Codes and Standards for Design and Construction of Concrete, Steel-Plate Composite, and Steel/Metal Structures

- **Moderator:** Jose Pires, Senior Level Advisor, RES/DE
- **Panelists/Speakers:**
  - NRC: Madhumita Sircar
  - ACI: Adeola Adediran
  - Purdue University: Amit Varma
  - ASME: Javeed Munshi
  - AISC: Mark Holland
  - EPRI: Hasan Charkas, Sam Johnson, Salvador Villalobos

NRC Standards Forum 2020

Codes and Standards for Design and Construction of Safety-Related Civil Engineering Structures

Madhumita Sircar and Jose Pires
Office of Nuclear Regulatory Research
U.S. Nuclear Regulatory Commission

October 13, 2020

Outline

Panel:

Codes and Standards for Design and Construction of Concrete, Steel-Plate Composite, and Steel/Metal Structures

- Purpose
- Goal
- Status update on Regulatory Guides (RGs)
- Current topics with ongoing research (examples)
- Potential issues (examples)
- Path forward

Purpose, Goal, RGs

- Purpose
  - Facilitate the discussion for enhancements and improvements of codes and standards on (but not limited to) advanced construction techniques, new materials, new performance requirements, technologies for structural monitoring.

- Goal
  - Engagement for moving towards consensus standards

- Status update on Regulatory Guides (RGs)
  - RG 1.142, Revision 3, "Safety-Related Concrete Structures for Nuclear Power Plants (Other than Reactor Vessels and Containments)" (May 2020)
  - RG 1.199 Revision 1, "Anchoring Components and Structural Supports in Concrete" (April 2020)
  - RG 1.136 (Revision 4, DG-1372), "Design Limits, Loading Combinations, Materials, Construction and Testing of Concrete Containments" issued for public comment (July 2020)
  - RG 1.238 (new, DG 1304), "Safety-Related Steel and Steel-Plate Composites Structures (Other than Containments)" issue draft guide for public comment in FY21 Q1
  - RG 1.35.1, Determining Prestressing Forces for Inspection of Prestressed Concrete Containments (July 1990)

Issues and Path Forward

- Current topics with ongoing research (examples)
  - Advanced construction techniques including steel-plate composite and modular construction
  - High Strength rebar
  - New materials such as, self-consolidated concrete (SCC), fiber reinforced concrete and other advanced cementitious materials
  - Inspection and monitoring

- Potential issues (examples)
  - Structures exposed to high temperature (material dependent) (Advanced Non Light Water Reactor - ANLWR) – Google search ML19228A263
  - Structures exposed to high irradiation (ANLWR and Long Term Operation)
  - Innovative inspection and monitoring technologies (buried structures, base isolation, sensors, remote inspection methods, etc.)
  - Other?

- Path forward
  - Continue engagement on current and future research and development towards consensus standards

Updates on ACI 349 Development of Codes and Standards

By

Adeola K. Adediran (SRR/Bechtel)

Chair, ACI 349 Committee

NRC Standards Forum

OUTLINE

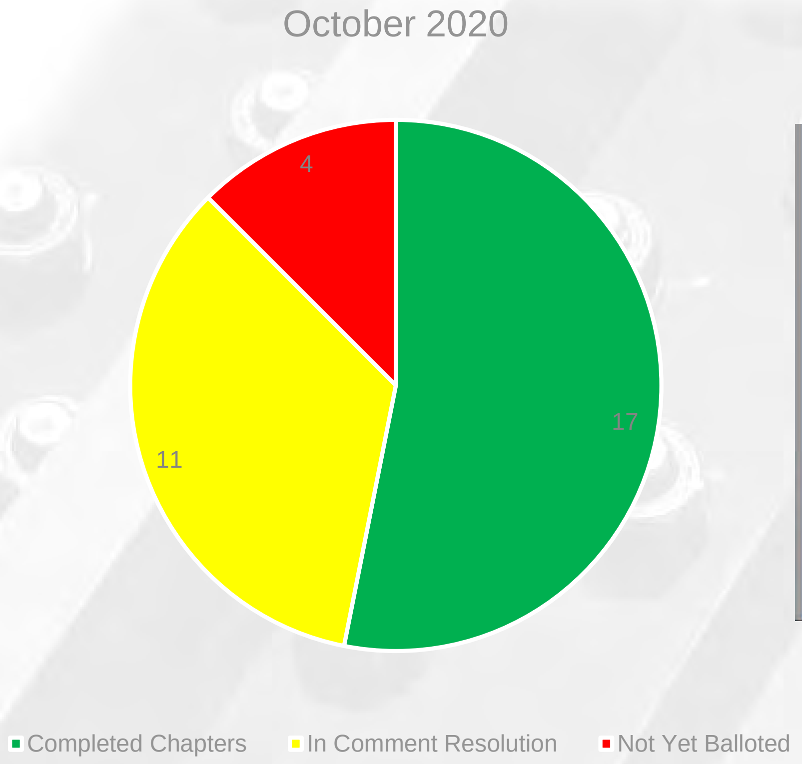
- ACI 349 Documents in the works and planned
- Update on ACI 349-XX code
- Codes & Standards Gaps
- Coordination with other Standards and discussion of jurisdiction woes
- Conclusion & Recommendations for Standards Development

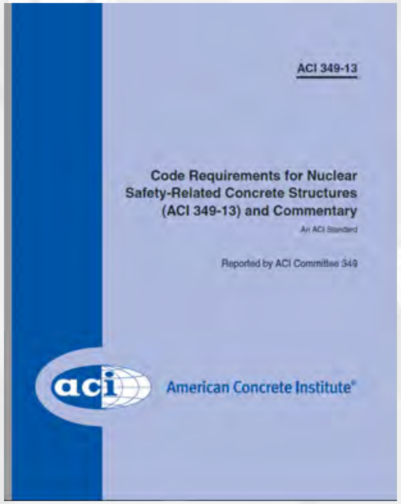
ACI 349 Documents in the works and planned

Technical Activities Committee Approved ACI 349 documents:

- *349: Code Requirements for Nuclear Safety-Related Concrete Structures (ACI 349-XX) and Commentary*
- *349.4R: (349-359-370)R: Report on the Design for Impactive and Impulsive Loads for Nuclear Safety Related Structures*
- *349.1R: Reinforced Concrete Design for Thermal Effects on Nuclear Power Plant Structures*
- *349.2R: Guide to the Concrete Capacity Design (CCD) Method--Embedment Design Examples*
- *349.3R: Report on Evaluation and Repair of Existing Nuclear Safety-Related Concrete Structures*
- *349.XR (New): Report on Blast Test Simulation Benchmark*
- *SP XX (New): Use of Advanced Finite Element Methods for Design of RC Nuclear Structures*

Update on ACI 349-XX





Update on ACI 349-XX

Chapter Full Title	Prepared by Lead	Checked by Chair	Out for Ballot	Negatives Resolved	Comments Incorporated	Ballot Summary Uploade
Chapter 1 - General	Complete	Complete	Complete	Complete	Complete	Complete
Chapter 2 - Notations and Terminology	Pending Anderson					
Chapter 3 - Referenced Standards	Pending Anderson					
Chapter 4 - Structural Systems Requirements	Complete	Complete	Complete	Complete	Complete	Complete
Chapter 5 - Loads	Complete	Complete	Complete	Pending 4 Negatives	Ballot Closes 10-12-20	
Chapter 6 - Structural Analysis	Complete	Complete	Complete	Pending 13 Negatives	Comment from Farhad; possibly discussing next week	
Chapter 7 - One-Way Slabs	Complete	Complete	Complete	Complete	Complete	Complete
Chapter 8 - Two-Way Slabs	Complete	Complete	Complete	Complete	Pending Galunic	
Chapter 9 - Beams	Complete	Complete	Complete	Complete	Complete	Complete
Chapter 10 - Columns	Complete	Complete	Complete	Complete	Complete	Complete
Chapter 11 - Walls	Complete	Complete	Complete	Complete	Complete	Complete
Chapter 12 - Diaphragms	Complete	Complete	Complete	Pending 8 Negatives		
Chapter 13 - Foundations	Complete	Complete	Complete	Complete	Complete	Complete
Chapter 14 - Plain Concrete	Complete	Complete	Complete	Complete	Complete	Complete
Chapter 15 - Beam-Column & Slab-Column Joints	Complete	Complete	Complete	Complete	Complete	Complete
Chapter 16 - Connections Between Members	Complete	Complete	Complete	Complete	Complete	Complete
Chapter 17 - Anchorage to Concrete	Complete	Complete	Complete	Pending 29 Negatives	scope language and grouted anchors; shear lugs	
Chapter 18 - Earthquake Resistant Structures	Complete	Complete	Complete	Pending 36 Negatives	Ready for Oct (under Sub B mtg); possiby post partial ballot	
Chapter 19 - Concrete Design and Durability	Complete	Complete	Complete	Complete	Complete	Complete
Chapter 20 - Steel Reinforcement Properties, Durabi	Complete	Complete	Complete	Pending 4 Negatives		
Chapter 21 - Strength Reduction Factors	Complete	Complete	Complete	Pending 7 Negatives	Pending phi 0.6 issue; ballot in Oct mtg	
Chapter 22 - Sectional Strength	Complete	Complete	Complete	Complete	Complete	Complete
Chapter 23 - Strut and Tie Models	Complete	Complete	Complete	Complete	Complete	Complete
Chapter 24 - Serviceability Requirements	Complete	Complete	Complete	Complete	Complete	Complete
Chapter 25 - Reinforcement Details	Complete	Complete	Complete	Complete	Ballot Closes 10-30-20	
Chapter 26 - Construction Documents and Inspectior	Complete	Complete	Complete	Complete	Complete	Complete
Chapter 27 - Strength Evaluation of Existing Structure	Complete	Complete	Complete	Complete	Complete	Complete
Chapter 28 - Shells	Complete	Complete	Complete	Complete	Pending Galunic	
Chapter 29 - Special Provisions for Impactive and Im	Pending Adediran					
Chapter 30 - Thermal Considerations	Complete	Complete	Complete	Complete	Complete	Complete
Chapter 31 - Alternative Load and Strength-Reductio	Complete	Complete	Complete	Pending 13 Negatives	Similar negatives to Ch21; phi 0.6; ballot in Oct mtg	
Commentary References	Pending Anderson					

Upcoming Major Changes

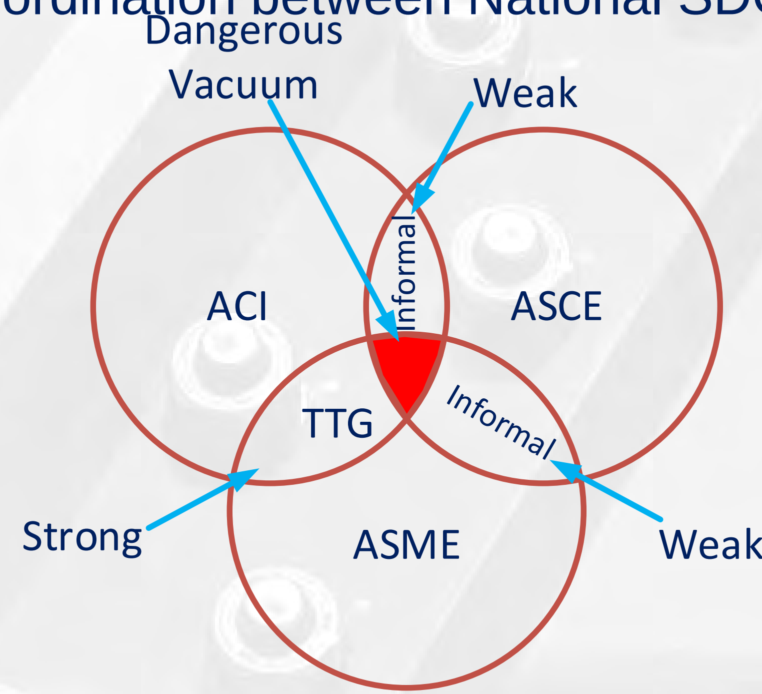
- Chapter 18 – Still Limit State D but new business to allow Limit State C in the next code cycle. Currently Conflicts with ASCE 43.
- Chapter 18 – Concrete strength of greater than 6000 psi is still not accepted in the code which deviates from ACI 318.
- Chapter 8 – New deflection limits and min slab thicknesses for two way slabs which is a first for ACI 349
- Chapter 17 – Inclusion of Dowel Rebar anchors and Cementitious bonded anchors
- Chapter 17 – New Shear Lug provisions
- Chapter 29 – New damage limits for impactive and impulse loads. These use support rotations not ductility.
- Chapter 29 – Includes for the first time in ACI 349 recommendations for equations to determine local behaviors

Codes & Standards Gaps

- New Construction processes – e.g. Modularization
- Advanced computational tools – Element based designs
- Benchmarking Lower Limits that still do not precipitate radiation release.
- Conformity across Standards with Load factors and Load combinations when Hybrid Structures are modeled.
- Jurisdictional conflicts between Standards, lags in coordination between Standards and structures that fall in the cracks between Standards.
- New and Advanced Reactors and their unique set of building constraints. For example SMR are most often buried structures, mega concrete tanks for nuclear waste disposal etc.

Codes & Standards Co-ordinations

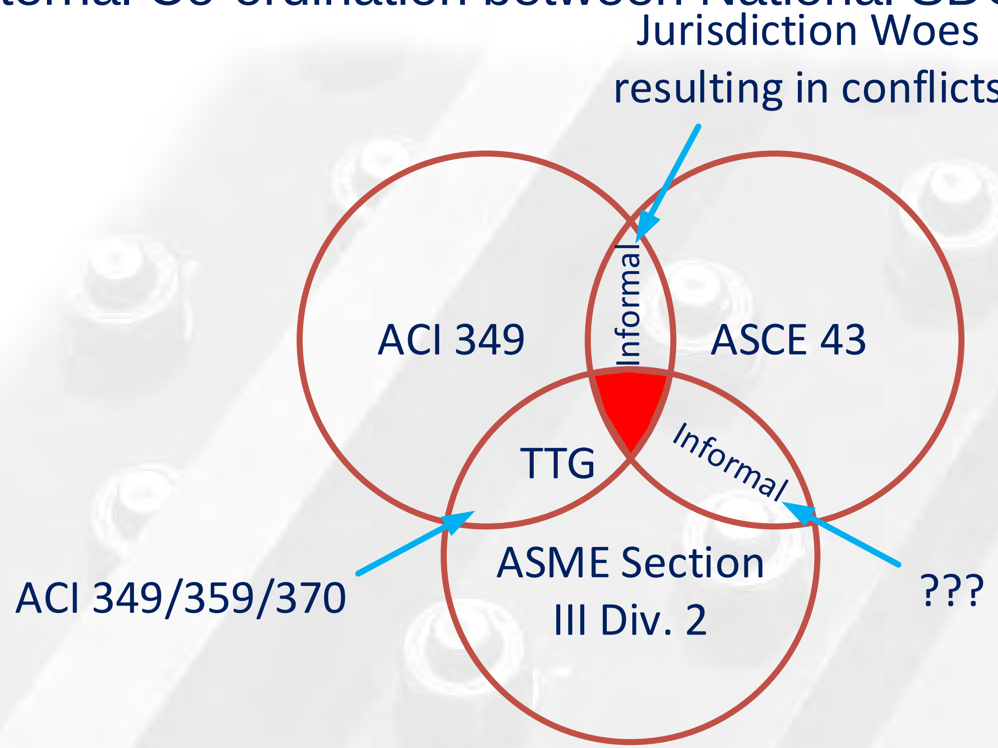
- ACI internal coordination is done two ways
  - First at the Technical Activities Committee level with committees with overlay sharing the same TAC rep and TAC forcing reviews by affected committees.
  - Second by task groups set up to facilitate discussions with groups with overlaying areas of jurisdictions.
- External Co-ordination between National SDO in Nuclear



- No Formal External Co-ordination between International SDOs

Codes & Standards Co-ordinations

- External Co-ordination between National SDO in Nuclear contd.



- Three areas of conflicts:
  - invoking ACI 349 for limit states B and C
  - Contradicting provisions for size effects for concrete shear strength for slabs and walls
  - Disagreement between ASCE and ACI on bi-strength interactions between in-plane and out-of-plane shear

CONCLUSION & RECOMMENDATION

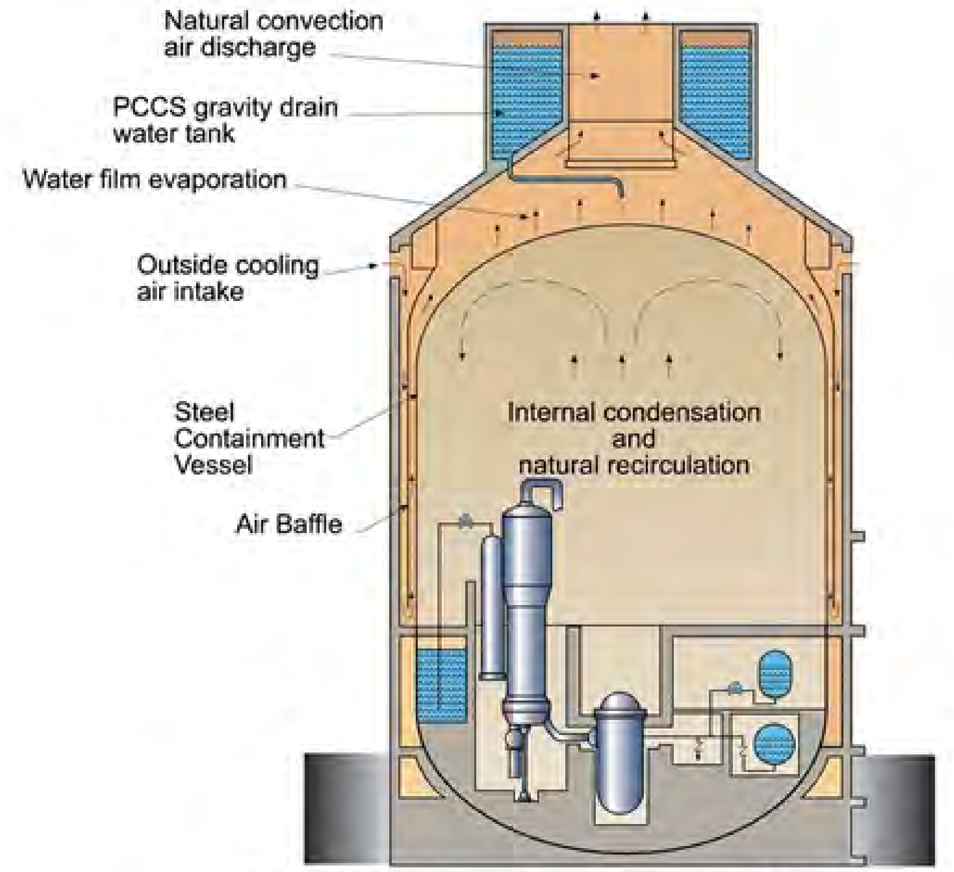
- Work is ongoing to resolve conflicts between US Codes and Standards.
- More research is needed to tie damages levels to F_{μ} and to determine threshold when radiation is released to the environment. This is needed to change the design philosophy of ACI 349 to recognize more damage.
- More research is needed to determine the effects of using organic or inorganic polymer/epoxy bonded anchors in the corrosive environment associated with structures also exposed to radiation.
- Future work being planned for ACI 349 not yet approved by TAC includes:
  - Revised Shell provisions with ACI 318.2
  - Moving some of the Element Based Design recommendations documented in the new SP to be created by ACI 349 to the Chapter 6 of the next code
  - Include the use of precast concrete for Nuclear applications when more damage levels are recognized.
- Recommendations:
  - A task group should be stood up between ACI and ASCE on Nuclear.
  - A task group should be stood up between ASME and ASCE on Nuclear.
  - Or one task group should be stood up between the oversight levels of ACI, ASCE and ASME.

Codes & Standards for Nuclear Structures

Future Developments and Possibilities

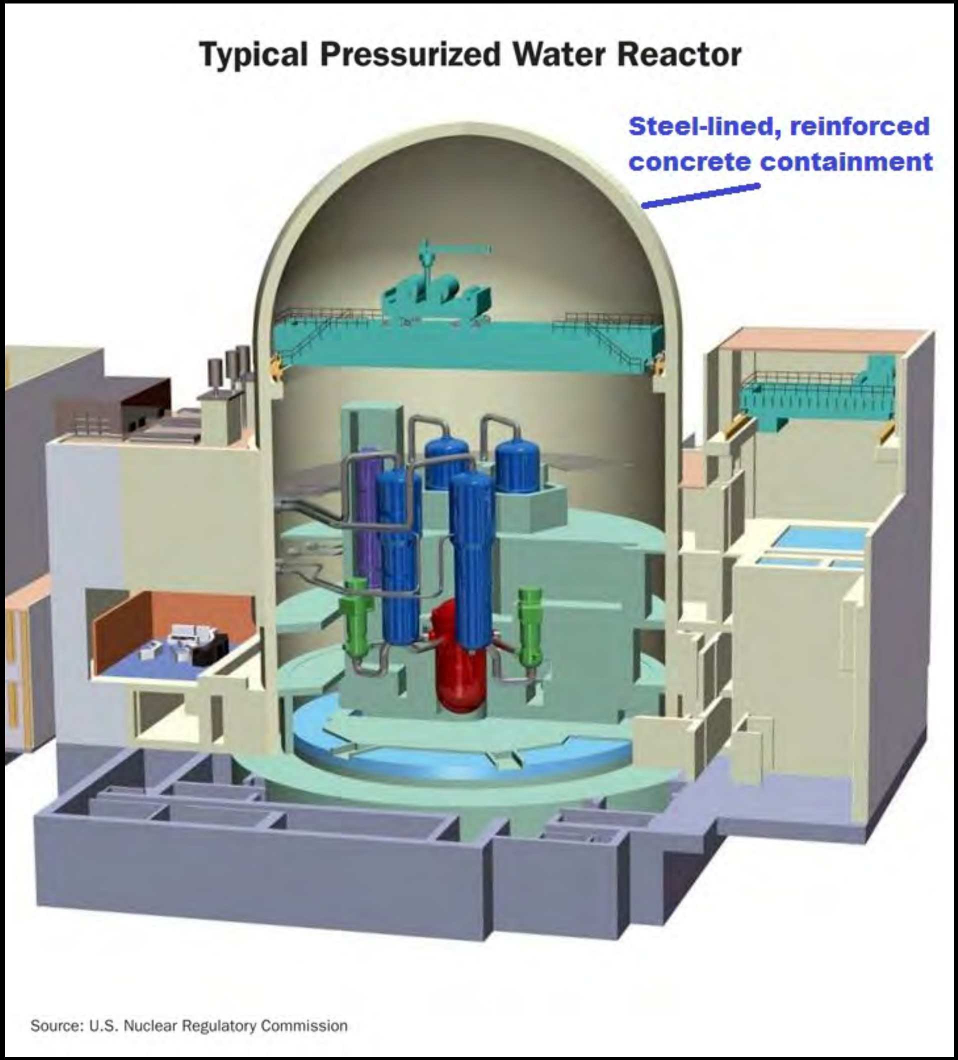
Amit Varma

CONVENTIONAL CONTAINMENT VESSELS

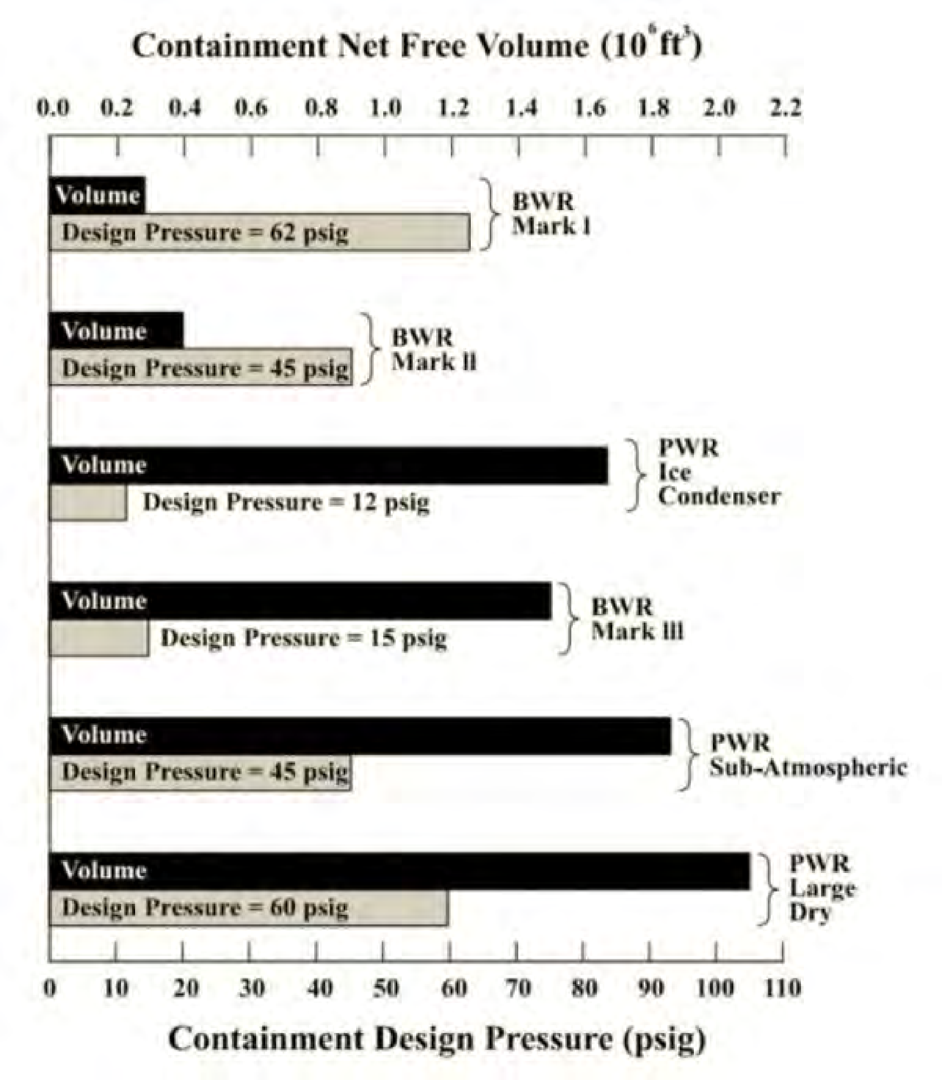


AP1000 Passive Containment Cooling System

CONVENTIONAL CONTAINMENT VESSELS



Conventional Containment Vessels



CONTAINMENT CRITICAL DESIGN

- ELASTIC BEHAVIOR, Onset of localized yielding for extreme loading condition
- CONTAINMENT PRESSURE, pressure barrier, leak barrier
- CONTAINMENT TEMPERATURE, elevated temperature and thermal effects on material and structure
- IMPACTIVE / IMPULSIVE LOADING, protect leak and pressure barrier
- EARTHQUAKE LOADING

A NEW TYPE OF CONTAINMENT

- Steel-Concrete Containment Vessel (SCCV)
- Vendors interested GE-Hitachi for conventional small modular reactor (SMR)
- Development of Design Code / Criteria under ASME BPV Code umbrella
- Vendors interested, molten salt reactors.
  - Functional containment
  - Much higher temperatures
  - Much smaller size

STEPS FORWARD

- Joint ACI-ASME Committee on Concrete Components for Nuclear Service (BPV III)
  - Presentation and committee engagement
  - Using AISC N690 as starting point
  - Latest research and developments

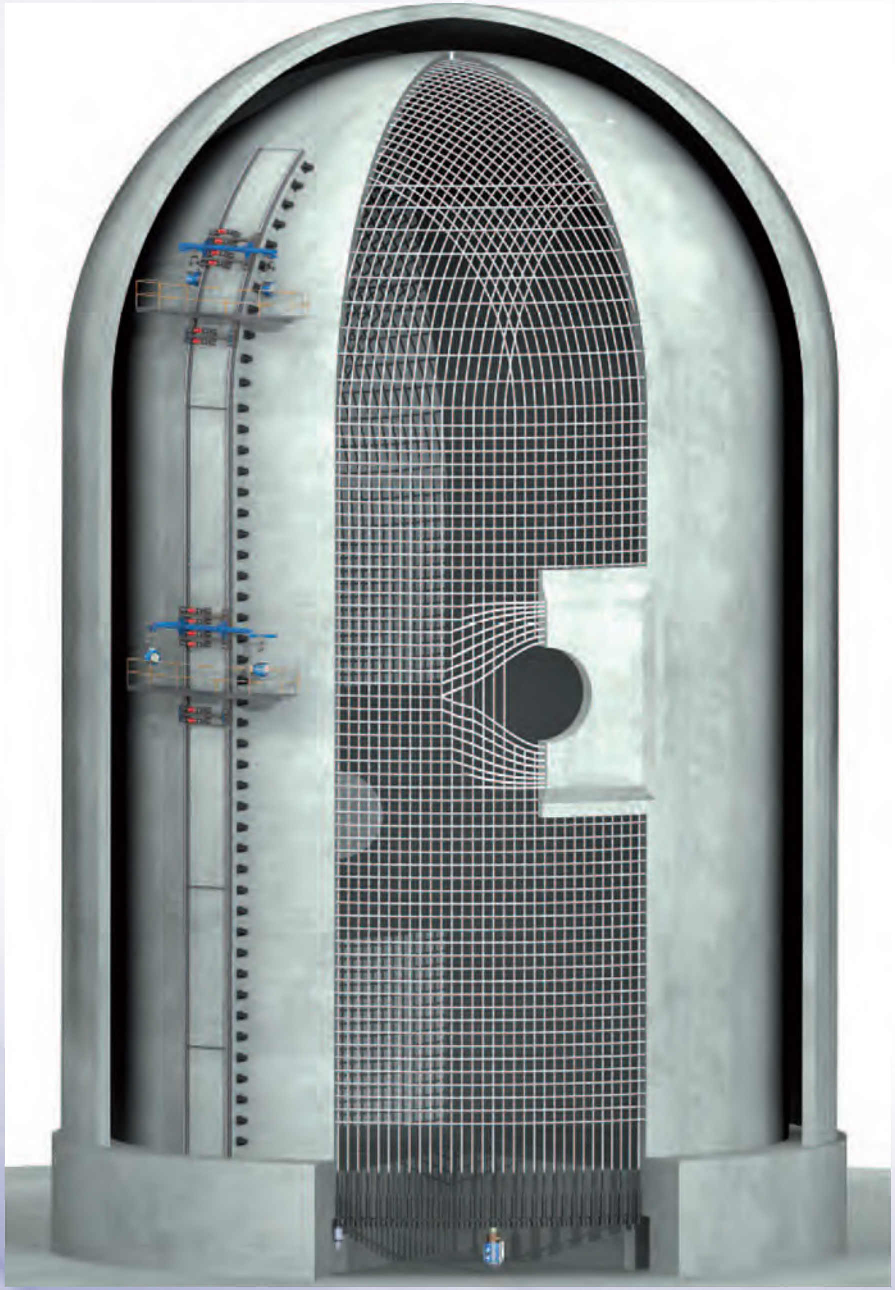
NRC Standards Forum

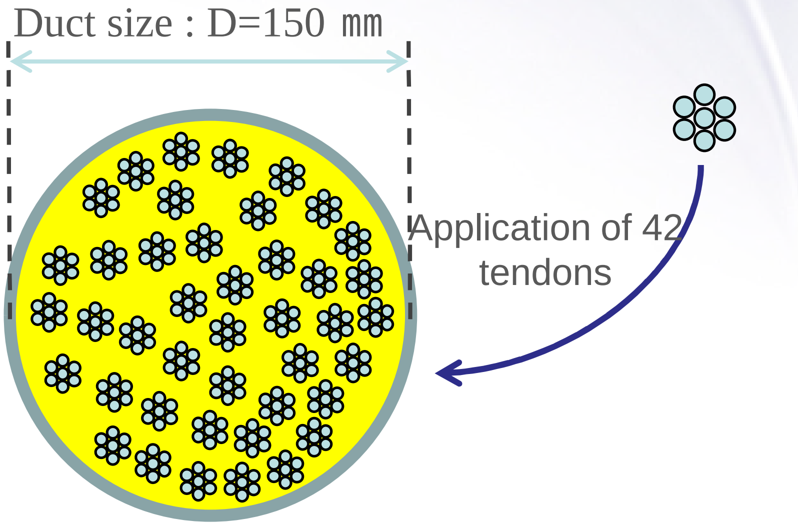
October 13, 2020

ASME Section III, Div. 2 Code

Javeed Munshi
ASME Section III, Div. 2

- **42 bare 7-wire strands (present APR1400)**
- Strand area : 140 ㎟ x 42 = 5,880 ㎟





Challenges

Concrete containments becoming obsolete

- Cost of material, labor
- Schedule
- Quality Assurance and Quality Control

Rebar and Concrete Costs ~ 10 times for Nuclear Construction

Liner plate ~ half of steel containment

It takes over a decade to build a commercial nuclear plant

Containment is usually on the critical path of the project impacting schedule

Opportunities

Conventional Containments - Optimize Design and Construction using Existing Code

Develop Next Generation Containment System and Codification

Support Next Generation SMRs

Conventional Containments - Optimization Opportunities

Cost reduction

Optimize the design, use commercial grade rebar, plate and concrete with optimized oversight and testing

Schedule

Optimize regulatory oversight, QA and QC and utilize automation in construction

<u>Key is to optimize unnecessary regulatory requirements in materials, design and construction that do not necessarily add value or safety</u>

Next Gen Containment

Use our expertise and provide technical leadership and a platform for development of viable concrete containments of the future

Use advancements in materials, design and construction techniques

Collaborate with all stakeholders and sponsor/oversea the necessary research and development

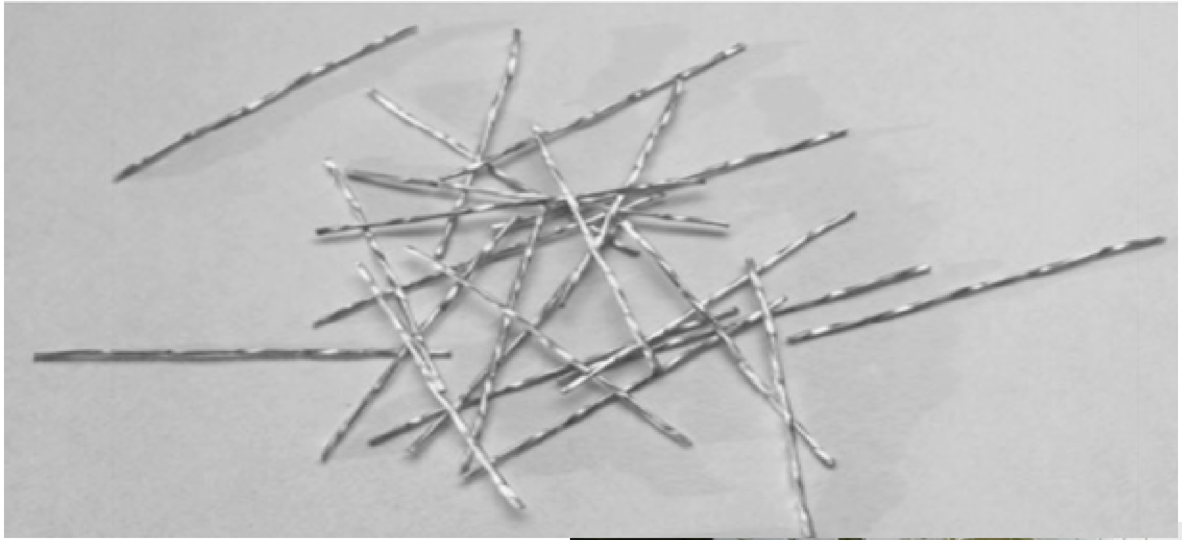
Next Gen Containment

- Use High-Strength/High-performance materials to handle both accident pressure and SSE events
- Eliminate/Minimize conventional reinforcing
- Eliminate liner plate
- Use flowable concrete SCC with fiber reinforcement to accelerate placement time, eliminate labor for consolidation
- Use automated construction process such as slip-forming or 3D printer

ASME SETTING THE STANDARD

Future Direction

Fiber Reinforcement and Self Consolidating Concrete (SCC)



SMRs

ASME Section III, Div. 2 CC-1110 SCOPE

- Establishes rules for material, design, fabrication, construction, examination, testing, marking, stamping, and preparation of reports for <u>prestressed and reinforced concrete containments</u>.

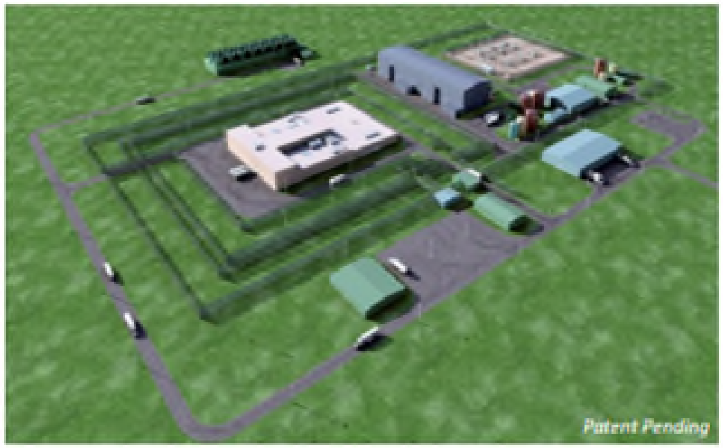
- <u>Containments having a Design Pressure greater than 5 psi (35 kPa)</u>

Specific Needs for Code Development

- Small Modular Reactors present a wide variety of technologies with different safety requirements
- The design requirements for the nuclear containment are different comparing to water cooled reactors
- Design pressure can be significantly lower, below the minimum pressure from Sec III, Div 2
- Some reactors do not have pressure differential (the pressure differential can be wind induced) however the containment contain flammable gas and the leak-tightness is required

Applicability to SMRs – Example Case

The B&W mPower Nuclear Plant



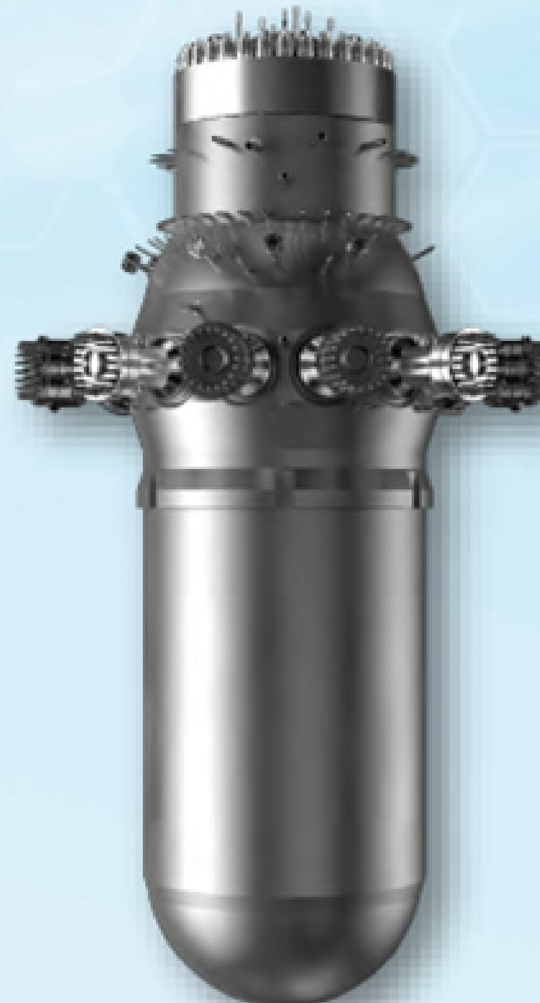
- **Generic Design**
  - "Twin-pack" mPower plant configuration
  - 40 acre site footprint
  - Low profile architecture
  - Water or air cooled condenser
  - Enhanced security posture
  - Underground containment
  - Underground spent fuel pool

- **Underground Nuclear Island**
  - Supplement to AISC N690-2011 (available in 2014)
  - Concrete design per ACI 349-06 and ACI 350.3.
  - Seismic analysis is based on ASCE 4-98, applicable sections of NUREG-0800, and with consideration to forthcoming changes in the next edition of ASCE 4
  - No exceptions anticipated
  - Turbine Island will use current commercial standards

- **Modular Construction**
  - Steel-concrete composites
    - No consensus standards in US
    - Supplement to AISC N690-2011 (available in 2014)
  - Civil Structural design standard for mPower
    - ACI 349, AISC N690

CAREM PROTOTYPE - BASIC FACTS

- **First NPP fully designed in Argentina**
  - Integral PWR type
  - Integrated Primary System
  - Natural circulation
  - Self-pressurized
  - 100 MW / 32 MWe
  - Enriched UO_2 fuel (3,1 and 1,8%)
  - Passive safety systems
  - Pressure suppression containment type
  - Operating cycle length of 18 months



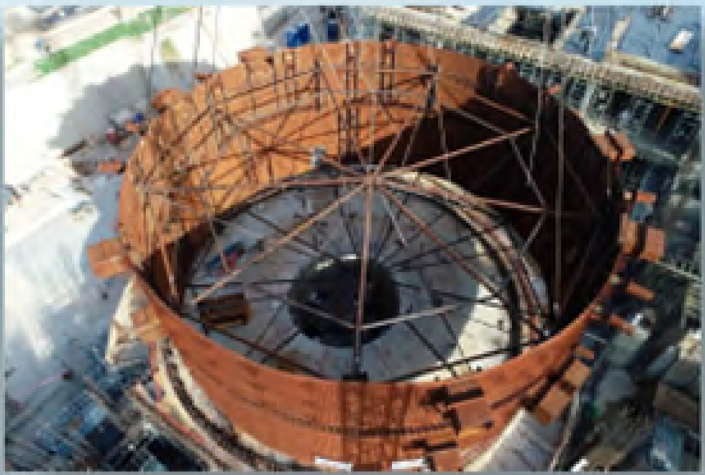
CAREM25

Comisión Nacional de Energía Atómica

CONTAINMENT LINER

ESTIMATED PROGRESS:

78%



CAREM25

Comisión Nacional de Energía Atómica

SETTING THE STANDARD

Applicability of Div. 2 to SMRs

- Mismatch of scale – Rightsizing
- Regulation – Optimization
- Cost and Schedule – Industry Collaboration and Optimization

Our T(Ask)

Optimization of regulatory requirements (materials, design and construction)

Support and collaboration to develop Next Gen Containment & Codification

Support and collaboration to help customize the design, construction and regulatory requirements for SMRs

Specification for Structural Stainless Steel Buildings (AISC 370: 2021)

Mark V. Holland, P.E. | Chief Engineer PVS
Chairman of AISC 370
Member of TC-11 (N690)

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Stronger.
Steel.

Table of Contents

A. General Provision
B. Design Requirements
C. Design for Stability
D. Design of Members for Tension
E. Design of Members for Compression
F. Design of Members for Flexure
G. Design of Members for Shear and Torsion
H. Design of Member for Combined Forces
I. Design of Composite Members
J. Design of Connections
K. Additional Requirements for HSS and Box-Sections
L. Design for Serviceability
M. Fabrication and Erection
N. Quality Control and Quality Assurance

Appendix 1. Design by Advanced Analysis
Appendix 2. The Continuous Strength Method
Appendix 3. Fatigue
Appendix 4. Structural Design for Fire Conditions
Appendix 5. Evaluation of Existing Structures
Appendix 6. Member Stability Bracing
Appendix 7. Modeling of Material Behavior

Similar to AISC's Specification for Steel Building AISC 360

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Schedule

- 2019
  - February ~ Kick off meeting (Complete)
  - June ~ First Draft distributed to Committee (Complete)
  - July ~ Committee comments on first draft (Complete)
  - September ~ AISC Submit PIN to ANSI (Complete)
  - November ~ Pre-Ballot One Review Draft available (Complete)

AMERICAN INSTITUTE OF STEEL CONSTRUCTION AISC FOUNDED 1921
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Schedule

- 2020
  - January ~ Draft Ballot 1
  - June ~ Draft Ballot 2 & Draft Public Review 1
  - September ~ Ballot 2 Responses due
  - October ~ Draft Ballot 3
- 2021
  - January ~ Final Consensus Ballot & ANSI Public Review
  - June ~ AISC Board Approval
  - July ~ ANSI Approval
  - December ~ Submit to IBC for IBC 2024

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Campaign Documents

AISC Code of Standard Practice for Structural Stainless Steel (AISC 313)

- Scheduled for AISC Board Approval June 2021
- Contract Side of Structural Stainless Steel

Steel Design Guide 27 Structural Stainless Steel

- Will act as a manual for the specification
- Available end of 2021 / early 2022

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NRC Standards Forum

EPRI Research on Relevant Topics

Hasan Charkas
Salvador Villabolos
Samuel Johnson

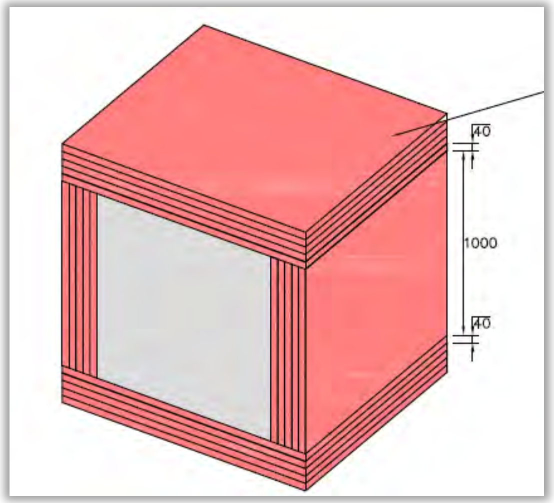
October 13, 2020

High Strength Large Rebar Research

- Explore lap splice behavior of large high strength rebars (No. 14 and No. 18) for use in earthquake-resistant structures
- Investigate mechanical couplers use in anchoring high strength rebars at base of structural walls subjected to cyclic loading
- Examine the anchorage capacity of groups of large high strength rebars at column and wall foundation connections subjected to cyclic loading
- Explore the possibility of establishing requirements based on experimental results and possibility of developing equations for inclusion in design standards

SCC as Mass Concrete – Proportioning & Testing – Status

- Some of nuclear power plants elements are defined as massive concrete elements
- The focus of this project is to explore various SCC mixtures that has a low adiabatic heat rise
- Value:
  - Improved concrete mix designs
  - Reduce risk of failed placements and improve schedule
- Other EPRI resources:
  - 3002007567 Demonstration and Evaluation of Self-Consolidating Concrete Mixtures
  - 3002007577 Mass Concrete Modeling and Thermal Control: Investigating of Delay Ettringite Formation and Thermal Cracking in Massive Concrete Structures
  - 3002013041 Optimization of Concrete Placements for Nuclear Power Plant Construction – A guide to Best Practices for Placing Concrete



High-Temperature Concrete for Advanced Reactors

Issue:

- Code-induced temperature limits are placed on hardened concrete during operations and accidents. For GENIV reactors operating temperature inside the containment maybe higher than the allowed limits
- The temperature limits is a design constraint and doesn’t take into consideration potential advances in concrete-material technologies

Scope:

- Identify existing body of research to determine if temperature limits can be relaxed
- Identify if changes in raw materials (e.g., cement, aggregate) will allow concrete to be exposed to higher temperatures.
- Identify potential functional changes to the design of structural elements such that it has internal cooling mechanisms or are layered to allow higher-temperature resistant material at the outer surface of the element

Value:

- Understand the effect of advanced reactor operating conditions on concrete structures
- Provide opportunities to inform advanced reactor designs

Assessment, Design and Analysis Guidance of SC Walls for Advanced Reactors and SMRs

Issue:

- Current and some of the future designs of nuclear power plants are relying on the constructability, efficiency of the modular steel-plate composite (SC) construction and their connections
- Current design guides and standards for SC construction were developed predominately for large light water reactor construction
- EPRI guidance on use of SC construction for SMRs and Advanced Reactors is needed to address specific structural and design issues (embedded structures, subsurface conditions, improved connections)

Scope:

- Review advanced reactors civil designs and collect unique structural and design features
- Determine whether (and to what degree) the current guidance address structural needs for SMRs and advanced reactors
- Identify solutions and propose performance-oriented guidance for addressing these issues.
- Analytically develop and experimentally verify approaches for repairing SC walls with critical flaws

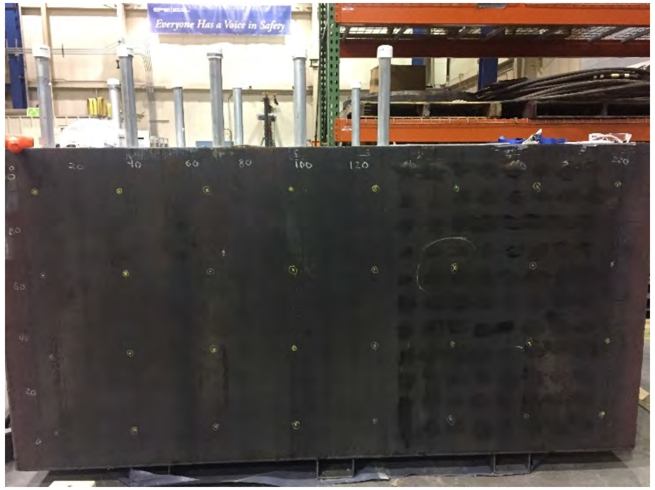
Value:

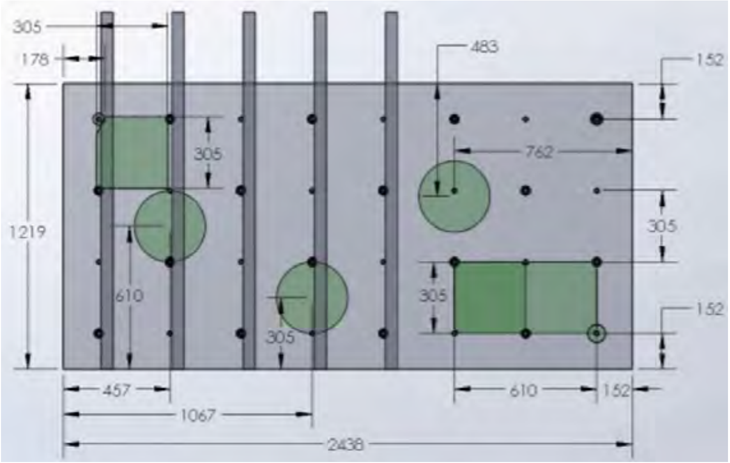
- Industry consensus guidance on use of SC construction to address design needs for GENIV and SMRs is vital to ensure successful implementation in the design.

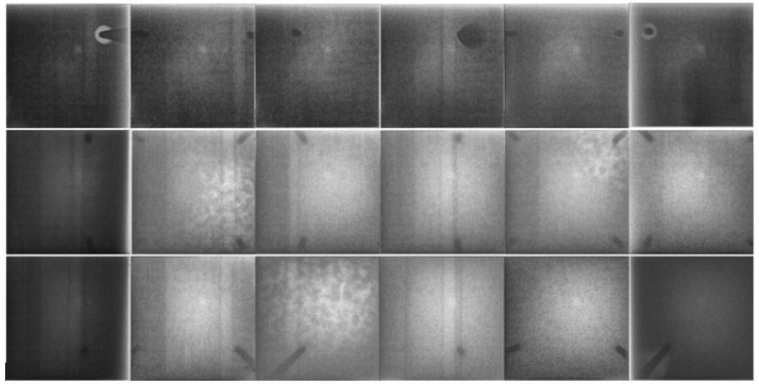
Steel – Concrete High Energy X-Rays

Testing performed on several mockup

- Impulse response, Impact Echo, embedded ultrasound sensors, shear wave array, direct ultrasound, hammer sounding, **cross hole sonic, guided wave, and high energy X-Rays**
- Continuing research on high energy X-rays to improve contrast

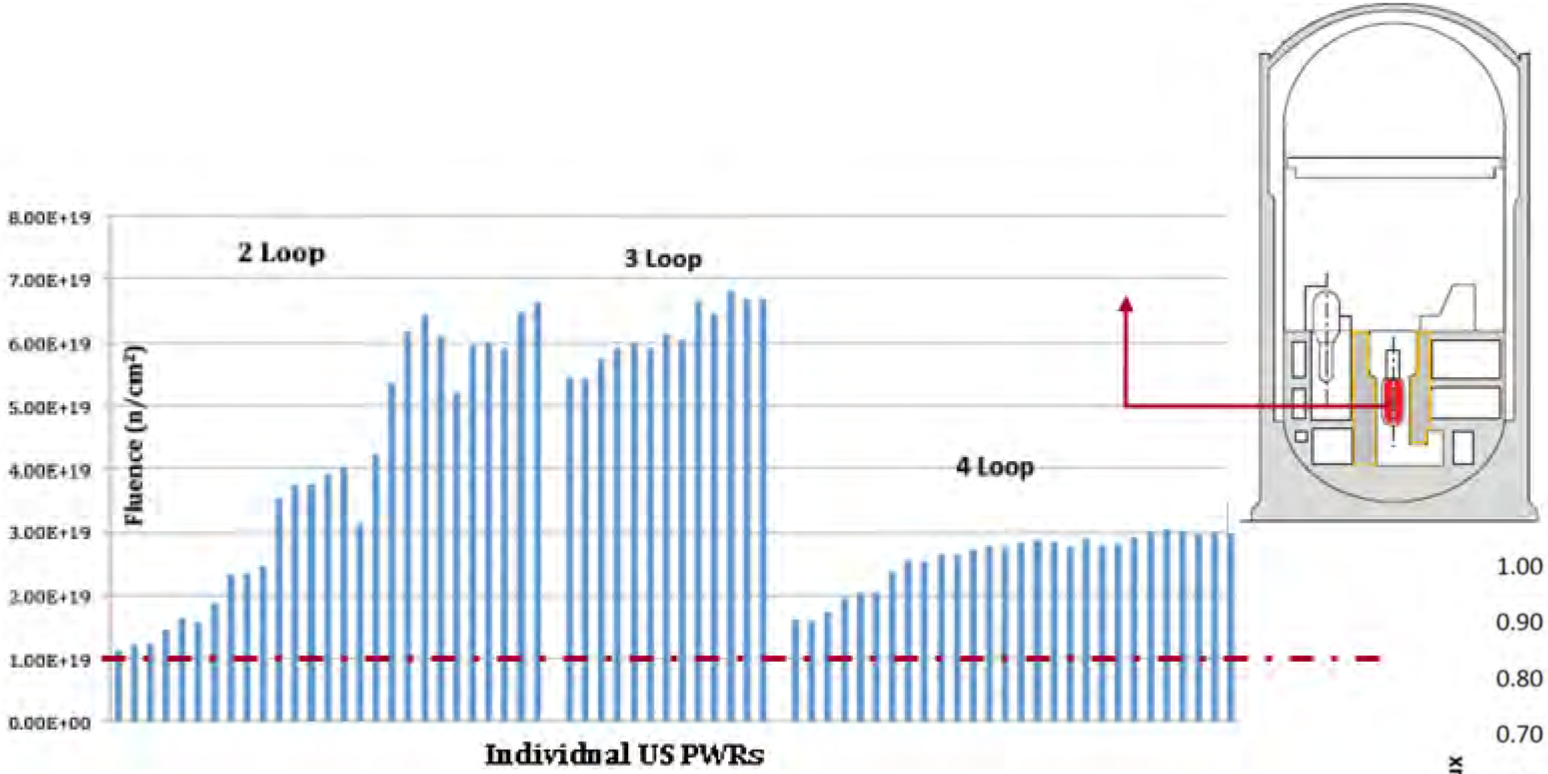


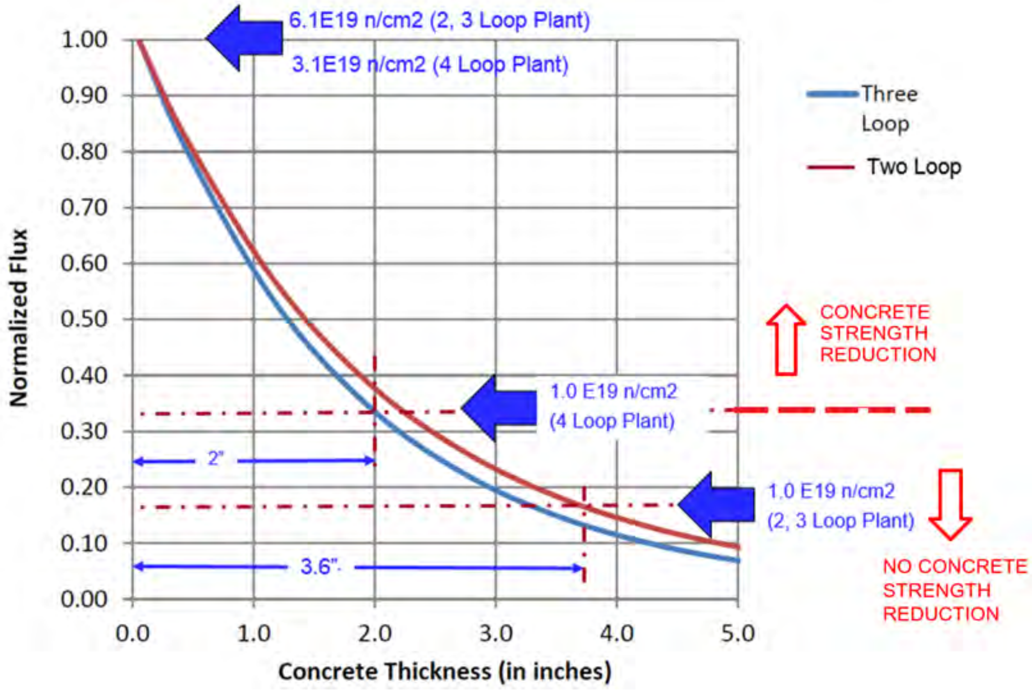




EPRI ELECTRIC POWER RESEARCH INSTITUTE

Concrete Irradiation





EPRI Research

Irradiation of Concrete Guidance and Technical Bases

2012
Effects of Radiation on Concrete – a Literature Survey and Path Forward
(**1025584**)

2014
Expected Condition of Reactor Cavity Concrete after 80 Years of Radiation Exposure
(**3002002676**)

2016
Structural Disposition of Neutron Radiation Exposure in BWR Vessel Support Pedestals
(**3002008128**)

2016
Long Term Operations – Impact of Radiation Heating on PWR Biological Shield Concrete
(**3002008129**)

2016
Structural Model of PWR Concrete Reactor Pressure Vessel Supports – Effects of Chronic Radiation Exposure on Margin (**3002007347**)

2018
Estimation Of Gamma Flux In Boiling Water Reactor Concrete Biological Shield Walls
(**3002013052**)

2018
Irradiation Damage of the Concrete Biological Shield that Utilizes a Neutron Shield Tank - Basis for Concrete Biological Shield Wall for Aging Management
(**3002013051**)

2018
Irradiation Damage of the Concrete Biological Shield - Example Evaluation of Concrete Biological Shield Wall for Aging Management
(**3002013995**)

2019
Long-term Operations: Estimation Of Gamma Dose In Boiling Water Reactor Concrete Biological Shield Walls
(**3002016055**)

2020
2020 Update to Irradiation of Concrete guidance: Basis for Evaluation of Concrete Biological shield Wall for Aging Management, Rev 1
(**3002018400**)

Together…Shaping the Future of Electricity