高速実験炉「常陽」
Experimental Fast Reactor

Safety Improvement and Regulatory Review on Experimental Fast Reactor *Joyo* under the New Regulatory Requirements in Japan

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IGORR 22nd
2025/6/16

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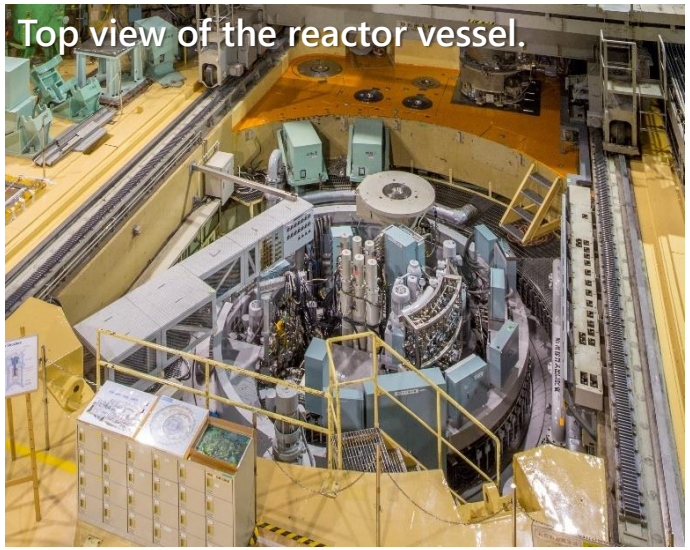
- Operation Plan & Application

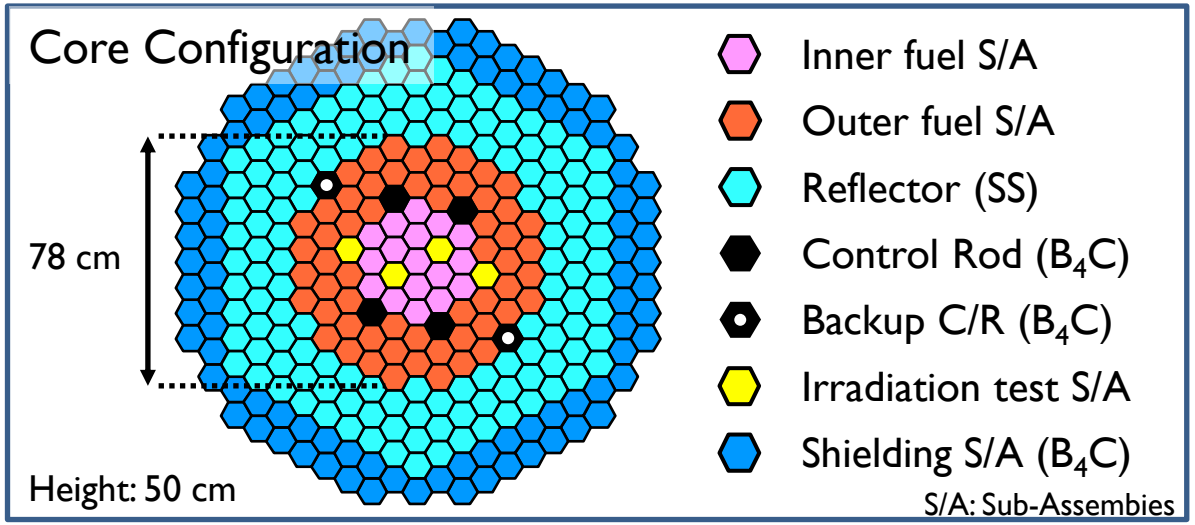
Introduction

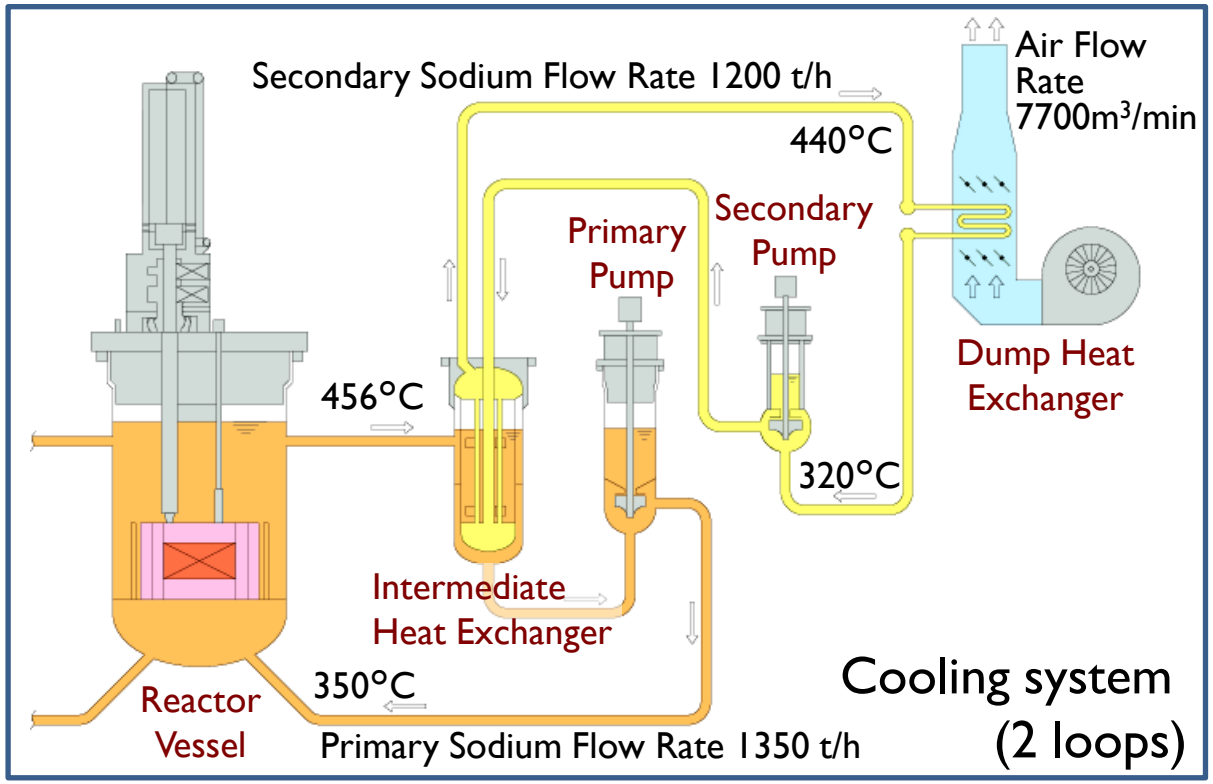
Experimental Fast Reactor *Joyo*


Top view of the reactor vessel.

Purpose of use

- R&D for fast breeder reactors
- Fuels & materials irradiation
- Fundamental research
- R&D for radioisotopes production





Thermal Power	100 MW
Fuel	U-Pu mixed oxide pellet Pu: < 32 wt%; ^{235}U: 18 wt% enriched
Coolant	Liquid Sodium
Electricity Generator	Not installed

Introduction

History

1970
Installation permitted

1977
Initial criticality, Apr. 24th

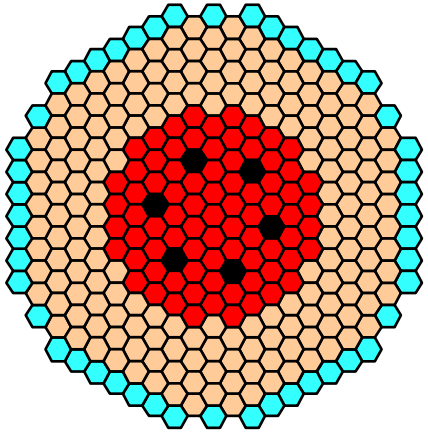
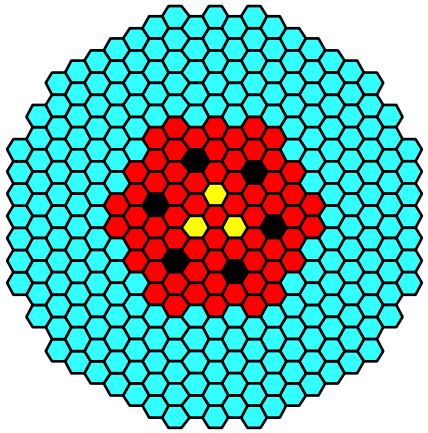
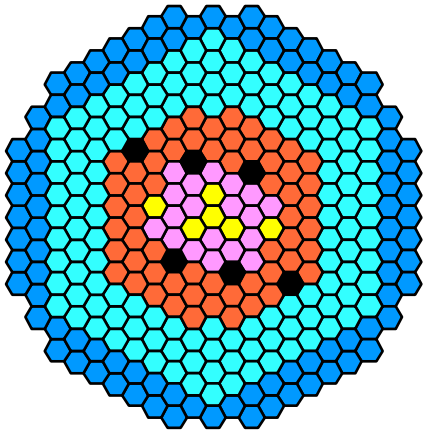
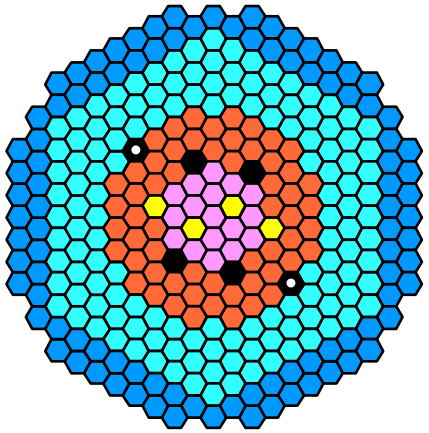
2011
The Great East Japan Earthquake

2012
The Nuclear Regulation Authority was established

2013
Enforcement of the new regulatory requirements

2017
Applied changes in reactor installation

2023
Changes in reactor installation permitted

Breeder core	Irradiation core		
MK-I	MK-II	MK-III	MK-VI
			
1977-1981	1982-2000	2003-2007	Target to restart in 2026
6-cycle operated Verification of nuclear fuel breeding Plant examinations for the sodium cooling system	**35-cycle operated** Irradiation tests of fuels & materials for fast reactors Obtaining experience in the operation & maintenance of the fast reactor	**6-cycle operated** Irradiation tests with enhanced irradiation ability	Irradiation tests with the modified core for the new regulatory requirements R&D on Radioisotopes production

Introduction

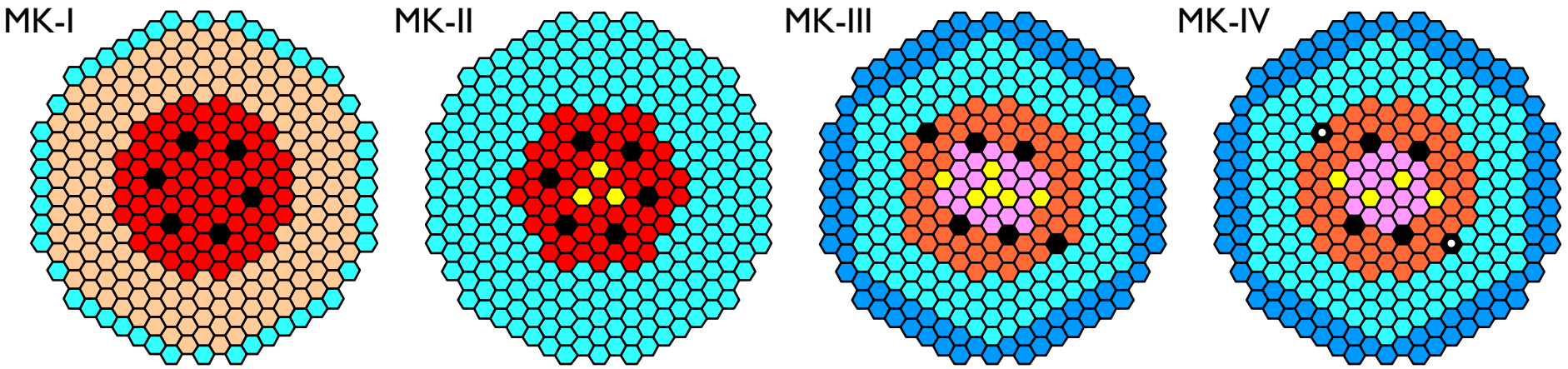
History

Operation Time

70,798 h

Heat Generation

6,244 GWh



Items	MK-I	MK-II	MK-III	MK-IV
Reactor thermal power [MWt]	50 → 75	100	140	100
Max. number of driver fuel	82	67	85	79
Blanket	Depleted UO_2	N/U	N/U	N/U
^{235}U enrichment [wt%]	< 23	18	18	18
Pu content [wt%] (Inner / Outer)				
Total	< 18	28	23 / 29	22 / 29
Fissile	< 14	20	16 / 21	16 / 21
Max. liner heat rate [W/cm]	320	400	420	330
Max. neutron flux [n/(cm^2·s)]				
Total	3.2×10^{15}	4.9×10^{15}	5.7×10^{15}	4.2×10^{15}
Fast (> 0.1 MeV)	2.2×10^{15}	3.2×10^{15}	4.0×10^{15}	2.9×10^{15}
Max. pin average burn-up [GWd/t]	42	75	90	90

- Driver Fuel S/A
- Blanket fuel S/A
- Inner fuel S/A
- Outer fuel S/A
- Reflector
- Control Rod
- Backup C/R
- Irradiation test S/A
- Shielding S/A

N/U: Not Used

Background

The New Regulatory Requirements in Japan

The Nuclear Regulation Authority of Japan has enforced new regulatory requirements in response to lessons learned from the Fukushima-Daiichi NPP accident.

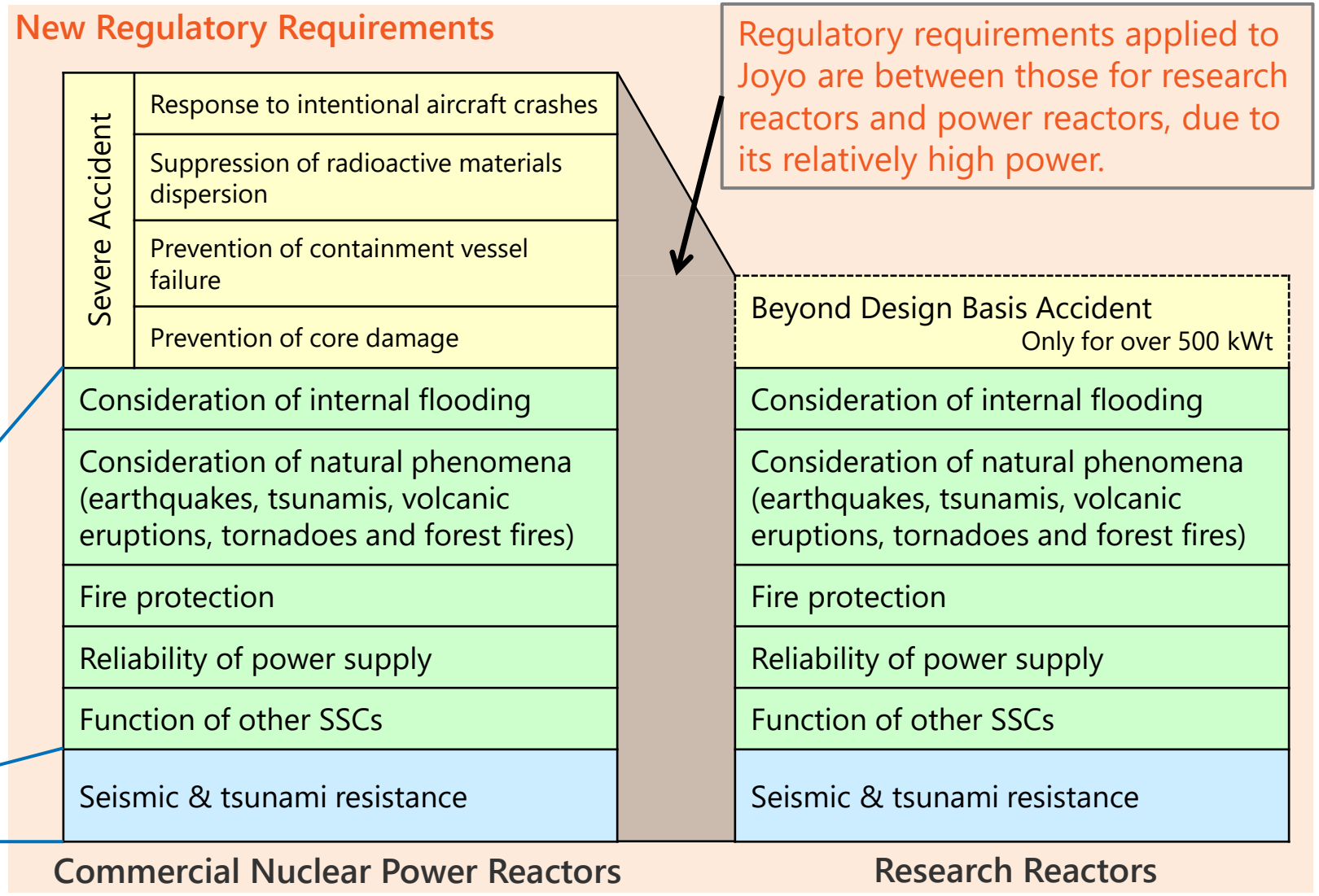
Numerous requirements have been newly introduced and reinforced not only for commercial nuclear power reactors but also for research reactors.

Previous Regulatory Requirements

- Consideration of natural phenomena (earthquakes and tsunamis)
- Fire protection
- Reliability of power supply
- Function of other SSCs*
- Seismic & tsunami resistance

* SSC: Structure, Systems and Components

New Regulatory Requirements



Regulatory requirements applied to Joyo are between those for research reactors and power reactors, due to its relatively high power.

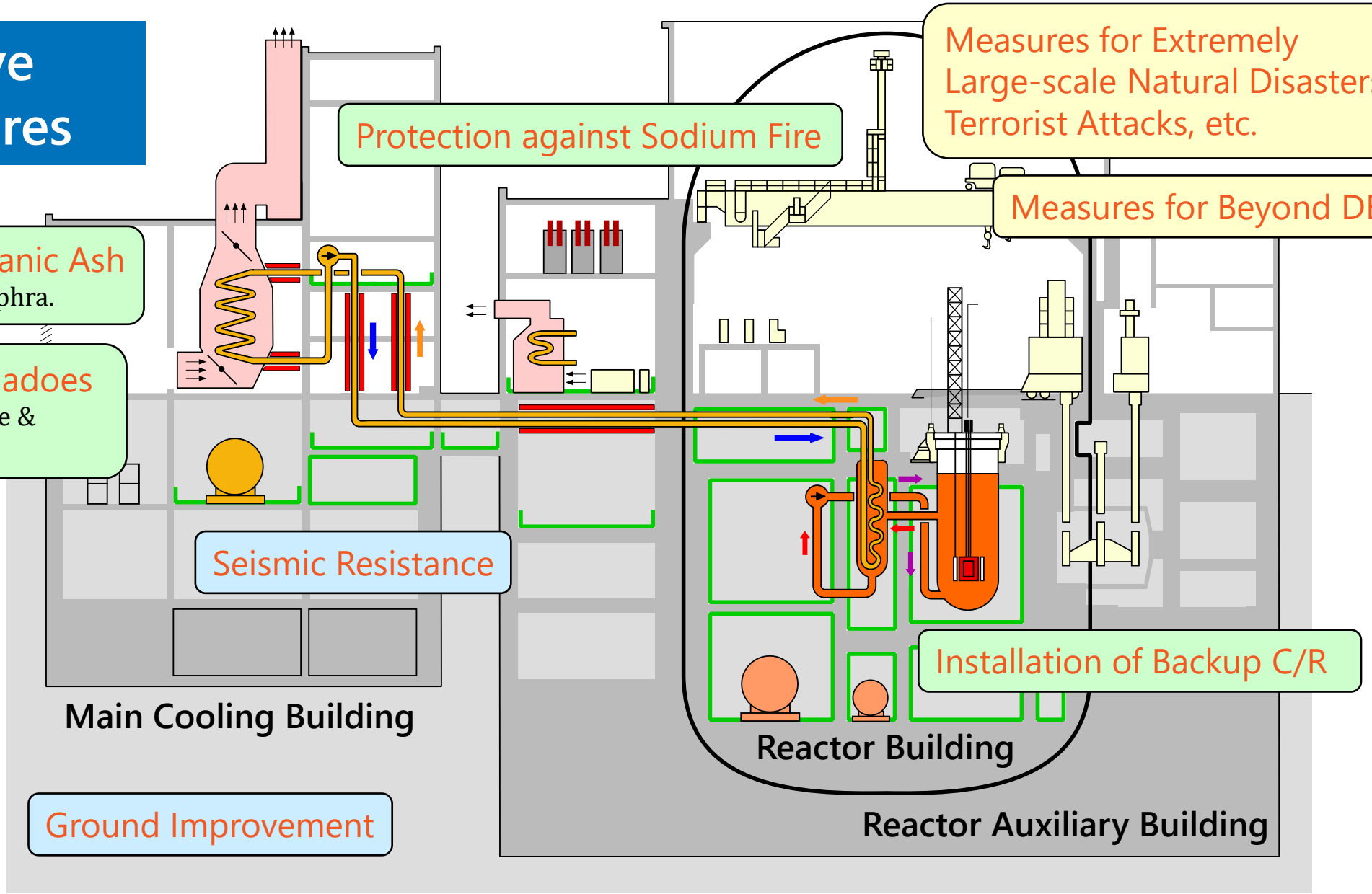
Outline of Compliance with Regulation

Representative Safety Measures

Protection against Volcanic Ash
Resistance to 50 cm layered tephra.

Protection against Tornadoes
Improve penetration resistance & prevent spalling on buildings.

No Tsunamis affect Facilities



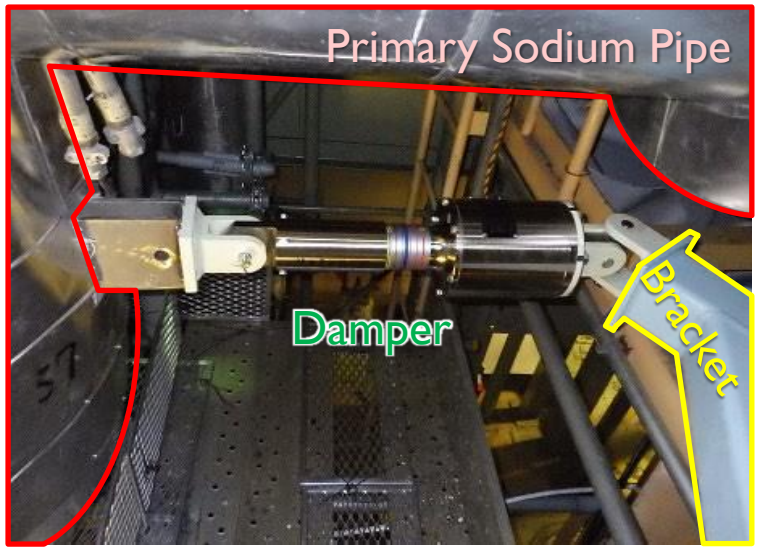
Safety Improvement & Regulatory Review

Seismic & Tsunami Resistance

Seismic Resistance

Max. acceleration of basic seismic motion for design:
0.36 G (350 gal) -> 0.99 G (973 gal)

Some auxiliary facilities, pipes and others are anti-seismic reinforced.



Dampers on	
Primary sodium pipes	
Upgraded	Approx. 230
Additional	+ Approx. 50
Secondary sodium pipes	
Upgraded	Approx. 130
Additional	+ Approx. 20

Anti-seismic Reinforcement
on the Main Stack

Tsunami resistance

The altitude of the site: over 35 m
Estimated reachable Tsunami to the site: 17.8 m

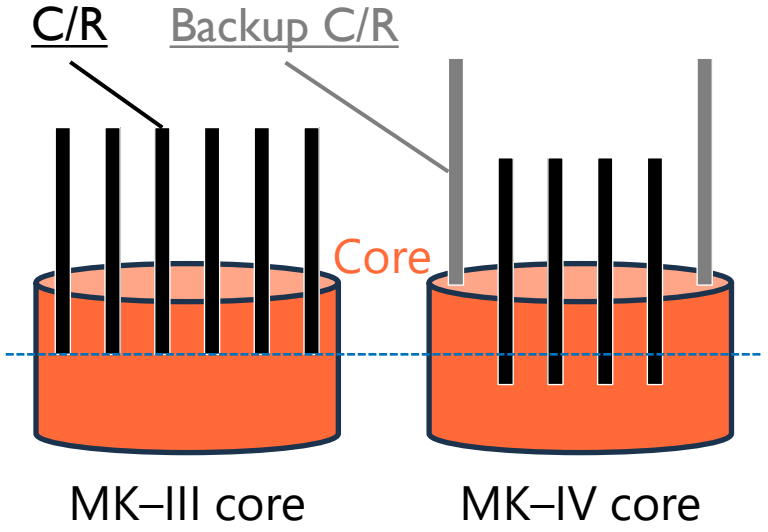
No Tsunami effects.

Safety Improvement & Regulatory Review

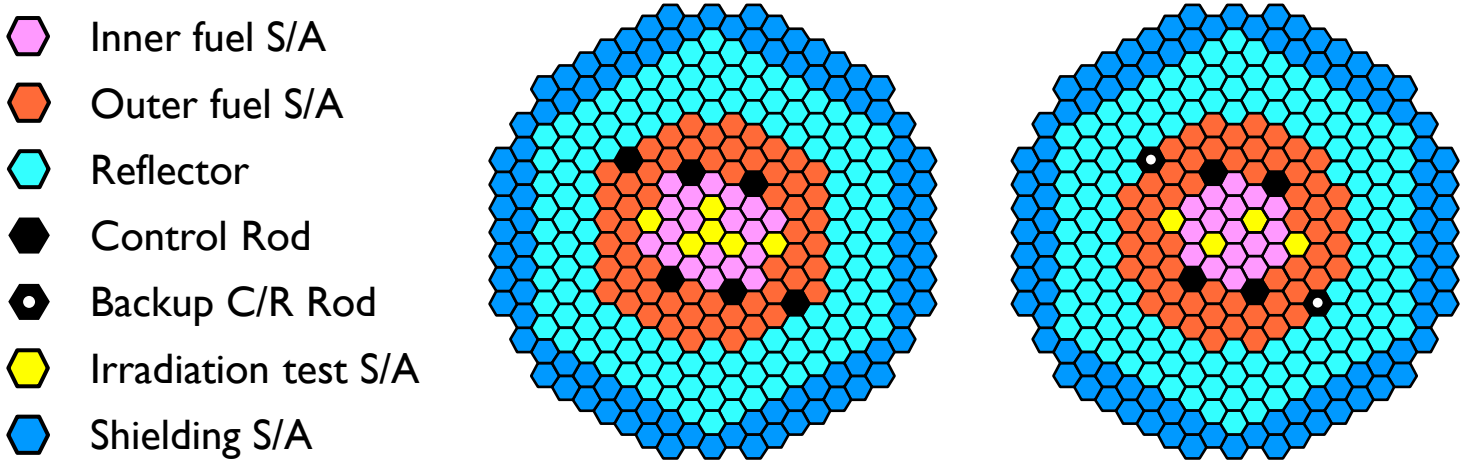
Installing Backup Shutdown System

The reactor shutdown system has been multiplexed by reclassifying two outer control rods as backup control rods and installing an independent logic circuit.

With this change, the limit of excess reactivity decreased to maintain a safety margin with reactor shutdown conditions. The number of fuel S/A and the thermal power have changed to satisfy the new limit of excess reactivity.



	MK–III core	MK–IV core
Thermal Power	140 MW	100 MW
Num of Fuel S/A	Max. 85	Max. 79
Control Rods	6 rods	4 rods
Backup Control Rods	Not Installed	2 rods
Max. Excess Reactivity	0.045 Δk/k	0.035 Δk/k



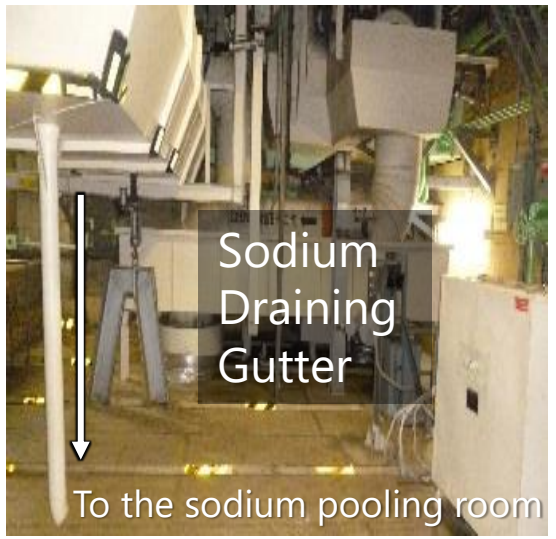
Safety Improvement & Regulatory Review

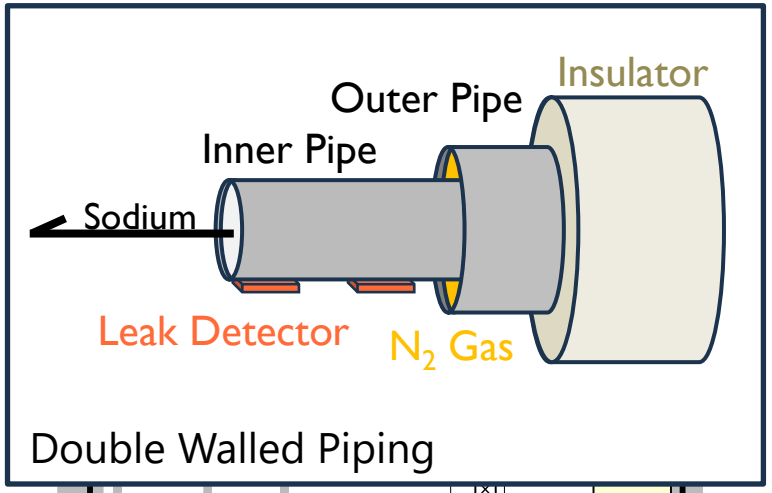
Protection against Sodium Fire

- Reinforced measures
- Existing measures

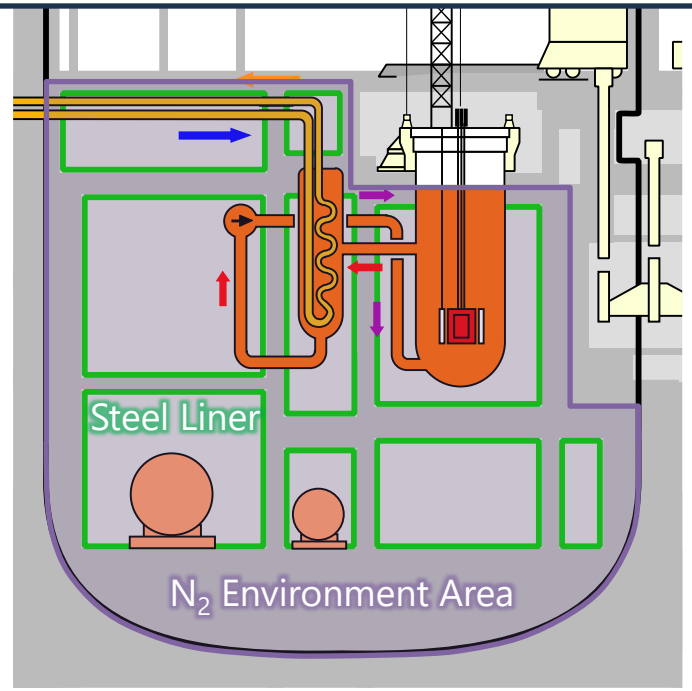
The Protection with reinforced measures & existing measures

- Anti-seismic reinforcement of sodium loops
- Emergency sodium dump to dump tanks
- Double walled piping for primary sodium loops
- Replacement of the atmosphere with an inert gas under the operating floor
- Steel liner to prevent sodium–concrete reaction
- Sodium draining gutter for secondary sodium loops
- Additional installation of sodium fire extinguishers





Double Walled Piping



Safety Improvement & Regulatory Review

Beyond Design Basis Accidents

NRA required JAEA to take characteristic safety measures for B-DBA & event in excess of B-DBA including a response to intentional aircraft crashes.

JAEA applied the PRA method for consideration, utilizing knowledge from previously conducted research.

Experimental Fast Reactor Joyo

AOO	
DBA	
B-DBA	Measures to prevent core damage
	Measures to prevent containment vessel failure
Event in excess of B-DBA	Measures to mitigate the large amount of radioactive material release

Assessment flow of B-DBA

Identification of accident sequences

↓

Planning measures to prevent core damage

↓

Effectiveness evaluation of measures to prevent core damage

⋮ Assume that the functions of all measures are lost.

Planning measures to prevent containment vessel failure

↓

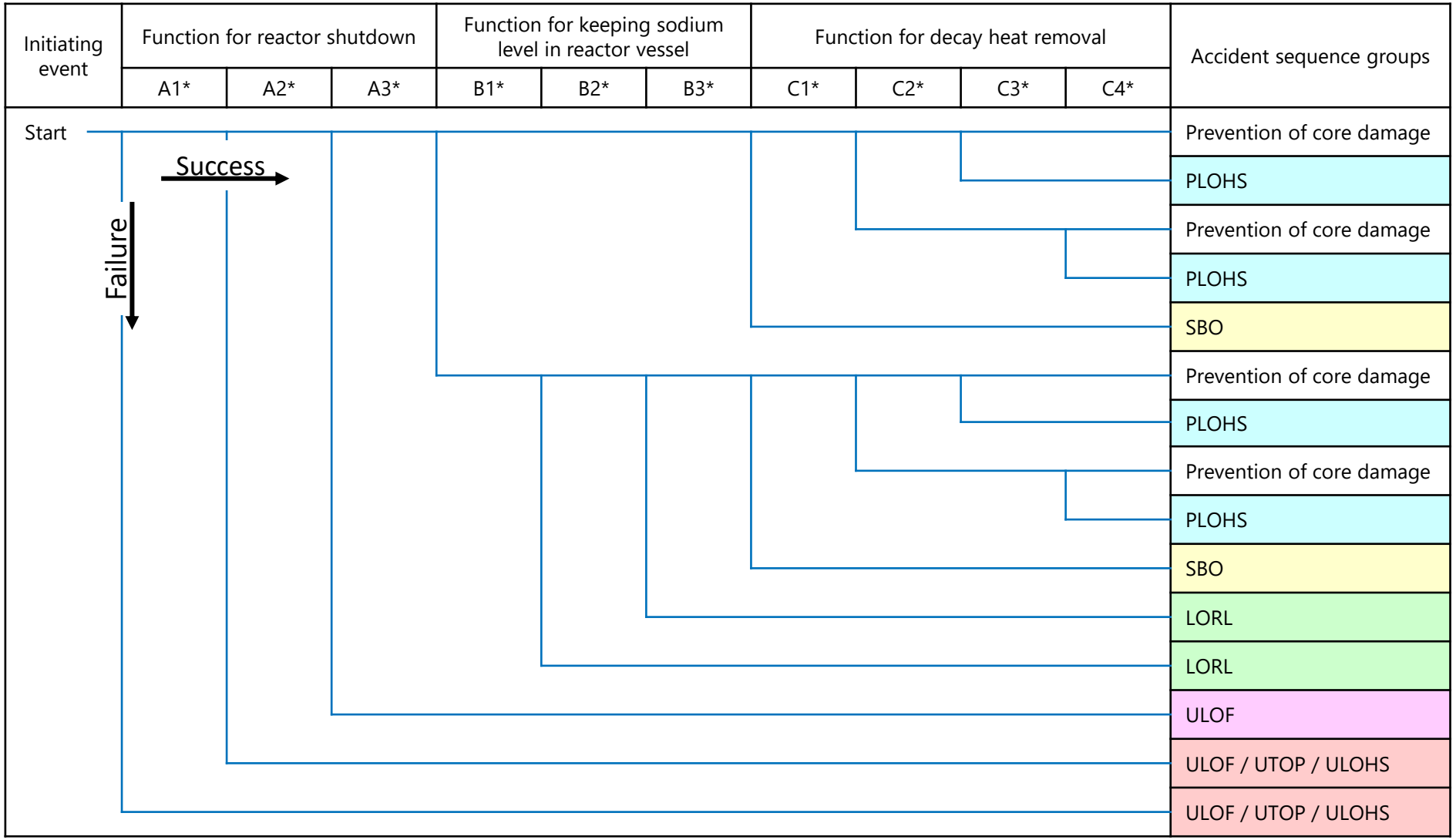
Effectiveness evaluation of measures to prevent containment vessel failure

The Method to Identify Accident Sequence Groups on B-DBA

* Details in the appendix

Master Logic Diagram Method

The accident sequence groups encompassed all possible accident cases on Joyo by using the PRA method.



Safety Improvement & Regulatory Review

The Identified Accident Sequence Groups on B-DBA

ULOF Unprotected Loss of Flow

Loss of flow on primary sodium loops
+ Failure of control rods insertion

3 sequences

UTOP Unprotected Transient Over Power

Anticipated transient
+ Failure of control rods insertion

2 sequences

ULOHS Unprotected Loss of Heat Sink

Loss of heat sink function on secondary sodium loops
+ Failure of control rods insertion

3 sequences

ATWSs
(Anticipated Transient Without Scram)

LORL Loss of Reactor Level

The core exposed caused by sodium external leak

3 sequences

SBO Station Blackout

Loss of normal & emergency power supply

1 sequence

PLOHS Protected Loss of Heat Sink

Loss of heat sink function on multiple systems

2 sequences

LOHRSs
(Loss of Heat Removal System)

This is the first experience on the review that uses the PRA methods to identify the accident sequences for fast reactors.

LF Local Faults

Failure of a fuel sub-assembly caused by local flow blockage

1 sequence

Local Faults

Safety Improvement & Regulatory Review

Installed Equipment for the Measures on B-DBA (A case of UTOP)

Anticipated transient with continuous C/R drawing
+ Failure of the reactor trip signal (High neutron flux in power range)

In measures to prevent core damage

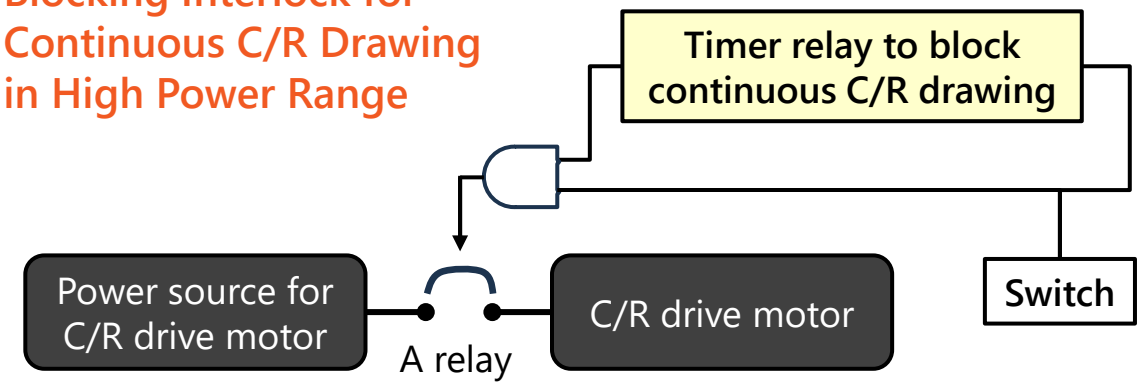
Failure → Success

Block continuous C/R drawing over 3 sec by the interlock → The alternate reactor trip signal (High coolant temp. at reactor vessel outlet) → Backup C/R insertion by signal from logic for backup reactor shutdown system → **Reactor shutdown**

Determination of the failure of the automatic reactor shutdown → Operator manual shutdown process (Manual scram, etc.) → **Reactor shutdown**

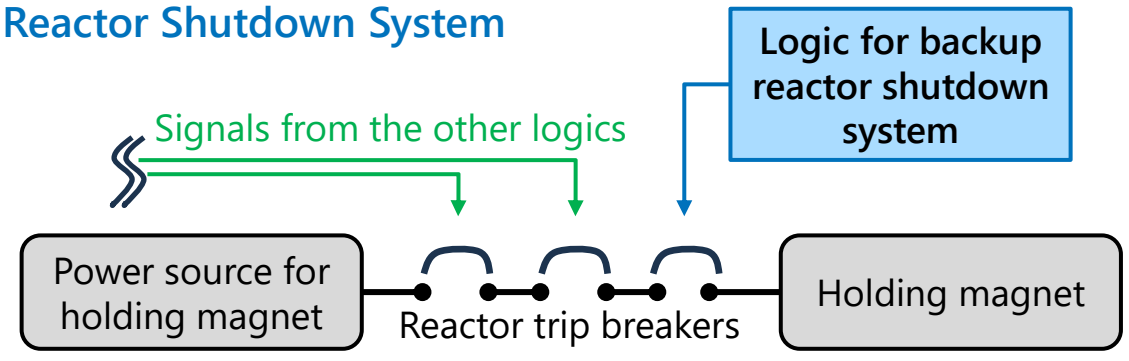
(Assume that the functions of all measures are lost.) → Measures to prevent containment vessel failure

Blocking Interlock for Continuous C/R Drawing in High Power Range



On Control Rod Drive Mechanism

Logic for Backup Reactor Shutdown System



On Backup Control Rod Drive Mechanism

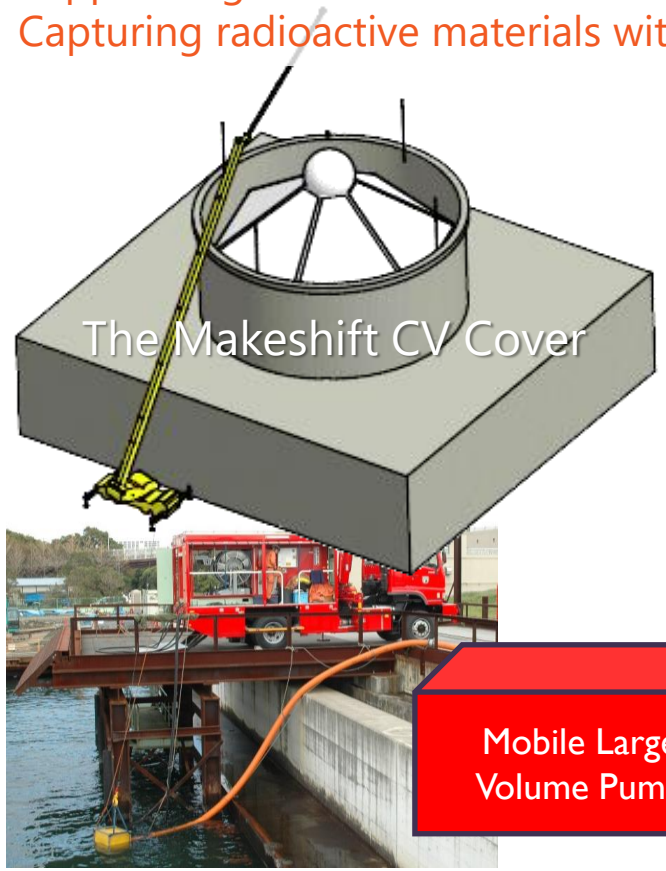
Safety Improvement & Regulatory Review

Event in excess of B-DBA

Assume extremely large-scale natural disasters, terrorist attacks or others occurred.

Measures to mitigate the large amount of radioactive material release

Suppressing radioactive materials with the makeshift CV cover
Capturing radioactive materials with downwind sprayed water

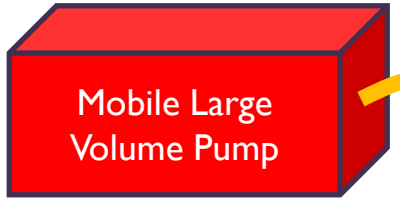


Preparation of multiple types of fire extinguishing methods

Choose the effective methods to extinguish the fire

For Sodium Fire

For Aviation Fuel Fire



Summary

- JAEA forwards the restart of Experimental Fast Reactor *Joyo* under the new regulatory requirements.
- Regulatory requirements applied to Joyo are between those for research reactors and power reactors, due to its relatively high power.
- Seismic resistance, protection against sodium fire, B-DBA, etc., were the focus of the regulatory review.
- NRA required JAEA to take characteristic safety measures for B-DBA & event in excess of B-DBA including a response to intentional aircraft crashes.
- JAEA applied the PRA method for consideration on B-DBA, utilizing knowledge from previously conducted research.
- All of the measures were reviewed by NRA, and JAEA obtained permission (the license) for Joyo.

Operation Plan & Application

Schedule

Japanese Financial Year (Apr. to Mar.)	2023	2024	2025	2026	2027	2028	2029
Regulatory Works	Changes in reactor installation permitted ☆		Review of "plan for construction works"				
Constructions	Preparation for constructions		Constructions on Structure, Systems and Components				
Operations				**Operation** • Fuels & materials irradiation test for demonstration reactors • R&D on the production of medical radioisotopes • International cooperation & examination for R&D on advanced reactors includes fusion reactors			

Operation Plan & Application

For Multidiscipline

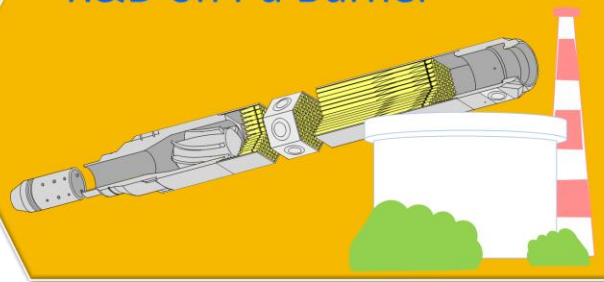
Green Transformation

Development of
- Japanese Demo - Fast Reactor
- Other Gen-IV Reactors

*https://www.mhi.com/news/23071202.html
incorporating research results of METI-commissioned project

Pu Management with Non-Proliferation

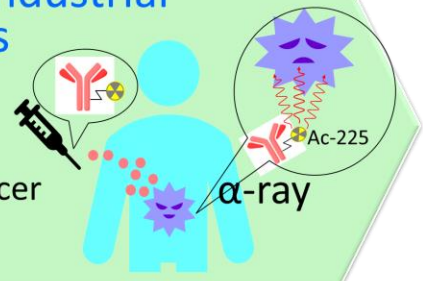
- R&D on Pu Burner

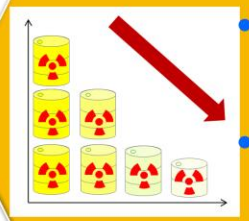


Radioisotopes Production

Medical & Industrial Applications

Targeted Alpha Therapy for Cancer Patients

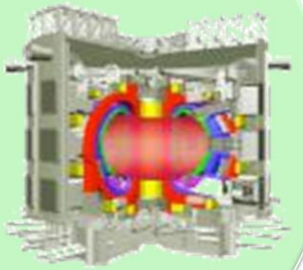




- MA Burning & Recycling
- Toxicity Reduction of LLFP

Sustainability of Nuclear Energy

- Basic Research
- Material Irradiation

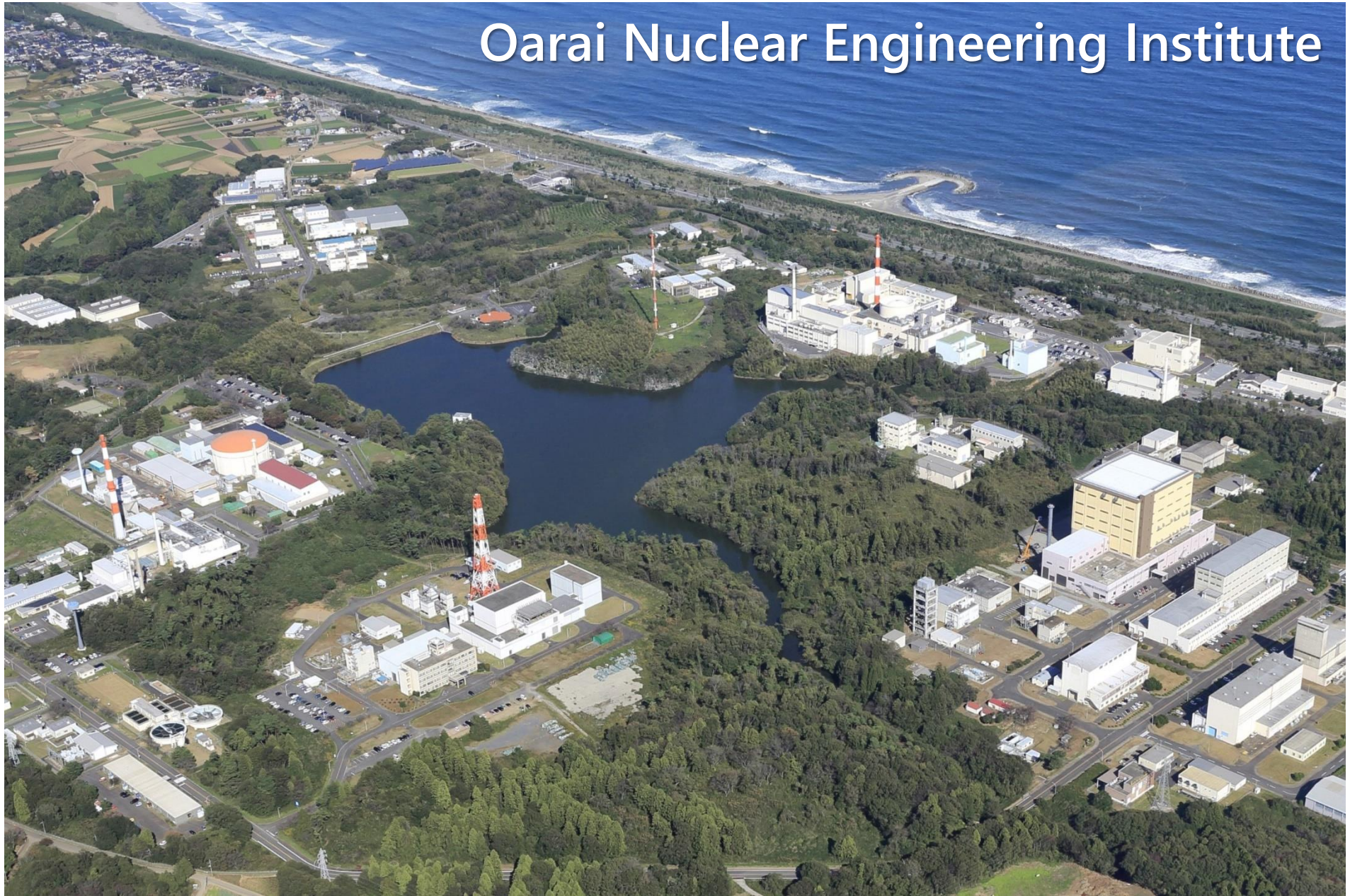


Versatile Usage

- Cooperation with Univ. & Inst.
- Acceptance of Researchers & Engineers for Training

Human Resource Development

Thank you for your attention



Appendix

Protection against Volcanic Ash & Tornadoes

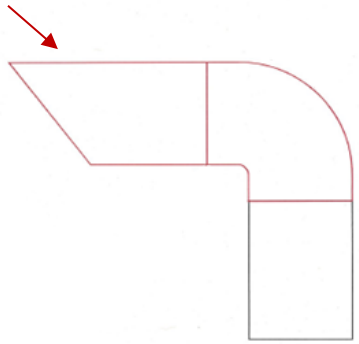
Incombustible coat
Aramid fiber sheet
Basecoat

Volcanic Ash

Estimated max. volcanic ash fall: 50 cm

All safety systems & buildings resist 50 cm of volcanic ash fall.

Weld a bent outlet

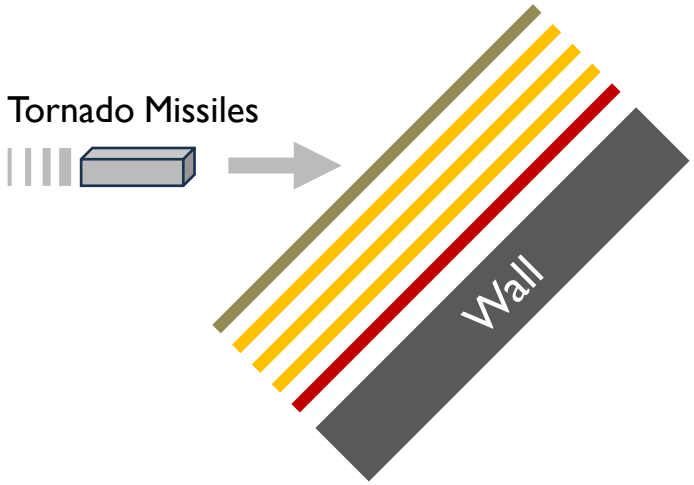


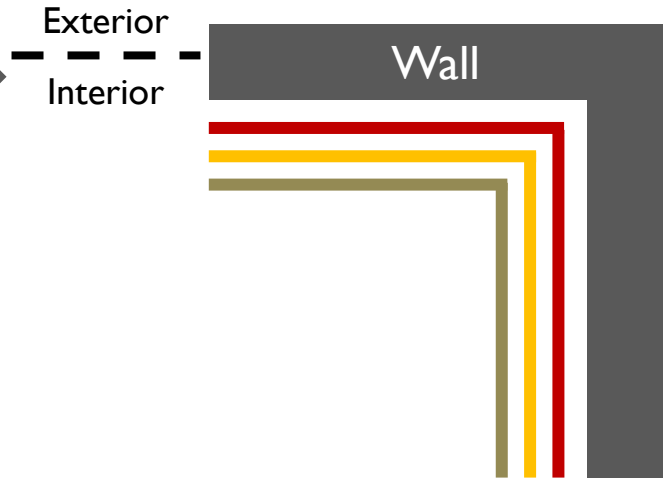
E.g., the Exhaust Stack of the Emergency Diesel Generator

Tornadoes

Estimated max. Tornadoes wind speed: 100 m/s

To prevent damage to the interior safety systems from tornado missiles, install aramid fiber sheets on building walls.





For Penetration Resistance

For Spalling Prevention

Appendix

A1:	Actuation of a primary scram signal
A2:	Scram by reactor protection systems
A3:	Insertion of primary control rods
B1:	Prevention of inner pipe failure in the primary loops of the main cooling system
B2:	(after B1 fails) Prevention of outer pipe failure in the compartment containing the failed inner pipe
B3:	(after B1 fails) Prevention of inner pipe failure in the primary loop of the main cooling system in a different compartment from that containing the failed inner pipe
C1:	Supply of an emergency electric power
C2:	Forced circulation by the primary pumps using pony motors
C3:	Decay heat removal by the secondary loops of main cooling system
C4:	Forced circulation by the auxiliary cooling system