U.S.NRC
UNITED STATES NUCLEAR REGULATORY COMMISSION
Protecting People and the Environment

STATE-OF-THE-ART REACTOR CONSEQUENCE ANALYSES

Advisory Committee on Reactor Safeguards Briefing
December 6, 2007

AGENDA

- Project Overview
- Accident Sequence Selection
- Containment System States
- Mitigative Measures
- MELCOR
- MACCS2
- Emergency Preparedness
- Peer Review
- Sample Sequence
- Reporting Latent Cancer Fatalities

SOARCA Objectives

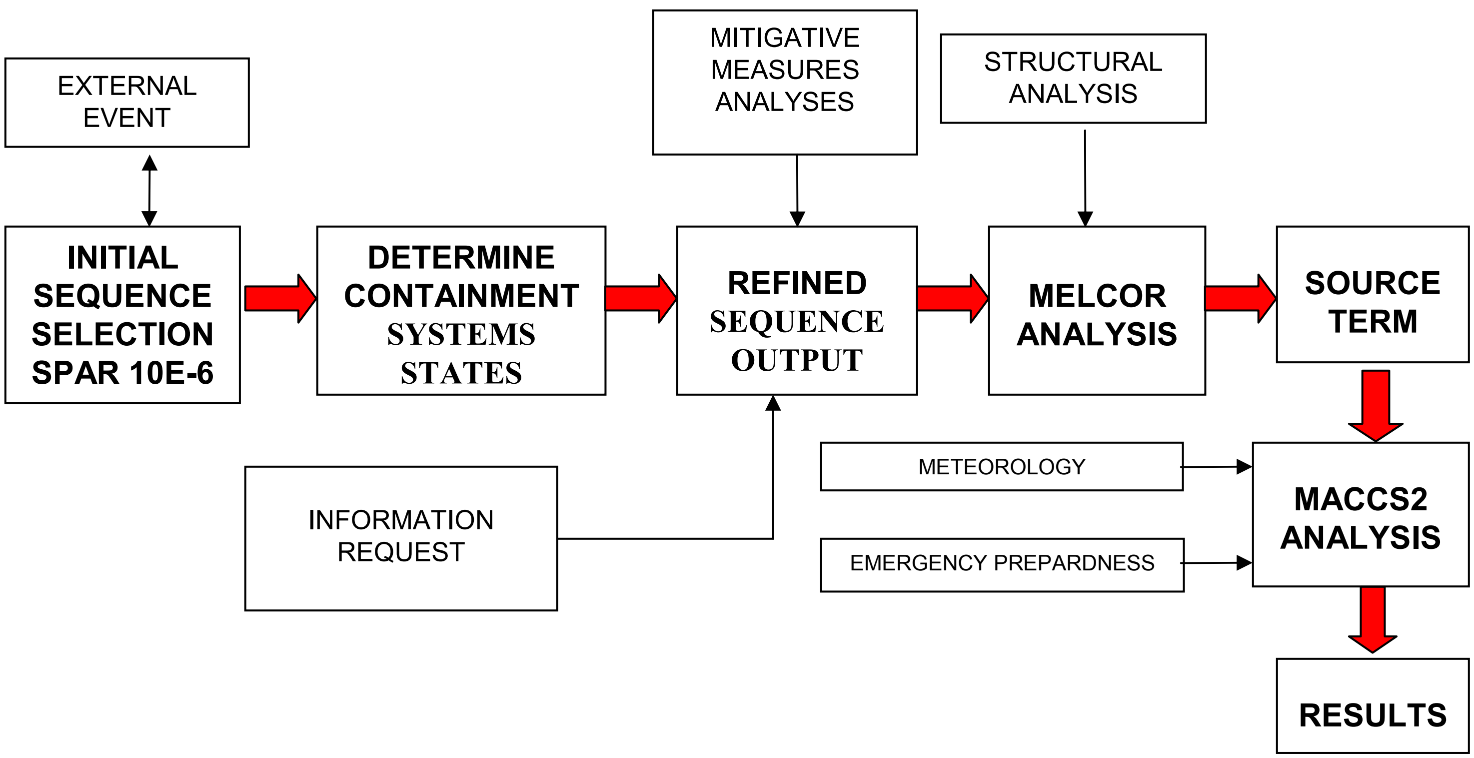
- Perform a state-of-the-art, realistic evaluation of severe accident progression, radiological releases and offsite consequences for frequency dominant core damage accident sequences
- Provide a more accurate assessment of potential offsite consequences to replace previous consequence analyses

Severe Accident Improvements

- 25 years of national and international research
- Regulatory improvements reduced the likelihood of severe accidents
- Improved modeling capability
- Improvements in plant design
- Other plant improvements

SOARCA OVERVIEW

SOARCA PROCESS



SOARCA Approach

- Full power operation
- Plant-specific sequences with a CDF$\geq 10^{-6}$ (CDF$\geq 10^{-7}$ for bypass events)
- External events included
- Consideration of all mitigative measures
- Sensitivity analyses to assess the effectiveness of different safety measures
- State-of-the-art accident progression modeling based on 25 years of research to provide a best-estimate for accident progression, containment performance, time of release and fission product behavior
- More realistic offsite dispersion modeling
- Site-specific evaluation of public evacuation based on updated Emergency Plans

SOARCA Insights

- Sequences dominated by external events, primarily large seismic events (PWR also includes bypass events)
- Previously used sequences have a significantly lower probability of occurrence or are not considered to be feasible
  - Alpha mode failure
  - High pressure melt ejection
  - ATWS
- Mitigative measures are proving to be effective at preventing core damage or containment failure

Sequence Screening Process

(Internal Events)

- Initial Screening - use enhanced SPAR models to screen out low CDF sequences with an overall CDF ≤1.0E-7 and sequences with a CDF <1.0E-8. This step eliminates <10% of the overall CDF (typically about 5%)
- Sequence Evaluation – identify and evaluate the dominant cutsets for the remaining sequences (~90% of initiator CDF). Determine system and equipment availability / unavailability and accident sequence timing
- Scenario Grouping - group sequences together that have similar times to core damage and equipment unavailability
- Select bounding sequences based on most limiting mitigative measures available

Sequence Screening Process

(External Events)

- Identify dominant externally initiated event sequences based upon available probabilistic risk assessment documentation from NUREG-1150, IPEEE submittals, as well as any additional and available supporting documentation
- Identify potential mapping between dominant external events and internally initiated events identified by the SPAR analysis
- Where mapping between external and internal events are not possible or appropriate, a unique externally initiated event or sensitivity study was recommended
- The resulting limited set of scenarios obtained for each SOARCA plant was used for subsequent accident progression and consequence analysis

Containment Systems States

The availability of engineered systems that can impact post-core damage containment accident progression, containment failure and radionuclide release

- Determine the anticipated availability of containment and containment support systems not considered in the Level 1 core damage analysis
- Determine the availability of non containment and non containment support systems such as low pressure injection that can impact containment accident progression

Mitigative Measures Analysis

- The mitigative measures analyses are qualitative, sequence-specific systems and operational analyses based on licensee identified mitigative measures from EOPs, SAMGs, and other severe accident guidelines that are applicable to, and determined to be available during a sequence groupings whose availability, capability and timing will be utilized as an input into the MELCOR analyses

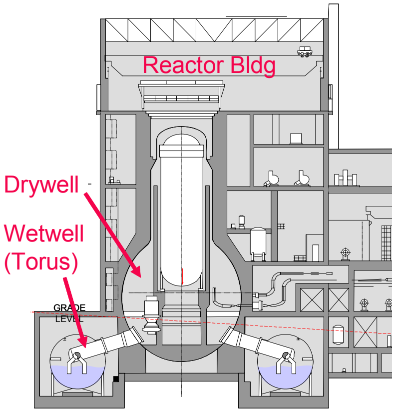
Mitigative Measures Analysis Process

- For those dominating sequences / sequence groupings within the scope of SOARCA, determine the potentially available mitigative measures
- Perform a system and an operational analysis based on the initial conditions and anticipated subsequent failures
- Determine the anticipated availability, capability and the time to implementation
- MELCOR will determine the effectiveness of the mitigative measures based on capability and estimated time of implementation

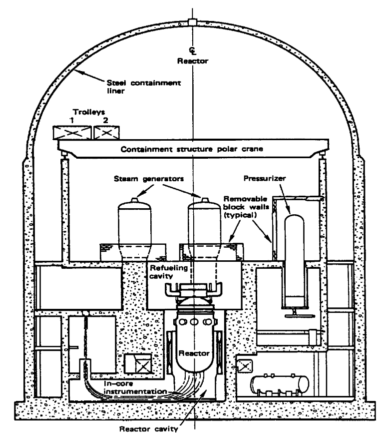
Structural Analyses Objective

Evaluate the behavior of containment structures under unmitigated severe accident conditions to predict the following performance criteria at the selected sites:

- Functional Failure Pressure - Leakage
- Structural Failure Pressure - Rupture
- Develop Leakage Rate and/or Leakage Area as a Function of Internal Pressure



Peach Bottom "Mark I – Steel Containment"



Surry "Reinforced Concrete Containment"

MELCOR Analyses

- MELCOR Code Improvements
  - MACCS2 Output Interface
  - Implement Fuel Collapse Model Logic
  - Update MELCOR Defaults
  - Pool Scrubbing Model
- Develop a plant-specific model
- Perform accident progression analyses for each plant using MELCOR computer code to determine source term, potential containment failure state, and time of release as input in the MACCS2 analyses

MACCS 2 Analyses

- MACCS2 Code Improvements
  - Increased number of evacuation cohorts
  - Alternative models for latent cancer fatality dose response
  - Increased angular resolution
  - More plume segments
  - Enable network evacuation model
  - KI ingestion
  - Evacuation speed modifiers by grid element and for precipitation
  - Enable parameter uncertainty
- Perform consequence analyses for each plant using MACCS2 computer code to determine early fatalities, and latent cancer fatalities

MACCS2 Assumptions

- No contaminated food or water consumed
- Latest federal guidelines used for dose conversion factors
- KI ingestion by half the 0 – 10 mile population, suboptimum timing
- Median values from US/CEC study of uncertainty for non-site specific parameter
- Site-specific population and meteorology
- Projected dose during emergency period, 5 rem relocate in 1 day; 2 rem, 2 days
- Return criteria: 0.5 rem in 1 yr for Peach Bottom, 4 rem in 5 yr for Surry
- In general,1-hr plume segments are used

Emergency Preparedness

- Model the protective response afforded by current site-specific Emergency Preparedness (EP) Programs to improve realism
- Used site-specific evacuation time estimates for evacuation of EPZ
- Used OREMs to model evacuation of 10 to 20 mile area
- Modeled cohort data
  - Population
  - Evacuation timing
  - Travel speed
  - Roadway network
- Data was used in MACCS2 to develop consequence estimates

Peer Reviews

- Internal
  - Staff
  - ACNW&M
  - ACRS
- External
  - National Experts
  - International Experts

Peach Bottom Accident Sequences

- PRA models indicate core damage frequency dominated by seismic event, which is functionally a long-term SBO ($1x10^{-6}$ to $5x10^{-6}$ /yr)
  - Fire and flood events would be similar in terms of core damage progression
- Internal events were all < 10^{-6}/yr
- Bypass events were very low frequency: <<10^{-7}/yr

Surry Accident Sequences

- Dominant PRA events
  - Long-term SBO ($1x10^{-5}$ to $2x10^{-5}$/yr)
  - Short-term SBO ($1x10^{-6}$ to $2x10^{-6}$/yr)
  - ISLOCA ($7x10^{-7}$/yr)
  - SGTR ($5x10^{-7}$/yr)
- SBO events are due to seismic, flooding and fire initiators, and are modeled as seismic event
  - Internal fire and internal flood events are less challenging, more mitigation available
- ISLOCA and SGTR are due to random equipment failures followed by operator errors

Sample Sequence
Loss of Vital AC Bus

- This sequence was selected and assessed for demonstration purposes, not within the scope of SOARCA, CDF $<10^{-6}$
- MELCOR analysis showed that this event can be mitigated

Sample Sequence Loss of Vital AC Bus – cont.

- Initiator: Loss of Div IV dc power resulting in
  - SCRAM, MSIV closure, containment isolation
  - RCIC automatically starts, 1 CRDHS pump active
- Operator actions (base case):
  - Load shed to maximize duration of DC power
  - Maximize flow from single CRDHS pump
  - Depressurize RCS at 1.5 hours
  - Secure CRDHS from 4 – 7 hrs to prevent RPV overfill
- Sufficient to prevent core damage

Sample Sequence
Loss of Vital AC Bus – cont.
Insights

- Sufficient injection capability to prevent core damage
  - SPAR does not credit CRDHS for coolant makeup
- RPV depressurization and maximizing CRDHS flow are important operator actions to optimize recovery
- SLC also available for high pressure injection
- Battery duration is important for RCIC operation and instrumentation

Reporting Latent Cancer Fatalities

- Commission Paper
- Options
  - Range of thresholds (0 – 5 rem)
  - Linear no threshold (LNT)
  - Estimate point value from Health Physics Society
    - 5 rem in one year, 10 rem in a life time
- ACNWM Full committee Meeting
  - Presentation on MACCS2
  - Initial suggestions included reporting dose and risk versus consequences
- In staff review