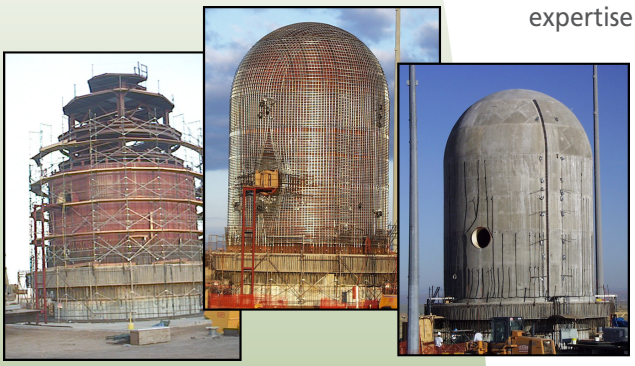
Sandia National Laboratories

Energy, Climate, & Infrastructure Security

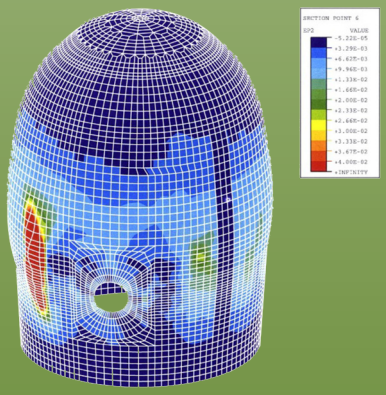
Containment Integrity Research



Quarter-scale containment is the largest and most comprehensively instrumented scaled nuclear reactor containment vessel model ever tested.

Vision

To enhance the nation's security and prosperity through sustainable, transformative approaches to our most challenging energy, climate, and infrastructure problems.



Finite Element Model – 3D Shell Response

Sandia is a nationally and internationally recognized leader in Nuclear Reactor containment research, supporting operations, lifetime extensions, security and vulnerability assessments, over a broad range of phenomena. Sandia's expertise includes evaluation of containment when subjected to high velocity impacts, enormous pressures and stresses, and attacks by saboteurs. Sandia's resources enable the completion of a complex scientific investigation in its entirety. Its engineers are capable of performing a numerical analysis in totality from modeling a structure in software to validating the calculations with experiments and journal data.

Sandia infra-structure and capabilities include the knowledge and broad technical expertise supporting the collection of experimental data, numerical simulation analyses tools and the knowledge bases needed to provide the NRC with the ability to make reliable and technically sound regulatory decisions. Sandia uses the latest engineering software both from industry (i.e. ABAQUS) and developed by Sandia (i.e. SIERRA Solid Mechanics). These codes provide the most sophisticated analyses that can be made for finite element analysis of structures. Sandia's high performance computing (HPC) platforms include some of the world's most powerful supercomputers, which are used for numerically intensive simulations. On-site experimental facilities include the rocket sled track for testing high-velocity impacts, the drop tower facility to observe damage to falling objects and a centrifuge, which can subject items to inertial forces as high as 300 Gs. The coupling of analytical expertise with the deep knowledge of the regulatory environment produces a comprehensive package uniquely available at Sandia. Sandia researchers reduce uncertainties in areas of potentially high safety or security risk or significance and develop the technical basis for risk-informed, performance-based regulations. Sandia maintains the breadth of technical capability and information needed for the resolution of nuclear safety and security issues, and provides technical support and consultation to the NRC in the related specialized disciplines.

Sandia provides independent assessments through the review, analysis, and evaluation of the safety performance of facilities licensed by the NRC.

Capabilities support the development and application of methods, data, standards, and modeling tools to assess the structural performance of structures, systems and components; the technical bases and computational methods to resolve structural engineering issues associated with security assessments; collection and analysis of data related to performance of structures and provide guidance for structural design elements. Sandia technical capabilities address emerging issues by providing the expertise supporting the revision and development of NRC Regulatory Guides (RGs), NUREG reports and responses to inquiries from the Commission, Advisory Committee on Reactor Safeguards (ACRS), and Congress.

Historical Milestones

Drawing on nearly 60 years of accrued knowledge and support provided to the NRC, Sandia applies its extensive knowledge of both regulation- based and extra-regulatory environments to model, test and analyze structures within the area of nuclear energy to address structural engineering and containment integrity issues.

1950 – WASH-3: Exclusion vs. Containment

1957 – Shippingport Nuclear Power Plant

1971 – 10 CFR 50, Appendix A: General Design Criteria

U.S. DEPARTMENT OF ENERGY

1973 – WASH-1250: Reactor Safety Study (definition of Severe Accidents)

1973 – ASME B&PV Code, Section III, Div. 2 (ACI-359) (concrete containment design rules)

1975 – WASH-1400: Rasmussen Report (estimates of containment capacity)

1979 – Three Mile Island, Unit 2 Accident

1981 – SNL Background Study on Containment Capacity

1982 – NRC-Sponsored Containment Integrity Program at SNL

1982 – 1:32 Scale Steel Model Tests

1984 – 1:8 Scale Steel Model Tests

1986 – NRC Qualitative Safety Goals

1986 – Individual Plant Examination Guidance

1987 – 1:6 Scale Reinforced Concrete Model Test

~1988 – SNL and EPRI/CTL Separate Effects Tests

~1988 – Personnel Airlock Test

1988 – F4 Phantom Jet Impact Test

~1989 – Electrical Penetration Tests

1989 – Sizewell-B 1:10 Scale Model Test

1990 – NUREG-1150: Risk Study (probabilistic risk assessment, PRA)

1991 – NUPEC-NRC Cooperative Containment Research Program at SNL

1994 – Containment Bellows Test

1996 – 1:10/1:4 Scale Steel Model Test

1996 – Watts Bar 1 (latest US commercial nuclear power plant)

2000 – 1:4 Scale Prestressed Concrete Model Limit State Test

2000 – NUPEC 1:10 Scale Seismic Capacity Tests

2001 – 1:4 Scale Prestressed Concrete Model Structural Failure Test

2005 – OECD/NEA/CSNI ISP#48 on Containment Capacity

2006 – Containment Integrity at SNL Summary

2005 – Seismic Behavior of Spent Fuel Storage Cask Systems

2006 – Completed Aircraft Threat Assessment for Nuclear Power Plants

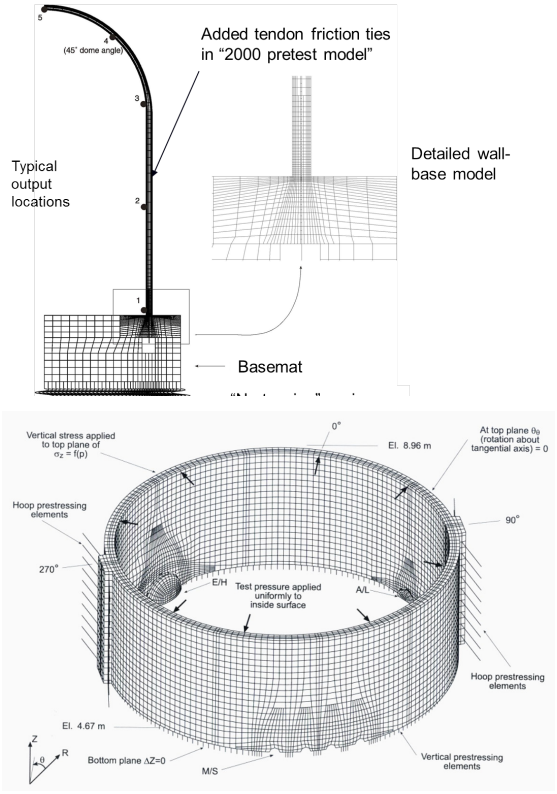
2009 – Began supporting OECD (IRIS) [on-going]

2012 – NUREG supporting NRC-AERB Collaboration on Grouted Tendons

2013 – IAEA Fukushima Di-ichi International Peer Review Team Assessment

2013 – NRC degraded containment program support [on-going]

Modeling of Containment Failure

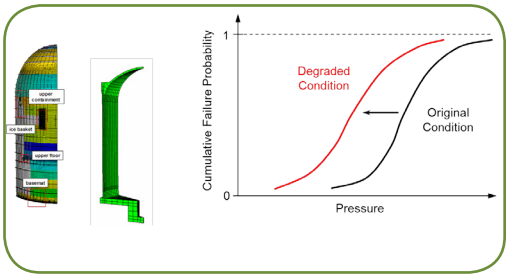


3DCM and Global Axi-Symmetric Modeling of prestressed concrete containment vessel tests

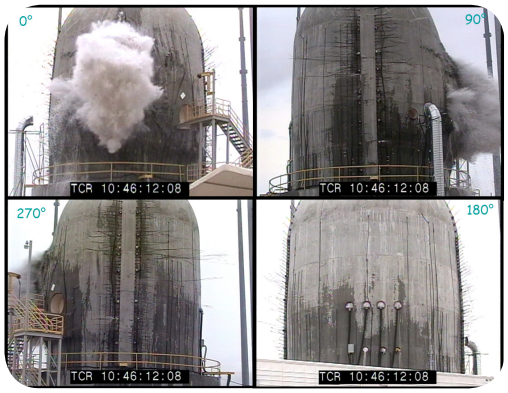
INTEGRATION OF CAPABILITIES

- Muti-scale, multi-process testing and experimental facilities
- Large-scale validation experiments and experimental facilities
- Materials science and characterization
- Chemical phenomenological modeling
- Structural phenomenological modeling
- Thermal phenomenological modeling
- Severe accident modeling
- Aerosol chemistry, dispersion, transport
- Computational simulation and High Performance Computing
- Uncertainty and sensitivity analysis
- Probabilistic risk assessment methods development and application
- Regulatory analysis
- Nuclear-rigor quality assurance

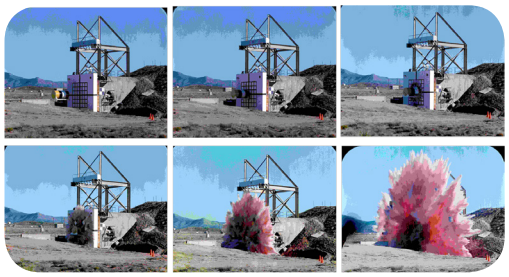
Structural Analysis of Complex Systems



Fragility Analysis of Degraded Containment



Containment Failure Test
Prestressed concrete containment vessel model structural failure mode testing.



Containment Vulnerability Studies
Water Slug Testing

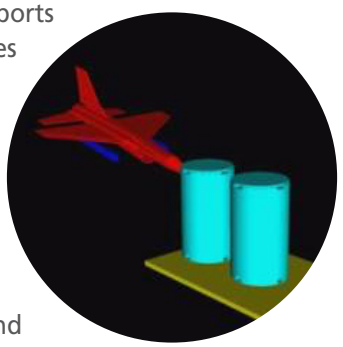
INTEGRATION OF CAPABILITIES

- Materials science and characterization
- Structural phenomenological modeling
- Thermal phenomenological modeling
- Computational simulation (various systems)
- Uncertainty and sensitivity analysis
- Probabilistic risk assessment methods development and application
- Regulatory analysis
- Nuclear-rigor quality assurance

A nationally and internationally recognized leader in complex systems analysis, structural/mechanical analysis and design in support of safety and security assessments of commercial nuclear power generation plants and fuel cycle facilities. Focusing on both probabilistic and deterministic risk analyses to support NRC regulatory investigations and high consequence engineering analysis and testing. We have planned and conducted large-scale structural tests and complex structural analyses using both commercial and Sandia codes. Computational methods developed in structural mechanics, heat transfer, fluid mechanics, shock physics, and many other fields of engineering can be an enormous aid to understanding the complex physical systems.

Sandia supports the NRC's regulations and regulatory guidance with regard to risk significance, burden reduction potential, and engineering design margins associated with facility systems, structures and components supporting existing and new reactor designs. Capabilities include development of methods, data, standards, and metallurgical modeling tools for evaluating degradation mechanisms on reactor pressure vessel steels; fracture mechanics measurement and analysis technologies; tools to quantitatively assess changes in structural reliability of nuclear plant systems, structures and components as a result of operating environment effects or aging of materials. Sandia infrastructure and capabilities include the multidisciplinary technical expertise and accrued knowledge needed to provide the NRC with the ability to make reliable and technically sound regulatory decisions. For instance, Sandia's Corrosion and Electrochemical Sciences Department conducts research and development in the areas of materials aging and materials interactions. Sandia's ongoing investment in electrochemical and surface analytical techniques and expertise enables us to quantify material behavior under accelerated aging conditions and to develop empirical, phenomenological and fundamental models and understanding of materials aging. Sandia material scientists are supporting many science and engineering functions that include vulnerability assessments, failure analyses, measurement of unknown material properties, development of improved materials, the correlation of secondary evidence with aging processes (e.g., chemical signatures), the development and deployment of predictive, physical-based mathematical models, the characterization of specific material-aging processes, and age-related defects.

Sandia addresses emerging issues and supports the revision and development of NRC Regulatory Guides (RGs), NUREG reports and responses to inquiries from the Commission, Advisory Committee on Reactor Safeguards (ACRS), and Congress. Sandia researchers reduce uncertainties in areas of potentially high safety or security risk or significance and develop the technical basis for risk-informed, performance-based regulations. Sandia maintains the breadth of technical capability and information needed for the resolution of nuclear safety and security issues, provides technical support and consultation to the NRC in the related specialized disciplines and supports independent assessments of the safety performance of facilities licensed by the NRC.



Historical Milestones

Sandia has performed structural and mechanical analyses supporting safety and risk analyses for many complex system accident scenarios. Built on a foundation of accrued knowledge involving multidisciplinary expertise these analyses have led to the development of technologies and design modifications to mitigate and prevent the consequences of a release of nuclear or radioactive material during severe accident scenarios.

NUREG/CR-3234 – The Potential for Containment Leak Paths Through Electrical Penetration Assemblies Under Severe Accident Conditions (1983)

NUREG/CR-3222 – The Search for a High Elongation Strain Gage System (1983)

NUREG/CR-3724 – Ultimate Strength Analyses of the Watts Bar, Maine Yankee, and Bellefonte Containments (1984)

NUREG/CR-4944 – Containment Penetration Elastomer Seal Leak Rate Test (1987)

NUREG/CR-5096 – Evaluation of Seals for Mechanical Penetrations of Containment Buildings (1988)

NUREG/CR-5099 – Evaluation of Materials of Construction for the Reinforced Concrete Reactor Containment Model (1988)

NUREG/CR-5096 – Evaluation of Seals for Mechanical Penetrations of Containment Buildings (1988)

NUREG/CR-5334 – Severe Accident Testing of Electrical Penetration Assemblies (1989)

NUREG/CR-6154 – Experimental Results from Containment Piping Bellows Subjected to Severe Accident Conditions (1995)

NUREG/CR-6906 – Containment Integrity Research at Sandia National Laboratories (2006)

NUREG/CR-6920 – Risk-Informed Assessment of Degraded Containment Vessels (2006)

NUREG-2110 – xLPR Pilot Study Report (2012)

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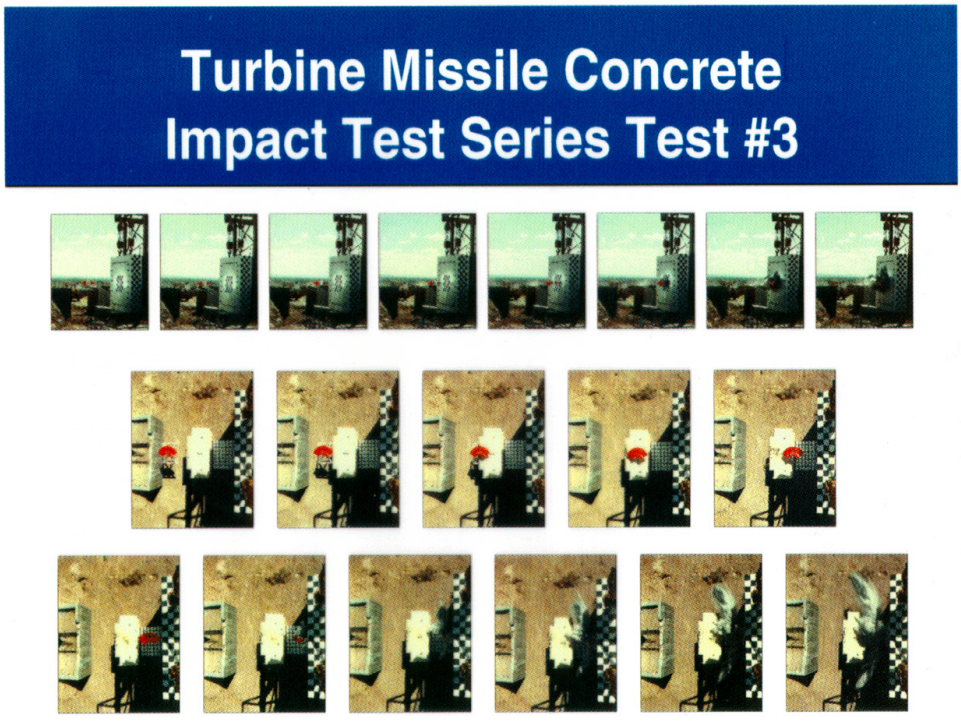

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