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Division V

REGULATORY GAPS AND CHALLENGES IN THE APPLICATION OF SEISMIC ISOLATION TECHNOLOGIES TO NUCLEAR POWER PLANTS

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ABSTRACT

Because Seismic Isolation (SI) is being considered for nuclear power plants (NPPs) in the United States (US), the Nuclear Regulatory Commission (NRC) initiated research activities on SI in 2009. That work, which focused around a risk-informed regulatory approach, resulted in a forthcoming draft NUREG/CR report that discusses considerations for the implementation of SI technology in NPPs. The draft NUREG/CR report provides a set of recommended performance objectives and criteria that could serve as the foundation for a broader set of guidance on the use of SI and related technology. Methods of analysis and design for NPPs using SI, have also been implemented in the recently published American Society of Civil Engineers Standard ASCE/SEI 4-16.

While these foundational documents provide a good starting point, they were, necessarily limited in scope. The focus of the guidance is the horizontal base isolation of surface-founded light water reactors (LWRs). To identify and address the limitations in the guidance, Idaho National Laboratory (INL) initiated several projects focused on further developing the technical and licensing underpinnings for facilities using SI technology, including non-LWR NPPs.

As part of the INL effort, the Advanced Nuclear Technology group recently sponsored work to identify regulatory gaps and challenges related to the use of SI technology in advanced reactors. This work resulted in two 2016 INL reports, INL/EXT-15-36945 and INL/EXT-16 40668 (Kammerer, Whittaker and Coleman 2016a and 2016b), which builds upon the guidance available to industry and the NRC. The report discusses gaps and challenges identified in several areas, including: (1) tools and methodologies, (2) the certified design process, (3) configurations and applications not addressed in the current guidance, (4) seismic qualification of the isolator units, and (5) construction and operations.

This paper summarizes the outcomes of the INL projects and discusses ongoing efforts to address the issues in support of efforts to effectively license facilities incorporating SI in the US.

INTRODUCTION

Over the last decade, particularly since implementation of the certified design regulatory approaches outlined in 10 CFR 52, interest has been increasing in the use of seismic isolation (SI) technology to support seismic safety in nuclear facilities. In 2009, the United States (US) Nuclear Regulatory Commission (NRC) initiated research activities to develop new guidance targeted at isolated facilities because SI is being considered for nuclear power plants (NPPs) in the US. One product of that research was a draft NRC nuclear regulatory commission contractor (NUREG/CR) report (Kammerer, Whittaker and Constantinou, 2017) that investigated and discussed considerations for use of SI in otherwise traditionally founded large light water reactors (LWRs).

The draft NUREG/CR was developed around a risk-informed regulatory approach consistent with NRC risk objectives. A coordinated effort led to new provisions for SI of safety-related nuclear facilities in the recently published American Society of Civil Engineers standard ASCE/SEI 4-16 (ASCE 2016). The risk-informed design philosophy that underpinned development of the technical basis for both of these documents led to a set of proposed performance objectives and acceptance criteria that was developed to serve as the foundation for future NRC guidance on the use of SI and related technology.

MOTIVATION FOR THE RECENT GUIDANCE EVALUATIONS

Although the guidance provided or expected to be provided in the draft NUREG/CR report and ASCE/SEI 4-16 provides a sound basis for further development of NPP designs incorporating SI, these initial documents focused on surface-founded or near-surface-founded LWRs and were, necessarily, limited in scope. For example, there is limited information in both the draft NUREG/CR report and ASCE/SEI 4-16 related to nonlinear analysis of soil-structure systems for deeply embedded reactors, isolation of components and systems inside a nuclear facility, and use of vertical isolation systems. Also not included in the draft NUREG/CR report are special considerations for licensing of isolated facilities using the certified design approach in 10 CFR 52 and a detailed discussion of seismic probabilistic risk assessments (SPRAs) for isolated facilities.

To identify and address limitations in the initial guidance, Idaho National Laboratory (INL) has initiated several projects focused on further developing the technical and licensing underpinnings for facilities using SI technology. These efforts include a 2014 workshop focused on SI (Coleman and Sabharwall, 2014), development of new structural analysis tools and methodologies appropriate for SI (Coleman et al., 2016), and development of two INL reports, INL/EXT-15-36945 and INL/EXT-16-40668 (Kammerer, Whittaker and Coleman, 2016a and 2016b)[1] focused on reducing regulatory risk for advanced reactors using SI technology.

The first of the two reports, INL/EXT-15-36945, identified and described regulatory guidance gaps and challenges related to licensing of advanced reactors using SI. Because nearly all of the gaps and challenges identified in INL/EXT-15-36945 fall outside the scope of current research and development efforts (including those at INL), INL/EXT-16-40668 was developed to build on information in INL/EXT-15-36945 by providing additional actionable details related to the scope and possible schedule of activities to address the gaps and challenges identified. Some discussions and issues in INL/EXT-15-36945 were updated or revised in the latter report as a result of peer review and feedback from experts and industry stakeholders. However, the latter report was intended to supplement, and not replace, the earlier report. Although design optimization and commercial aspects related to the use of SI have been identified in Coleman and Sabharwall (2014) and elsewhere as possible issues or areas of opportunity, only topics that may impact efficient and successful licensing were investigated in this project.

NEEDS FOR LICENSING OF ADVANCED REACTORS

[1] The reports are publically available for download at the following URLs:

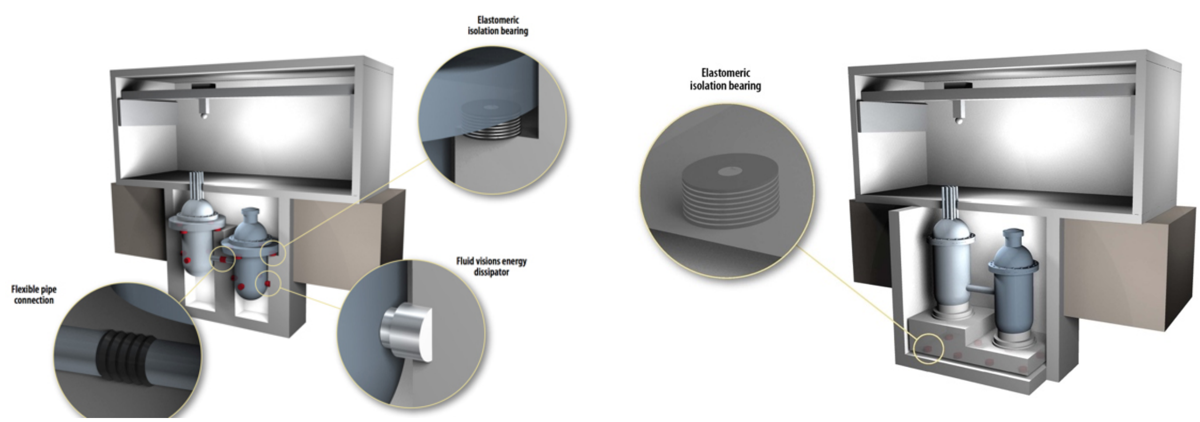
https://seismic-research.inl.gov/SitePages/Home.aspx

https://www.researchgate.net/publication/299506456_Regulatory_gaps_and_challenges_for_licensing_advanced_reactors_using_seismic_isolation

https://www.researchgate.net/publication/311800136_Proposed_activities_for_addressing_regulatory_gaps_and_challenges_for_licensing_advanced_reactors_using_seismic_isolation

Because efforts to date related to regulatory guidance development for SI (e.g., the draft NUREG/CR report) have principally considered designs similar to the light water reactor technologies currently being licensed, the existing literature (as discussed in INL/EXT-15-36945) is reflective of traditional LWR designs. However, the regulatory guidance gaps and challenges that apply to large surface-founded LWRs also apply to advanced reactors; and the LWR case often provides a simplified example as compared to the range of cases found in advanced reactors. Additionally, advanced reactor designs also lead to new gaps and challenges not faced in LWR design. Although both INL reports discuss advanced reactors broadly, the exact set of challenges and potential solutions for any particular reactor design is technology-specific. The activities detailed in this report necessarily require some level of specificity. However, significant effort was made to develop the activities to be as technology neutral as possible.

Advanced reactors will likely be designed and constructed very differently from LWRs. Many of the current designs are housed in deeply embedded structures. Several of the topics and tasks identified in this report support the design and licensing of advanced reactors, regardless of whether SI technology is used, particularly if the NPPs are deeply embedded. In several cases, SI is being considered for isolation of large components or systems, rather than for a traditional base-isolation approach, as shown schematically in Figure 1.



a. Component isolation b. Internal system isolation

Figure 1. Deeply-embedded advanced reactor incorporating seismic protective systems (from Kammerer, Whittaker and Coleman, 2016b)

GUIDANCE EVALUATION RESULTS AND DOCUMENTATION

The 19 unique gaps and challenges identified and evaluated in the INL reports fall into several general categories.

- Engineering tools and methodologies
  - Nonlinear soil-structure-interaction tools and methods
  - Application and limitations of a 1-dimensional assumption site response analysis
  - Ground motion selection and modification
  - SPRA for facilities using SI

- Isolation of equipment: Tools and guidance

- Regulatory approaches and terminology

- Use of the certified design process for isolated facilities
- Clarification of the word "foundation" in current requirements and guidance

- Licensing commitments for construction and operations
  - Considerations for inspection, testing, analysis and acceptance criteria (the ITAAC) for construction
  - In-service inspections, testing and operations

- Other topics
  - Design and analysis considerations for the stop
  - Seismic qualification requirements for
  - Configurations and environmental conditions not addressed in upcoming guidance

Each of the 19 topics was assigned a Topic number and tasks needed to address an issue were numbered using the associated Topic numbers. Table 1, reproduced from INL/EXT-16-40668, provides a summary roadmap of identified tasks, including possible timelines. A prioritization is also provided.

The prioritization considers the following elements:

- The potential level of regulatory risk

- The potential for the work to provide high-impact and high-value in terms of supporting efficient licensing activities

- The sequencing of the issue to resolving other gaps and challenges identified.

Based on the roadmap provided, it is recommended that four Topics should be prioritized for funding:

- Development of NLSSI tools and guidance, including verification and validation activities. (Topic 1)

- Development of SPRA methodologies for seismically isolated facilities, with an emphasis on advancement of methods applicable when linear scaling assumptions do not apply. (Topic 6)

- Clarification of the approaches to licensing of facilities using seismic isolation technology within the certified design process and the associated clarification of the intent of the term "foundation" in existing requirements and guidance (Topics 12 and 14)

- Development of approaches and guidance for isolation of large equipment (Topic 4)

CURRENT AND FUTURE ACTIVITIES

As a result of the evaluations documented in the two INL reports, follow up efforts have been initiated to address Topic 1. These include a laboratory-testing program intended to produce data available for verification and validation of NLSSI tools and development of guidance for NLSSI modelling. New tools for performing NLSSI are also being developed as part of a broader INL initiative focused on developing next generation tools for advanced SPRA.

REFERENCES

10 CFR 52. "Licenses, Certifications, and Approvals for Nuclear Power Plants."

American Society of Civil Engineers (ASCE). (2016). "Seismic analysis of safety-related nuclear structures," ASCE/SEI Standard 4-16, Reston, VA.

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Coleman, J.L., Bolisetti, C., Veeraraghavan, S., Parisi, C., Prescott, S.R., Gupta, A., and Kammerer, A.M. (2016). "Multi-hazard advanced seismic probabilistic risk assessment tools and applications," INL report INL/EXT-16-40055, Idaho National Laboratory, Idaho Falls, ID.

Kammerer, A.M, Whittaker, A.S. and Coleman, J.L. (2016a). "Regulatory gaps and challenges for licensing advanced reactors using seismic isolation," INL report INL/EXT-15-36945, Idaho National Laboratory, Idaho Falls, ID.

Kammerer, A.M., Whittaker, A.S. and Coleman, J.L. (2016b). "Proposed activities to address regulatory gaps and challenges for licensing advanced reactors using seismic isolation", INL/EXT-15-36945, Idaho National Laboratory, Idaho Falls, ID.

Kammerer, A.M., Whittaker, A.S. and Constantinou, M.C. (2017). "Technical considerations for the seismic isolation of nuclear facilities," NUREG/CR-xxxx, United States Nuclear Regulatory Commission, Washington, D.C. (in publication)

Table 1. Summary of identified topics, importance, and proposed resolutions (from INL/EXT-16 40668)

Issue	Sect. No.	Topic No.	Task No.	Importance/ Regulatory Risk	Time-frame	Proposed Actions and Path Forward	Depends on task	Project year									
								1	2	3	4	5	6	7	8	9	10
Orange highlighted activities are those identified as addressing the most high-impact and high-value topics.																	
Lack of verified and validated tools for nonlinear soil-structure-interaction (SSI)	2.1.1	1	1-1	High	Medium	Identify, catalog, and document existing soil models. Develop needed 1D, 2D, and 3D nonlinear constitutive soil models, as needed.											
			1-2	High	Medium	Verify 1D, 2D, and 3D nonlinear constitutive models. Develop, solve, and document sample problems.	1-1										
			1-3	High	Short	Plan and execute 1D, 2D, and 3D static and dynamic element-level tests on soil samples.											
			1-4	High	Medium	Validate 1D, 2D, and 3D nonlinear constitutive models using experimental data.	1-3										
			1-5	High	Medium	Verify accuracy of computer codes for site-response analysis (SRA) and SSI analysis.	1-1 to 1-4										
			1-6	High	Short	Plan and execute tests in 1D geotechnical laminar box.											
			1-7	High	Medium	Validate accuracy of computer codes for SRA and SSI analysis.	1-3 and 1-6										
			1-8	High	Short	Plan and execute gapping and sliding tests on an earthquake simulator.											
			1-9	High	Medium	Validate accuracy of computer codes for gapping and sliding.	1-7 and 1-8										
Lack of technical bases related to cases where assumption of 1D vertically propagating shear waves does not apply	2.1.2	2	2-1	High	Medium	Develop stylized designs for example deeply-embedded advanced reactors.											
			2-2			Develop acceleration time series appropriate for input to SSI models.											
			2-3			Perform SSI analysis in MOOSE to understand impact of inclined waves on a variety of NPP configurations.											
			2-4			Prepare guidance based on the results.	2-1 and 2-2										
Lack of technical basis or guidance for GMSM	2.1.3	3	3-1	Medium	Medium	Identify optimal spectral representation and scaling for SSI analysis and how to scale earthquake ground motions to that representation.											
			3-2	Medium	Medium	Determine minimum number of sets of ground motions for design and SPRA.											
			3-3	Medium	Medium	Prepare guidance appropriate for an upcoming revision of ASCE/SEI 4.	3-1 and 3-2										

Table 1. Continued

Issue	Sect. No.	Topic No.	Task No.	Importance/ Regulatory Risk	Time-frame	Proposed Actions and Path Forward	Depends on task	Project year 1	2	3	4	5	6	7	8	9	10
Orange highlighted activities are those identified as addressing the most high-impact and high-value topics.																	
Lack of guidance for isolation of equipemnt	2.2	4	4-1	High	Medium	Identify candidate components of advanced reactors for seismic protection.											
			4-2			Develop example non-proprietary seismic protective solutions for candidate components.											
			4-3			Validate numerical models for the seismic protective solutions.											
			4-4			Identify performance criteria for protected components consistent with NRC goals.											
			4-5			Develop guidance for analysis, design, and testing of seismically protected equipment.	4-1										
Lack of guidance for design and analysis considerations for the stop	2.3	5	5-1	High	Short	Develop trial stylized designs for stops for example isolated components. Analyze 2D and 3D stops for the isolated equipment, considering a range of NPP sites.	4-1 and 4-2										
			5-2	High	Medium	Develop guidance for isolated equpment, including both small and very large equipment.											
No robust SPRA calculation procedure for risk assessment of isolation systems in full range of possible base-isolated NPPs	2.4.1	6	6-1	High	Short	Implement the Huang et al. SPRA methodology for highly non-linear SSI systems in MOOSE.											
			6-2	High	Short	Develop process for assessing fragility of umbilicals using both the Huang et al. SPRA methodology and using traditional SPRA.											
			6-3	Medium	Medium	Characterize the assumption of isolator correlations on capacity and on demand.											
			6-4	High	Medium	Develop a process for determining demands to SSCs for a traditional SPRA.											
		7	7-1	Medium	Medium	Develop trial designs civil/structural systems and safety-realted SSCs (including fragility functions) for an isolated advanced reactor(s) to use in a sample SPRA.											
			7-2	Medium	Medium	Develop accident sequences (event trees and fault trees) for sample reactor designs.											
			7-3	Medium	Medium	Perform SPRA calculations for sample reactors and develop documents with guidance and examples.	7-1 and 7-2										

Table 1. Continued

Issue	Sect. No.	Topic No.	Task No.	Importance/ Regulatory Risk	Time-frame	Proposed Actions and Path Forward	Depends on task	Project year									
								1	2	3	4	5	6	7	8	9	10
Orange highlighted activities are those identified as addressing the most high-impact and high-value topics.																	
No robust SPRA calculation procedure for large isolated components	2.4.2	8	8-1	High	Short	Develop protocols for incorporation of large isolated components in Huang et al SPRA methodology and traditional plants response analysis.											
			8-2	High	Medium	Develop fragility methods for the protective systems and safety-related umbilical lines.											
			8-3	High	Medium	Develop example event trees and fault trees needed to develop the plant response analysis. Perform SPRA for stylized reactors.	4-1 and 4-2										
			8-4	High	Medium	Development of guidance for incorporating isolation systems for large systems and components into SPRA.											
Implementation of advanced human factors approaches in SPRA	2.4.3	9	9-1	Low	Medium to Long	Follow the work of EPRI as it progresses. Characterize the benefit of lesser shaking demands and building damage on the reliability of operator response and risk reduction.											
Development of guidance for SPRA feedback to design	2.4.4	10	10-1	Medium	Medium	Develop guidance for design process that incorporates risk analysis as a fundamental element of the design process.											
Assessment of applicability of screening tables due to V/H changes	2.4.5	11	11-1	Low	Medium	Develop write-up of the history of the tables and discuss the potential issues related to vertical motion to be included in one of the other related reports.											
Development of updated approach and terminology for certified design approach applied to isolated NPPs	3.1	12	12-1	High	Short	Evaluate best approaches using case studies and develop new terminology related to licensing of advanced reactors using the certified design process.											
			12-2			Develop of a report.	12-1										
Identification of issues related to vertical loading	3.2	13	13-1	Medium	Medium to Long	Identify where issues exist related to the relative increase of the V/H ratio.											

Table 1. Continued

Issue	Sect. No.	Topic No.	Task No.	Importance/ Regulatory Risk	Time-frame	Proposed Actions and Path Forward	Depends on task	Project year									
								1	2	3	4	5	6	7	8	9	10
Orange highlighted activities are those identified as addressing the most high-impact and high-value topics.																	
Identify and address possible regulatory issues due to use of legacy terminology	3.3	14	14-1	High	Short	Identify legacy words in key regulatory documents, determine the function, and map to current terminology.											
			14-2			Summarize findings report in support of licensing of advanced reactors and reactors using SI.	14-1										
		15	15-1	Low	Short	Produce short write-up on the background of the term Design Basis Earthquake and include it in report for Topic 14, as appropriate.											
Use of isolators in new environmental and radiological conditions	4.1	16	16-1	Low	Medium to Long	With industry partner, investigate the use of isolators in new environmental conditions.											
Seismic qualification of isolator units	5	17	17-1	Medium	Short	Develop a guidance document on the application of the CDG process as an appropriate equivalent approach to the qualification of seismic isolator units.											
Documentation for ITAAC for isolation technology	6.1	18	18-1	High	Short	Develop a guidance document on development of the SI-related ITACC for advanced reactors.											
In-service testing and operations requirements and documentation	6.2	19	19-1	High	Short	Develop best practice approaches and more complete documentation of testing and operation needs and considerations											