DPO Case File for DPO-2020-004

The following pdf represents a collection of documents associated with the submittal and disposition of a differing professional opinion (DPO) from an NRC employee involving NuScale SER Chapter 3.8.4, “Seismic Category 1 Structures.”

Management Directive (MD) 10.159, “The NRC Differing Professional Opinions Program,” describes the DPO Program. https://www.nrc.gov/docs/ML1513/ML15132A664.pdf

The DPO Program is a formal process that allows employees and NRC contractors to have their differing views on established, mission-related issues considered by the highest level managers in their organizations, i.e., Office Directors and Regional Administrators. The process also provides managers with an independent, three-person review of the issue (one person chosen by the employee). After a decision is issued to an employee, they may appeal the decision to the Executive Director for Operations (or the Commission, for those offices that report to the Commission).

Because the disposition of a DPO represents a multi-step process, readers should view the records as a collection. In other words, reading a document in isolation will not provide the correct context for how this issue was reviewed and considered by the NRC.

It is important to note that the DPO submittal includes the personal opinions, views, and concerns by NRC employees. The NRC’s evaluation of the concerns and the NRC’s final position are included in the DPO Appeal Decision.

The records in this collection have been reviewed and approved for public dissemination.

Document 1: DPO Submittal
Document 2: Memo Establishing DPO Panel
Document 3: DPO Panel Report
Document 4: DPO Decision
Document 5: DPO Appeal
Document 6: Statement of Views
Document 7: DPO Appeal Decision

Document 1: DPO Submittal

NRC FORM 680
(09-2019)
NRC MD 10.159

U.S. NUCLEAR REGULATORY COMMISSION

DIFFERING PROFESSIONAL OPINION

DPO Case Number	Date Received
DPO-2020-004	9/17/2020

Name and Title of Submitter	Organization	Telephone Number (10 numeric digits)
John S. Ma	NRR/DEX/ESEB	(301) 415-2732

Name and Title of Supervisor	Organization	Telephone Number (10 numeric digits)
Joseph Colaccino	NRR/DEX/ESEB	(301) 415-7102

When was the prevailing staff view, existing decision or stated position established and where can it be found?

Date 07/23/2020 **Where (i.e., ADAMS ML#, if applicable):** ML20205L405

Subject of DPO
NuScale SER Chapter 3.8.4, "Seismic Category 1 Structures"

Summary of prevailing staff view, existing decision, or stated position.
Below is the management response to my NCP - 2019-004:

Regarding the concerns expressed by the NCP-submitter that NRO Engineering Management did not respond to his concerns (i.e., provide evidence of the applicability of the PRA method to predict building collapse, nor that the PRA result demonstrates "NO COLLAPSE" of the NuScale reactor building, and is taking no action to resolve the problem of whether the NuScale reactor building will collapse or not during the RLE), Management has had multiple conversations with the NCP-submitter to understand his perspective. During these conversations, NRO management indicated that the ground motion acceleration screening threshold of 1.67 times design basis SSE is a Commission policy that is implemented using the guidance in SRP Section 19.0, "Probabilistic Risk Assessment and Severe Accident Evaluation for New Reactors." SRP Section 19.0 notes that using the PRA-based SMA is acceptable at the DC review stage. Further, as discussed above, the seismic margin analysis is intended to measure the robustness of the plant to withstand earthquakes of a given g-level and identify specific seismic vulnerabilities for which the plant may need strengthened protection based on the HCLPF values for critical SSCs. Therefore, there is not a "no collapse" standard defined by the Commission policy approved in SRM SECY 93-087. The evaluation using "accepted structural engineering methods" is applied using the design basis SSE and that is where the need to demonstrate the structure capacity (including seismic) is greater than the demands expected on the structure. Therefore, applying a "no collapse" acceptance criteria to the PRA-based seismic margins assessment approach approved by SRM SECY 93-087 would be inconsistent with Commission direction and would effectively redefined the design basis safe shutdown earthquake ground motion acceleration for the NuScale design to a value 1.67 times greater.

> *I have read through the references in this NCP, ISG-020, SECY-93-087 and the related SRM, and several of NuScale's RAI responses related to this issue. The NRO Engineering Management team has met with the NCP-Submitter several times. In addition, the structural engineering staff, and the appropriate PRA staff have also met with the submitter. Following careful consideration of all available information, I have concluded that the approach taken by NuScale in their DCA for seismic evaluation is in accordance with agency policies, regulations and guidance. The approach that the agency staff has used to review the NuScale submittal has also been in accordance with our policies and guidance. Further, I have concluded that SRM-SECY-93-087 does not impose a "no collapse" acceptance criteria for ground motion of one and two-thirds of the Design Basis SSE. Instead, the ground motion level referenced by is intended to be used to identify design specific seismic vulnerabilities and does not supersede the requirements associated with the design basis earthquake."*

U.S. NUCLEAR REGULATORY COMMISSION

DIFFERING PROFESSIONAL OPINION (Continued)

DPO Case Number	Date Received
DPO-2020-004	9/17/2020

Reason for DPO, potential impact on mission, and proposed alternatives.

Reason for DPO: The former NRO/DE management prohibited the use of the structural engineering analysis/design method for the NuScale reactor building when it is subjected to the review-level earthquake (RLE), and that action resulted in (1) whether the building can sustain an earthquake beyond or greater than the certified seismic design response spectra (CSDRS), including the review-level earthquake (RLE), is unknown - a significant safety concern, (2) the actual seismic margin of the building is also unknown - a demonstrated minimum seismic margin of 1.5 is required by the structural engineering profession (engineers, codes and standards, local building officials-building departments), and (3) there are indications that the building might not have properly designed at the CSDRS level (the major indication is described in the DPO write-up).

Potential impact on mission: The mission of the NRC is to protect the life and health of the public. The design of the NuScale reactor building is incomplete, with unknown seismic margin, and is likely unsafe, and that does not meet the NRC mission.

Proposed alternatives: Perform and complete the design in accordance with the requirement and practice of the structural engineering profession as described and demonstrated in this attached DPO write-up.

Describe the (a) importance of prompt action on the issue, (b) safety significance of the issue, and (c) the complexity of the issue.

(a)the NuScale reactor building design is incomplete for not providing (1) proper seismic margin evaluation, (2) assurance that it would not collapse when the building is subjected to an earthquake greater than the safe-shutdown earthquake (SSE) or the certified seismic design response spectra (CSDRS) for new reactor design certification, including the review-level earthquake (RLE = 1.67 SSE or 1.67 CSDRS) in important nuclear power plant buildings, and (3) sufficient evidence to show that it does not have failure in local structural elements or collapses in structural components (members) or of the whole building, as the structural engineering profession requires and normally does.

(b) A joint meeting between the Structural Engineering Branch (SEB) and the Probabilistic Analysis Branch (PRA) of NRO, including the former NRO/DE management, was held on November 29, 2018. The PRA staff stated that (1) the NuScale reactor building is an important seismic Category I structure and it should not be allowed to collapse during the RLE, (2) the SEB is responsible for ensuring that the building would not collapse during the RLE, and (3) the PRA staff is not capable of assessing whether the building will collapse or not because that is not their expertise and is only capable of assessing the "consequence" of the building collapse, such as the core melt probability resulted from the building collapse. The **collapse** of the reactor building during the RLE could cause a potentially early and large release of radioactive materials into the atmosphere and ground, which could kill people. Therefore, to ensure that the reactor building **will not collapse** during the RLE is important and necessary.

(c) The issue is not complex to a knowledgeable and competent professional engineer with design experience in important buildings who understands the requirements of building codes and standards and the practice of the structural engineering profession.

Do you believe the issue represents an immediate public health and safety concern?	☑ **No**	☐ **Yes, (Explain in box above with importance of prompt action and safety significance.)**
Is the issue directly relevant to a decision pending before the Commission?	☐ **No**	☑ **Yes, Reference Document (i.e., ADAMS ML#)** See statement below
☑ **Informal discussions took place (Identify with whom and time frame of discussions)**		☐ **Extenuating circumstances prevented informal discussions**

I do not believe the issue represents an immediate public health and safety concern because no plant has started to build yet. I believe that the issue is directly relevant to a decision pending before the Commission (to the NRR Office level) to issue a certification. The management has no discussion with me on my DPO concerns since it dismissed my Non-concurrence (NCP-2019-004).

Proposed panel members are (in priority order):

1. Weijun Wang
2. Zuhan Xi
3. [redacted]

☐ **No names of potential panel members will be provided.**

NRC FORM 680
(09-2019)
NRC MD 10.159

U.S. NUCLEAR REGULATORY COMMISSION

DIFFERING PROFESSIONAL OPINION (Continued)

DPO Case Number	DPO-2020-004
Date Received	9/17/2020

List of area(s) of technical expertise needed to properly assess the issue (e.g., electrical engineering, operator licensing).
Professional engineers with knowledge and experience in building designs

When the process is complete, I would like management to determine whether public release of the DPO case file (with or without redactions) is appropriate (Select "No" if you would like the DPO case file to be non-public): ☑ Yes ☐ No

Please note that your DPO submittal may be shared on a need-to-know basis in an effort to resolve the concern, determine the most appropriate regulatory actions in response to the concern, and identify key agency resources to evaluate the concern.

Signature of Submitter: John S. Ma
Digitally signed by John S. Ma
Date: 2020.09.14 09:42:48 -04'00'

Signature of Co-Submitter (If any):

Submit by E-mail:

Signature of DPO Program Manager: Gladys J. Figueroa Toledo
Digitally signed by Gladys J. Figueroa Toledo
Date: 2020.09.21 12:52:25 -04'00'

☐ DPO returned ☑ DPO accepted

Differing Professional Opinion
The Design of the NuScale Reactor Building is Incomplete
with Unknown Seismic Margin and Likely Unsafe

by

John S. Ma, Ph.D., P.E.

Senior structural engineer and a charter member of the NRC

Member of American Concrete Institute (ACI) and American Society of Civil Engineers (ASCE)

Recipient of the Raymond C. Reese Structural Research Award Medal from ACI

September 10, 2020

Chapter 1

Introduction

This differing professional opinion addresses a safety concern of the NuScale reactor building design for not providing (1) proper seismic margin evaluation, (2) assurance that it would not collapse when the building is subjected to an earthquake greater than the safe-shutdown earthquake (SSE) or the certified seismic design response spectra (CSDRS) for new reactor design certification, including the review-level earthquake (RLE = 1.67 SSE or 1.67 CSDRS) in important nuclear power plant buildings, and (3) sufficient evidence that it does not have failure in local structural elements or collapses in structural components (members) or of the whole building, as the structural engineering profession requires and normally does.

The structural engineering profession (engineers, codes and standards, building officials – building departments) worldwide uses two levels of earthquake intensities (hazards) for the design and review of important buildings. The first level of earthquake intensity is called the design-basis earthquake (DE) in conventional buildings, and the SSE, or the CSDRS for new reactor design certification in nuclear power plant buildings, so that the building meets "functional" criteria. The second level of earthquake intensity is called the maximum considered earthquake (MCE) in conventional buildings, and the RLE in nuclear power plant buildings, so that the designed building **"should not collapse"** at that level of earthquake intensity. This design procedure is called **"collapse prevention"** in the structural engineering profession. The ratio of the earthquake intensity of the MCE divided by the intensity of the DE is a seismic margin measurement, and the value of 1.5 is the minimum requirement for important buildings (see Chapter 4) by the structural engineering profession. This minimum required seismic margin of 1.5 is <u>**explicitly**</u> designed into a building by using the structural engineering analysis/design method to ensure that the building **"will not collapse"** during the MCE. The method and the process in designing the required seismic margin into a building use the following steps:

1. Performs a structural engineering analysis with the input of design-basis earthquake (DE) to a building, then designs the building for “functional” criteria based on the analysis results.
2. Performs a structural engineering analysis with the input of the required seismic margin 1.5 times the DE to the building, then designs the building for “no collapse” or “collapse prevention” criteria (see Chapter 4).
3. The above step number 2 is a trial-and-error structural engineering analysis/design process and is repeated until the final design of the building meets the “no collapse” criteria.

The NRC Policy in SECY 93-087 (reference 1) states: “The Commission approves the use of 1.67 times the Design Basis SSE for a margin-type assessment of seismic events.” As stated in Table 1.19-40 of Chapter 19 of NuScale Final Safety Analysis Report (FSAR), NuScale Probabilistic Risk Analysis and Severe Accident Evaluation, “Seismic Category I structures (i.e., the RXB (reactor building) and the CRB (control building) meet the seismic margin requirement of 1.67 * CSDRS for site-specific seismic hazards (e.g., sliding, overturning)” is a key assumption for the seismic margin assessment. This key assumption implies that the RXB should not collapse when it is subjected to the RLE = 1.67 times CSDRS because the collapse could cause an early and large release of radioactive materials into the environment that could injure or/and kill people. This assumption must be verified, and it can only be properly and adequately verified by the structural engineering analysis/design method by inputting the RLE to the building and results in “no collapse,” as stated above in steps 2 and 3. This is because the structural engineering analysis/design method is based on the theory of natural laws of physics and has been verified by physical seismic test data in laboratories. An example of that verification is shown in Chapter 3. The details of this method are described in Chapter 4. The design process of buildings with seismic margins of 1.8 and 3.0 being designed into them are described in Chapter 5.

However, the NuScale reactor building has only been analyzed/designed for the CSDRS but not the RLE. Therefore, it is unknown whether the building will collapse or not if the earthquake intensity exceeds or greater than the CSDRS, including the RLE, and the seismic margin of the building is also unknown because steps 2 and 3 as mentioned above had not been performed.

Furthermore, there are indications that the design of the NuScale reactor building is likely unsafe even at the CSDRS level because several structural elements were already overstressed under the CSDRS level of loads. More discussions on this likely unsafe design at the CSDRS level will be demonstrated in Chapter 7. Had the building been analyzed by the RLE as required by the structural engineering profession, those already overstressed structural elements could have been further overstressed into failure and those elements that were not overstressed under the CSDRS could have been overstressed and failed and some structural components (members) could have been collapsed, and the whole building could also have been collapsed.

The major differences between the approach of the structural engineering profession and the NuScale approach for the design of the NuScale reactor building are: (1) that the structural engineering approach **explicitly** use the seismic margin of 1.67 into the building design while the NuScale design approach did not, and (2) that the approach of the structural engineering ensures that the building will not collapse at the RLE because the RLE loading level was considered in the building analysis and design while the NuScale approach is limited only to the CSDRS. As pointed out earlier, even at the CSDRS level, there are indications that the building might not have been properly designed, and those deficiencies would have been exposed by the analysis using the RLE load as input. The fact that there is no demonstration that the NuScale reactor building can sustain an earthquake intensity beyond or greater than the CSDRS, including the RLE, clearly shows that this building neither meet the minimum seismic margin of 1.5 required by the structural engineering profession, nor the 1.67 times the CSDRS required by the NRC. Therefore, it would be inaccurate for the NRC to tell the public that the design of the NuScale reactor building is safe.

Chapter 2

Sequence of Presentation

Chapter 3 explains the meaning of seismic margin for a building or a structure and defines the numerical value of the seismic margin. Chapter 4 describes the structural engineering process and analysis/design method to ensure that the required seismic margin is designed into a building. Chapter 5 describes the need of **"No collapse"** criteria for building design and provides design examples with that criteria. Chapter 6 summarizes the established process and methodology of designing the required seismic margin into a building. Chapter 7 describes the likely unsafe design of the reactor building for the CSDRS. Chapter 8 confirms that the reactor building should not collapse at RLE and the Structural Engineering Branch of NRO should ensure it. Chapter 9 describes my Non-concurrence filing and the management's dismissal. Chapter 10 illustrates the former NRO/DE management's lack of understanding of knowledge and practice of structural engineering, and lack of understanding of the **"No collapse"** criteria that should not be in the NRC Policy and the management's use of the absence of that criteria in the NRC Policy as the justification for excluding the use of the structural engineering analysis/design method for the RLE is illogical. Chapter 11 is the conclusion of this differing professional opinion.

Chapter 3

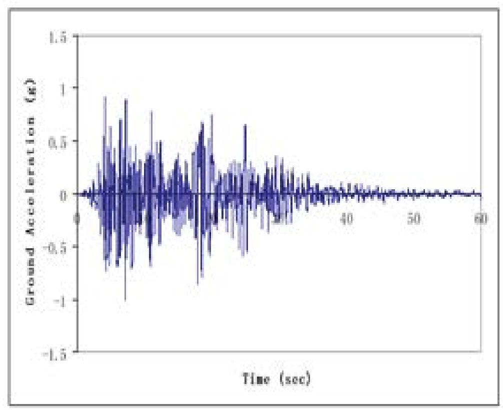
What is Seismic Margin?

A building consists of structural components (members), such as roofs, walls, beams, columns, slabs, connections, and foundations. Each structural component (member) is further divided into structural elements for easy mechanics analysis. The whole building and its structural components and structural elements are designed to withstand certain intensity of earthquakes which is called design-basis earthquake (DE) in conventional buildings, and Design Basis SSE or SSE in nuclear power plant buildings. If the intensity of the earthquake starts increasing beyond its DE or SSE to certain degree, some of the structural elements will be overstressed, components (members) may start to collapse, and that phenomenon is called partial collapse of a building. If the earthquake intensity keeps increasing, more structural elements failed due to overstress and more components (members) collapse, and eventually the whole building will collapse, and that phenomenon is called a whole building collapse. The intensity of the earthquake that causes the building to collapse beyond the intensity of the design-basis earthquake DE or SSE is the seismic margin that the building possesses. Mathematically, the seismic margin is defined by dividing the earthquake intensity that causes the building to collapse by the intensity of the design-basis earthquake – it should be a numerical value greater than 1.0. The larger of seismic margin a building possesses the safer the building against building collapse due to earthquake.

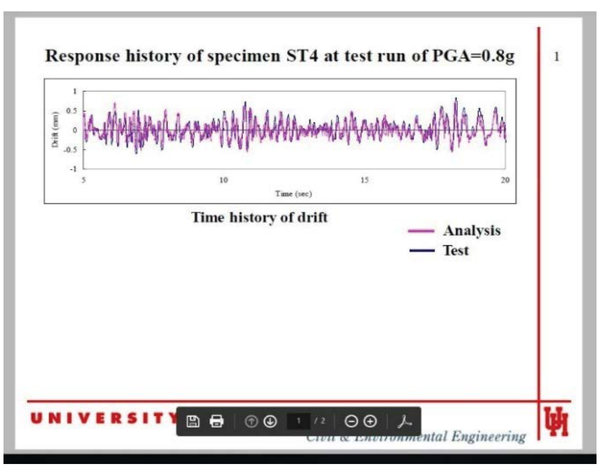
The definition and calculation of seismic margin can be better understood by the presentation of the following reinforced concrete wall tests on an earthquake shake-table with actual earthquake ground motions actuation input at the bottom of the wall which is attached and anchored to the earthquake testing table.

The wall and the earthquake shake table in the laboratory is shown on the left, and the actual earthquake ground motions input to the shake table is shown on the right. Wall movements during the earthquake testing (which is called "response" to earthquake) are recorded. Prediction of wall movements during the earthquake ground motions by a structural engineering analysis are also provided. The comparison between test data and analytical predictions on the response of the wall is excellent both on magnitudes and phases as can be seen in the two "Response history" diagrams in Figure 1 below.

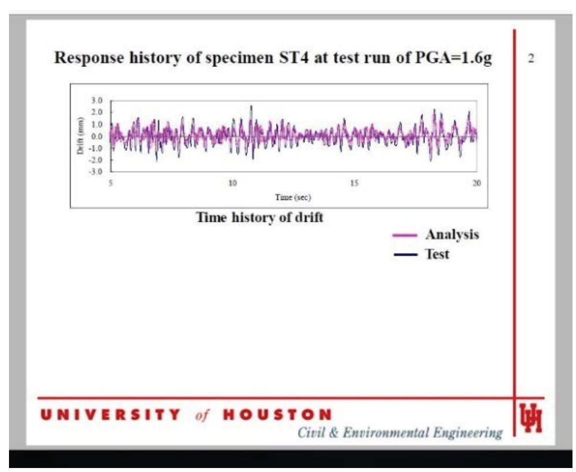
A concrete wall tested on an earthquake shake table



Input of actual earthquake ground motions



Wall movement during PGA=0.8g earthquake



Wall movement during PGA=1.6g earthquake

Figure 1. A Concrete Wall Shake Table Test

The above two diagrams show the response of the wall for the two important earthquake intensities in structural engineering design: the one at left with a peak ground acceleration (PGA) = 0.8g that corresponds to the intensity of the design-basis earthquake (DE) when steel reinforcing bars start to yield, and the other at right with a PGA = 1.6g when the wall collapsed. The recorded data of the wall movements (responses) from the shake table is in black color, and the wall movements from the structural engineering analysis is in purple color.

The response at PGA = 0.8g is important because that American Concrete Institute (ACI) building codes allow the yielding of steel reinforcing bars in structural elements and components (members) for conventional buildings at the design-basis earthquake (DE) and for seismic Category I buildings in nuclear power plants at the Design Basis SSE. Since the wall collapsed at 1.6g, the seismic margin of the wall is 2.0 (1.6g divided by 0.8g = 2.0). This wall design meets the NRC Policy because the wall possesses a seismic margin greater than 1.67 or the wall had not collapsed at the PGA = 1.34g (the design basis earthquake of 0.8g x the NRC required seismic margin of 1.67 = 1.34g). **The structural engineering analysis/design method to ensure that a building possesses a certain seismic margin starts with inputting the intensity of an earthquake with the required seismic margin times the design-basis earthquake to shake the building, and ends with the building of "no collapse", just like the wall test that at the seismic margin of 1.67 it did not collapse at PGA = 1.34g.**

Chapter 4

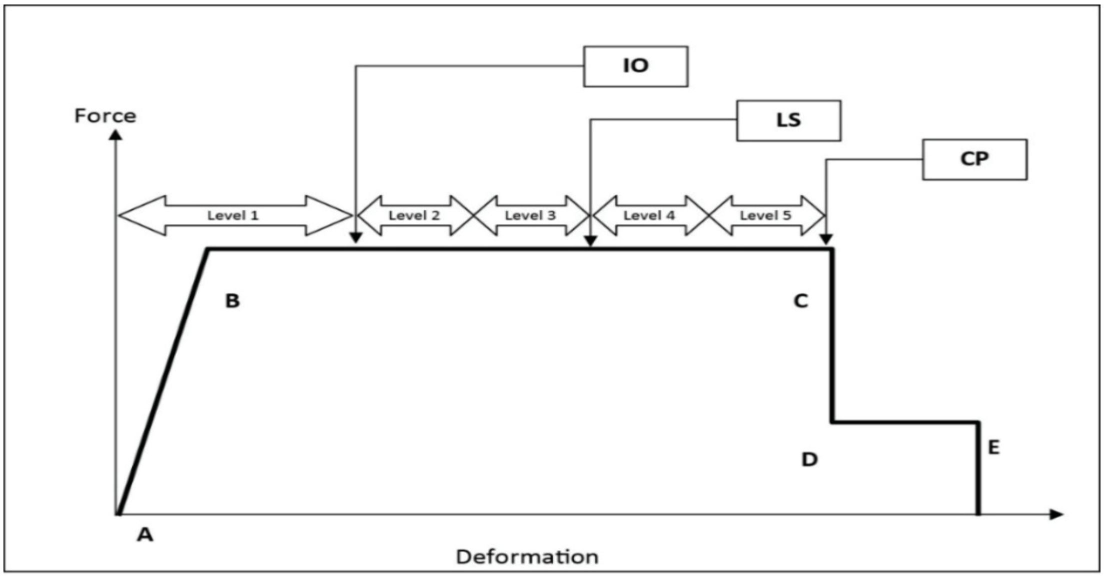
What is the Required Seismic Margin for Building Design and How is it Designed into a Building?

The "Stanford Seismic Design Guidelines (for Engineers & Architects)," published by Stanford University (reference 2) is a document that represents the practice of the structural engineering profession for the minimum seismic margin of 1.5 that is required by the profession, and how the margin is designed into new buildings or retrofitted to existing buildings. Excerpts from this document are listed below to illustrate the design process and methodology for achieving the required seismic margin:

> "In 1987, Stanford adopted a performance-based design approach to seismic engineering in recognition of the potential consequences of a major earthquake in Northern California. While the design of campus buildings must meet the minimum life safety provisions prescribed by code, performance-based design provides an added measure of structural design analysis to help achieve specific performance goals and to ensure that the design of campus buildings keeps pace with the most current knowledge base of seismic engineering and testing."
>
> "Stanford developed risk-based, site-specific spectra for the evaluation and design of its buildings and facilities. For this purpose, the main campus has four (4) zones for which previous spectra have been updated to ASCE 7-16 Earthquake Spectra (MCE_R), Design Earthquake Response Spectra (DE), and ASCE 41-17 BSE-1N and BSE-2N spectra and should be used by consulting engineers. For the assessment and retrofit of existing buildings, Stanford considers BSE-1N and BSE-2N, which are equivalent to ASCE 7-16 MCE_R and DE, appropriate."

“Stanford has identified five building performance levels as described in this section: • Level 1 – Immediate Occupancy • Level 2 – Limited Damage • Level 3 – Life Safety/Seismic Resiliency • Level 4 – Life Safety • Level 5 – Collapse Prevention.”

“All performance levels and facilities classifications are subject to the following two earthquake hazard levels: MCE_R/BSE-2N and DE/BSE-1N, which are used for performance-based evaluations and designs of Stanford buildings.



IO: Immediate Occupancy; **LS:** Life Safety; **CP:** Collapse Prevention

Figure 2. Deformation Limits vs. Earthquake Performance - Levels 1 through 5

"Stanford has identified five building performance levels, same as identified in codes, standards, and structural/earthquake engineering journals:
• Level 1 – Immediate Occupancy
• Level 2 – Limited Damage
• Level 3 – Life Safety/Seismic Resiliency
• Level 4 – Life Safety
• Level 5 – Collapse prevention

PERFORMANCE EVALUATION

When evaluating a building, the engineer of record (EOR) should determine the expected performance level of the building (structural components, non-structural components, and equipment) under the postulated earthquake levels DE/BSE-1N and MCE_R /BSE-2N. This determination should be based on <u>a structural analysis</u> (underline added by me to emphasize that the need of a structural analysis as opposed to the management’s order of no need or not applicable for a structural analysis for the RLE) of the building’s lateral load resisting system and non-structural elements such as appendages, parapets, etc. (as described in the previous section).

New Building: For a new building, the performance should be based on an evaluation of the performance of individual building components such as shear walls, floor diaphragms, coupling beams, and collectors following standard design procedures. Performance of non-structural components and equipment should also be evaluated. When all these elements meet a specific performance level, then the building is identified as meeting the performance level. Particular attention should be provided to irregular buildings to ensure proper and complete load path and to detailing that adequately deals with the irregularities."

John Ma's summary of the Stanford Seismic Design Guidelines (for Engineers & Architects):

1. **Two earthquake intensity (hazard) levels** for designing its new buildings and for retrofitting its existing buildings, as stated and defined in the "Minimum Design Loads and Associated Criteria for Buildings and Structures," of ASCE 7-16 Standard (reference 3). The reasons for using two earthquake intensity levels are stated in the ASCE 7-16 Standard as *"The first basis for seismic design in the standard is that structures should have a suitably low likelihood of collapse* (underline added by me to contrast with the management's incorrect use of no collapse criteria being specified in the NRC Policy as the reason to conclude that a structural engineering analysis for the RLE is neither applicable nor required for the RLE) *in the rare events defined as the maximum considered earthquake (MCE) ground motion. A second basis is that life-threatening damage, primarily from failure of nonstructural components in and on structures, is unlikely in a design earthquake ground motion (defined as two-thirds of the MCE)."* Notice that the inverse of 2/3 is 1.5 (1.0 divided by 2/3 = 1.5), which is the minimum required seismic margin beyond the design-basis earthquake for buildings.
2. The structural components (members), such as beams, columns, connections, shear walls, floor diaphragms, coupling beams, and collectors and the whole building should be evaluated for meeting their performance levels: Collapse Prevention (CP) under MEC_R and Life Safety (LS), or life-threatening damage as stated in the ASCE 7-16 standard, under DE, as shown in Figure 1 in the Stanford Seismic Design Guidelines.
3. It states that its identification of five building performance levels are the same as identified in codes, standards, and structural/earthquake engineering journals.
4. The minimum seismic margin required in the ASCE 7-16 Standard remains to be 1.5, which has been used in the structural engineering profession for quite sometimes. The Stanford University requires its buildings to possess this minimum seismic margin of 1.5. This seismic margin can be seen, for an example, on the first row in the table below: the seismic margin, MCE_R/DE horizontal spectra = 0.66/0.44 = 1.50; MCE_R/DE vertical spectra = 0.68/0.45 = 1.51.
5. It prefers the use of little or no lateral system irregularities and recognizes that the structural irregularities would be a challenge for seismic design and cost more than the regular buildings to design and build that Stanford University tries to avoid.

Table 7: Horizontal and Vertical MCE_R/BSE-2N and DE/BSE-1N Response Spectra Values
5% Damping

Zone 3 Spectra				
Period	Horizontal MCE_R/BSE-2N per ASCE 7-16	Vertical MCE_R /BSE-2N per ASCE 7-16	Horizontal DE/BSE-1N per ASCE 7-16	Vertical DE/BSE-1N per ASCE 7-16
(sec)	(g)	(g)	(g)	(g)
0.01	0.66	0.68	0.44	0.45
0.02	0.72	0.68	0.48	0.45
0.03	0.77	0.91	0.51	0.61
0.05	0.87	1.82	0.58	1.210
0.065	0.95	1.82	0.63	1.21
0.075	1.00	1.82	0.67	1.21
0.10	1.13	1.82	0.75	1.21
0.15	1.39	1.82	0.92	1.21
0.18	1.53	1.60	1.02	1.07
0.20	1.53	1.46	1.02	0.98
0.30	1.57	1.08	1.05	0.72
0.40	1.71	0.87	1.14	0.58
0.50	1.65	0.83	1.10	0.55
0.75	1.56	0.78	1.04	0.52
1.00	1.56	0.78	1.04	0.52
1.50	1.19	0.60	0.80	0.40
2.00	0.97	0.49	0.65	0.32
3.00	0.74	0.37	0.49	0.25
4.00	0.60	0.30	0.40	0.20
5.00	0.38	0.19	0.25	0.130
7.50	0.18	0.091	0.12	0.060
10.00	0.14	0.070	0.090	0.050

Higher numerical values of seismic margin have been used for building design due to structural irregularities and high occupancy (high risk of casualty and injury to people resulted from the building collapse) and new types of structural elements for design and construction for buildings due to the lack of knowledge and experience on how these new structural elements would behave under loads, including earthquake loads.

An extremely irregular building due to the constrain of the building land (lot), the Vancouver House building in Vancouver, Canada, was designed for a seismic margin of 3.0 (three times of the design-basis earthquake) or 2.0 MCE_R (reference 4). The Salesforce Tower building in San Francisco, California, which was required to use an additional 20% seismic margin (actual seismic margin = 1.5 x 1.2 = 1.8) by the local building officials due to the potential high consequence of death and injury to people caused by the building collapse because it houses more than 5000 people (reference 5).

The design of the shield building of AP1000 nuclear power plant used a new type of structural element for construction: concrete poured and bonded by two exterior steel plates, which had never been used for any major buildings. Because the use of this new structural element, the structural element was physically tested in a laboratory to have possessed a seismic margin of 3.0. The whole shield building was analyzed by a structural engineering analysis method to have possessed a seismic margin of 3.0.

Therefore, a minimum seismic margin of 1.5 is required by the structural engineering profession (licensed design engineers – engineer of record (EOR), building codes and standards, and building officials.) Besides the requirements imposed by the structural engineering profession and the local building code, the use of seismic margin greater than the 1.5 value for the design of a building is a choice and decision to be made by the building owner as to the building performance level it wants during and after a major earthquake, such as the MCE_R: Immediate Occupancy (IO), Life Safety (LS), or Collapse Prevention (CP), as shown in Figure 1 of the Stanford Seismic Design Guidelines (as shown in Figure 2 above in this document). The use of the minimum seismic margin of 1.5 to achieve CP may save a building from collapse during the MCE_R, but the building will be significantly damaged to the point that may need to be demolished, or it cannot be reoccupied until the repaired work is completed. If an owner chooses to use a high seismic margin for design and put the building performance at the level of IO, the owner will spend more money initially for the design and construction of the building but will bear much less financial consequence after major earthquakes.

More detailed technical reasons for requiring the analysis/design of buildings with the input of MCE or RLE to building design and more actual design examples, and guidelines for shortening the analysis/design and reanalysis/redesign process for important buildings in nuclear power plants to achieve a final successful design with the NRC required seismic margin, are provided in a paper entitled “Guidelines for the Performance-Based Seismic Design of Seismic Category 1 Concrete Structures in Nuclear Power Plants” (reference 4). Additional information for the current knowledge and practice in concrete structure design for earthquake and the mathematical formulations of structural responses (behaviors) resulting from steel reinforcing bars yielding and concrete cracking under increasing intensities of earthquakes and mathematical solutions can be found in the title “The State of Knowledge and Practice in Concrete Structure Design for Earthquake,” of the book “Concrete Structures in Earthquake.” (reference 5)

Chapter 5

The "No Collapse" Criteria for Building Design and Design Examples

Recommended Seismic Provisions for New Buildings and Other Structures in FEMA P-750 / 2009 Edition by National Earthquake Hazards Reduction Program (NEHRP) (reference 6) states *"The primary intent of the NEHRP Recommended Seismic Provisions for New Buildings and Other Structures is to prevent, for typical buildings and structures, serious injury and life loss caused by damage from earthquake ground shaking. Most earthquake injuries and deaths are caused by structural **collapse*** (underline added by me to contrast with the management's incorrect use of no collapse criteria being specified in the NRC Policy as the reason to conclude that a structural engineering analysis for the RLE is neither applicable nor required); *therefore, the major thrust of the Provisions is to prevent **collapse** for very rare, intense ground motion, termed the maximum considered earthquake (MCE) ground motion. The intent remains the same in the 2009 Provisions; however, the prevention of **collapse** is redefined in terms of risk-targeted maximum considered earthquake (MCE_R) ground motions. This change is explained fully in the commentary to the Part 1 modification to ASCE/SEI 7-05 Section 11.2."*

It is well known that the primary cause of deaths in an earthquake is not the earthquake itself, but the results of collapse of buildings. Therefore, the design for preventing building **collapse** is a major goal by the structural engineering community (engineers and regulatory agencies), and in building codes and standards. The **collapse** of the reactor building during the RLE could cause a potentially early and large release of radioactive materials into the atmosphere and ground, which could kill people. Therefore, to ensure that the reactor building **will not collapse** during the RLE is important and necessary. The structural engineering profession has established the process and method to achieve that goal as described in the Stanford Seismic Design Guidelines (for Engineers & Architects) in Chapter 4.

As the name of collapse prevention (CP) or no collapse implies, it prevents the **collapse** of buildings. As shown in Figure 1 in the Stanford Seismic Design Guidelines, the CP point represents the **collapse** of structural components (members) or the whole building, which is a required reference point for calculating the seismic margin, just like the PGA = 1.6g when the wall collapsed during the wall seismic test in Chapter 3.

Vancouver House building used seismic margin of 3.0

The picture and description of the design for the extremely irregular Vancouver House building (reference 7) are excerpted below. Due to the extreme irregularity of the building, especially with respect to torsional effects generated by earthquakes, it was a prudent choice to use a seismic margin of 3.0 (or no collapse at 3.0 times the design-basis earthquake) for the design of the building.

Figure 3. Topped-out Vancouver House tower north view (left) and south view (right).

Excerpt from the description of the design:

"*Models of the structure with post-yield structural element properties were created using PERFORM3D and run against selected ground motions tailored to the project site (1.0x Maximum Credible Earthquake – or MCE).* *Strain compatibility and stresses of critical elements* (underline added by me to emphasize that this criterion controls whether the structural element fails or not) *were checked under this level and then increased to 2.0x MCE. It is essential to understand the cumulative crack widths at the core walls and post-tensioned concrete flat slab diaphragms, the sum of which will propagate* *the lateral displacement* (underline added by me to emphasize that this criterion controls whether the whole building will be stable to sustain vertical load or not during the building lateral movement or will collapse) *of the tower. The design of the system followed the analysis to limit the cracks at these critical elements. Ultimately, the residual set of the structure was analyzed to confirm near elastic performance under 1.0x MCE and* *vertical stability and safety under 2.0x MCE* (underline added by me to emphasize that the analysis results demonstrate that building possesses a seismic margin more than 3.0 – not reaching the CP point yet in Figure 1 of the Stanford Seismic Design Guidelines). *Both service level gravity and seismic load cases were also evaluated."*

The Salesforce Tower used seismic margin of greater than 1.8

The **final** design (after trials-and-errors of analysis/design and reanalysis/redesign) from the Salesforce Tower meets these two criteria: no structural element failures that ensures no component collapse, and no whole building collapse in the Salesforce Tower can also be seen in graphical presentations for the Salesforce Tower design (reference 8) below. In the graphics all the stresses and strains in the building are less than their allowable criteria (prior to reaching the CP point), and the whole building's lateral (horizontal) story drifts are within allowable drift limits (prior to reaching the CP point) during the MCE.

Figure 4. Salesforce Tower.

The Salesforce Tower was required to possess a seismic margin greater than 1.8 due to the high occupancy reason.

The design description for the Salesforce Tower states *"Where predicted demand levels exceeded Acceptance Criteria, design modifications* (underline added by me to show that reanalysis/redesign is a necessary process to reach a final successful design) *were implemented. In particular, core wall thicknesses were tuned* (underline added by me to emphasize that design experience is needed to tune a building to become a successful design) *to reduce and control shear demands within acceptable limits at the tower's base and the location of a core setback at Level 50. Ultimately, it was demonstrated that all Acceptance Criteria had been achieved, and the building's enhanced performance was confirmed. As shown in Figure 4* (Figure 5 in this document), *story drifts and coupling beam rotations typically fall well within acceptable limits, wall shear demands remain elastic, and vertical wall strains are quite modest with only limited yielding predicted."*

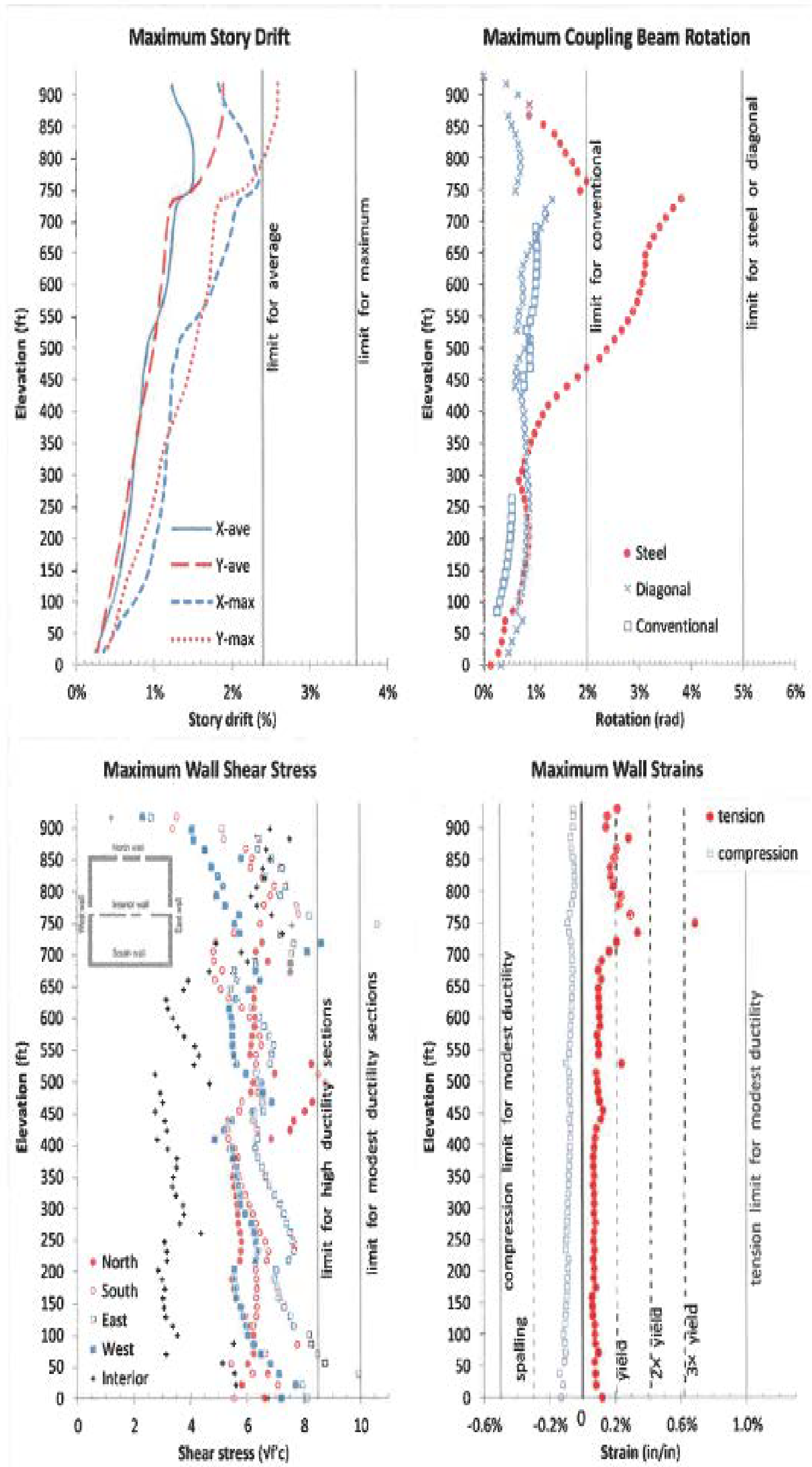

Maximum Story Drift
Elevation (ft)
Story drift (%)
limit for average
limit for maximum
X-ave
Y-ave
X-max
Y-max
Maximum Coupling Beam Rotation
Elevation (ft)
Rotation (rad)
limit for conventional
limit for steel or diagonal
Steel
Diagonal
Conventional
Maximum Wall Shear Stress
Elevation (ft)
Shear stress (√f'c)
limit for high ductility sections
limit for modest ductility sections
North
South
East
West
Interior
Maximum Wall Strains
Elevation (ft)
Strain (in/in)
tension
compression
compression limit for modest ductility
spalling
yield
2× yield
3× yield
tension limit for modest ductility

Figure 5 (Figure 4 in reference 8). Confirmation of Salesforce Tower's Enhanced Performance.

The shield building of the AP1000 nuclear power plant possesses a seismic margin of 3.0

I was a reviewer for the design of the shield building of the AP1000 nuclear power plant. The shield building used a new type of structural elements: concrete would be poured into and bonded by two exterior steel plates, which had never been used in the design and construction for important buildings. The behavior of such a new type of structural elements under loads had not been unknown. Therefore, the structural element in critical locations of the building was physically tested in a laboratory to have possessed a seismic margin of 3.0 and the whole building was analyzed/designed by a structural engineering method to have possessed a seismic margin of 3.0.

Chapter 6

Summarizing the Established Process and Methodology of Designing the Required Seismic Margin into a Building by the Structural Engineering Profession

1. Input the design-basis earthquake (DE) to a building for a structural analysis and make sure that the building response (behavior) will be at least at Life Safety (LS) stage or Immediate Occupancy (IO) stage in Figure 1 in the Stanford Seismic Design Guidelines.
2. Input the required seismic margin times the DE to the building: the maximum considered earthquake, $MCE_{R,}$ which is 1.5 times the DE, or the preferred seismic margin of 3.0 times DE due to the extreme structural irregularity, such as the Vancouver House, or the shield building of AP1000 due to the use of a new type of structural elements, and make sure that the whole building does not collapse (or reach the collapse prevention (CP) point in Figure 1 of the Stanford Seismic Design Guidelines).
3. Building design is a trial-and-error process of analysis/design and reanalysis/redesign. Where predicted demands (forces or/and deformations) exceed acceptance criteria in structural elements and components (members) and the whole building, reanalyze/redesign them (or modifications or tuned as stated in the Salesforce Tower design) until all acceptance criteria have been achieved and the building does not collapse.

When the above three steps are completed, the minimum required seismic margin of 1.5 or the required or preferred seismic margin greater than 1.5 has been **explicitly** quantified and achieved for the building because: (1) the seismic margin times the design-basis earthquake was input to the building for a structural analysis and design, (2) the trial-and-error process of analysis/design and reanalysis/redesign (or modifications or tuned) was implemented for structural elements and components (members) and the whole building until all acceptance criteria are met, which demonstrates and ensures that the building possesses that level of seismic margin and will not collapse at the earthquake of the seismic margin times the design-basis earthquake. These three steps are fundamentals of structural engineering to the design of important buildings.

The Stanford University requires its new buildings and retrofits its existing buildings with a quantified minimum seismic margin of 1.5, because its buildings are normal buildings with no irregularity and without high occupancy. The Salesforce Tower was required to possess a seismic margin greater than 1.8 due to the high occupancy reason. The Vancouver House with a seismic margin of 3.0 due to its extreme structural irregularity problem. The AP1000 shield building with a seismic margin of 3.0 due to the use of a new type of structural elements. All the buildings are designed or retrofitted through a structural engineering analysis/design method with the above **three steps for a seismic margin of 1.5 or greater.** However, the NuScale reactor building has only performed step 1, which equivalent to a seismic margin of **1.0, and has not started steps 2 and 3.** Consequently, the NuScale reactor building design is incomplete, its actual seismic margin is unknown, and whether the building will collapse during or prior to the RLE is also unknown. The incomplete design that violates the fundamentals of structural engineering design process is a significant **safety** issue. In addition to that violation, there are indications that the design is likely unsafe even at the CSDRS level, as will be described in Chapter 7. Therefore, it would be inaccurate for the NRC to state that the NuScale reactor building design is safe.

Chapter 7

NuScale Reactor Building Design is Likely Unsafe

Since the NuScale reactor building has not been analyzed/designed for the RLE, the response (behavior) of the building during the RLE is unknown, the seismic margin of the building is unknown, and whether the building will collapse or not prior to or during the RLE is also unknown. Besides no analysis/design for the RLE, there are indications that the building design is **likely unsafe**.

The major indication of the **likely unsafe** design is that several structural elements have already been overstressed (or the capacity of the element is less than the demand) when the building is subjected to the CSDRS. For an example, Table 3B-50: Element Averaging of IP Shear Exceedance of Reactor Building Wall at Grid Line 3 lists the wall length of 37 feet 9 inches which is divided into 10 structural elements. It showed that the Element number 4942 has a demand of the in-plane shear force of 3791 kips (1 kip = 1000 pounds), but only has a shear capacity of 1184 kips. The applicant calculated the total shear demand of the 10 elements to be 11083 kips, and the total shear capacity to be 11531 kips. Because the total shear capacity is slightly greater than the total shear demand, the applicant considered that the design for in-plane shear acceptable. However, there are two problems about the acceptance. The first problem is that the shear capacity of 1184 kips of Element 4942 was calculated based on the ACI code's ultimate strength method, which represents the ultimate failure value of that element. Can that element resist a shear force demand of 3791 kips (more than three times of its shear capacity) without been sheared-off failure or shear-compression failure? The answer is no unless physical tests for such a condition prove otherwise. The second problem is that shear demand forces will increase when the building is subjected to the RLE = 1.67 SSE, but the shear capacity will remain the same because that is the ultimate shear capacity. This is the reason why it is important and necessary to perform a structural analysis for the reactor building with the RLE input and then modify and/or tune the design of the building based on analyses results, as it did during the Vancouver House building design, the Salesforce Tower and other building designs, which is required by the structural engineering profession.

As stated in the president's memo of the American Concrete Institute, dated January 2020 (reference 9), the probable cause of the March 15, 2018 collapse of the pedestrian bridge over a roadway at Florida International University in Miami, FL., was design error by **underestimating the demand** that drives the actual capacity/demand (C/D) ratios of critical structural elements **toward 1.0**. Some of the structural elements in the NuScale reactor building were already **less than 1.0** (the actual capacity is less than the demand) during the CSDRS input to the building and would be **further less than 1.0** during the RLE input to the building. Had a structural engineering analysis been performed with the RLE input to the reactor building (step 2 of the fundamentals of structural engineering to the design of buildings in Chapter 6**)**, the analysis result could have shown (1) the amount of structural element failures and their locations (critical or not), (2) whether there are structural components (members) collapses or not, and (3) whether the whole building had collapsed or not. The above facts show that the design of the NuScale reactor building is **likely unsafe.**

Chapter 8

The NuScale Reactor Building is an Important Building and the SEB of NRO Should Ensure it Will Not Collapse during the RLE

A joint meeting between the Structural Engineering Branch (SEB) and the Probabilistic Analysis Branch (PRA) of NRO, including the former NRO/DE management, was held on November 29, 2018. The PRA staff stated that (1) the NuScale reactor building is an important seismic Category I structure and it should not be allowed to collapse during the RLE, (2) the SEB is responsible for ensuring that the building would not collapse during the RLE, and (3) the PRA staff is not capable of assessing whether the building will collapse or not because that is not their expertise and is only capable of assessing the "consequence" of the building collapse, such as the core melt probability resulted from the building collapse.

Chapter 9

Non-concurrence Filing and Dismissal

I filed non-concurrence (NCP-2019-004) on June 10, 2019 because the management prohibited me to ask the NuScale reactor building to be analyzed/designed for the RLE loading level. The Office of Enforcement then held a meeting with its staff, the former NRO/DE management, and me. During the meeting, I reiterated that the management's action to forbid me for requesting the applicant to perform a structural engineering analysis/design of the reactor building for the RLE had resulted in (1) an incomplete design with unknown seismic margin, and no assurance that the building will not collapse during the RLE, (2) such an incomplete design without a quantified minimum seismic margin of 1.5 does not meet the knowledge and practice of the structural engineering profession (engineers, building codes and standards, and building officials), and (3) the unknown seismic margin also does not meet the NRC Policy in SRM-SECY-93-087. The management did not challenge my statement in items (1) and (2). However, the management stated that it did not agree with my interpretation of the NRC Policy. I then challenged the management in the meeting to check with the Office of General Council (OGC) for its interpretation to resolve the different interpretations between the management and me. Unfortunately, there is no sign that the management took my challenge and checked with the OGC.

The management dismissed my non-concurrence filing by stating the following:

> *Regarding the concerns expressed by the NCP-submitter that NRO Engineering Management did not respond to his concerns (i.e., provide evidence of the applicability of the PRA method to predict building collapse, nor that the PRA result demonstrates "NO COLLAPSE" of the NuScale reactor building, and is taking no action to resolve the problem of whether the NuScale reactor building will collapse or not during the RLE), Management has had multiple conversations with the NCP-submitter to understand his perspective. During these conversations, NRO management indicated that the ground motion acceleration screening threshold of 1.67 times design basis SSE is a Commission policy that is implemented using the guidance in SRP Section 19.0, "Probabilistic Risk Assessment and Severe Accident Evaluation for New Reactors." SRP Section 19.0 notes that using the PRA-based SMA is acceptable at the DC review stage. Further, as discussed above, the seismic margin analysis is intended to measure the robustness of the plant to withstand earthquakes of a given g-level and identify specific seismic vulnerabilities for which the plant may need strengthened protection based on the HCLPF values for critical SSCs. Therefore, there is not a "no collapse" standard defined by the Commission policy approved in SRM SECY 93-087. The evaluation using "accepted structural engineering methods" is applied using the design basis SSE and that is where the need to demonstrate the structure capacity (including seismic) is greater than the demands expected on the structure. Therefore, applying a "no collapse" acceptance criteria to the PRA-based seismic margins assessment approach approved by SRM SECY 93-087 would be inconsistent with Commission direction and would effectively redefined the design basis safe shutdown earthquake ground motion acceleration for the NuScale design to a value 1.67 times greater.*
>
> *I have read through the references in this NCP, ISG-020, SECY-93-087 and the related SRM, and several of NuScale's RAI responses related to this issue. The NRO Engineering Management team has met with the NCP-Submitter several times. In addition, the structural engineering staff, and the appropriate PRA staff have also met with the submitter. Following careful consideration of all available information, I have concluded that the approach taken by NuScale in their DCA for seismic evaluation is in accordance with agency policies, regulations and guidance. The approach that the agency staff has used to review the NuScale submittal has also been in accordance with our policies and guidance. Further, I have concluded that SRM-SECY-93-087 does not impose a "no collapse" acceptance criteria for ground motion of one and two-thirds of the Design Basis SSE. Instead, the ground motion level referenced by is intended to be used to identify design specific seismic vulnerabilities and does not supersede the requirements associated with the design basis earthquake."*

Chapter 10

The Management's Lack of Knowledge and Practice in Structural Engineering, and Lack of understanding that "No collapse" is a Structural Engineering Design Criterion that Should Not be in the NRC Policy

The management's lack of knowledge and practice in structural engineering is the cause for its unreasonable decision:

1. The management's belief that the structural engineering analysis/design method is only applicable to a building when it is subjected to SSE but not to the RLE is

incorrect because the structural engineering profession requires that both levels of earthquakes to be performed by the same method (see Chapters 4, 5, and 6).
2. The management's belief that the reactor building should not be analyzed/designed for the RLE is incorrect because the structural engineering profession requires that a building should be designed for two levels of earthquake intensities: one for "functional" criterion and the other for "collapse prevention" or "no collapse" criteria (see Chapters 4, 5, and 6).
3. The management's belief that to demonstrate seismic margin for a building the PRA method should replace the structural engineering analysis/design method is incorrect, because seismic margin is a structural engineering design subject and it is required to be designed into a building and has been doing that way by the structural engineering profession in practices (see Chapters 4, 5, and 6).
4. The management's belief that the SSE would be redefined into the RLE if a structural engineering analysis/design method is performed on the reactor building with the RLE input to it is incorrect because the NRC defines that important buildings should be "functional" at the SSE, and possess a seismic margin of 1.67 at the RLE.
5. The management should know that all buildings are designed and stamped by licensed professional engineers using structural engineering analysis/design methods, and none by the PRA analysts using the PRA method (I told the management in meetings).
6. The management was in the SEB and the PRA joint meeting on November 29, 2018, and should remember that the PRA staff made it clear that the SEB should ensure that the reactor building would not collapse during the RLE, not the PRA staff because that is not their expertise.

The management's lack of understanding that "no collapse" is structural design criteria and it should not be in the NRC Policy

1. The Stanford Seismic Design Guidelines, Figure 1, indicates that "Collapse Prevention" point is the "no collapse" criteria for building design.
2. The Recommended Seismic Provisions for New Buildings and Other Structures in FEMA P-750 / 2009 Edition by National Earthquake Hazards Reduction Program (NEHRP) states that "no collapse" is the goal for building design.
3. The management could not find a "no collapse" criteria in the NRC Policy in SECY-93-087, and used that as a justification that the Policy excluded the structural engineering analysis/design method for the RLE without recognizing that it had searched for a wrong subject in a wrong place.
4. The management should know that the NRC Policy in SECY 93-087 states: "The Commission approves the use of 1.67 times the Design Basis SSE for a margin-type assessment of seismic events" and that Table 1.19-40 of Chapter 19, NuScale Probabilistic Risk Analysis and Severe Accident Evaluation assumed that the reactor building would not collapse during the RLE. Therefore, although the words of "no collapse" are not in the Policy and it should not be, the way to achieve the seismic margin of 1.67 does go through the "no collapse" criteria for the reactor building during the RLE.
5. During the meeting among the staff of Office of Enforcement, the NRO/DE management, and me, I challenged the management in the meeting to check with the OGC on the different interpretations between it and me on the NRC Policy. Had the management done that, the OGC could have brought it out from its illogical conclusions that the structural engineering analysis/design neither

applicable and nor required to the RLE and that the SSE would be re-defined to become the RLE as it had believed and stated.

Chapter 11

Conclusion

Every building is required to be designed for "functional" criteria, such as no excessive accelerations or movements of the building, during a design-basis earthquake (DE). Seismic margin is a numerical value beyond or greater than the DE that the building can sustain "without collapse." The structural engineering profession has established the minimum seismic margin of 1.5 for important buildings and to ensure that the buildings would not collapse when they are subjected to the maximum considered earthquake (MCE), which is 1.5 times DE. The seismic margin is **explicitly** designed into a building through the structural engineering analysis/design method. Buildings with irregular shapes require higher seismic margins due to the less knowledge in structural response during seismic events, such as the Vancouver House building that used a seismic margin of 3.0. Buildings that house high occupancy and their collapse would cause significant injuries or deaths require higher seismic margins, such as the Salesforce Tower building, which houses more than 5000 people, possesses a seismic margin greater than 1.8. Buildings used new structural elements that their structural response during seismic was unknown to the structural engineering profession required higher seismic margins, such as the shield building of AP1000 nuclear power plant because it used concrete poured and bonded between two exterior steel plates that had not been used for important building construction. The method and the process in designing the required seismic margin into a building use the following steps:

1. Performs a structural engineering analysis with the input of design-basis earthquake (DE) to a building, then designs the building for "functional" criteria based on the analysis results.
2. Performs a structural engineering analysis with the input of the required seismic margin (1.5, or 1.8, or 3.0) times the DE to the building, then designs the building for "no collapse" criteria.
3. The above step number 2 is a trial-and-error structural engineering analysis/design process and is repeated until the final design of the building meets the "no collapse" criteria.

The NRC Policy in SECY 93-087 states: "The Commission approves the use of 1.67 times the Design Basis SSE for a margin-type assessment of seismic events." Table 1.19-40 of Chapter 19, NuScale Probabilistic Risk Analysis and Severe Accident Evaluation, states that *"Seismic Category I structures (i.e., the RXB and the CRB) meet the seismic margin requirement of 1.67 * CSDRS for site-specific seismic hazards (e.g., sliding, overturning)"* is a key assumption for the seismic margin assessment. This key assumption implies that the RXB will not collapse when it is subjected to the RLE = 1.67 times CSDRS.

However, the NuScale reactor building, which is an important building and should not collapse during the RLE = 1.67 times CSDRS, has only been analyzed and designed for the CSDRS but not the RLE. Therefore, the building design is incomplete, with unknown seismic margin, and whether the building will collapse or not beyond the CSDRS, including the RLE, is unknown because it has not started the step 2 analysis/design as stated above and that is a major deficit in building design with respect to safety. Furthermore, a major indication of likely unsafe design for the NuScale reactor building showed up even at the CSDRS level, as stated in Chapter 7. The combination of these two major deficits supports the claim that the current design of the reactor building is **likely unsafe**.

The existing buildings in Stanford University will be retrofitted by, and new buildings will be designed to, the minimum required seismic margin of 1.5, which has been established by the structural engineering profession using the structural engineering process and method as stated in Chapter 4 or the three steps outlined above. By contrast, the NuScale reactor building has only been analyzed and designed with a seismic margin of 1.0 and has not been analyzed and designed beyond its design basis CSDRS. The seismic margin of 1.0 is less than the minimum required value of 1.5 established by the structural engineering profession. Should anyone be satisfied by knowing that the NuScale reactor building may have smaller seismic margin than that of buildings in the Stanford University campus?

As a summary, the facts:

1. all the buildings are designed by the structural engineering profession using the structural engineering analysis/design method because the method is based on the theory of natural laws of physics and verified by seismic testing in the laboratories to be adequate for building design during earthquakes,
2. no building was designed by the PRA analysts using the PRA method because the method is based on the theory of probability and it can only assess the “consequence” of building collapse, such as the core melt probability resulted from the reactor building collapse, but not the design for the building for “no collapse” or the seismic margin of the building,
3. the structural engineering profession has established the structural engineering analysis/design process and method that can predict whether a building can sustain or survive the MCE or the RLE without collapse, as described and demonstrated in Chapters 2, 4, 5, and 6,
4. the structural engineering profession has used the structural engineering analysis/design process and method to design the required seismic margin into a building so that it can sustain or survive an earthquake intensity equals to the seismic margin times the design-basis earthquake without collapse, as described and demonstrated in Chapters 2, 4, 5, and 6. However, the PRA method cannot do that, and
5. the NuScale reactor building **has not been analyzed/designed** beyond the CSDRS, whether it can sustain or survive an earthquake greater than the CSDRS, including the RLE, without collapse is **unknown**, and its seismic margin is also **unknown**.

The NRO/DE management’s actions and inactions:

1. it forbidden the use of the structural engineering analysis/design process and method for the RLE, and replaces it by a PRA method, and that action resulted in fact #5,
2. it did not provide any technical reason on why the structural engineering analysis/design process and method is only applicable to and required for the reactor building design when it is subjected to the SSE but not to the RLE, which is diametrically opposite of the approach established by the structural engineering profession,

3. it did not provide any technical reason on why the PRA method should replace the structural engineering analysis/design process and method when the reactor building is subjected to the RLE without recognizing that the PRA method cannot do that as stated in facts #1 and #2, and
4. it did not provide any technical reason on why the PRA method can be used for the design of the reactor building when it is subjected to the RLE and why the PRA method could demonstrate that the reactor building would not collapse during the RLE as stated in facts #3 and #4.

In dismissing my non-concurrence filing, the management states ”*Regarding the concerns expressed by the NCP-submitter that NRO Engineering Management did not respond to his concerns (i.e., provide evidence of the applicability of the PRA method to predict building collapse, nor that the PRA result demonstrates “NO COLLAPSE” of the NuScale reactor building, and is taking no action to resolve the problem of whether the NuScale reactor building will collapse or not during the RLE,..”* The management acknowledged in the above statement that it understood my concerns, but its actions and inactions as stated above demonstrated that **none** of the concerns and the problems it had created was resolved by the management.

Furthermore, the management’s statement “*I have concluded that the approach taken by NuScale in their DCA for seismic evaluation is in accordance with agency policies, regulations and guidance. The approach that the agency staff has used to review the NuScale submittal has also been in accordance with our policies and guidance”* cannot be true in comparison with the five facts and the management’s four actions and inactions as stated above.

Based on the five facts and the management’s four actions and inactions as stated above, it leads a clear conclusion that the NuScale reactor building design is incomplete for not providing (1) proper seismic margin evaluation, (2) assurance that it would not collapse when the building is subjected to an earthquake greater than the safe-shutdown earthquake (SSE) or the certified seismic design response spectra (CSDRS) for new reactor design certification, including the review-level earthquake (RLE = 1.67 SSE or 1.67 CSDRS) in important nuclear power plant buildings, and (3) sufficient evidence to show that it does not have failure in local structural elements or collapses in structural components (members) or of the whole building, as the structural engineering profession requires and normally does.

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3. “Minimum Design Loads and Associated Criteria for Buildings and Structures,” ASCE/SEI 7-16 Standard, by the American Society of Civil Engineers, 2016.

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7. “Vancouver House”, by Geoff Poh, P.Eng. *Structure* magazine, January 2020.

8. “Salesforce Tower” by Ron Klemence, P.E., S.E., Michael T. Valley, P.E. and John D. Hooper, P.E., S.E.; *Structure* magazine, June 2017.

9. “Concrete International” Magazine, January 2020.

Document 2: Memo Establishing DPO Panel

UNITED STATES
NUCLEAR REGULATORY COMMISSION
WASHINGTON, D.C. 20555-0001

October 6, 2020

MEMORANDUM TO: Jose A. Pires, Panel Chairperson
Office of Nuclear Regulatory Research

Vladimir Graizer, Panel Member
Office of Nuclear Regulatory Research

Weijun Wang, Panel Member
Office of Nuclear Reactor Regulation

THRU: George A. Wilson, Director
Office of Enforcement

George A. Wilson Digitally signed by George A. Wilson Date: 2020.10.06 15:52:55 -04'00'

FROM: Gladys J. Figueroa-Toledo ***/RA/***

Differing Views Program Manager
Office of Enforcement

SUBJECT: AD HOC REVIEW PANEL - DIFFERING PROFESSIONAL OPINION ASSOCIATED WITH THE NUSCALE SAFETY EVALUATION REVIEW (SER) CHAPTER 3.8.4, "SEISMIC CATEGORY 1 STRUCTURES" (DPO-2020-004)

In accordance with Management Directive (MD) 10.159, "The NRC Differing Professional Opinion Program;" and in my capacity as the Differing Professional Opinion (DPO) Program Manager; and in coordination with George Wilson, Director, Office of Enforcement, Ho Nieh, Director, Office of Nuclear Reactor Regulation; and the DPO submitter; you are being appointed as members of a DPO Ad Hoc Review Panel (DPO Panel) to review a DPO submitted by an U.S. Nuclear Regulatory Commission (NRC) employee.

The DPO (Enclosure 1) involves the NuScale SER Chapter 3.8.4, "Seismic Category 1 Structures". The DPO has been forwarded to Mr. Nieh for consideration and issuance of a DPO Decision.

CONTACT: Gladys Figueroa-Toledo, OE
(301) 287-9497

Ian Gifford, OE
(301) 287-9216

The DPO Panel has a critical role in the success of the DPO Program. Your responsibilities for conducting the independent review and documenting your conclusions in a report are addressed in the handbook for MD 10.159 in Section II.F and Section II.G, respectively. The DPO Web site also includes helpful information, such as a Differing Views Best Practices Guide, tables with status information and timeliness goals for open DPO cases , and closed DPO case files (which include DPO panel reports). We will also be sending you additional information that should help you implement the DPO process.

Timeliness is an important DPO Program objective. Thus, the disposition of this DPO should be considered an important and time sensitive activity. Although the DPO MD identifies a timeliness goal of 75 calendar days for the DPO panel review and report and 21 additional calendar days for the issuance of a DPO Decision, the DPO Program also sets out to ensure that issues receive a thorough and independent review. Therefore, the overall timeliness goal will be based on the significance and complexity of the issues, schedule challenges, and the priority of other agency work. Process Milestones and Timeliness Goals specific to this DPO will be discussed and established at a kick-off meeting.

Communication of expected timelines and status updates are important in the effectiveness and their overall satisfaction with the Differing Views Program. If you determine that your activity will result in the need for an extension beyond your timeliness goal, please send an e-mail to Mr. Nieh, the DPO submitter, and DPOPM.Resource@nrc.gov and include the reason for the extension request and a proposed completion date for your work. Mr. Nieh is responsible for subsequently forwarding the request for a new DPO Decision issuance timeliness goal to the EDO for approval.

An important aspect of our organizational culture includes maintaining an environment that encourages, supports, and respects differing views. As such, you should exercise discretion and treat this matter appropriately. Documents should be distributed on an as-needed basis. In an effort to preserve privacy, minimize the effect on the work unit, and keep the focus on the issues, you should simply refer to the employee as the DPO submitter. Avoid conversations that could be perceived as “hallway talk” on the issue and refrain from behaviors that could be perceived as retaliatory or chilling to the DPO submitter or that could potentially create a chilled environment for others. It is appropriate for employees to discuss the details of the DPO with their co-workers as part of the evaluation; however, as with other predecisional processes, employees should not discuss details of the DPO outside the agency. If you have observed inappropriate behaviors, heard allegations of retaliation or harassment, or receive outside inquiries or requests for information, please notify me or Ian Gifford.

On an administrative note, please ensure that all DPO-related activities are charged to Activity Code ZG0007. Managers should report time to their Management/Supervisor Activity Code. Administrative Assistants should report time to their Secretary/Clerical Activity Code.

We appreciate your willingness to serve and your dedication to completing a thorough and objective review of this DPO. Successful resolution of the issues is important for NRC and its stakeholders. If you have any questions or concerns, please feel free to contact me or Ian Gifford. We look forward to receiving your independent review results and recommendations.

Enclosures:

1. DPO-2020-004 Submittal
2. Process Milestones and Timeliness Goals

cc: H. Nieh, NRR
A. Veil, NRR
M. Gavrilas, NRR
R. Taylor, NRR
L. Betancourt, NRR
C. De Messieres, NRR
J. Ma, NRR
J. Bowen, RES
L. Lund, RES
D. Seber, RES
J. Colaccino, NRR
G. Wilson, OE
F. Peduzzi, OE
D. Solorio, OE
G. Figueroa-Toledo, OE
I. Gifford, OE

SUBJECT: AD HOC REVIEW PANEL - DIFFERING PROFESSIONAL OPINION ASSOCIATED WITH THE NUSCALE SAFETY EVALUATION REVIEW (SER) CHAPTER 3.8.4, "SEISMIC CATEGORY 1 STRUCTURES" (DPO-2020-004) DATE: 10/06/2020

ADAMS Package: ML20280A530
MEMO: ML20280A542
Enclosure 1 – ML20280A501
Enclosure 2 – ML20280A551

OE-011

OFFICE	OE: DPO/PM	OE: D
NAME	GFigueroaToledo	GWilson George A. Wilson Digitally signed by George A. Wilson Date: 2020.10.06 15:52:22 -04'00'
DATE	10/05/2020	10/06/2020

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Document 3: DPO Panel Report

UNITED STATES
NUCLEAR REGULATORY COMMISSION
WASHINGTON, D.C. 20555-0001

April 19, 2021

MEMORANDUM TO: Andrea Veil, Director
Office of Nuclear Reactor Regulation

FROM: Jose A. Pires, Panel Chairperson
Office of Nuclear Regulatory Research

Weijun Wang, Panel Member
Office of Nuclear Regulatory Research

Vladimir Graizer, Panel Member
Office of Nuclear Regulatory Research

SUBJECT: AD HOC REVIEW PANEL - DIFFERING PROFESSIONAL OPINION ASSOCIATED WITH THE NUSCALE SAFETY EVALUATION REVIEW (SER) CHAPTER 3.8.4, "SEISMIC CATEGORY 1 STRUCTURES" (DPO-2020-004)

In a memorandum dated October 6, 2020, we were appointed as members of a Differing Professional Opinion (DPO) Ad Hoc Review Panel (DPO Panel or Panel) to review a DPO regarding the Nuscale safety evaluation review (SER) Chapter 3.8.4, 'Seismic Category I Structures,' (DPO-2020-004). The scope of our work was limited to a review of the issues identified in the DPO as clarified through a Summary of Issues developed by the Panel and confirmed by the DPO Submitter. The Panel evaluated the issues through interviews of knowledgeable NRC staff and a review of various documents, including official agency records.

The DPO panel report details the results of the DPO Panel's evaluation of the concerns raised in the DPO. Based on our review of concerns raised in the DPO, the DPO Panel made the following conclusions:

- Current regulations for seismic design of seismic Category I building structures in nuclear power plants require that these buildings meet general design criteria in Appendix A of 10CFR50 for the specific seismic design basis ground motion level, which is the Safe Shutdown Earthquake (SSE) for site-specific conditions and the Certified Seismic Design Response Spectrum (CSDRS) for the design certification. The design of the NuScale reactor building met the acceptance criteria in the Standard Review Plan (SRP), Section 3.8.4 for seismic Category I structures other than pressure vessels and containments. Therefore, the seismic design of the NuScale reactor building meets the design requirements in the applicable regulations and is complete for the design certification scope.

- Regarding the Submitter's concern that some structural components of the NuScale reactor building are over-stressed under the design basis seismic loading, the panel concluded that all overstress involved stresses in a few finite elements used in the modeling of structural components (mostly interior walls) modeled using several finite elements. Those structural components were either redesigned by adding additional reinforcement or by averaging finite element stresses along component cross-sections in agreement with the procedures in the NuScale FSAR. The results following this averaging or redesign show that there are no overstressed structural components, therefore the Panel did not find any safety issue related to structural component overstress for the NuScale reactor building.

- The Seismic Margin Analysis (SMA) for the NuScale certified design used PRA insights to support a margin-type assessment of seismic events. It used a PRA-based SMA that considered sequence-level High Confidence, Low Probability of Failures (HCLPFs) and fragilities for sequences leading to core damage and containment failures (releases) up to approximately 1.67 times the ground motion level for the design basis ground motion (CSDRS at the design certification stage). The applicant for the NuScale design followed the guidance in interim staff guidance ISG-DC-COL-20 for the SMA.

- The DPO panel concluded that the guidance in ISG-DC-COL-20 provides an adequate method for the SMA, including the seismic margin of the NuScale reactor building, in order to meet the purpose of the Commission direction in SRM to SECY 92-087. This guidance and its proper implementation by the applicant provide reasonable assurance of the quality of the structural design for the reactor building at the design basis level needed to meet the Commission policy for seismic safety goals in SRM to SECY 93-087.

- On the basis of its evaluation presented in the entire Panel report, the Panel concludes that the design of the NuScale reactor building is complete for the design certification scope and that the DPO Submitter's request to use the structural engineering analysis/design method, as understood by the Submitter in the DPO submittal, to analyze the structure's response at the RLE level of 1.67 times the CSDRS as input is not necessary.

The DPO panel offers the following recommendations for your consideration:

1. Development and implementation of knowledge management activities to:

    a. Clarify to the staff the intent and purpose of the Commission policy goals for seismic safety in SRM to SECY 93-087.

    b. Conduct staff workshops on Seismic Margin Analysis with PRA insights and associated seismic fragility analysis.

    c. Clarify to the staff the differences and similarities in seismic design criteria for safety-related nuclear power plant structures and commercial buildings including important and critical ones.

2. Fostering of staff engagement with codes and standards and the staff representatives to those codes and standards for cognizance of developments on generic and standardized provisions on the use of finite element analysis results in conjunction with methods in codes and standards to assess the capacity of structural components.

3. Continue staff encouragement to raise safety issues, including the formulation of Requests for Additional Information, using thorough technical considerations that may include considerations from engineering practice outside the scope of the NRC jurisdiction.

Enclosure:
Panel Report

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IGifford, OE/CRB
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CDeMessieres, NRR
LBetancourt, NRR
CTilton, NRR/DSS/STSB

ADAMS Package Accession No.: ML21109A360

OFFICE	RES/DE/SGSEB	RES/DE/SGSEB	RES/DE
NAME	WWang	VGraizer	JPires
DATE	04/19/2021	04/19/2021	04/19/2021

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DIFFERING PROFESSIONAL OPINION ON NUSCALE SER CHAPTER 3.8.4, "SEISMIC CATEGORY 1 STRUCTURES" (DPO-2020-004)

Differing Professional Opinion Panel Report

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Jose Pires, Panel Chair

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Weijun Wang, Panel Member

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Vladimir Graizer, Panel Member

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Date

Enclosure

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1 Introduction

Differing Professional Opinion (DPO)2020-004: NuScale SER Chapter 3.8.4, "Seismic Category 1 Structures," submitted on September 14, 2020, raises questions regarding the method used in the NuScale reactor building seismic margin assessment, and thus questioning whether the reactor building can sustain an earthquake with intensity beyond or greater than the certified seismic design response spectra (CSDRS)including a review level earthquake (RLE)equal to 1.67 times the CSDRS. To address these issues, a DPO Panel was established via memorandum on October 6, 2020 and asked to review and disposition the issues described in the DPO.

The Panel held a kick-off meeting on October 29, 2020 with the participation of all panel members, the Submitter, the Director of Office of Nuclear Reactor Regulation (NRR) staff from Office of Enforcement (OE)and other staff from NRR including Technical Assistants to the NRR Office Director. During the meeting, the Submitter briefly described the main issues of the DPO and answered questions from the Office director. The Project Manager for this DPO explained the DPO procedures and planned schedule.

The Panel met with the Submitter on November 4, 2020, and orally established a statement of concerns with the Submitter. Following this meeting, the Panel created a Summary of Issues (SOI)and asked, in writing, for a review of the SOI by the Submitter. The Submitter revised the SOI proposed by the Panel, and the Panel and Submitter agreed on a final SOI on March 2, 2021. The final SOI is in Section 2 of this panel report.

On March 3, 2021, the Submitter provided to the Panel a series of emails that recorded interactions between the Submitter and his supervisor and other staff regarding the issues described in this DPO during the safety review of the NuScale application in 2017 and 2018.

The Panel collected and reviewed numerous documents related to this DPO, and interviewed cognizant staff members, including staff identified or suggested by the Submitter. In addition, the Submitter provided a number of documents to the DPO panel. A list of the documents collected and reviewed is provided in Section 6.

The key issue of this DPO is whether a proper method was used to assess the seismic margin (SM)for a safety-related structure in NuScale application. The current NRC guidance on the SM is part of a probabilistic risk assessment (PRA) that follows the Commission direction in staff requirements memorandum (SRM) dated July 21, 1993, in response to the NRC staff recommendations in SECY-93-087, "Policy, Technical, and Licensing Issues Pertaining to Evolutionary and Advanced Light-Water Reactor (ALWR)Designs," dated April 2, 1993. Specifically, the SRM direction is:

> The Commission approves the use of 1.67 times the Design Basis SSE for a margin-type assessment of seismic events.
>
> The Commission approves the following staff recommendation, as modified: PRA insights will be used to support a margins-type assessment of seismic events. A PRA-based seismic margins

> analysis will consider sequence-level High Confidence, Low Probability of Failures (HCLPFs) and fragilities for all sequences leading to core damage or containment failures up to approximately one and two-thirds the ground motion acceleration of the Design Basis SSE.

The NRC later issued an interim staff guidance, DC/COL-ISG-020 (NRC, 2009), "Interim Staff Guidance on Implementation of a Probabilistic Risk Assessment-Based Seismic Margin Analysis for New Reactors," that provides detailed guidance on how to assess SM for new reactors by using a PRA-based method.

A relevant background aspect provided by the Submitter in relation to the key issue in the DPO, is the Submitters' understanding of the relation of the seismic margin in SRM to SECY 93-087 to the engineering practice for the design of commercial buildings under the jurisdiction of local and state building codes. The Submitter considers that the SM should be assessed by the methods used by structural engineering profession with the design of commercial buildings, which the Submitter refers to as "engineering method." The Submitter describes the "engineering method" as a deterministic method that is based on a model of the physics of the structural response and used in structural design and analysis under anticipated loading conditions.

In the view of the Submitter, the safety-related structures in NuScale design should be analyzed by using the "engineering method" with 1.67 times the certified seismic design response spectra (CSDRS) (specified in NuScale application) as a loading input in structure's design and analysis. This would be done to demonstrate that the structures will not collapse under such loading condition thus ensuring the adequate seismic margin of the structure other than using the PRA method to determine the SM.

The Submitter also noted that some finite elements in the modeling of the NuScale reactor building structure and its structural components are over-stressed under the design basis seismic loading, which could question the safety of the reactor building.

The Panel carefully reviewed the issues described in the DPO, the Submitter's views presented at the Panel meeting, the information provided by staff persons interviewed by the Panel, all documents, including related emails, submitted by or mentioned by the Submitter and staff persons interviewed, and other pertinent documents collected by the Panel members. Based on the reviews, the Panel performed independent evaluation and reached its own conclusions that are presented in Section 4. In Section 5, the Panel provides generic recommendations informed by its review this DPO.

2 Summary of Issues

On September 17, 2020, Dr. John S. Ma, Sr. Structural Engineer in NRR/DEX/ESEB, submitted a differing professional opinion (DPO) on the subject of "NuScale SER Chapter 3.8.4, 'Seismic Category 1 Structures'," which has control number DPO-2020-004 (hereafter referred to as the DPO). Following the kickoff meeting for the DPO on October 27, 2020, the DPO panel used the following to develop its Summary of Issues (SOI) for the DPO:

- DPO submittal, namely the completed NRC Form 680, and its attachment provided by the DPO submitter.

- DPO panel meeting with the submitter on 11/4/2020 to listen to the submitter briefing of the DPO issues and attachment contents.
- Email sent by the submitter to the DPO panel members on 11/5/2020 with additional clarifications and information on the issues.
- DPO panel meeting on 12/3/2021 to discuss the draft of the SOI draft
- DPO panel meeting on 02/24/2021.
- DPO panel meeting with the submitter on 03/02/2021 and incorporation of submitter comments to the draft SOI.

Summary of Issues

1. Safety concerns of the design of the NuScale reactor building as expressed by the submitter are summarized as follows:
   a. The design of the NuScale reactor building is incomplete because it is unknown whether the building can sustain an earthquake beyond or greater than the certified seismic design response spectra (CSDRS), including the review level earthquake (RLE). The basis for this conclusion is that the applicant did not demonstrate that the reactor building would not have collapsed (partially or wholly) when it is subjected to an earthquake greater than the certified seismic design response spectra (CSDRS), including the review-level earthquake (RLE = 1.67 CSDRS).
   b. The actual seismic margin of the reactor building is also unknown as opposed to structural engineering practice (by engineers, in codes and standards, by local building officials and building departments) for important conventional buildings or with high consequence of death or injury or financial loss if the buildings collapse, which requires a minimum seismic margin of 1.5.
   c. There are indications that the building might not have been properly designed for the CSDRS level, which the DPO attachment refers to in the statement "several structural elements have already been overstressed (or the capacity of the element is less than the stress or force demand) when the building is subjected to the CSDRS."
2. Differing view on seismic margin determination for structures and submitter's request
   a. The submitter considers that correct ways to determine the structure seismic margin (SM) are:
      i. Building codes require and practicing structural engineers have been using the structural engineering analysis/design method to analyze the response of the structure with two levels of seismic hazards inputs to the structure: one is the design seismic hazard (occurs frequently) and the other with a minimum of 1.5 or more times the design seismic hazard (occurs infrequently). When the structure so designed does not collapse (partially or wholly) during the minimum of 1.5 or more times the design seismic hazard input to the structure, it demonstrates that the structure has possessed a seismic margin of 1.5 or more. For the reactor building, the NRC policy requires an RLE input (1.67 times ~~of~~ the design basis seismic hazard to demonstrate no building collapse (partial or whole)
      ii. Laboratory model testing to determine the maximum seismic loading input under which the structure will collapse, then the ratio of seismic intensity (peak ground motion acceleration) of the maximum seismic loading to the design basis seismic loading is the seismic margin.

b. Regarding the PRA method, the submitter's concern is that the PRA method is based on the theory of probability and it can only assess the "consequence" of building collapse, such as the core melt probability resulting from the reactor building collapse, but not the design of the building for "no collapse" or the seismic margin of the building. The submitter also wrote "[t]he PRA staff stated in a meeting that the PRA staff is not capable of assessing whether the building will collapse or not because that is not their expertise and is only capable of assessing the "consequence" of the building collapse, such as the core melt probability resulted from the building."

c. The submitter requests performing and completing the design of the NuScale reactor building in accordance with the requirement and practice of the structural engineering profession by using the structural engineering analysis/design method to analyze the structure's response at the RLE level of 1.67 times the CSDRS as input seismic hazard to the reactor building.

3 Evaluation

3.1 Regulatory Requirements and General Practices on SMA

3.1.1 Regulatory Requirements and Commission's Policy Goals

The regulatory requirements for keeping adequate seismic margin for structures, systems and components important to safety against natural phenomena, including earthquakes for nuclear power plants are specified in the following Code of Federal Regulations (CFR).

10 CFR Part 50, Appendix A, "General Design Criteria for Nuclear Power Plants." In General Design Criterion 2, it states that:

> *Criterion 2 – Design bases for protection against natural phenomena*. Structures, systems, and components important to safety shall be designed to withstand the effects of natural phenomena such as earthquakes, tornadoes, hurricanes, floods, tsunami, and seiches without loss of capability to perform their safety functions. The design bases for these structures, systems, and components shall reflect: (1) Appropriate consideration of the most severe of the natural phenomena that have been historically reported for the site and surrounding area, with sufficient margin for the limited accuracy, quantity, and period of time in which the historical data have been accumulated, (2) appropriate combinations of the effects of normal and accident conditions with the effects of the natural phenomena and (3) the importance of the safety functions to be performed.

10 CFR 52.47 "Contents of applications; technical information" subsection (a)(27) requires that:

> "[t]he application must contain a final safety analysis report (FSAR) that describes the facility, presents the design bases and the limits on its operation, and presents a safety analysis of the structures, systems, and components and of the facility as a whole, and must include the following information: A description of the design-specific probabilistic risk assessment (PRA) and its results."

In response to NRC staff recommendations in SECY-93-087 (NRC, 1993a), "Policy, Technical, and Licensing Issues Pertaining to Evolutionary and Advanced Light-Water Reactor (ALWR) Designs," the Nuclear Regulatory Commission issued a staff requirements memorandum (SRM) (NRC, 1993b), regarding the seismic margin assessment, which states:

> The Commission approves the use of 1.67 times the Design Basis SSE for a margin-type assessment of seismic events.
>
> The Commission approves the following staff recommendation, as modified: PRA insights will be used to support a margins-type assessment of seismic events. A PRA-based seismic margins analysis will consider sequence-level High Confidence, Low Probability of Failures (HCLPFs) and fragilities for all sequences leading to core damage or containment failures up to approximately one and two-thirds the ground motion acceleration of the Design Basis SSE.

It is clear the regulations and Commission policy require that:

1. **For nuclear power plant, all safety-related structures, systems and components shall be designed to withstand the effect of the design basis seismic loading established with appropriate consideration of the most severe of the natural phenomena that have been historically reported for the site and surrounding area, with sufficient margin for the limited accuracy, quantity, and period of time in which the historical data have been accumulated;**
2. **For new reactor applications, a PRA is required and the results must be presented; and**
3. **The Commission approved to use of 1.67 times the design basis seismic loading for a margin-type assessment of seismic events that will use PRA-like insights.**

The goal of the NRC Commission is that all safety-related nuclear power plant structures should have reasonable assurance that they shall be designed and built to withstand design basis earthquakes established with adequate safety margin to account for uncertainties. In addition, the Commission policy goal in SECY 93-087 directs the use of PRA insights to support a margins assessment of seismic events for accident sequences with HCLPFs for seismic loading levels up to 1.67 times the design basis seismic loading.

3.1.2 General Staff Practices \ Guidance for Implementation of Regulatory Requirements and Policy Goals

The staff follows the regulations, with the staff guidance outlined in standard review plans (SRP) and regulatory guidance (RG) that provide detailed approaches for implementation of the regulations, during the safety evaluation of structures in reactor applications. The guidance includes:

- **Standard Review Plan for the Review of Safety Analysis Reports for Nuclear Power Plants: LWR Edition (NUREG-0800) 3.8.4 "Other Seismic Category I Structures," (NRC, 2013). This SRP section provides guidance on the review of areas relating to all seismic Category I and safety related structures, requirements for applications and acceptant criteria for NRC staff. This SRP section described the requirement to conclude that "[t] he applicant has met the requirements of GDC 2 by designing the safety-related structures described in this section to withstand the most severe** earthquake that has been established for the site with sufficient margin and the combinations of the effects of normal and accident conditions with the effects of environmental loadings such as earthquakes and other natural phenomena." The margin referred to in this statement is the same as that in the GDC 2 and refers to the margin for establishing the design basis seismic loads. Regulatory Guide 1.208 provides a method to establish the design basis site-specific loads in agreement with GDC 2.

- Standard Review Plan (NUREG-0800) 19.0 "Probabilistic Risk Assessment and Severe Accident Evaluation for New Reactors," (NRC, 2015). This SRP section provides guidance on staff review of the design specific probabilistic risk assessment (PRA) for a design certification (DC) and plant-specific PRA for a combined license (COL) application, respectively. This section describes the scope of seismic margin assessment for DC applications: "[t]he scope of a DC review is limited to the design-specific aspects within the scope of the design certification. The design-specific PRA developed during the DC stage may not identify site specific information (e.g., local hazards, switchyard and offsite grid configuration, and ultimate heat sink) and may not explicitly model all aspects of the design (e.g., balance of plant). A seismic PRA cannot be performed without a site-specific probabilistic seismic hazard analysis (PSHA) and as-built information. Consequently, a PRA-based seismic margin analysis (SMA) is acceptable."

In general, the NRC staff review practices follow the SRP guidance to evaluate whether the applications meet the requirements of pertinent regulation. For safety evaluation of safety-related structures, the staff follows the guidance in SRP 3.8.4 to evaluate the safety of the structures with consideration of all anticipated natural phenomena, including earthquake induced seismic loading.

The PRA-based seismic margin analysis is in the scope of Chapter 19 and the staff review is in accordance with SRM to SECY-93-087, and DC/COL-ISG-020, "Interim Staff Guidance on Implementation of a Probabilistic Risk Assessment-Based Seismic Margins Analysis for New Reactors," dated March 15, 2010.

Regarding nuclear power plant safety-related structure design and analyses including seismic margin assessment, the nuclear power plant applicants also follow the guidance outlined in regulatory guide (RG)1.70 "Standard Format and Content of Safety Analysis Reports for Nuclear Power Plants (LWR Edition)" RG 1.142 "Safety-Related Concrete Structures For Nuclear Power Plants (Other Than Reactor Vessels And Containments)" RG 1.174, "An Approach for Using Probabilistic Risk Assessment in Risk-Informed Decisions on Plant-Specific Changes to the Licensing Basis," and RG 1.200, "An Approach for Determining the Technical Adequacy of Probabilistic Risk Assessment Results for Risk- Informed Activities," as well as RG 1.206, "Combined License Applications for Nuclear Power Plants (LWR Edition)"

3.1.3 Structure Seismic Margin Assessment Practices Outside the NRC

The objective of the Commission policy goal in SRM to SECY 93-087 is to obtain a clear understanding of significant seismic vulnerabilities and other seismic insights to demonstrate the seismic robustness of a plant design. It recognizes the possibility that a nuclear power plant may be subjected to earthquake ground motions greater than the design basis, therefore ground motion above the Safe Shutdown Earthquake (SSE) or the design-basis earthquake (DBE) is needed for a seismic margin analysis. In new reactor designs under 10 CFR Part 52, the certified seismic design response spectra (CSDRS)is the design-basis earthquake for the certified, standard design while the site-specific design basis ground motion is the SSE.

In the nuclear industry, the Electric Power Research Institute (EPRI)published "A Methodology for Assessment of Nuclear Power Plant Seismic Margin", initially published on October 1, 1988 and revised (Revision 1)on August 1, 1991 (EPRI, 1991) which provides guidance on how to perform SMA for a nuclear power plant. The goal of the SMA is to provide the maximum earthquake under which the nuclear power plant can still safely operate. This maximum earthquake ground motion is typically referred to as the High Confidence Low Probability of Failure (HCLPF)ground motion. The EPRI seismic margin analysis of the plant consists of three steps:

i. Setting screening table,
ii. Performing seismic fragility analysis, and
iii. Conducting system analysis.

A review level earthquake (RLE) or equivalent seismic margin earthquake, anchored to the screening level is then defined as seismic input in seismic fragility analysis. In engineering applications, the RLE is taken as 1.67 times the DBE to indicate that the seismic risk is acceptably low.

Seismic fragility analysis can be performed either by the Fragility Analysis (FA) method or by Conservative Deterministic Failure Margin (CDFM) method. Based on fragility analyses results, HCLPF capacities of systems, structures and components (SSCs) of the power plant can be calculated. Integration of fragility / capacity data with system analysis permits the evaluation of the plant capacity, and is executed either by a systematic approach making use of event trees and fault trees, or by a further simplified approach utilizing the "success path" concept. The output of this system analysis is the plant-level HCLPF capacity, representing the plant seismic margin above the DBE.

The EPRI SMA methodology including its fragility analysis approach has been endorsed by the NRC and, specifically, it is endorsed in ISG-DC-COL-20 (NRC, 2009) when used with a systems analysis that uses event trees and fault trees as in seismic PRA.

In engineering practice for commercial buildings, there are other methods (denoted by the Submitter and in this Panel report as "engineering methods") that can be used to determine the margin of seismic safety for a structure. There are two possible uses for these methods as follows:

a) Use of 'engineering methods' to establish or verify the adequacy of prescriptive methods of design and analysis for implementation in building design standards or codes. These are applied research projects (FEMA, 2009a; NIST, 2010) to establish or validate prescriptive design methods for building codes that provide the necessary safety margin intended by the design standards or codes. These methods use nonlinear time-response analyses to verify the response of the building structures.

b) Use of the 'engineering method' in conjunction with permitted Performance-Based Seismic Design (PBSD) approaches for a variety of conditions listed in Section 3.2.1 of this Panel report. For these uses, the building codes and standards already prescribe the minimum performance criteria for the primary design-basis seismic ground motion. The building owner uses the 'engineering method' to design the building to meet the design-basis criteria of collapse prevention. The building owner can also specify more strict criteria than those in the standards or code.

The use of the 'engineering method' in a) has been used to establish or validate the prescriptive design approaches for seismic design of building structures. It has been used to inform the methods, provisions and requirement for seismic design in the ASCE 7-16 (ASCE, 2017) standard, which is the basis for most seismic design provisions in buildings codes in the United States. Rather than being a seismic margin analysis for a specific building, this is an analysis aimed at providing simpler approaches for design that provide the desired performance.

The use of the 'engineering method' as described in b) above also is not a margin analysis in the strict sense. Instead, it is a 'engineering method' analysis at a ground motion level that is in effect the primary design basis ground motion in the ASCE 7-16 and building codes based on ASCE 7-16, and is called the Maximum Credible Earthquake (MCEr) as further discussed in Section 3.2.1 of this Panel report. Building owners can choose to use ground motion levels greater than the MCEr when using PBSD approaches.

One method to determine the margin in a design is the experimental method, which normally sets up a model structure on a shake table with base input that simulates a selected earthquake event. By increasing the amplitude of the input force until the structure collapses, a "collapse earthquake" for that structure can be determined, and a DBE can then be determined with desirable safety margin. However, it is infeasible that a one-to-one scale structure can be tested by a shake table, and all scaled down models will have model scaling factors issues that will affect the direct use of dynamic testing results. Instead, these approaches are used together with analyses of the tests to obtain understanding of critical design aspects, such as the overstrength of components and their ductility as well as to develop adequate modeling approaches for the methods of analyses used as described in a) and b) above.

The use of the 'engineering method' for the purposes listed in a) is still the most common. Structural collapse analyses are subject to considerable uncertainties as noted in Villaverde (2007) and in the Commentary C16.1.1 for Chapter 16 'Nonlinear Response Time History Analysis' of ASCE 7-16 (underlining emphasis provided):

[redacted]

The commentary goes on to say:

[redacted]

Even when permitted nonlinear history-response analysis methods are used, the standard still provides implicit metrics for use as indication of collapse rather than the actual formation of progressive collapse mechanisms. Those metrics are story drifts and element (or component) level deformation-based or force-based criteria. The standard also provides considerations related to the numerical convergence of the numerical methods used. The standard also has simple prescriptive requirements to assure minimum adequate stiffness and strength for the structure that may not be clearly identified given the complexities, flexibilities and uncertainties of the nonlinear analyses of the 'engineering method.'

The 'engineering method' is largely deterministic and cannot take many uncertainties into consideration in a structure seismic margin assessment. The uncertainties involved include but are not limited to (e.g., Villaverde, 2007) the characteristics of the ground motion (e.g., intensity, frequency content, and duration) the dynamic properties of the structure; the geometry of the structure (e.g., torsional effects) the post-elastic and post-buckling behavior of its components; the strength and stiffness of these components; the degradation of this strength and this stiffness after several loading cycles; the interaction between vertical loads and lateral drifts; the interaction of the structure with its nonstructural components (e.g., the effect of components such as stairways and cladding on structural stiffness and strength) residual stresses and initial imperfections (e.g. the influence of fabrication residual stresses and member out-of-straightness on member stiffness) and soil-structure interaction (e.g., the additional lateral displacements and damping introduced by the flexibility of the foundation soil, or the changes in the configuration of the structure due to large soil settlements or localized soil failures)

3.2 Disposition of Concerns from the Summary of Issues (direct responses to issues)

3.2.1 Seismic Design of Conventional Buildings and Safety-Related Buildings in Nuclear Power Plants

In the DPO and in the attachment to the DPO, the Submitter provides background for the key issue raised in the DPO. In that background, the Submitter draws parallels (compares) between the practice for the seismic-resistant design (seismic design) of commercial buildings with the seismic design criteria used by the NRC for the design of safety-related buildings in nuclear power plants. Specifically, the Submitter refers to the practice for the seismic design approach of commercial buildings, which follows the approach in the American Society of Civil Engineers (ASCE) standard ASCE 7-16 (ASCE, 2017) with a few additions and exceptions by authorities having jurisdiction of local building design. The following sections clarify those aspects of the seismic design practice for conventional buildings and compare them to the seismic design criteria used by the NRC that are relevant to the background provided by the Submitter and for the evaluation of the DPO.

<u>Overview of Seismic Design Approach in ASCE 7-16, FEMA P-695 and FEMA P-750)</u>

The seismic design philosophy for commercial building (in the ASCE 7-16 standard) is to prevent system collapse (structural collapse) at the ground shaking level called the <u>Maximum Considered Earthquake (MCEr)</u>. For buildings, this is achieved by following the procedures and requirements specified in Chapter 11 and Chapter 12 of ASCE 7-16.

Those prescriptive procedures and requirements define a set of system performance parameters (see FEMA P-695 (FEMA, 2009a) and ASCE 7-16), which together with the systems detailing requirements specified in the construction-specific design standards referenced in ASCE 7-16 (an example is the American Concrete Institute standard for reinforced concrete structures) ensure minimum target probabilities of system collapse given the MCEr ground shaking. The system performance parameters in the ASCE 7-16 standard are:

R = a response modification coefficient that reduces the seismic demand forces calculated assuming elastic response to those that can be transmitted by the yielding of the structural system

Ωo = a system overstrength factor that accounts for the higher actual strength of the structural system as compared to the minimum specified in the standard

Cd = a deflection amplification factor that multiplies structural deflections calculated using the reduced seismic demands and elastic analysis.

Figure 1, adapted from FEMA P-695, illustrates the response modification factor, R, and the system overstrength (Vmax – V), where Vmax is the actual strength and V the design yield strength V. As shown in Figure 1, the standard permits reductions in the seismic forces in the structure calculated assuming linear elastic response by recognizing and accepting that structures (if adequately detailed) can yield to acceptable deformations and limit the forces transmitted to the foundation and structural components.

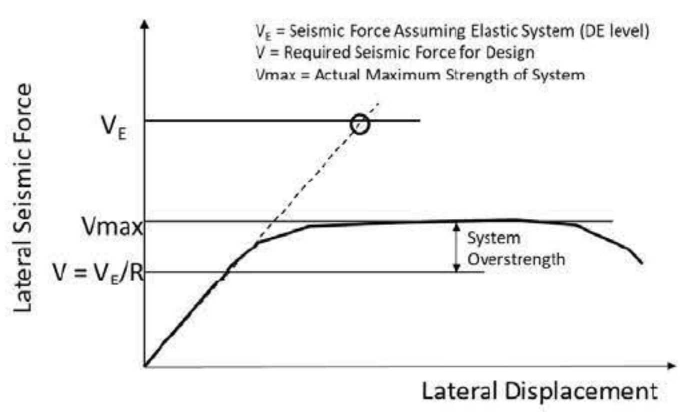

Figure 1. Illustration of system performance factor, R, and system overstrength

The standard identifies risk categories. The basic risk categories are Risk Categories I and II. For the more stringent risk categories, Risk Categories III and IV, the standard also uses an Importance Factor, Ie, which multiplies the seismic demands. This factor is 1.15 for Risk Category III and 1.5 for Risk Category IV and is used to achieve lower probabilities of collapse given the MCEr seismic ground motion.

Design Earthquake (DE)ground motion – The ASCE 7-16 standard defines another ground motion level, which it calls the DE level ground shaking which is equal to 2/3 of the MCEr ground shaking. Research documented in FEMA P-695 developed a methodology to establish and verify the building system performance factors, which, when implemented in the seismic design process, will result in the target collapse safety intended in the design standards, namely the ASCE 7-16 as well as the design codes based on ASCE 7-16. With the ASCE 7-16 approach, which is the basis for local building codes, the seismic design forces used in seismic design process (V_E in Figure 1, which is still further reduced by R) are computed using linear elastic analysis in conjunction with the DE ground motion, which is 2/3 of the MCEr ground motion. An additional explicit analysis at the MCEr level is not required. This is clearly shown in FEMA P-750 (FEMA, 2009b) which says:

> This approach has substantial historical precedent. In past earthquakes, structures with appropriately ductile, regular, continuous systems designed for reduced forces have performed acceptably. In the standard, such design forces are computed by dividing the forces that would be generated in a structure behaving linearly when subjected to the design ground motion by the response modification coefficient, *R,* and the design ground motion is taken as two-thirds of the MCE ground motion

The response modification factor, R, in the above quote is one of building system performance factors that depends on the type of structure and its level of detailing and is specific in the ASCE 7-16 standard. In the seismic design of conventional buildings inelastic deformations are expected at the MCEr level and even at the DE level with the level of inelastic deformation depending on the risk category of the building. This allows reduction of the seismic design forces calculated at the DE level as compared to the safety-related buildings in nuclear power plants which requires use of the forces calculated using the results of the elastic analysis. The amount of the force reduction depends on aspects such as the type of structure, the level of detailing, height, structural irregularities and detailing.

Explicit collapse analysis at the MCEr level

The ASCE 7-16 standard does not require an explicit analysis of the building collapse at 1.5 times the DE ground motion level. Instead, the basic seismic design process in ASCE 7-16 uses prescribed requirements and procedures which, together with the seismic forces computed using the DE ground motion, elastic analyses and system performance factors, ensure the intended target probability of collapse at the MCEr level.

In addition to collapse prevention, the standard has additional seismic design requirements, which ensure achieving adequate serviceability, strength and stiffness. The implementation of these requirements also uses seismic forces at the DE ground motion level and the system performance parameters, R, Cd and Ωo as well as the Importance Factor Ie.

Important Buildings (Risk Categories III and IV)– The ASCE 7-16 standard uses the Importance Factor, Ie, for buildings in the more stringent risk categories III and IV. However, the prescriptive approaches in the standard that use design forces calculated using the DE-level earthquake (2/3 of the MCEr)are still used in conjunction with the system performance parameters and the Importance Factor in a manner that ensures the target safety goals against collapse prevention. An explicit collapse analysis with the MCEr is not required.

Higher-level Analysis with the MCEr ground motion and Performance-Based Seismic Design (PBSD)

The ASCE 7-16 standards permits higher-level of seismic analysis that provide a direct estimate of the likelihood of structural collapse at the MCEr level for the design of any structure. These analyses are used at the discretion of the building owners. In some cases, the building owner can choose to use these methods in order to avoid unnecessarily prescriptive approaches that can result in ineffective designs. An example of this lack of effectiveness is the required increase of the seismic forces by the Importance Factor of 1.25 for a Risk Category III structure that, when used together with the prescriptive methods, may result in excessive forces on the foundations (Klememcic et al., 2017) The ASCE 7-16 standard also permits these analyses, and may even recommend them, for building structures that use alternative structural systems or do not fully comply with the conditions for use of the prescriptive requirements in the standard.

Specifically, the standard explicitly permits the use of nonlinear time-history analyses using ground motions compatible with the MCEr ground motion level. These PBSD methods aim at ensuring that the computed probability of collapse at the MCEr ground motion level meets the target performance goals in the standard.

To use those PBSD procedures, the ASCE 7-16 standard provides acceptance criteria, story drifts and element/component-level strength or deformation criteria that, in conjunction with the results of the nonlinear structural analyses, can conservatively provide assurance that collapse is not eminent at the MCEr level. An explicit collapse analysis leading to the formation of progressive collapse mechanisms is not part of the standard requirements.

When these advanced methods are used, the ASCE 7-16 standard also requires analysis using the basic requirements in the standard for strength and stiffness with allowed exceptions. This ensures that the design meets minimum strength and stiffness requirements which may not be fully captured by the approach chosen for the non-linear time-history analyses.

The Submitter provided an example (Chapter 5 of the Attachment to DPO-2020-004)in which a building owner used PBSD approaches permitted by the ASCE 7-16 standard to design a 1,070-foot tall building in San Francisco, namely the Salesforce Tower (Klemencic, et al., 2017) This is a Risk Category III building structure. The following quote in the article by Klemencic, et al., who are the structural designers of the building, provides the motivation for the use of these PBSD methods, permitted but not required by the ASCE 7-16 standard:

> Traditional structural design methods adopt an "enhanced strength" approach when attempting to improve seismic safety and performance. This approach, while easy to implement by applying code-specified seismic forces that have been amplified by and Importance Factor (1.25 for Category III buildings), fails to ensure enhanced building performance when subjected to extreme

> seismic ground shaking. In fact, in the context of historical seismic design of ductility and energy absorption, enhanced strength may, in fact, be detrimental to building performance. Stronger buildings *resist more force* rather than *absorbing* the energy of the ground' shaking. In resisting these higher forces, shear stresses and foundation demands increase to undesirable levels and building performance can be compromised. Instead, a rigorous Performance-Based Seismic Design (PBSD) approach was implemented to allow for, quantify, and control desired building performance at an enhanced level compared to other commercial office buildings.

The structural designers of the Salesforce Tower chose to use a PBSD approach permitted by the applicable standard (ASCE 7-16) and local building codes to achieve a design that meets the intended level of life safety (collapse prevention) and is economic and feasible to implement. The two latter aspects were an important performance aspect especially in relation to reduction of the forces to be transmitted to the foundation. The use of the PBSD approach permitted this evaluation using directly the MCEr level seismic ground motion and without the Importance Factor of 1.25.

Summary

- The design process in commercial codes and standards uses prescribed methods such that when used in conjunction with loads calculated at the (2/3) of the MCEr, the DE level, already provide assurance of meeting the target collapse probabilities at the MCEr level. Explicit collapse analysis at the MCEr level is not required except in special cases such as seismically isolated structures and structures with mechanical energy dissipation devices.
- The actual design basis ground motion for the primary seismic design performance requirements in the standard, which is life safety by collapse prevention with specified target probabilities, is the MCEr ground motion level. The prescriptive design and analysis requirements in the standard also provide adequate stiffness and strength requirements for the building design. The MCEr to DE ratio of 1.5 is not a factor of safety.
- The standard permits, at the building owner discretion or for a set of conditions listed above in this section, the use of PBSD methods (using the 'engineering method' analyses) in conjunction with the MCEr ground motion to demonstrate compliance with the target collapse probabilities. When these methods are used, the standard also has prescriptive requirements to achieve minimum strength and stiffness requirements that may not be adequately addressed with the more advanced analyses alone.
- Establishing two ground motions levels, the MCEr level and the DE ground motion level, provides a building owner the flexibility of using a graded approach in the PBSD. The owner can require low damage suitable for immediate occupancy for those ground motion levels with higher probability of occurring during the operation of the building while specifying greater damage levels only for those ground motion levels with very low probability of occurring during the operation of the building. The following further addresses this aspect of the PBSD.

Additional Performance-Based Seismic Design Guidelines

Building owners or institutions having jurisdiction over buildings constructed on their campuses, can implement additional PBSD guidelines and associated building classification provided they also comply with the local building codes. Local building codes are typically based on the ASCE 7-16 standard with additions and exceptions. In Chapter 4 of the Attachment to the DPO, the Submitter refers to the Stanford Seismic Design Guidelines (SDG) The SDG are an example of seismic design guidelines with various building classes associated with defined performance levels.

Performance levels in those PBSD guidelines as in the case of the SDG are, for example, immediate occupancy (IO) light damage (LD) life safety (LS)and collapse prevention (CP) The owners can specify which ground motion level, DE or MCEr to use to verify the design for the specific performance levels for each building class. This permits the use of a graded approach to design that tailors the engineering performance to acceptable risks.

Figure 2, in the Attachment to the DPO illustrates building classes and performance-levels for those classes. Examination of that figure shows that the performance levels for the most critical facilities in the SDG, which are facilities essential to emergency response, involve, low damage and inelastic deformations far from collapse.

For facilities essential to emergency response, the availability of two ground motion levels can be used with a graded approach that specifies Immediate Occupancy (very light damage)at levels corresponding to the more likely DE ground motion and re-occupancy shortly after the rare event associated with the highest ground motion level considered, the MCEr. More damage but still light damage is expected at the MCEr level.

Analyses and design detailing for the light damage required for Immediate Occupancy and delayed occupancy would prevent collapse at the maximum ground motion level considered. In fact, analyses at the DE and MCEr levels for deformations near the collapse conditions are not required because the design and detailing provided will preclude the collapse at the ground motion levels considered. The 'engineering method' analysis in this case are only required to ensure that the light damage limits associated with the immediate occupancy are not exceeded.

The SDG also permits the use of the prescriptive approaches in ASCE 7-16 (those using the DE level ground motion as inputs)for the less critical building classes in order to ensure severe damage and damage short of collapse, provided the buildings do not have gross irregularities.

Target Collapse Probabilities in Seismic Design of Conventional Buildings

To more completely contrast the design of commercial buildings, including important or critical facilities, it is useful to consider the target collapse probabilities associated with the ASCE 7-16 seismic design philosophy of system collapse prevention in ASCE 7-16 and FEMA P-695. For the less critical facilities (Risk Categories I and II) the intended collapse probability over time is 1% in 50 years (approximately 1 in 4,975 per year)and the collapse probability conditional on the MCEr ground motion is 10%. For the important or critical buildings, the intended collapse probabilities conditional on the occurrence of the MCEr shaking are 5% for risk category III and 2.5% for risk category IV. It is presumed that the collapse probability over 50 years for buildings in risk categories III and IV would be less than 1% in 50 years.

Table 1. Target collapse probabilities in ASCE 7-16 (conventional buildings)

Risk Category	Collapse Probability at the MCEr Level	Lifetime Collapse Probability
Lower consequences (I and II)	10%	1% in 50 years (1 in 4,975 per year)
Higher consequences (III)	5%	< 1% in 50 years
Highest consequences (IV)	2.5%	<1% in 50 years

As indicated above, the prescriptive methods in the ASCE 7-16 standards use the Importance Factor, Ie, to increase the seismic demand and building strength as well as to achieve the desired lower probability of collapse given the MCEr for the important or critical buildings. By increasing the overall strength and stiffness of the building the Importance Factor also enhances serviceability.

Overview of Seismic Design Approach for Safety-Related Buildings in Nuclear Power Plants

Design Basis Criteria and Design Basis Ground Motion (SSE or CSDRS)

The expected performance for Seismic Category I structures in nuclear power plants is that at the design basis earthquake ground motion level structural components will have essentially elastic behavior with negligible structural damage. This is in contrast with the design philosophy for conventional buildings which is to prevent system collapse at the ground shaking level called the maximum considered earthquake (MCEr). The design basis ground motion is either the Certified Seismic Design Response Spectrum (CSDRS) for the certified design stage or the Safe Shutdown Earthquake (SSE) for a site-specific design.

For a nuclear power plant, the SSE is derived from ground motions associated with occurrence probabilities between 1 in 10,000 and 1 in 100,000 per year. The current approach for the seismic design of nuclear power plant structures follows a deterministic process using as design basis, the CSDRS for the certified design and the SSE for the site-specific conditions. Although the design follows a deterministic approach, the process to determine the SSE is such that when the SSE is considered in conjunction with the provisions in the building design codes endorsed by the NRC, it is anticipated that the likelihood of exceeding the expected design performance of structural components, essentially elastic behavior with negligible structural damage, is of the order of 1 in 100,000 per year. However, given that the design uses a deterministic approach this is not an actual design performance target.

Table 2. Contrasting the Seismic Design and Safety Philosophy of Conventional Buildings and Safety-Related Buildings in Nuclear Power Plants

Design or Margin Aspect	Conventional Buildings (ASCE 7-16)	Seismic Category I Structures
Design Philosophy	Prevent collapse (building level response) at the MCEr ground shaking level (life safety criterion).	Essentially elastic response at the structural component level (limited or negligible damage) chosen to address functional requirements

Design or Margin Aspect	Conventional Buildings (ASCE 7-16)	Seismic Category I Structures
		(The closest requirements for commercial buildings would be those associated with immediate occupancy, which for commercial building are, however, required for significantly less rare ground motion levels)
Underlying Performance Expectations	Collapse probability: • 1 in 4,975 per year for Risk Categories I and II • < 1 in 4,975 per year for Risk Categories III and IV	Probability of exceeding essentially elastic response at the component level of the order of 1 in 100,000 per year (The design follows a deterministic approach and this probability is not an actual performance target)
Analysis and Design	Calculation of seismic forces for proportioning of structural components to meet the design philosophy above done with the DE level (MCEr/1.5) and using appropriate system performance factors, including those for reduction of seismic demands. Using the DE level ground motion with the prescriptive requirements in the codes and standards ensures meeting the collapse probability targets at the MCEr level and an explicit collapse analysis is not required. Use of the MCEr in the analysis – Performance-Based Seismic Design (PBSD) methods are permitted, which use explicit analysis at the MCEr level. With PBSD methods, basic prescriptive methods are still used with adequate modifications to ensure minimum strength and stiffness.	Calculation of seismic forces for the proportioning of structural components done at the SSE level using elastic analysis and without reduction in seismic demands (see V_E in Figure 1.)
Functional considerations	In addition to the main design criteria of collapse prevention at the MCEr level the standard has tools and prescriptions to address serviceability and functionality although without specific performance targets. Serviceability – Provisions to provide adequate stiffness and deflection control to ensure serviceability.	The SSE and the CSDRS are functional earthquakes • Vibratory ground motion for which the structure is designed to remain functional to assure the capability to shut down the reactor and maintain a safe shutdown condition as well as the other requirements in 10 CFR 100 Appendix A.

Design or Margin Aspect	**Conventional Buildings** (ASCE 7-16)	**Seismic Category I Structures**
	Functionality – Provisions to ensure stiffness, deflection control and strength to maintain, for example, the intended function of the facility following chosen levels of ground shaking.	This is achieved by requiring essentially elastic response at the structural component level (limited or negligible damage). Operating Basis Earthquake (OBE) • Vibratory ground motion level for which those features of the nuclear power plant necessary for continued operation without undue risk to the health and safety of the public are designed to remain functional.
Owners Requirements and Guidelines	Owners can specify building classes associated with performance levels such as Immediate Occupancy, Light Damage, Life Safety and Collapse Prevention. As in the case of the Stanford Seismic Design Guidelines (SDG), referred to in Chapter 4 of the DPO, the owners can make use of the DE or MCEr ground motion level to achieve a graded approach for the design of a given building classes.	
Margin: performance beyond the maximum considered earthquake in design	MCEr is the maximum considered earthquake in design. In fact, the MCEr is the design basis ground motion level for the design philosophy and primary design criterion in the standard and local building codes. The standards and building codes do not require explicit assessments for ground motion levels greater than the MCEr. Building owners can impose more strict performance requirement and use PBSD methods. In the case of the Vancouver House (Poh, 2020) referred to by the Submitter, the owner choose to use the 'engineering method' at ground motion levels beyond the MCEr (In this case, twice the MCEr level). The Vancouver House is a 515-	Seismic Margin Assessment at 1.67 SSE to provide a robust understanding of plant seismic vulnerabilities and other seismic insights for accident sequences with: • High confidence (95%) of low probability (not greater than 5%) of leading to core damage or containment failures (release) In the case of a reactor building, the SMA assumes that that gross structural damage would lead to core damage (or a release). The expectation of the SMA is to verify the quality of the design achieved at the SSE level provided by adequate ductility detailing and overstrength required in structural design codes. The ground motion for

Design or Margin Aspect	Conventional Buildings (ASCE 7-16)	Seismic Category I Structures
	foot tall building with major geometric irregularities and non-symmetric configuration. These include a narrower footprint at the base than at the top, a twisted shape and offset columns between floors. The owner chose to use the PBSD approach to ensure light damage at the MCEr level and moderate damage at twice the MCEr level.	the sequences HCLPF is 1.67 times the SSE or CSDRS.

Summary

Based on the overview of the seismic design approach for conventional buildings and the seismic design approach for seismic Category I building structures in nuclear power plants, the panel for DPO 2020-004 concludes the following:

- The seismic design philosophy for seismic Category I building structures and for commercial buildings including important and critical ones are fundamentally different and not readily comparable.
- For nuclear power plants seismic Category I buildings, the safety criterion to be met at the design basis ground motion (SSE or CSDRS) is a functional requirement achieved by requiring essentially elastic deformation at the structural component level with minimum or negligible damage.
- The primary design criterion for commercial buildings is life safety for the occupants achieved by collapse prevention of the structural system at the design basis earthquake called the Maximum Considered Earthquake, MCEr.
    - Seismic forces calculated at (2/3)MCEr, the DE level, and with further reductions for acceptable nonlinear response, are used together with prescriptive codes and standards requirements to ensure target probabilities of collapse without requiring explicit analysis at the MCEr level without requiring explicit collapse analyses at the MCEr.
    - Functional and serviceability design goals are implicit in the ASCE 7-16 seismic design provision but without specific target performance goals in the ASCE 7-16 standard other than, generally, minimum strength and stiffness requirements.
    - Building owners can choose to use a Performance-Based Seismic Design (PBSD) approach that uses the 'engineering method' for explicit analysis at the MCEr level.
- The ratio of 1.5 between the MCEr ground motion level and the DE ground motion level rather than implying a factor of safety of 1.5 is a means to define two ground motion levels that give flexibility to the seismic design process.
    - By default, a building owner uses the prescriptive methods in the codes and standards (ASCE 7-16) in conjunction with the DE ground motion level to meet implicitly the collapse prevention target goals at the MCEr level.

- The codes and standards (ASCE 7-16) permit that a building owner who wishes to use Performance-Based Seismic Design (PBSD) approaches can directly use the MCEr with the 'engineering method'.

3.2.2 Issues Related to Finite Element Overstresses and Averaging of Finite Element Results

During finite element (FE) analysis, it is not uncommon to find that the external forces/loadings induce stresses, or demands (D), on some structural elements used to model structural components that can be greater than component capacities (C) as defined in design codes and standards. These exceedances are reflected on D/C ratios greater than 1.0. The element exceedances can be real or can be caused by the limitation of the direct use of the results of finite element analysis results in the modeling of large structural components, especially shear wall panels, in conjunction with the capacities of structural components as defined in codes and standards. When many small finite elements are used in the model of a wall panel and because stresses are related to the derivatives of displacements, stress concentrations are calculated that are not necessarily related to the component capacity as defined in design codes and standards.

In engineering practice, averaging of stresses over several elements within a larger component in a structure is often used to make the FE analysis results more consistent with the capacities defined in the design codes and standards. However, the averaging method should be used with great caution and development of generic approaches for averaging or, alternatively, aggregate finite element results along component cross-sections for comparison with components' capacities in codes and standards continues to be proposed (Andersen, 2018).

There are structure finite elements exceedances in NuScale design as in the following tables in NuScale FSAR Tier 2, Appendix 3B (NuScale 2019):

- Table 3B-3: Summary of D/C Ratios for Reactor Building Wall at Grid Line 3;
- Table 3B-8: Summary of D/C Ratios for Reactor Building Wall at Grid Line 4;
- Table 3B-11: Summary of D/C Ratios for RXB Wall at Grid Line 6;
- Table 3B-15: Summary of D/C Ratios for Reactor Building Slab at EL. 100'-0";
- Table 3B-23: Summary of D/C Ratios for Reactor Building Pool Wall at Grid Line B;

The results of the stresses averaging for the affected structural components in which no more exceedances, are listed are in the following tables in in NuScale FSAR Tier 2, Appendix 3B:

- Table 3B-7: Summary of D/C Ratios for Reactor Building Wall at Grid Line 3 After Averaging Affected Elements;
- Table 3B-10: Summary of D/C Ratios for RXB Wall at Grid Line 4 After Averaging Affected Elements;
- Table 3B-13: Summary of D/C Ratios for Reactor Building Wall at Grid Line 6 after Averaging Affected Elements;
- Table 3B-17: Summary of D/C Ratios for Reactor Building Slab at EL. 100'-0" After Averaging Affected Elements; and
- Table 3B-25: Summary of D/C Ratios for Reactor Building Pool Wall at Grid Line B After Averaging Affected Elements.

In NuScale FSAR Tier 2, Appendix 3B, the applicant describes how the averaging method was used with the results of the structural FE analyses: "[w]hen necessary for averaging purposes of finite element analysis generated element forces and moments, the length of the failure plane considered is taken approximately 4 times the thickness of the element;" "[f]or the in-plane shear stress check used to demonstrate acceptable wall and slab thickness, average demand shear stresses over the full available section length of wall or slab cross-sections are used." During the safety review of the NuScale application, the NRC staff reviewed the structural element exceedances and the averaging method and did not identify any issues.

As indicated above, generic approaches for averaging or, instead, aggregate finite element results along component cross-sections in a manner suitable for comparison with components' capacities in codes and standards continue to be proposed and researched (Andersen, 2018) These methods involve averaging of stresses along specified planes, aggregating finite element results along cross-section to component level in-plane shear and bending moments, consideration of reinforcement detailing of the component to enable redistribution of forces to adjacent or nearby elements, and whether elevated stress simply reflect a particular stress concentration associated with, for example, a re-entrant corner, which are addressed with the provided component detailing but would not affect the component stability. Detailing for the NuScale walls includes out-of-plane reinforcement for all walls that mainly uses #9 bars (1.125-inch in diameter)at spacing that typically ranges from 1/3 to 1/5 of the thickness of the walls.

3.2.3 MeetingIntentofRegulationsandCommission'sPolicyGoals

PRA-based Seismic Margin Assessment at 1.67 (SSE or CSDRS)

In SRM to SECY 93-087 (NRC, 1993b) the Commission approved the staff recommendation as follows:

> PRA insights will be used to support a margins-type assessment of seismic events. A PRA-based seismic margins analysis will consider sequence-level High Confidence, Low Probability of Failures (HCLPFs) and fragilities for all sequences leading to core damage or containment failures up to approximately one and two-thirds the ground motion acceleration of the Design Basis SSE.

As indicated above in this report, the ground motion level corresponding to the sequence-level HCLPF came to be referred as the Review Level Earthquake (RLE) In SRM to SECY 93-087, the Commission set this RLE level at 1.67 times the SSE in order to adequately capture the accident sequences necessary for a clear understanding of the plant seismic vulnerabilities and seismic insights.

Interim Staff Guidance ISG-DC-COL-20 (ISG-20)(NRC, 2010)provides guidance for the implementation of this Commission policy goal. The ISG-20 defines the HCLPF as the earthquake motion level at which there is a high confidence (95%)of a low probability of failure (at most 5%) For the SMA, failure is either core damage or containment failure (release)

The purpose of the SMA is to provide a clear understanding of significant seismic vulnerabilities and other seismic insights to demonstrate the seismic robustness of a plant design. The SMA includes all accident sequences that can lead to the core damage or release. Most of these sequences involve the seismic performance of equipment in the plant, including equipment mounted on buildings.

The SMA also includes sequences involving the collapse of buildings (or buildings severely damage by an earthquake for which collapse is assumed) An assumption in the NuScale SMA, as reported in Chapter 19 of the Final Safety Analysis Report (FSAR)for NuScale, is that collapse of the reactor building would lead to core damage or a release.

In the case of Seismic Category I structures or buildings, the goal of the SMA is to verify the quality of the design achieved by the analysis and design at the SSE ground motion level (or CSDRS level for design certification)using the codes and standards endorsed by the NRC as well as other applicable NRC guidance. This is achieved by verifying that the design provides capacity beyond the SSE level by, for example, providing adequate ductility and overstrength.

The motivation in the SRM for a SMA assessment at 1.67 times the SSE (or CSDRS)design-basis ground motion has no relation to the 1.5 ratio between the MCEr and the DE ground motion levels in the design of commercial buildings including important and critical buildings. For seismic Category I structures, the SMA is an actual margin assessment of the entire plant, including equipment response and operator actions, to understand seismic vulnerabilities revealed by accident sequences with low probability of failure up to 1.67 times the design basis seismic load level. In the design of commercial buildings, the MCEr ground motion level is the design basis ground motion level for the primary design criterion (design philosophy)for commercial buildings. When the design used the prescriptive methods in the codes and standards (ASCE 7-16)for seismic design, the prescribed design process uses a DE ground motion level equal to (2/3)of the MCEr that ensures the meeting the collapse target reliabilities at the MCEr level without requirements for explicit collapse analyses.

SMA Process

The PRA-based seismic margin analysis includes:

1) Analyzing the design specific system and accident sequences
2) Evaluating the seismic fragility of structures, systems and components (SSCs)
3) Determining sequence and plant level HCLPFs.

PRA analysts perform elements 1)and 3)in this process. Structural engineers with experience in fragility analysis usually perform element 2) The fragility analysis evaluates the SSC fragility, which is the probability of failure of the SSC conditional on the intensity of the ground motion.

The guidance in ISG-DC-COL-20 provides the methods, technical references such as EPRI TR-103959 (EPRI, 1984) EPRI TR-NP-6041 (EPRI, 1991) EPRI TR-1002988 (EPRI, 2002) and standards acceptable to the staff, namely the ASME/ANS PRA Standard (ASME/ANS, 2009) to determine the seismic fragility of SSCs. The fragility analysis methods in those reports have been under development by the industry and under evaluation by the NRC for several decades as documented, for example, in NUREG/CR-5270 (NRC, 1988) for use in seismic margin calculations.

As by the ISG-20 guidance, at the design certification stage the basis for the fragility analysis is design-specific information provided in the scope of the Design Certification (DC) application. The fragility analysis makes use of the analysis, design methods and detailing used and required at the SSE level which already involve:

i. Selection of adequate gravity and seismic force-resistant systems with appropriate, continuous and regular load paths so that the structure acts as a unit in responding to the ground shaking.
ii. Analysis of the structure subjected to the lateral and vertical ground motions as well as gravity loads using adequate mathematical models (finite element models used with time-history analyses or response spectrum analyses).
iii. Sizing and proportioning of structural components and components to have adequate lateral and vertical stiffness and strength as well as detailing of components per the requirements of the structural design codes endorsed by the NRC to provide adequate ductility.

The fragility analysis methods in the ISG-DC-COL-20 use the above design information together with mechanistic assessments based on understanding of the margins (overstrength) provided by design codes and standards, and required detailing (to assess ductility capacity), and engineering analysis, together with probabilistic models to account for uncertainties. Figure 2, adapted from the standard ASCE 43-19 (ASCE, 2019), conceptually illustrates the following:

- Code capacity of a structural component
- Mean yield capacity of a structural component
- Ductility of a structural component (deformation beyond yield without significant reduction in the load carrying capacity)
- Ultimate capacity of a component
- Onset of component collapse

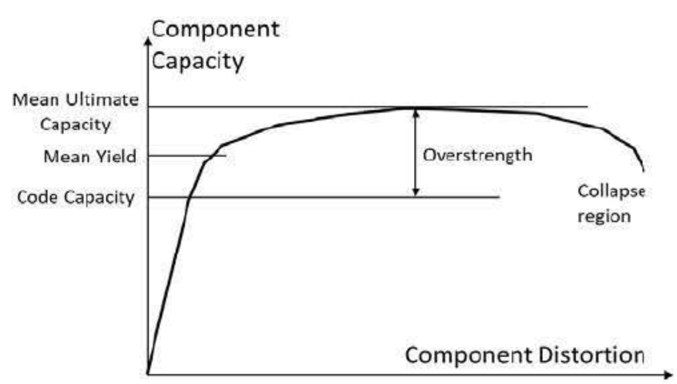

Figure 2. Component Code Capacity and Overstrength

As indicated above, the fragility analysis uses the design information at the SSE (or CSDRS) level, the analysis results and the modeling at the SSE (or CSDRS) level together with the understanding of the design margins (overstrength) provided by design codes requirements. In addition, it also uses the understanding of the additional capacity, in terms of ground motion level, provided by the component ductility based on the provided (and required by code) component detailing as well as related experimental data (see Section 3.1.3) The fragility analysis combines all of the above information using data from experiments as well as mechanistic and probabilistic methods to estimate the median capacity of the component in terms of the ground motion intensity level.

The median component capacity is then used in conjunction with information on the uncertainties in the component capacities and in the calculation of seismic forces as well as adequate assumptions on the underlying probability distribution function of the fragility, to calculate the HCLPF ground motion level. For the component fragility. Typically, once the HCLPF for the major structural components are determined, the lowest calculated HCLPF (that for the weakest component)governs the HCLPF for the structure.

The fragility analyses for the NuScale used a method called the Fragility Analysis (FA)method that closely follows the conceptual method outlined in the previous two paragraphs. It also used a simplified version of this approach, called the Conservative Deterministic Failure Margin (CDFM) which directly calculates the component HCLPF instead of calculating first the median fragility and then the HCLPF. Both methods follow the same general principles outlined above using specific methodologies and supporting data in the fragility analysis methods endorsed in the ISG-DC-COL-20.

Were the Commission's policy goals met and how?

NuScale used the PRA-based seismic margin analysis method in ISG-20, including the seismic fragility analyses methods endorsed in ISG-DC-COL-20, to calculate the HCLPF for all sequences leading (or assumed to lead)to core damage and release. The calculated HCLPFs for those sequences are greater than or equal to 1.67 times the CSDRS. The ISG-DC-COL-20 is the guidance for the implementation of the Commission policy in SRM to SECY-93-087. By following the guidance in ISG-DC-COL-20 and calculating HCLPFs greater than or equal 1.67 times the CSDRS for all sequences leading to core damage or a release, the applicant met the Commission Policy Goals to understand plant-level seismic vulnerabilities and other seismic insights to demonstrate the seismic robustness of a standard design

The Seismic Margin Analysis assumes building collapse is a single event accident sequence that directly leads to core damage. The licensee used the methods in ISG-DC_COL-20, which includes fragility analyses methods acceptable to the staff to calculate the HCLPF for the safety-related buildings including the reactor building. The FSAR for NuScale reports the values of the calculate HCLPF for the reactor building which is greater than the 1.67 times the CSDRS.

Specifically, in response to Request for Additional Information RAI No.: 8899, Question No.: 19.01-1, the applicant clarified the following:

> The review level earthquake (RLE) is defined relative to the certified seismic design response spectrum (CSDRS) peak ground acceleration (PGA), with a scaling factor of 1.67.
>
> The RLE and associated CSDRS are the seismic inputs for the fragility evaluation of structures, systems, and components (SSCs).

Subsequently, the applicant accordingly modified Sections 19.1.5.1.1.1, 19.1.5.1.1.2 and 19.1.5.1.1.3 of the NuScale FSAR. The NuScale FSAR also states in Section 19.1.5.1.1.1:

> The PRA-based SMA for the NuScale Power Module (NPM) (single module) is performed in accordance with the applicable NRC guidance documents DC/COL-ISG-020 (Reference 19.1-56), and with the applicable PRA-based SMA guidance in Part 5 of ASME-ANS Ra-Sa-2009 (Reference 19.1-2) as endorsed by RG 1.200. As discussed in DC/COL-ISG-020, the purpose of a PRA-based SMA is to provide an understanding of significant seismic vulnerabilities and other seismic insights. Consistent with DC/COL-ISG-020, the seismic margin is evaluated with respect to a review level earthquake (RLE) of 1.67 times the safe shutdown earthquake (SSE). The peak ground acceleration of the certified seismic design response spectra (CSDRS) is the SSE.

<u>Submitter's request</u>

The submitter requests performing and completing the design of the NuScale reactor building in accordance with the requirement and practice of the structural engineering profession by using the structural engineering analysis/design method to analyze the structure response the RLE level of 1.67 times the CSDRS as input seismic hazard to the reactor building.

For this request, the Submitter invokes an analogy between (1)the Maximum Considered Earthquake, MCEr, ground motion level considered in the design of commercial buildings and the Design Earthquake (DE)ground motion level equal to (2/3)the MCEr, and (2)the seismic design basis ground motion (SSE or CSDRS)for seismic Category I structures and the Review Level Earthquake RLE equal to 1.67 times the SSE.

The Panel evaluation did not find an analogy between (1)the MCEr and the DE used with commercial buildings and (2)the SSE (or CSDRS)and the RLE used with seismic Category I structures. For commercial buildings including important and critical ones, the MCEr is the design basis ground motion for the seismic design philosophy of collapse prevention of commercial buildings while the DE is a ground motion level used in the prescriptive design process to achieve the collapse prevention goal without a required explicit analysis at the MCEr level. For nuclear power plants, the SSE (or CSDRS)is the design basis, and the RLE is a review level earthquake to evaluate plant level vulnerabilities and derive seismic insights for ground motions beyond the design basis. In the case of seismic Category I buildings, which includes the NuScale reactor building, the purpose of the Seismic Margin Analysis (SMA) is to ensure a quality design with adequate margin for each critical component as shown in Figure 2 and, therefore, adequate seismic margin for the building without cliff edge effects at the SSE or CSDRS levels.

The Panel evaluation did not conclude that the MCEr ground motion level represents factor of safety of 1.5 or higher factor for safety against collapse for commercial buildings. Instead, the MCEr is the ground motion level for the main design objective which is collapse prevention. The codes and standards for commercial buildings use prescriptive methods in conjunction with structural analysis at (2/3)of the MCEr level to ensure the target probabilities of collapse without explicit analyses at the MCEr level.

The codes and standards for commercial buildings <u>permit</u> but do not require the use of analysis like those in the 'engineering method' in conjunction with Performance-Based Seismic Design (PBSD) methods. PBSD methods provide flexibility for building owners to achieve more effective designs using methods other than the prescriptive methods in the codes and standard. PBSD methods use 'engineering method' analyses at the MCEr ground motion level to meet collapse performance targets complemented with prescriptive approaches that ensure minimum strength and stiffness that may not be provided by the 'engineering method' analysis used.

As in commercial buildings, including important and critical ones, the design at the SSE (or CSDRS)level already ensures satisfactory component and structural performance for seismic demands greater than the design basis level (see Figure 2) The design that meets the NRC guidance uses codes and standards like those used for commercial buildings with additional requirements. In addition, this guidance does not permit the reduction in seismic forces and inelastic deformations accepted in commercial buildings at design basis loads. It is therefore reasonable to conclude that the design provides margin beyond the design basis SSE or CSDRS.

Nevertheless, an applicant still performs a SMA approach for building structures endorsed in ISG-DC-COL-20, uses to verify the quality of design achieved for the design at the SSE or CSDRS ground motion levels in order to provide adequate margin achieved by adequate overstrength and ductility detailing in conjunction with the mathematical models used for the design basis analysis, which ensure the response of the structure as a unit with and adequate load path for the seismic loads.

The NuScale applicant used the staff endorsed approach and guidance for a SMA that meets the objective of the Commission seismic policy goals in SRM to SECY 92-087. Therefore, the applicant met the regulations and demonstration of the Commission policy goals for seismic safety.

Based on the above, the Panel concludes that the design of the NuScale reactor building is complete for the design certification purposes by the applicant's use of the staff approved guidance to meet the applicable general design criteria in the regulations as well as for implementation of the Commission policy goal for seismic safety of Light Water Reactors in SRM to SECY 93-087.

4 Conclusions

Current regulations for seismic design of seismic Category I building structures in nuclear power plants require that these buildings meet general design criteria in Appendix A of 10CFR50 for the specific seismic design basis ground motion level, which is the Safe Shutdown Earthquake (SSE)for site-specific conditions and the Certified Seismic Design Response Spectrum (CSDRS)for the design certification. The design of the NuScale reactor building met the acceptance criteria in the Standard Review Plan (SRP) Section 3.8.4 for seismic Category I structures other than pressure vessels and containments. Therefore, the seismic design of the NuScale reactor building meets the design requirements in the applicable regulations and is complete for the design certification scope.

Regarding the Submitter's concern that some structural components of the NuScale reactor building are over-stressed under the design basis seismic loading, the panel concluded that all overstress involved stresses in a few finite elements used in the modeling of structural components (mostly interior walls) modeled using several finite elements. Those structural components were either redesigned by adding additional reinforcement or by averaging finite element stresses along component cross-sections in agreement with the procedures in the NuScale FSAR. The results following this averaging or redesign show that there are no overstressed structural components, therefore the Panel did not find any safety issue related to structural component overstress for the NuScale reactor building.

The Seismic Margin Analysis (SMA)for the NuScale certified design used PRA insights to support a margin-type assessment of seismic events. It used a PRA-based SMA that considered sequence-level High Confidence, Low Probability of Failures (HCLPFs)and fragilities for sequences leading to core damage and containment failures (releases)up to approximately 1.67 times the ground motion level for the design basis ground motion (CSDRS at the design certification stage) The applicant for the NuScale design followed the guidance in interim staff guidance ISG-DC-COL-20 for the SMA.

The DPO panel concluded that the guidance in ISG-DC-COL-20 provides an adequate method for the SMA, including the seismic margin of the NuScale reactor building, in order to meet the purpose of the Commission direction in SRM to SECY 92-087. This guidance and its proper implementation by the applicant provide reasonable assurance of the quality of the structural design for the reactor building at the design basis level needed to meet the Commission policy for seismic safety goals in SRM to SECY 93-087.

On the basis of its evaluation presented in the entire Panel report, the Panel concludes that the design of the NuScale reactor building is complete for the design certification scope and that the DPO Submitter's request to use the structural engineering analysis/design method, as understood by the Submitter in the DPO submittal, to analyze the structure's response at the RLE level of 1.67 times the CSDRS as input is not necessary.

5 Recommendations

The DPO panel did not identify recommendations specific to the design of the NuScale reactor building which the Panel concluded is complete for the design certification scope. The Panel has the following generic recommendations for consideration by the NRC management that may facilitate similar future reviews of the seismic design of safety-related building structures and related staff concerns:

1. Development and implementation of knowledge management activities to:
    a. Clarify to the staff the intent and purpose of the Commission policy goals for seismic safety in SRM to SECY 93-087.
    b. Conduct staff workshops on Seismic Margin Analysis with PRA insights and associated seismic fragility analysis.
    c. Clarify to the staff the differences and similarities in seismic design criteria for safety-related nuclear power plant structures and commercial buildings including important and critical ones.
2. Fostering of staff engagement with codes and standards and the staff representatives to those codes and standards for cognizance of developments on generic and standardized provisions on the use of finite element analysis results in conjunction with methods in codes and standards to assess the capacity of structural components.

3. Continue staff encouragement to raise safety issues, including the formulation of Requests for Additional Information, using thorough technical considerations that may include considerations from engineering practice outside the scope of the NRC jurisdiction.

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Document 4: DPO Decision

UNITED STATES
NUCLEAR REGULATORY COMMISSION
WASHINGTON, D.C. 20555-0001

May 19, 2021

MEMORANDUM TO: John S. Ma, Senior Civil Engineer
Structural, Civil, Geotech Engineering Branch
Division of Engineering and External Hazards
Office of Nuclear Reactor Regulation

FROM: Andrea D. Veil, Director
Office of Nuclear Reactor Regulation

Andrea Veil Signed by Veil, Andrea on 05/19/21

SUBJECT: DIFFERING PROFESSIONAL OPINION CONCERNING THE NUSCALE SAFETY EVALUATION REPORT CHAPTER 3.8.4, "SEISMIC CATEGORY 1 STRUCTURES" (DPO-2020-004)

The purpose of the memorandum is to respond to your differing professional opinion (DPO) submitted on September 17, 2020, in accordance with Management Directive 10.159, "The Nuclear Regulatory Commission Differing Professional Opinions Program" (Agencywide Documents Access and Management System (ADAMS) Accession No. ML15132A664). DPO-2020-004, (ADAMS Accession No. ML20280A501), documents your concerns with the staff's NuScale safety evaluation report (SER) Chapter 3.8.4, "Seismic Category 1 Structures" (ADAMS Accession No. ML20205L405).

I commend you for your commitment and dedication to the Nuclear Regulatory Commission's mission. Your willingness to raise concerns with your colleagues and managers and ensure that your concerns are heard and understood is admirable and vital to ensuring a healthy safety culture within the Agency. I also want to thank you for the time you dedicated to having additional discussions with me and my staff to ensure that I fully understood your perspectives.

My response to your DPO, including associated follow-up actions, is described in the Enclosure.

Enclosure:
As stated

CONTACT: Caroline Tilton, NRR
(301) 415-0990

DIFFERING PROFESSIONAL OPINION CONCERNING THE NUSCALE SAFETY EVALUATION REPORT CHAPTER 3.8.4, SEISMIC CATEGORY 1 STRUCTURES (DPO-2020-004) DATE May 19, 2021

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DIRECTOR'S DECISION FOR DIFFERING PROFESSIONAL OPINION

NUSCALE SAFETY EVALUATION REPORT CHAPTER 3.8.4.

"SEISMIC CATEGORY 1 STRUCTURES" (DPO-2020-004)

Background

In differing professional opinion (DPO) 2020-004, you expressed concerns with the overall structural design of the NuScale reactor building. Specifically, you indicated the building may not have been properly designed, the capability of the building to sustain an earthquake beyond the design bases earthquake (certified seismic design response spectrum or CSDRS) is unknown, and that an evaluation of the seismic margin of the building was not completed, and is therefore not known.

The DPO Ad Hoc Review Panel (the Panel) issued their report to me on April 19, 2021, after reviewing the applicable documents, conducting internal interviews with relevant individuals, and completing their deliberations. On April 20, 2021, I discussed the Panel report with the DPO Panel Chair and a member of the Panel. On April 21, 2021, you and I discussed your insights and comments based on the Panel report findings.

To inform my decision regarding your DPO, I reviewed your DPO submittal, the Panel's report, and considered our discussion on April 21, 2021. During our discussion, you provided a document entitled "Submitter Supplemental Information for DPO-2020-004" (ADAMS Accession No. ML21132A136), where you explained the differences between your DPO and the Panel's report. To better understand your concerns, I assigned the Deputy Office Director for Engineering and a Technical Assistant from my office to assist in the evaluation and documentation of my decision. They gathered information through discussions with you, the DPO panel, and other knowledgeable staff who reviewed documents pertinent to your DPO submittal. The information collected provided independent insights and perspectives for my consideration.

Summary of Issues:

The Panel grouped your DPO concerns into two major areas:

1. Safety concerns of the design of the NuScale reactor building:

   a. The design of the NuScale reactor building is incomplete because it is unknown whether the building can sustain an earthquake beyond the certified seismic design response spectra (CSDRS), including the review level earthquake (RLE). The basis for this conclusion is that the applicant did not demonstrate that the reactor building would not have collapsed (partially or wholly) when it is subjected to an earthquake greater than the certified seismic design response spectra (CSDRS), including the review-level earthquake (RLE = 1.67 CSDRS).

   b. The actual seismic margin of the reactor building is also unknown as opposed to structural engineering practice (by engineers, in codes and standards, by local building officials and building departments) for important conventional buildings or with high consequence of death or injury or financial loss if the buildings collapse, which requires a minimum seismic margin of 1.5.

Enclosure

c. There are indications that the building might not have been properly designed for the CSDRS level, which the DPO attachment refers to in the statement "several structural elements have already been overstressed (or the capacity of the element is less than the stress or force demand) when the building is subjected to the CSDRS."

2. Differing view on seismic margin determination for structures:

   a. You contend that the correct methods to determine the structure seismic margin (SM) are the structural engineering/analysis design method and laboratory test modeling:

      i. Use of the structural engineering analysis/design method to analyze the response of the structure includes analysis of two levels of seismic hazards inputs to the structure: one is the design seismic hazard (occurs frequently) and the other with a minimum of 1.5 or more times the design seismic hazard (occurs infrequently). When the structure does not collapse (partially or wholly) during the minimum of 1.5 or more times the design seismic hazard input to the structure, it demonstrates that the structure has a seismic margin of 1.5 or more. For the reactor building, the Nuclear Regulatory Commission (NRC) policy requires an RLE input (1.67 times of the design basis seismic hazard to demonstrate no building collapse (partial or whole).

      ii. Laboratory model testing determines the maximum seismic loading input under which the structure will collapse, then the ratio of seismic intensity (peak ground motion acceleration) of the maximum seismic loading to the design basis seismic loading provides the appropriate seismic margin.

   b. Regarding the probabilistic risk analysis (PRA) method, your concern is that the PRA method is based on the theory of probability and it can only assess the "consequence" of building collapse, such as the core melt probability resulting from the reactor building collapse, but not the design of the building for "no collapse" or the seismic margin of the building. You also wrote "[t]he PRA staff stated in a meeting that the PRA staff is not capable of assessing whether the building will collapse or not because that is not their expertise and is only capable of assessing the "consequence" of the building collapse, such as the core melt probability resulted from the building."

   c. You request the applicant complete the design of the NuScale reactor building using the structural engineering analysis/design method to analyze the structure's response at the RLE level of 1.67 times the CSDRS as input seismic hazard to the reactor building.

<u>My Assessment of the Panel Conclusions:</u>

The Panel concluded that the seismic design of the NuScale reactor building meets the design requirements in the applicable regulations, the acceptance criteria in the Standard Review Plan, Section 3.8.4, "Other Seismic Category I Structures," and is complete for the design certification scope. The Panel noted that re-analyzing the structure's response at the RLE level using the structural engineering analysis/design method, as described in your DPO submittal, is not necessary to ensure safety.

The Panel also concluded that no safety issue exists relative to structural component overstress for the NuScale reactor building since all overstress involved stresses in a few finite elements used in the modeling of structural components, and these were either redesigned (by adding additional reinforcement) or re-evaluated (by averaging finite element stresses along component cross-sections).

In addition, the Panel concluded that the guidance in ISG-DC-COL-20, "Interim Staff Guidance on Implementation of a Probabilistic Risk Assessment-Based Seismic Margin Analysis for New Reactors," and its proper implementation by the applicant, lays out an adequate method for the seismic margin analysis (SMA), provides reasonable assurance of the quality of the structural design for the reactor building, and meets the Commission policy for seismic safety goals in the Staff Requirements Memorandum (SRM) to SECY 93-087, "Policy, Technical and Licensing Issues Pertaining to Evolutionary and Advanced Light-Water Reactors (ALWR) Designs." The SRM to SECY 93-087 describes a PRA-based SMA as considering sequence-level High Confidence, Low Probability of Failures (HCLPFs) and fragilities for all sequences leading to core damage, including reactor building collapse, up to approximately one and two thirds (1.67) the ground motion acceleration of the design basis safe shutdown earthquake (CSDRS at the design certification stage). The panel concluded that the applicant for the NuScale design followed the interim staff guidance.

I agree with the Panel's conclusions. I find that the staff's review of the seismic design of the reactor building is adequate and ensures safety. The basis for my decision is described below.

With regard to your concern on whether the NuScale reactor building would collapse at the CSDRS earthquake level, Appendix A of Title 10 of the *Code of Federal Regulations* Part 50 General Design Criteria 2, "Design bases for protection against natural phenomena," requires the applicant to design the reactor building to withstand the effects of the CSDRS without losing the capability to perform its safety function. This requirement bounds the "no collapse" evaluation and it is performed using a structural engineering deterministic analysis method which is similar to the engineering method that you proposed. This engineering method incorporates data collected from laboratory testing which informs codes and standards in the structural engineering field. There is inherent margin built into this design approach. By demonstrating that the reactor building can withstand the effects of the CSDRS without losing the capability to perform its safety function, the applicant also demonstrated that the building will not collapse. The NRC staff independently reviewed the applicant's CSDRS analysis to ensure that the design provides reasonable assurance of adequate protection.

Regarding your concern that the NuScale reactor building was not adequately designed since there were overstressed elements of the building, my review did confirm that there were locations in the reactor building finite element model showing overstressed finite elements. However, these overstressed elements were limited to specific locations within the discrete finite element model of a specific component and did not carry out to the actual component as a whole. To address the overstresses, the applicant averaged the forces within the same component and showed that the component retained its structural capacity for the same intensity input and would not result in a building collapse.

With regard to your concern whether the NuScale reactor building would collapse at the RLE level and that the seismic margin is unknown, the Commission policy seismic safety goals, as documented in the SRM to SECY 93-087, does not require that the staff verify through its independent review, with 100 percent certainty, that the reactor building would not collapse when subjected to the RLE. The SMA approach, delineated by the policy and stated above, provides reasonable assurance of adequate protection by validating the adequacy of the design with a high degree of confidence. The NRC staff's responsibility is not to recreate the applicant's design, but to verify that it is acceptable.

In support of your concern that the seismic margin of the building was not correctly performed; you make a direct comparison between the minimum seismic margin of 1.5 used in commercial building seismic design and the SMA hazard input level of 1.67 CSDRS. This comparison is not appropriate since these two values are used to assess different things..[1] In addition, you maintain that laboratory model testing or a deterministic calculation to assess the explicit seismic margin at the RLE intensity should be performed. Such activities have never been required in the nuclear industry nor are they necessary to ensure safety.

It's important to note that nuclear reactor building structural designs follow stricter requirements than those of commercial buildings because they serve different purposes. For example, nuclear reactor building structural designs require elastic deformation only with allowance of localized and negligible inelastic deformation (damage) when subjected to the CSDRS. In contrast, structural design for commercial buildings may allow more inelastic deformations (damage/failure) and at times even partial collapse when subjected to a design basis earthquake. In addition, the return periods (which serve as an indication of ground motion intensity) for the design basis earthquake in nuclear power plant structures are at least two times greater than those considered in commercial building design.

It is also important to note that once an applicant has entered the combined operating licensing stage and a location for the reactor building is selected, the applicant must consider site-specific seismic information, and must complete a seismic-PRA analysis. These additional requirements ensure that the building design is sufficient to meet the site-specific ground motion.

To address your concern that the PRA-based SMA method is based on the theory of probability and it can only assess the "consequence" of building collapse, I want to summarize the methodology used by the NRC staff. The PRA-based SMA method can be described in three main steps: (1) analyzing the design specific system and accident sequences; (2) evaluating the seismic fragility of structures, systems and components; and (3) determining sequence and plant level HCLPFs. PRA analysists perform steps (1) and (3). The fragility analysis evaluates the probability of failure of SSCs conditional on the intensity of the ground motion and as such, the analysis goes beyond assessing the consequences of building collapse. You also expressed concern that PRA staff are not capable of assessing whether the building will collapse. The SMA process defined in ISG-DC-COL-20 ensures that the review incorporates both PRA analysts and structural engineers. Structural engineers with experience in fragility analysis usually perform step (2). The SMA methodology has been used previously by the NRC

[1] The 1.5 factor used in commercial buildings is not a seismic margin. It is a factor used in the design process to reduce the maximum considered seismic design level to account for nonlinear response as well as to define a ground motion level used to provide minimum structural strength and stiffness in addition to meeting the principal design criteria of collapse prevention. The 1.67 times the CSDRS defines the range of seismic ground motion levels above the design basis for which plant vulnerabilities will be assessed using PRA insights and a PRA-based SMA. It is an input to the SMA and meant to estimate the plant level seismic margin in a PRA-based approach. The SMA is not a design tool but rather a tool used to evaluate the adequacy of the design and ensure there is sufficient margin.

staff to assess the RLE including the AP1000 and the EBWR reactor buildings.

I appreciate the Panel's thoughtful assessment of the concerns raised in the DPO as well as your perspectives. The DPO panel did not identify recommendations specific to the design of the NuScale reactor building which the Panel concluded is complete and acceptable for the design certification scope. The Panel has the following generic recommendations for consideration by NRC management. My responses to the Panel's recommendations are provided below.

<u>Response to Recommendation 1</u>

(Panel Recommendation 1) Development and implementation of knowledge management activities to:

a. *Clarify to the staff the intent and purpose of the Commission policy goals for seismic safety in SRM to SECY 93-087.*

b. *Conduct staff workshops on Seismic Margin Analysis with PRA insights and associated seismic fragility analysis.*

c. *Clarify to the staff the differences and similarities in seismic design criteria for safety-related nuclear power plant structures and commercial buildings including important and critical ones.*

I agree with the Panel's Recommendation 1, in that NRR is a learning organization and knowledge management activities ensure we continue to provide high-quality reviews of future applicant's seismic designs and continue to foster an in-depth understanding of the NRC's regulations, guidance, and policies. Sharing and capturing the information we used in assessing your concerns would be of value to our organization. However, workshops may not be the most long-lasting and efficient way to share this information. I am tasking the Structural, Civil, Geotech Engineering Branch in the Division of Engineering and External Hazards, with ensuring that this information is captured using an existing platform and in a way that is durable and easily accessible such as a Nuclepedia page or a recorded Executive Team Significant Topic discussion. The information shared should reflect the lessons learned during this evaluation and should include clear guidance on: (1) how to apply the Commission policy goals for seismic safety to a review; (2) how PRA-based SMA verifies the adequacy of a design; and, (3) the differences and similarities between the seismic design criteria in the nuclear field and commercial buildings.

<u>Response to Recommendation 2</u>

(Panel Recommendation 2) Fostering of staff engagement with codes and standards and the staff representatives to those codes and standards for cognizance of developments on generic and standardized provisions on the use of finite element analysis results in conjunction with methods in codes and standards to assess the capacity of structural components.

I agree with the Panel's Recommendation 2. Therefore, I am tasking the Structural, Civil, Geotech Engineering Branch in the Division of Engineering and External Hazards, with establishing a mechanism, using a process already in place (e.g., Nuclepedia, a MS Teams channel or a community of practice), for keeping relevant staff up-to-date on these advancements in order to continue to perform seismic reviews in the future.

Response to Recommendation 3

(Panel Recommendation 3) Continue staff encouragement to raise safety issues, including the formulation of Requests for Additional Information, using thorough technical considerations that may include considerations from engineering practice outside the scope of the NRC jurisdiction.

I agree with the Panel's Recommendation 3, in that we need to continue to encourage staff to raise safety issues, even when they may include considerations outside of the NRC's jurisdiction. Request for additional information (RAIs) should have a clear regulatory basis and be focused on the information necessary for the NRC staff to make its safety findings. After evaluating this issue in light of the NRC's broader safety and security mission and holistically considering all information available to me, I found that NRR Office Instruction LIC-115, "Processing Requests for Additional Information," provides a clear opportunity for NRR staff to issue RAIs, when necessary, to support reasonable assurance findings on the safety of a design, in accordance with the NRC rules and regulations and for issues within the NRC's jurisdiction.

Concluding Remarks

I found that your DPO positions were well documented in your submittal. A summary of the DPO will be included in the Weekly Information Report (when the case is closed) to advise employees of the outcome. Thank you for raising your DPO and for your active participation in this process. I commend you for your commitment and dedication to the NRC mission. Your willingness to raise concerns with your colleagues and managers is admirable and is vital to ensuring a healthy safety culture within the NRC.

Document 5: DPO Appeal Submittal

NRC FORM 690
(08-2015)
NRCMD 10.159

U.S. NUCLEAR REGULATORY COMMISSION

DIFFERING PROFESSIONAL OPINION -- APPEAL

DPO Case Number	Date Appeal Received
DPO-2020-004	06/14/2021

Name and Title of Submitter	Organization	Telephone Number (10 numeric digits)
John Ma, Senior Structural Engineer	NRR/DE/ESEB	301-415-2732

Name and Title of Supervisor	Organization	Telephone Number (10 numeric digits)
Colaccino, Joseph, Chief of ESEB	NRR/DE/ESEB	301-415-7102

Basis for filing appeal. Focus should be on perceived flaws in the DPO Decision and why the agency should come to a different conclusion. (Use continuation pages or attach Word document)

See attachment.

SIGNATURE OF SUBMITTER	DATE

SIGNATURE OF CO-SUBMITTER (If any)	DATE

SCAN THE SIGNED AND DATED FORM (INCLUDING CONTINUATION PAGES OR WORD DOCUMENTS) AND EMAIL TO: DPOPM.Resource@nrc.gov

SIGNATURE OF DPO PROGRAM MANAGER	DATE
Ian Gifford	06/17/2021

[X] DPO appeal accepted [ ] DPO appeal returned

Delete Continuation Page

Add Continuation Page

Appeal to EDO

by

John S. Ma, Ph.D. in structural engineering

Senior structural engineer and a charter member of the NRC

Member of American Concrete Institute (ACI) and American Society of Civil Engineers (ASCE)

Recipient of the Raymond C. Reese Structural Research Award Medal from ACI

Licensed and registered professional engineer in civil/structural engineering

June 10, 2021

INTRODUCTION AND CONCLUSION:

I am appealing the rejection of my differing professional opinion by the Director of the Office of Nuclear Regulatory Regulation (NRR) regarding the NRC approved unsafe design of the Nuscale Reactor Building. The Director of the Office of NRR decision on my DPO 2020-004 is concerning because the detrimental effect it will have on the public health, safety, and the environment, and is contrary to the NRC mission statement. I consider it to be my professional and civic duty to raise alarm when I see that (1) the reactor building design is incomplete and inadequate and has no proof that it will not collapse during the design-basis earthquake (SSE or CSDRS) due to two major deficiencies: no design modifications were made when demand forces exceed capacities in several structural elements (Element number 4942 exceeds more than 300%) and no post-yield structural element properties were used to capture the element behaviors after the demand force exceeds the capacity, (2) no seismic margin was designed into the reactor building, and (3) no proof that the building will not collapse at RLE because no structural engineering analysis/design was performed for the RLE.

The unsafe design of the reactor building was caused by the NRR management decision to replace structural engineers by probabilistic risk analysts for the review of the building safety at RLE and seismic margin of the building and to substitute the PRA method for the structural engineering analysis/design method at the RLE. Such a replacement of the right people by the wrong people and a substitution of the right method by a wrong method for the evaluation of the reactor building safety at the RLE and its seismic margin naturally led to wrong results.

When the Deputy Director of the Office of NRR and her technical assistant asked for my view on the DPO panel report, I said that it copied much information from literatures into its report then added its own opinions, but did not address those three fundamental differences between the DPO report and mine as listed in my email, dated April 21,2021, to the Director of the Office of NRR (reference 1). My email stated that these fundamental differences need to be questioned and resolved: (1) the definition or interpretation of the NRC Policy in SECY 93-087 with respect to the seismic margin of the reactor building because I provided it in my DPO report but the DPO panel did not provide its definition or interpretation in its report, (2) I believe that the PRA method should not and cannot be used for the evaluation of the building safety at RLE and its seismic margin, because the method cannot predict building movements and behaviors under earthquakes, but the DPO panel believes it can without presenting evidence of one existing building that had been designed by the PRA method under my request (reference 1), and (3) I believe that the NuScale reactor building design is incomplete and inadequate and unsafe even for the design-basis earthquake (CSDRS), and the DPO panel improperly answered that question (see discussions in Section 3.3).

The Director of the Office of NRR did not provide her own definition or interpretation of seismic margin either. She stated that the NRC Policy in SECY 93-087 does not require that the reactor building "would not collapse" when subjected to the RLE. Her statement collided with the ultimate goal of building design by the structural engineering profession, which is to prevent the "collapse" of buildings (or "collapse prevention" or CP point in the "Stanford Seismic Design Guidelines (for Engineers & Architects)," Figure 2, page 6 in my DPO report. Her statement also contradicted to a senior probabilistic risk analyst, who agreed with my interpretation that the applicant used the PRA method to conclude that the reactor building would not collapse during the RLE (references 2 and 3). Her understanding of the NRC Policy in SECY 93-087 is incorrect because the NRC Policy in SECY 93-087 only established the magnitude of 1.67 as the required seismic margin but does not say that "the reactor building would not collapse when subjected to the RLE" is not required, as she believed and stated. The NRC Policy in SECY 93-087 properly left how to design that seismic margin of 1.67 into a building to the proper profession, and that proper profession is the structural engineering profession for building design and safety, not the PRA profession as she and other NRR managers have believed and directed.

The following facts should be sufficient to demonstrate that the opinions expressed by the DPO panel and the Director of the Office of NRR and other NRR manager are contradictory to physics and the practice of the structural engineering profession and therefore their opinions are incorrect with respect to the safety and seismic margin of the reactor building design:

1. all buildings are designed and evaluated by structural engineers, and none by probabilistic risk analysts,
2. building codes require the use of structural engineering analysis/design method for the design and evaluation of buildings, and does not allow or even mention the PRA method,
3. this is because the structural engineering analysis/design method is based on physics (establishing building movements and behaviors relative to earthquake ground motions) and has been verified to be adequate on shake table tests in laboratories and by seismic sensors and strain gages embedded in real buildings during earthquakes,
4. the PRA method is not based on physics, and it cannot predict building movements and behaviors relative to earthquake ground motions and cannot predict whether a building will collapse or not,
5. neither the DPO panel nor the Director of the Office of NRR and other NRR managers could identify a building that was designed by the PRA method under my challenge (reference 1),
6. the structural engineering profession has clearly defined "seismic margin" and has developed and provided a straightforward process and method to design that seismic margin into a building,
7. that process is to use the seismic margin times the intensity of the design-basis earthquake (SSE or CSDRS) = RLE as an input to the building and by this process the seismic margin is **<u>explicitly</u>** designed into the building when the building can be

demonstrated that it does not collapse, as shown in the building design examples in my DPO report,

8. the method to demonstrate that the building does not collapse is the structural engineering analysis/design method, not the PRA method, as illustrated in the four building design examples in my DPO report, and with more theoretical foundations and discussions of the method in references 4 and 5 of my DPO report,
9. neither the DPO panel nor the Director of the Office of NRR provided their definition or interpretation of “seismic margin” under my request (reference 1). With no definition or interpretation of seismic margin, meaningful discussions on how to achieve the seismic margin would be impossible,
10. as a result of no definition of “seismic margin” and the substitution of the PRA method for the structural engineering analysis/design method and the replacement of the structural engineers by the probabilistic risk analyst, no seismic margin has been **<u>explicitly</u>** designed into the reactor building, because the PRA method and the probabilistic risk analyst could not design the seismic margin into the reactor building,
11. the reactor building design for the deign-basis earthquake is incomplete and inadequate because no “design modification” and no “post-yield structural element properties” were used when the demand force exceeds the capacity of a structural element (the force acting on Element number 4942 exceeds more than three times of its capacity or strength),
12. the NuScale reactor building is no different in shape or in materials or in construction methods from other important buildings, and the seismic margin of 1.67 in the NRC Policy is just a little higher than the minimum seismic margin of 1.5 required by the structural engineering profession for important buildings, such as all buildings (new and existing) in the Stanford University campus, and is lower than other important buildings, such as the Vancouver House building, the Salesforce Tower building, and the AP1000 shield building,
13. while other important buildings are designed by structural engineers and the required or specified seismic margins are designed into buildings and the buildings are analyzed and demonstrated for “no collapse” at the earthquake intensity equal to the seismic margin times the design-basis earthquake using the structural engineering analysis/design method, the NuScale reactor building safety at the RLE and its seismic margin are evaluated by the probabilistic risk analysts, who are not trained in building design, and used the PRA methods, which are not based on physics, and cannot predict building movements and behaviors during earthquakes,
14. as a result of assigning the wrong people (probabilistic risk analysts) and using the wrong method (the PRA method), no seismic margin was designed into the reactor building, and no structural engineering analysis/design was conducted for the building during the RLE and thus no proof that the building will not collapse during the RLE,
15. however, the applicant used the PRA method and concluded that the reactor building would not collapse during the RLE and the NRC staff concurred with that method and conclusion (references 2 and 3). This statement of “no collapse” at RLE is incorrect and false due to the use of wrong method and wrong people and,
16. this false statement has detrimental effect on the public health, safety, and the environment, and is contrary to the NRC mission statement, and must be exposed and corrected.

Since the three fundamental differences between the DPO panel report and mine, as listed in my letter, dated April 21,2021, to the Office Director of NRR (reference 1) have not been properly addressed and resolved by the DPO panel and the Director of the Office of NRR, I will address these fundamental differences below in hope that the EDO will understand and properly resolve them:

1. <u>What is seismic margin?</u>

The concept of a seismic margin is simple. It is the intensity of the earthquake that causes a building to "collapse" (partial or whole) beyond (or greater than) the intensity of the design-basis earthquake (SSE or CSDRS in the NuScale case). Mathematically, the seismic margin is defined by dividing the earthquake intensity that causes a building to collapse by the intensity of its design-basis earthquake. Therefore, the seismic margin must be designed into a building so that it will possess this amount of seismic margin. The design-basis earthquake is known (either required as a minimum by regulatory agencies, such as local building departments (a minimum of 1.5 by the structural engineering profession), or the NRC (1.67), or specified by owners of a building for having a greater seismic margin than the required minimum by regulatory agencies, as a result of consultations with, or recommendation by, design structural engineers (3.0 for the Vancouver House building and the AP1000 shield building, and 1.8 for the Salesforce Tower building.) The use of a greater seismic margin than the minimum required one can afford the building to be reoccupied immediately after a large earthquake without any repair or just a small repair and therefore may continue to collect rents with financial benefits.

The structural engineering profession and community have been using a required minimum seismic margin of 1.5 for important building design based on public safety concerns. The NRC staff had recommended a seismic margin of 2.0 for important buildings in nuclear power plants, but the nuclear industry proposed the minimum required seismic margin of 1.5, required by the structural engineering profession, for important nuclear power plant buildings. The NRC commissioners took the middle of the road and approved the value of 1.67 for the required seismic margin in the year of 1993, as documented in the SRM to SECY 93-087. The NRC Policy in SECY 93-087 states: "The Commission approves the use of 1.67 times the Design Basis SSE for a margin-type assessment of seismic events."

In my DPO report, a reinforced concrete wall had a design-basis earthquake intensity of 0.8g and it collapsed at 1.6g on a shake table testing with actual earthquake ground motions input to the wall. Therefore, that wall possessed a seismic margin of 2.0 (1.6g divided by 0.8g). In my DPO report, the Stanford Seismic Design Guidelines (for Engineers & Architects) required a seismic margin of 1.5 for new building design and for retrofitting existing buildings in its campus. The structural engineer designed a seismic margin of 3.0 into the Vancouver House building in Vancouver, Canada (Figure 3 on page 11 in my DPO report) due to the extremely unusual shape of the building. The Salesforce Tower building in San Francisco, California, United States (Figure 4 on page 12 in my DPO report) was required by the building department to design a seismic margin of 1.8 (20% more than the minimum seismic margin of 1.5) into the building because it houses more than 3000 people and the collapse of the building would have a grave impact on the numbers of people's life. In my DPO report, due to the use of a new type of structural elements (concrete filled the voids between two steel plates) that had never been used in important buildings, the critical structural elements in that building design was laboratory tested for having possessed of a seismic margin of three (3) and the whole building was also demonstrated to have possessed of a seismic margin of three (3) using the structural engineering analysis/design method for the AP1000 shield building of which I was a reviewer.

However, the Director of the Office of NRR states in her decision that “With regard to your concern whether the NuScale reactor building would collapse at the RLE level and that the seismic margin is unknown, the Commission policy seismic safety goals, as documented in the SRM to SECY 93-087, does not require that the staff verify through its independent review, with 100 percent certainty, that the reactor building would not collapse when subjected to the RLE.” The Office Director’s statement of a seismic margin with no need of referencing building “collapse” at a specific earthquake intensity level, such as the RLE, contradicted with that established by the structural engineering profession and community. Furthermore, her statement also contradicted by the statement provided by an NRC senior probabilistic risk analyst that NuScale Chapter 19, PRA statement: "Seismic Category I structures (i.e., the RXB and the CRB) meet the seismic margin requirement of 1.67 * CSDRS for site-specific seismic hazards (e.g., sliding, overturning)," does mean that the reactor building will not collapse at the RLE (references 2 and 3). The NRR Office Director’s statement of no collapse involvement in the definition of a seismic margin is wrong. Seismic margin is a numerical value, such as the 1.67 in the NRC Policy, and two reference points are needed to establish a seismic margin, such as between the SSE (CSDRS) and the other point beyond (or greater than) the SSE where the building collapses. Without the reference point of “collapse” beyond the SSE, a seismic margin cannot be calculated or established. The Director of the Office of NRR did not state what her definition of seismic margin is and how the 1.67 seismic margin in the NRC Policy can be demonstrated without a reference point of building collapse, such as the RLE.

2. <u>How to design seismic margin into, or demonstrate it for, a building?</u>

For a building to possess a seismic margin, the margin must first be designed into the building. The design approach of a required or specified seismic margin into a building is a straightforward process which has been developed and used by the structural engineering profession and community (such as structural engineering analysis/design courses in colleges, professional license examinations for structural engineers, building codes, structural engineering design firms, and local building officials or departments).

To design a required or specified seismic margin into a building is to use the required or specified seismic margin times the intensity of the design-basis earthquake and input that earthquake intensity to, or shake, the building (mathematical model), and to demonstrate that the building will not collapse (partial or whole). If the building collapses partially, such as the roof of the NuScale reactor building collapses and falls into the spent fuel pool, modify the roof design until it will possess that required seismic margin and then it will not collapse. If the whole building collapses, revise the whole building design until it will not collapse. Therefore, the design of a seismic margin into a building is a straightforward process and requires a trial-and-error procedure to get it right.

This trail-and-error procedure uses **the structural engineering analysis/design method.** The method is based on physics to calculate the movements of the building and its components (such as roofs, walls, beams, columns, and slabs) and structural elements that made the components. With the known relative movement values of the structural elements in the components of the building, strains or stresses (or forces) in the structural elements can be calculated. The adequacy of the method has been verified by laboratory testing, such as the wall tested on a shake table with the actual earthquake records as input in my DPO report. The calculated magnitudes and phases of the wall movements by **the structural engineering analysis/design method** match well with that of test values for the entire period of the earthquake (Figure 1 on page 4 in my DPO report). The adequacy of the method has also been verified by records from the embedded seismic sensors and strain gages in real buildings during earthquakes. Regardless of the different magnitudes of seismic margins of 1.5 (buildings in the Stanford University campus, or 1.8 (the Salesforce Tower building), or 2.0 (the seismic tested concrete wall), or 3.0 (the Vancouver House building and the AP1000 shield building), **the structural engineering analysis/design method** was used exclusively by the structural engineers to **explicitly** design the seismic margin into the buildings.

However, the Director of the Office of NRR believed that the PRA method was acceptable and did not believe that **the structural engineering analysis/design method** is required for achieving or demonstrating that the reactor building possesses the required seismic margin of 1.67 at RLE. She stated" The SMA approach, delineated by the policy and stated above, provides reasonable assurance of adequate protection by validating the adequacy of the design with a high degree of confidence. The NRC staff's responsibility is not to recreate the applicant's design, but to verify that it is acceptable." What is the criterion of "that it is acceptable" and how to verify it? She neither provided her definition of seismic margin nor elaborated the method to achieve that 1.67 seismic margin.

The PRA method is based on the theory of probability, not physics, and therefore it may be able to estimate the "consequence" of an early and large release of radiation into the environment resulting from the building collapse (partial or whole), during earthquakes, but it cannot predict or demonstrate whether the building possess a required seismic margin of 1.67 and will not collapse at the RLE. The fact that all buildings are designed by structural engineers, using **the structural engineering analysis/design method,** and stamped by a structural engineer as "Engineer of Record" with a valid license in structural engineering, but none by probabilistic analysts using the PRA method is a testimony that the PRA method has not been used for the design of buildings, and the PRA staff are not professional engineers in structural engineering and they are not trained and licensed to perform building safety evaluation. Therefore, the EDO should seriously question (1) the validity and suitability of the Office of NRR's acceptance of the substitution of the PRA method for **the structural engineering analysis/design method** and (2) the unusual and strange decision to hand the structural engineers' responsibility for designing and demonstrating the safety at the RLE and seismic margin of the reactor building to the probabilistic risk analysts**.**

Almost all NRR managers, whom I have interacted with from the RAI stage during the certification review thru the non-concurrence stage and the DPO stage, had told me that they interpreted that the words "margin-type" in the NRC Policy, as stated in SECY 93-087, were associated with, and required, the risk type of analysis (or the PRA) method. When I challenged them to go to OGC to argue and clarify the meaning and substance of the NRC Policy, as stated in SECY 93-087, they refused and just issued their decision in accordance with their own interpretation and judgment. When I mentioned to the NRR managers that buildings are usually analyzed and designed in meeting building codes requirements and no PRA method was allowed or even mentioned in building codes should be another testimony that the PRA method is not a right method or tool for building design or evaluation, they just ignored it.

The NRR managers abandoned or prohibited the use of **the structural engineering analysis/design method** and substituted it by the PRA method for the review of the building safety at the RLE and the seismic margin of the reactor building. T**he structural engineering analysis/design method** produces the real building movements and behaviors during earthquakes while the PRA method cannot and did not. Structural engineers are trained to design and evaluate buildings and its safety and seismic margin while the PRA staff are not trained to design or evaluate buildings and its seismic margin. Using the wrong method and wrong people to design or evaluate buildings and its safety and its seismic margin will naturally end up with wrong results. This mistake made by the NRR managers results in no design of seismic margin into the NuScale reactor building and no proof that it will not collapse during the RLE. A major indication that the building is likely to collapse prior to or during the RLE will be presented in Section 3.3.

The "Civil Engineering Source" reported on June 2, 2021 that City of Los Angeles constructed the St. Francis Dam between 1924-1926, which failed catastrophically on the night of March 12-13, 1928 and caused the deaths of at least 432 people. The Chief engineer and General manager said "Don't blame anybody else, you can just fasten it on me. If there is an error of human judgement, I was the human." The EDO needs to investigate whether the NRR managers had made the apparent wrong human judgment by substituting the PRA method for **the structural engineering analysis/design method** and by replacing the structural engineers by the PRA staff for performing the review of the NuScale reactor building safety at the RLE and its seismic margin.

3. What are the design requirements unfulfilled for the reactor building when it is subjected to the design-basis earthquake (CSDRS)?

3.1 Design modification:

As stated previously, structural engineering design of a building is a trial-and-error procedure. When a structural element is overstressed (force acting on the element exceeds its capacity or strength), design changes are usually made to either reduce the force or increase the capacity or both for that structural element. The design procedure for the Salesforce Tower building is excerpted here as a demonstration of how the design changes were made "Where predicted demand levels exceeded Acceptance Criteria, design modifications were implemented. In particular, core wall thicknesses were tuned to reduce, and control shear demands within acceptable limits at the tower's base and the location of a core setback at Level 50. Ultimately, it was demonstrated that all Acceptance Criteria had been achieved." (see page 12 in my DPO report). However, the Nuscale reactor building design did not do that type of modification when structural elements were overstressed.

3.2 Use the right structural element:

When a structural element is overstressed (force acting on the element exceeds its capacity), it yields if the element is ductile or being crushed or sheared-off if the element is brittle or less ductile. The Vancouver House building design states "Models of the structure with post-yield structural element properties were created" (see page 11 in my DPO report). Only the use of post-yield structural element properties can predict the structural element behavior adequately after the demand force exceeds the capacity of the element. However, the NuScale reactor building design did not create and use the post-yield structural element properties and thus it could not predict the actual condition or behavior of the overstressed elements.

3.3 Overstressed conditions in NuScale structural elements were improperly resolved:

Several structural elements in the NuScale reactor building were overstressed when the building was only subjected to the design-basis (CSDRS) earthquake. For an example, the in-plane shear force (the demand) acting on Element number 4942 is 3791 kips (1 kip = 1000 pounds) but the structural element only has a shear capacity (or strength) of 1184 kips. The force (the demand) acting on the element is more than three times greater than its capacity. No design modification was done, and no post-yield structural element properties were created and used to capture the condition or behavior of these overstressed structural elements when the reactor building is only subjected to the design-basis (CSDRS) earthquake. The applicant arbitrarily brought down the high shear stress by averaging the shear stress of ten structural elements (see page15 in my DPO report). The DPO panel report stated that “During the safety review of the NuScale application, the NRC staff reviewed the structural element exceedances and the averaging method and did not identify any issues,” as the basis to accept the design being adequate. The fact is that I had drafted 18 questions for the audit meeting and 10 RAIs both with respect to the reactor building for the design-basis (CSDRS) earthquake, but all of them were rejected by the NRR management and my questions for the audit and RAIs were not sent to the applicant (references 4 and 5). These references had also been sent to the DPO panel on March 3, 2021 and therefore, the DPO panel’s statement “staff did not identify any issues” is not true. Even if that were true, the panel’s justification is technically flawed because the lack of the staff’s raising issues cannot and should not be used as a justification for the adequacy of the building design, and it may only signify the incompetence of the staff.

On page 16 in My DPO report, it stated that the ACI president of the American Concrete Institute issued a memo, dated January 2020, warning that the probable cause of the March 15, 2018 collapse of the pedestrian bridge over a roadway at Florida International University in Miami, FL., was design error by underestimating the demand that drives the actual capacity/demand (C/D) ratios of critical structural elements toward 1.0. That collapse resulted in six (6) deaths and ten (10) injuries. Several structural elements in the NuScale reactor building, the demands were already greater than their capacity during the design-basis (CSDRS) earthquake. Therefore, it is unknown whether the reactor building will collapse or not during the design-basis (CSDRS) earthquake because design modification and the post-yield structural element properties were not used in the seismic analysis/design. Since the capacity of structural elements remains unchanged due to “no design modification” was conducted for the building design, the demand (force acting on the element) will certainly increase when the earthquake intensity is increased beyond (or greater than) the CSDRS towards the RLE. Therefore, the capacity/demand will be significantly less than 1.0 and this is a major indication that the building is likely to collapse prior to or during the RLE since no seismic margin was designed into the building and no structural engineering analysis/design was performed for the building for the RLE as a result of the NRR management’s decision.

RECOMMENDATION:

Buildings are designed and evaluated by structural engineers in compliance with building codes requirements and stamped as “Engineer of Record” by structural engineers with a valid license and reviewed by structural engineers at the local building department. Building codes require the use of **the structural engineering analysis/design method** for the design and evaluation of building safety, and they do not allow or even mention the PRA method. Therefore, no building was designed by the PRA method. Neither the DPO panel nor the Director of the Office of NRR could identify one building under my request (reference 1). The reason is simple because the PRA method is not based on physics and cannot predict building movements and behaviors during earthquakes. The PRA method may be able to assess the “consequence” of building collapse (partial or whole). However, use it to predict whether a building will collapse or not is obviously inappropriate and wrong. These reasons alone should cause ordinary people to wonder why the NRR management would replace structural engineers by the probabilistic risk analysts and substitute **the structural engineering analysis/design method** by the PRA method for evaluating the adequacy of the reactor building at the RLE and its seismic margin.

The fact that some structural elements were already overstressed (force acting on element number 4942 exceeds its capacity or strength by more than three times) when the reactor building was only subjected to the design-basis earthquake (CSDRS) is a major indication that the building may collapse during the CSDRS and is likely to collapse prior to or during the RLE. However, the applicant used its PRA method to conclude that the building will not collapse during the RLE and the NRC probabilistic risk analyst concurred with that PRA method and conclusion (references 2 and 3). Since the PRA method cannot predict whether a building will collapse or not as described above, the NRC is aiding the applicant to present a false statement and false confidence of the reactor building design to the public.

The definition of seismic margin for buildings is defined by the structural engineering profession, as stated in my DPO report, and the process and the method used to design that margin into a building is described in the "Stanford Seismic Design Guidelines (for Engineers & Architects)," in my DPO report. The method used by the structural engineering profession to design that seismic margin into a building is **the structural engineering analysis/design method**. This method was shown in my DPO report to match its predicted wall movements and collapse loading and seismic margin well to that of the shake table testing data with actual earthquake input to the wall. In my DPO report, three real building designs (the Vancouver House building, the Salesforce Tower building, and the AP1000 shield building) demonstrated the process and method used to <u>**explicitly**</u> design their seismic margins into their buildings. This is a straightforward approach used by the structural engineering profession and community (practicing structural design engineers and local building officials or departments).

However, neither the DPO panel nor the Director of the Office of NRR provided their definition for "seismic margin" even after my request (reference 1). Due to the replacement of structural engineers by the probabilistic risk analyst and the substitution of the PRA method for **the structural engineering analysis/design method** by the NRR managers**,** no seismic margin was designed into the reactor building and no proof that the building will not collapse at the RLE because no structural analysis/design for the building during the RLE.

The approach used by the structural engineering profession will design the seismic margin of 1.67 required by the NRC Policy in SECY 93-087 into the reactor building and demonstrate that the building will not collapse during the RLE by **the structural engineering analysis/design method**. On the other hand, the approach used by the NRR managers resulted in no seismic margin designed into the reactor building and no proof that the building will not collapse during the RLE because the PRA method cannot predict building movements and behaviors during earthquakes. However, the applicant used the PRA results to conclude that the reactor building will not collapse during the RLE, and this is an obviously incorrect and false statement. Even worse is that the NRC concurred with that false conclusion.

If the EDO is still not convinced that no seismic margin has been designed into the reactor building and no proof that the building will not collapse during the RLE, the EDO can get answers easily and quickly and correctly to ensure the safety of the reactor building with the required seismic margin as specified in the NRC Policy in SECY 93-087 by asking:

1. any of the structural engineering firm that have designed important buildings (two in my DPO report and several more in my non-concurrence submittal) to shake the existing NuScale reactor building design by the RLE and see if it will collapse or not, and
2. any building departments that have reviewed important building designs, such as Los Angles, San Francisco, and Seattle, (1) whether they accept the PRA method for building design/evaluation or not, and (2) how they define seismic margin for a building and how that margin should be demonstrated to them in order to get a building permit.

References

1. John Ma email to NRR Office Director, Andrea Veil, 4/21/2021, 8:17 AM, “Fundamental Differences and Questions Need to be Answered and Resolved between the DPO panel report and mine, DPO-2020-004, John Ma, April 20, 2021”
2. John Ma email to Hanh Pham, 8/21/2020 2:42 PM, “Is my understanding correct that the PRA results in NuScale Chapter 19, PRA, indicate that the reactor building will not collapse during the 1.67 times the design-basis earthquake?”
3. Hanh Pham email to John Ma, 4/21/2020 3:22 PM, “Yes, your understanding is correct.”
4. John Ma email to Jose Pires, Vladimir Graizer, Weijun Wang, 3/3/2021 8:37 AM, “My 18 questions for the audit or 10 RAIs for NuScale reactor building design with respect to the design-basis earthquake were disapproved by the NRR management and were not sent to the applicant”
5. John Ma to SEB Branch Chief, Sujit Samaddar, 3/20/2019, 11:02 AM, “SEB cannot state that NuScale reactor building is properly designed because it has not been analyzed for RLE and that my 18 questions for audit or 10 RAIs with respect to the design-basis earthquake were blocked and not sent to the applicant by the NRR management and thus safety questions were not resolved.”

Document 6: Statement of Views

UNITED STATES
NUCLEAR REGULATORY COMMISSION
WASHINGTON, D.C. 20555-0001

June 29, 2021

MEMORANDUM TO: Margaret M. Doane
Executive Director for Operations

FROM: Andrea D. Veil, Director
Office of Nuclear Reactor Regulation

Signed by Veil, Andrea
on 06/29/21

SUBJECT: STATEMENT OF VIEWS REGARDING APPEAL OF DIFFERING PROFESSIONAL OPINION CONCERNING DPO-2020-004

The purpose of this memorandum is to provide my statement of views on the appeal of differing professional opinion (DPO)-2020-004, concerning the U.S. Nuclear Regulatory Commission (NRC) staff's NuScale Safety Evaluation Report Chapter 3.8.4, "Seismic Category 1 Structures."

On September 17, 2020, a Senior Structural Engineer from the Office of Nuclear Reactor Regulation (NRR) submitted a DPO regarding the NRC staff's NuScale Safety Evaluation Report Chapter 3.8.4, "Seismic Category 1 Structures" (Agencywide Documents Access and Management System (ADAMS) Accession No. ML20205L405). On October 6, 2020, a DPO Ad Hoc Review Panel was established and tasked to meet with the submitter, review the DPO submittal, and issue a DPO panel report, including conclusions and recommendations, regarding the disposition of the issues presented by the submitter in the DPO. On April 19, 2021, after reviewing the applicable documents, performing internal interviews of relevant individuals, and completing their deliberations, the Panel issued their report to me, the NRR Office Director (ADAMS Accession No. ML21109A360). On May 21, 2021, I issued the Director's Decision memorandum to the DPO submitter documenting my assessment and decision regarding the DPO (ADAMS Accession No. ML21137A357). On June 14, 2021, the DPO submitter sent an appeal to you, the Executive Director for Operations, and expressed views on the Director's Decision memorandum.

CONTACT: Caroline Tilton, NRR
301-415-0990

In the appeal, the submitter specified three fundamental differences between the DPO submittal and the DPO panel report that were not properly addressed and resolved by the Director's Decision memorandum.

1. the definition or interpretation of the NRC policy in SECY 93-087 with respect to the seismic margin of the reactor building;

2. the adequacy of the probabilistic risk assessment (PRA) method to evaluate building safety at the review level earthquake (RLE) and seismic margin because it cannot predict building movements and behaviors under earthquakes; and

3. the NuScale reactor building design is incomplete, inadequate and unsafe even for the design-basis earthquake (certified seismic design response spectra or CSDRS).

My views on these three fundamental differences are as follows:

1. In my Director's Decision memorandum, I reference the Commission's policy for seismic safety goals contained in the Staff Requirements Memorandum (SRM) to SECY 93-087, "Policy, Technical and Licensing Issues Pertaining to Evolutionary and Advanced Light-Water Reactors Designs". This policy indicates that a PRA-based seismic margin analysis (SMA) that considers sequence-level High Confidence, Low Probability of Failures (HCLPFs) and fragilities for all sequences leading to core damage up to approximately one and two thirds (1.67) the ground motion acceleration of the design basis safe shutdown earthquake (CSDRS at the design certification stage) is acceptable.

   Also, in my Director's Decision memorandum, I describe the PRA-based SMA method in three main steps: (1) analyzing the design specific system and accident sequences; (2) evaluating the seismic fragility of structures, systems and components; and (3) determining sequence and plant level HCLPFs. The PRA-based SMA method is described in more detail in ISG-DC-COL-20, "Interim Staff Guidance on Implementation of a Probabilistic Risk Assessment-Based Seismic Margin Analysis for New Reactors." The SMA process defined in ISG-DC-COL-20 ensures the review incorporates both PRA analysts and structural engineers. Structural engineers with experience in fragility analysis usually perform step (2).

   A PRA-based SMA is acceptable because, as described in SECY 93-087 and combined with a seismic PRA, it yields meaningful measures of the seismic capability of a proposed design. As I stated in my Director's Decision memorandum, the PRA-based SMA approach, delineated by the Commission policy and stated above, provides reasonable assurance of adequate protection by validating the adequacy of the design with a high degree of confidence. In addition, the PRA-based SMA measures the robustness of the plant to withstand earthquakes of a given intensity. It also eliminates the uncertainty in the seismic hazard curve for the site and identifies potential design-specific seismic vulnerabilities. In addition, it helps to identify all the important accident sequences using the event trees and fault trees. The value of the minimum HCLPF for important components is calculated and used to measure the plant's robustness and to provide an acceptable estimate of the earthquake ground motion which the plant is expected to be able to survive without core damage. HCLPF calculations also indicate which components limit the seismic capability of the plant.

In my Director's Decision memorandum, I explain that once an applicant has entered the combined operating licensing stage and a location for the reactor building is decided, site-specific seismic information is considered, and a seismic-PRA analysis is used. These additional requirements ensure that the building design is sufficient to meet the site-specific ground motion. Also, the approach of using a PRA-based SMA for the design certification stage and a seismic PRA once a location for the reactor building is identified, takes advantage of the strengths of both PRA and margin methods and allows for a comprehensive and integrated treatment of the plant's response to an earthquake.

2. In my Director's Decision memorandum, I explain how the applicant is required by regulation to design the reactor building to withstand the effects of the design basis safe shutdown earthquake (CSDRS) without losing the capability to perform its safety function. I also state that this requirement is performed using a structural engineering deterministic analysis method and the approach contains inherent margin. The NRC staff independently reviews the applicant's CSDRS analysis to ensure the design provides reasonable assurance of adequate protection.

   As stated in my Director's Decision memorandum, for the beyond design basis earthquake (RLE) analysis, the Commission's policy, as documented in the SRM to SECY 93-087, allows the use of PRA and does not require the staff to verify with 100 percent certainty, that the reactor building would not collapse. The PRA-based SMA approach, delineated by the policy, provides reasonable assurance of adequate protection by validating the adequacy of the design with a high degree of confidence. In the memorandum, I also include additional information on the differences between nuclear reactor and commercial building structural designs. Notably, nuclear reactor structural designs follow requirements that are even more strict and have greater margin than commercial building structural designs. The SMA methodology has been used previously by the NRC staff to assess the RLE including the AP1000 and the EBWR reactor buildings.

3. In my Director's Decision memorandum, I explain how the overstressed elements locations in the reactor building finite element model were limited to specific locations within the discrete finite element model of a specific component and did not carry out to the actual component as a whole. I also explain how the applicant adequately addressed these overstresses by averaging the forces within the same component which showed that the component retained its structural capacity for the same intensity input.

Accordingly, I conclude that the submitter has not raised any issues that fundamentally impact the conclusions of the DPO panel report and my Director's Decision memorandum. For this reason, my decision regarding DPO 2020-004 remains the same.

STATEMENT OF VIEWS REGARDING APPEAL OF DIFFERING PROFESSIONAL OPINION CONCERNING DPO-2020-004 DATE June 29, 2021

DISTRIBUTION: DPO 2020-004

MDoane, OEDO
AVeil, NRR
AKock, NRR
AVegel, OE
MLombard, NSIR
JMa, NRR/DEX/ESEB
GFigueroaToledo, OE/CRB
IGifford, OE/CRB
JThompson, NRR/DEX/EXHB
CTilton, NRR/DSS/STSB
CDeMessieres, NRR

ADAMS Accession No.: ML21176A128; ML21176A127 *** via email OE-011**

OFFICE	NRR			
NAME	AVeil *AV*			
DATE	Jun 29, 2021			

OFFICIAL RECORD COPY

Document 7: DPO Appeal Decision

UNITED STATES
NUCLEAR REGULATORY COMMISSION
WASHINGTON, D.C. 20555-0001

February 8, 2022

MEMORANDUM TO: John Ma, Ph.D., Senior Civil Engineer
Division of Engineering and External Hazards
Office of Nuclear Reactor Regulation

FROM: Daniel H. Dorman
Executive Director for Operations

Signed by Dorman, Dan on 02/08/22

SUBJECT: DIFFERING PROFESSIONAL OPINION APPEAL CONCERNING DPO-2020-004

The purpose of this memorandum is to inform you of my considerations and conclusions regarding the Differing Professional Opinion (DPO) appeal you submitted on June 14, 2021. The appeal raised concerns regarding the U.S. Nuclear Regulatory Commission (NRC) staff's NuScale Final Safety Evaluation Report Chapter 3.8.4, "Seismic Category 1 Structures." Specifically, you raised issues related to the NuScale reactor building design and the structural collapse of that building due to shaking from the review level earthquake.

After careful consideration of your appeal, I conclude that the basis for accepting NuScale's stress averaging approach of the reactor building design was not sufficiently documented. I am tasking the Office of Nuclear Reactor Regulation to 1) document its evaluation of the stress averaging approach used in the NuScale design certification application, including, if necessary, updating the Final Safety Evaluation Report for the NuScale design certification application and assessing whether there are any impacts to the NuScale standard design approval issued in September 2020 and 2) evaluate and update guidance, or create knowledge management tools, as appropriate, on how to evaluate applications that use stress averaging for structural building design.

Your DPO appeal raised two specific issues. A paraphrased summary of issues and my conclusions for each are as follows:

Issue 1: The NuScale reactor building design is incomplete, inadequate, and unsafe for the design basis earthquake (safe shutdown earthquake/Certified Seismic Design Response Spectra). This is primarily because no design modifications were made when demand forces exceeded the capacity.

Answer 1: The staff's evaluation of the stress averaging approach for the reactor building used in the NuScale application was not sufficiently documented.

CONTACT: Suzanne Dennis, OEDO
301-415-0760

Issue 2: Structural collapse due to shaking from the review level earthquake (RLE) was not evaluated for the NuScale reactor building, so there is no seismic margin incorporated into the structural design. This is, in part, because the NRC has not provided a definition or interpretation of the NRC policy in SECY-93-087 with respect to seismic margin. Using a probabilistic risk assessment (PRA) method alone for evaluation of building safety at the RLE is incorrect.

Answer 2: Based on my review, structural collapse was evaluated, the agency has provided an interpretation of seismic margin, and the PRA-based seismic margin analysis is an appropriate method for conducting safety evaluations for design certification applications.

Thank you for taking the time to raise your concerns to me and for the detailed information you provided to support your position and my review. Your willingness to raise concerns through the DPO process is consistent with our organizational values of Openness and Commitment. More in-depth analysis of each of the issues you raised is provided below.

In accordance with MD 10.159, a summary of this appeal decision will be included in the Weekly Information Report posted on the NRC's public website to advise interested employees and members of the public of the outcome.

DEPUTY EXECUTIVE DIRECTOR FOR REACTOR PROGRAMS-LED APPEAL REVIEW TEAM ANALYSIS

To better understand your concerns, the former Executive Director for Operations, Margaret Doane assigned the Deputy Executive Director for Materials, Waste, Research, State, Tribal, Compliance, Administration, and Human Capital Programs (now the Deputy Executive Director for Reactor Programs (DEDR)), an Executive Technical Assistant from my office, a subject matter expert from the Office of Nuclear Regulatory Research, a subject matter expert from the Office of Nuclear Reactor Regulation (NRR), and an attorney from the Office of the General Counsel, to review the issues raised in your appeal. This DEDR-led appeal review team gathered information through discussions with you, the NRR Director, the Differing Professional Opinion (DPO) Panel, and other knowledgeable staff who reviewed documents pertinent to your appeal. The appeal review team also gathered additional information through their own independent reviews of the NuScale application and associated documents, the staff's evaluation of the application, and other agency documents. The information collected provided independent insights and perspectives for my consideration.

On September 17, 2020, you submitted a DPO on "NuScale SER Chapter 3.8.4, 'Seismic Category 1 Structures.'" On October 6, 2020, an Ad Hoc Review Panel was formed and tasked by the U.S. Nuclear Regulatory Commission (NRC) Differing Views Program to review your DPO. The DPO Panel subsequently issued their findings report to the Director of NRR on April 19, 2021. With respect to the concerns discussed in your appeal, the DPO Panel concluded that 1) the seismic design of the NuScale reactor building meets the design requirements in the applicable regulations; 2) there were no safety issues related to overstressed structural components in the NuScale reactor building; 3) NuScale's seismic margin analysis followed agency guidance, and the guidance provides reasonable assurance of adequate protection; and 4) the design of the NuScale reactor building is complete for the design certification scope.

On May 19, 2021, the Director of NRR issued their decision regarding the DPO's concerns as informed by the DPO Panel report and their own review. The Director agreed with the DPO Panel's findings and directed staff to complete knowledge management activities to ensure the lessons-learned during the process were captured.

On June 14, 2021, you submitted an appeal. This appeal stated two continuing concerns. The first concern was that the NuScale reactor building design is incomplete, inadequate, and unsafe for the design basis earthquake (SSE/CSDRS). This is primarily because no design modifications were made when demand forces exceeded capacity in several structural elements in the finite element analysis, and no post-yield structural element properties were used to capture element behavior after the demand exceeded the capacity. The second was that the NuScale reactor building has no seismic margin incorporated into the structural design because 1) structural collapse due to shaking from the review level earthquake (RLE) was not evaluated; 2) the NRC has not provided a definition or interpretation of the NRC policy in SECY-93-087 with respect to seismic margin; and 3) using a probabilistic risk assessment (PRA) method alone for evaluation of building safety at the RLE is incorrect. The appeal review team's assessment is limited to these issues. The Director of NRR issued their statement of views on June 29, 2021.

Response to Issue 1

On September 22, 2021, members of the DPO appeal review team met with you to gain a better understanding of your concerns regarding the reactor building design for the design basis earthquake. This discussion highlighted your view that there is no basis for averaging stresses across multiple elements at locations where stresses from the finite element analysis exceed allowable stresses.

Section 3B.1.1.1 of the applicant's Final Safety Analysis Report (FSAR) notes that element forces and moments were averaged over the length of the failure plane, which is approximately four times the element thickness, where the element thickness is generally equal to the structure section thickness.[1] When evaluating in-plane shear, the demand was averaged over the available section length. In the final safety evaluation report (FSER) documenting the staff's review of the NuScale design certification (DC) application, the staff noted that it found the applicant's approach of averaging demand acceptable "because it is a realistic engineering practice to consider adjacent finite elements' demand forces and moments when calculating [demand/capacity] D/C ratio exceedances over a single finite element."[2]

Design equations in structural engineering codes such as ACI-349[3] are based on experimental data and empirical equations, which are most representative of the overall global or component response. Historically, seismic loads were developed using lumped-mass-beam-models, and structures were evaluated at the component level with these dynamic loads. Due to improvements in computational power, practitioners now use detailed finite element analyses with shell and solid elements that provide structural stresses at a much finer detail. However, not all structural engineering codes have been updated to achieve consistency with these analytical results.

Averaging finite element analysis stresses can be acceptable for evaluating the adequacy of a structural design. ANSI/AISC N690-18,[4] "Specification for Safety-Related Steel Structures for Nuclear Facilities," is one example where stress averaging is explicitly allowed in a structural design code. In ANSI/AISC N690-18, stress averaging is limited to no larger than twice the section thickness. Another approach proposed by Kohli et al. (2006)[5] uses the overall axial force, bending moment, or shear force acting over a group of elements as opposed to using a single element as the basis for evaluating structural demand. The appeal review team's understanding of how the structural engineering codes are developed along with these cited references show that averaging stresses across multiple elements is used in structural engineering practice.

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[1] NuScale Design Certification Application, FSAR, Revision 5, Tier 2, Appendix 3B, "Design Reports and Critical Section Details" (Aug. 28, 2020), (Agencywide Document Access and Management System (ADAMS) Accession No. ML20224A491).
[2] NuScale Design Certification Application Final Safety Evaluation Report (Aug. 28, 2020), (ADAMS Accession No. ML20205L405).
[3] American Concrete Institute. (2014). ACI 349-13 Code Requirements for Nuclear Safety-Related Concrete Structures and Commentary.
[4] American Institute of Steel Construction. (2018). ANSI/AISC N690-18 Specification for Safety-Related Steel Structures for Nuclear Facilities." American Institute of Steel Construction.
[5] Kohli, T., Orhan, G., and Ostadan, F. (2006). "Integrated Seismic Analysis and Design of Shear Wall Structures." *Proceedings of the 8th U.S. National Conference on Earthquake Engineering*, Earthquake Engineering Research Institute, San Francisco, California, USA.

In the appeal review team's review of the information related to the reactor building in the NuScale FSAR, the demand/capacity ratio exceedance (D/C > 0.8) occurred at the following locations:

- Wall at Grid Line 3 (FSAR Table 3B-3)
- Wall at Grid Line 4 (FSAR Table 3B-8)
- Wall at Grid Line 6 (FSAR Table 3B-11)
- Slab at Elevation 100'-0" (FSAR Table 3B-15)
- Pool Wall at Grid Line B (FSAR Table 3B-23)

Stresses at these locations were averaged over various lengths. For example, when evaluating the adequacy of horizontal and vertical reinforcement in the wall at grid line 3, stresses were averaged over three elements (4951, 4431, and 4421, or 4951, 4950, and 4949). The length over which stresses were averaged range from approximately 2 to 2.5 times the wall section thickness. At grid line 4, stresses were averaged over three elements (16180, 16479, 16778) spanning a length of approximately four times the section width.

The DPO appeal review team finds stress averaging is generally acceptable in engineering practice to make finite element results more consistent with capacities defined in design codes and standards; however, as noted by the Ad Hoc Review Panel, since there is no universal guidance on using the averaging method, this method should be used with caution. When the applicable design code does not provide specific guidance on the use of stress averaging, the basis for accepting such an approach should be well documented. The appeal review team finds that the basis for accepting the applicant's averaging method was not sufficiently documented by the staff in its FSER. The DPO appeal review team recommends that the staff document its evaluation of the stress averaging approach used in the NuScale DC application. This documentation should focus on averaging over the failure plane length that extends up to approximately four times the section thickness and in-plane shear demand over the full available section length. The staff should document the results of its evaluation of the stress averaging approach used by the applicant and, if necessary, update the FSER for the NuScale design certification application and assess whether there are any impacts to the NuScale standard design approval issued in September 2020. Additionally, NRR should consider guidance updates or development of knowledge management tools on this topic, as appropriate. Because the staff's evaluation and basis for accepting the stress averaging approach used by NuScale in its DC application is not adequately documented in its FSER, the appeal review team does not reach a conclusion on adequate protection.

Response to Issue 2

Section 19.1.5.1 of the NuScale FSAR provides a description of the PRA-based seismic margins assessment (SMA) performed by the applicant. The selection of structural failures to model was based on a qualitative assessment of the external mechanisms that could damage the Nuclear Power Module. The failure of select walls, the crane support structure, roof, and basemat of the reactor building were assumed to result in building collapse. In all cases of analyzed structural collapse and nearly all cases of analyzed structural failure, the consequences were assumed to lead to both core damage and large release without opportunity for mitigation.[6] The applicant evaluated structural failure modes which include

[6] See NuScale Design Certification Application, FSAR, Tier 2, Section 19.1.5.1.1.3, "Seismic Fragility Evaluation" (ADAMS Accession No. ML20224A508).

structural collapse in its SMA, and the staff found NuScale's PRA-based SMA adequate for demonstrating sufficient margin for plant safety.[7]

Regarding the interpretation of seismic margin, General Design Criterion (GDC) 2 states that systems, structures, and components (SSCs) important to safety at nuclear power plants must be designed to withstand the effects of natural phenomena such as earthquakes, tornados, hurricanes, floods, tsunami, and seiches without loss of capability to perform their intended safety functions. The design bases for these SSCs reflect consideration of the most severe of the natural phenomena that have been historically reported for the site and surrounding area. The design bases also reflect margin to account for the limited accuracy, quantity, and period of time in which the historical data have been accumulated. The seismic design bases for currently operating nuclear power plants were either developed in accordance with or meet the intent of GDC 2 and 10 CFR Part 100, Appendix A.[8] Although the regulatory requirements in Appendix A to 10 CFR Part 100 are fundamentally deterministic, the NRC process for determining the seismic design basis ground motions for new reactor applications after January 10, 1997, as described in 10 CFR 100.23, requires that uncertainties be addressed through an appropriate analysis such as a probabilistic seismic hazard analysis.

In addressing the severe accident preventions and mitigations for new reactors, 10 CFR 52.47(a)(27) requires that the FSAR for a DC application describe the design-specific PRA and its results. Regulatory Guide 1.206 further states that the scope of this assessment should be a Level 1 and Level 2 PRA that includes internal and external hazards and addresses all plant operating modes.[9] However, it may not be practical for a DC applicant to perform a seismic PRA because a DC application typically does not contain site-specific seismic hazard information.[10] As an alternative approach to a seismic PRA, the staff proposed a PRA-based seismic margin analysis (PRA-based SMA)[11] approach in SECY-93-087, "Policy, Technical, and Licensing Issues Pertaining to Evolutionary and Advanced Light-Water Reactor (ALWR) Designs."[12] The Commission approved the staff's approach with slight modification in the corresponding staff requirements memorandum.[13] The recommendation, as approved, states:

> PRA insights will be used to support a margins-type assessment of seismic events. A PRA-based seismic margins analysis will consider sequence-level High Confidence, Low Probability of Failures (HCLPFs) and fragilities for all

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[7] See NuScale Design Certification Application Final Safety Evaluation Report, Section 19.1.4.8.1, "Seismic Risk Evaluation" (ADAMS Accession No. ML20205L410).
[8] Certain operating nuclear plants' construction permits were based on the proposed General Design Criteria published by the Atomic Energy Commission (32 Fed. Reg. 10,213).
[9] Regulatory Guide 1.206, "Combined License Applications for Nuclear Power Plants (LWR Edition)," (June 2007) (ADAMS Accession No ML070630023).
[10] See Standard Review Plan, NUREG-0800, Section 19.0, "Probabilistic Risk Assessment and Severe Accident Evaluation for New Reactors," Revision 3 (ADAMS Accession No. ML15089A068) (NUREG-0800).
[11] This proposal was based on the culmination of significant staff research on the topic that began in the 1980s when the NRC formed an "Expert Panel on Quantification of Seismic Margins," to establish an approach for evaluating seismic margin of nuclear power plants. See, e.g., NUREG/CR-4334, "An Approach to the Quantification of Seismic Margins in Nuclear Power Plants," (ADAMS Accession No. ML090500182) that presents a technique the expert panel developed for studying the issue of quantifying seismic margins.
[12] SECY-93-087 (April 2, 1993), (ADAMS Accession No. ML003708021).
[13] The staff recommended the use of two times the DBE for a margin assessment of seismic events. Instead, the Commission approved 1.67 times the DBE. Staff Requirements—SECY-93-087— Policy, Technical, and Licensing Issues Pertaining to Evolutionary and Advanced Light-Water Reactor (ALWR) Designs (July 21, 1993), (ADAMS Accession No. ML003708056).

sequences leading to core damage or containment failures up to approximately one and two-thirds the ground motion acceleration of the Design Basis SSE.

This approved approach preserves certain key elements of a seismic PRA to the maximum extent possible and estimates the design-specific plant seismic capacity in terms of sequence-level HCLPF capacities and fragility for all sequences leading to core damage or containment failures up to approximately 1.67 times the ground motion acceleration of the design basis SSE.

Using this approach, a DC applicant can demonstrate acceptably low seismic risk for its design. Additionally, an applicant that references a design certification must show that the PRA-based SMA results envelop its site.[14] The NRC has issued guidance on the PRA-based SMA method and its implementation for DC applications.[15] The PRA-based SMA includes (1) analyzing the design-specific system and accident sequences, (2) evaluating the seismic fragility, and (3) determining the plant-level HCLPF. The DPO appeal review team agrees that an approach that does not involve a multi-disciplinary team, including civil/structural engineers, in the PRA-based SMA would be insufficient. A typical team generally includes, but is not limited to, risk analysts, system engineers, civil/structural engineers, electrical engineers, and reactor operators. Both NRC and industry guidance documents highlight the role of structural engineers in the SMA development.[16] The PRA-based SMA includes developing an event tree to evaluate the plant HCLPF for the design certification application. Structural engineers are responsible for identifying the structural failure modes and quantifying the HCLPF capacity for the failure modes that can lead to core damage.

Additionally, the American Society of Civil Engineers (ASCE) Structural Engineering Institute (SEI) recognizes the PRA-based seismic margin analysis method as a means to "demonstrate sufficient margin over the design earthquake level to find any 'weak links' that might limit the plant's capability to safely shut down after a seismic event bigger than the design earthquake."[17] The ASCE/SEI 4-16 standard supports the position that the PRA-based seismic margin analysis approach is acceptable practice for conducting safety evaluations in the structural engineering profession.

As part of the NRC's technical review of the NuScale design certification application, per ISG-20 and NUREG-0800, NRC structural engineering staff determined whether all appropriate failure modes were considered in the seismic margin analysis, that HCLPF capacities are evaluated for

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[14] See 10 CFR 52.79(a)(46) and 10 CFR 52.79(d)(1). See also 10 CFR 50.72(h), which requires, in part, that a COL applicant develop and maintain a level 1 and a level 2 PRA.

[15] See, e.g., DC/COL-ISG-20, "Implementation of a Probabilistic Risk Assessment-Based Seismic Margin Analysis for New Reactors" (ADAMS Accession No. ML100491233). ISG-20 includes detailed elements with respect to the PRA-based SMA implementation in design certification applications and post-design certification updating activities, including updates for Combined License (COL) applications referencing certified designs to incorporate site and plant-specific features and post-COL verifications.

[16] See, e.g., NUREG/CR-4334, "An Approach to the Quantification of Seismic Margins in Nuclear Power Plants"; EPRI NP-6041-SL, Revision 1, "A Methodology for Assessment of Nuclear Power Plant Seismic Margin"; and ASME/ANS PRA Standard RA-Sa-2009, "Standard for Level 1/Large Early Release Frequency Probabilistic Risk Assessment for Nuclear Power Plant Applications," Addendum A to RA-S-2008, as endorsed by Regulatory Guide 1.200. RA-Sa-2009, for example, contains multiple high-level requirements in which civil and structural engineering knowledge is essential to accomplish the requirements. See also, EPRI NP-6041-SL, Revision 1, "A Methodology for Assessment of Nuclear Power Plant Seismic Margin (Revision 1)," an industry-developed guideline for performing seismic margin analyses, which indicates that the team should consist of systems engineers, seismic capability engineers, and plant operations personnel who are most familiar with the specific plant.

[17] American Society of Civil Engineers. (2017). *ASCE/SEI 4-16 Seismic analysis of safety-related nuclear structures*.

appropriate components, and that HCLPF values are reasonable. The appeal review team concludes that the PRA-based seismic margin analysis performed for NuScale is appropriate.

Conclusion

The use of a PRA-based SMA to evaluate the robustness of the seismic design in a DC application is a method approved by the NRC to demonstrate that the design has low seismic risk. The NRC has provided guidance for DC applicants on performing a PRA-based SMA and guidance to applicants that may reference such a design certification. Furthermore, while stress averaging is generally acceptable in engineering practice, some codes applicable to the NuScale design do not provide specific guidance on the use of stress averaging.

As such, I direct NRR to do the following:

1. Document its evaluation of the stress averaging approach used in the NuScale DC application. This documentation should focus on averaging over the failure plane length that extends up to approximately four times the section thickness and in-plane shear demand over the full available section length. The staff should document the results of its evaluation and, if necessary, update the FSER for the NuScale design certification application and assess whether there are any impacts to the NuScale standard design approval issued in September 2020.

2. Evaluate and update guidance, or create knowledge management tools, as appropriate on how to evaluate applications that use stress averaging.

I want to thank you for bringing your concerns to my attention. I appreciate you taking the time to document and share your concerns. Our agency relies on dedicated professionals, such as yourself, who are willing to raise concerns that could impact the NRC mission.

cc: D. Roberts, OEDO
S. Dennis, OEDO
A. Veil, NRR
J. Rankin, NRR
J. Ma, NRR
T. Weaver, RES
C. Ng, NRR
J. Ezell, OGC
M. Lombard, OE
T. Martinez Navedo, OE
G. Figueroa Toledo, OE

SUBJECT: DIFFERING PROFESSIONAL OPINION APPEAL CONCERNING DPO-2020-004
DATED: February 8, 2022

ADAMS Accession No. **ML22021B617**

OFFICE	OEDO/ETA	RES/DE	NRR/DRA
NAME	SDennis	TWeaver	CNg
DATE	01/27/22	01/25/22	01/24/22
OFFICE	OGC	OEDO/DEDR	OEDO/EDO
NAME	JEzell	DRoberts	DDorman
DATE	01/27/22	02/02/22	02 / 08 /22

OFFICIAL RECORD COPY

Respond and Request to EDO

by

John S. Ma, Ph.D. in structural engineering

Senior structural engineer and a charter member of the NRC

Member of American Concrete Institute (ACI) and American Society of Civil Engineers (ASCE)

Recipient of the Raymond C. Reese Structural Research Award Medal from ACI

Licensed and registered professional engineer in civil/structural engineering

February 14, 2022

INTRODUCTION

I thank the EDO's letter, dated February 8, 2022 to my Appeal to EDO report, dated June 10, 2021. On issue #1, I agree with the EDO's answer and applaud its open mind to accept the DEDR-led appeal review team's finding and task the NRR to perform a necessary evaluation on the "stress averaging" issue that the Director of the Office of the NRR and the DPO panel had not considered to be necessary. I appreciate the DEDR-led appeal review team's dedication to find out that the original DPO panel's acceptance of the applicant's "stress averaging" approach had no or inadequate basis and to present the truth to the EDO.

On issue #2, the EDO's letter did not address my DPO's concern. This is because that the EDO's letter assumed that the PRA-based SMA (seismic margin analysis) result for the entire **plant** safety either had included, or were applicable to, the seismic margin issue for the single reactor **building** safety. This assumption is invalid and untrue. The truth is that the PRA-based SMA for the entire **plant** safety is distinctively different from the seismic margin for the single reactor **building** safety. The PRA-based SMA for the entire **plant** safety belongs to the discipline (or field) of probability and performed by probabilistic risk analysts (the PRA Branch) while the seismic margin of a building belongs to the discipline of structural engineering and performed by structural engineers (the Structural Engineering Branch). The two disciplines are distinctively different and require different approaches and different expertise to conduct their own missions. The PRA-based SMA uses a probabilistic risk approach while the building design and its required seismic margin uses a deterministic approach.

In short, the PRA-based SMA approach cannot be used in the design of a building and its required seismic margin. Building codes and building departments in the United States and some of other countries require a structural engineering approach (method and process) for the design of important buildings and their required seismic margin but do not allow or even mention the PRA approach. No building has ever been designed by the PRA approach because it is not science-based, and all buildings and their required seismic margin are designed by the structural engineering approach because it is science-based. The recognition of this distinction is fundamentally important. It is the lack of this recognition that had caused the previous NRO management to move the review for the seismic margin of the reactor building from structural engineers (Structural Engineering Branch) to probabilistic risk analysts (the PRA Branch), and that action led to the result of no seismic margin being designed into the reactor building without even being noticed by causal readers. I had challenged the previous NRO and current NRR management to name an existing building that had been designed by the PRA approach in an effort to wake them up, but they were silent and ignored my challenge, and thus my effort failed to wake them up. This lack of recognition of the distinction between the two disciplines had caused significantly fundamental problems for the reactor building design, its required seismic margin, and its safety. The problems are (1) no seismic margin has been **explicitly** designed into the reactor building while other important buildings have, including the AP1000 shield building, and (2) the PRA staff had concurred with the applicant's **false claim or implication** that the reactor building possessed a seismic margin of 1.67 and would not collapse during the RLE. These two major fundamental problems and their proper resolutions will be explained and discussed below in this report.

Issue #1

EDO directs the NRR to "Document its evaluation of the stress averaging approach used in the NuScale DC application….. The staff should document the results of its evaluation and, if necessary, update the FSER for the NuScale design certification application and assess whether there are any impacts to the NuScale standard design approval issued in September 2020."

I fully agree with the EDO's directive to the NRR for the resolution of this issue. To assist the NRR staff's evaluation, I provide the following information:

1.1 The correct method and the proper way to evaluate the problem when the acting force on a structural element (Demand or D) exceeds its (elastic) capacity (or C)

As stated in my Appeal to EDO report, "The Vancouver House building design states *"Models of the structure with post-yield structural element properties were created" (see page 11 of my DPO report)."* Only the use of post-yield structural element properties can predict the structural element behavior adequately after the demand force exceeds the (elastic) capacity of the structural element. Whether a structural element will fail or not during the force acting on it (demand) exceeds its (elastic) capacity depends on the amount of **ductility** that had been designed into that structural element. The more ductile of a structural element, the more stress excessive over the (elastic) capacity can be redistributed to its neighboring structural elements. A structural analysis is required under such a condition and the analysis result will show whether the structural element can redistribute the excessive stress over its (elastic) capacity to its neighboring structural elements or not without failure. No one should use his/her judgement to determine whether the stress redistribution is possible or not and how much and to how many structural elements because that subjective approach has no basis just like the "stress averaging" issue in issue #1. This is a structural analysis issue not a judgment issue.

The EDO letter states *"ANSI/AISC N690-18, "Specification for Safety-Related Steel Structures for Nuclear Facilities," is one example where stress averaging is explicitly allowed in a structural design code. In ANSI/AISC N690-18, stress averaging is limited to no larger than twice the section thickness,"* to imply that "stress averaging" is allowed. I want to point out that (1) the AISC standard is only applicable to steel structures and steel material is inherently ductile, and does not apply to concrete structures, such as the NuScale reactor building, because concrete material is brittle, and (2) if the "stress averaging" is limited to no larger than twice the section thickness for ductile steel material, how could anyone justify the use of "stress averaging" with four times the section thickness for brittle concrete material for the NuScale reactor building as stated in the NuScale DC application?

1.2 The EDO's letter on the total amount of structural elements with the demand over capacity or D/C greater than 0.8 is not inclusive as demonstrated below. The EDO letter stated:

"In the appeal review team's review of the information related to the reactor building in the NuScale FSAR, the demand/capacity ratio exceedance (D/C > 0.8) occurred at the following locations:

- *Wall at Grid Line 3 (FSAR Table 3B-3)*
- *Wall at Grid Line 4 (FSAR Table 3B-8)*
- *Wall at Grid Line 6 (FSAR Table 3B-11)*
- *Slab at Elevation 100'-0" (FSAR Table 3B-15)*
- *Pool Wall at Grid Line B (FSAR Table 3B-23)*

Stresses at these locations were averaged over various lengths. For example, when evaluating the adequacy of horizontal and vertical reinforcement in the wall at grid line 3, stresses were averaged over three elements (4951, 4431, and 4421, or 4951, 4950, and 4949). The length over which stresses were averaged range from approximately 2 to 2.5 times the wall section thickness. At grid line 4, stresses were averaged over three elements (16180, 16479, 16778) spanning a length of approximately four times the section width."

The above excerpt from the EDO's letter does not include the example that I provided in my DPO report and in Appeal to EDO report. That example has a structural element with D/C > 3.0, much greater than the D/C > 0.8, and used **<u>ten</u>** structural elements, many more than the three elements as stated above, for "stress averaging". That example in my Appeal to EDO report is copied below:

"The in-plane shear force (the demand) acting on Element number 4942 is 3791 kips (1 kip = 1000 pounds) but the structural element only has a shear capacity (or strength) of 1184 kips. The force (the demand) acting on the element is more than three times greater than its capacity. No design modification was done, and no post-yield structural element properties were created and used to capture the condition or behavior of these overstressed structural elements when the reactor building is only subjected to the design-basis (CSDRS) earthquake. The applicant arbitrarily brought down the high shear stress by averaging the shear stress of ten structural elements (see page15 in my DPO report)."

<u>Request #1</u>

The NRR's evaluation of the applicant's "stress averaging" should include the example documented in my DPO report because it has high D/C = 3.2 value and used stress averaging over ten structural elements.

<u>Issue #2</u>

The EDO's letter stated "Answer 2: Based on my review, structural collapse was evaluated, the agency has provided an interpretation of seismic margin, and the PRA-based seismic margin analysis is an appropriate method for conducting safety evaluations for design certification applications.

I am not disputing the adequacy of the EDO's answer, but the above answer does not address or apply to my DPO issue. My DPO issue is not about the PRA-based seismic margin analysis for the entire **plant**. My DPO issue is about that the required seismic margin for the reactor **building** has not been designed into the building. The PRA-based seismic margin analysis for the entire **plant** and the required seismic margin for the single reactor **building** are two different subjects that require two different approaches. The former belongs to the discipline (or field) of probability while the latter belongs to the discipline of structural engineering. The reason that no seismic margin had been designed into the reactor building was because the lack of recognition of this distinction between the two subjects. The lack of this distinction was caused by that the previous NRO (now NRR) management had prohibited the use of the structural engineering approach (method and process) for seismic margin design for the reactor building and replaced it by the PRA approach and moved the review responsibility from structural engineers (Structural Engineering Branch) to probabilistic risk analysts (PRA Branch). This management action resulted not only in no seismic margin being designed into the reactor building but also in **a false claim or implication** that the building possessed a seismic margin of 1.67 and would not collapse during the review level earthquake (RLE) without being noticed to causal readers. The no seismic margin analysis/design and the false claim or implication are presented and discussed below.

2.1 No seismic margin was designed into the reactor building while other important buildings have including the AP1000 shield building

The structural engineering profession established its structural engineering approach (method and process) to design the required seismic margin into important buildings. The structural engineering method is based on physics, or is science-based, and the adequacy of the method was verified by laboratory tests and data from seismic sensors embedded in buildings during earthquakes. The process uses the required seismic margin times the intensity of the design-basis earthquake (SSE or CSDRS in NuScale) as an input to the building and by this process the seismic margin is **explicitly** designed into the building when the structural engineering analysis results demonstrated that the building did not collapse. A concrete wall test on a dynamic shake table with actual seismic ground motion records input to the wall was documented and results shown in graphic presentations in my DPO report. The actual recorded wall movements during the entire period of earthquake ground motions and its seismic margin of 2.0 when the wall collapsed were perfectly matched to those predictions by the structural engineering approach. That is the verification of the adequacy of the structural engineering approach (method and process) for designing the seismic margin into a building and predicting the seismic intensity that cause the collapse of that building.

For important buildings, the structural engineering profession established a required **minimum** seismic margin of 1.5. My DPO report stated or showed that buildings in the Stanford University campus in California, the Vancouver house building in Canada, the Salesforce Tower building in San Francisco, and the certified AP1000 shield building have all used the structural engineering method and process to demonstrate that they possessed the minimum seismic margin of 1.5 (1.5 for Stanford University buildings, 1.8 for the Salesforce Tower building, and 3.0 for the Vancouver House building and the AP1000 shield building). However, no seismic margin was **explicitly** designed into the NuScale reactor building because no seismic analysis/design was performed for the reactor building with a seismic intensity greater than that of the design basis earthquake (SSE or CSDRS) input to the building.

2.2 The subtly false claim or implication that the reactor building possessed a seismic margin of 1.67 and would not collapse during RLE should be corrected in the FSER for the NuScale design certification application

The NuScale DC application subtly claim or implied that its PRA result indicated that the reactor building possessed a seismic margin of 1.67 and it would not collapse during the RLE. This subtle claim or implication was confirmed by a senior probabilistic risk analyst in the NRC and was documented in references 2 and 3 in my Appeal to EDO report. It is copied below for the demonstration:

2. *John Ma email to Hanh Pham, 8/21/2020 2:42 PM, "Is my understanding correct that the PRA results in NuScale Chapter 19, PRA, indicate that the reactor building will not collapse during the 1.67 times the design-basis earthquake?"*
3. *Hanh Pham email to John Ma, 8/21/2020 3:22 PM, "Yes, your understanding is correct."*

That confirmation from the senior PRA staff led to my statement in my Appeal to EDO report *"…., the applicant used the PRA results to conclude that the reactor building will not collapse during the RLE, and this is an obviously incorrect and false statement. Even worse is that the NRC concurred with that false conclusion."* I made that statement because I knew well that the PRA approach cannot predict whether a building will collapse or not because the method is not science-based, and only the structural engineering method can because it is science-based, and that no building codes had allowed or even mentioned the PRA approach. If the PRA approach cannot be used to design a building, how could the applicant claim or imply that the reactor building would not collapse during the RLE and possessed a seismic margin of 1.67 and concurred by the NRC staff? This is not only a technical blunder, but the false statement or implication impacted the building safety grievously. This technical blunder and the false statement or implication were caused by moving the structural engineer's review responsibility to probabilistic risk analysts, who have no expertise in structural engineering.

2.3 The lack of distinction between the *PRA-based SMA* for the entire plant safety and the seismic margin for the single reactor building safety has caused the unsafe design for the reactor building

The EDO's letter states *"The failure of select walls, the crane support structure, roof, and basemat of the reactor building were assumed to result in building collapse. In all cases of analyzed structural collapse and nearly all cases of analyzed structural failure, the consequences were assumed to lead to both core damage and large release without opportunity for mitigation. The applicant evaluated structural failure modes which include structural collapse in its SMA, and the staff found NuScale's PRA-based SMA adequate for demonstrating sufficient margin for **plant** (emphasis added by me) safety."*

The above descriptions made two assumptions all related to the *PRA-based SMA* for the entire plant, and the result is also related to the entire plant safety. Neither the assumptions nor the results are related or applicable to the seismic margin of the reactor building. It must be recognized that the *PRA-based SMA* for the entire plant safety is totally different from the seismic margin for the single reactor building safety. The former belongs to the PRA Branch and its staff and the latter belongs to the Structural Engineering Branch and its staff, based on their respective expertise. Wrongly moving the review responsibility for the design of the reactor building and its seismic margin from structural engineers to the probabilistic risk analysts resulted in the unsafe design plus a false claim or implication on the safety for the reactor building.

2.4 The unsafe design of the certified reactor building and the subtle claim or implication that the reactor building possessed a seismic margin of 1.67 and it would not collapse are wrong and need to be corrected

The NuScale reactor building is an important building because its collapse could cause early and large release of radioactive materials into the atmosphere that can kill or harm people. As stated above, important buildings are required to design for a **minimum** seismic margin of 1.5 which was established by the structural engineering profession and practiced by structural engineers and enforced by building departments in the United States and some other countries, such as Canada and China.

The actual value of seismic margin that is required to be designed into a building above the minimum value of 1.5 depends on the risk consequence of the building collapse. The Stanford University decided to use seismic margin of 1.5 for designing its new buildings and retrofitting its existing buildings on its campus. The Salesforce Tower used seismic margin of 1.8 for the design because it houses more than 5000 people. The building collapse would cause more deaths and injuries than buildings that house less people, and thus required a seismic margin higher than the minimum. The Vancouver House building used seismic margin of 3.0 for its design because the shape of the building would cause unusual or extreme torsional problems during earthquakes. The structural engineering profession has the least knowledge and confidence in the subject of torsion among all other subjects, such as bending for beams and axial force for columns. Thus, the use of a high seismic margin of 3.0 over the minimum value of 1.5 is prudent. The type of construction of AP1000 shield building, pouring concrete between two steel plates, had never been used in any important buildings and its behavior during earthquake is unknown or much less known to the structural engineering profession. Therefore, critical structural elements in the AP1000 shield building were physically tested in the laboratory to reach a seismic margin of 3.0, and the whole building was analyzed using the structural engineering method and process to demonstrate that it possessed a seismic margin of 3.0. Again, the reason for using a high seismic margin of 3.0 for the AP1000 shield building, same as that used by the Vancouver House building, higher than the minimum required values of 1.5, is due to the lack of knowledge and confidence in the behavior of such a type of building during earthquake.

During the development of the NRC Policy for seismic margin for nuclear power plants and buildings, the NRC staff had proposed a value of 2.0, but the nuclear industry countered with 1.5, and the Commissioners chose the value of 1.67. During the time of debating between the staff proposed value of 2.0 and the 1.5 value proposed by the nuclear industry, the structural engineering profession had established and used the value of 1.5 as the minimum required seismic margin for important buildings and thus the nuclear industry had a good basis for its argument for its proposed seismic margin of 1.5. During a meeting among the NRO staff in discussing the requirement of using the value of 1.67 seismic margin in the NRC Policy for the NuScale reactor building a few years ago, an NRO manager stated that he would consider rescinding that NRC Policy. I told him that even if that Policy were being rescinded, the NuScale reactor building was still required to design for a minimum seismic margin of 1.5 because that is required by the structural engineering profession which the NRC has no power to rescind.

It is now clear that with no seismic margin being designed into the reactor building is certainly wrong and improper regardless the existence or interpretation of the NRC Policy on the value of the required seismic margin for important buildings in nuclear power plants. The subtle claim or implication from *the PRA results in NuScale Chapter 19, PRA,* that the reactor building possessed a seismic margin of 1.67 and would not collapse during the RLE is also wrong and should be corrected in the FSER for the NuScale design certification application.

2.5 Moving the structural engineer's review responsibility to the probabilistic risk analysts is improper (this is the first time occurred in my more than 47-year service in the NRC) and that improper action resulted in unsafe design and that action should be corrected

As stated in issue #1, the forces acting on the structural element number 4942 are more than three times of the (elastic) capacity of that element, D/C = 3.2, while the building was only subjected to the design-basis earthquake (SSE or CSDRS.) No post-yield structural element properties were used for the structural analysis and no structural design modifications were done for the reactor building by the applicant. For experienced structural engineers, the above conditions would automatically raise a red light on the safety of the building design. However, the probabilistic risk analysts cannot see the red light because that is not their training or expertise on building design and building safety. This is the consequence by wrongly moving the structural engineer's review responsibility to the probabilistic risk analysts (the PRA staff) who have no training and no expertise in building design.

2.6 The two major problems for the certified reactor building and their proper resolution

The problems as stated above include (1) no seismic margin was **explicitly** designed into the reactor building while other important buildings have, including the AP1000 shield building, and (2) the PRA staff had concurred with the applicant's **false claim or implication** that the reactor building possessed a seismic margin of 1.67 and would not collapse during the RLE, which is obviously wrong. To clearly understand the problems and properly resolve these problems, I encourage the EDO to read the portion of my DPO report (pages 3 through 5), dated September 10, 2020, on the concrete wall testing that provides a clear understanding about the definition of seismic margin of a building and demonstrates the adequacy of the structural engineering approach (method and process) for the design of important buildings and their required seismic margins. I also encourage the EDO to read the portion of my DPO report (pages 5 through 14) on the design of buildings within the Stanford University campus, the Vancouver House building, the Salesforce Tower building, and the AP1000 shield building because they clearly provide the structural engineering method and process for designing the required seismic margin into their buildings by using *post-yield structural element properties* and design modifications when demand exceeds capacity and thus ensuring safety for those buildings during earthquake.

I am hopeful that the EDO, after reading through the recommended portions in my DPO report, will agree with me (1) that the certified reactor building is inadequate and unsafe because there was no design for the seismic margin into the reactor building while other important buildings have, including the AP1000 shield building, and (2) that the false claim or implication that the reactor building possessed a seismic margin of 1.67 and would not collapse during the RLE is dangerously wrong, and it will ruin the public trust in the NRC if it is discovered later by the public that the NRC was unwilling to correct its own mistakes. The proper way for resolving these two problems is to perform a structural engineering analysis/design for the reactor building with the RLE input to the building, just like the same process used by any other important buildings in the United States and some of other countries. The results of this new analysis will show that the reactor building currently certified is inadequate and unsafe and will require design modifications to ensure it possesses the required seismic margin of 1.67 and would not collapse during the RLE (this conclusion is based on my knowledge in structural engineering and my design and review experiences for buildings).

Request #2:

2.1 The EDO needs to obtain an answer from the NRR on whether the certified reactor building will collapse during the RLE or not, and the basis for that answer, and the value (numerical number, such as 1.5 or 1.67 or any other numbers) of seismic margin that the reactor building possessed so that the public can see the adequacy of the reactor building design and its actual seismic margin value.

2.2 The EDO needs to obtain an answer from the NRR explaining its logic and reason for prohibiting the use of structural engineering approach and replacing it by the PRA approach for assessing the seismic margin and safety of the reactor building so that the public can see and judge whether such an action is proper, or it had resulted in unsafe design for the reactor building.

If the EDO wants to get the correct answers for Request #1 and request #2, it can contact the American Concrete Institute and/or American Society of Civil Engineers, building departments that have issued permits for important buildings, such as Los Angeles, San Francisco, and Seattle, and any structural engineering firms that have designed and sealed the design for important buildings.

From:	Rodriguez, Hector
To:	Vrahoretis, Susan; Ezell, Julie; Figueroa Toledo, Gladys; Roth, Dave; Solorio, Dave
Subject:	FW: Receipt of response to NuScale DPO Appeal decision
Date:	Tuesday, March 15, 2022 9:32:45 AM
Attachments:	response and request to EDO.docx Memo to John Ma, From Dan Dorman, ref DPO-20220-004 Appeal Review Report.pdf

FYI

Hector (Pronouns: They/He/She)

From: Dorman, Dan <Dan.Dorman@nrc.gov>
Sent: Tuesday, March 15, 2022 9:28 AM
To: Ma, John <John.Ma@nrc.gov>
Cc: Rodriguez, Hector <Hector.Rodriguez-Luccioni@nrc.gov>
Subject: Receipt of response to NuScale DPO Appeal decision

Greetings Dr. Ma,

I received your response dated February 14, 2022 (attached) to my decision on the DPO-2020-004 appeal, dated February 8, 2022 (also attached). While there is no requirement or guidance under the DPO process regarding correspondences submitted after the DPO appeal decision has been issued, I value your work, thoughts, and concerns, and, for this reason, I asked the appeal review team to review your response to my decision on the DPO-2020-004 appeal. After reviewing your response, discussing it with the appeal review team, and careful consideration, I have directed NRR to review your response to the DPO appeal decision and to take the information you provided into consideration when addressing the tasks mandated in the DPO appeal decision.

Thank you for your hard work and for raising your concerns with me.

Sincerely,

Dan Dorman