Overview of Fukushima Accident and Lessons Learned

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Hideki Masui
Deputy Chief Nuclear Officer
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Contents

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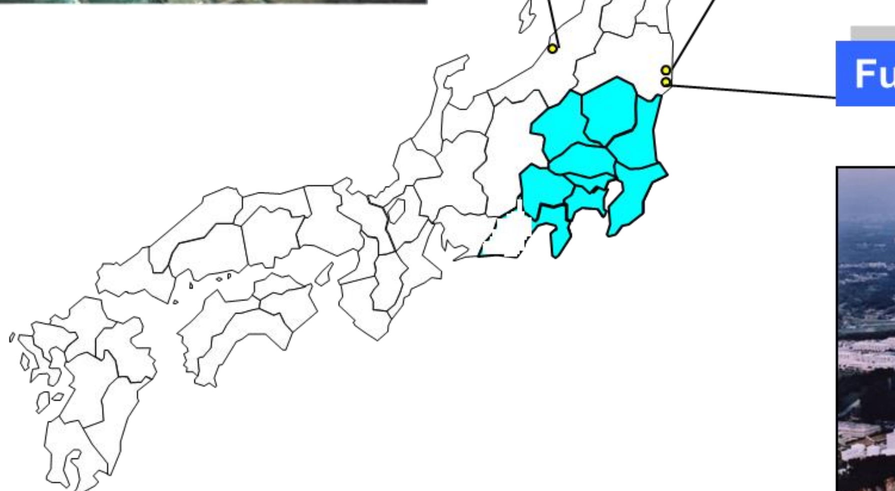
1.Overview of Fukushima Accident

TEPCO Nuclear Power Stations



Kashiwazaki Kariwa NPS 8212MWe

1 2 3 4 5 6 7

Fukushima Daiichi NPS 4696MWe

1 2 3 4 5 6

Fukushima Daini NPS 4400MWe

1 2 3 4

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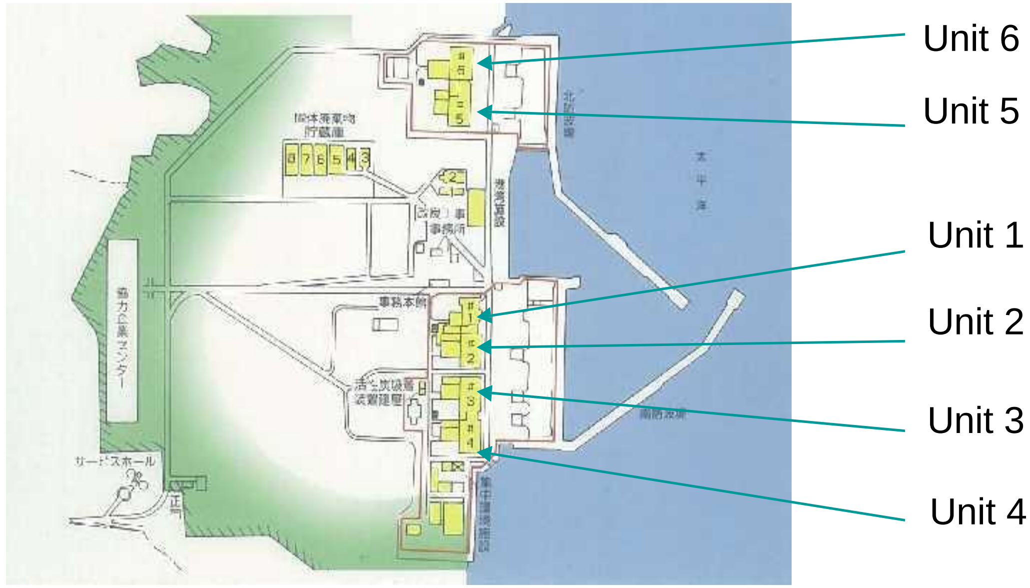
Outline of Fukushima Daiichi (1F) NPS



Unit	Commercial Operation	Type	Output (MWe)	Main Contructor
1	1971.3	BWR-3	460	GE
2	1974.7	BWR-4	784	GE/Toshiba
3	1976.3	BWR-4	784	Toshiba
4	1978.10	BWR-4	784	Hitachi
5	1978.4	BWR-4	784	Toshiba
6	1979.10	BWR-5	1100	GE/Toshiba

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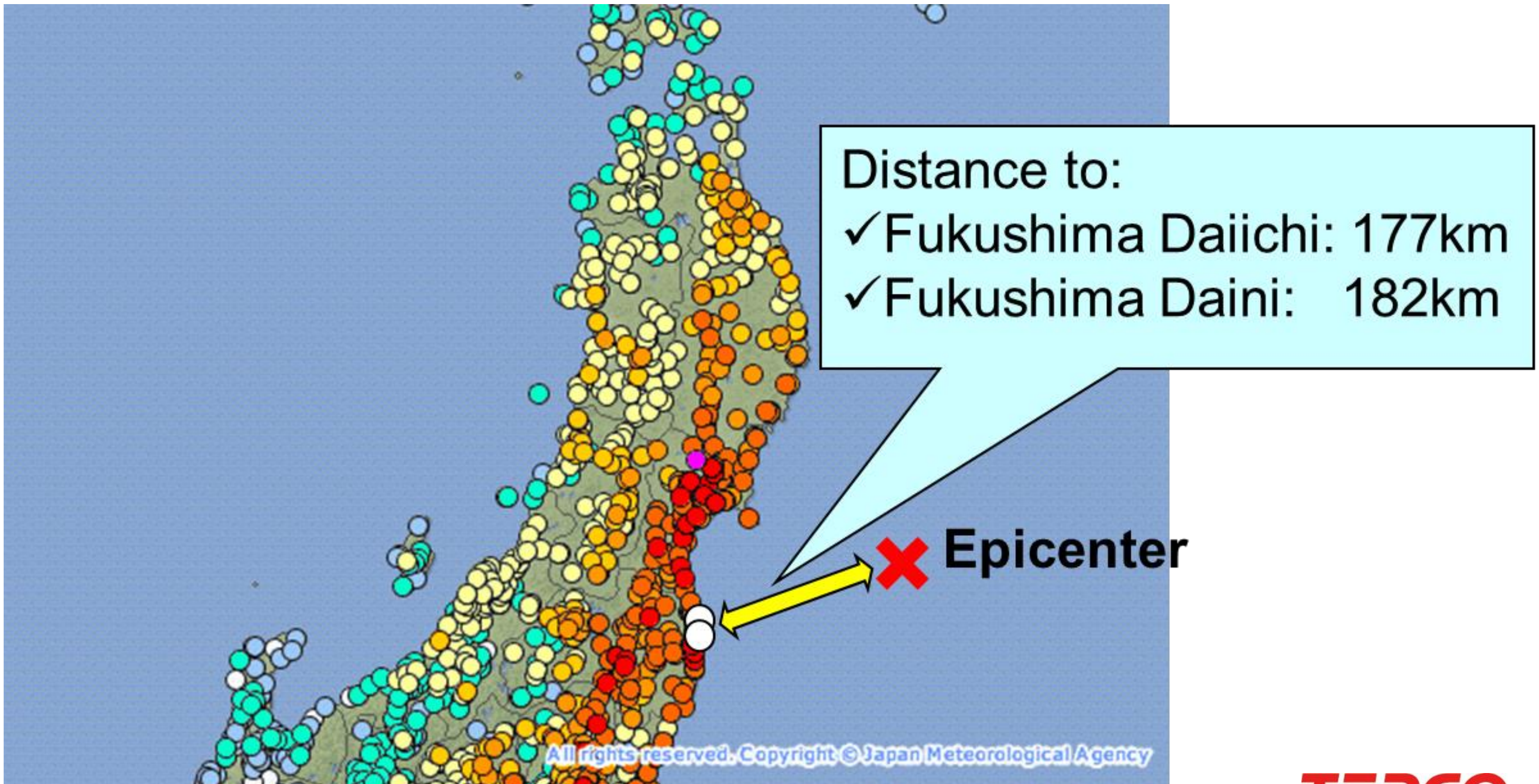
Great East Japan Earthquake

- 2011.3. 11(Fri) about 14:46
- Depth 25km, Magnitude 9.0
- The largest earthquake recorded in Japan
- Death toll about 18,400(including missing person)



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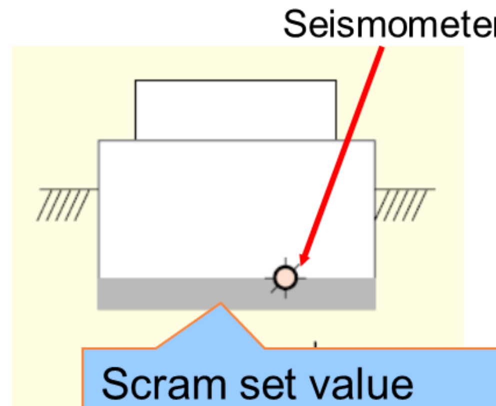
Earthquake Acceleration (Fukushima Daiichi)

Observation Point (R/B Base Mat)		Acceleration (gal) NS	EW	UD
Fukushima Daiichi	Unit 1	460※	447※	258※
		487	489	412
	Unit 2	348※	550※	302※
		441	438	420
	Unit 3	322※	507※	231※
		449	441	429
	Unit 4	281※	319※	200※
		447	445	422
	Unit 5	311※	548※	256※
		452	452	427
	Unit 6	298※	444※2	244
		445	448	415

Upper	Observed Value
Lower	



Scram set value
Horizontal : 135gal
Vertical: 100gal

※: Recording was terminated in 130 – 150 seconds after earthquake

Damage caused by Earthquake

No significant damages to safety-related SSC were caused by the quake.

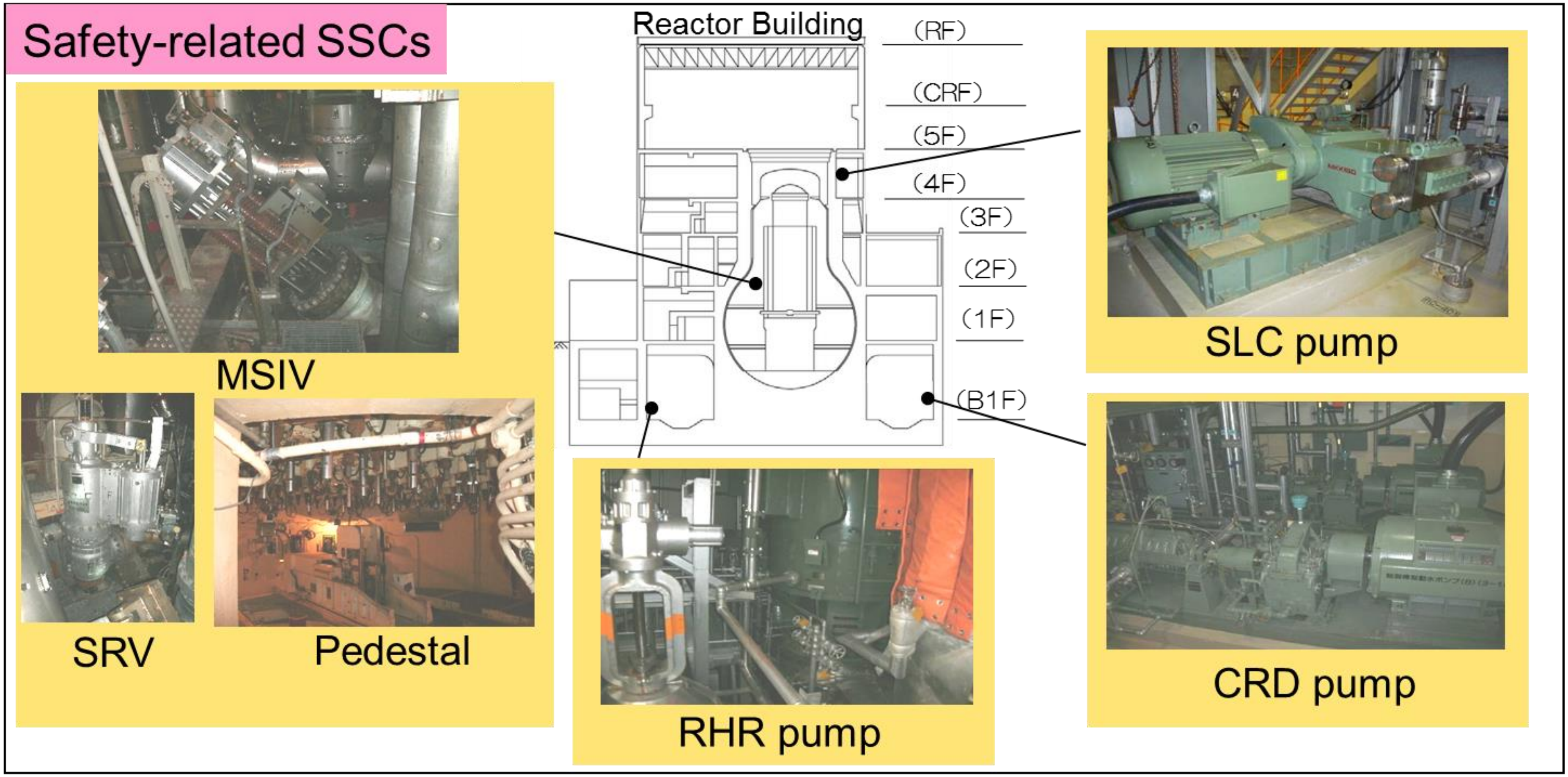
1. Plant response between quake and tsunami shows no indication of LOCA or MSLB.
2. Seismic response analysis shows no damage on safety-related SSCs
3. Walkdown of Fukushima Daiichi unit 5 and 6 shows no damage on safety-related SSCs

Example of Seismic Response Analysis

Equipment (Mpa)		Unit 1		Unit 2		Unit 3	
		Calculated value	Assessment criteria value	Calculated value	Assessment criteria value	Calculated value	Assessment criteria value
Reactor core support structure		103	196	122	300	100	300
Reactor pressure vessel		93	222	29	222	50	222
Main steam system piping		269	374	208	360	151	378
Reactor containment vessel		98	411	87	278	158	278
RHR (SHC for Unit 1)	pump	8	127	45	185	42	185
	piping	228	414	87	315	269	363

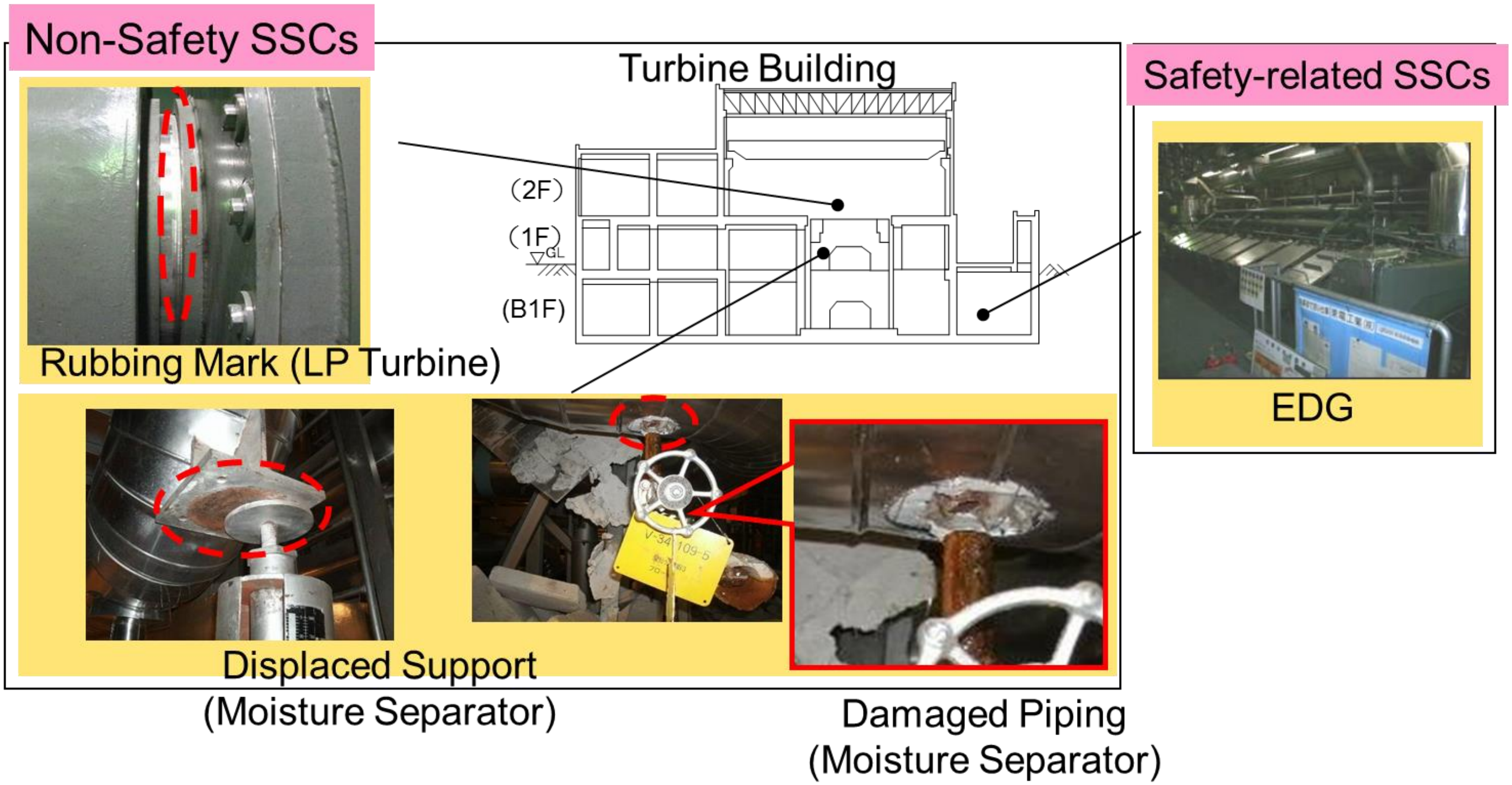
Walkdown of Unit 5 and 6 (Reactor Building)

- No significant damage was identified in Safety-related SSCs



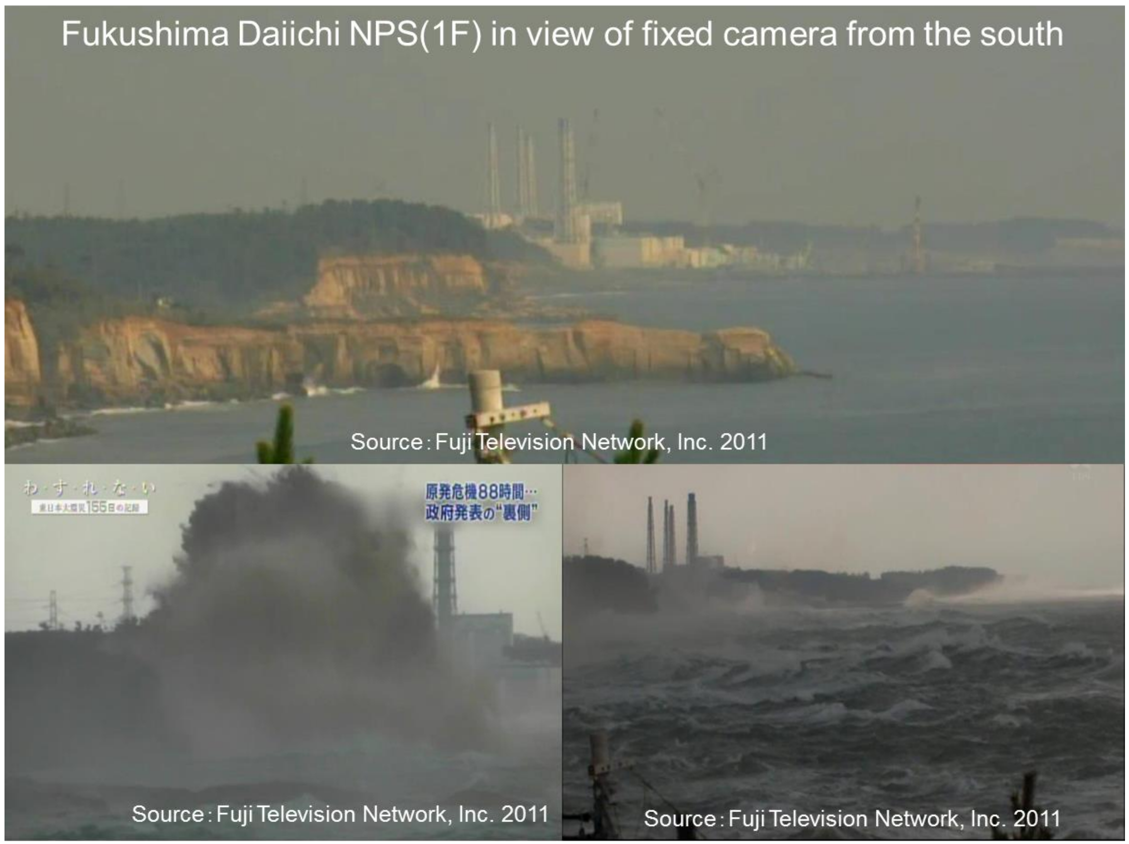
Walkdown of Unit 5 and 6 (Turbine Building)

- No significant damage was identified in Safety- SSCs
- Some damages were identified in Non-Safety SSCs



Height of Tsunami at Fukushima Daiichi

Observed Value (Inundation Height)	11.5-15.5m
Design Value (Tsunami Height)	5.7-6.1m



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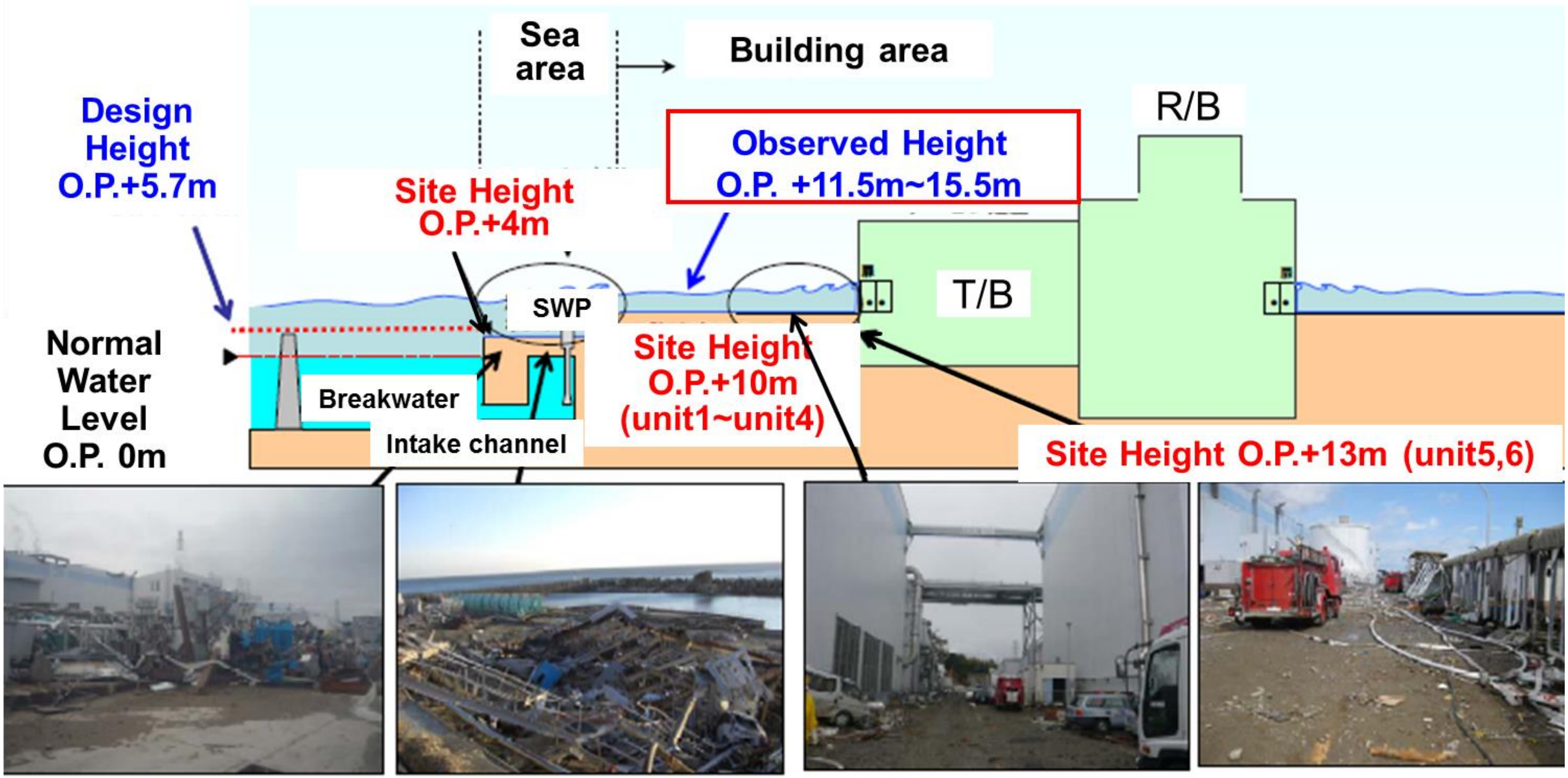
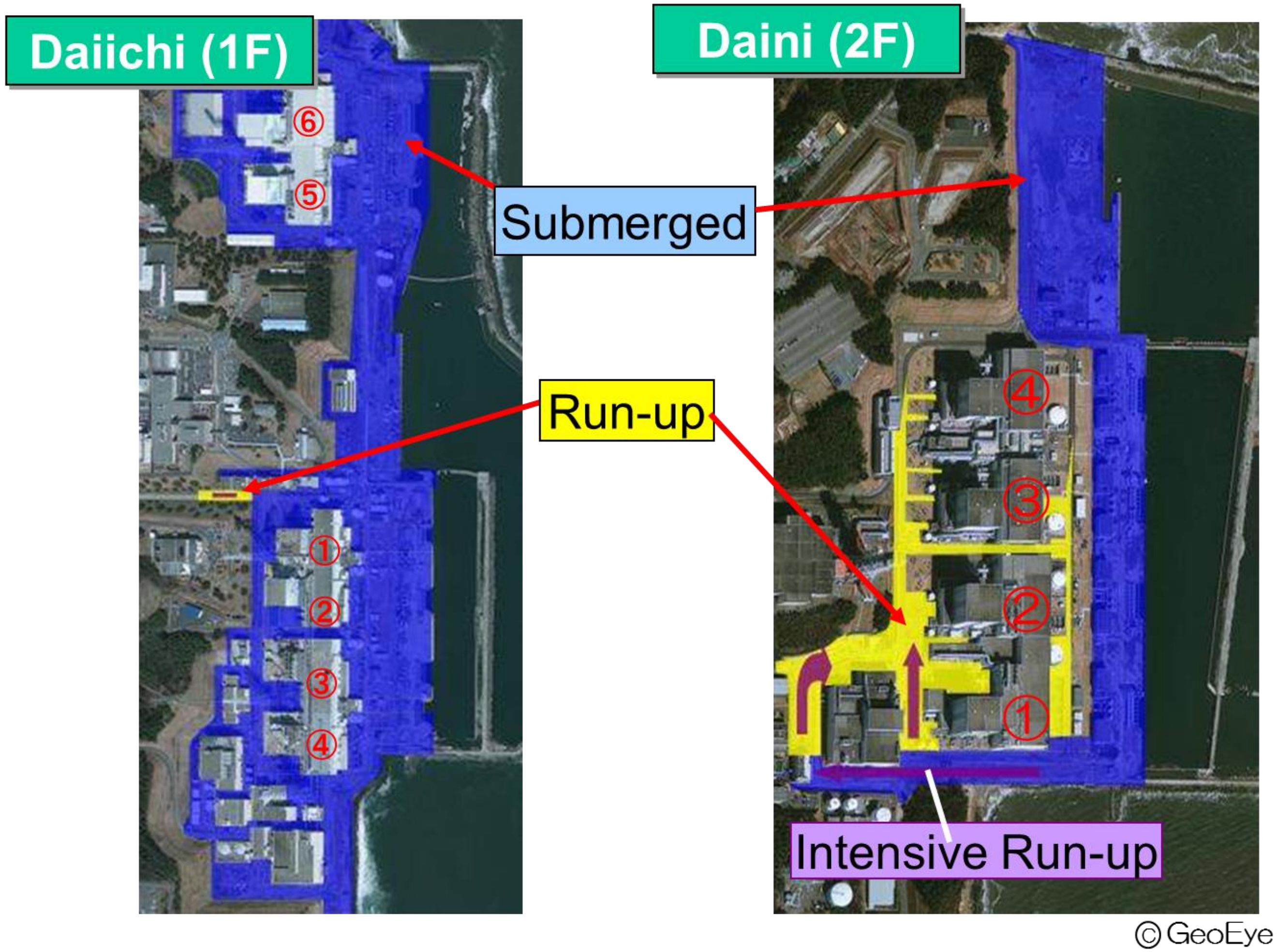
Situation of Tsunami (Fukushima Daiichi)



Submerged Area



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Tsunami Observed at Fukushima Daiichi

Pictures taken from around unit 5

Picture taken from Radwaste Building

Tank Height 5.5m (Site Height 10m)

Completely Submerged

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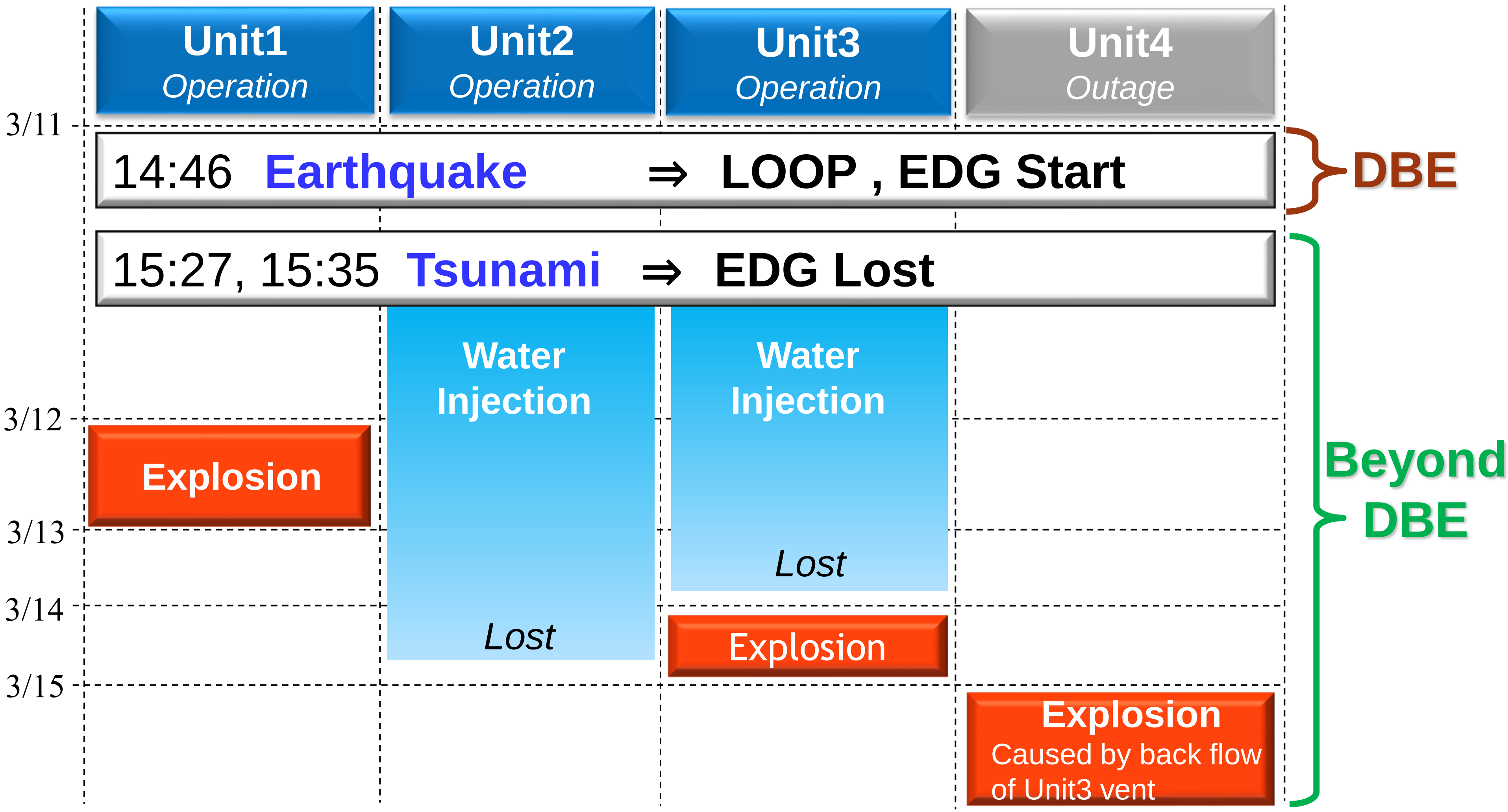
Events at Fukushima Daiichi



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Difficulty with Immediate Recovery Action (1)

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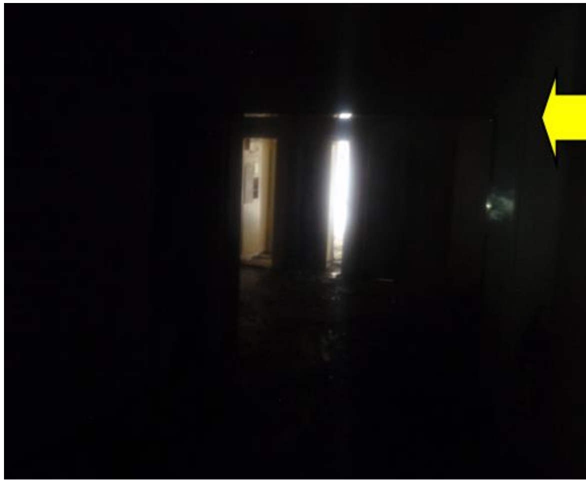
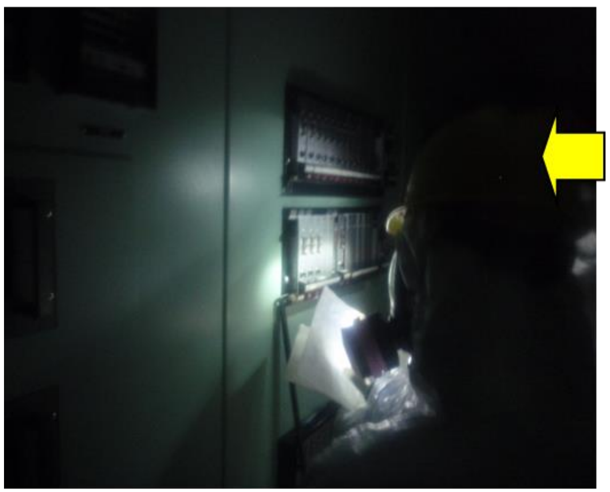
Difficulty with Immediate Recovery Action (2)



Work under darkness

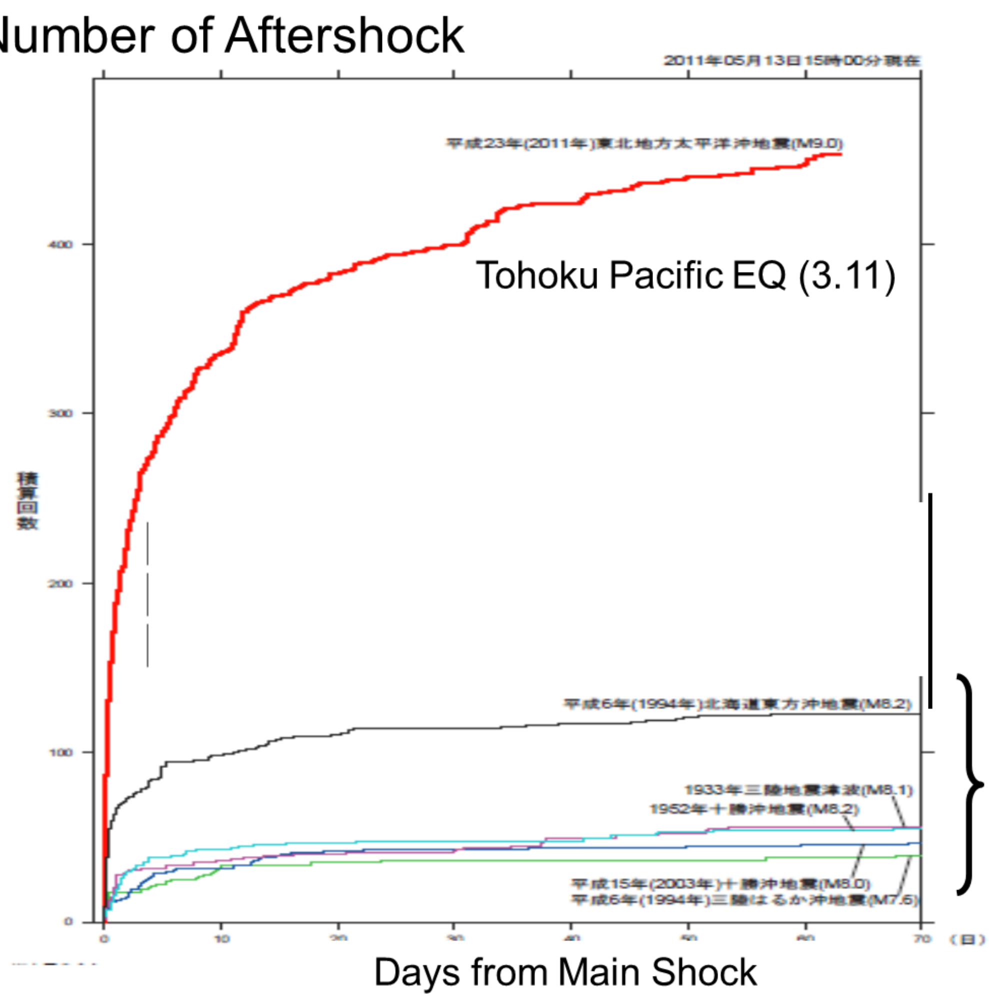
Battery for instrumentation



Checking parameter reading with flashlight

Operator with full-face mask in MCR

Difficulty with Immediate Recovery Action (3)



Frequent aftershock posed obstacle to recovery work

Past EQ

(magnitude 5 or more)

Press release from JMA

2. Lessons Learned and Safety Upgrade

Causes of Accident

Insufficiency of

1) Measures against Tsunami
2) Measures for severe accident
3) Preparation for emergency response

↓ Root Cause

Insufficiency of

1) Safety 1st Mentality
2) Technical Competence
3) Communication Capability

Redefinition of Vision and Mission

Vision	Keep the Fukushima Nuclear Accident firmly in mind; we should be safer today than we were yesterday, and safer tomorrow than today; we are committed to become nuclear power plant operators that keep creating unparalleled safety.
Mission	Nuclear power generation with the highest safety level and efficiency in the world
Values	1. Safety first mentality 2. Technical competence 3. Communication capability

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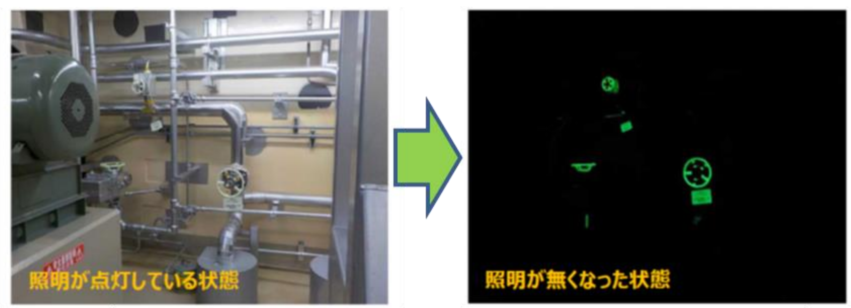
Safety first mentality

- Reflection day of Fukushima accident
- Safety upgrade
- Independent oversight and monitoring
- Enhancement of management observation
- Dialogue with cooperating companies
- Safety proposal competition

On-site check of NSAB

*NSAB: Nuclear Safety Advisory Board



example of safety proposal
(Luminous paint (visibility at SBO))

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Evaluation flow of Natural Hazards

44 natural hazards
(picked up from various documents such as NRC, ASME, etc.)

↓

Incident location
Distant enough not to affect NPP
→ Yes: Snow avalanche, Sandstorm, etc.

↓ No

Time to speed
Long enough to detect and eliminate the hazard
→ Yes: Extreme High temperature (air, seawater), etc.

↓ No

Effect to facilities
Within original design before Fukushima accident
→ Yes: Frost, Dense fog, etc.

↓ No

Effect to facilities
Covered by other hazard
→ Yes: Hail, Storm surge, etc.

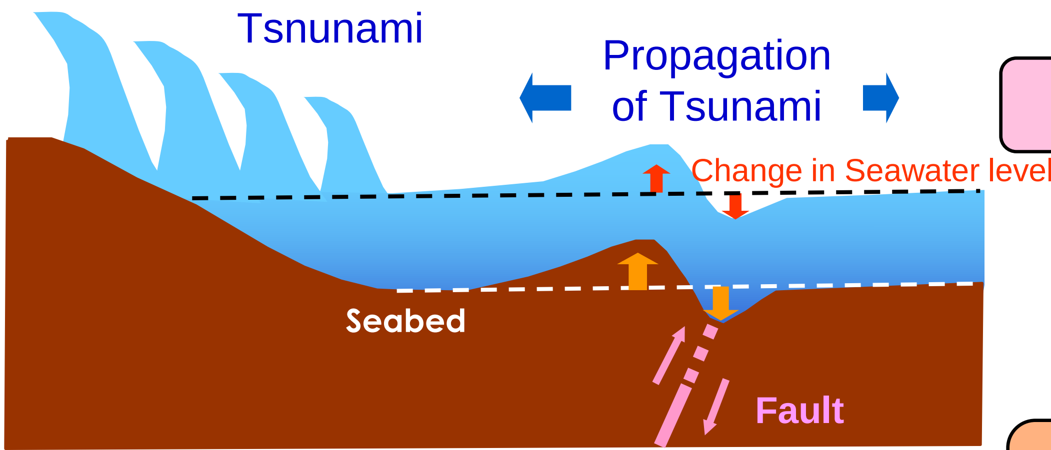
↓

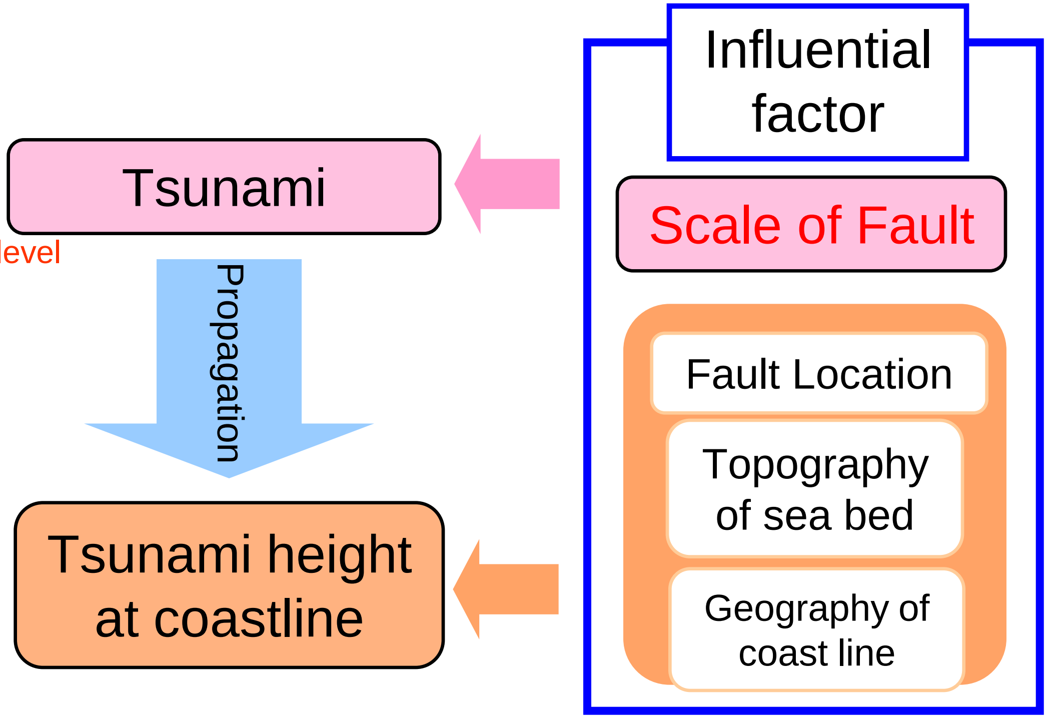
11 events

Earthquake, Tsunami, Tornado, Volcano, High wind, Extreme low temperature, Heavy rain, Snow cover, Lightning strike, Landslide and Biological event

Mechanism of Tsunami

- Tsunami is generated by deformation of seabed caused by underneath fault movement
- Therefore the extent of deformation has very dominant effect to determine the height of tsunami.
- Postulation of fault scale is the most important factor upon estimating tsunami height

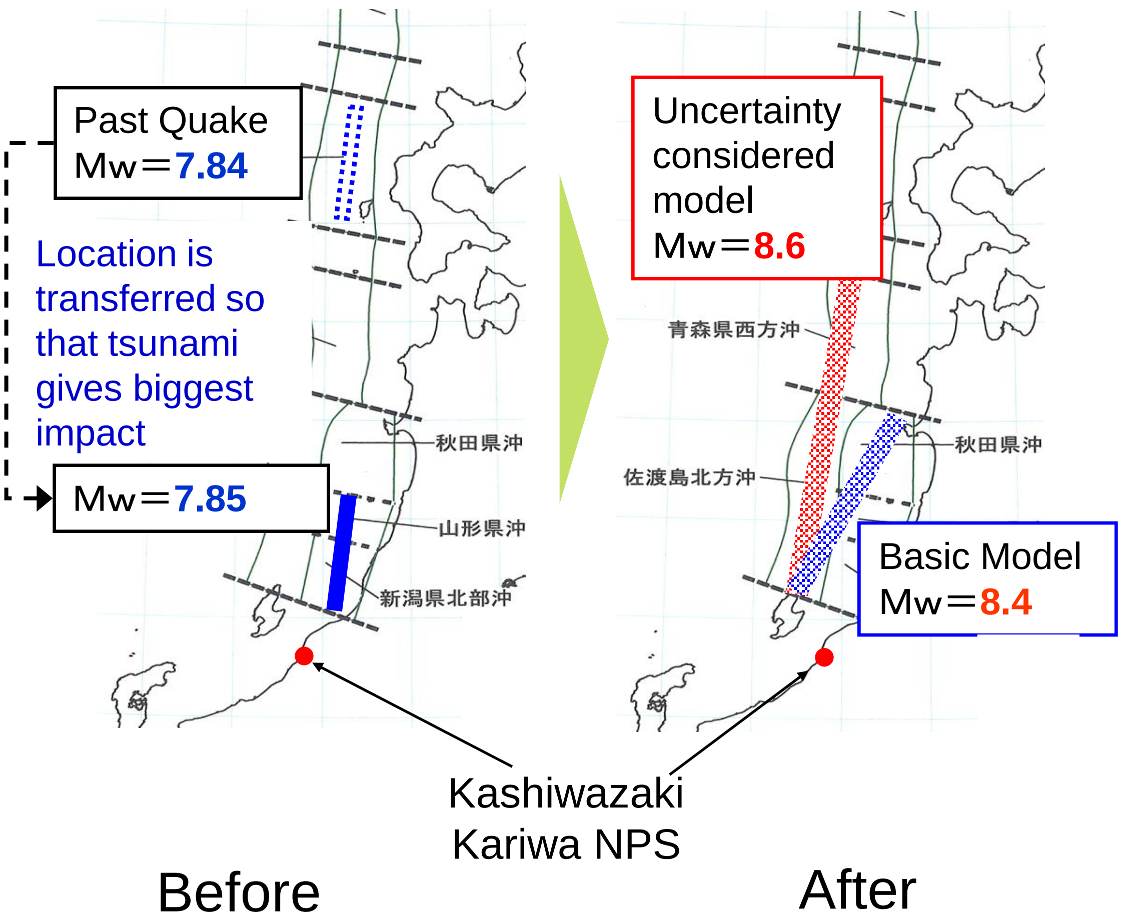




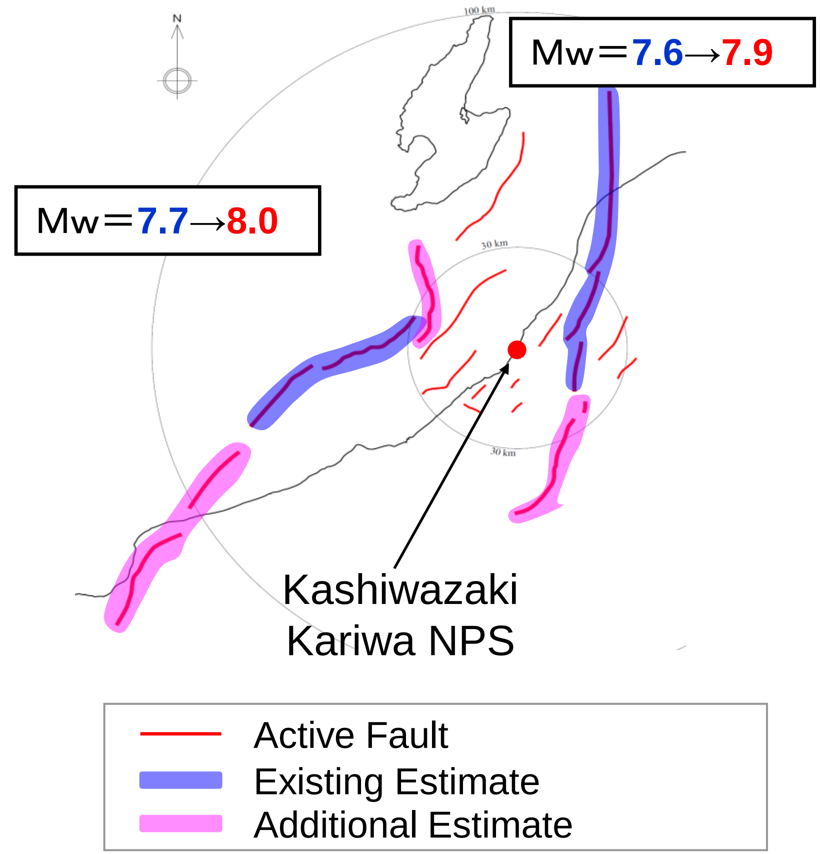
Formulation of Design Base Tsunami (1)

■ Based on new knowledge about fault, scale of faults has been revised

Sea of Japan Eastern Ridge



Seaside around NPS



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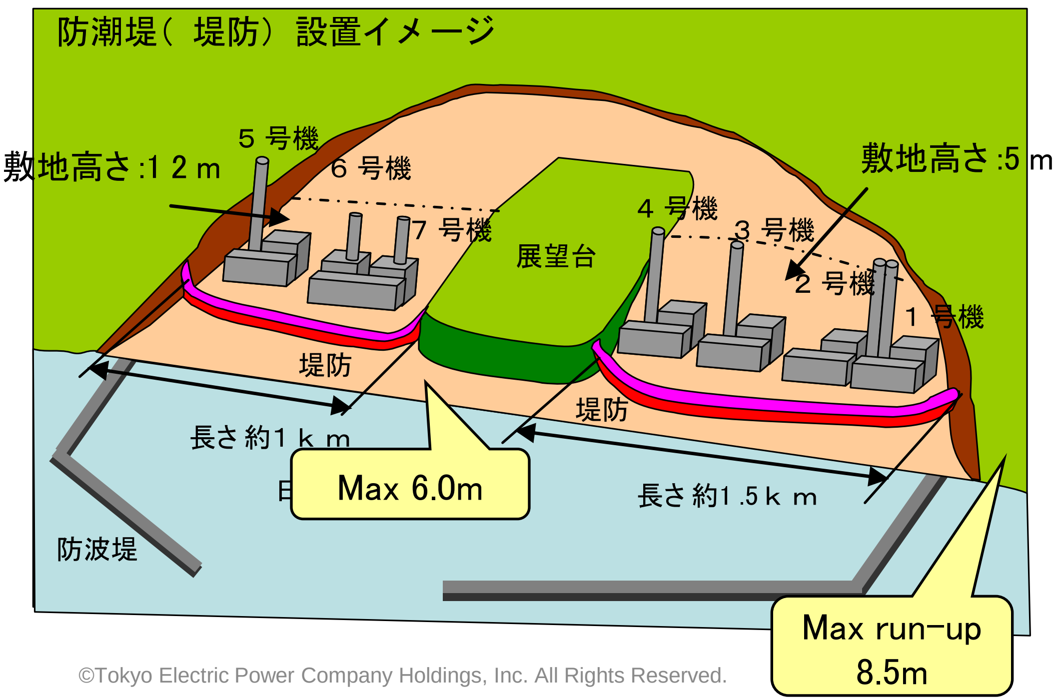
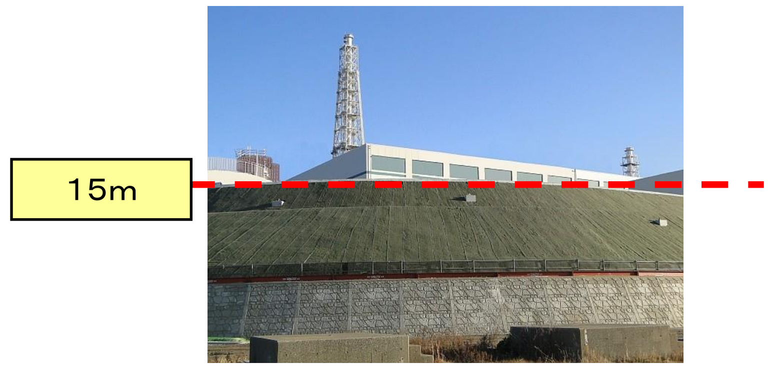
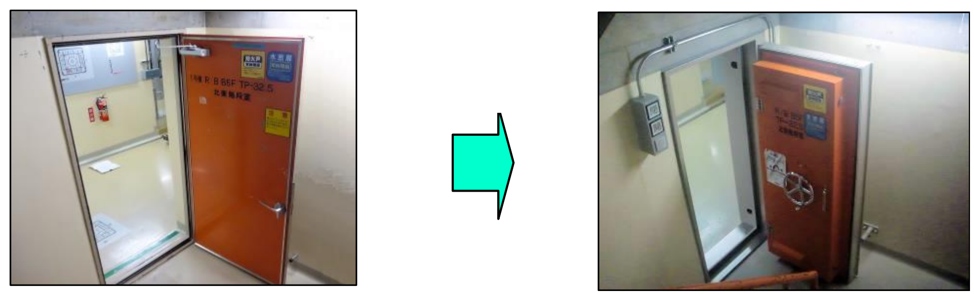
Formulation of Design Base Tsunami (2)

- Design Base Tsunami height is 6.0m at water intake (This used to be 3.3m). Run-up height is 8.5m
- Since site elevation of unit 6/7 is 12m, there is no chance to run up this area.
- In terms of Defense in Depth, additional measures (ex. installation of tsunami wall and water-tight door) have been taken so that entire site can withstand 15 m tsunami.





Tsunami Barrier for unit6/7 side



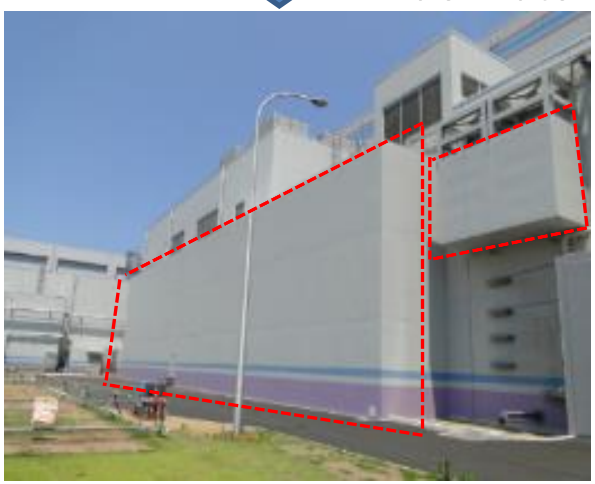
Water-tight door

Measures for Tsunami (Kashiwazaki-Kariwa)

Tsunami Wall

If flooded

Tide wall
Tide Plate



If flooded

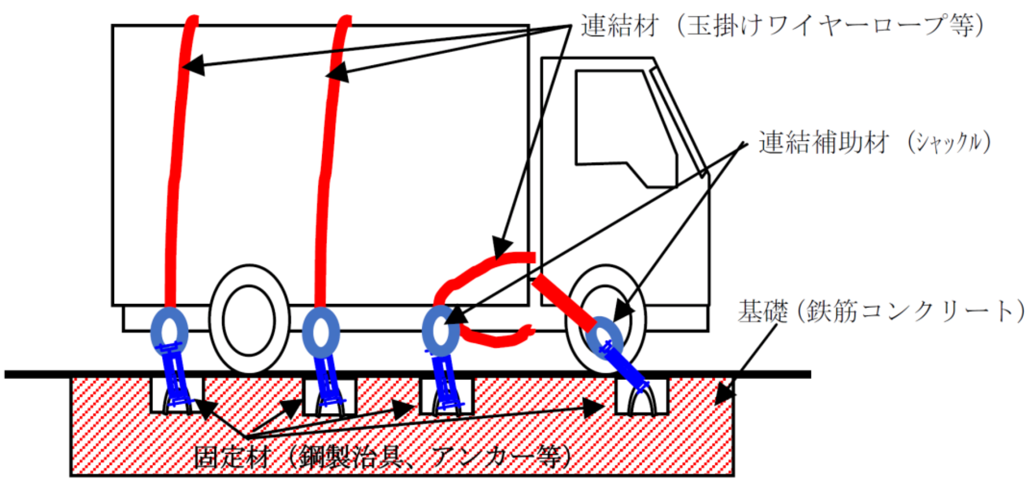
Watertight door

If flooded

Drainage system

Measures against other natural hazards

- Tornado : Prevention not to fly objects (ex. lashing the cars)
  Protective measures at facilities (ex. tornado protection net)
- Volcano : Measures for ash (ex. Timely replacement of filters)
- Others : No necessity to improve equipment (based on analysis)



Lashing the cars around R/B

Tornado protection net at louvers

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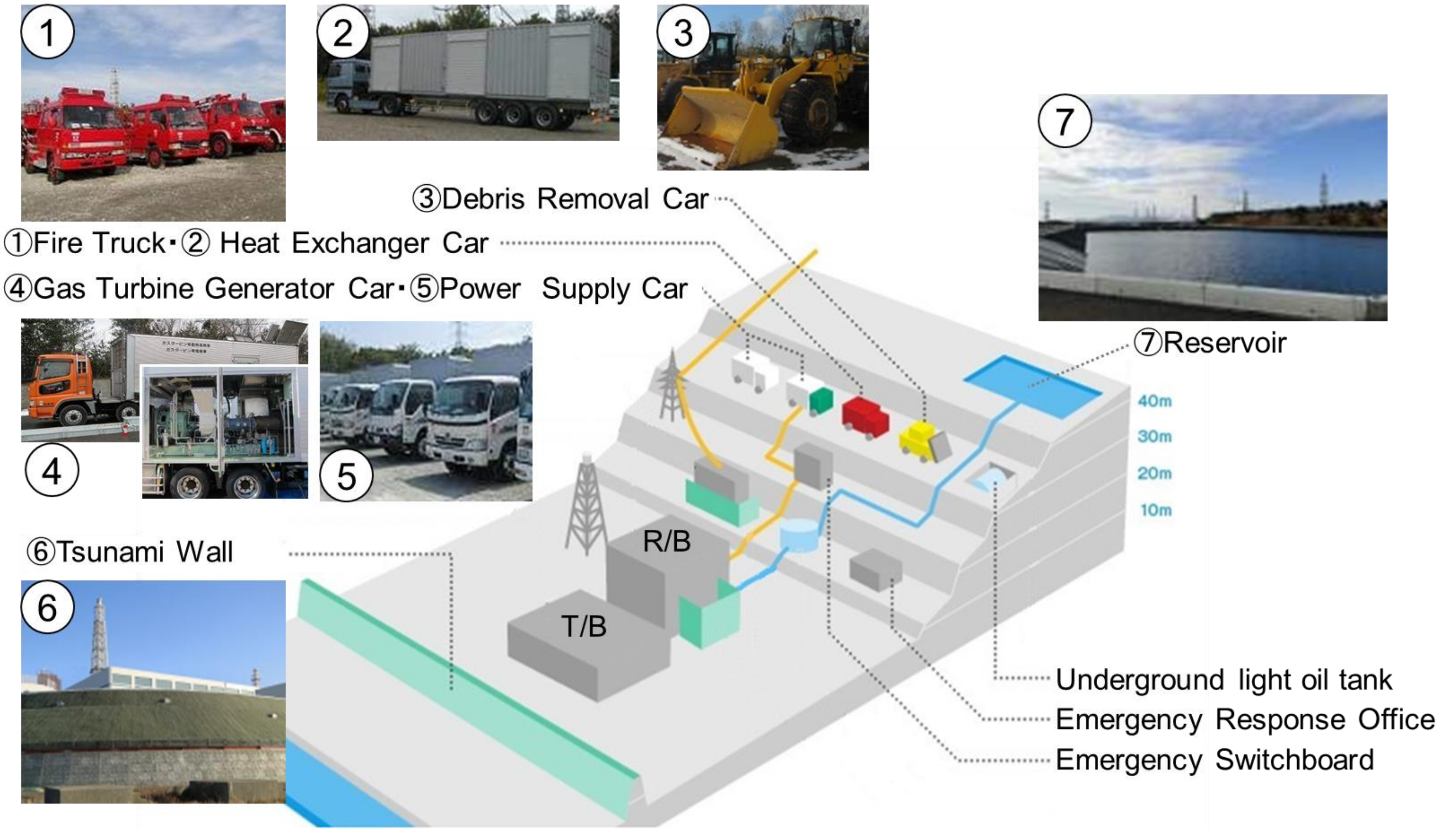
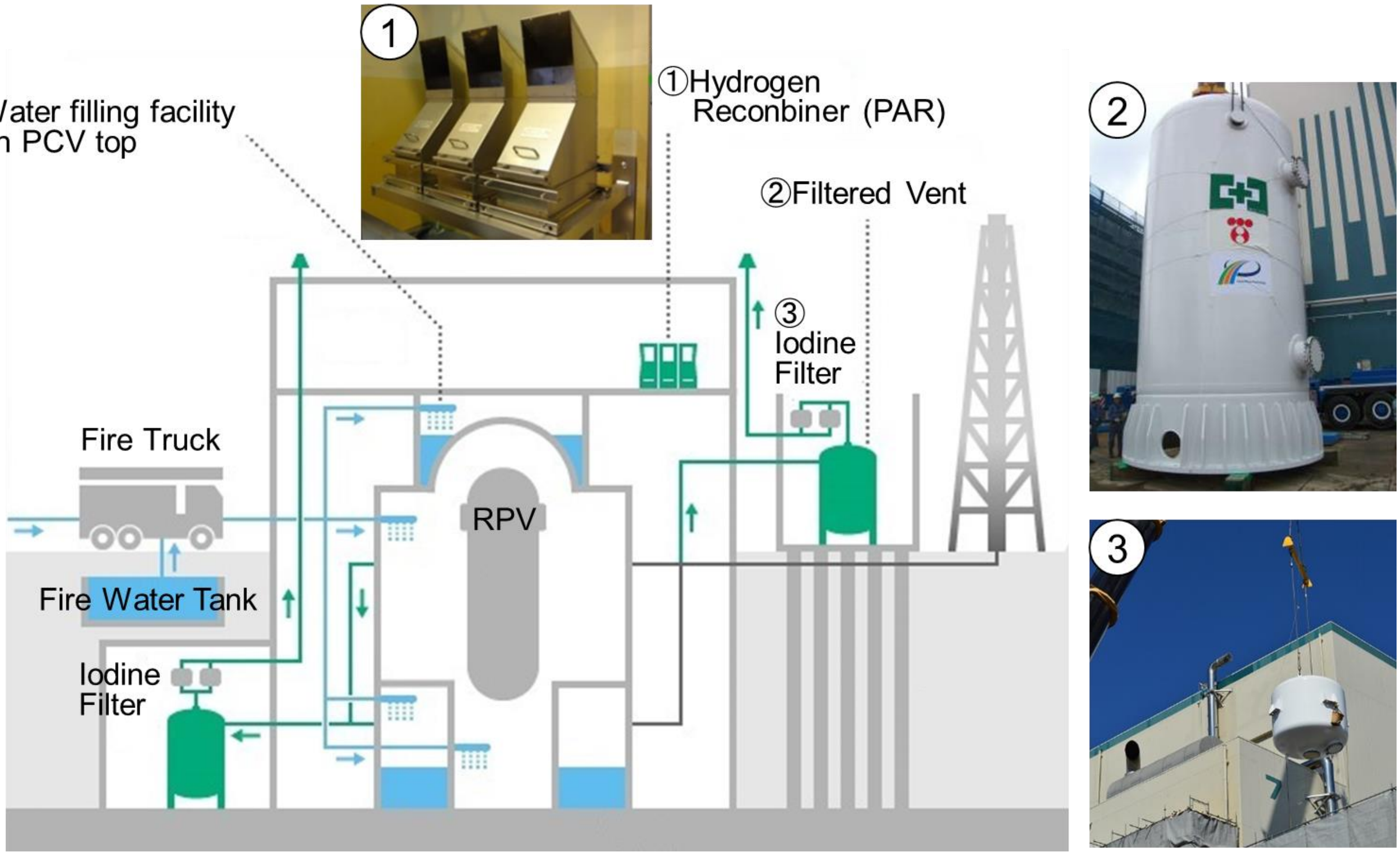
Safety Upgrade at Kashiwazaki-Kariwa



Safety Upgrade at Kashiwazaki-Kariwa



Training for Emergency Response

Simulator

Startup of
gas turbine generator car

Operation of fire engine

Rubble removal

Water discharge

Comprehensive training

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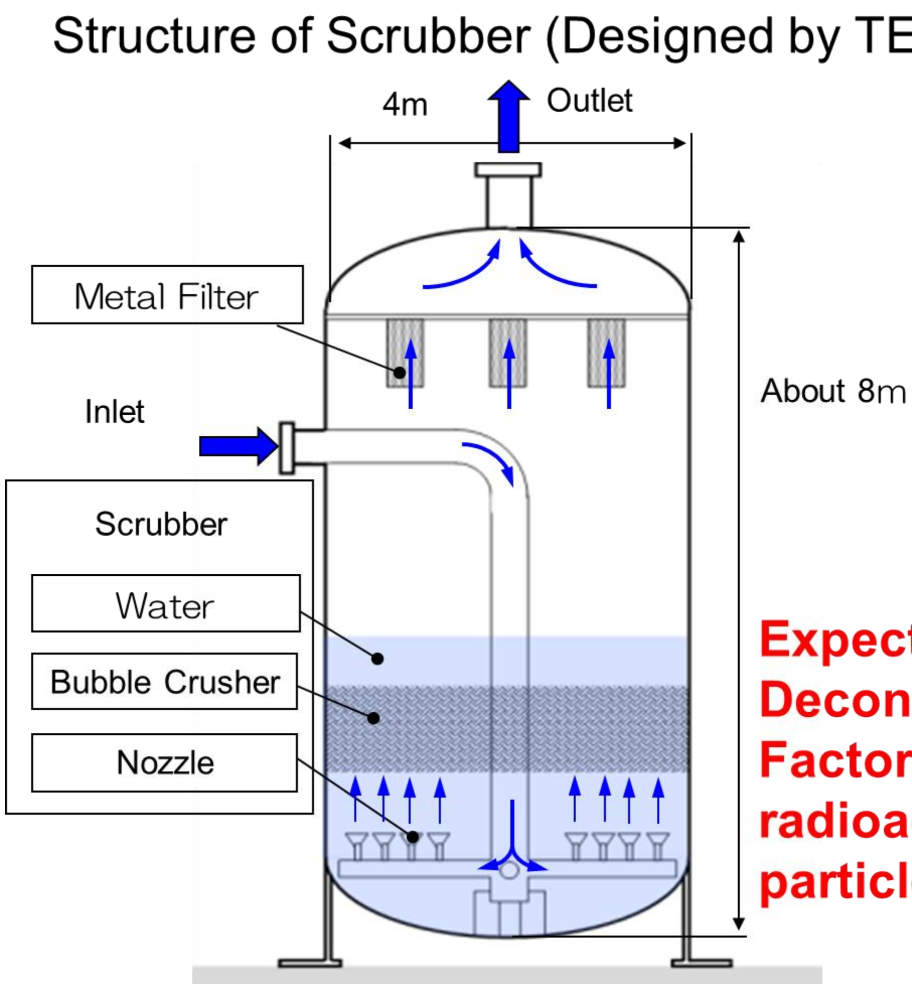
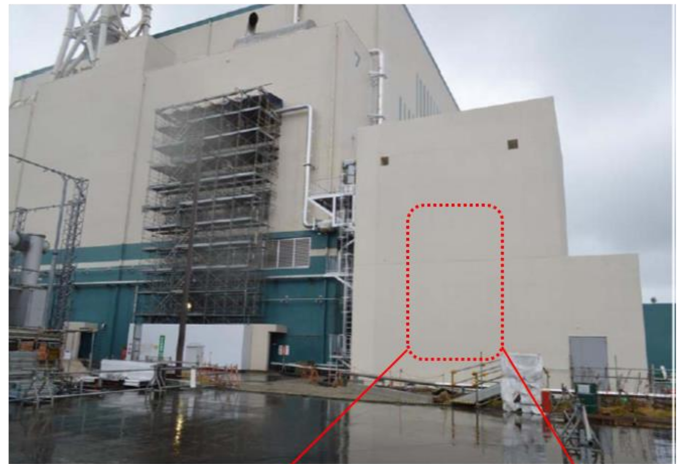
Technical competence (in-house design)





Expected Decontamination Factor for radioactive particle is 1,000

Communication capability

- Communication booth at broader local areas
- Briefing session for local residents
- Visit to all houses in NPP located municipality
- Monthly press conference
- Site tour for general public
- Encouragement of participate in regional events

Communication booth(VR experience)

Briefing session

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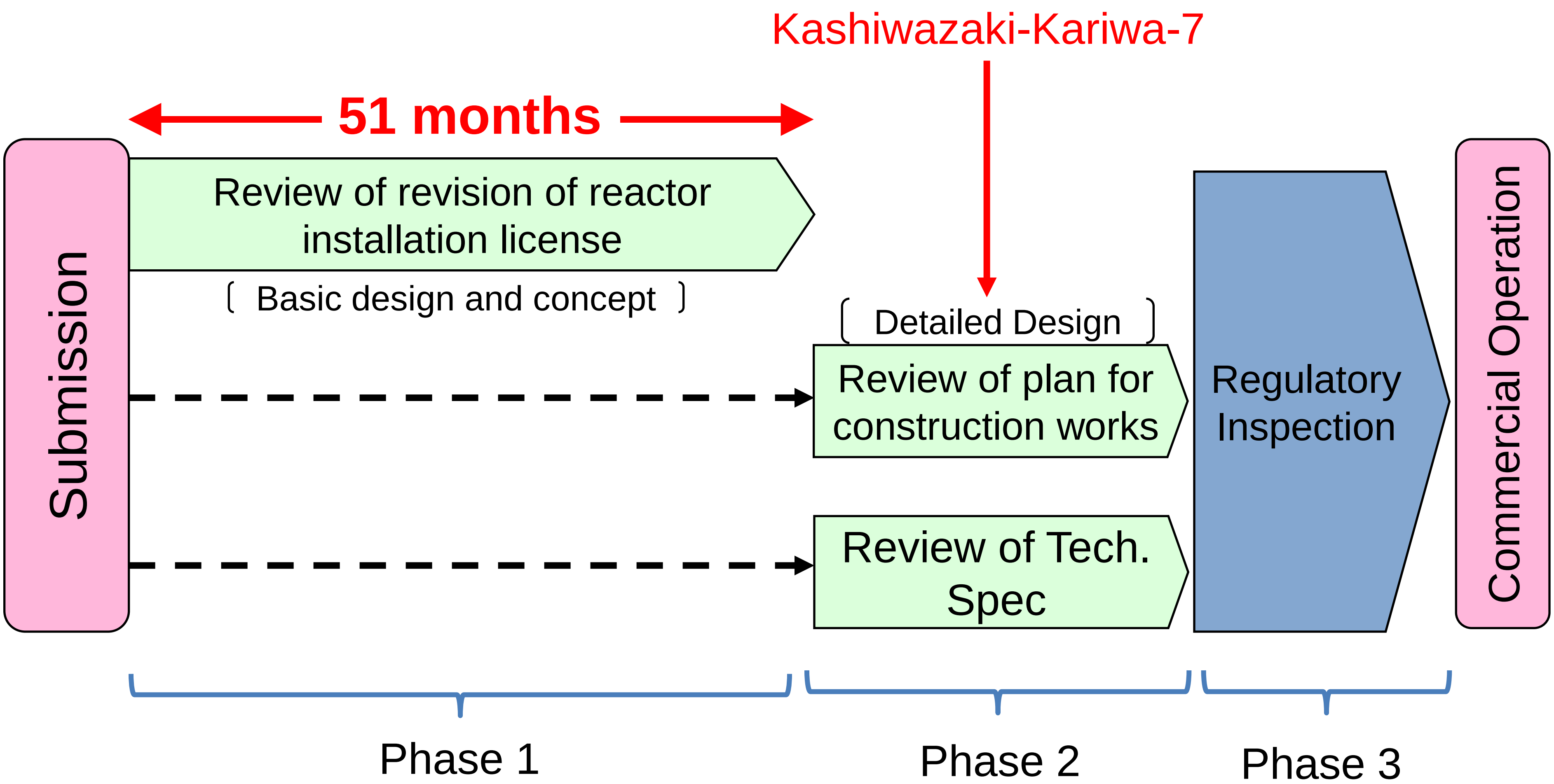
Procedures of Regulatory Review



Outline of Higashidori NPP

Unit 1: 1385 MWe (ABWR)
Unit 2: 1385 Mwe(ABWR)

Unit 1 is under construction with 9.7% progress.

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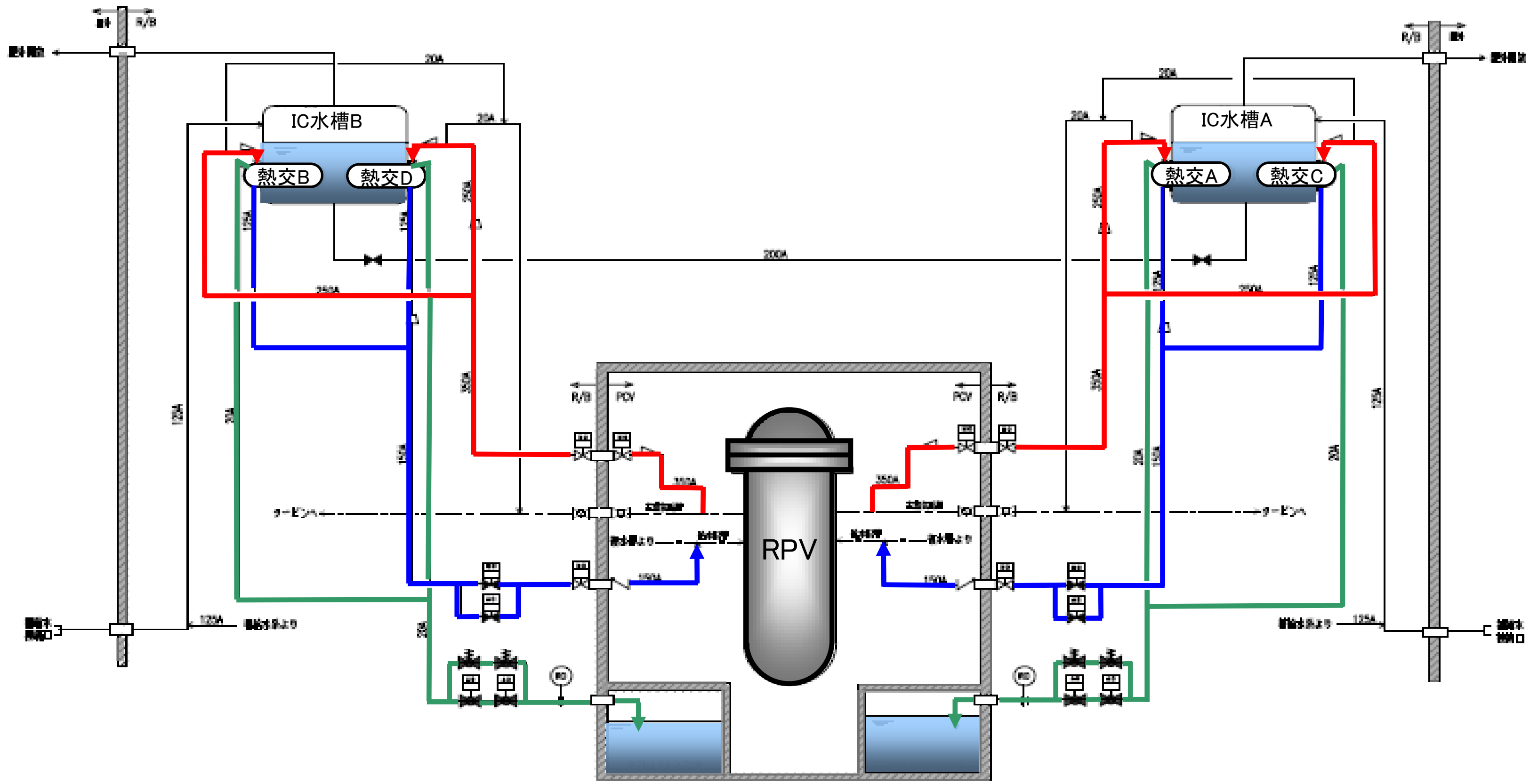
Example of ABWR design upgrade

Fukushima lessons learned and preceding plants knowledge are inputted to new construction plant. For example, ICs(Passive safety systems) will be installed to update design.



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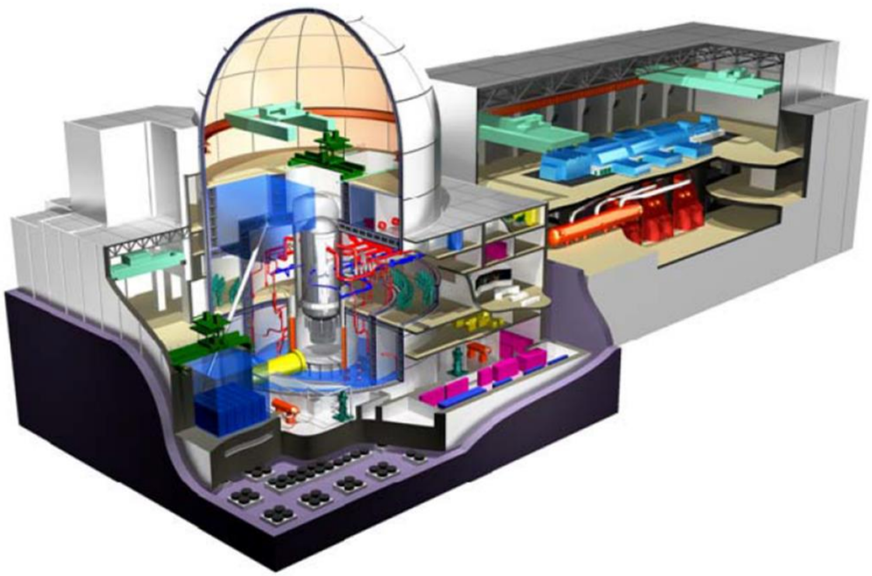
3. Information on Future Technology

Next Generation BWR (Before Fukushima)

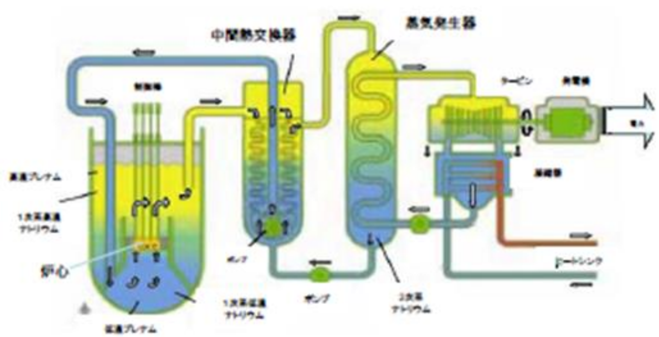
Next generation reactors R&D had been on going for domestic reactors replace and overseas business towards 2030s.



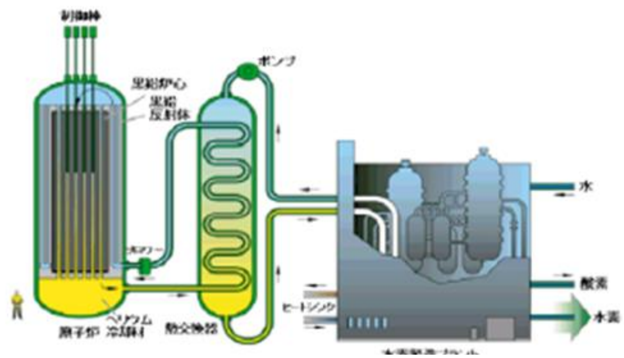
Requirement	
Output	✓1700～1800MWe *can be suitable for smaller output (80～100Mwe)
Safety	✓Severe accident response （aircraft crash, etc.） ✓Seismic isolation buildings, etc.
Economic O&M performance	✓Cost reduction : 30M period construction, etc. ✓High availability：97% （24M cycle operation） ✓Burn-up：70GWd/t, full-MOX ✓Maintenance volume：50% cut ✓Usability upgrade : controllability, maintainability, etc.

http://www.iae.or.jp/wp/wp-content/uploads/2014/09/nxt_generation_lwr/lwr20100817_1.pdf

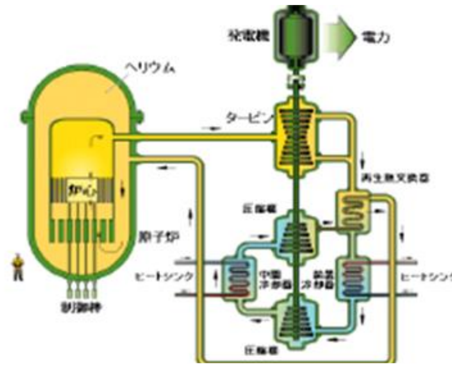
Generation IV Reactor



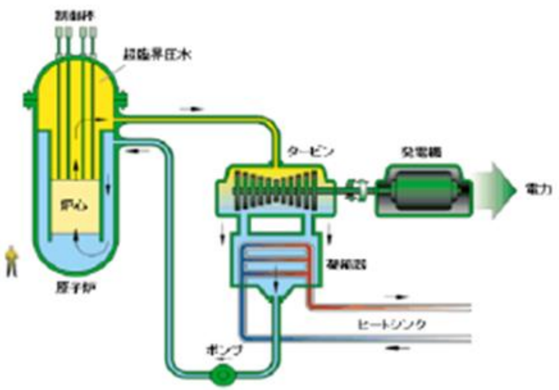
SFR
(Sodium-Cooled Fast Reactor System)



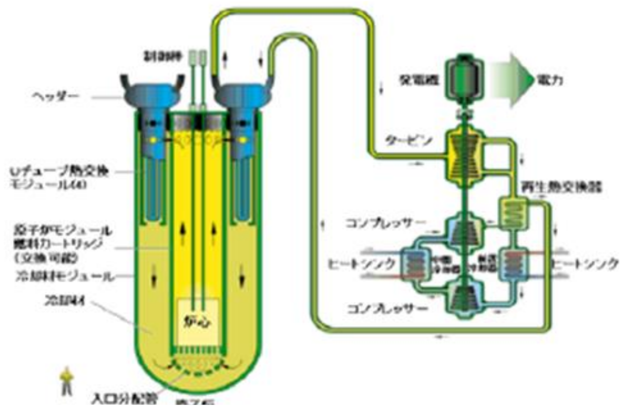
VHTR
(Very-High-Temperature Reactor System)



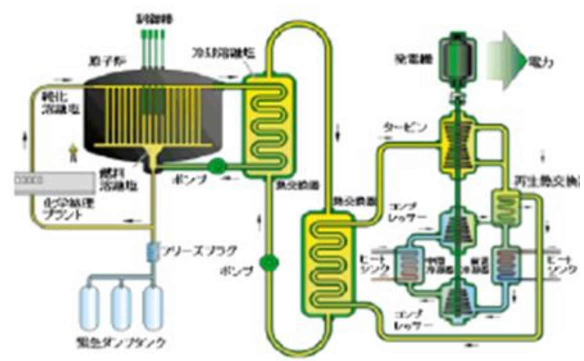
GFR
(Gas-Cooled Fast Reactor System)



SCWR
(Supercritical Water-Cooled Reactor System)



LFR
(Lead-Cooled Fast Reactor System)



MSR
(Molten Salt Reactor System)

https://www.pref.shizuoka.jp/bousai/kakushitsu/antai/documents/shiryou1_280330.pdf

Generation IV Reactor

System	Neutron spectrum	Coolant	Outlet temperature (℃)	Fuel cycle	Output (10MWe)
SFR	Fast	Sodium (Na)	500–550	Closed	5–150
VHTR	Thermal	Helium (He)	900–1000	Open	25–30
GFR	Fast	Helium (He)	850	Closed	120
SCWR	Thermal / Fast	Water	510–625	Open / Closed	30–150
LFR	Fast	Lead (Pb)	480–570	Closed	2–120
MSR	Thermal / Fast	Fluorine salt	700–800	Closed	100

https://www.pref.shizuoka.jp/bousai/kakushitsu/antai/documents/shiryou1_280330.pdf

SFR in Japan

- The constructions and operations of the experimental reactor ‘Joyo’ and the prototype reactor “Monju” had been completed in Japan so far. (“Monju” is under decommissioning now.)
- Based on the gained knowledge and the overseas, next step are to be proceeded in Japan.

Outline of “Monju”

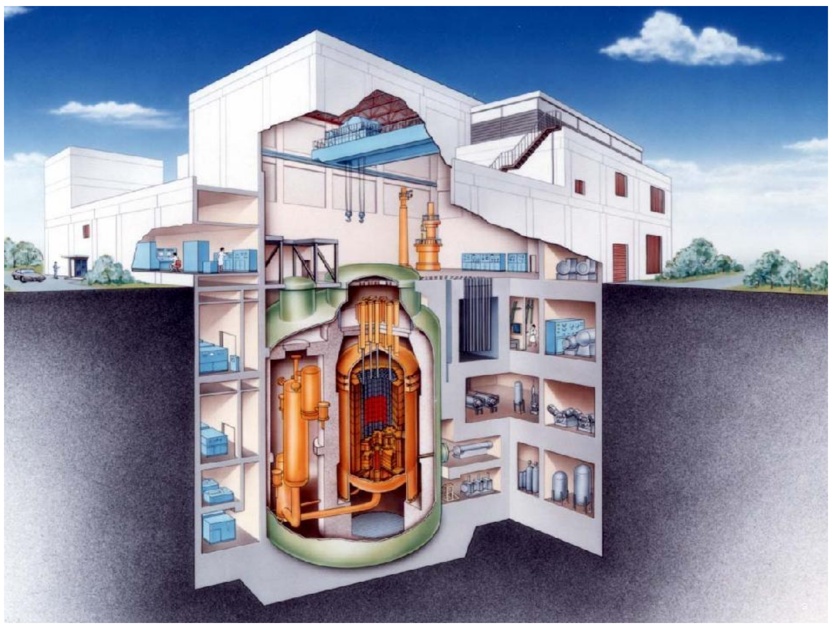
1983:Reactor Installation License
1994:First critical
1995:Na leakage accident (40% output)
2010:test restart (0MWe)
Device falling accident
After that, never restart again
(NRA pointed out that JAEA was ineligible for operation)
2016:Determine Decommissioning

Output=280MWe

https://www.jaea.go.jp/04/turuga/monju_site/page/facilities.html

HTTR：Higt Temperature engineering Test Reactor

- HTTR is an experimental nuclear reactor, and is a Gas-Cooled Reactor system that uses helium as the coolant.
- HTTR has demonstrated that it is capable of providing high temperature nuclear heat for hydrogen production available for the world's first.
- JAEA plan to demonstrate the production of hydrogen by high temperature gas supplied by the HTTR, which would contribute to the development of future energy strategies.



https://httr.jaea.go.jp/

Specification of "HTTR"

Operator :JAEA (Japan Atomic Energy Agency)

Reactor Thermal Power	: 30MW
Reactor Outlet Coolant Temperature	:850℃/950℃
Primary Coolant Pressure	:4MPa

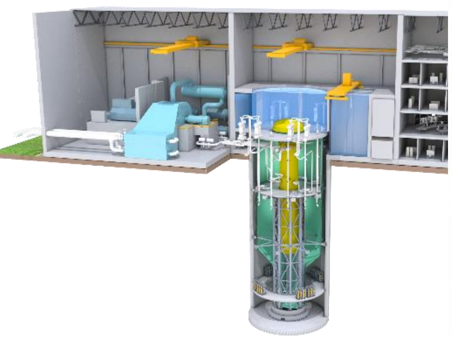
Outline of "HTTR"

1969:R&Ds start
1990:Reactor Installation License
1998:First critical
2002:Rated power operation, Safty Demonstration Test
(30MW,850℃&950℃)
2007:850℃/30days Operation
2010:950℃/50days Operation

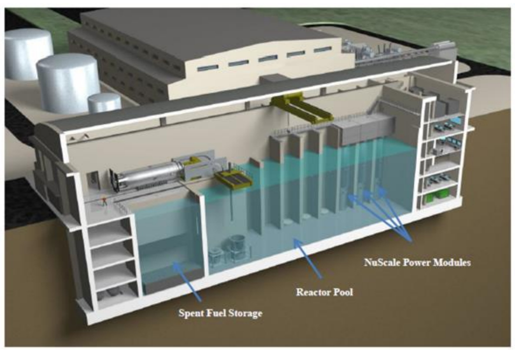
Concept of SMR

- Expectations for SMR’s feature
  - Safety : automatic and passive cooling at severe accident (due to low power)
  - Low project risk : reduction of initial cost and expansion ability in the future
  - Construction : high quality and short period (due to assembly at factory)
  - Decentralized power supply : unnecessary of large scale infrastructures
  - Nuclear security :less opportunities of transport (due to long-term operating cycle)

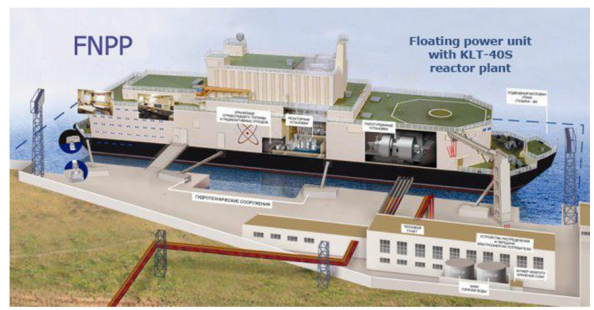
Example of SMR images



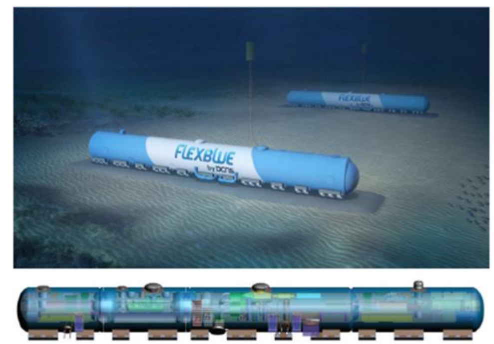
BWR X-300
(Hitachi-GENE, Japan)



NuScale
(NuScale Power Inc., USA)



KLT-40S
(OKBM Afrikantov, Russia)



Flexblue
(DCNS, France)

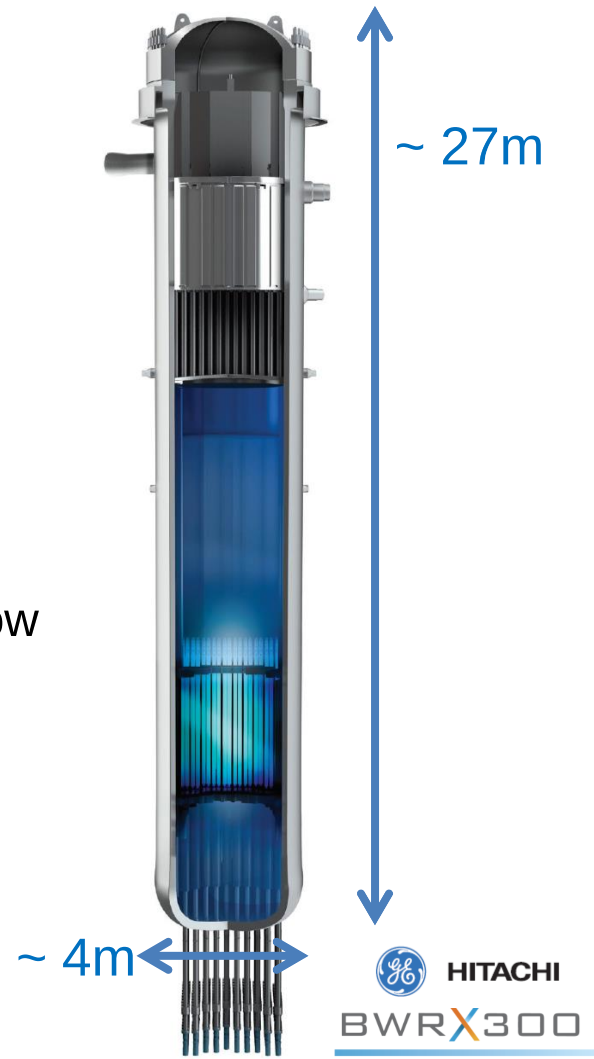
https://www.iaea.org/NuclearPower/Downloadable/SMR/files/IAEA_SMR_Booklet_2014.pdf

Examples of SMRs

BWRX-300's case

• Features

- ~300MWe / unit
- World class safety: eliminates loss-of-coolant accidents (LOCA) enabling simpler passive safety
- Cost competitive: projected to have up to 60% less capital cost per MW when compared with typical water-cooled SMR
- Passive cooling: steam condensation and gravity allow BWRX-300 to cool itself for a minimum of 7 days without power or operator action
- Proven technology: most of the technology and components either have had many years of proven operation experience or have undergone significant testing and licensing as part of the ESBWR program



https://nuclear.gepower.com/build-a-plant/products/nuclear-power-plants-overview/bwrx-300

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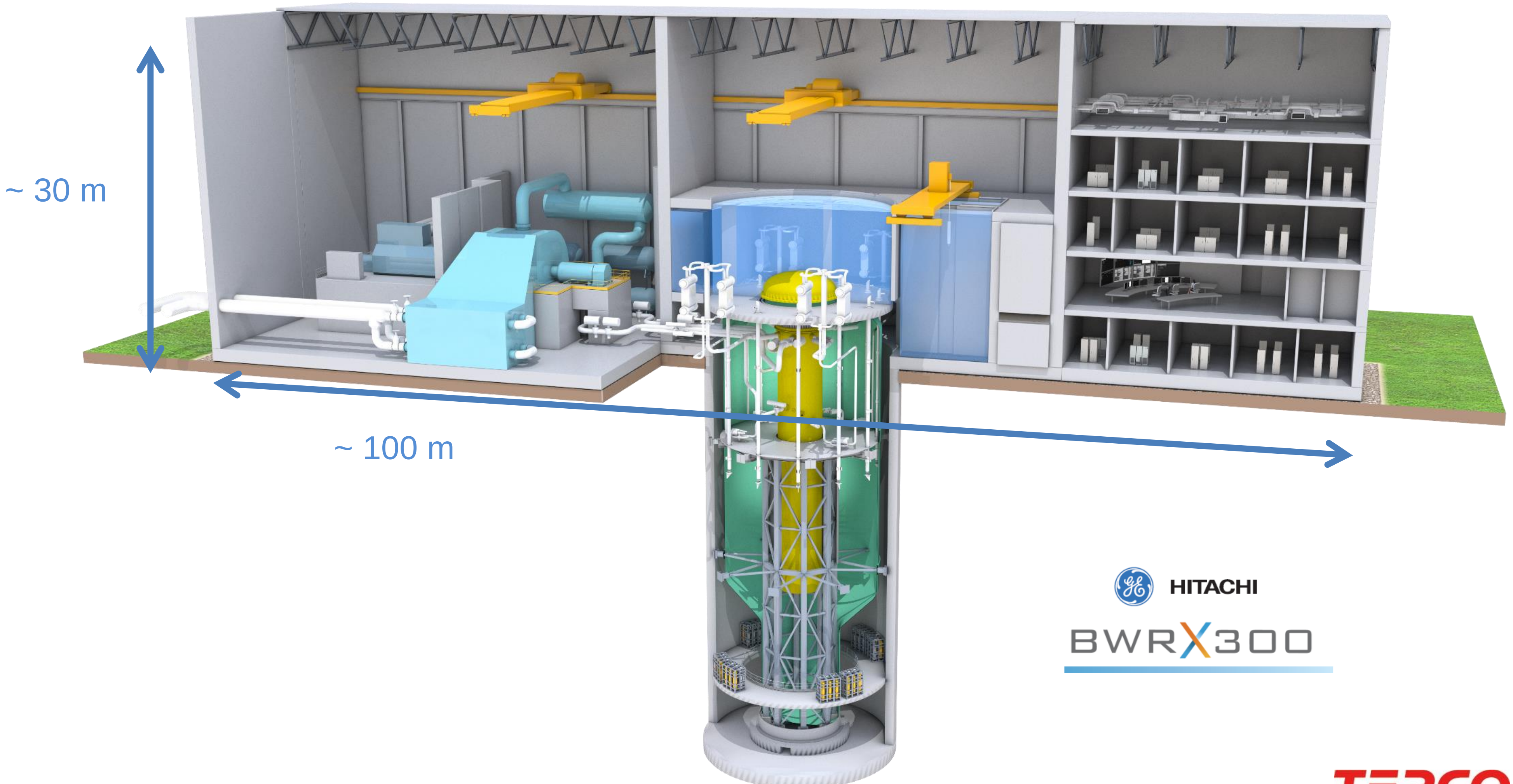
Examples of SMRs

Construction period : ~30 months (targeted duration including startup test)

Image of entire single unit buildings of BWRX-300 (300 MWe)



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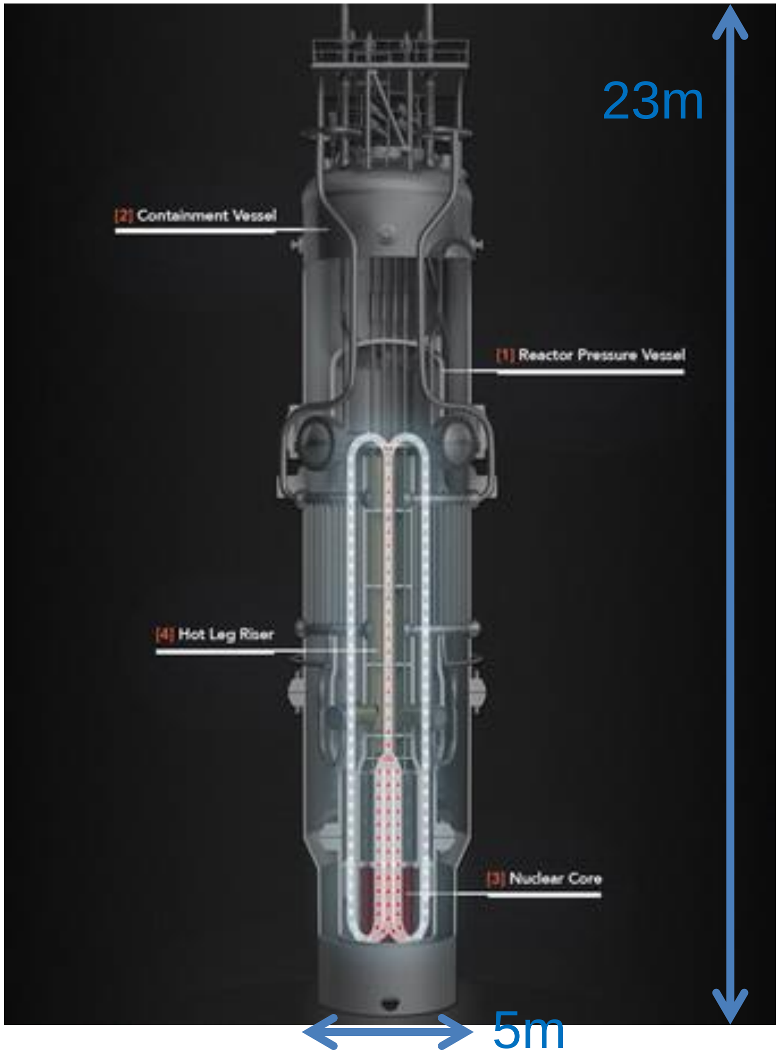
Examples of SMRs



http://www.nuscalepower.com/our-technology/technology-overview

Nuscale's case

- Features
  - 50MWe / module
  - Integrated module encompassing the reactor, steam generators, and pressurizer
  - Adaptable to power demand
  - Application of many Off-the shelf products
- Trends
  - DCA have been submitted in Dec.2016
  - FSAR will be published in 2020

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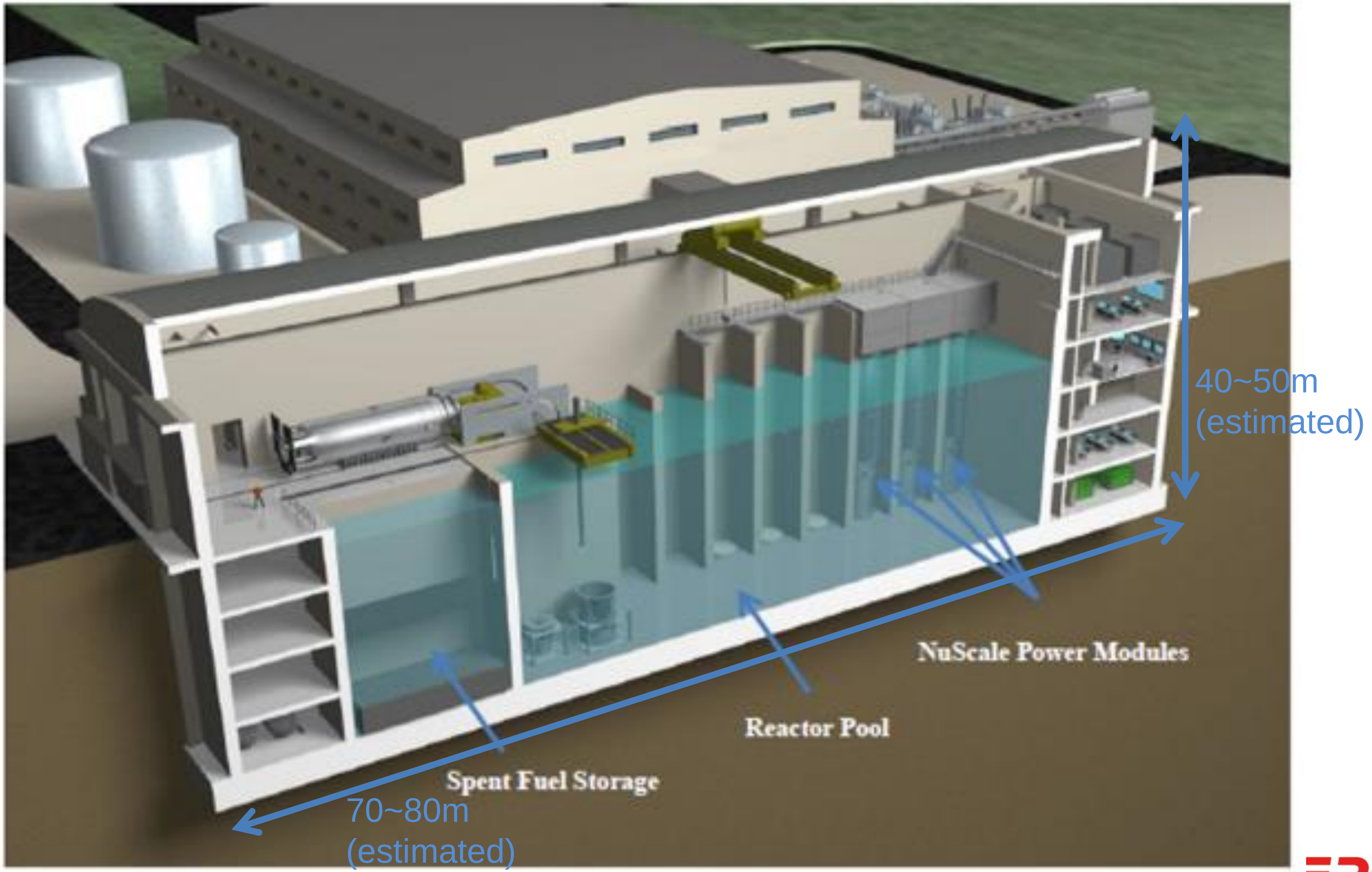
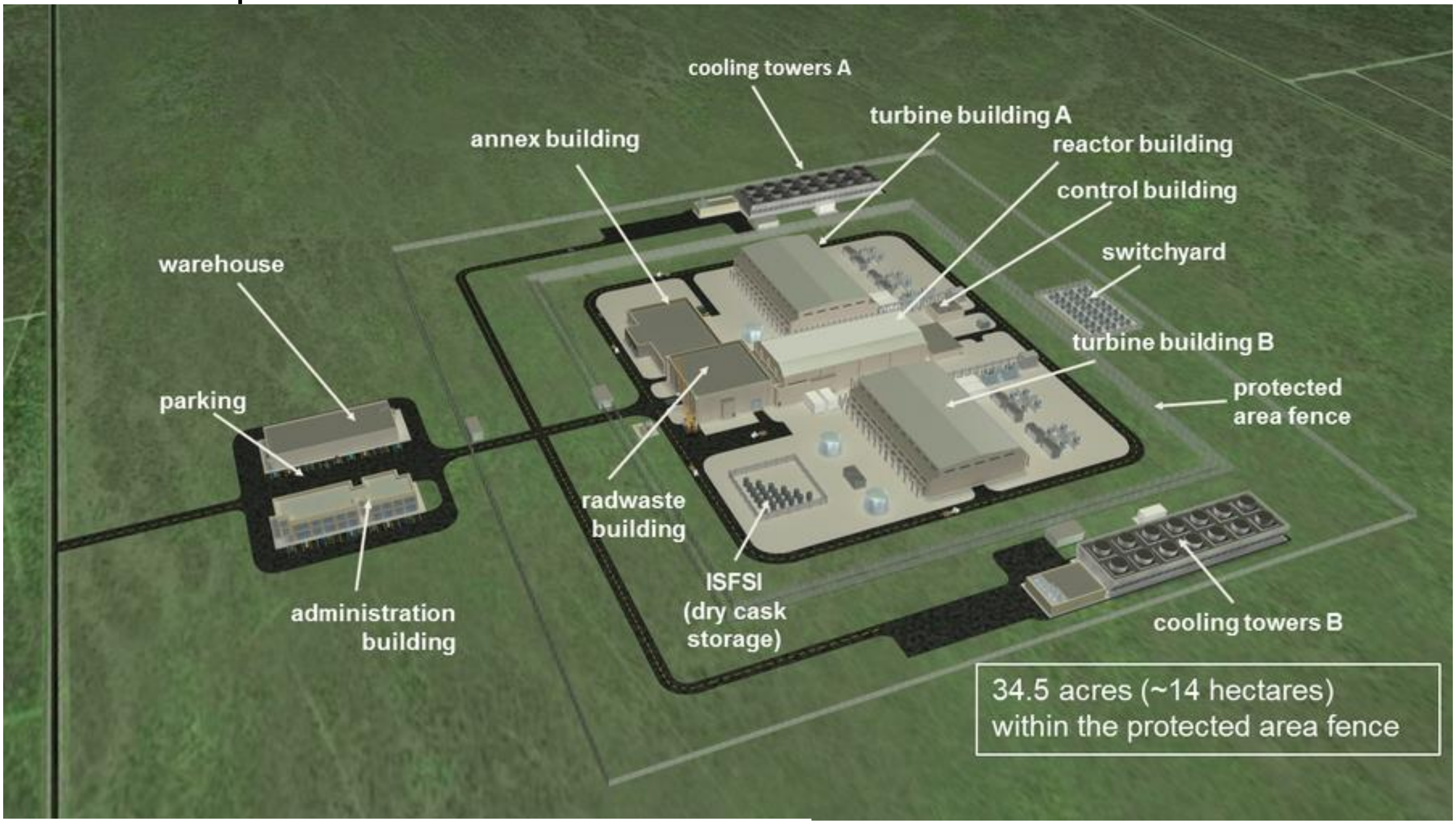
Examples of SMRs

Image of Reactor Building (50MWe × 12modules = 600MWe)



Examples of SMRs

Construction period : 28.5 months



http://www.nuscalepower.com/smr-benefits/simple

Thank you for Your Attention!　Question?

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