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JAEA White Paper

Design-related Licensing Information for the FSIS Paired SMR (FSIS-R) Plant

Revision 0

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Japan Atomic Energy Agency
IHI Corporation
JGC Corporation

Revision Log

Revision	Doc Number	Description of Changes
0	DR070706-02	Preliminary draft for comment
0	DR070706-02NP	For public release (Proprietary information redacted)

Table of Contents

1. Introduction

1.1 Purpose

The purpose of this White Paper is to assist the staff of the U.S. Nuclear Regulatory Commission (USNRC) in its planned review of licensing and pre-licensing submittals regarding the Floating Seismic Isolation System (FSIS) being developed by Japan Atomic Energy Agency (JAEA) and its corporate partners IHI Corporation and JGC Corporation (henceforth collectively referred to as the Consortium). The Consortium intends to submit, in accordance with Subpart E of Title 10, Part 52, “Licenses, Certifications and Approvals for Nuclear Power Plants,” of the Code of Federal Regulations, an application for a Standard Design Approval (SDA) involving the FSIS and a paired nuclear power plant design. To facilitate the USNRC staff review of the future SDA application and to support successful licensing, the Consortium is conducting pre-application interactions with, and submitting documents for review by, the USNRC staff.

This White Paper is an early submittal during the pre-application regulatory engagement. It facilitates the engagement by preliminarily describing design-related information in support of licensing an FSIS-paired small modular reactor (SMR) plant (the paired plant henceforth referred to as FSIS-R).

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This White Paper does not seek formal USNRC approval of any aspect of the information presented herein. However, the Consortium would greatly appreciate any feedback the USNRC staff may provide. We hope that the White Paper will facilitate our ongoing activities for the FSIS-R preliminary design and the staff’s review of Topical Reports (TRs) to follow. We also intend to use the staff’s feedback to help ensure we have identified the applicable design-related licensing requirements and guidance, which in turn will help us ensure our future design-related licensing submittals will be successful.

1.2 Scope

This white paper provides design-related licensing information, including:

- Design requirements and principal design criteria (PDC)
- Applicable design-related regulatory requirements and guidance
- Applicable codes and standards of major licensing significance
- Summary-level FSIS-R conceptual standard design
- Differences identified between the USNRC-approved [[ ]] SMR [[ ]] design and the FSIS-R design, and planned actions to address those differences in support of issuance of an SDA for the FSIS-R

Section 2 describes the principal design criteria specific to the FSIS-R applicable requirements of US NRC regulations, and applicable guidance in NRC Regulatory Guides (RGs) and industrial codes and standards. Section 3 provides an overview of the FSIS-R conceptual design, focusing on the design features and performance functions provided for the pairing of the FSIS with an SMR, highlighting the [[ ]]. Section 4 describes differences we have identified between the [[ ]] and the FSIS-R in the areas of technical design, regulatory requirements and guidance, and applicable codes and standards. The resolutions proposed to address the differences and support the future SDAA for the FSIS-R design are then discussed.

The NRC feedback on the matters discussed in this white paper will be reflected in the development of future regulatory submittals and will support ongoing development of the FSIS-R preliminary standard plant design, including design requirements, seismic and structural designs, probabilistic risk analysis, and seismic safety analysis.

1.3 Abbreviations and Acronyms

ABS	: American Bureau of Shipping
ACI	: American Concrete Institute
AISC	: American Institute of Steel Construction
ANSI	: American National Standard Institute
ASCE	: American Society of Civil Engineers
BPVC	: Boiler and Pressure Vessel Code
CFR	: Code of Federal Regulations
CRB	: Control Building
CSDRS	: Certified Seismic Design Response Spectrum
DBE	: Design Basis Event
[[	:]]
FEM	: Finite Element Method
FIRS	: Foundation Input Response Spectrum
FMEA	: Failure Mode and Effects Analysis
FSIS	: Floating Structure Isolation System
FSIS-R	: FSIS paired SMR Plant
GDC	: General Design Criteria
GMRS	: Ground Motion Response Spectrum
JAEA	: Japan Atomic Energy Agency
LWR	: Light Water Reactor
OPS	: Offshore Power Systems
PDC	: Principal Design Criteria
QA	: Quality Assurance
RAP	: Reliability Assurance Program
REP	: Regulatory Engagement Plan

RWB	: Radwaste Building
RXB	: Reactor Building
SDA	: Standard Design Approval
SDAA	: Standard Design Approval Application
SI	: Seismic Isolation
SI-CSDRS	: Seismically-Isolated Certified Seismic Design Response Spectrum
SI-FIRS	: Seismically-Isolated Foundation Input Response Spectrum
SMR	: Small Modular Reactor
SRP	: Standard Review Plan
SSCs	: Structures, Systems and Components
SSE	: Safe Shutdown Earthquake
SSI	: Soil Structure Interaction
TLEM	: Thin Layer Element Method
TGB	: Turbine Generator Building
TR	: Topical Report
USNRC	: United States Nuclear Regulatory Commission
WP	: White Paper

2. Design Requirements and Guidance for the FSIS-R

This section identifies the significant requirements and guidance applicable to the standard design of the FSIS-R.

2.1 Principal Design Criteria

In describing the FSIS-R PDCs, the Consortium uses the USNRC definition of Design Criteria (GDC) found in Appendix A to 10 CFR Part 50: "The principal design criteria establish the necessary design, fabrication, construction, testing, and performance requirements for structures, systems, and components important to safety; that is, structures, systems, and components that provide reasonable assurance that the facility can be operated without undue risk to the health and safety of the public."

The FSIS-R plant will be designed in accordance with the General Design Criteria in Appendix A to 10 CFR Part 50 General Design Criteria for Nuclear Power Plants, with certain exceptions. [[ ]], the Consortium is developing a complete list of applicable regulatory requirements, and this may lead to identification of the need for additional exemptions related to the FSIS and its interface with the reactor. We will also identify impacts (if any) of the FSIS pairing on the existing [[ ]] exemptions that we believe may require revision to those exemptions. We will keep the USNRC staff apprised of any such proposed (or revised) exemptions we identify and provide the technical and regulatory bases to justify them in a future topical report (TR), which is included among planned future submittals in Section 5.

We will also include in a future WP, identified in Section 5, a description of how the design complies with each GDC that is (1) applicable to the FSIS, (2) applicable to the FSIS interface with the [[ ]], and/or (3) affected by any changes in the reactor necessitated by its pairing with the FSIS.

In addition to the GDCs, the Consortium has identified the following principal design criteria focused on the FSIS and its interface with the paired SMR:

PDC1: [[ ]] safety-related systems, structures, and components (SSCs) of a reactor plant are placed and supported on a floating platform in a pool to reduce seismic impacts.

PDC2: [[ ]] The platform provides three-dimensional base seismic isolation, buoyancy for weight support, and floating stability for the paired SMR plant.

PDC3: The floating structure isolates the paired SMR from a bounding Ground Motion Response Spectrum (GMRS), established to envelope the GMRS found in most if not all areas of the Continental United States and elsewhere[[ ]]

PDC4: [[ ]]such that equivalent static analysis may be applied with conservatism to the paired SMR SSCs.

PDC5: The pool is a non-safety-related [[ ]] structure that is embedded in the ground. [[ ]]

Additional design criteria will likely be identified as the design work proceeds and the design is further developed.

2.2 Applicable Regulatory Requirements

The FSIS-R plant is being designed in compliance with the following major regulatory requirements. In support of development for a future TR on preliminary standard design and the FSIS-R SDA application (SDAA), we will assess compliance of the design with all applicable regulatory requirements, and we plan to identify any proposed exemptions, and a basis for each.

1) 10 CFR Part 50, "Domestic Licensing of Production and Utilization Facilities" [4], with focus on compliance with design-related requirements from Part 50 that are referenced in Part 52 Subpart E Standard Design Approval, or applicable design-related regulatory requirements referenced in NUREG-0800, the Standard Review Plan

2) 10 CFR Part 52, "Licenses, Certifications, and Approvals for Nuclear Power Plants" [5], Subpart E Standard Design Approval

2.3 Industry Codes and Standards

The FSIS-R SSCs is being designed in accordance with industry codes and standards including:

1) ASCE/SEI 4-16 "Seismic Analysis of Safety-Related Nuclear Structures" [6] - requirements in Section 12, Seismically Isolated Structure

2) ASCE/SEI 43-19 "Seismic Design Criteria for Structures, Systems, and Components in Nuclear Facilities" [7]- requirements in Section 9, Seismically Isolated Structures

3) ACI 349-13 "Code Requirements for Nuclear Safety-Related Concrete Structures and Commentary" [8] - Requirements in this code will be applied to the concrete structures of nuclear safety-related buildings on the floating structure

4) ANSI/AISC N690-18 "Safety-Related Steel Structures for Nuclear Facilities" [9]
   The ANSI/AISC N690-18 standard addresses the design approaches, characterization of loads and load combinations, materials, and construction technologies, including nuclear-related steel structures. The requirements in this standard will be applied to the confirmatory design for the FSIS floating platform as a safety-related structure. The standard will also be referenced in the design of the steel and steel-plate composite safety-related buildings for the paired reactor plant

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2.4 Regulatory Guidance

The FSIS-R SSCs are also being designed with reference to NRC regulatory guidance, including:

1) NUREG-0800 "Standard Review Plan for the Review of Safety Analysis Reports for Nuclear Power Plants: LWR Edition" [12] – evaluation required by 10 CFR 52.137(a)(9)

2) Design-Specific Review Standard for the [[ ]] Small Modular Reactor Design [13]

3) RG 1.29 Rev. 6, "Seismic Design Classification for Nuclear Power Plants" [14]

4) RG 1.243, Rev. 0, "Safety-Related Steel Structures and Steel-Plate Composite Walls for Other Than Reactor Vessels and Containments" (August 2021) [15]
   This RG discusses and endorses, with exceptions and clarifications, the procedures and standards of the ANSI/AISC N690-18, noted in Section 2.3.

5) RG 1.142 Rev. 3, "Safety-Related Concrete Structures for Nuclear Power Plants (Other than Reactor Vessels and Containments)" (May 2020) [16]
   This RG discusses and endorses, with certain exceptions, ACI 349-13, noted in Section 2.3, except for Appendix D, "Anchoring to Concrete." Appendix D to ACI 349-13 is addressed by RG 1.199, "Anchoring Components and Structural Supports in Concrete."

6) NUREG/CR-7253 "Technical Considerations of Seismic Isolation of Nuclear facilities" [13]
   This technical report states that its purpose is to provide technical information necessary for NRC staff to develop regulatory guidance on the use of seismic isolation (SI) technology. We were unable to locate additional guidance on the USNRC website, so we would appreciate feedback on availability of any such guidance.
   The report has been prepared to develop performance and design recommendations, technical considerations addressing the design construction, and operational needs for SI systems that consider the seismic performance of SSCs. The development described

the report references the ASCE, ASI and AISC condes and standards identified earlier in Section 2.3 of this WP.

Although vertical isolation systems are not discussed in detail in this report, the report notes that the principles and recommendations contained therein can be extended to vertical isolation systems given additional considerations, constraints and recommendations.

3. Summary-level Conceptual Standard Design of FSIS-R

This section provides a summary-level FSIS-R conceptual standard design overview. The conceptual design has been developed in detail sufficient to confirm the feasibility of proposed major SSCs in terms of their design features, performance and safety functions provided for the pairing of the FSIS with SMR in accordance with the design requirements and guidance, in particular the FSIS-specific PDC listed in Section 2.

3.1 The FSIS-R Power Plant

3.1.1 Plant Layout

Addressing PDC1, all major safety-related SSCs of the [[ ]] are integrated with and supported on a FSIS floating platform, as shown in Figure 3-1. The non-safety related systems including the cooling towers for turbine steam condensers and switchyards, not shown in the figure, are to be located off the floating platform.

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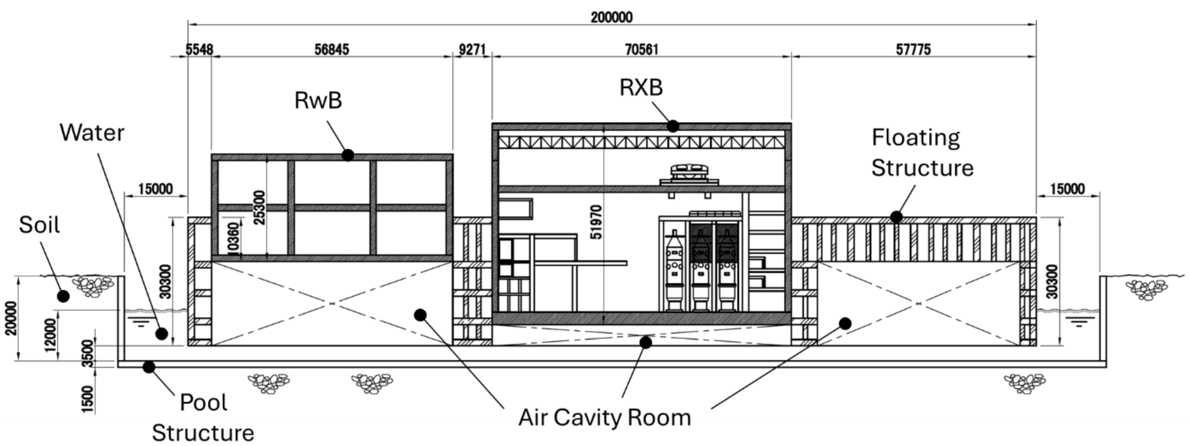

(b) Cross-section (A-A) view

Figure 3-1 FSIS-R plant conceptual arrangement (numbers in the figure are in millimeter)

3.1.2 Plant Floating Platform

Addressing PDC2, The FSIS floating platform [[ ] is designed to perform three primary functions for the paired SMR: (1) three-dimensional base seismic isolation, (2) weight support by buoyancy, and (3) stability support, each of which is described in the following

(1) Three-dimensional base seismic isolation

Addressing PDC3, the FSIS platform design is required to provide significant seismic isolation for the paired SMR. The design provides this function through utilizing the fixed-sized air cavities and orifices built into the bottom of the floating platform, a method demonstrated in large-scale system testing [2]. The number and size of the cavities and orifices can be adjusted according to the scale of weight and dimensions of the paired reactor plant and to the seismic performance levels required.

The air cavities are sized to decrease the natural vibration frequency of the floating plant in the vertical direction until it is outside the range of frequency significant to the safety-related SSCs in response to earthquake motions. The orifice contained in each of the air cavities provides additional damping of the floating structure, generated by the turbulent air flow through the orifice. The natural vibration frequency of the floating plant in horizontal directions is reduced naturally due to inability of the pool water to transfer shear stress from the ground seismic motions to floating body.

Addressing PDC4, the Consortium has conducted the large-scale FSIS testing that is used for verification and validation (V&V) of the FSIS analysis model. The resulting analytical model is then used for specific representation of the dynamic behavior of the FSIS paired SMR to compute on-platform and in-structure responses to seismic input motions. In the White Paper submittal in 2024 [2], the Consortium reported the preliminary results of the modeling and V&V, and we established the seismic isolation performance levels as identified in Table 3-2. The development since has yielded a better performance level, which will be included in a future TR on final results.

Table 3-2 FSIS seismic isolation performance levels [2]

Directions	Level of reduction from ground seismic acceleration input	Applicable natural frequency of ground seismic input
Horizontal direction	more than 2/3	[[ ]]
Vertical direction	more than 2/3	[[ ]]

[[

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(2) Weight support by buoyancy

The design of the floating platform ensures that the buoyancy is naturally maintained. Even if the air pressure in one or all of the air cavities is lost, due to leaks in the hulls surrounding the cavities, resulting in a loss of buoyancy provided by the air pressure in the cavities, the upper deck of the floating structure is designed such that it provides enough access buoyancy to remain afloat above the water surface.

(3) Stability support

The stability support for the floating FSIS-R plant will be achieved, similar to the practice of large ship designs, through balancing weights and distancing the center of gravity from the center of buoyancy through design, as well as constantly monitoring and adjusting these stability parameters through the use of ballast water during operation and maintenance.

Referring to the schematic shown in Figure 3-2, the stability of a floating body is evaluated in consideration of the distance d_x between the metacenter, M and the COG (Center of gravity), G. The metacenter, M is the point where the vertical line through the new center of buoyancy intersects the original vertical line through the COG of the body. The floating body is considered stable when d_x is a positive value.

The expression and estimated d_x for the FSIS-paired [[ ]] configuration in Figure 3-1 are as follows:

$$d_x = I_x/V - b = 337\text{m} \gg 0$$

Where I_x is X-axis secondary moment, V is displaced water volume, and d_x and b are denoted in Figure 3-2. Since d_x is substantially positive, instability of the floating structure is unlikely.

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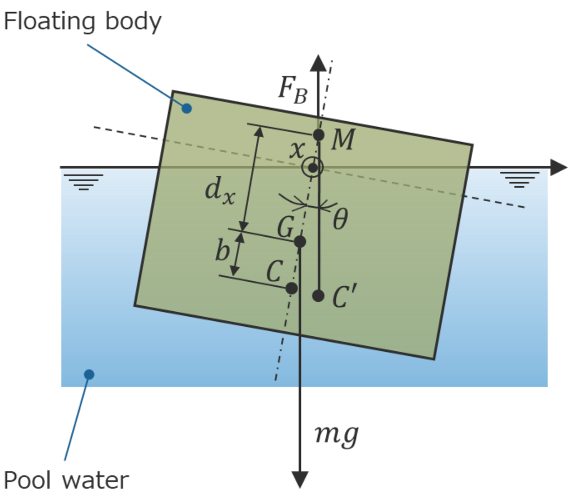

Symbols in the figure:

b	: Distance between G and C
C	: Center of buoyancy at still
C`	: Center of buoyancy when inclined
d_x	: Distance between M and G
F_B	: C and C` intersect
G	: Center of gravity
M	: Metacenter
mg:	: Mass
x	: X-axis
θ	: Inclined angle due to rolling

Figure 3-2 Schematic of floating body

3.2 The Pool System

The pool system consists of a fresh water pool, a reservoir and a maintenance dock. These facilities are connected by waterways and partitioned by water locks as shown for a multi-plant system in Figure 3.3. The reactor plants are moved into the water pools during operation and to the maintenance dock during equipment services. Refueling may be performed in situ by each reactor plant. Alternatively, the task of refueling could be centralized and perform in the maintenance dock area for the multiple reactor plants housed on a site. A canal is provided for offshore delivery of the reactor plant and connected to the pool system. The reservoir is connected to a river, and/or other water sources, for water makeup. [[
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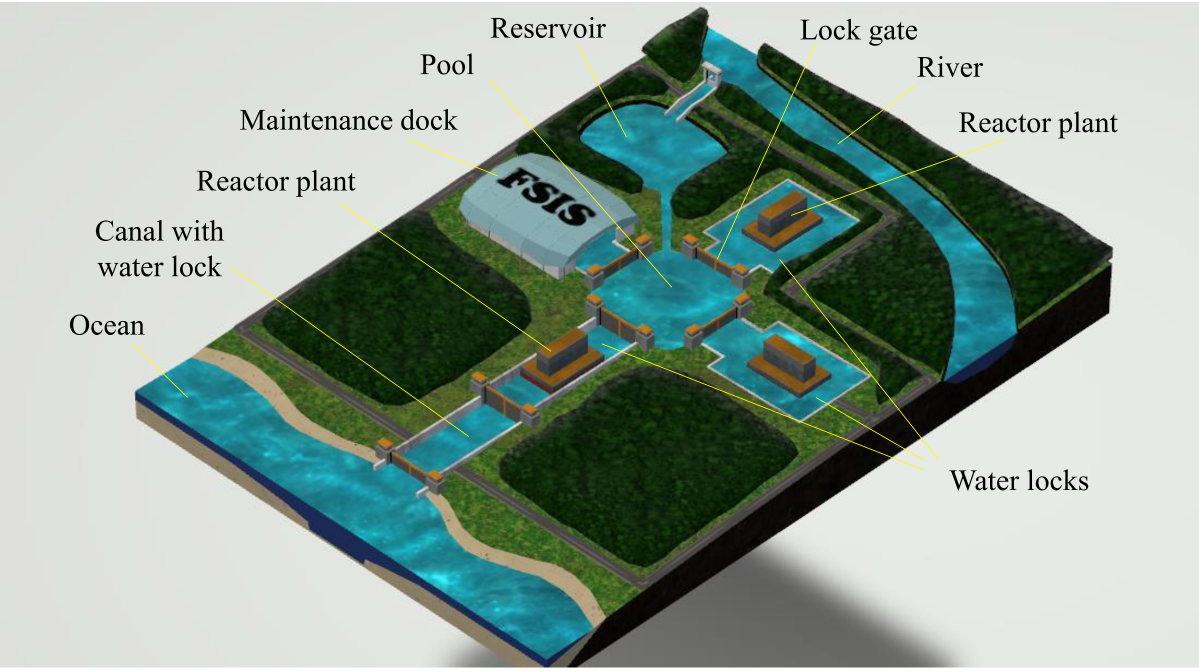

Fig. 3-3 Site arrangement features of FSIS-R with multiple reactor plants

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Addressing PDC5, the pool is designed to perform the non-safety-related function of limiting water leakage. [[

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Furthermore, the pool design is required to maintain an acceptable level of integrity during an SSE, excluding structural collapse. Even if cracks develop in the pool structure during an SSE, the pool would remain watertight due to natural buildup of earth pressure of the aforementioned impervious barriers.

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The water needed for the various makeup requirements for the site can be sourced from one or more of the following:

- River
- Lake
- Groundwater
- Desalinated seawater or seawater

In sum, we consider it acceptable for the pool to be non-safety-related because its function to limit water leakage is not relied upon during or after a DBE to ensure reactor safety, consistent with the definition of safety-related SSCs in 10 CFR 50.2.

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The planned design activities to formally establish the function and structural requirements for the pool system through engineering study are described in Section 4.2.1(4).

4 Analysis of Differences between the [[ ]] and the FSIS-R

The Consortium has performed a preliminary evaluation of differences between the USNRC-approved [[ ]] [[ ]] design and that of the FSIS-R. This section discusses the identified differences in Subsection 4.1, and describes the plan for demonstrating the regulatory acceptability and compliance of the changes in Subsection 4.2.

4.1 Identification of Differences

4.1.1 Technical Differences

The most significant technical differences, including design features and performance characteristics, between the [[ ]] and the FSIS-R standard design are described in this section.

(1) Seismic design

In the [[ ]], seismic design is based on a set of CSDRS for SSCs with the plateau accelerations of 1.15g for horizontal and 1.06g for vertical directions, respectively. Also, an additional set of CSDRS-HF (high frequency) is applicable for SSCs with the plateau acceleration of 1.6g for horizonal and 1.3g for vertical directions, respectively. The dynamic analysis method is applied to compute in-structure seismic responses and seismic loads of the reactor SSCs according to [[ ]] 3.7.2.

In the FSIS-R, a set of seismically isolated CSDRS based on smooth-shaped broadband spectra with a plateau acceleration of 0.5g in a frequency range of 1-33 Hz for both horizontal and vertical directions is defined for the FSIS floating platform. The equivalent static method is then applied to compute seismic loads of the paired reactor SSCs according to SRP 3.7.2.

(2) Seismic analysis method

In the [[ ]], the in-structure seismic response spectra and seismic loads acting on high seismic category SSCs are computed by dynamic analysis applying the structure-soil interaction (SSI) method.

In the FSIS-R, two methods are applied according to SRP 3.7.2: dynamic analysis method and equivalent static load method. The dynamic analysis method is applied to the system consisting of the soil, pool structure, pool water, and the FSIS platform including the air cavity. The fluid-structure-soil interaction method (FSSI) has been developed by adding additional fluid finite elements for air and water in the traditional SSI method. The resulting FSSI method is further described in Section 4.2.3 (1).

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Accordingly, the equivalent static load method based on the fore-mentioned smooth-shaped broadband spectra will be applied to estimate seismic loads for the paired SMR SSCs on the floating structure in reference to the acceptance criteria of SRP 3.7.2.II.

(3) Basemat

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]]The platform is designed to provide three-dimensional base seismic isolation, floating weight support, and floating stability for the paired SMR, as described below:

a) Base seismic isolation

Seismic isolation in the horizontal directions is provided naturally due to inability of water to transmit sheer forces to the floating structure from ground motions. The phenomenon is consistent with the observation in the large-scale FSIS testing [2].

Seismic isolation in the vertical direction is provided by a number[[ ]] of air cavities built into the bottom side of the floating structure. The cavities are sized and configured such that the natural frequency of the floating structure is reduced and removed from the frequency range of the paired reactor SSCs. In addition, a fixed-size orifice is installed in each of the air cavities to increase structural response damping and thereby reduce the seismic response amplification for the floating structure. Significant seismic response reduction as much as two-thirds of seismic input acceleration in the vertical direction was confirmed in the large-scale testing.

b) Floating weight support

The draft depth of the floating structure provides the buoyancy for the weight support of the FSIS-R reactor plant on the platform. The hulls of the structure are double-walled and compartmented, as is the conventional practice in shipbuilding, to limit loss of buoyancy.

c) Floating platform stability

Several conventional approaches for stability design and operation of large ships are also applied to the FSIS floating plant. [[ ]]

d) Inspection and maintenance

The floating structure is designed and periodically inspected and maintained against degradation of the structure such as corrosion to ensure continuing capability of performing safety-related functions.

(4) Foundation

In the [[ ]], the plant is embedded in the site foundation soils with geological condition limitations subject to site permit approval.

In the FSIS-R, the plant is placed afloat in the pool system. The pool is dug in the site foundation soils with geological conditions enveloped by the standard site parameters postulated in the standard design approval. The geological conditions shall exclude any active seismic fault, a condition that is typical of nuclear plant siting.

(5) Buildings and building arrangement

In the [[ ]], [[

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In the FSIS-R, these buildings are three-dimensionally base isolated from the ground motions, and consequently the in-structure seismic response and loads are significantly smaller as compared to the [[ ]] SDA design. As a result, these buildings are expected to be designed and constructed of steel and concrete with reduced mass, reducing the carrying weight of the floating structure.

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(6) Access route to buildings

In the [[ ]], personnel access to the buildings will be on the ground.

In the FSIS-R, access routes to the buildings on the floating structure will be established across water gaps between the floating structure and the ground. The access routes will be designed and restricted as needed to ensure they do not interfere with the ability of the water gaps to provide a physical protection barrier surrounding the perimeter of the floating plant.

(7) Turbine steam condenser cooling

In the [[ ]], [[

]]water-cooled condensers are used.

In the FSIS-R, the main condenser cooling source is pool water. The pool water is in turn cooled by once-through circulation of cooling water from river, ocean, or other water source; or by evaporative cooling towers located some distance from the pool.

4.1.2 Regulatory Impacts of the FSIS-R

The USNRC has determined that the [[ ]] complies with applicable regulations in 10 CFR Parts 50 and 52, subject to certain approved exemptions. The agency has also concluded that the [[ ]] satisfactorily addresses the staff's guidance in NUREG-0800 and the Design-Specific Review Standard for [[ ]] Small Modular Reactor Design, which contains guidance that supersedes some guidance in NUREG-0800.

The FSIS-R design complies with the same regulatory requirements as those identified by [[ ]] and confirmed by the NRC staff in its SDAA review. The Consortium is performing a detailed review of the regulations and guidance to identify any needed exemptions not already identified by [[ ]] for the [[ ]] SDAA, and whether any already approved exemptions need to be revised for the FSIS-R. Pairing the FSIS with the [[ ]] requires certain design changes and will impact how the modified [[ ]] meets the requirements in several areas.

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(1) Quality Standards and Records (10 CFR 50 Appendix A Criterion 1, SRP 3.2.1, SRP 3.2.2)

The FSIS-specific SSCs, that are not present in the [[ ]], will be newly classified in the FSIS-R based on existing definition of categorization and classification, and quality assurance basis.

(2) Design Bases for Protection Against Natural Phenomena (10 CFR 50 Appendix A Criterion 2, SRP 3.3.1, SRP 3.3.2, [[ ]] 3.7.1)

In the [[ ]], natural hazards were identified and the safety evaluations against them were performed for the design.

In FSIS-R, because of the FSIS and related SSCs introduced, the design bases for natural hazards such as earthquake, tornado, hurricane, flood, tsunami, and seiche, will be different from those applicable to the [[ ]] design.

(3) Aircraft Impact Assessment (10CFR50.150, SRP 19.5)

In the [[ ]], aircraft impact assessment was performed based on the conditions of the RXB embedded in soil.

In the FSIS-R, since the plant is floating in the pool water, different dynamic behaviors of the plant from the soil-embedded plant will arise in case of an aircraft impact.

(4) Seismic Design ([[ ]] 3.7.2, [[ ]] 3.7.3, SRP 3.7.4, SRP 3.9.2)

In the [[ ]], seismic analyses for high seismic category structures were performed using SSI analyses with generic site soil conditions.

In the FSIS-R, the equivalent static load method will be used to compute the seismic loads of the SMR SSCs based on the SI-CSDRS defined on the FSIS platform.

(5) Probabilistic Risk Assessment and Severe Accident Evaluation (SRP 19.0)

It is necessary to investigate how fault conditions in FSIS-specific structures would affect the SMR plant. Such accident sequences will be incorporated as part of probabilistic risk assessment and severe accident evaluation which are beyond-design basis conditions in the FSIS-R.

(6) FSIS Specifications (SRP 1.0, [[ ]] 3.8.5, [[ ]] 16.0, SRP 16.1)

In the FSIS-R, FSIS-specific technical specifications, including for the floating platform and interfaces with the remainder of plant, will be prepared.

Table 4-1: FSIS Impact on the Regulatory Requirements for [[ ]] SDAA
(Numbers in parentheses in fifth column refer to text above.)

4.1.3 Notable Codes and Standards for the FSIS-R

Notable codes and standards applicable to the FSIS-R are described in Section 2.3. The consistency of the FSIS-R design with the codes and standards is discussed below, in comparison with the practice in the USNRC-Approved [[ ]] and the USNRC licensing experience with the Offshore Power Systems floating power plant where appropriate. The codes and standards referenced in the [[ ]] SDAA and not mentioned here will likely continue to apply to the FSIS-R, though that will be confirmed in future work.

(1) Seismic isolation (Section 9 in ASCE43-19, Section 12 in ASCE4-16)

In the [[ ]], no codes and standards regarding seismic isolation are applied.

For the FSIS-R, the seismic isolation design and analysis will comply with ASCE43-19 Section 9 with respect to the seismic design criteria for seismically isolated structures, and with ASCE4-16 Section 12 with respect to seismic analysis requirements for seismically isolated structures.

(2) Buildings (ANSI/AISC.N690-18)

In the [[ ]], ANSI/AISC N690-18 is applied to the design of SC (Steel-plate Composite) walls for the RXB.

For the FSIS-R, ANSI/AISC N690-18 is similarly applied to the SC wall design. In addition, the standard, endorsed with exceptions and qualifications by RG 1.243, will be applied to the steel structure design for seismically-isolated light-weight buildings described in Section 4.1.1 (5).

(3) Floating steel structure ([[ ]], ANSI/AISC N690-18, RG 1.243, [[ ]])

As noted in Section 2.3, the [[ ]] will be applied to the design of the hull structures and balance systems such as the ballast system and mooring system for the FSIS floating platform.

The ANSI/AISC N690-18, which is endorsed, with exceptions and clarifications, by NRC RG 1.243, will be applied to the confirmatory design to qualify the hull designs as nuclear safety-related structures. Note that the former edition of the ANSI/AISC N690 standard, as well as dated papers and books, were applied to the hull design of Offshore Power Systems (Figure 4-1), which is the offshore nuclear power plant for which a manufacturing license was issued by the USNRC [20][21].

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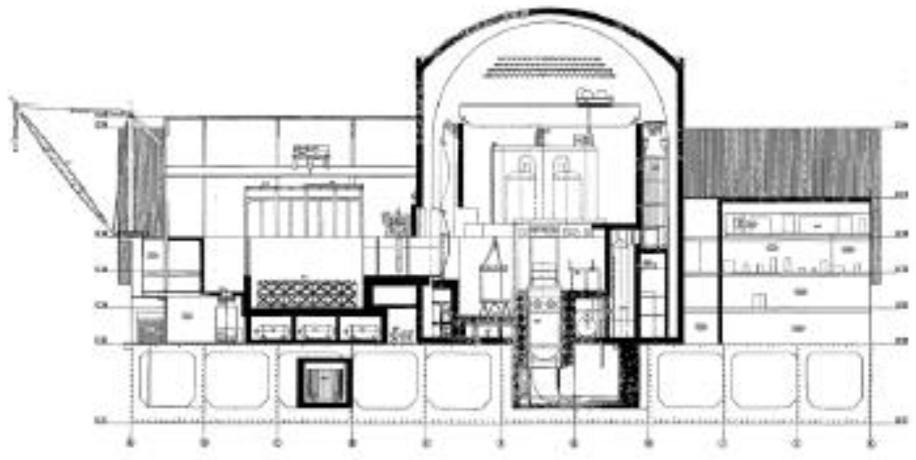

Fig. 4-1 Example of past floating nuclear plant OPS Offshore Power Systems by Westinghouse with NRC manufacturing license approval
(Design Report Part I ML20204A662, Part 2 ML20204A664)

4.2 Planned Actions to Address Differences

This section describes the planned actions to be taken in order to address the technical, regulatory, and code and standard differences identified in Section 4.1 between the USNRC-approved [[   ]] and the FSIS-R for demonstrating the regulatory acceptability and compliance of the changes in support of a future FSIS-R SDA.

4.2.1 Planned Actions to Address Technical Differences

(1) Seismic design method

The equivalent static method is selected for the seismic design for the seismically-isolated FSIS-R standard design. The bases for this selection are described in Section 4.1.1(1). The technical bases include tests and post-test analyses. The preliminary results of the analyses were described in a White Paper [2] and reviewed by NRC [3]. Regarding the tests, the NRC staff asked that the test instrumentation locations and results be provided to help them understand the test conditions as well as the final results and how certain unrealistic test parameters may have been filtered from the final results, with adequate justifications.

The Consortium plans to document such additional information and present the final result of the seismic design method development in a TR. This submittal is included among all the future planned design-related TRs and other documents discussed in this WP.

(2) Seismic analysis method

The Consortium has conducted the large-scale FSIS testing to provide the data necessary for verification and validation (V&V) of the FSIS analysis codes. The resulting validated analytical method FSSI will enable specific model representation of the dynamic behavior of the FSIS paired SMR to create the standard design envelope SI-CSDRS as discussed in Section 4.1.1 (2).

The FSSI method expands on the NRC-endorsed SSI code by adding the water and air fluid model elements, which are unique for the FSIS system. The preliminary results of V&V were described in a White Paper [2] and reviewed by NRC [2].[[

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The Consortium has recently published the additional verification results [19]. The planned verification steps will be concluded with the results to be documented in a TR submittal to the NRC in 2026.

(3) Floating platform structure

The Consortium plans to develop the preliminary standard design for the FSIS-R and document the design results in the following areas, except for a), in a future draft TR. The result in a) area is the topic of a separate TR. The schedule of both submittals to the NRC is described in Section 5.

a) Seismic isolation safety

Following the NRC acceptance of the TRs demonstrating the regulatory acceptability and compliance of the FSIS-specific seismic design and analysis methods described in (1) and (2) above, the Consortium plans to document the application of these methods to the following procedure proposal for the FSIS-R standard design seismic isolation and safety analysis:

1) Develop a set of bounding Ground Motion Response Spectra (GMRS) in both horizontal and vertical directions to envelope most if not all areas of the Continental United States and in selected other countries[[ ]]
2) Define a set of seismically-isolated Certified Seismic Design Response Spectra (SI-CSDRS) in both horizontal and vertical directions on the FSIS floating platform. [[ ]]
3) Compute the seismically-isolated foundation Input Response Spectra (SI-FIRS) on the FSIS platform using the bounding GMRS as seismic input. The computation is performed on the plant representation modelled using the FSSI analysis method.
4) The SI-CSDRS defined for the FSIS-R standard design is acceptable when it completely envelopes the SI-FIRS. [[ ]]
5) Then, seismic loads for the seismically isolated standard design reactor plant SSCs on the platform are calculated using the equivalent static load method against the SRP 3.7.2 acceptance criteria.

b) Structural design

The floating platform is [[ ]] designed to provide buoyancy for weight support, in addition to supporting seismic isolation function in a) above and floating stability function in c) below, for the paired SMR plant.

The structural design of the floating platform for the paired SMR SSCs will be performed according to the rules for the hull design and construction of [[ ]] steel ships, taking into account structural integrity, floating stability, operation, and maintenance.

The qualification of the platform design as a safety-related structure will then be evaluated using confirmatory design according to the procedures and standards of the ANSI/ASCI N690-18 as well as referencing NRC RG 1.243 guidance that endorses, with exceptions and clarifications, the ANSI/ASCI N690-18 for the design, fabrication, and erection of safety-related steel structures and SC walls for other than reactor vessels and containments [9].

c) Stability of floating structure

[[

]]

Section 3.1.2(3) mentions several balancing systems including ballast system and mooring system commonly used in the construction and operation of large ships. These systems are selected and designed for the FSIS-R [[ ]]. The functional requirements of the systems will be developed using PRA as part of the design. Also, the failure modes of the system SSCs will be investigated to develop the safety case for the FSIS-R plant.

Confirmatory design for the safety-related SSCs identified in these systems to demonstrate the regulatory acceptability and compliance will be carried out as described in Section 4.1.3 (3).

d) Inspection and maintenance

As part of the maintenance activities, the floating structure will be painted periodically in a manner similar to the painting of ship hulls. The continued integrity of the structure will be validated through periodic inspections and surveillance.

(4) Pool system facilities

Addressing PDC5, the Consortium plans to perform a civil engineering evaluation for the pool system concept described in Section 3.2. The evaluation will document design calculations to support the functional and structural requirements for the pool system facilities and formally establish the design specification and classification for the pool system SSCs. The failure modes of the pool system SSCs and their impact on the reactor will be evaluated as part of planned PRA, as planned in Section 4.2.2(6), in support of the safety case for the FSIS-R standard design.

(5) Access to the floating plant

A bridge or bridges between the ground and the floating structure will be provided. The bridge design will include a capability of compensating for the relative displacement between the ground and the floating structure. [[

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With regard to electric cables connecting to SSCs on the ground from the floating structure, it is possible for cables with flexibility and redundant length to absorb large displacements between the ground and the floating structure. Also, moderate-pressure piping running between the ground and the floating structure, such as part of utility facilities, will be prepared as flexible piping to absorb the relative displacements.

(6) Buildings and building layout

In the FSIS-R, [[

]] light-weight buildings are necessary to lower the carrying weight of the floating plant to improve structural and seismic designs. The buildings may be designed according to the standards of ANSI/AISC.N690-18 [9] for steel and RC buildings and ACI 349-13 [8] for concrete buildings. The regulatory compliance of the safety-related building designs may be evaluated according to RG 1.142 [15] and RG 1.243[16].

Furthermore, building layout optimization will be performed to reduce the plant plot area [[ ]]. The goal is to reduce the plant plot [[ ]]to permit factory construction of the whole facility of the floating plant. To help meet this objective, the possibility for further downsizing buildings, [[ ]]will also be investigated.

(7) Turbine steam condenser cooling

In an FSIS-R power plant, the non-safety function of turbine steam condenser cooling will be provided utilizing the pool water. [[ ]] The pool water is in turn cooled by a combination of the pool surface evaporation and a circulating cooling water. The latter is connected to river, ocean, or other cooling water source; or to an evaporative cooling tower.

4.2.2 Planned Actions to Address Regulatory Matters

(1) Quality Standards and Records (10 CFR 50 Appendix A Criterion 1, SRP 3.2.1, SRP 3.2.2)

FSIS-specific SSCs will be classified in consideration of safety cases.

(2) Design Bases for Protection Against Natural Phenomena (10CFR 50 Appendix A Criterion 2, SRP 3.3.1, SRP 3.3.2, [[ ]])

The design countermeasures for each natural hazard will be evaluated. Protection against earthquakes will be demonstrated by the reduction effect of seismic response as a result of the FSIS specific seismic performance. Protection against tornadoes, hurricanes, and winds will be confirmed by external missile evaluations. [[ ]] Drainage systems and physical barriers to floods and tsunamis will be designed, and their performance evaluated.

(3) Other 10 CFR 50 Appendix A GDCs, NUREG-0800, and [[ ]] [[ ]]

Compliance with all other applicable GDCs will be demonstrated. Analyses of all applicable NUREG-0800 [[ ]] sections will be provided as required by 10 CFR Part 52 Subpart E. Subjects considered challenging for licensing the FSIS-R will be addressed in the planned TRs or other documents scheduled for submission in Section 5.

(4) Aircraft Impact Assessment (10 CFR 50.150, SRP 19.5)

Dynamic analyses of aircraft impacts will be performed, demonstrating how the plant with the floating structure will respond. Differences from the response of the [[ ]] [[ ]] embedded into the soil layer will be identified and evaluated.

(5) Seismic Analysis ([[ ]] 3.7.2, [[ ]] 3.7.3, SRP 3.7.4, SRP 3.9.2)

Fluid-structure-soil interaction (FSSI) analyses for FSIS-R will be developed. The preliminary results of the method validation have been published [19]. The final results will be documented in a TR for NRC review in 2026 as planned.

(6) Probabilistic Risk Assessment and Severe Accident Evaluation (SRP 19.0)

The failure modes of the FSIS-specific SSCs for the FSIS-R standard design will be identified. The accident sequences will then be developed. Failure probabilities and their uncertainties for each SSC will be identified. Then, the assessment of beyond-design-basis events will be performed. The PRA and SAR are the subjects of future submittals identified in Section 5.

(6) FSIS Specifications (SRP 1.0, [[ ]] 3.8.5, [[ ]] 16.0, SRP 16.1)

The specifications of FSIS-specific SSCs such as those in the floating structure and the pool system will be developed for identification of the unique design requirements such as the inclination criterion for the floating structure.

4.2.3 Planned Actions to Address Differences in Codes and Standards

(1) Seismic isolation (Section 12 in ASCE4-16, Section 9 in ASCE43-19, NUREG/CR-7253)

Section 4.1.1 (2) describes the development approach for the FSSI method based on the SSI method. The FSSI method is applied with reference to the relevant sections for seismically isolated structures in ASCE 4-16 and ASCE 43-19. Table 4-2 summarizes the model elements included in the FSSI and compares treatment of each to that of the SSI method applied to the [[ ]] seismic design analysis.

The preliminary information on validation of the FSSI method has been published [19] and also reviewed in a White Paper by the US NRC [3]. The final information will be described in a future TR.

Table 4-2 Comparison of seismic design and analysis methods for [[ ]] and FSIS-R

No.	Object	Seismic Analysis Model		Remarks
		[[ ]] SDAA: SSI	FSIS-R: FSSI	
1	Soil	Thin Layer Element Method (TLEM)	TLEM	[[ ]] adopts soil libraries consisting of soil impedance matrices [20]. FSIS-R will also use the same method.
2	Pool Wall	N/A	Finite Element Method (FEM)	Pool wall acts as moat walls in FSIS-R.
3	Isolator (Pool water and floating structure)	N/A	FEM	Although the isolator modelling methods are defined in Section 12.2.2 of ASCE4-16 and Section 9.2.2 of ASCE43-19, a new modelling method using fluid-structure interaction will be applied to the FSIS isolator consisting of pool water and floating structure.

4	Foundation	FEM	FEM	The pool structure is deeply embedded into soil as a foundation of FSIS-R. The SSI analyses for soil and pool structure will be performed based on Section 12.4.1.3 "Dynamic Analysis: Frequency-Domain solution" in ASCE 4-16.
5	Building	FEM	FEM (decoupled)	The seismic analysis model for buildings on the floating structure will be decoupled from the SSI analysis model because of the low amplification of seismic responses [[ ]]

(2) Steel structural design ([[ ]], ANSI/AISC.N690-18, RG 1.243, [[ ]])

[[ ]] Regulatory compliance of the design as safety-related structures will be assessed according to the ANSI/AISC N690-18 standard and guidance RG 1.243 and documented as parts of the preliminary design information in a TR submittal to the US NRC.

5. Conclusion

The white Paper provides a preliminary discussion of design-related licensing information for the FSIS-R plant [[ ]]. It summarizes the design requirements, highlights the design features of the FSIS and its pairing with the [[ ]], discusses the impacts of the FSIS pairing on the original [[ ]] design, and summarizes the proposed approaches to addressing the impacts in future licensing documents.

Future planned design-related TRs and other documents, discussed in this WP, will include:

Submittals	Description	Expected year
Topical Report	FSIS seismic design method: Design requirements, site envelope, regulations and guidance, codes and standards, and technical bases	2025
Topical Report	FSIS seismic analysis method: Validation and verification of SSI-based code FSSI for FSIS seismic analysis	2026
White Paper	Probability risk analysis (PRA): Identification of failure modes and sequences for FSIS-specific SSCs, probability and consequence assessment of the identified events.	2026
Draft Topical Report	FSIS-R preliminary standard design: Site envelope parameters, structural design, seismic design and response	2026
Draft Topical Report	Safety analysis report (SAR); Seismic safety analysis; Analysis of other FSIS-related design basis events and beyond design basis events	2027
White paper	FSIS-R standard design compliance analysis with GDCs	2027
Topical Report	Exemptions to be sought	2028
White Paper	FSIS-R SDA application readiness assessment	2028

USNRC staff feedback on this WP will be greatly appreciated. Any comments will be carefully studied and appropriately reflected in the ongoing development for the preliminary plant design. We would particularly appreciate feedback on:

1) Whether the approaches to addressing the differences between [[ ]] and the FSIS-R appear reasonable and achievable
2) Whether the WP identifies the appropriate regulatory references, as well as the appropriate codes and standards,

6. References

[1] JAEA Consortium, Regulatory Engagement Plan for Floating Seismic Isolation System (FSIS), Revision 0, July 2024. ML24211A033

[2] JAEA Consortium, White Paper, Description of Floating Seismic Isolation System (FSIS) – Verification, Design Criteria and Analysis Methodology, Revision 0, October 2024. ML24302A168

[3] U.S. NRC Summary of November 20, 2024, Public Meeting with the Japan Atomic Energy Agency on the Quality Assurance Program Description and the Floating Seismic Isolation System Technology for Small Modular Reactors, ML25056A116

[4] 10 CFR Part 50, Domestic Licensing of Production and Utilization Facilities.

[5] 10 CFR Part 52, Licenses, Certifications, and Approvals for Nuclear Power Plants.

[6] ASCE/SEI 4-16, Seismic Analysis of Safety-Related Nuclear Structures. American Society of Civil Engineers (2017)

[7] ASCE/SEI 43-19, Seismic Design Criteria for Structures, Systems, and Components in Nuclear Facilities. American Society of Civil Engineers (2019)

[8] ACI 349-13, Code Requirements for Nuclear Safety-Related Concrete Structures and Commentary. American Concrete Institute. (2014)

[9] ANSI/AISC.N690-18, Specification for Safety-Related Steel Structures for Nuclear Facilities. American Institute of Steel Construction. (June 28, 2018)

[10] [[ ]]

[11] [[ ]]

[12] U.S. NRC, NUREG-0800, Standard Review Plan for the Review of Safety Analysis Reports for Nuclear Power Plants: LWR Edition.

[13] [[ ]]

[14] NRC RG 1.29 Rev. 6, Seismic Design Classification for Nuclear Power Plants", July 2021

[15] NRC RG 1.243, Safety-Related Steel Structures and Steel-Plate Composite Walls for Other Than Reactor Vessels and Containments, August 2021

[16] NRC RG 1.142 Revision 3, Safety-Related Concrete Structures for Nuclear Power Plants (Other than Reactor Vessels and Containments), May 2020

[17] U.S. NRC, NUREG/CR-7253, Technical Considerations for Seismic Isolation of Nuclear Facilities. February 2019.

[18] [[ ]]

[19] Y. Sato, S. Kataoka, I. Ota, Y. Morimoto, A. Otani, S. Kai and X. Yan, Fluid-Structure-Soil Interaction Analysis Applicable to Seismic Design for Floating Seismic Isolation System, Proceedings of the ASME 2025 Pressure Vessels and Piping Conference PVP2025, July 20-25, 2024, Montreal, Quebec, Canada, PVP2025-152929.

[20] Manufacturing License Application Plant Design Report for Offshore Power Systems Part 1 ML20204A662, Part 2 ML20204A664, January 1973

[21] NUREG-293, Safety Evaluation Report Atlantic Generating Station Units 1 and 2, July 1977, ML19256E661