Docket No. 99902114
Docket Name: JAEA Floating Seismic Isolation System for SMRs

ENCLOSURE 2

LR050818-01

Non-proprietary

Docket No. 99902114 Non-proprietary

DR050818-02

Overview of Floating Seismic Isolation System for SMRs (FSIS) Technology

Kick-off Meeting

September 5, 2023

US NRC HQ, Washington DC, USA

Contact: Xing L. Yan
Japan Atomic Energy Agency
Email: yan.xing@jaea.go.jp

Who are we?

- Japan Atomic Energy Agency (JAEA) and its corporate partners (collectively, JAEA Consortium) are developing the FSIS concept, paired with a SMR design or designs, for possible deployment in the U.S., Japan, and elsewhere. This meeting kicks off the FSIS pre-application engagement with the US NRC.
- Each organization brings specific strengths and competencies, and each will have specific roles in various project stages
  - » JAEA – originated concept, lead for development, conceptual design, and pre-application engagement
  - » IHI Corporation – co-invented concept, engineering and manufacturing expertise for nuclear plant equipment
  - » JGC Corporation – engineering and construction expertise for large energy projects including floating plants

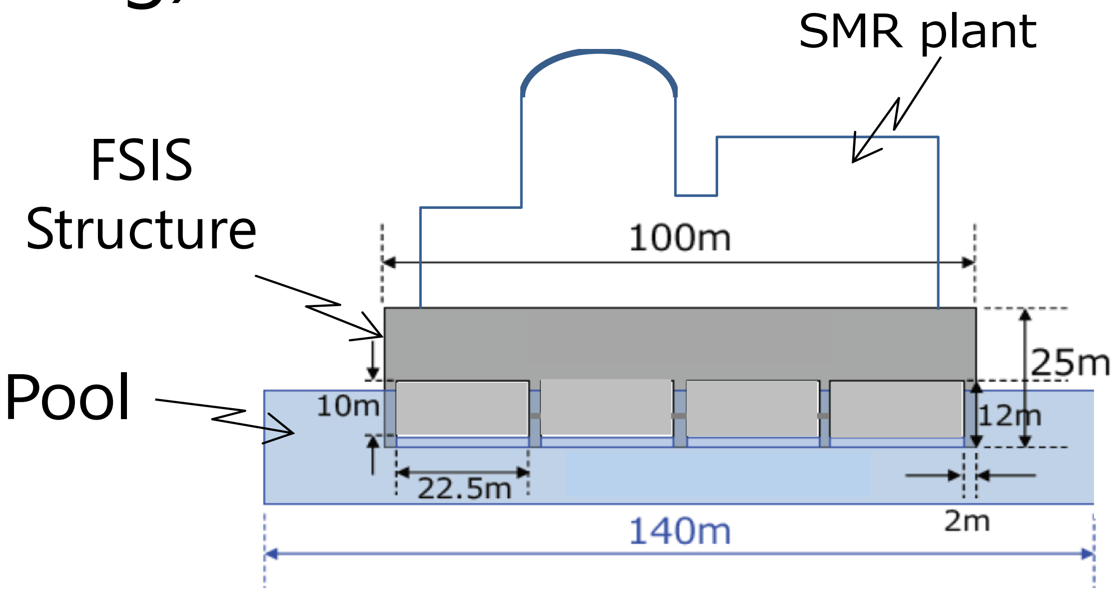
Objectives for this presentation

1. Overview of the FSIS technology and benefits for NPP
2. Overview of FSIS plant design (SMR) concept
3. Summary of pre-application engagement plan with the US NRC

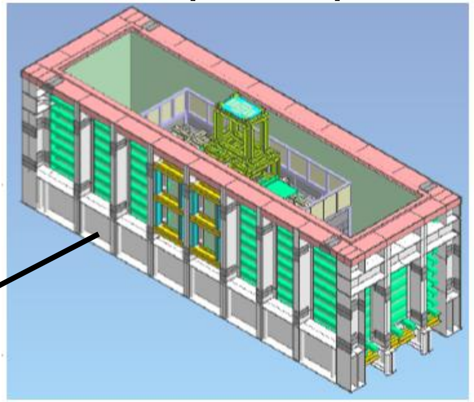
1. Overview of the FSIS technology and benefits for NPP

The FSIS Technology (patents pending)

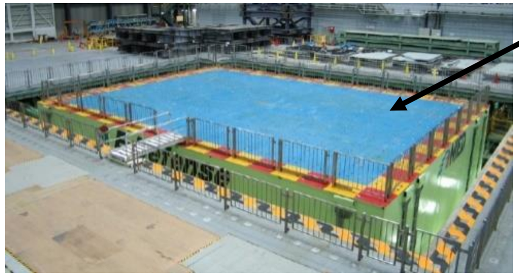
- A platform structure consisting of air cavities and orifices and pairing an SMR plant floats in a water pool
- Reduce seismic accelerations in horizontal and vertical directions by about an order of magnitude
- Performance is adjustable by re-configuring cavities and orifices
- Provide robust safety in BDBE
- Enhance design standardization for reactor and more siting flexibility in areas of relatively high seismicity



1/15 scale plant mockup in a pool



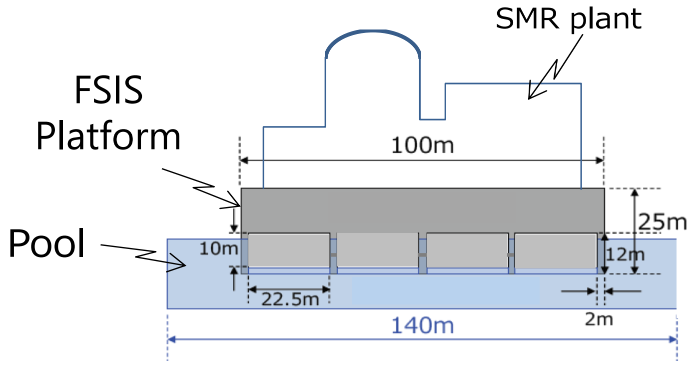
Technology is being validated by tests on world`s largest shaking table in Japan



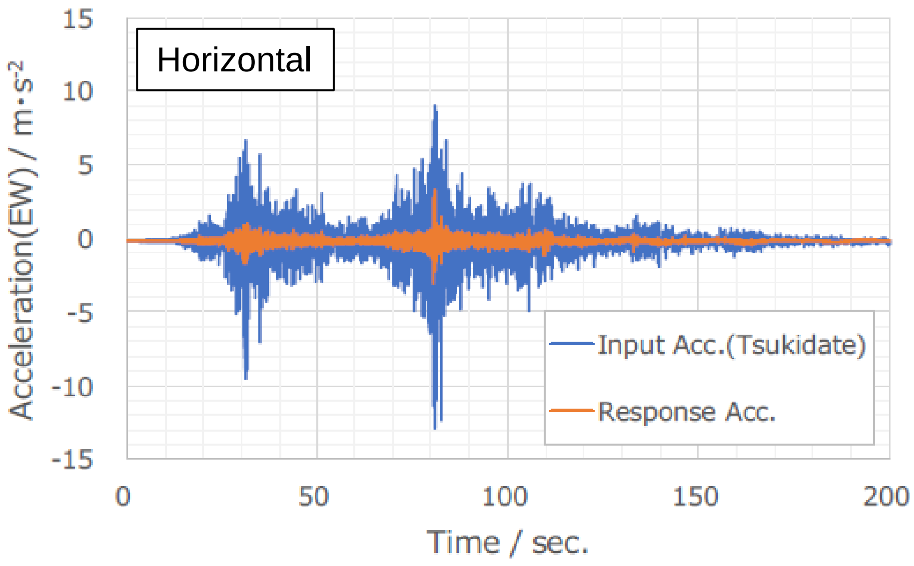
FSIS Seismic Isolation Performance (1/2)

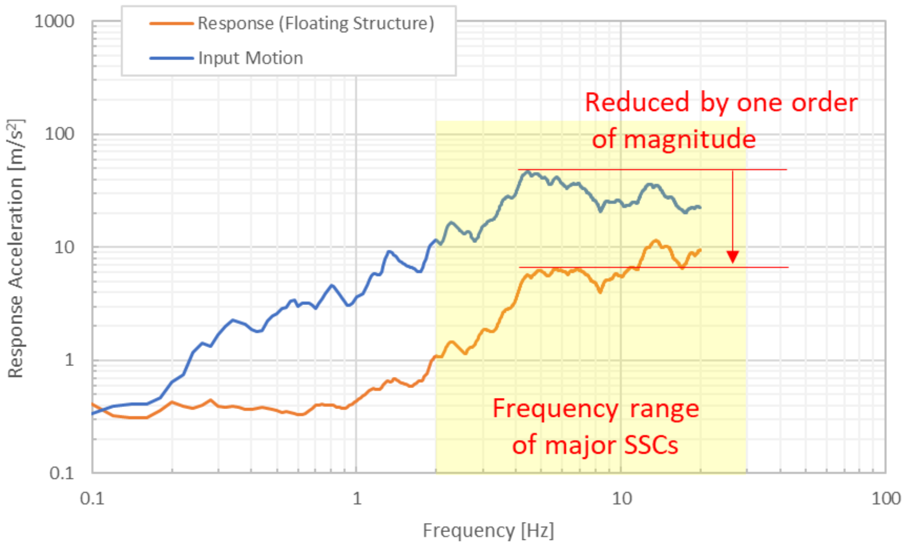
CFD Simulation for a FSIS paired SMR plant

- Reduce horizontal seismic response acceleration by an order of magnitude



FSIS paired SMR plant layout



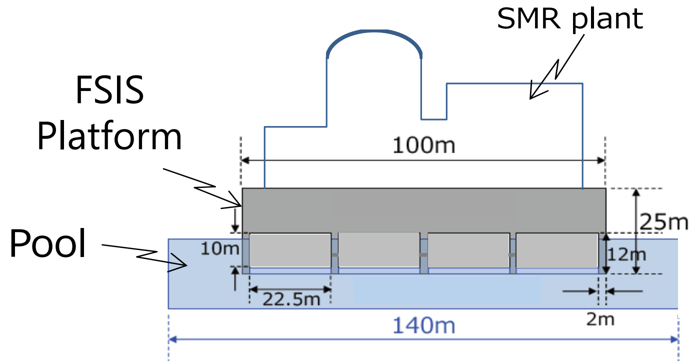


- Solver: Flow 3D (Flow Science, Inc.)
- Input Motion: 2011.3.11 The Great East Japan Earthquake @ Tsukidate

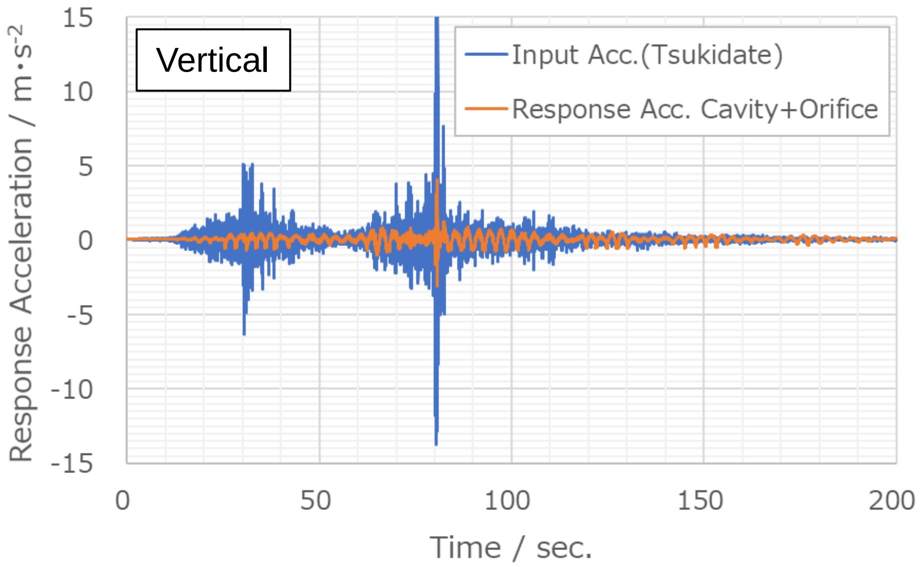
FSIS Seismic Isolation Performance (2/2)

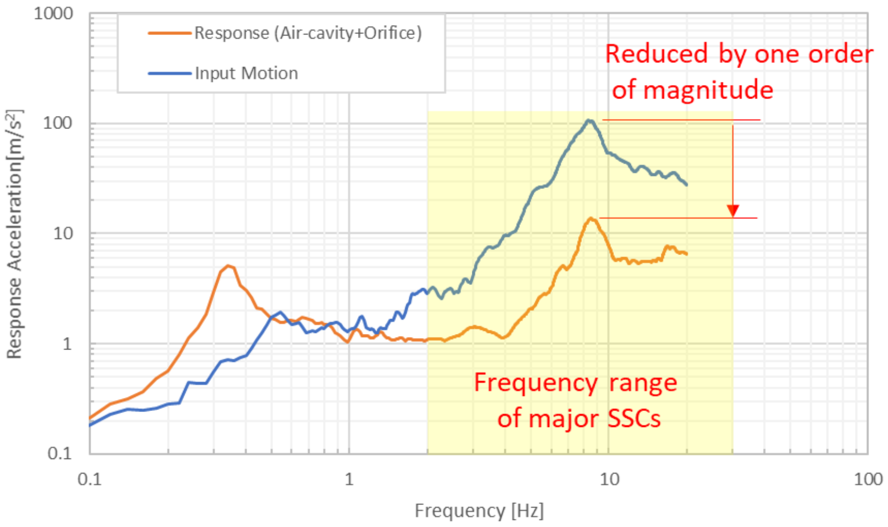
CFD Simulation for a FSIS paired SMR plant

- Reduce vertical peak response by an order of magnitude
- Reduce residual vibration of the floating body



FSIS paired SMR plant layout



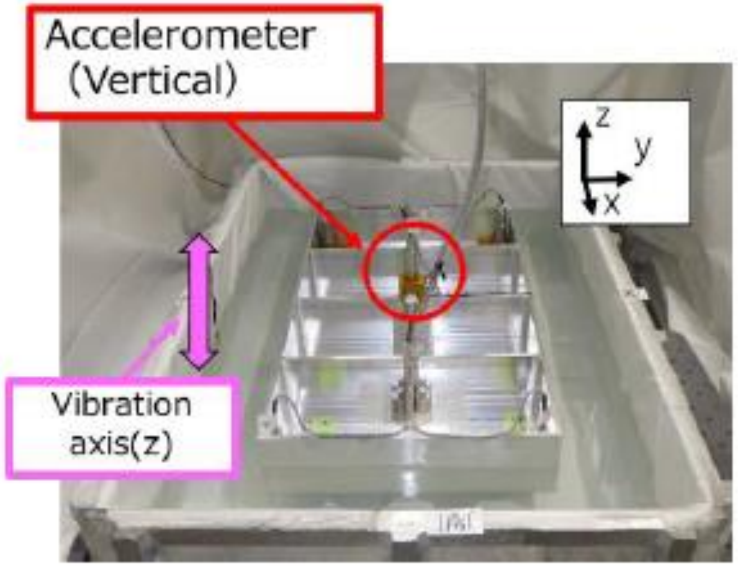


- Solver: Flow 3D (Flow Science, Inc.)
- Input Motion: 2011.3.11 The Great East Japan Earthquake @ Tsukidate

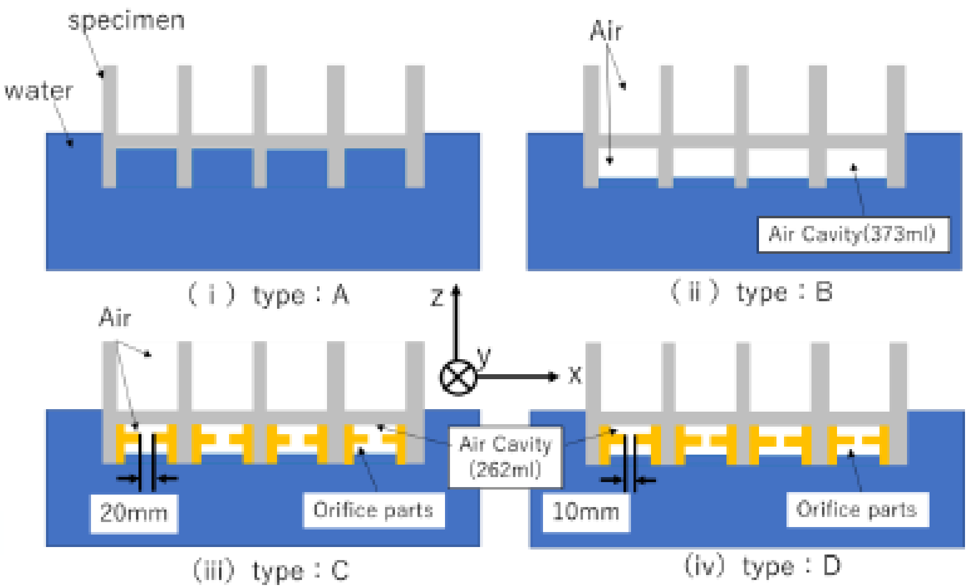
Small scale tests for proof of principle : Test model

- 1/200 scale model of an SMR plant, having various configurations of air cavities and orifices for comparison
- Tests were conducted using random waves and seismic waves on electromagnetic shaker with wide bandwidth

	The similarity law (Scaling ratio:1/200)
Length	1/200
Mass	$1/200^3$
Frequency	200
Time	1/200
Acceleration	200



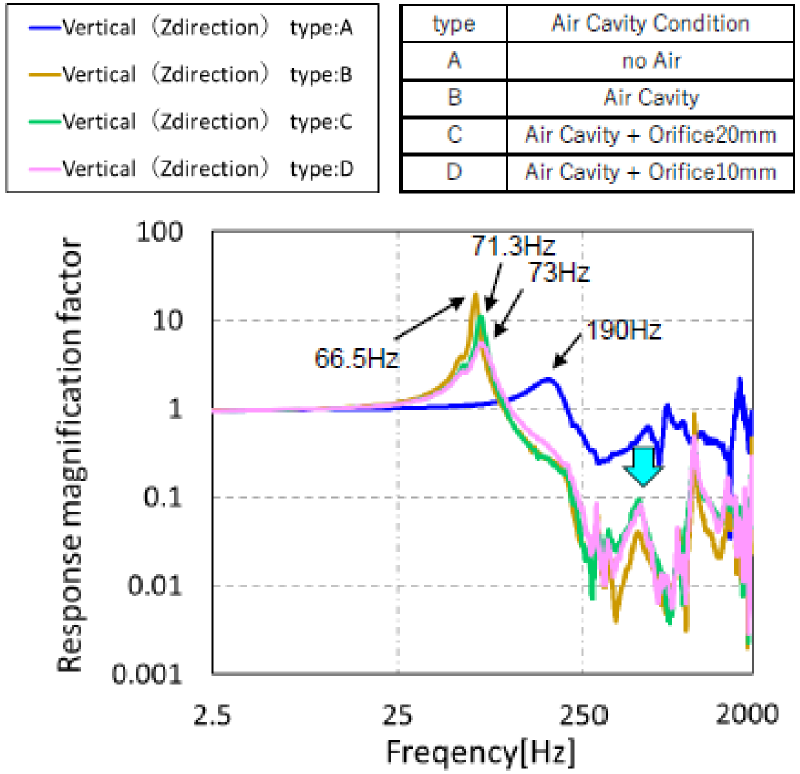
Floating body in water pool



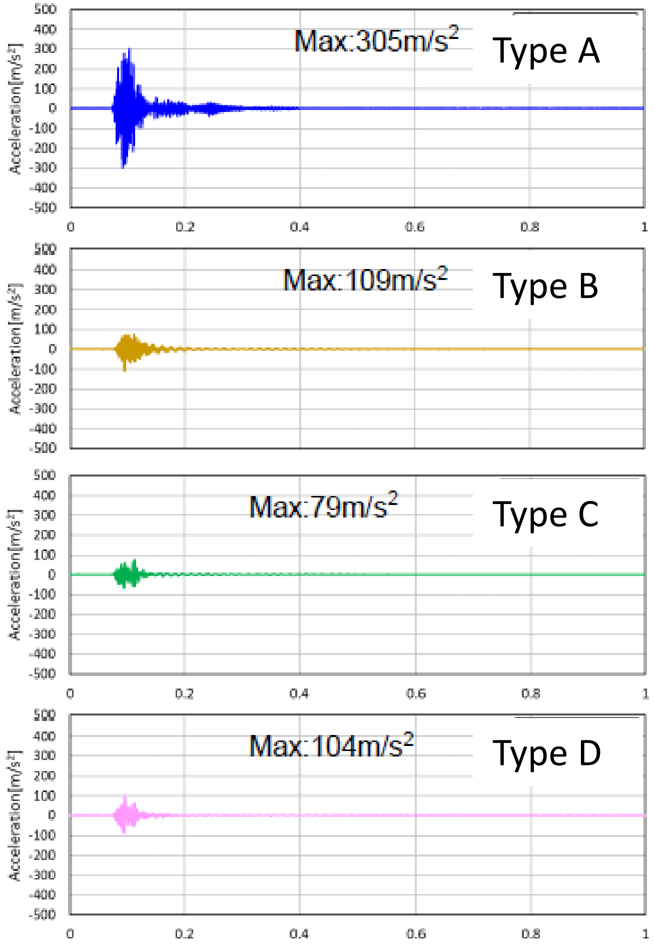
Small scale tests for proof of principle : Test results

- Natural frequency is reduced by air cavities
- Both amplitude and residual of response are remarkably reduced

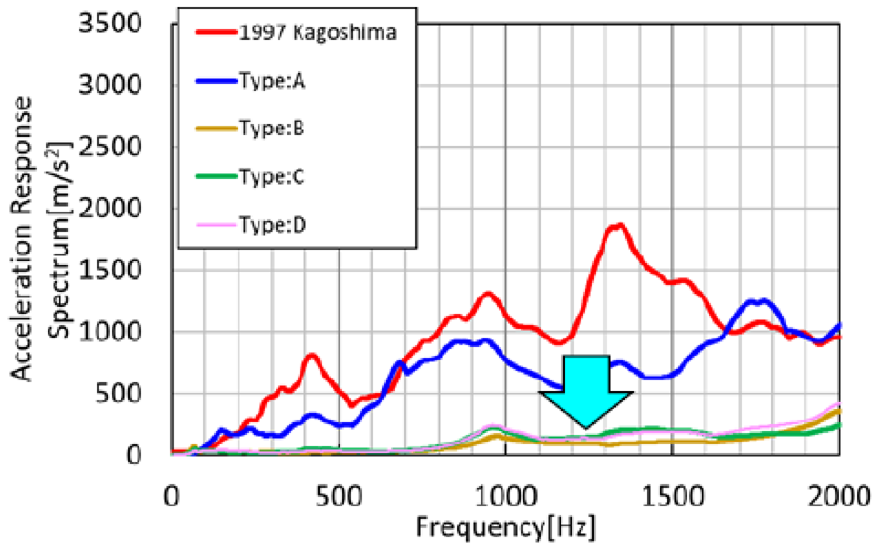
type	Air Cavity Condition
A	no Air
B	Air Cavity
C	Air Cavity + Orifice20mm
D	Air Cavity + Orifice10mm



Seismic Response magnification factor



Seismic response acceleration in time (sec)



Seismic response acceleration spectra

JAEA JGC IHI

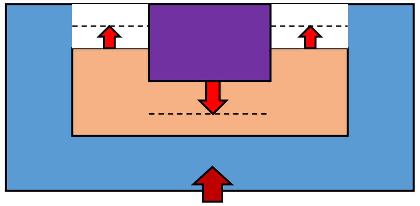
Plan for large-scale experiments for V&V

- Validate 3D seismic isolation performance of FSIS
  - Four configuration patterns of test pieces
    - Solid floating body
    - Floating body with air cavities
    - Floating body with air cavities and orifices, namely, FSIS
    - Floating body with FSIS and additional internal pools
- Verify design analysis codes from experimentally generated database
- Identify any unknown issue and its resolution regarding FSIS performance
- Experiments are currently under construction. The tests will be performed in January - February 2024

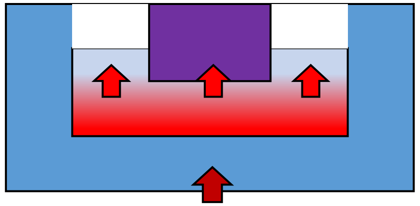
Design parameters of full-scale plant and experimental model

Parameter		Full-scale plant	1/15 Scale model
Length and width of floating body [m]		135 x 45	9 x 3
Hight to center of gravity [m]		24.8	1.65
Weight of floating body [ton]		61,200	18
Pool length, width and bottom gap d0		240 x 60 x 27	16 x 4 x 1.8
Natural frequency [Hz] Vertical mode of intact floating body	1st mode (Gravity domain)	0.12	0.45
	2nd mode	7.6	113
Natural frequency [Hz] Vertical mode of floating body with cavity	1st mode (Gravity domain)	0.12	0.45
	2nd mode	0.17	2.6
Natural frequency [Hz] Sloshing (Gravity domain)	Longitudinal	0.04	0.16
	Lateral	0.11	0.44

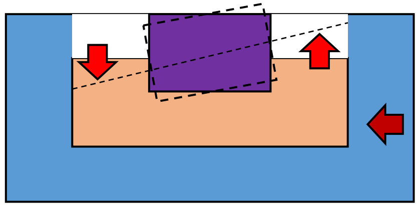
1st mode



2nd mode



Sloshing



JAEA JGC IHI

Scale-down for experiments

- Facility for experiment is E-Defense※, the world's largest shaking table at Hyogo Prefecture, Japan
- The mockup model is scaled down from the HTGR plant by a linear ratio of 1/15, limited by the size and operation parameters of the shaking table.

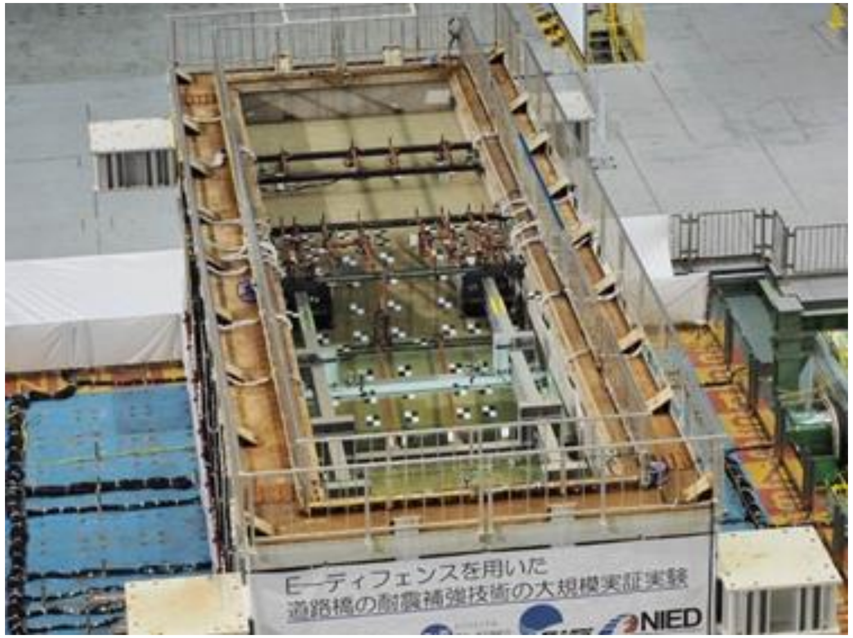
Table Size	20m x 15m	
Payload Capacity	12MN (1200tonf)	
Shaking Direction	X, Y - Horizontal	Z - Vertical
Max. Acceleration	900Gal	1500Gal
Max. Velocity	200Kine	70Kine
Max. Displacement	±100cm	±50cm
Frequency range	～30Hz	

※ E-Defense, facility of National Research Institute for Earth Science and Disaster Resilience（NIED)

Equipment for large-scale Experiments

- Use of NIED's existing equipment, Soil Vessel
  - ➢ Water Pool for large-scale experiments
  - ➢ Dimensions length x width : 16m x 4m

Water Pool for large scale experiments

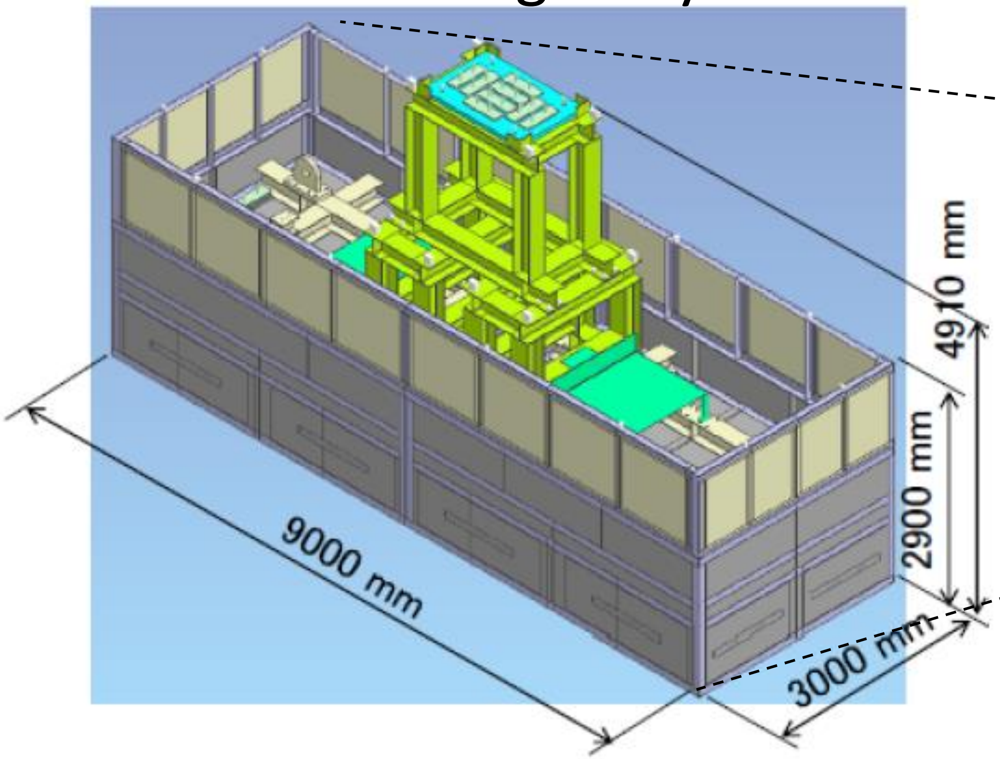


Reference
https://xtech.nikkei.com/atcl/nxt/column/18/00142/00045/

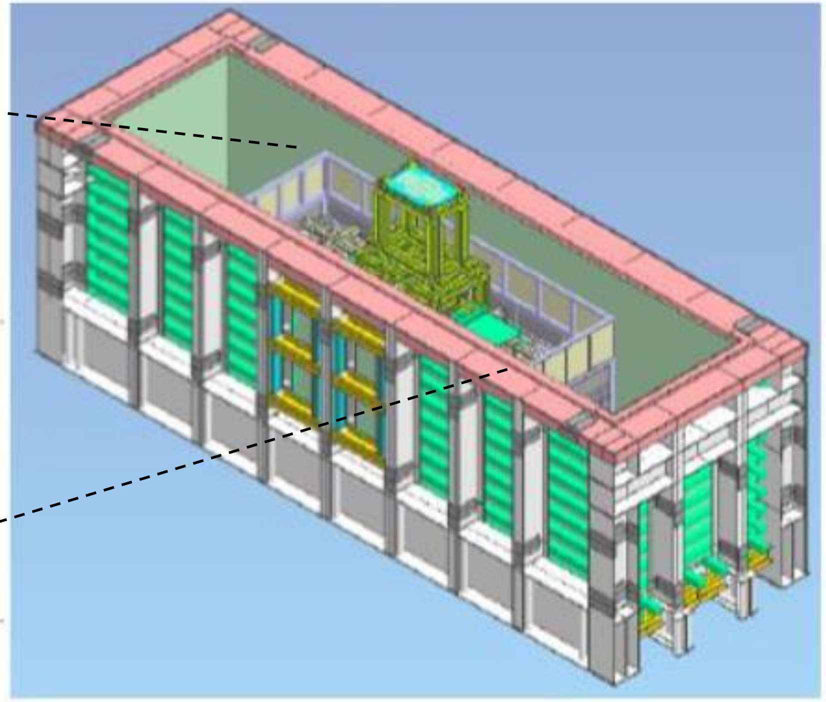
Mockup model for large-scale experiments

- Center of gravity tuned by structure of the floating body
- Air cavities arranged at bottom of the floating body
- 3.5m and 0.5m gaps of floating body from the pool side walls
- 1.8m gap of floating body from the pool floor

Floating body



Installed in water pool



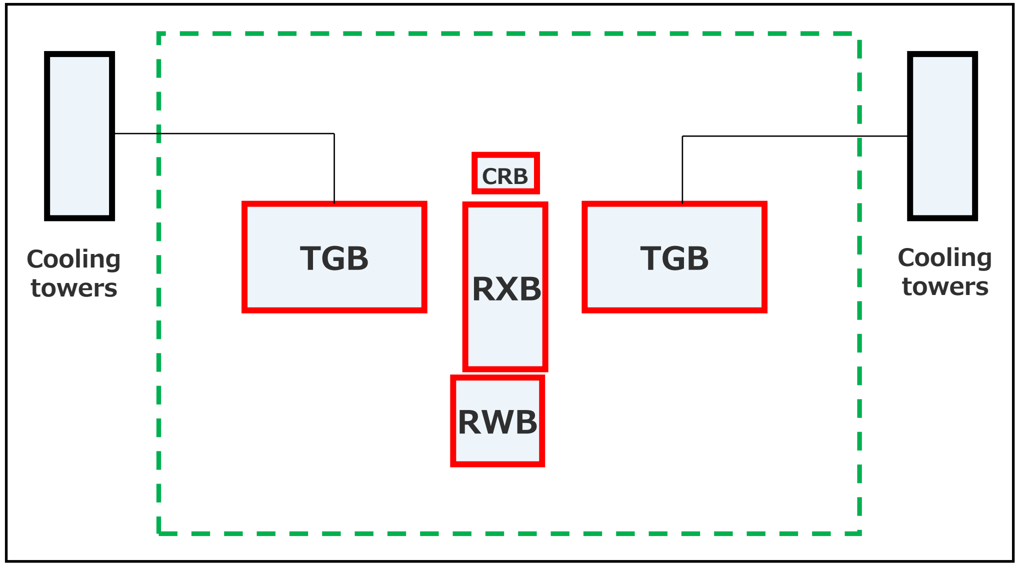
Summary : FSIS specific benefits for NPP

- 3D base seismic isolation (SI)
  - ➢ Reduce seismic force by an order of magnitude in all directions
- SI Performance reliability
  - ➢ Support nonseismic load by natural buoyancy
  - ➢ Resist seismic load using few devices (cavities and orifices)
- Simplified seismic design
  - ➢ Standardize NPP design at certified seismic isolation design response spectrum (SIDRS)
- Enhanced economics and safety
  - ➢ Reduce seismic supports and cost for components
  - ➢ Provide large design margin of SSCs against beyond-design-basis earthquake (BDBE)

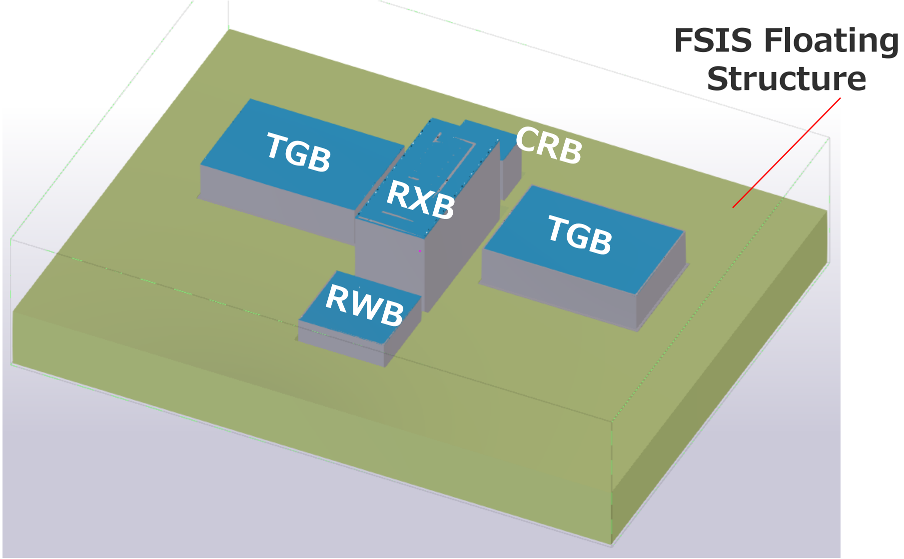
2. Overview of FSIS plant design (SMR) concept

FSIS paired nuclear power plant concept

- The plant may include one or more reactors and turbine generators
- Nuclear Island including buildings for reactor (s), radwaste, control room, etc. and turbine buildings are located on an FSIS floating structure
- Cooling towers (shown in the plan view) may be located off the FSIS floating structure to minimize the plot area of the structure.



Plant Layout (plan view)



Floating Plant Layout (birds eye view)

RXB : reactor building
RWB : radwaste building
CRB : control building
TGB : turbine building

Design Requirements and Criteria

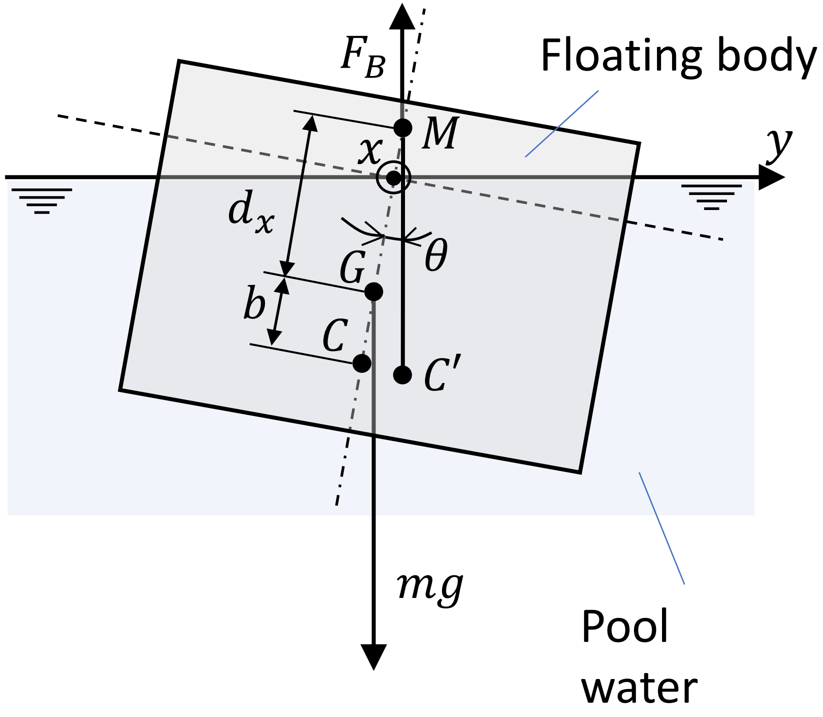
- FSIS paired reactor plant design is developed and optimized in compliance with the design requirements from the following regulations, regulatory guidance, and industry standards identified to date.
- Others may be identified as required in future.

1) Principal Design Criteria
   - 10 CFR Part 52, Licenses, Certifications, and Approvals for Nuclear Power Plants (with references to Part 50 appendices below)
   - 10 CFR Part 50 Appendix A, General Design Criteria for Nuclear Power Plants (Specific criteria to be identified)
   - 10 CFR Part 50 Appendix S, Earthquake Engineering Criteria for Nuclear Power Plants
   - NUREG-0800, Standard Review Plan (applicable sections to be identified)
2) Design Criteria for Seismic Isolation
   - NUREG/CR-7253, Technical Considerations for Seismic Isolation of Nuclear Facilities
   - Regulatory Guide 1.60, Design Response Spectra for Seismic Design of Nuclear Power Plants, Rev. 2, 2014
   - Regulatory Guide 1.208, A Performance-based Approach to Define the Site-specific Earthquake Ground Motion, 2007
   - DC/COL-ISG-017, Interim Staff Guidance on Ensuring Hazard-Consistent Seismic Input for Site Response and Soil-Structure Interaction Analysis
3) Industry Consensus Standards
   - ASCE 4-16, Seismic Analysis of Safety-Related Nuclear Structures
   - ASCE 43-19, Seismic Design Criteria for Structures, Systems, and Components in Nuclear Facilities

Design Evaluation (1/4)

1) Floating Stability

If the distance between M (metacenter) and G (center of gravity) is positive, the floating body can be considered stable as a floating structure



For x direction;

d_x = 360.22 m >> 0

For y direction;

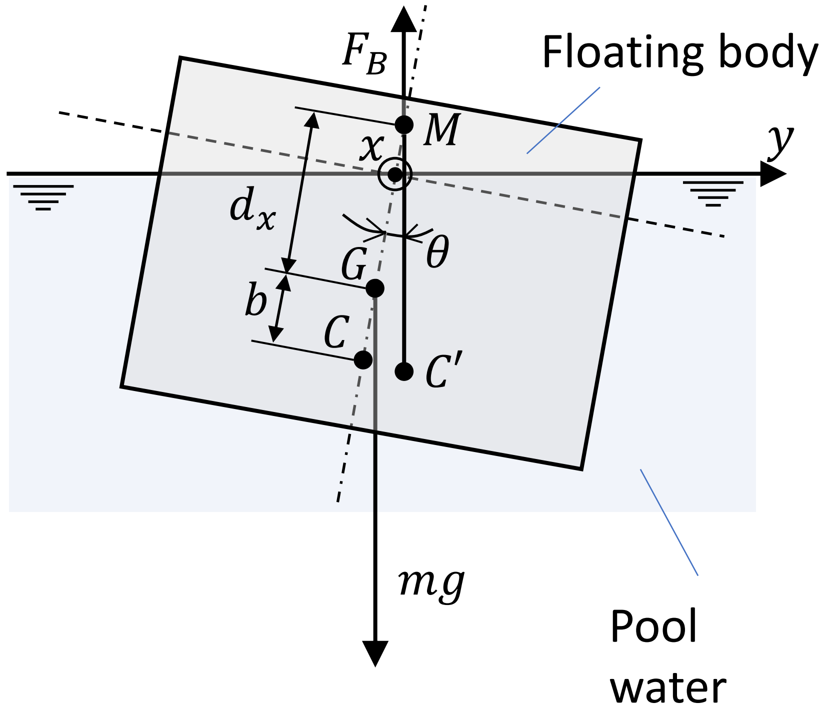
d_y = 786.31 m >> 0

I_x: Second moment of area
V : Volume of water excluded from floating body
C : Center of buoyancy
C': Centre of buoyancy with maximum tilt
G: Center of Gravity
M: Metacenter
(Intersection point between original buoyancy axis and new buoyancy axis)
b: Distance between point C and G

Floating body using the as-is plant properties has been confirmed as *stable*.

Design Evaluation (2/4)

2) Natural Frequency for Rolling



Natural frequency of rolling vibration for x-axis;

f_{rx} = 0.327 Hz

Natural frequency of rolling vibration for y-axis;

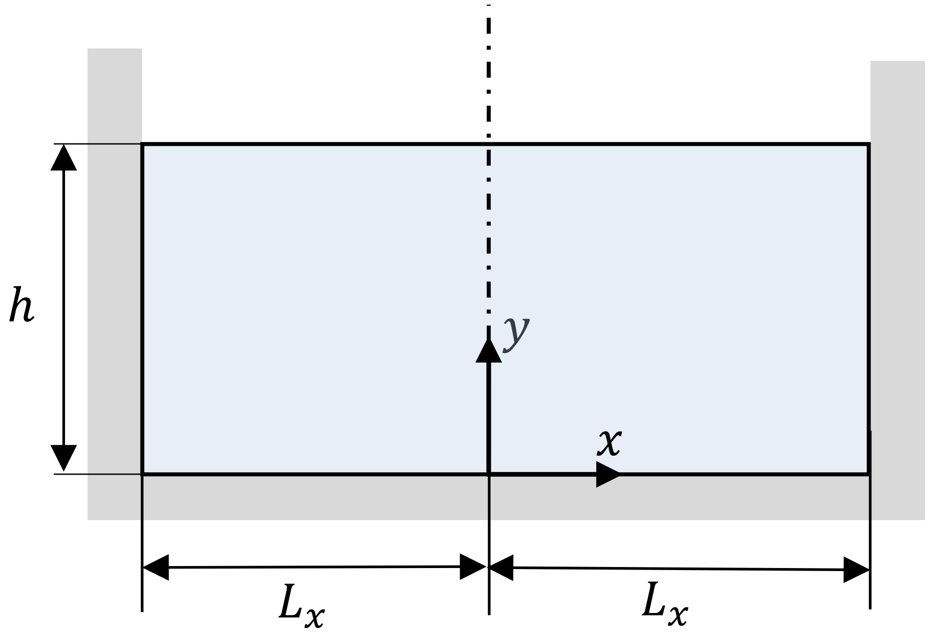
f_{ry} = 0.247 Hz

Natural frequency is sufficiently low and will avoid amplification of rolling resonance to seismic input.

Design Evaluation (3/4)

3) Natural Frequency for Sloshing

No.	Parameter / Calculated value	Variable name	Numerical value	Unit
1	Gravitational acceleration	g	9.80665	m/s^2
2	Depth of seismic isolation pool	h	14.06	m
3	Isolation pool width (X-direction)	L_x	350	m
4	Isolation pool width (Y-direction)	L_y	250	m



Natural frequency of sloshing for x direction;

f_{sx} = 0.017 Hz

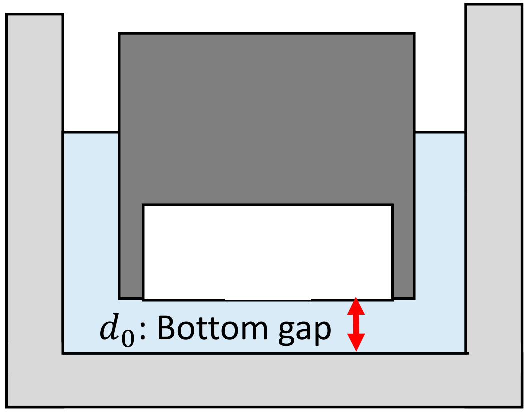
Natural frequency of sloshing for y direction;

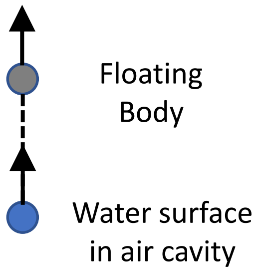
f_{yx} = 0.024 Hz

Natural frequency is low and will avoid amplification of sloshing resonance to seismic input.

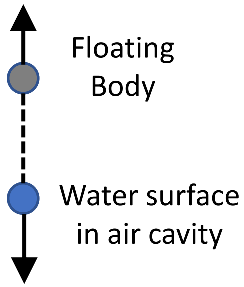
Design Evaluation (4/4)

4) Seismic Isolation for Vertical Motion

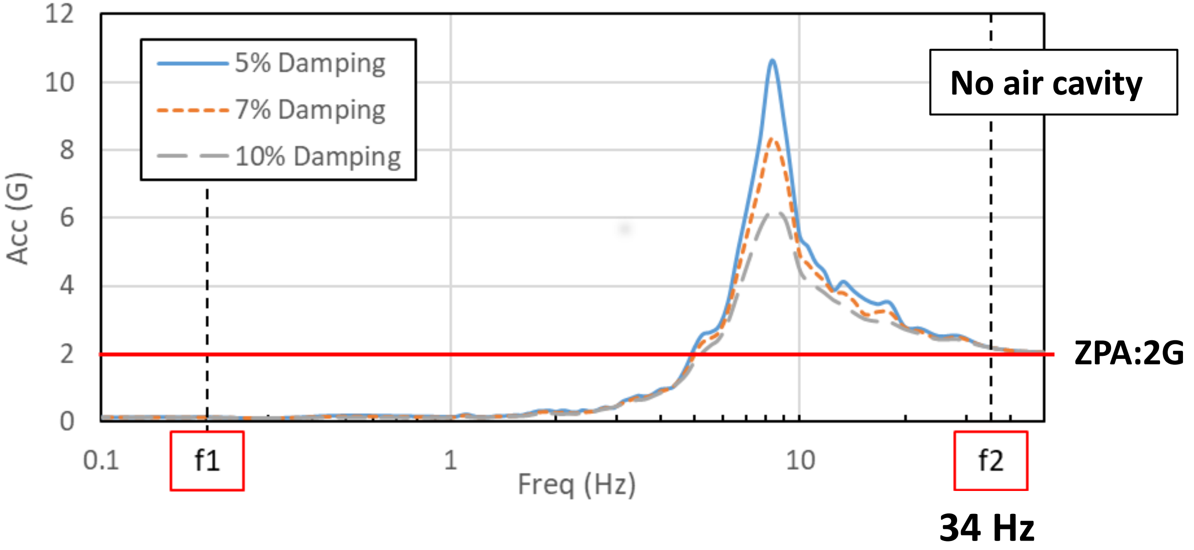




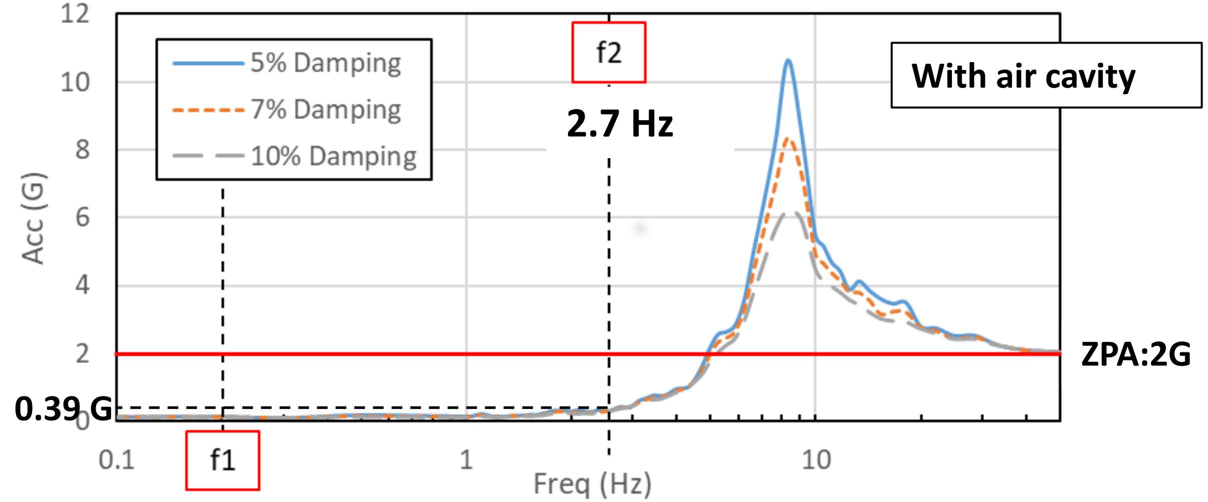
1st mode



2nd mode



f2 Natural Frequency is decreased because of air cavity at the bottom of Floating Structure



March 11, 2011 earthquake at Tsukidate obtained from K-net (NIED)
https://www.kyoshin.bosai.go.jp/

Floating body with cavity

$$f_2 = \frac{1}{2\pi}\sqrt{\frac{AK_V'}{d_0(\rho A d_0 + m)}}$$

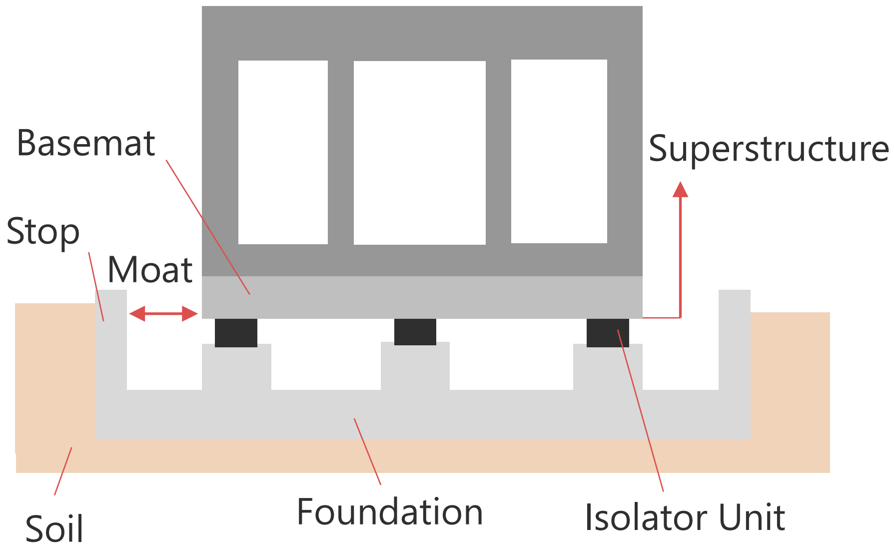
where $$K_V' = \frac{K_a K_w}{\alpha(K_a - K_w) - K_a}$$

$$\alpha = \frac{V_a}{V_w + V_a}$$

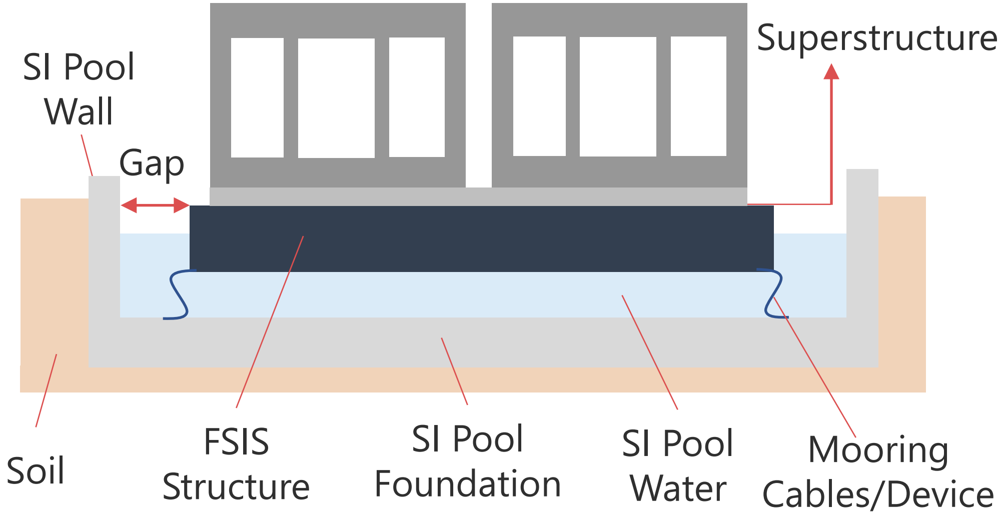
K_w, K_a, K_v` – Bulk modulus of water, air, and equivalent water-air volume

The natural frequency of the 2nd mode reduces with increasing compressibility of the water-air volume, thus providing seismic isolation by avoiding structural resonance to seismic motion.

Seismic isolation (SI) design procedure



Existing SI Model



FSIS Model

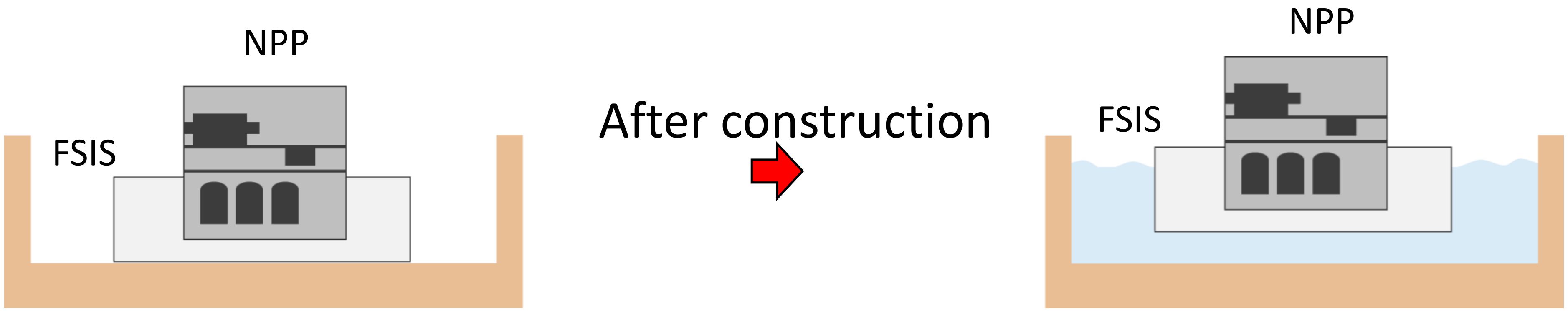
No.	Existing SI methods		FSIS methods	
	Object	Analysis Model	Object	Analysis Model
1	Soil	FEM/TLBM	Soil	FEM/TLBM
2	Moat Wall	FEM	SI Pool Wall	FEM
3	Foundation	FEM	SI Pool Bottom Slab	FEM
4	Isolator Unit	**Nonlinear or Equivalent linear beam**	SI Pool Water FSIS Structure Mooring Cable/Device	**CFD and/or FEM**
5	Superstructure (One building)	FEM	Superstructure (Two or more buildings)	FEM

1. NUREG/CR-7253 and ASCE 4-16 provide for following analysis approaches: 1) Coupled time-domain, 2) Coupled frequency-domain, 3) Multi-step
2. In coupled methods, soil-foundation-isolator-superstructures are integrated in one model, whereas in the multi-step method, time domain analysis for foundation-isolator-superstructure is conducted in the 2nd step using foundation seismic input SIDRS generated in the 1st step
3. Existing SI Modelling approaches are applicable to all FSIS components except the isolator
4. Methods for the FSIS model use CFD or FEM or a combination of two, taking into account of soil-structure and fluid-structure interactions. Verification will be conducted by experiments and analyses.

FSIS plant constructability

One of the construction methods under consideration involves two steps of construction on site:

- The FSIS and paired NPP are constructed in the empty seismic isolation pool and a crane or other equipment is used for lifting during the construction (Step 1).
- After the construction is competed, the pool is flooded with water to raise the FSIS paired NPP (Step 2).



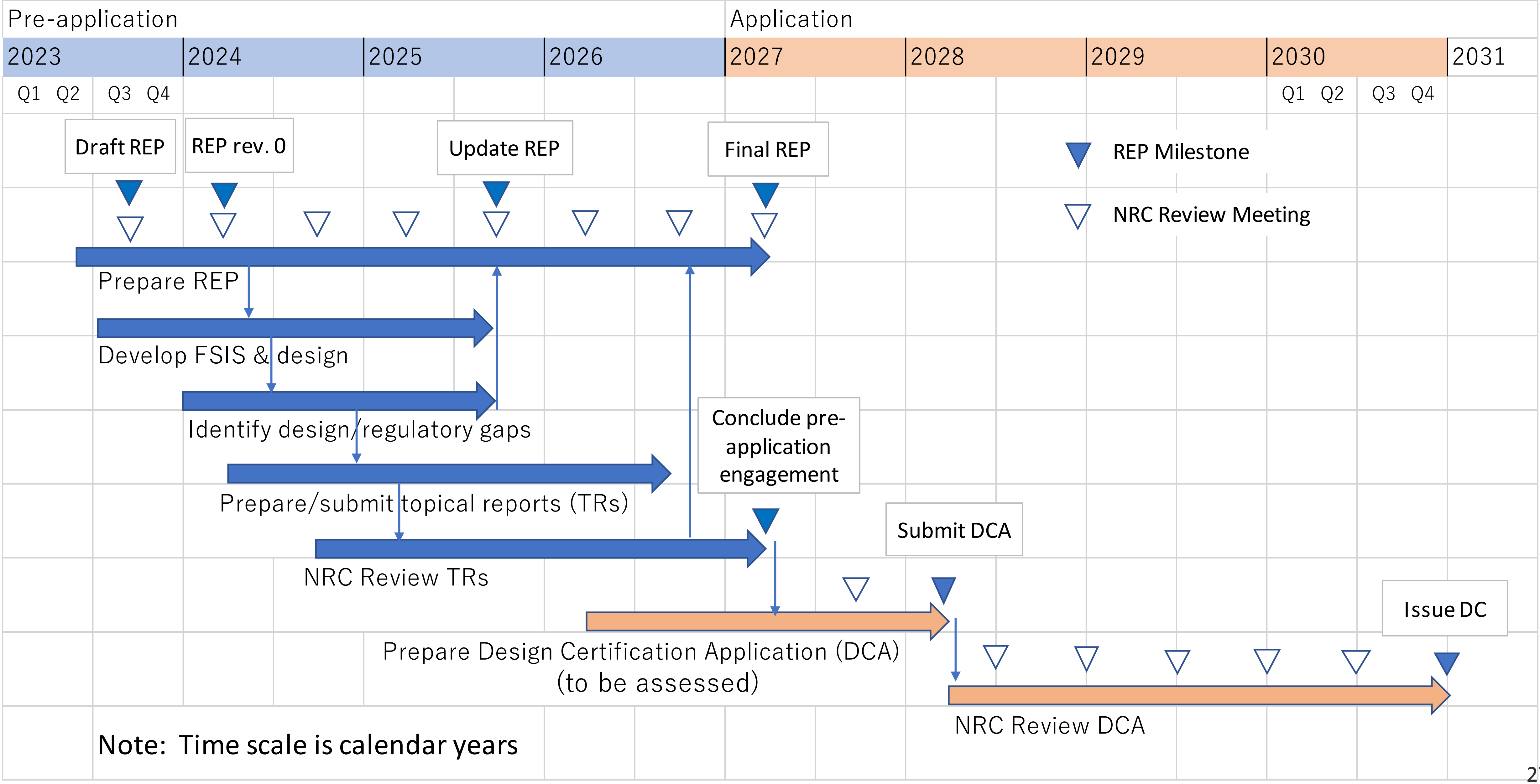
Step 1 **Step 2**

3. Summary of pre-application engagement plan with the US NRC

Regulatory Engagement Plan (REP) : Objectives

- JAEA Consortium developing the concept of FSIS paired SMR plant design will present evidence over the next months and years as to its enhanced safety and its potential appeal to customers that we believe will make it competitive in the new reactor market in the US and elsewhere
- The REP is key to reducing licensing uncertainties and related risks to support a business decision to pursue a future licensing application.
- A proposed REP timeline is on next slide

Proposed FSIS Regulatory Engagement Plan (REP) Timeline



Note: Time scale is calendar years

Regulatory Engagement Plan : Engagement focus

- While the FSIS technology is potentially deployable for various types and designs of nuclear power plants, the pre-application engagement will focus on the FSIS paired with a LWR-SMR design
- A decision on which reactor design to pair with the FSIS for a future licensing application and on the identity of the applicant will be made during the course of, or at the conclusion of, the REP; that decision will be informed in part by the outcome of engagements with the NRC proposed in the REP.
- We will be very attentive to your feedback and comments to ensure both the pre-application and application phases are conducted as efficiently and effectively as possible

Questions/comments?