Technical Issues in Nuclear Reactor Regulation

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Agenda

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- **Introduction to Research at the NRC**
- **Technical Issues**
  - Operating reactors
  - New reactors
  - Advanced reactors
  - International collaboration
  - Technical issues on the horizon
- **Questions and Answers**

NRC's Office of Nuclear Regulatory Research (RES)

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- **Who we are:**
  - Mandated by Congress
  - About 250 staff
  - Engineers, scientists, analysts
  - >$68M funding
  - Located at 21 Church St.,Rockville, MD

RES: What We Do

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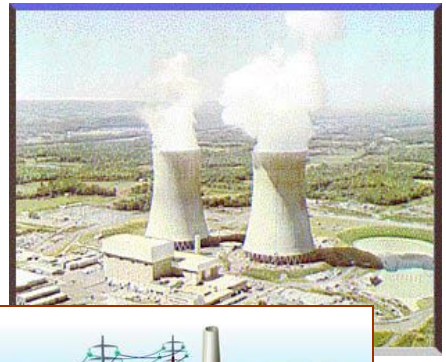
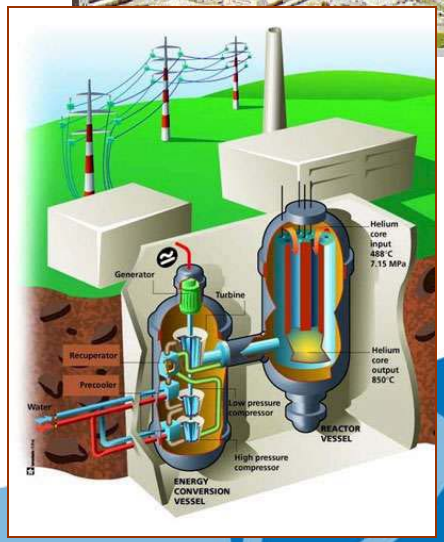
- Develop technical bases to support regulatory decisions
  - Technical tools, data, and analytical models
  - Confirmatory research and analyses
- Provide in-house technical expertise to regulatory offices and the Regions
- Anticipate NRC's future needs
  - Develop technical infrastructure for advanced reactor licensing reviews
  - Support new reactor licensing
  - Develop Long-Term Research Plan





Why Perform Research?

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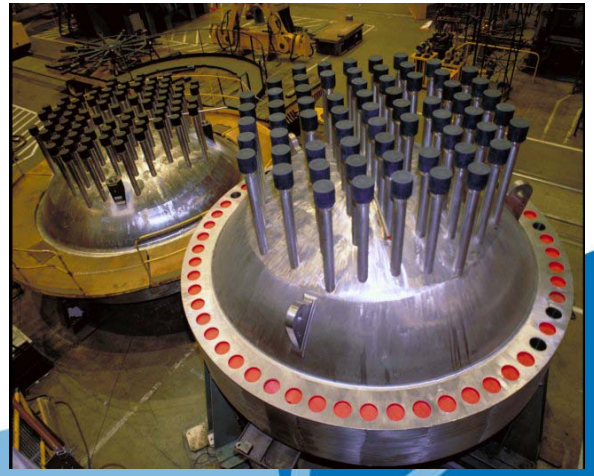
- Support regulatory decisions on nuclear reactors, nuclear materials, and radioactive waste
- Identify and resolve safety issues for current and new designs and technologies
- We accomplish this through:
  - Testing
  - Code and data development
  - Analyses
  - National and international collaboration

•Cladding oxidation



•Reactor Pressure Vessel Head

Principal Areas of Research

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- Materials science
- Digital instrumentation & control and electrical
- Nuclear fuel behavior under accident conditions
- Health physics
- Environmental transport
- Structural engineering
- Seismic & geotechnical
- Accident Sequence Precursor analyses
- New and advanced reactors infrastructure development
- Thermal-hydraulics, severe accidents, reactor physics, and safety analyses
- Probabilistic risk assessment
- Human factors and reliability
- Fire research
- Analysis of Operating Experience

* - See NUREG-1925 for more information

Technical Issues: Operating Reactors

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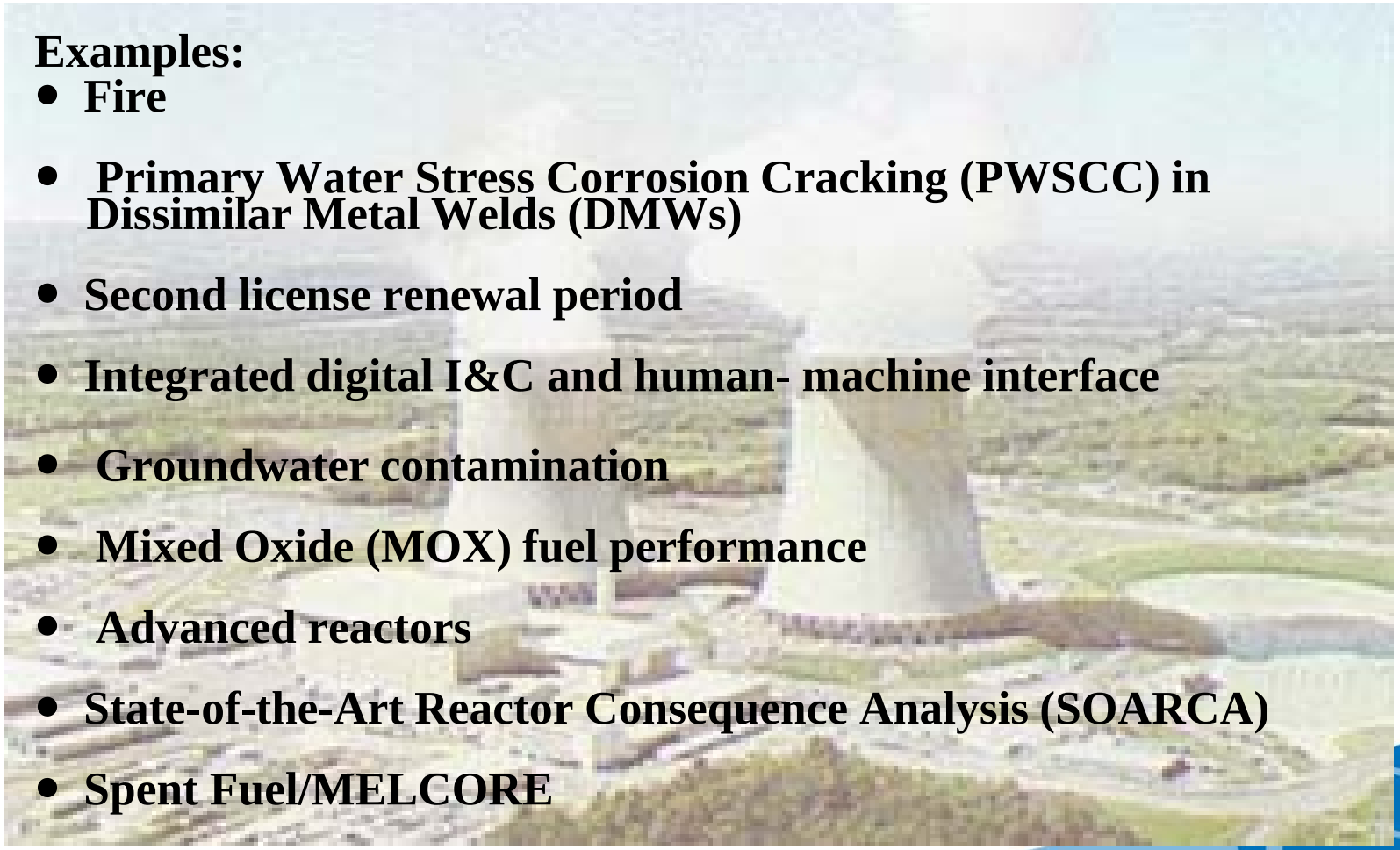

Examples:

- **Fire**
- **Primary Water Stress Corrosion Cracking (PWSCC) in Dissimilar Metal Welds (DMWs)**
- **Second license renewal period**
- **Integrated digital I&C and human- machine interface**
- **Groundwater contamination**
- **Mixed Oxide (MOX) fuel performance**
- **Advanced reactors**
- **State-of-the-Art Reactor Consequence Analysis (SOARCA)**
- **Spent Fuel/MELCORE**

Technical Issue: Fire

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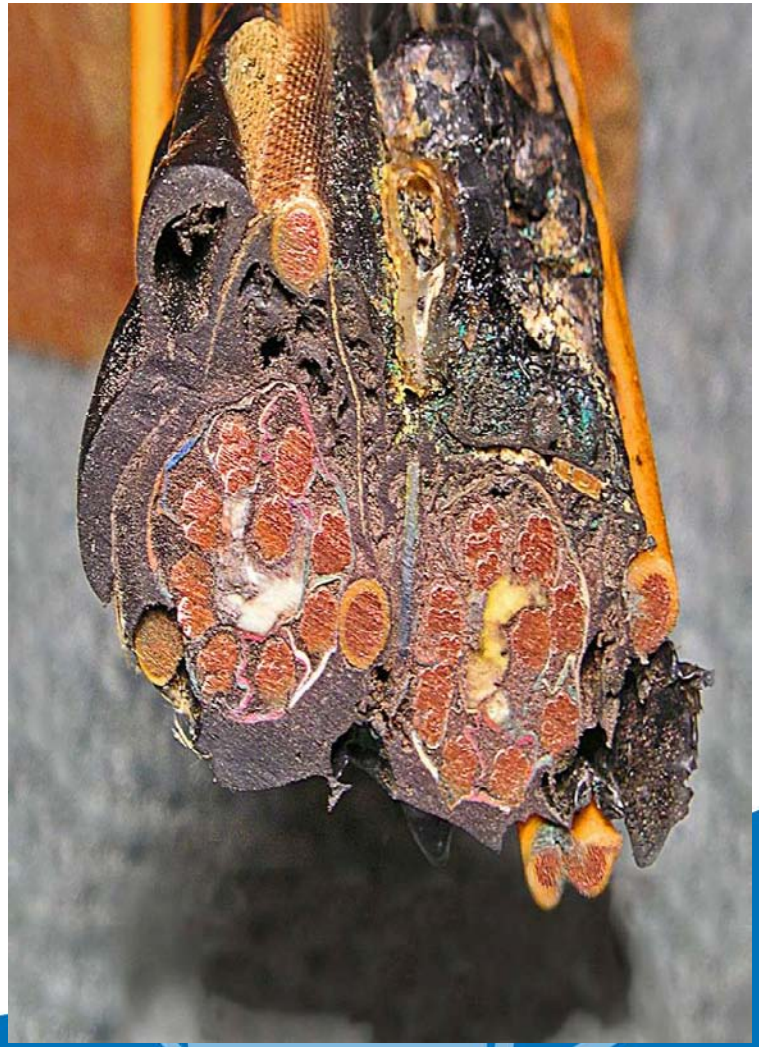
- **Fire barrier performance**
  - Potential issues with performance of Thermo-Lag and other barrier systems
  - Confirmatory studies
    - HEMYC performance
- **Cable performance**
  - Potential for multi-conductor cable failures in fires
  - Confirmatory studies
    - CAROLFIRE testing
      - AC Circuits (2008)
    - DESIREE-FIRE testing
      - DC Circuits (in progress)



Technical Issue: PWSCC

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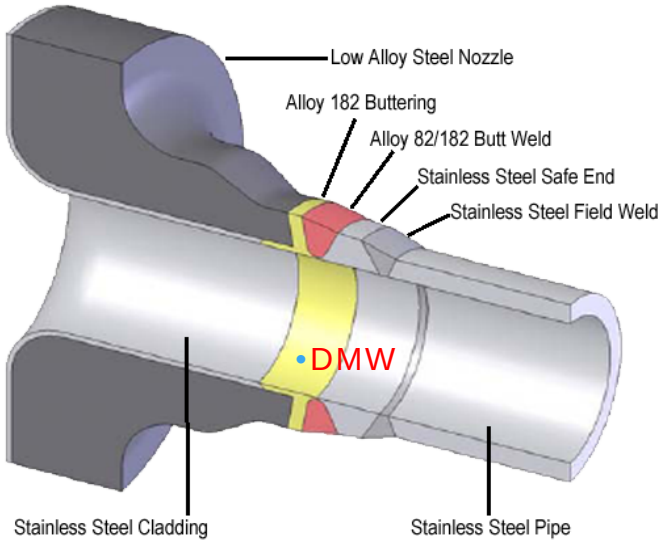
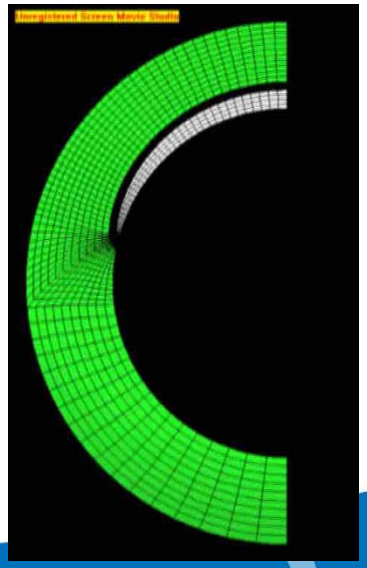
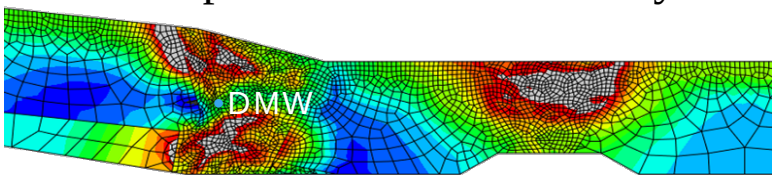
- Primary water stress corrosion cracking (PWSCC) is a form of degradation that occurs in aging PWR reactors.
- Inspections identify numerous PWSCC events since 1993.
- PWSCC evaluated to ensure continued safe operation.
- Mitigation processes such as weld overlays used to curtail PWSCC growth with engineered compressive stresses.

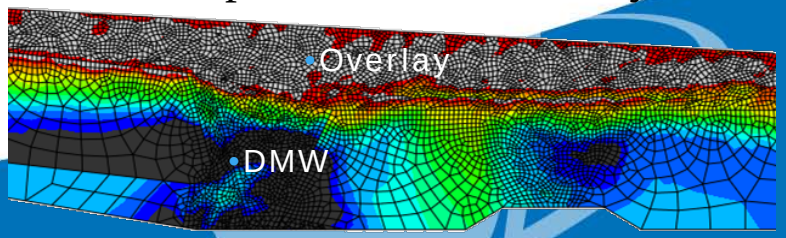




•Hoop Stress Prior to Overlay



•Hoop Stress After Overlay



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Aging Management Research

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- The NRC is conducting research into potential technical issues that may challenge long-term safe operation of existing commercial nuclear power plants in second, and subsequent, license renewal periods (i.e., “Life Beyond 60”)
  - License renewal process has been successfully implemented
- Challenges include:
  - Reactor vessel and internals
  - Cable insulation
  - Buried / submerged structures
  - Concrete exposed to high temperature and radiation

License Renewal Effects

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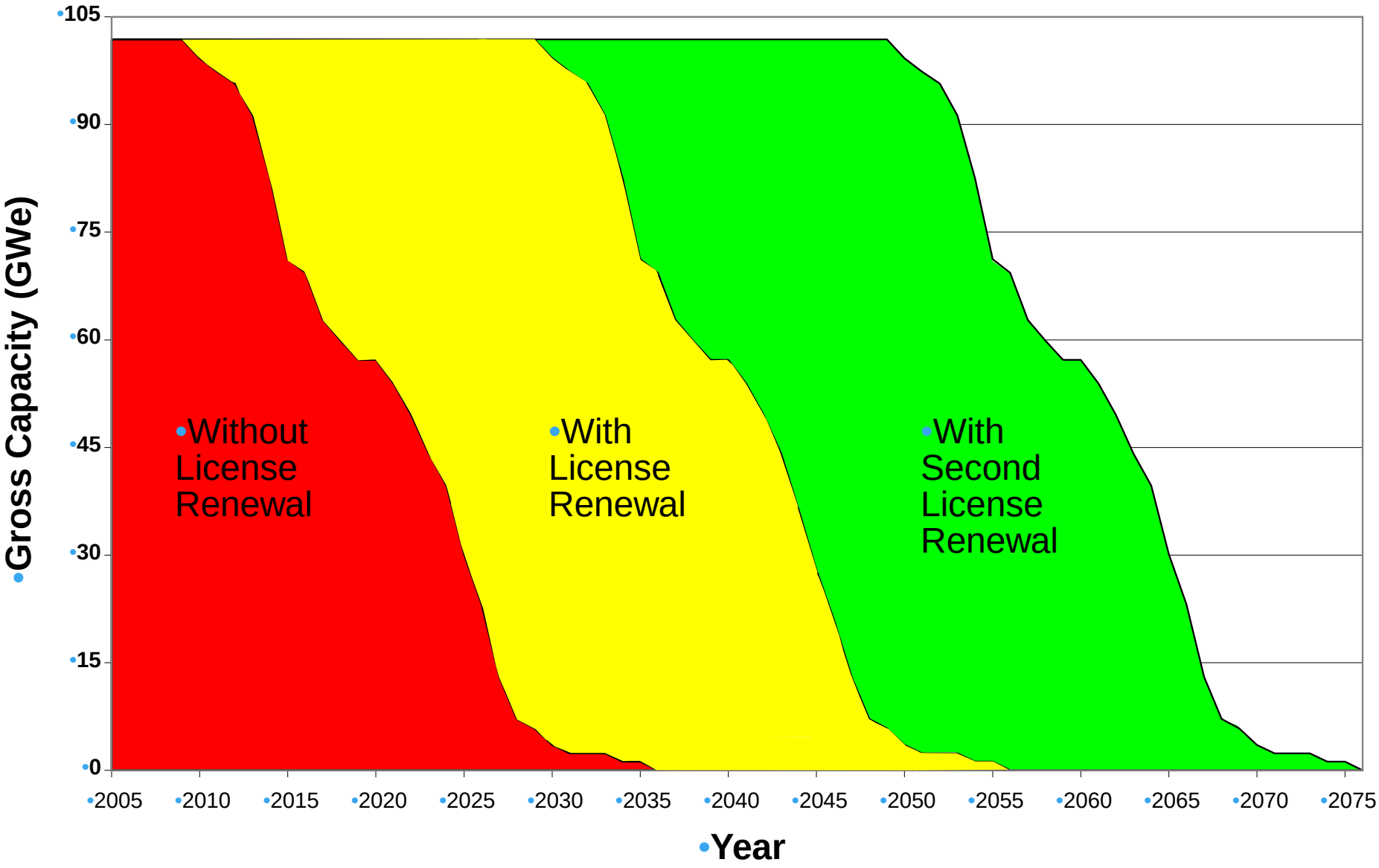

NRC Perspective

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- The NRC ensures that safety-significant issues are identified and resolved in a timely manner.
- It is not the NRC's responsibility to solve, for the industry, any potential aging issues that may affect continued safe operation of the existing fleet.
- The NRC is willing to collaborate with industry and others in an integrated and holistic program to ensure long-term safety.
- In order to be ready for potential second renewal applications, ground work needs to start now.

Technical Issue: State-of-the-Art Reactor Consequence Analysis (SOARCA)

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- Perform a state-of-the-art, realistic evaluation of severe accident progression, radiological releases and offsite consequences for important reactor accident sequences
  - Phenomenologically based, consistent, integral analyses of radiological source terms
- Provide a realistic assessment of potential offsite consequences to replace previous consequence analyses
  - E.g., NUREG/CR-2239 (1982 Sandia Siting Study)

Motivation

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	Plant Design and Operations	Severe Accident Phenomenology	Emergency Planning
1982 Sandia Siting Study	Total CDF: $1x10^{-4}$/yr to $1x10^{-5}$/yr	Alpha Mode Failure due to in-vessel steam explosions Early containment failure due to direct containment heating (DCH) by rapid heating of containment atmosphere by small, hot particles Conservative Accident Progression - Large and fast radiological release assumed	Generic (bounding) EP modeling
2008 SOARCA	Improved Plant Performance Total CDF: $1x10^{-5}$/yr to $1x10^{-6}$/yr Additional Mitigative Measures	Alpha Mode Failure is remote & speculative based on improved modeling techniques No early containment failure due to DCH because of trapping of small, hot particles in other compartments, reducing containment pressure Realistic accident progression analysis – release is smaller with a slower evolution	Improved Site Specific EP Modeling

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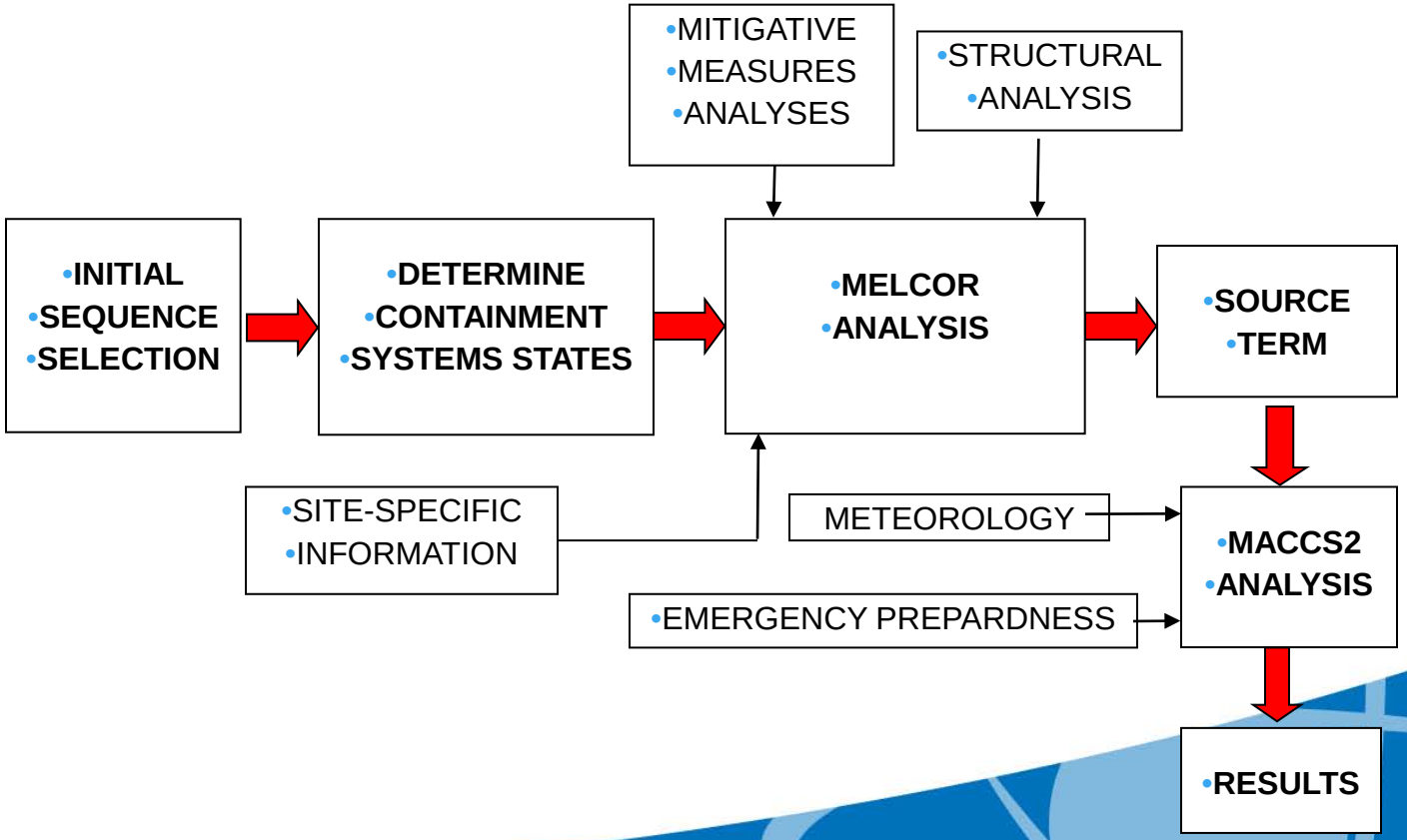
Process for Estimating Offsite Radiological Consequences



Sample BWR Mark I Long Term Station Blackout Compared to Sandia Siting Study SST-1 Source Term

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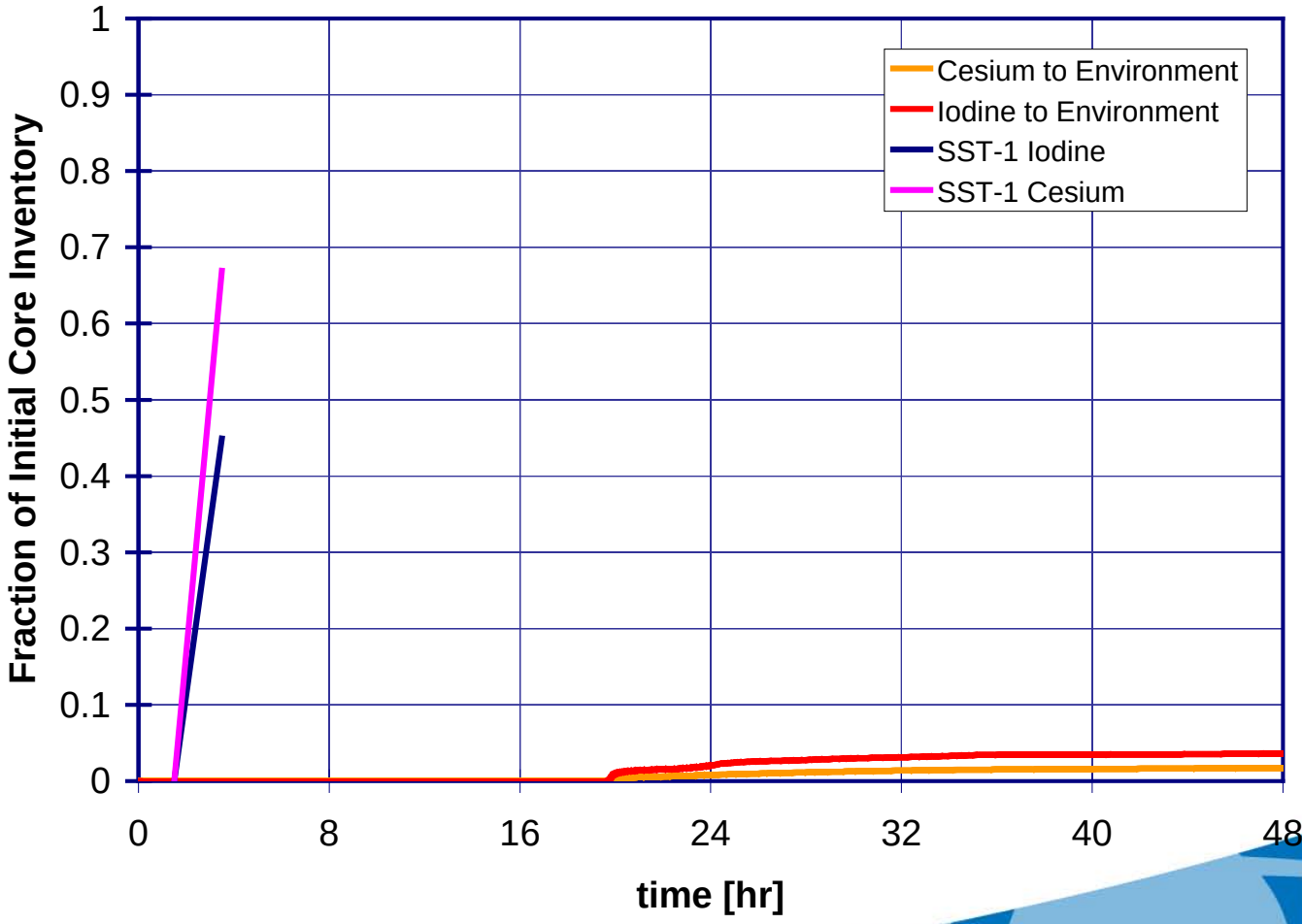

Technical Issues: New Reactors

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Digital instrumentation and control

- Highly-Integrated Control Room communications issues:
  - Interchannel communications
  - Communications between safety and non-safety channels
- Diversity and Defense in Depth
- Cyber security
- Digital system risk
  - Digital system (software) failure modes
- Analytical safety assessment of digital systems

Advanced Reactor Designs

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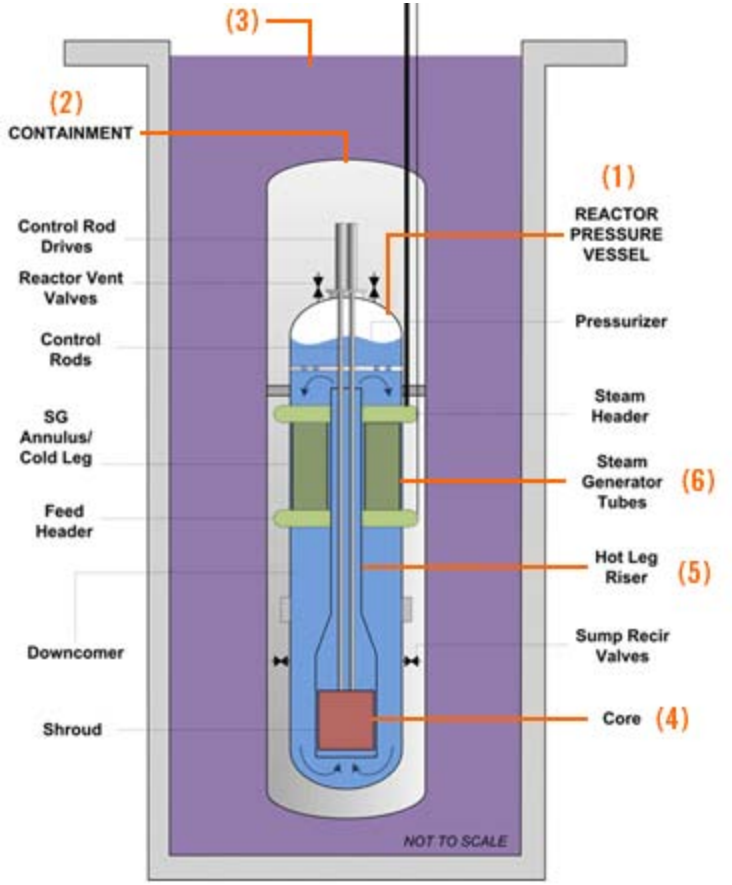
- Gas cooled reactors
  - MHTGR
  - PBMR
  - ANTARES
- Liquid metal reactors
  - 4S
  - PRISM
- Other technologies
  - IPWRs
  - Hyperion



•NuScale Design

Technical Issues: HTGR

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- Selection of licensing basis events
- Containment vs. Confinement
- Core performance, e.g.
  - Graphite conductivity degrades significantly (depends on irradiation temperature)
  - Integrity of silicon carbide barrier
- How much dust is created and is it released during a LOCA (confinement performance requirements)?
- Is passive decay heat removal effective (peak fuel temperature <1600C)?

Computational Fluid Dynamics

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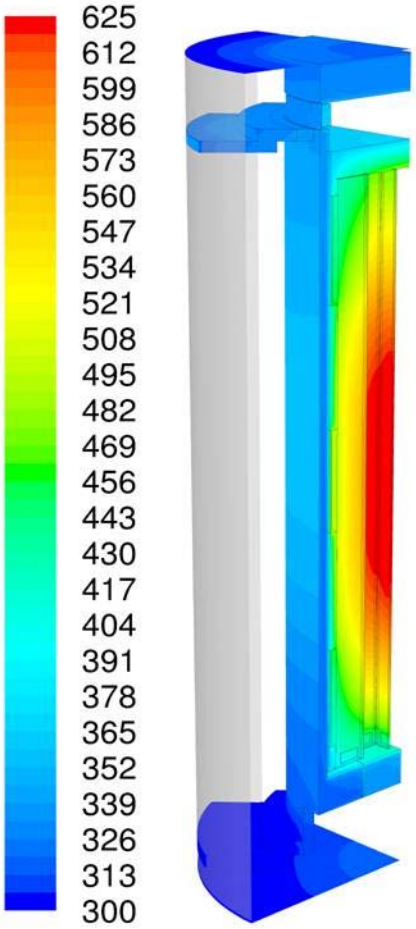

- Temperatures in a Dry Cask

- CFD use in thermal-hydraulics
  - Three-dimensional details not available from system codes
  - Reduce uncertainty in licensing decisions
- RES capabilities
  - State-of-the-art 200 processor cluster
  - FLUENT
  - STAR-CCM+

CFD Applications

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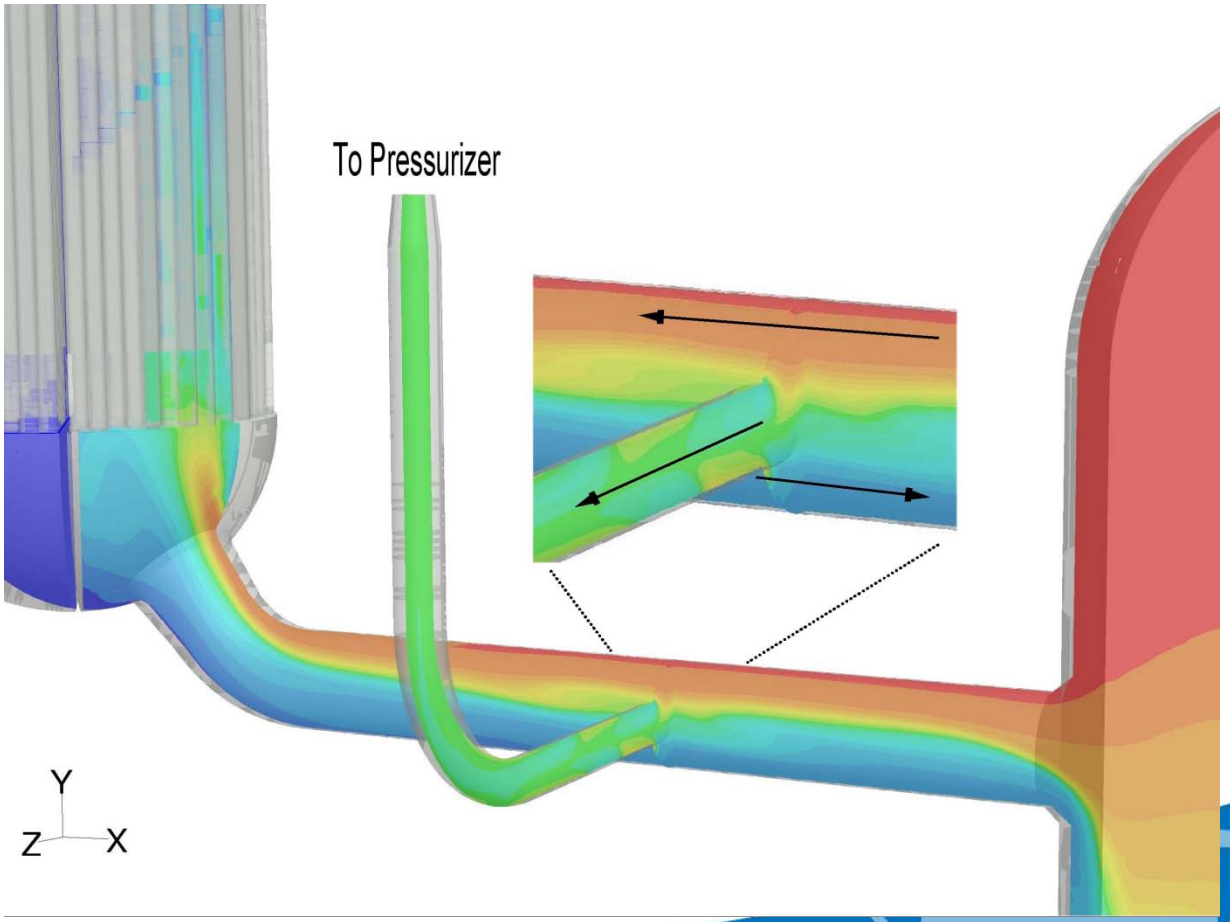

Hot gases circulate during a severe accident scenario

International Collaboration

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What technical issues are being addressed?

- Operating events assessments and implications
- Fire
- Risk assessments and methods
- Materials degradation
- Seismic
- Halden Reactor Project
- Human Reliability Analysis
- Life Beyond 60
- CAMP???

Technical Issues on the Horizon

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- Cross-Cutting and Emergent Technologies
  - Advanced Analytical Capabilities
  - Advanced Fabrication Techniques
  - Extended In-Situ and Real-Time Inspection & Monitoring Techniques
  - Offsite Mitigation Strategies
  - Risk Assessment for Advanced Reactor/Fuel Cycle Facilities
  - Fire Effects on Fiber-Optic Cables

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Questions & Answers

REFERENCE LIST

U.S.NRC
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- www.nrc.gov
- **NUREG-1925, "Research Activities 2009"**
- **NUREG-1338**: Preapplication Safety Evaluation Report for MHTGR
- **IAEA HTGR Knowledge Base**
  www.iaea.org/inis/aws/htgr
- **Long-Term Research Plan**
  http://www.nrc.gov/about-nrc/regulatory/research.html
- **CAROLFIRE**
  http://www.nrc.gov/reading-rm/doc-collections/nuregs/contract/cr6931/
- **NUREG-1860**: Feasibility Study for a Risk-Informed and Performance-Based Regulatory Structure for Future Plant Licensing