University at Buffalo

Final Scientific/Technical report

Reducing the Overnight Capital Cost of Advanced Reactors Using Equipment-Level Seismic Protective Systems

Contract DE-AR0000978

Award:	DE-AR0000978
Sponsoring agency	USDOE, Advanced Research Project Agency—Energy (ARPA-E)
Lead recipient:	University at Buffalo
Project team members:	Massachusetts Institute of Technology Electric Power Research Institute Simpson, Gumpertz, and Heger Exponent TerraPower X-energy Idaho National Laboratory LucidCatalyst
Project title:	Reducing the overnight capital cost of advanced reactors using equipment-level seismic protective systems
Project director:	Dr. Joseph King
Principal investigator:	Dr. Andrew Whittaker
Contract administrator:	Ms. Alison Michal
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This report contains no Protected Data.

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Public Executive Summary

Consideration of the effects of earthquake shaking on the design and construction of nuclear power plants adds substantially to the overnight capital cost, with anecdotal estimates as high as 35+%, attributed to additional construction materials, need for one-off and sub-optimal designs of equipment due to conflicting design choices, the high cost of seismic qualification of equipment, and regulatory review. Safety-critical equipment in large light water reactors is designed and qualified for seismic demands imposed by the supporting reactor building, optimal mechanical designs are not possible, and designs of a given piece of equipment may vary with height above grade. Similar negative impacts are expected for advanced reactors unless the seismic design paradigm is changed.

The overarching goal of this *transformational* MEITNER project, which involved a multidisciplinary engineering team and designers of three fundamentally different advanced reactors, was to adapt proven seismic isolation and damping technologies to operationalize modular protective systems for safety-class *equipment* inside advanced reactor buildings. Such seismic protective systems would be tightly integrated into design development for reactor support systems and balance-of-plant construction. The adoption of the technology, which is widely used in non-nuclear sectors, would simplify plant design, enable the use of *standardized* equipment and buildings, optimized for operational performance, and reduce plant size and weight. The need for site-specific equipment would be eliminated, enabling identical equipment to be used across multiple plants sited across the US and economies of scale, and catalyzing new interest and investment. The equipment-based protective systems would allow siting of advanced reactors in regions of high seismic hazard.

The project team achieved the goal by executing a series of tightly integrated tasks, including 1) determining how the total cost of safety-grade equipment increases with incremented earthquake shaking, including costs associated with analysis, design, and qualification, 2) deploying a framework, via design spaces, to implement seismic protective systems inside advanced reactor buildings, 3) developing theory and numerical tools to enable seismic fluid-structure-interaction analysis of vessels for water-cooled, molten salt, and liquid metal reactors, 4) designing and prototyping seismic protective systems for these generic pieces of equipment, involving proof-of-concept experiments on a 6 DOF earthquake simulator, 5) verifying and validating numerical models of the protective systems, and implementing them in commercial and DOE computer codes, 6) advancing model-in-the-loop simulation procedures to revolutionize procedures for seismic qualification of equipment, 7) writing the guidance and commentary needed for engineers to implement equipment-based protective systems inside reactor buildings, and 8) aggressively move the research and development products into the US domestic nuclear energy industry, helping to maintain US leadership in the field. This technical approach was based in part on highly successful projects completed in the early 2010s that enabled 2D horizontal seismic isolation of new large light water reactor buildings.

Acknowledgments

The information, data, or work presented herein was funded by the Advanced Research Projects Agency-Energy (ARPA-E), U.S. Department of Energy, under Award Number DE-AR0000978. Kairos Power contributed knowledge and hardware for the experiments. The views and opinions of the Principal Investigator expressed herein do not necessarily state or reflect those of the United States Government or any agency thereof, or the Massachusetts Institute of Technology, Simpson, Gumpertz & Heger, Exponent, Electric Power Research Institute, TerraPower, X-energy, and Kairos Power.

Many individuals contributed to the success of this project, including those listed below:

University at Buffalo: Dr. Michael Constantinou, Kaivalya Lal, Faizan Ul Haq Mir, Sharath Sai Parsi, Dr. M. Sivaselvan, Dr. Ching-Ching Yu

Massachusetts Institute of Technology: Zhiyan Cheng, Dr. Jinyong Feng, Dr. Koroush Shirvan

Simpson, Gumpertz, & Heger: Dr. Benjamin Kosbab, Kaniel Tilow

Exponent: Dr. Troy Morgan

Electric Power Research Institute: Hasan Charkas

TerraPower: Michael Cohen

X-energy: Harlan Bowers, Paul Kirchman

Kairos Power: Matthew Clavelli, Dr. Oded Doron, Dr. Nam Nguyen, Dr. Per Peterson, Brian Song

Idaho National Laboratory: Dr. Chandrakanth Bolisetti

LucidCatalyst: Justin Aborn, Eric Ingersoll

Earthquake Protections Systems contributed the seismic isolators used for the earthquake-simulator experiments. Kairos Power contributed the core barrel, reflector blocks, head-mounted oscillators, pebbles, and reactor head used in the third and fourth sets of experiments.

Accomplishments and Objectives

This award allowed the University at Buffalo and its project partners to demonstrate that overnight capital cost of advanced reactors could be reduced with the deployment of seismic protective systems.

A number of tasks and milestones were laid out in Attachment 3, the Technical Milestones and Deliverables, at the beginning of the project. The actual performance against the stated milestones is summarized below. Several milestones were extended, consistent with the no-cost extension to June 30, 2022. All milestones were met either before or by the scheduled time.

Table 1. Milestones and deliverables

Milestone	Milestones and deliverables
M1.1	Milestone (from SOPO): Complete work plan approved by the Program Director and submitted to the ARPA-E Deputy Director of Technology. Milestone (actual achievement): Work plan completed and submitted during the negotiation phase and prior to contract award.
M1.2	Milestone (from SOPO): Generate Impact Sheet that describes the desired impact the project team would like to have by the end of the project. Milestone (actual achievement): Impact sheet submitted to ARPA-E.
M2	Milestone (from SOPO): Document safety-class equipment in both reactors for study. Milestone (actual achievement): Three pieces of equipment were selected for two reactor types: reactor vessel, control-rod drive mechanisms and steam generators.
M3.2	Milestone (from SOPO): Develop cost data. Milestone (actual achievement): Questionnaire delivered to 32 domain experts; 11 responses received. Data processed and presented to ARPA-E team on December 11, 2019. Results documented in an ICAPP paper presented in March 2021 and an EPRI report.
M4.4	Milestone (from SOPO): Document the safety, operational, and cost impacts for the down-selected, seismically protected equipment of WBS 2. Milestone (actual achievement): Documentation included in a quarterly report; information used to support the writing of a proposal, led by MIT, on a horizontally configured high-temperature gas reactor.
M5.1	Milestone (from SOPO): Develop cost estimates for models. Milestone (actual achievement): Cost estimates developed for Models 1, 2 and 3; cost totals less than amounts budgeted; data shared with ARPA-E.
M5.5	Milestone (from SOPO): Curated dataset available at a Department of Energy (DOE) website. Milestone (actual achievement): Data from earthquake-simulator experiments has been curated and archived. Data to be uploaded to the NSF-supported DesignSafe archive before the end of 2022.

M6.4	Milestone (from SOPO): Transmit the V+V'd models and test examples for inclusion in MASTODON and commercial software. Milestone (actual achievement): Verified and validated models, and test examples, were implemented in MASTODON for lead-rubber and Friction Pendulum seismic isolation bearings, and nonlinear fluid viscous dampers. Advanced models of lead-rubber bearings are also available in the commercial software ABAQUS and LS-DYNA and the open-source code OpenSees. Advanced models of single-concave Friction Pendulum bearings are available in OpenSees. A numerical model of nonlinear fluid viscous damper is available in LS-DYNA. Information on these open-source models is available as follows: Lead rubber isolator, theory, and user manual: https://www.mooseframework.org/mastodon/manuals/include/materials/lr_isolator-theory.html https://www.mooseframework.org/mastodon/manuals/include/materials/lr_isolator-user.html Single Friction Pendulum isolator, theory, and user manual: https://www.mooseframework.org/mastodon/manuals/include/materials/fp_isolator-theory.html https://www.mooseframework.org/mastodon/manuals/include/materials/fp_isolator-user.html Nonlinear fluid viscous damper, theory, and user manual: https://www.mooseframework.org/mastodon/manuals/include/materials/fv_damper-theory.html https://www.mooseframework.org/mastodon/manuals/include/materials/fv_damper-user.html The open-source code for these elements is available at: https://github.com/idaholab/mastodon/ tree/devel/src/materials.
M7.4	Milestone (from SOPO): Data comparing dynamics of MIL system with design characteristics. Milestone (actual achievement): Concept for 1D MIL demonstration completed; test system modeling, control design and implementation completed; MIL system configured for seismic testing and qualification.
M7.6	Milestone (from SOPO): Document the process for qualifying large, safety-class equipment, with and without protective systems, through MIL and identify necessary changes to equipment-qualification standards. Milestone (actual achievement): Process documented in a project report delivered to ARPA-E on June 28, 2021, via email; MCEER report and papers published or under review; see Project Outputs.
M8.2	Milestone (from SOPO): Draft mandatory language and commentary for equipment-based seismic protective systems for inclusion in ASCE/SEI Standard 4-21. Milestone (actual achievement): Chapter 12 of ASCE/SEI Standard 4-21 (now likely 4-23) reorganized with a new table of contents, balloted, and passed. Language and commentary for equipment-based seismic protective systems
M8.4	Milestone (from SOPO): Ballot proposed mandatory language and commentary

	Milestone (actual achievement): Work on ASCE 43 will begin once the ASCE 4 cycle is completed, likely in late 2023. Material to update Chapter 9 of ASCE 43 is now available.
M9.3.1	Milestone (from SOPO): Engagement, year 1. Milestone (actual achievement): Papers and presentations at SMiRT25; two papers written for ICAPP 2020 in Abu Dhabi; two journal papers submitted for review and possible publication. See Project Output.
M9.3.2	Milestone (from SOPO): Engagement, year 2 onwards Milestone (actual achievement): Papers and presentations at conferences; engagement with ASME and ANS via conferences and meetings; presentations to the USNRC; presentations at the DOE NPH meeting. See Project Output.
M9.4.1	Milestone (from SOPO): Submit journal articles for publication Milestone (actual achievement): See Project Output
M9.4.2	Milestone (from SOPO): Submit journal articles and publish project results in MCEER report series Milestone (actual achievement): See Project Output
M9.5	Milestone (from SOPO): Write-up project results for dissemination to stakeholders Milestone (actual achievement): All project tasks completed as planned; see Project Output for research products completed to date; raw data archived at DesignSafe.

Project Activities

The project had three foci, namely, 1) develop effective solutions for the seismic protection of safety-related equipment, characterizing the benefits and possible pitfalls, 2) quantify the financial benefits of seismically isolating safety-related equipment, and 3) prepare guidance for implementation of seismically isolated equipment in advanced reactors. The foci were addressed in a coordinated manner by the project team, involving techno-economic assessments, development of theory, numerical studies to verify and validate models of fluid-filled equipment such as reactor vessels, code development and implementation in the DOE platform Mastodon, four sets of first-of-a-kind earthquake-simulator experiments, development of model-in-the-loop procedures to support qualification of equipment in advanced reactors, and preparation of mandatory language and commentary for inclusion in the next releases of ASCE/SEI standards 4 and 43.

Two no-cost extensions were granted by DOE on account of delays caused by the COVID-19 pandemic. Milestones were moved in consultation with DOE. There was no change in scope.

Project Outputs

A. Journal articles (published, submitted, in preparation)

Yu, C.-C., and A. S. Whittaker, "Analytical solutions for seismic fluid-structure interaction of head-supported cylindrical tanks," *Journal of Engineering Mechanics*, Vol. 146, No. 10, October 2020, DOI: 10.1061/(ASCE)EM.1943-7889.0001831.

Mir, F. U. H., C.-C. Yu, and A. S. Whittaker, "Experimental and numerical studies of seismic fluid-structure-interaction in a base-supported cylindrical vessel," *Earthquake Engineering and Structural Dynamics*, Vol. 50, No. 5, pp. 1395-1413, April 2021, DOI: 10.1002/eqe.3402.

Yu, C.-C., and A. S. Whittaker, "Review of analytical studies on seismic fluid-structure interaction of base-supported cylindrical tanks," *Engineering Structures*, Vol. 233, April 2021, DOI: 10.1016/j.engstruct.2020.111589.

Yu, C.-C, and A. S. Whittaker, "Verification of numerical models for seismic fluid-structure-interaction analysis of internal components in liquid-filled advanced reactors," *Earthquake Engineering and Structural Dynamics*, Vol. 50, No. 6, pp. 1692-1712, May 2021, DOI: 10.1002/eqe.3417 .

Yu, C.-C, and A. S. Whittaker, "Calculations of added mass for a cylindrical component submerged in a confined fluid," digital appendix to Yu and Whittaker, 10.1002/eqe.3417, *Earthquake Engineering and Structural Dynamics*, DOI: 10.6084/m9.figshare.13547642.

Mir, F. U. H., C.-C. Yu, and A. S. Whittaker, "Rocking response of liquid-filled cylindrical tanks," *Earthquake Spectra*, Vol. 37, No. 3, pp. 1698-1709, July 2021, DOI: 10.1177/8755293020981973.

Yu, C.-C., F. U. H. Mir, and A. S. Whittaker, "Validation of numerical models for seismic fluid-structure interaction analysis of nuclear, safety-related equipment," *Nuclear Engineering and Design*, Vol. 379, August 2021, DOI: 10.1016/j.nucengdes.2021.111179.

Lal, K. M., S. S. Parsi, B. D. Kosbab, E. Ingersoll, H. Charkas, and A. S. Whittaker, "Towards standardized advanced nuclear reactors: seismic isolation and the impact of the earthquake load case," *Nuclear Engineering and Design*, Vol. 386, January 2022, DOI: 10.1016/j.nucengdes.2021.111487.

Yu, C.-C, and A. S. Whittaker, "A process to verify numerical models for seismic fluid-structure interaction in advanced reactor vessels," *Nuclear Engineering and Design*, Vol. 387, February 2022, DOI: 10.1016/j.nucengdes.2021.111580.

Parsi, S. S., K. M. Lal, B. D. Kosbab, E. Ingersoll, K. Shirvan, and A. S. Whittaker, "Seismic isolation: a pathway to standardized advanced nuclear reactors," *Nuclear Engineering and Design*, Vol. 387, February 2022, DOI: 10.1016/j.nucengdes.2021.111445.

Mir, F. U. H., K. M. Lal, M. C. Constantinou, and A. S. Whittaker, "Validation of a numerical model of a fluid-filled, seismically isolated cylindrical vessel," *Earthquake Engineering and Structural Dynamics*, Vol. 51, No. 8, pp. 1857-1873, July 2022, DOI: 10.1002/eqe.3642.

Dhulipala, S. L. N, C. Bolisetti, L. B. Munday, W. H. Hoffman, C.-C. Yu, F. U. H. Mir, F. Kong, A. D. Lindsay, and A. S. Whittaker, "Development, verification, and validation of comprehensive acoustic fluid-structure interaction capabilities in an open-source

computational platform," *Earthquake Engineering and Structural Dynamics*, Vol. 51, No. 10, pp. 2188-2219, August 2022, DOI: 10.1002/eqe.3659.

Mir, F. U. H., and A. S. Whittaker, "Dynamic responses of submerged components in advanced reactors: experimental and numerical studies" *Earthquake Spectra*, Vol. 38, No. 4, pp. 3063-3088, November 2022, DOI: 10.1177/87552930221112689.

Mir, F. U. H., N. Nguyen, B. Song, B. D. Kosbab, and A. S. Whittaker, "Sloshing loads on the roof of an annular, cylindrical tank," published on-line, *Nuclear Technology*, September 2022, DOI: 10.1080/00295450.2022.2118484.

Mir, F. U. H., A. S. Whittaker, B. D. Kosbab, and N. Nguyen, "Characterizing the seismic response of a molten salt nuclear reactor," submitted to *Earthquake Engineering & Structural Dynamics*, September 2022.

Mir, F. U. H., A. S. Whittaker, B. D. Kosbab, and N. Nguyen, "Recommendations for numerical seismic analysis of a fluoride-salt cooled high-temperature reactor," submitted to *Nuclear Engineering and Design*, September 2022.

Parsi, S. S., M. V. Sivaselvan, and A. S. Whittaker, "Nuances in modeling and impedance-inspired control of shake tables for ground-motion trajectories," submitted to *Earthquake Engineering & Structural Dynamics*, September 2022.

Lal, K. M., A. S. Whittaker, and M. C. Constantinou "Mid-height seismic isolation of equipment in nuclear power plants," submitted to *Earthquake Engineering & Structural Dynamics*, September 2022.

Parsi, S. S., M. Verma, M. V. Sivaselvan, and A. S. Whittaker, "Conceptualization and development of a novel impedance-matching control design strategy for executing model-in-the-loop simulations," submitted to *Earthquake Engineering & Structural Dynamics*, October 2022.

Lal, K. M., A. S. Whittaker, and M. V. Sivaselvan, "Mid-height isolation of safety-class equipment in advanced nuclear power plants: numerical simulations and design recommendations," to be submitted to *Engineering Structures*, November 2022.

Parsi, S. S., M. V. Sivaselvan, and A. S. Whittaker, "Validation of an impedance-matching control design strategy for model-in-the-loop simulations," to be submitted to *Journal of Structural Engineering*, November 2022.

B. Conference papers and technical reports (published)

Mir, Faizan U.-H, C.-C. Yu, M. Cohen, P. Bardet, J. Coleman, and A. S. Whittaker, "Dataset generation for validation of fluid-structure interaction models," *Transactions*, 25th International Conference on Structural Mechanics in Reactor Technology (SMiRT25), Charlotte, NC, August 2019.

Yu, C.-C., F. U.-H. Mir, M. Cohen, J. Coleman, P. Bardet, and A. S. Whittaker, "Verification of numerical models for seismic fluid-structure interaction analysis of advanced nuclear reactors," *Transactions*, 25th International Conference on Structural Mechanics in Reactor Technology (SMiRT25), Charlotte, NC, August 2019.

Parsi, S. S., M. Kumar, M. Kumar, C. Bolisetti, J. Coleman, and A. S. Whittaker, "Implementation and benchmarking of seismic protective devices in MASTODON,"

Transactions, 25th International Conference on Structural Mechanics in Reactor Technology (SMiRT25), Charlotte, NC, August 2019.

Lal, K., S. S. Parsi, D. Scott, K. Shirvan, M. Cohen, P. Kirchman, B. Kosbab, and A. S. Whittaker, "Cost basis for utilizing seismic isolation for nuclear power plants," *Transactions*, 25th International Conference on Structural Mechanics in Reactor Technology (SMiRT25), Charlotte, NC, August 2019.

Yu, C.-C., and A. S. Whittaker, "Analytical and numerical studies of seismic fluid-structure interaction in liquid-filled vessels," Technical Report MCEER-20-0003, University at Buffalo, State University of New York, Buffalo, New York, August 2020.

Yu, C.-C., F. U. H. Mir, and A. S. Whittaker, "Verification of numerical models for seismic fluid-structure interaction of advanced reactor internals," *Proceedings*, 17th World Conference on Earthquake Engineering, Sendai, Japan, September 2021.

Mir, F. U. H., C.-C. Yu, and A. S. Whittaker, "Experiments for validation of FSI models for seismic response of advanced reactor internals," *Proceedings*, 17th World Conference on Earthquake Engineering, Sendai, Japan, September 2021.

Parsi, S. S., K. Lal, K. Shirvan, B. D. Kosbab, M. Cohen, P. Kirchman, and A. S. Whittaker, "Equipment-level seismic protective systems for advanced nuclear reactors," *Proceedings*, 17th World Conference on Earthquake Engineering, Sendai, Japan, September 2021.

Doulgerakis, N., P. K. Tehrani, I. Talebinejad, B. D. Kosbab, M. Cohen, and A. S. Whittaker, "Software commercial grade dedication guidance for nonlinear seismic analysis," *Developed as part of a project funded by the Department of Energy under grant number DE-NE0008857*, United States Department of Energy, Washington, DC, September 2021.

Mir, F. U. H., C.-C. Yu, H. Charkas, and A. S. Whittaker, "Validation of numerical models for seismic fluid-structure-interaction analysis of advanced reactors," *Proceedings*, 2021 International Congress of Advances in Nuclear Power, Abu Dhabi, United Arab Emirates, October 2021.

Lal, K. M., S. S. Parsi, H. Charkas, K. Shirvan, M. Cohen, P. Kirchman, B. Kosbab, and A. S. Whittaker, "Reducing capital cost of nuclear power plants using seismic isolation," *Proceedings*, 2021 International Congress of Advances in Nuclear Power, Abu Dhabi, United Arab Emirates, October 2021.

Mir, F. U. H., C.-C. Yu, and A. S. Whittaker, "Validation of numerical models for seismic analysis of submerged components in advanced reactors," *Proceedings*, 2021 International Topical Meeting on Probabilistic Safety Assessment and Analysis, American Nuclear Society, Columbus, OH, November 2021.

Parsi, S. S., M. V. Sivaselvan, and A. S. Whittaker, "Model-in-the-loop control design for seismic testing of base-isolated nuclear equipment," *Proceedings*, 2021 International Topical Meeting on Probabilistic Safety Assessment and Analysis, American Nuclear Society, Columbus, OH, November 2021.

Yu, C.-C., F. U. H. Mir, and A. S. Whittaker, "Theoretical analysis and numerical simulation of the seismic response of liquid-filled, head-supported reactor vessels," *Proceedings*,

2021 International Topical Meeting on Probabilistic Safety Assessment and Analysis, American Nuclear Society, Columbus, OH, November 2021.

Mir, F. U. H., K. M. Lal, B. D. Kosbab, K. Tilow, B. Song, N. Nguyen, M. Clavelli, M. Peres, and A. S. Whittaker, "Earthquake-simulator experiments of a seismically isolated Gen IV reactor model," *Proceedings*, 12th National Conference on Earthquake Engineering, Salt Lake City, UT, June 2022.

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Parsi, S. S., M. V. Sivaselvan, and A. S. Whittaker, "Some nuances in modeling and control of servo-hydraulic shake tables," *Proceedings*, 12th National Conference on Earthquake Engineering, Salt Lake City, UT, June 2022.

Doulgerakis, N., P. Tehrani, I. Talebinejad, B. D. Kosbab, M. Cohen, and A. S. Whittaker, "Software commercial grade dedication guidance for nonlinear seismic analysis," *Transactions*, 26th International Conference on Structural Mechanics in Reactor Technology (SMiRT26), Potsdam, Germany, July 2022.

Mir, F. U. H., K. M. Lal, A. S. Whittaker, and M. C. Constantinou, "Physical and numerical simulations of seismic fluid-structure-interaction in advanced nuclear reactors," Technical Report MCEER-22-0002, University at Buffalo, State University of New York, Buffalo, New York, August 2022.

Parsi, S. S., M. V. Sivaselvan, and A. S. Whittaker, "Impedance-matching control design for shake-table testing and model-in-the-loop simulations," Technical Report MCEER-22-0003, University at Buffalo, State University of New York, Buffalo, New York, October 2022.

Mir, F. U. H., K. M. Lal, A. S. Whittaker, and M. C. Constantinou, "Earthquake-simulator experiments of a model of a seismically isolated, fluoride-salt cooled high temperature reactor," Technical Report MCEER-22-0004, University at Buffalo, State University of New York, Buffalo, New York, October 2022.

Mir, F. U. H., K. M. Lal, B. D. Kosbab, K. Tilow, B. I. Song, N. Nguyen, M. Cavelli, and A. S. Whittaker, "Overview of earthquake-simulator experiments of a Gen IV pebble-bed reactor," *Proceedings*, ANS Winter Meeting, Phoenix, AZ, November 2022.

Lal, K. M., A. S. Whittaker, and M. C. Constantinou, "Mid-height seismic isolation of safety-class equipment in advanced nuclear power plants," *Proceedings*, ANS Winter Meeting, Phoenix, AZ, November 2022.

C. Status reports

Nil

D. Media reports

Nil.

E. Invention disclosures

One invention was disclosed and posted to iEdison:

Title: Commodifying nuclear energy by standardizing plant deployment using seismic protective systems and algorithmic design

Inventors: Andrew Whittaker and Eric Ingersoll (LucidCatalyst)

F. Patent applications/issued patents

Nil.

G. Licensed technologies

Nil.

H. Networks/collaborations fostered

This project has forged networks and collaborations with several organizations and companies, including the American Nuclear Society, American Society of Mechanical Engineers, Southern Operating Company, Kairos Power, SC Solutions, and TerraPraxis.

I. Websites featuring project work results

Nil.

J. Other products

The data generated in the experiments described in the journal articles, conference papers, and reports will be curated and made available on the NSF-supported DesignSafe platform.

The research products have informed the writing of the seismic isolation chapter in ASCE/SEI Standard 4 and will influence the seismic isolation design provisions of ASCE/SEI Standard 43.

Follow-on Funding

Three projects have funded, building from early results of the ARPA-E project:

Source	Funding	Subject
USDOE	$500,000	Topical report on seismic isolation of nuclear power plants Lead: Southern Company Lead contractor: University at Buffalo
USDOE, ARC-20	$5,000,000	Horizontally configured high-temperature gas reactor Lead: MIT Contractor: University at Buffalo
USDOE, NEUP	$800,000	Gamma irradiation of seismic protective devices Lead: University at Buffalo