



# **Research Related to Concrete Technology at USNRC**

**Syed Ali, Senior Technical Advisor for Civil/Structural Issues  
Office of Nuclear Regulatory Research, USNRC**

**Concrete Subgroup Meeting - CSNI-NEA Working Group IAGE  
Paris, France  
April, 2012**

# Topics



- Round Robin Study on Containment Post-tensioning Methods
- Modeling of Concrete Behavior under Impact Loads
- Degraded Containment Research
- Standards and Guidance for Design of Modular Composite Structures
- Analysis and Modeling for Safety-Related SC Structures
- Spent Fuel Pool (SFP) Scoping Study
- Radiation Effects on Concrete
- Expanded Proactive Materials Degradation Analysis (EMDA)
- Research Related to Transportation Casks
- Revision of USNRC Regulatory Guides
- Future Potential Research for Concrete in NPPs

# Round Robin Study on Containment Post-tensioning Methods



- Scope:
  - Investigate the structural behavior of a concrete containment vessel with grouted and un-grouted tendon systems
  - Document and compare in-service inspection requirements in peer-reviewed standards and codes for grouted and un-grouted tendons
  - Examine if corrosion protection used for grouted and un-grouted tendons are adequate for the expected life of the structure.
- Organization doing work for NRC: Sandia National Labs (SNL)

# Round Robin Study on Containment Post-tensioning Methods (Cont'd)



- Progress made in last 2 years:
  - Project initiated in September 2010
  - Sandia began with NASTRAN model, and has started the process to convert to Abaqus and in-house code Presto
  - Focus is to study structural behavior, strength, and expected failure modes
  - Participated in Expert Meeting of the OECD Post Tensioning Methodologies for Containment Building hosted by Electricite de France, April 20-21, 2011.

MS1

**Slide 4**

---

**MS1**

Added slide 17.  
MXS13, 3/11/2011

# Modeling of Concrete for Impact Loads



- NRC participates in a multiple partner, international experimental research program, called IMPACT, carried out by the Technical Research Center of Finland (VTT).
- The IMPACT program uses small and medium scale tests to collect data on the behavior of reinforced and pre-stressed concrete slabs subjected to missile impacts.
- IMPACT also collects data on the behavior of various types of missiles (soft and hard) and their loads on structural components.
- NRC uses the test data to benchmark codes that the staff and its contractors utilize to analyze concrete components of nuclear power plants subject to impact loads.

# Modeling of Concrete for Impact Loads (Cont'd)

- Current NRC analyses use the LSDYNA code and the Winfrith concrete model with strain rate effects (LSDYNA material 84).
- The testing and related analysis address various parameters and effects including:
  - Soft and hard missiles, and liquid-filled missiles
  - Impact speed
  - Transverse reinforcement type (stirrups and T-headed bars) and amount
  - Global and local failure/damage modes of the slabs such as flexure and punching shear
  - Hydrodynamic impact loads, and
  - Concrete models

# Degraded Containment Research



- NRC sponsors research at SNL to study the effects of degradation on the performance of several types of containments in a risk-informed manner.
- The NRC anticipates that the results of this research will be used to inform on a case-by-case basis regulatory processes such as:
  - license renewal reviews if containment degradation is detected
  - decisions on inspection, monitoring and repair
  - review of containment repairs
- It is anticipated that results of the program will support identifying the relative risk significance of potential degradation processes.
- Study has integrated structural analysis results with pre-existing probabilistic risk assessment (PRA) models (NUREG-1150) for severe accident conditions
  - It used structural analysis to develop fragility curves for concrete containments with and without cases of hypothetical liner degradation.



# Degraded Containment Research (Cont'd)



- Early phases of the study indicated that risk metrics such as Large Early Release Frequency (LERF) used in conjunction with Regulatory Guide (RG) 1.174 guidance for risk-informed acceptability may not fully capture effects of liner corrosion.
- The study then progressed to the investigation of other potential metrics, e.g., consequences, to assess containment degradation in a risk-informed manner.
- Currently, the study is investigating metrics such as Small Early Release Frequency (SERF), not addressed in RG 1.174, and also the binning of LERF and SERF used in the PRA models.
- The study also plans to assess potential effects of containment repair operations on containment performance (e.g., repairs from steam generator replacement operations).

# Standards and Guidance for Design of Modular Composite Structures



- Modular composite construction consisting of concrete reinforced with steel faceplates (SC) is being proposed for safety-related structures of new reactor designs
  - This construction technique is outside the scope of current U.S. design codes and standards such as ACI 349 and AISC N690
- International codes for this type of construction already exist
  - Japan Electric Association JEAC-4618 (2009)
  - Korea's KEPIC-SNG Steel Plate Concrete Structures (2010)
- U.S. consensus standard planned as an appendix to AISC N690 is in advanced stages of preparation
  - Being prepared by a subcommittee to AISC Task Committee 12 (N690)

# Standards and Guidance for Design of Modular Composite Structures (Cont'd)



- To support development of guidance for the design of SC structures, NRC is reviewing existing international standards and their technical bases
  - NRC is assessing the adequacy and sufficiency of the technical bases for the development of design specifications. Outside experts informed the staff on this effort.
  - Staff participates in the activities of AISC's TC 12 subcommittee developing US standard for safety-related SC structures
- NRC is sponsoring research on the evaluation of the technical bases for the SC structures, namely in upgrading and benchmarking of modeling tools for independent confirmatory analysis

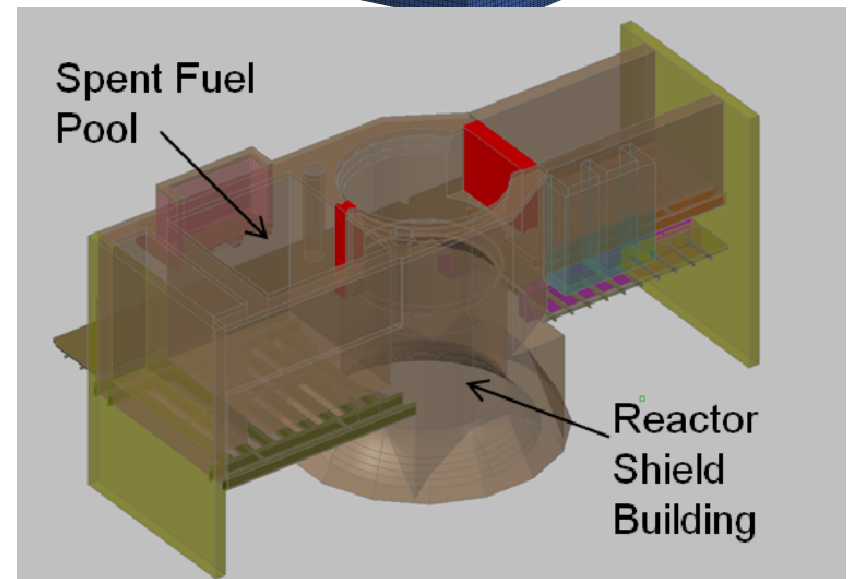
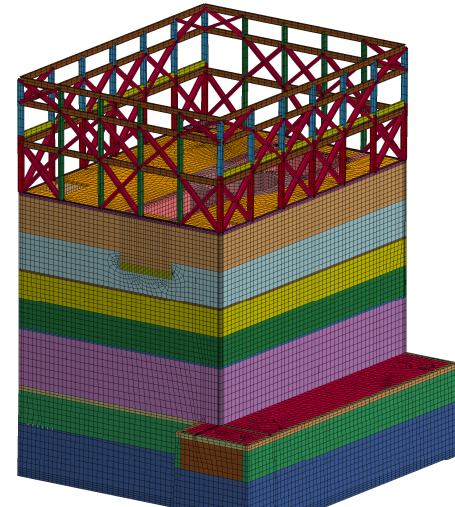
# Analysis and Modeling for Safety-Related SC Structures



- NRC sponsored the upgrading of a finite element modeling tool for reinforced concrete structures for the analysis and modeling of SC structures
  - Benchmarking against test data from Japan and other large-scale testing indicates that the tool captures the full range of response of various components including shear critical components and is useful in interpreting testing data.
  - Results have been published in the Journal of Nuclear Engineering and Design and presented at the ACI 2012 Spring Convention
- Through a research grant to the University of Toronto the NRC is continuing this modeling effort and extending the modeling tool to layered shell elements
  - An objective of the research is to obtain a simple tool that can capture load redistributions and be used for earthquake time-history analyses in independent confirmatory analysis by NRC staff and NRC contractors.
  - As an example, the enhanced software would support assessment of safety margins implicit in certain provisions of consensus design standards.

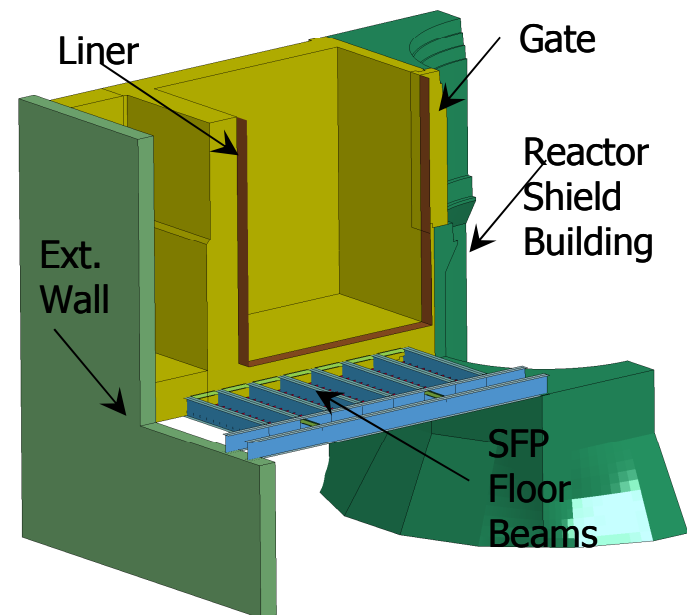
# Spent Fuel Pool (SFP) Scoping Study

- Focus: reexamination of the effects on SFP consequences of moving older fuel to dry cask in an expedited manner
- Two conditions to be considered
  - high-density loading
  - low-density loading
- Elements of the study include
  - Seismic and structural assessment
  - SCALE analysis (dose rates)
  - MELCOR accident progression analysis
  - Emergency planning assessment
  - MACCS2 offsite consequence analysis
  - Probabilistic considerations

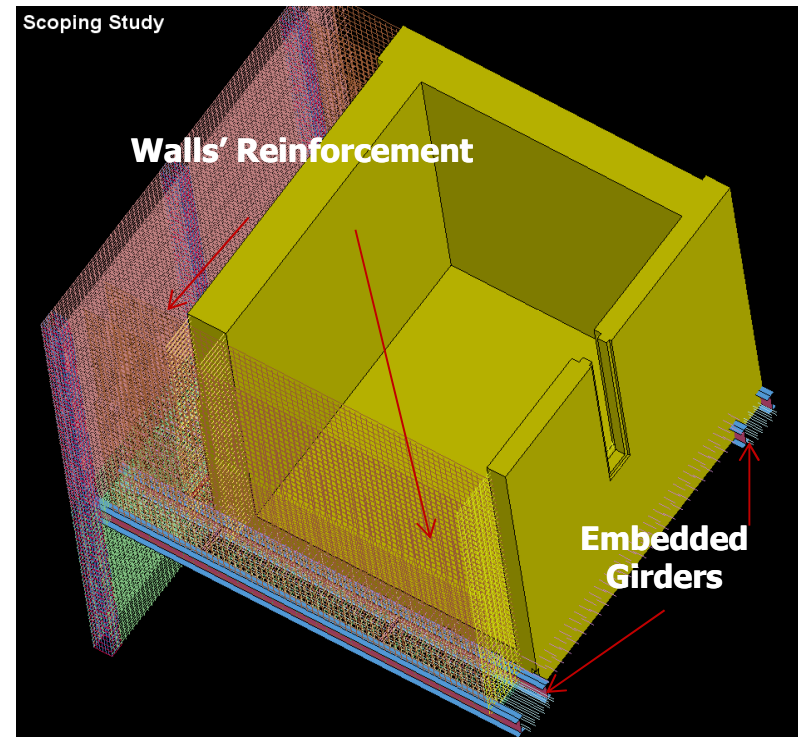
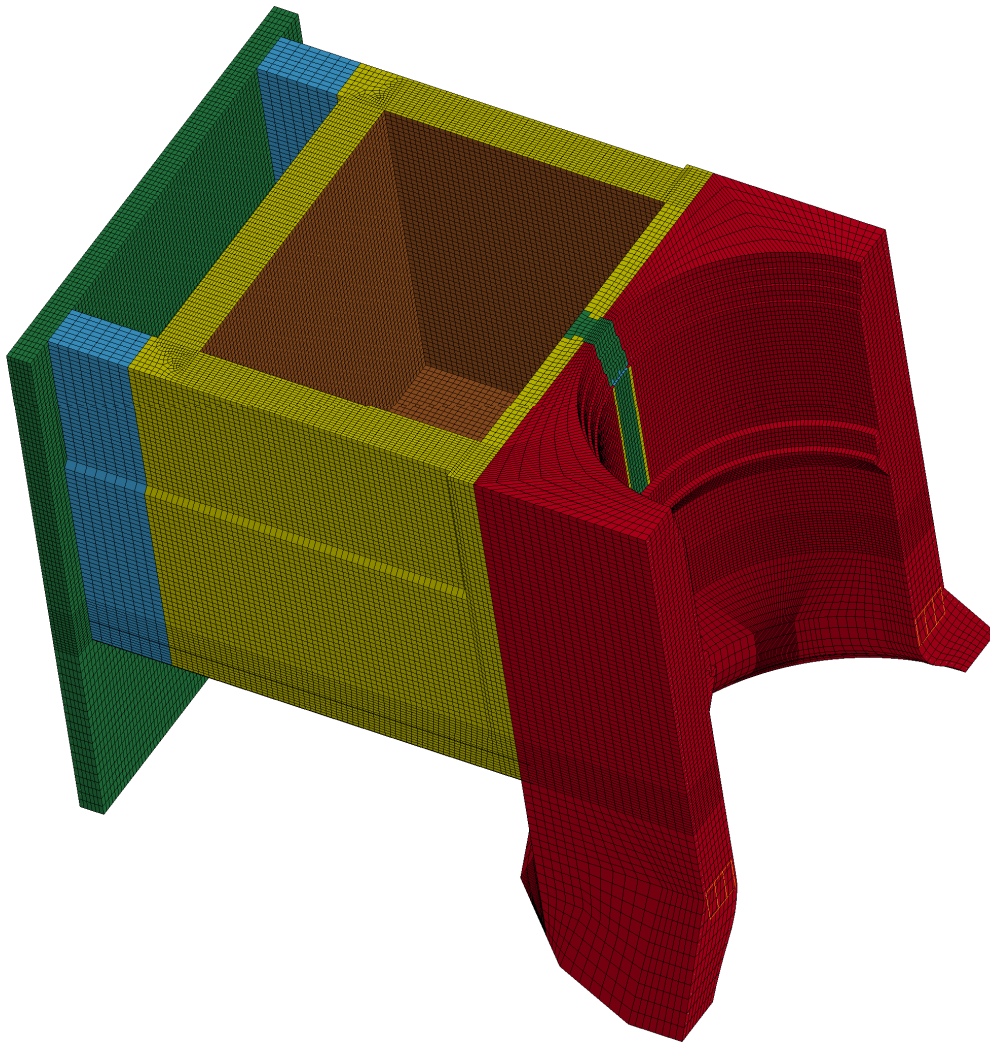


# Seismic and Structural Input

- Seismic Event
  - Challenging but very low frequency of occurrence event (greater than the design basis for Central and Eastern US plants)
  - Updated ground motion characterization models (United States Geological Survey, 2008)
  
- Structural Assessment
  - To determine starting point for accident progression analysis
  - Assesses performance of SFP structure and liner, SFP penetrations, reactor building structure above the SFP, racks and fuel, relevant reactor shutdown systems and other relevant structures
  - Informed by past studies and new analyses
  - Nonlinear finite element analysis of the SFP structure (pseudo-dynamic)



# Finite Element Analysis of the SFP



# Radiation Effects on Concrete



- Scope:
  - Determine if current methods used to evaluate radiation fluencies on concrete structures are sufficient to determine concrete properties for new reactor designs
- Organization doing Work for NRC: Oak Ridge National Labs (ORNL)
- Progress in last 2 years:
  - Project initiated October 2010.
  - Started assemblage of information on effects of radiation on concrete properties
  - Participated in meetings of the Concrete Irradiation Damage Working Group (EPRI; NRC; Savannah River Lab)
- Expected completion: September 2012



# Expanded Proactive Materials Degradation Analysis (EMDA)



- In collaboration (and co-funding) with the U.S. Department of Energy's Office of Nuclear Energy's (DOE:NE) Light Water Reactor Sustainability Program (LWRSP), the NRC initiated an expert panel to utilize a modified Phenomena Identification and Ranking Technique (PIRT) process to evaluate aging degradation phenomena on the Core Internals and Primary Systems; Balance of Plant Systems and Components; Reactor Pressure Vessel (RPV); **Concrete Structures**; and Electric Cabling.
- This work expands on the original NUREG 6923, Proactive Materials Degradation Analysis, and looks forward 40 years to at least 80 years of operating life.
- The first three volumes of the Draft EMDA report (e.g., RPVs, concrete, and cables) have been completed and are under staff review. The time line for completing the final reviews and publishing the full EMDA reports is April 2012.

# Research Related to Transportation Casks



- NRC is analyzing full-scale and scaled drop tests conducted by Germany's Federal Institute for Materials Research and Testing (BAM)
  - A goal is to reaffirm staff and industry practices for the design and review of spent nuclear fuel transportation (SNFT) casks
- Analysis of a full scale CONSTOR<sup>®</sup> cask manufactured by German Company GNS
  - The test was a 30-foot regulatory side drop test
  - The cylindrical container of this cask consists of two co-axial steel cylinders with a specially designed concrete infill for radiation shielding (high density aggregate)
  - Results of analysis with LSDYNA are generally consistent with the test data

# Research Related to Transportation Casks (Cont'd)



- BAM tested full-scale and 1:2.5 scale models of the MSF type cask of Mitsubishi Heavy Industries (MHI) for a variety of regulatory drop tests
  - Analysis will compare analysis results to test data from 30 feet side and end drops for full and scaled models.
  - The study will use analysis and test data to investigate scale effects.

# Revision of USNRC Regulatory Guides (Cont'd)



- Update of RG 1.90 [DG-1197, issued for Public comment in April, 2011]:
  - Guide describes an acceptable approach in developing an appropriate surveillance program for prestressed concrete containment structures with grouted tendons
  - Public Comments have been reviewed. Final RG 1.90, rev. 2 is under management review
- Update of RG 1.107 [revised and reissued in June, 2011]:
  - Guide describes quality standards for Portland cement grout as the corrosion inhibitor for pre-stressing tendons in prestressed concrete containment structures
  - Endorses the ASME Section III, Div. 2, Code
  - Endorses ASTM standards for the specific grouted tendon program

# Revision of USNRC Regulatory Guides (Cont'd)



- A new RG on implementation of PRA-based seismic margin assessments is under preparation. This RG will provide guidance on a technically acceptable approach that satisfies regulations.

# Future Potential Research For Concrete In Nuclear Installations



- Update design approach from prescriptive to performance-based concrete materials design
- Establish concrete performance criteria
- Develop standard tests and procedures to verify compliance with criteria
- Modeling of concrete degradation
- Aging and degradation of concrete
  - Structural implications of alkaline-aggregate reactions (AAR) in nuclear power plants
  - Degradation mechanisms for concrete in long term storage of spent fuel in dry casks
- Research supporting review of consensus standards for the design of safety-related SC structures
  - Harmonization of international standards
- Monitoring and surveillance of nuclear power plant structures to assess degradation, monitoring of repairs and condition of new construction

# Future Potential Research For Concrete In NPPs (Cont'd)



- Integration with Seismic Research
  - Base-Isolation for NPP Structures and Components
  - Soil-structure interaction modeling with degraded structural elements
  - Seismic assessment of degraded conditions
  - Post-earthquake "as-is" condition assessment
  - Performance of concrete structures in Kashiwazaki-Kariwa Nuclear Power Plant Facilities during July 16, 2007 earthquake
  - Performance of concrete structures following the March 11, 2011 Miyagiken-Oki earthquake