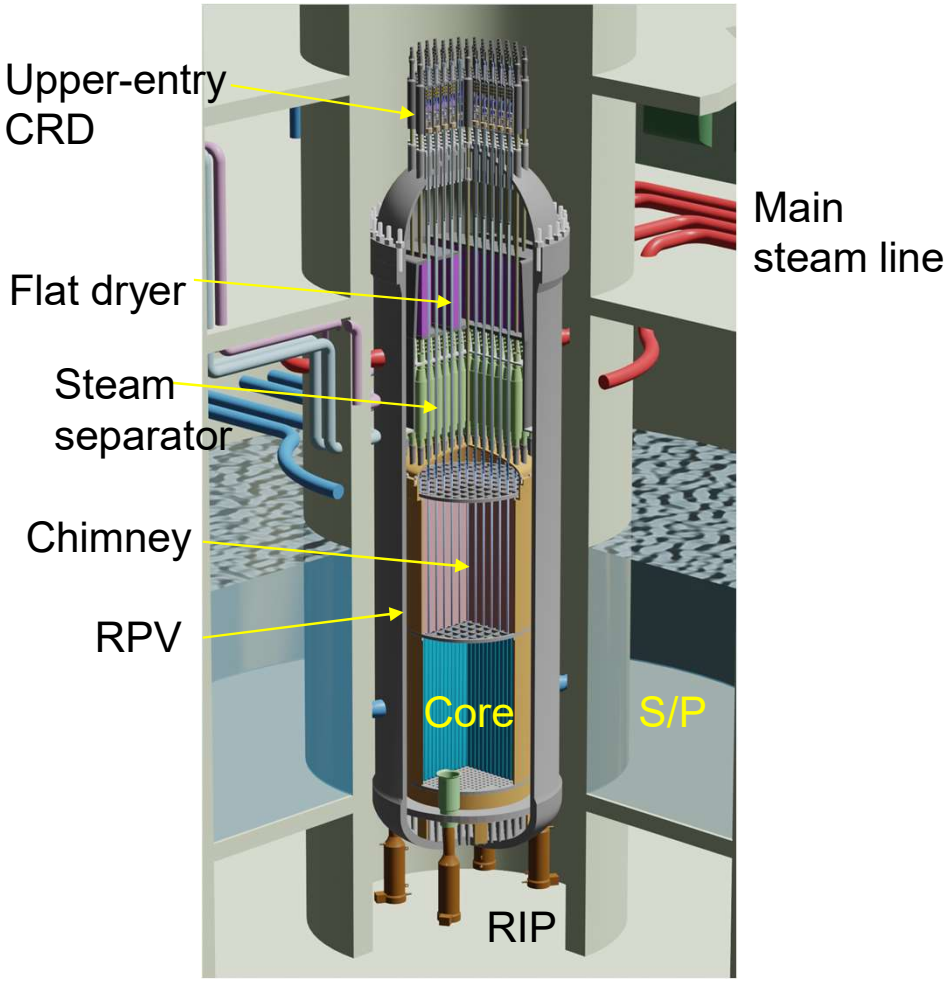
Isolation Condenser or Passive Cooling System

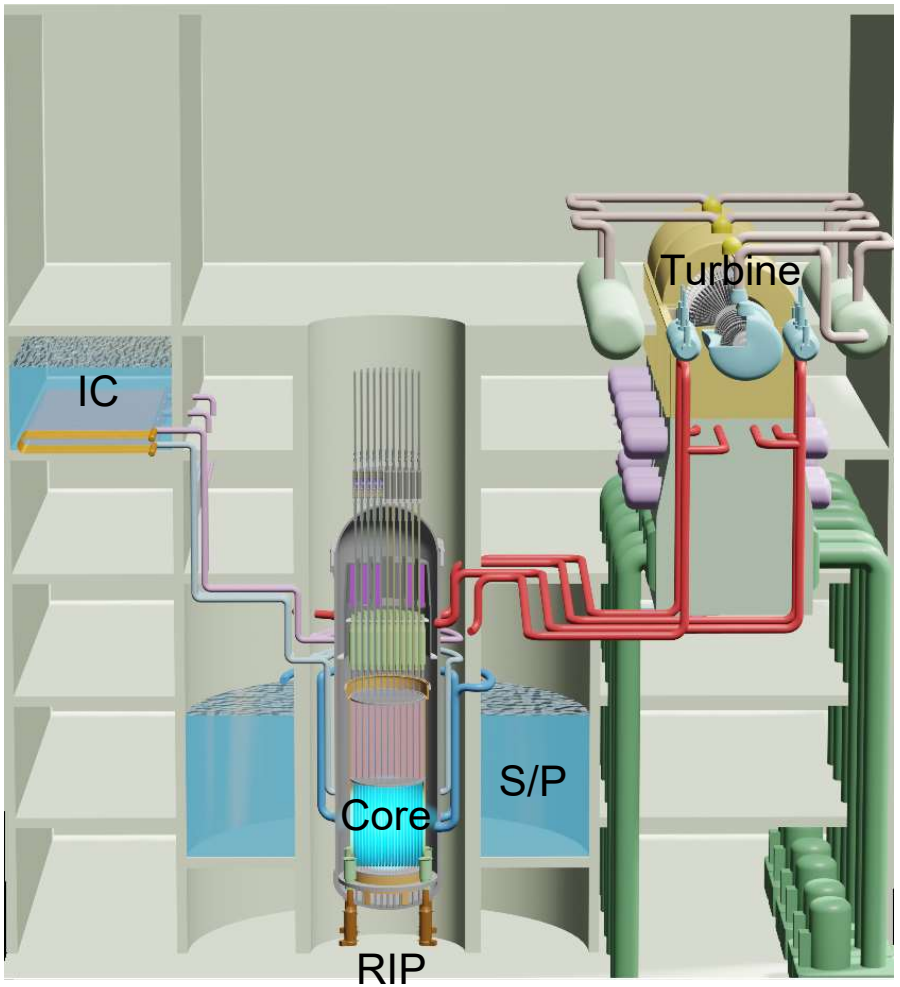
This is fine for the arrangement of the heat transfer tubes of the IC, so make sure that the heat transfer tubes are exposed to the cut surface so that they can be seen more clearly.



The water color of the suppression pool (S/P) should be light blue instead of gray.

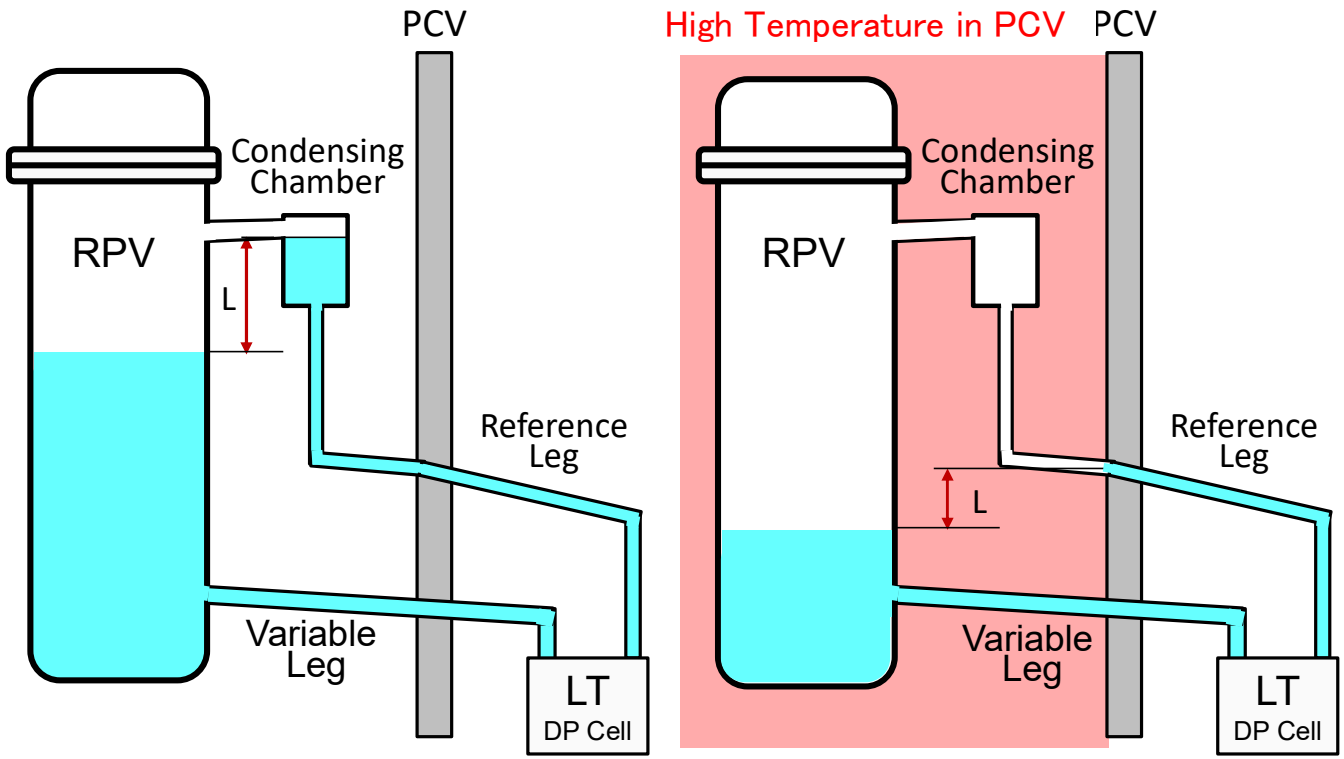
Load Follow with Fluctuating Renewable Energy



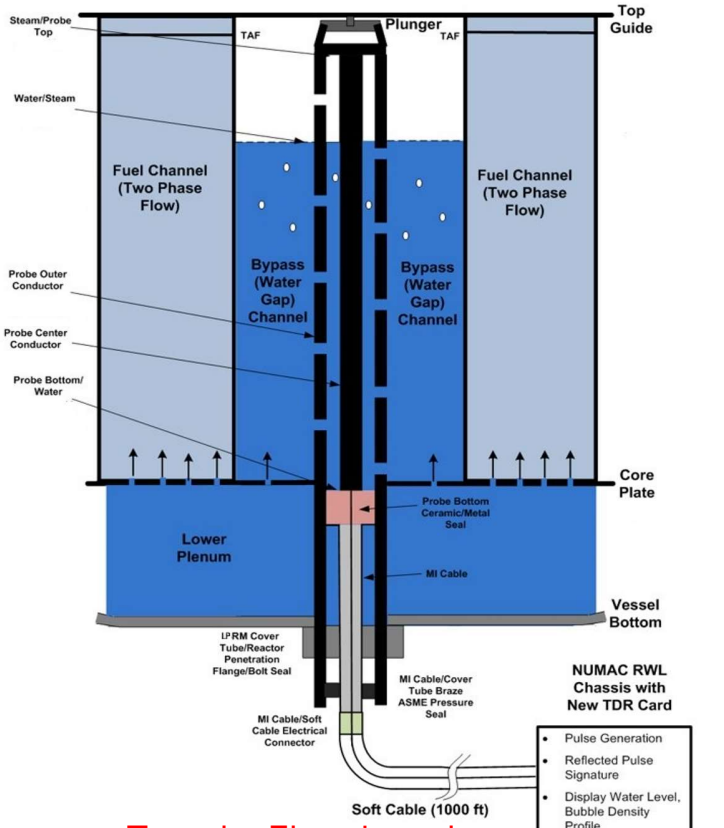


New Technology of Water Level Measurement: TDR

Water Level: Differential Pressure method



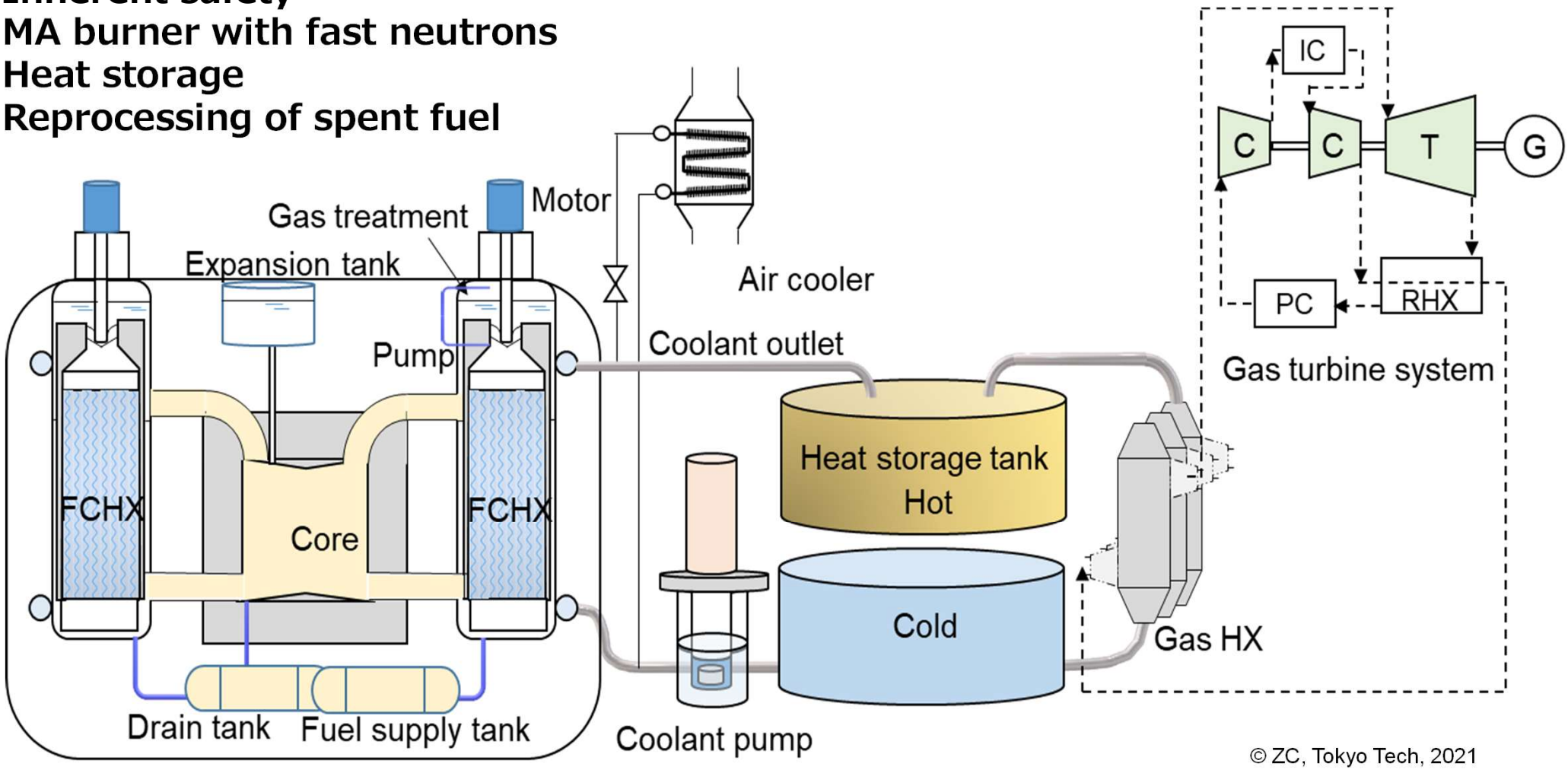
TDR: Time Domain Reflectometry



Tsugoku Electric and
Ge-Hitachi Nuclear Energy

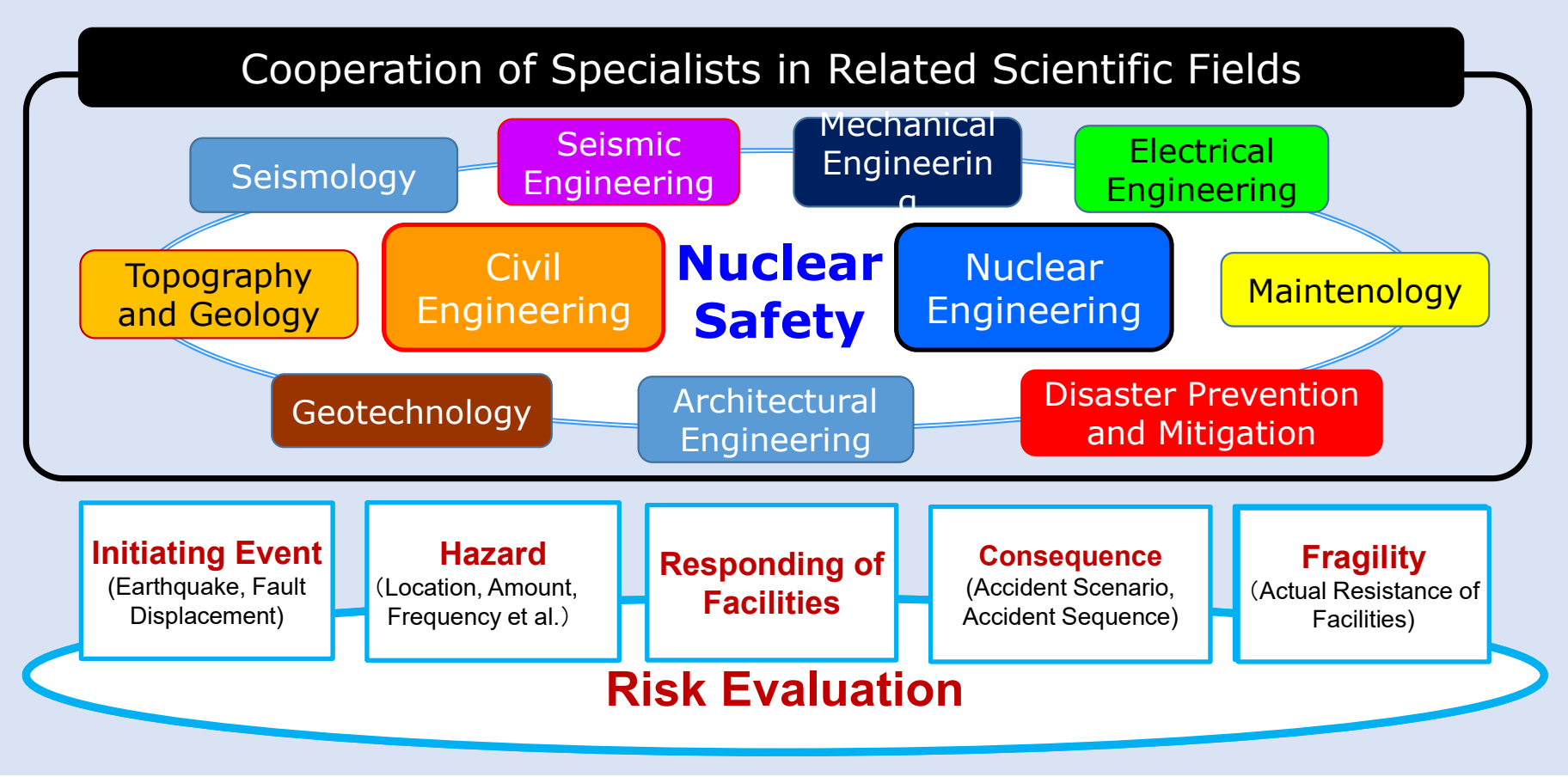
SMR: Integrated MSFR, Spent Fuel Reprocessing

Inherent safety
MA burner with fast neutrons
Heat storage
Reprocessing of spent fuel



Objectives of the Faults Committee

- AESJ established the committee to develop risk evaluation methods and measures for fault movement by engineering approach with cooperation of specialists in various scientific fields on Oct. 2013.



Damage by Displacement at Chuetsuoki Earthquake

Damage by High Acceleration

e.q. Service Water Tank
- ✓ Side Wall Buckling
- ✓ Damage of Anchorage Bolts

Damage by Subsidence and Displacement

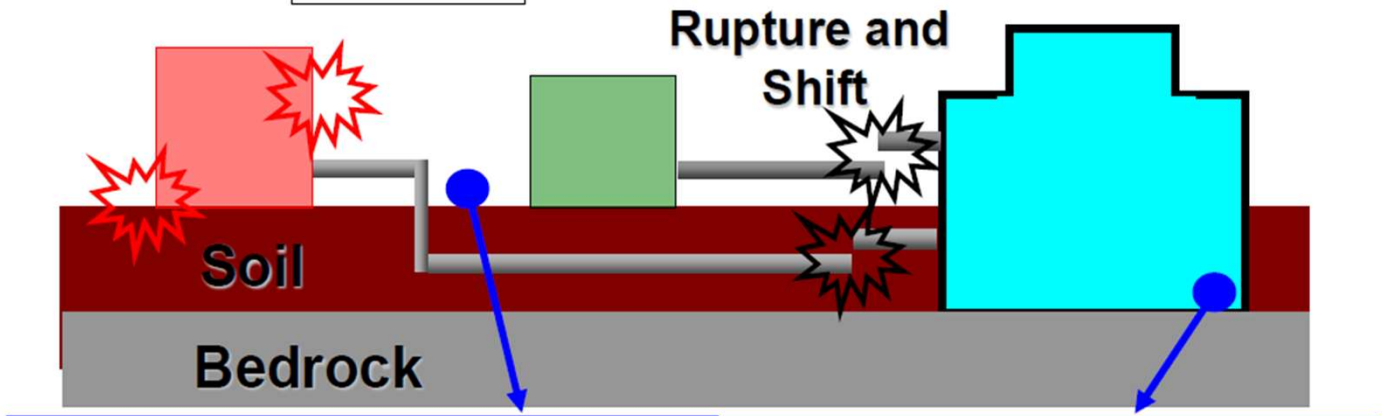
e.q. Transformer
- ✓ Connecting Bus Bar Shift

e.q. Fire Protection Piping
- ✓ Rupture

Class C

No or Minor Damage in the Building

Class As,A,B



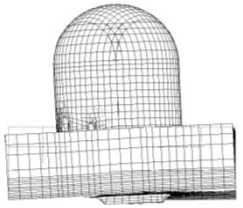
Damage Evaluation for Faults Movements

Input → Response → Capacity → Damage in Reactor Building

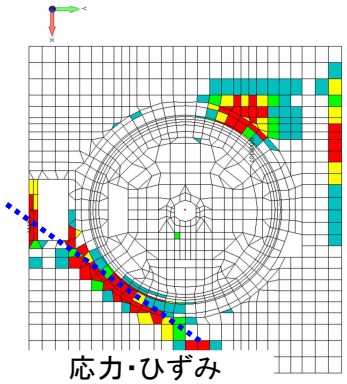
- **Faults Position**
- **Faults Dimensions**
- **Displacement of Faults**

3D Non Linier FEM

Allowable Limit

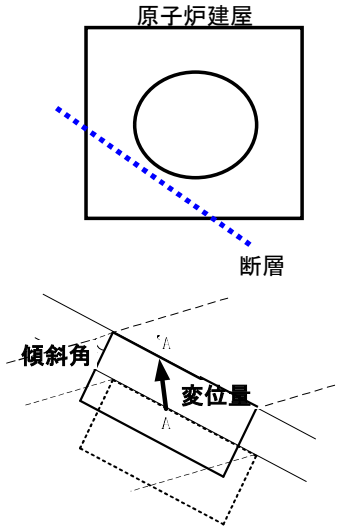


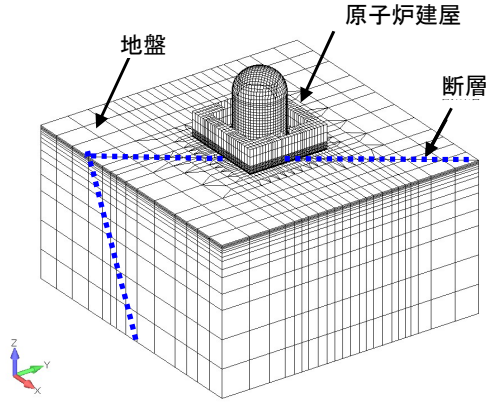
変形



応力・ひずみ

Damage Evaluation for Components and Piping



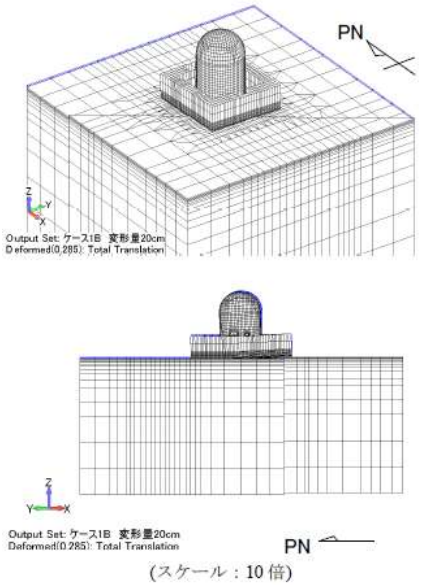


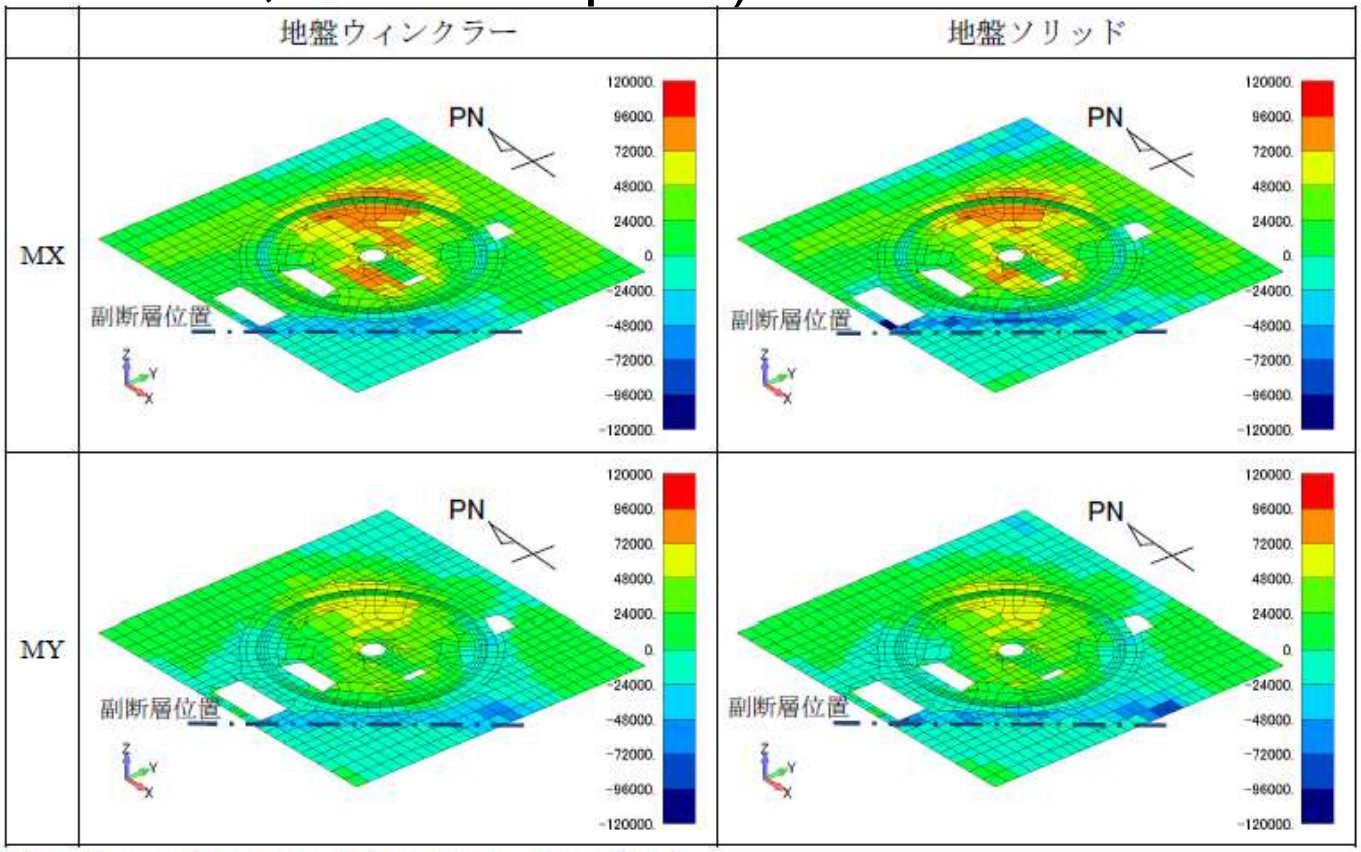
解析モデル
（全体モデル又は部分モデル）

Evaluation of Mat for Faults Displacement

FEM analysis were conducted for Mat
(Displacement 20cm, JANSI Reports)

Solid model



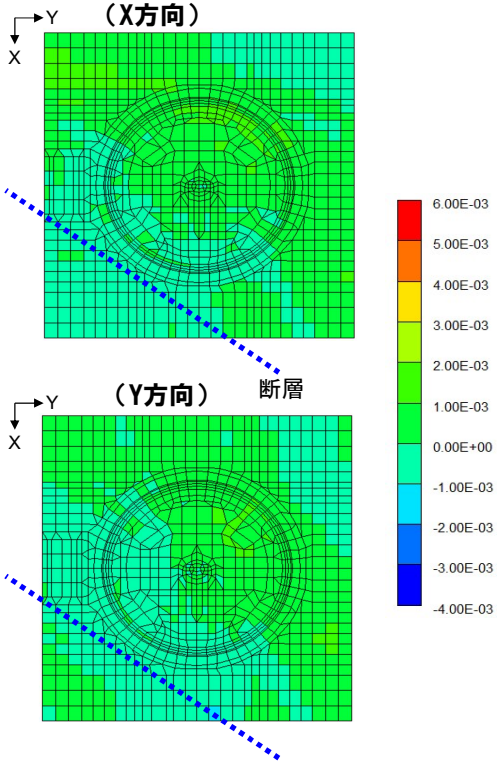


原子力発電所敷地内断層の変位に対する評価手法に関する調査・検討報告書
平成２５年９月

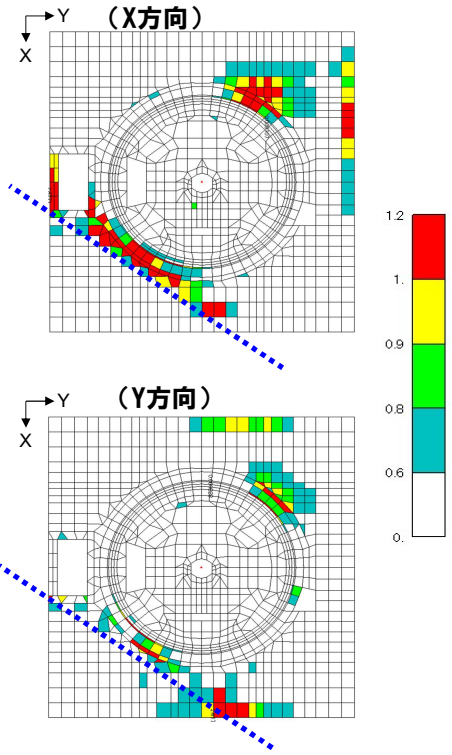
Evaluation of Mat Damage for Faults Displacement

Analysis Results (Stress, Strain)：Vertical Displacement 30cm

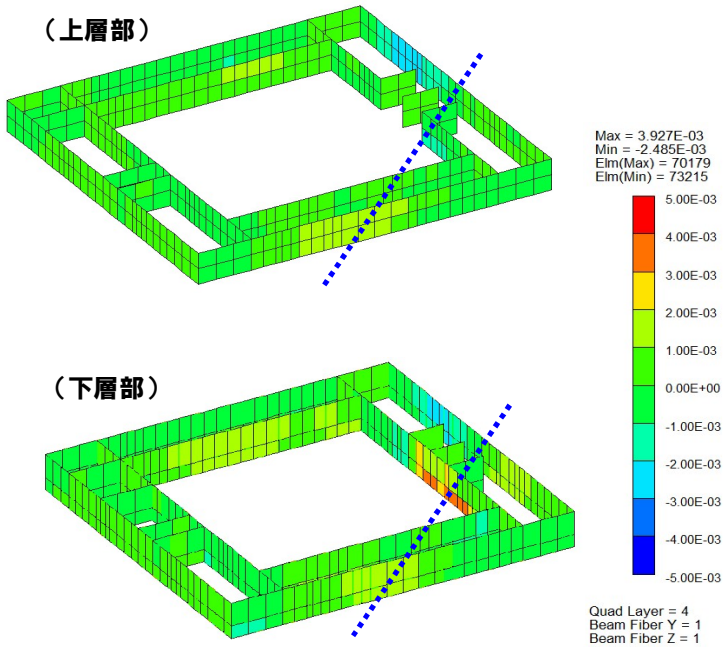
Strain in Iron Bars



Strain at outer Mat（Caribulated）



Reactor Building
Shear Strain



【Output】

Building Damage ← **•Additional Stress and Strain** → **Components and Piping**

Damaged Components and Piping for PWR

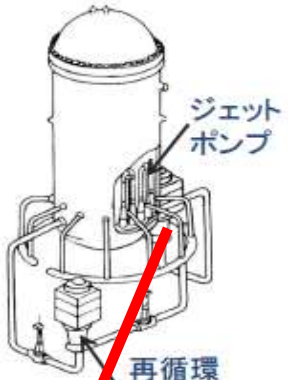
Almost all the damage in primary piping in PWRs are the event of LOCA Scenario.

Damaged Components and Piping（ABWR,BWR/5）

Almost all the damage in primary loop and ECCS piping in BWR's Containments Vessel are the event of LOCA Scenario.

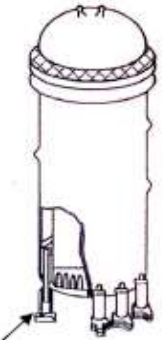
PLR and ECCS Piping and PCV

BWR-3/4/5/5改良型



外部再循環ポンプ
（ジェットポンプ採用により
ポンプの数を低減）

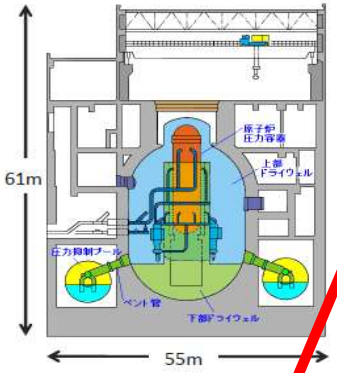
ABWR



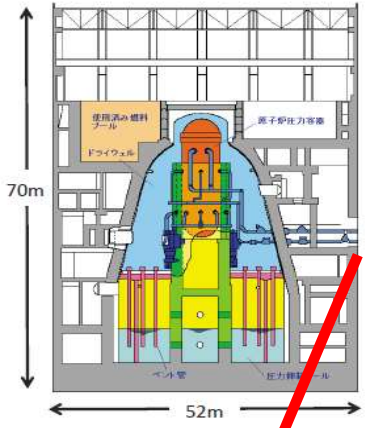
原子炉内臓再循環ポンプ
（外部ループ削除）

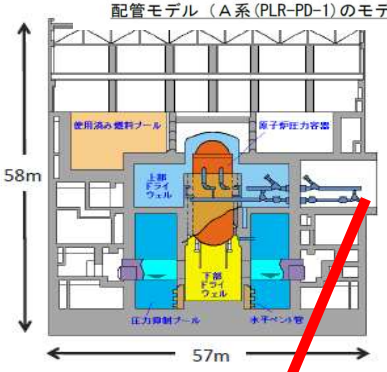
BWRの型式分類：原子炉格納容器

MARK-Ⅰ（改）

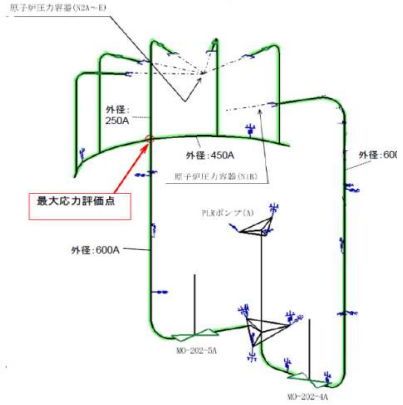


MARK-Ⅱ（改）





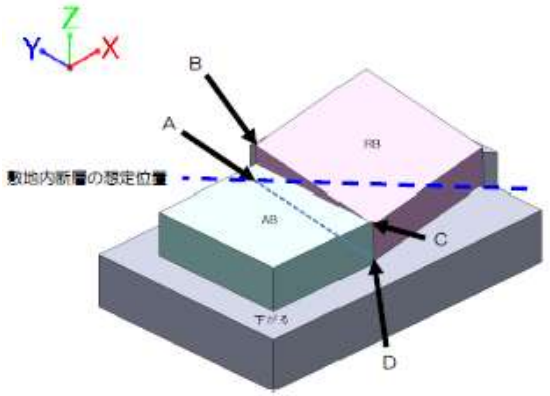
RCCV：Reinforced Concrete Containment Vessel（鉄筋コンクリート製格納容器）



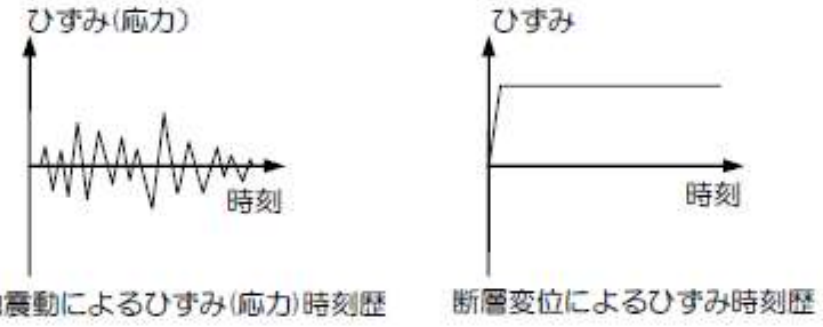
配管モデル（A系(PLR-PD-1)のモデルを示す）

Piping Damage FEM Analysis by Faults Displacement in Reactor Building

（JANSI Report）

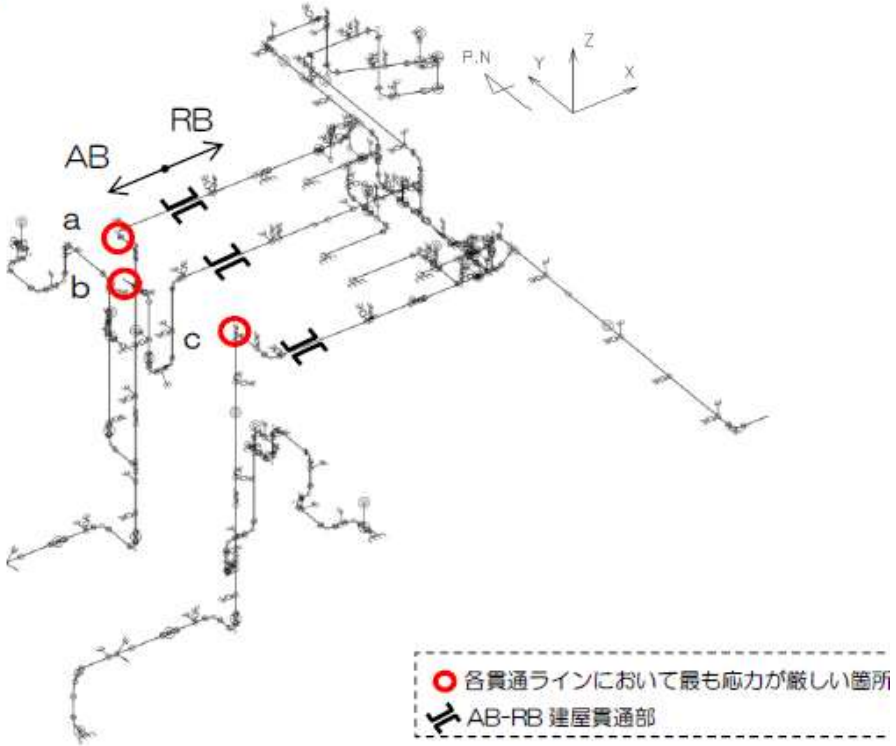


（敷地内断層の変位モード）
※わかり易さのため変位量を拡大している。



地震動によるひずみ(応力)時刻歴　　断層変位によるひずみ時刻歴

＜配管解析モデル＞



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平成２５年９月

Position Statement of AESJ on the Necessity of the Safety Review of the NPPs based on the Scientific and Rational Perspectives and Information Sharing

The Atomic Energy Society of Japan would like to promote by establishing a study committee,

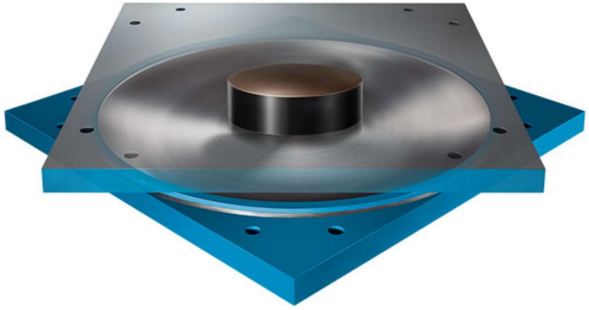
(1) An open fruitful discussion by experts in the area of earthquake, geology, geotechnical, civil, and aseismic design as well as other stakeholders such as academia professors, nuclear reactor engineers, regulators, and licensees,

(2) Investigation to select the most advanced scientific and rational judgment based on the domestic and global knowledge obtained so far, and,

(3) Continuous discussions and efforts in the global field in order to collect and organize this knowledge and to reflect the global standards and nuclear regulations, such as definition and evaluation method for the active faults and prevention of severe accidents, based on the accumulated database in the world.

Japan, as a frequent earthquake country, has a responsibility to resolve these issues to continue utilizing the nuclear power, based on the risks and importance levels in the scientific and rational manner.

Seismic tests and seismic isolation technology



Conclusion (1)

- Due to the accident at the Fukushima Daiichi Nuclear Power Station caused by the Great East Japan Earthquake on March 11, 2011, only 10 units were able to restart, and examinations for other restarts have been prolonged. After the Chernobyl nuclear accident in 1984, Toshiba started developing a simplified BWR (SBWR) in cooperation with GE and Hitachi, and after 1995, started developing SMRs.
- Nuclear power generation is a stable basic power source that does not emit CO_2 on the premise of ensuring safety, and has recently been re-evaluated as an attractive option from the viewpoint of energy security and environmental protection.
- Factors such as the recent sluggish power demand, power grid capacity limits, and initial investment limits to avoid risks do not favor large-scale plant output. To globalize nuclear power generation to mitigate the greenhouse effect, we need a small modular reactor (SMR) that can be easily adopted in any country and can be modularized and manufactured in factories with short construction periods.

Conclusion (2)

- The concept proposed here is to provide flexibility for different site conditions and power demands, reduce investment risk and promote public acceptance. Finally, the author also introduces a new LLBWR (Load-following and Long operating symbiotic BWR for renewable energy), which uses a reactor internal recirculation pump (RIP) to load follow with fluctuating renewable energy and enhance facilitates for stable grid control.
- Since a reactor building was usually a reinforced concrete structure, it was impossible to fabricate component modules with the building module. In the shipbuilding industry, ship hull structure is applied for a large size ship such as a 500,000 tons class. Though the ship hull structure is lighter than the reinforced concrete structure, it has enough strength and appropriate characteristics to apply for a nuclear reactor building. By using this ship hull structure, it is possible to fabricate modules containing RPV and PCV components and parts of the building at a shop at the same time.