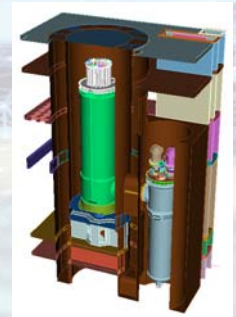
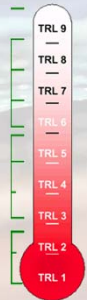




# Seismic isolation of nuclear reactor buildings and equipment

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SUNY Distinguished Professor  
University at Buffalo  
Chair, ASCE Nuclear Standards Committee  
[awhittak@buffalo.edu](mailto:awhittak@buffalo.edu)





## Outline

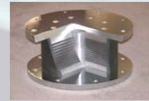
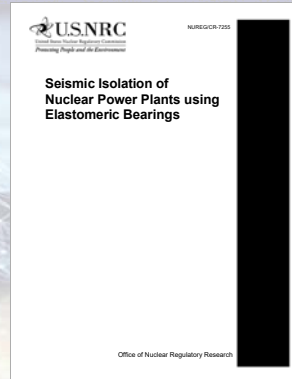
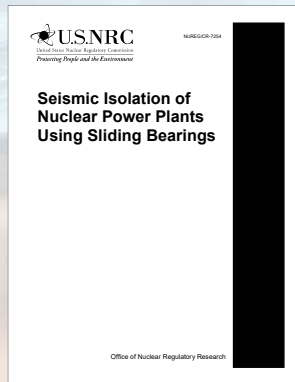
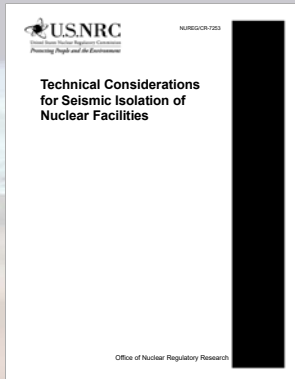
- USNRC-funded research
- Nuclear facility standards for seismic isolation
- ARPA-E and EPRI-funded research, OCC, equipment
- Regulatory gaps
- Pathway to Nth-of-a-Kind advanced reactors

**RIC** 2020



**U.S.NRC**  
United States Nuclear Regulatory Commission  
*Protecting People and the Environment*  
#NRCRIC2020

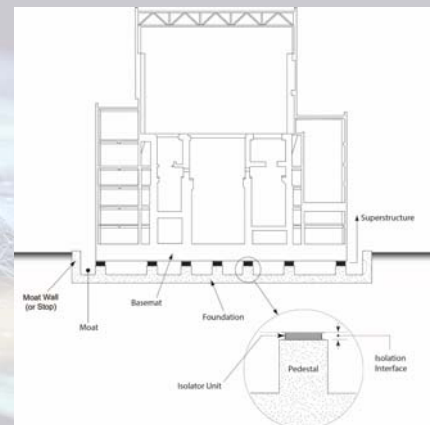
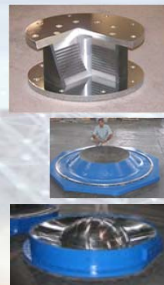
# USNRC-funded research, 2010 to 2018





# USNRC funded research, 2010 to 2018

- NUREG/CR-7253
  - Large light water reactors
  - LDR, LR, and FP bearings
  - Analysis methods
  - Performance criteria
  - Design, construction and operation





Ground motion levels	Isolation system			Superstructure design and performance	Umbilical line design and performance	Moat or stop design and performance
	Isolator unit and system design and performance criteria	Approach to demonstrating acceptable performance of an isolator unit				
GMRS+ <sup>2</sup> Envelope of RG 1.208 GMRS and the minimum foundation input motion <sup>3</sup>	No long-term change in mechanical properties. Extremely high confidence of the isolation system surviving without damage when subjected to the mean displacement of the isolator system under the GMRS+ loading.	Perform production testing on each isolator for the mean system displacement under the GMRS+ loading and corresponding axial force.		Superstructure design and performance to conform to NUREG-0800 for GMRS+ loading.	Umbilical line design and performance to conform to NUREG-0800 for GMRS+ loading.	Moat gap sized such that there is less than 1% probability of the superstructure impacting the moat or stop for GMRS+ loading.
BDBE GMRS <sup>4</sup> Envelope of the UHRS at a MAFE of $1 \cdot 10^{-5}$ and 167% of the GMRS+ per ISG 20	90% confidence of each isolator and the isolation system surviving without loss of gravity-load capacity at the mean displacement under BDBE GMRS loading.	Perform prototype testing must be performed on a sufficient number of isolators at the CS <sup>5</sup> displacement and the corresponding axial force to demonstrate acceptable performance with 90% confidence. Limited isolator unit damage is acceptable but load-carrying capacity must be maintained.		Less than a 10% probability of the superstructure contacting the moat or stop under BDBE GMRS loading.	Greater than 90% confidence that each type of safety-related umbilical line, together with its connections, shall remain functional for the CS displacement. Performance may be demonstrated by testing, analysis or a combination of both. <sup>6</sup>	Moat gap sized such that there is less than a 10% probability of the superstructure impacting the moat or stop for BDB GMRS loading. Stop designed to survive impact forces associated with isolation system displacement to 95 <sup>th</sup> percentile BDBE isolation system displacement. <sup>7</sup> Limited damage to the moat or stop is acceptable but the moat/stop should perform its function.

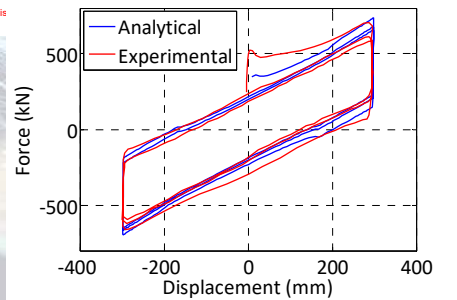
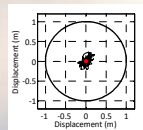
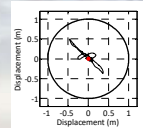
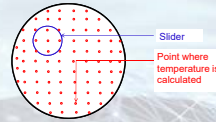
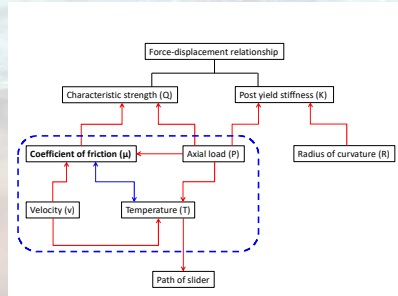
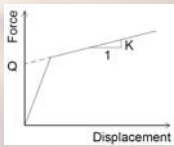
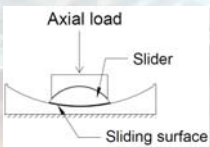
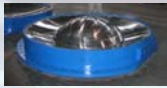
1. Analysis and design of safety-related components and systems shall conform to NUREG-0800.
2. 10CFR50 Appendix S requires the use of an appropriate free-field spectrum (often the RG 1.60 spectral shape) with a peak ground acceleration of no less than 0.10g at the foundation level.
3. The analysis can be performed once using a composite spectrum or twice using the GMRS and the minimum spectrum separately.
4. The analysis can be performed once using a composite spectrum or twice using the  $1 \cdot 10^{-5}$  MAFE UHRS and the 167%GMRS+ separately.
5. CS=Clearance to the Stop
6. Seismic Category 2 SSCs whose failure could impact the functionality of umbilical lines shall also remain functional for the CS displacement.
7. Impact velocity calculated at the displacement equal to the CS assuming cyclic response of the isolation system for motions associated with the 95<sup>th</sup> percentile (or greater) BDB GMRS displacement.





# USNRC funded research, 2010 to 2018

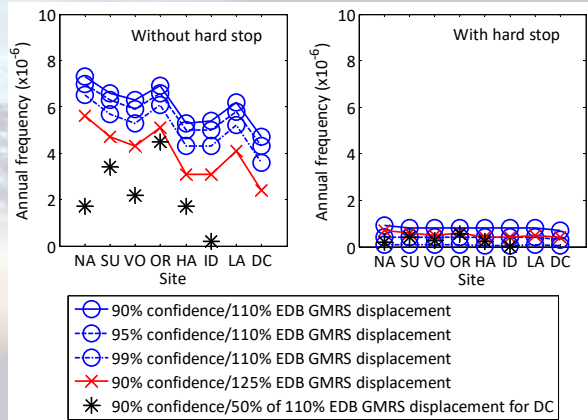
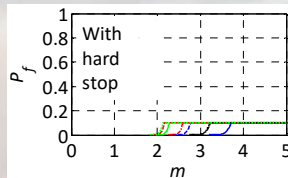
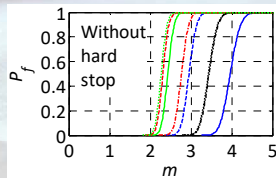
- NUREG/CR-7254: Sliding bearings





# USNRC funded research, 2010 to 2018

- NUREG/CR-7254: Sliding bearings





# USNRC funded research, 2010 to 2018

- NUREG/CR-7255: Elastomeric bearings

Table 2.4: Modeling of elastomeric seismic isolators and software programs

Properties	3DBASIS	SAP2000	PERFORM3D	LSDYNA	ABAQUS	OpenSees	New elements <sup>1</sup>
Coupled horizontal directions	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Coupled horizontal and vertical directions	No	No	No	No	No	No	Yes
Different tensile and compressive stiffness	No	No	Yes	Yes	Yes	Yes	Yes
Nonlinear tensile behavior	No	No	No	No	Yes	Yes	Yes
Cavitation and post-cavitation	No	No	No	No	No	No	Yes
Nonlinear compressive behavior	No	No	No	No	Yes	Yes	Yes
Varying buckling capacity	No	No	No	No	No	No	Yes
Heating of lead core	No	No	No	No	No	No	Yes

1. New elements created for LDR and LR bearings in OpenSees and ABAQUS at the University at Buffalo, with funding from USNRC

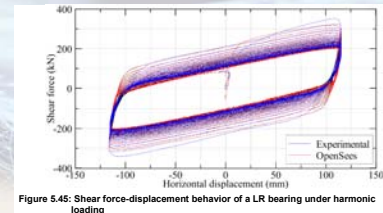
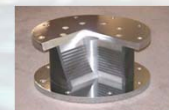


Figure 5.45: Shear force-displacement behavior of a LR bearing under harmonic loading

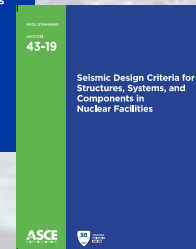
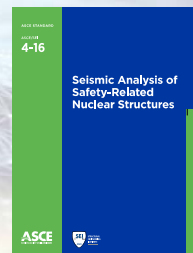






# Nuclear standards for seismic isolation

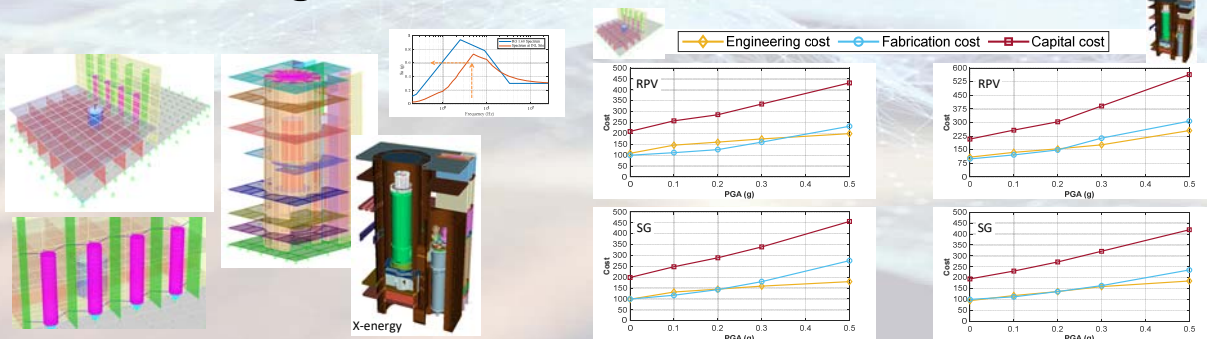
- Isolation of safety-critical buildings and facilities
- ASCE/SEI Standard 4-16
- ASCE/SEI Standard 43-19
- Technical basis for ASCE 4 and 43
  - USNRC-funded research
  - MCEER-funded research





# ARPA-E and EPRI funded research

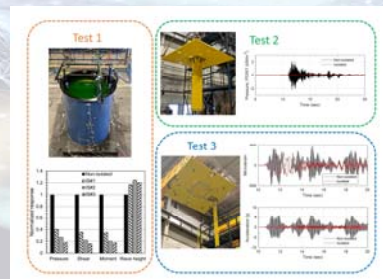
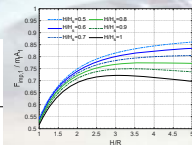
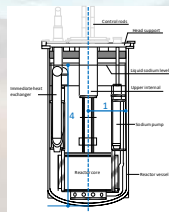
- ARPA-E: Equipment-based seismic protective systems
- EPRI: Building a business case for seismic isolation





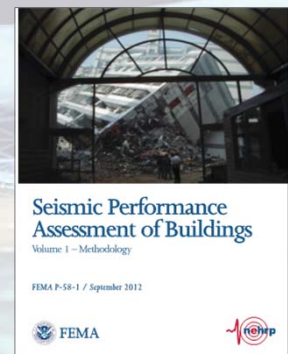
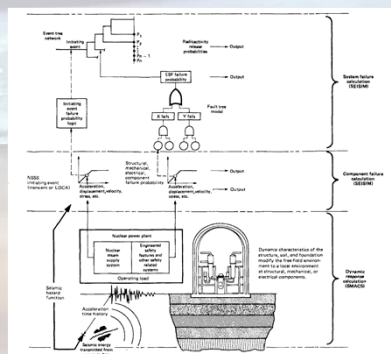
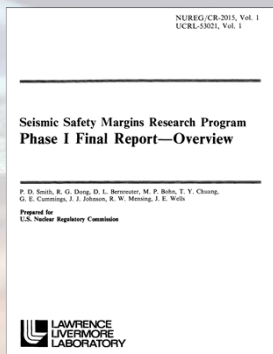
# ARPA-E funded research

- Equipment-based seismic protective systems
- Portfolio of seismic protective solutions
- Revisions to Chapter 12 of ASCE/SEI Standard 4 underway



# Regulatory gaps

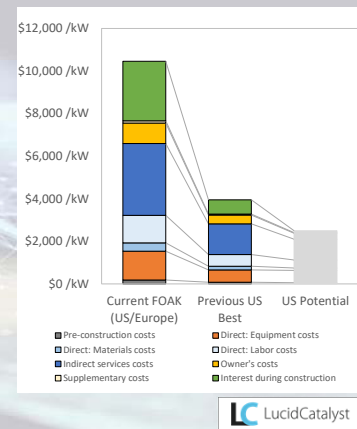
- Seismic probabilistic risk assessment





# Pathway to NoaK advanced reactors

- Price point is \$2,500 per kWe
  - Vogtle 3 and 4: \$12,500 per kWe
- Seismic isolation
  - Standards and guidance in place, high TRL
  - Proven US supply chains, 30 years of manufacturing experience
  - Identical NoaK buildings and equipment
    - One-time design and qualification
  - Drastic reductions in engineering costs and time for regulatory review
  - Encourage construction innovation and investments in advanced manufacturing
- New procurement architecture and project delivery







# Acknowledgments

- US Nuclear Regulatory Commission
  - Jose Pires, Annie Kammerer, and many others
- Lawrence Berkeley National Laboratory
  - Robert Budnitz, Robert Kennedy, James Johnson, Antonio Godoy
- Advanced Research Projects Agency—Energy
  - Rachel Slaybaugh, and her team
- US Department of Energy
  - Justin Coleman, Mark Peters, and others
- Southern Nuclear, TerraPower, X-energy, Kairos Power
- LucidCatalyst
  - Eric Ingersoll and Kirsty Gogan

