Concrete Expert Panel Workshop

February 24-25, 2015

Rockville, MD

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Workshop Objectives

- Enhance the existing technical bases related to Dry Cask Storage Systems (DCSSs) for evaluating:
  – Concrete degradation modes
  – Concrete inspection and monitoring techniques
  – Functional assessment
- Identify relevant knowledge and practices from non-nuclear concrete structures
- Identify potential information needs
  – NRC
  – Overall

Schedule

Time Slot	February 24	February 25
0830-0845	Introduction and Welcome	Introduction and Recap
0845-1015	Degradation Mechanisms	Inspection and Monitoring
1030-1200	Degradation Mechanisms, continued	Aging Management Programs
1300-1415	Prevention and Mitigation Strategies	Time Limited Aging Analyses
1430-1530	Inspection Techniques and Technologies	Remediation, Repair, and Replacement
1530-1615	Public Comment Period	Public Comment Period
1615-1630	Recap, Flex, and Conclusion	Recap, Flex, and Conclusion

EXPERT PANELISTS

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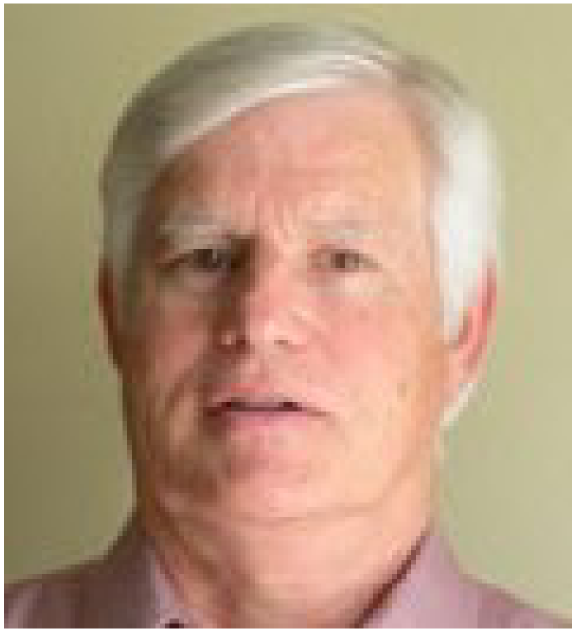
Neal Berke

- Tourney Consulting Group, LLC
  - Vice President, Research
- Concrete technology and durability
- Corrosion
- FACI, FASTM, FNACE

Larry Jacobs

- Georgia Institute of Technology
  - Professor and Associate Dean for Academic Affairs
- Quantitative non-destructive evaluation methodologies
  - Non-linear ultrasound
  - Microstructure
  - Damage

Randy James



- ANATECH
  - Senior Associate and Director of Structures
- Structural Analyses
  - Impact
  - Seismic
  - Failure
  - Degraded Concrete Capacity
- Numerical Methods
  - ANACAP

Hamlin Jennings

- Massachusetts Institute of Technology
  - Executive Director, Concrete Sustainability Hub
- Cement Based Materials
  - Micro-, Nanostructure
  - Hydration
  - Mechanics
  - Mechanisms of Creep and shrinkage

John Popovics

- University of Illinois, Urbana-Champaign
  - Associate Professor, Civil and Environmental Engineering
- Non-destructive evaluation, sensing and imaging
- Mechanical properties of cement-based infrastructure materials

Yunping Xi

- University of Colorado, Boulder
  - Professor, Civil, Environmental, and Architectural Engineering
- Long-term durability for concrete structures
- Evaluation of existing nuclear power plant structures

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Motivation

- DCSSs are required to operate longer than anticipated
  - Up to 60 years for first license renewal
  - From 60-300 years for analysis of extended storage and transportation
- Concrete structures may degrade in these timeframes
- NRC requires adequate technical basis to demonstrate that concrete structures will perform their intended safety functions during the licensing period

Degradation Mechanisms

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Technical Information Needs Report

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Identification and Prioritization of the Technical Information Needs Affecting Potential Regulation of Extended Storage and Transportation of Spent Nuclear Fuel

May 2014

ML14043A402

- Commission Directed in expectation of extended use of DCSS
- *"This report presents the results of NRC staff evaluation of the technical information needs for continued extended dry storage . . . focuses on the degradation phenomena that may affect dry storage systems, and how these phenomena may affect the ability of the systems to fulfill their regulatory functions."*

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Concrete Degradation

Degradation	Initiation Time	Propagation Rate	Mechanism Termination	Inspection Capability
Shrinkage	H	H	H	Visual
Creep	H	H	H	Visual
Fatigue	H	H	H	Visual
Corrosion	H	M	L	Vis, Elect-Chem
Carbonation	M	M	L	Vis, Core
Leaching	H	H	H	Visual
Sulfate Attack	H	H	M	Vis, Petro
ASR	H	M	L	Vis, Petro
Radiation	H	M	M	Vis, Radiation
Freeze-Thaw	H	M	M	Vis, Petro
Desiccation	M	M	L	Testing
Ther. Deg.	M	M	L	Testing
Coupled	M	M	L	Vis, Petro

Salt Scaling

Observations

- Identified by several experts:
  - Jacobs
  - Popovics
  - Berke
- Mechanisms are not fully understood
  - Crystallization pressure
  - Interdependence with ice pressure
- Causes surface deterioration

Questions

- Is salt addition required or are environmental salt sources enough?
- Is this cosmetic or is there structural significance?
- Can this phenomenon occur on vertical surfaces?

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Acid / Ion Attack

Observations

- Aggressive Ions of many types can negatively affect concrete health
- Many other mechanisms are "Ion Attack" (e.g. sulfate attack)
- Mg, Acids, Chloride, others
- Tied to concrete transport properties

Questions

- How widespread is this issue for other structures?
- Are aggressive ions commonly found in soil, or is another source needed?
- What "ionic criteria" lead to problems?

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Delayed Ettringite Formation

Observations

- Sulfate phases are prevented from forming during curing or are dissolved
- Later precipitate as ettringite with large net volume change
- Elevated temperature plays a key role

Questions

- Are any components pre-cast / steam cured?
- Monosulfoaluminate dissolution from canister heat load?

Thermal Desiccation

Observations

- Temperatures not high enough to degrade chemically bound or gel water, but could dry pore water
- This drying could precede other transport related mechanisms
- Thermally induced cracking

Questions

- Are there any other known consequences of moderate drying?
- Could significant moisture or thermal gradients form in high humidity environments?

Creep

Observations

- Creep rate
- Repair and subsequent load changes
- Potential for coupling with other mechanisms
- Creep rate slows with age

Questions

- Would time dependent deformation of the concrete be a significant degradation mode?
- Has concrete creep been a primary cause of problems in other structures?

Alkali-Silica Reactivity

Observations

- ASR has received much attention
  - Seabrook
  - Transportation structures
- Ongoing NRC sponsored research at NIST
- Much research in the transportation industry

Questions

- Can ASR confidently be excluded through testing?
- Do we know the structural effects of ASR?
- Would ASR be functionally limiting for DCSSs?

Radiation

Observations

- The mechanisms of radiation damage seem poorly understood
- The dose levels in DCSSs are lower than bio shield walls
- Recent NUREG/CR 7171
- Evidence of coupling with ASR

Questions

- Are total fluence limits adequate to ensure performance?
- Could radiation couple with other mechanisms?

Freeze-Thaw

Observations

- Expansion from freezing pore water creates tensile pressure in the pore network which can cause cracking
- Typically linked with cycles of freezing and thawing, not just one deep freeze
- Micro-diffusion, pore size distribution vs saturation
- Differential CTE

Questions

- How does this integrate with Salt Scaling?
- What are the concrete parameters influencing freeze thaw susceptibility?
- Is this a candidate for coupling with other mechanisms?

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Corrosion

Observations

- Steel section loss and cover delamination
- Medium to high w/c ratios
- Cover thickness likely not designed for 300 year life
- Coupled with thermal desiccation

Questions

- What are the key parameters for initiation and progression of corrosion?
- What are the structural consequences of corrosion?

Coupled Mechanisms

Observations

- Coupling of mechanisms seems under-developed in the literature
- Linkage between micro cracking and increased transport
- Coupling of stimuli is also relevant

Questions

- Is there any active research on linked or coupled degradation?
- Which mechanisms would likely precede other mechanisms?

Prevention and Mitigation Strategies

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Prevention vs Mitigation

Prevention

- Actions taken during construction or installation in response to potential or expected degradation
- “Best Practices”
- Influenced by design life

Mitigation

- Actions taken once a problem is identified
- Different than remediation, repair and replacement

Prevention Strategies

- Concrete mix design
  - w/c
  - Supplementary cementitious materials
  - Aggregate selection
  - Admixtures
- Construction practices
  - Detailing
  - Cover thickness
  - Precast vs Cast in place

Mitigation Strategies

- Exclusion strategies
  - De-watering
  - Moisture barriers, coatings etc.
- Chemical Mitigation
  - Lithium application (ASR)
  - Cathodic protection (Corrosion)
- Others

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Inspection Techniques and Technologies

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Inspection Technique Categories

- Visual
  - Imaging
  - Walk-downs
- Chemical Analysis
  - Surface pH
  - Corrosion potential
  - Various chemical tests on core samples
  - Laser Induced Breakdown Spectroscopy
- Mechanical
  - Impact echo
  - Ultrasound (some techniques)
  - Mechanical testing of cores
- Non-visual imaging
  - Ultrasound (numerous techniques)
  - Radar
  - Microwave
- Acoustic Monitoring

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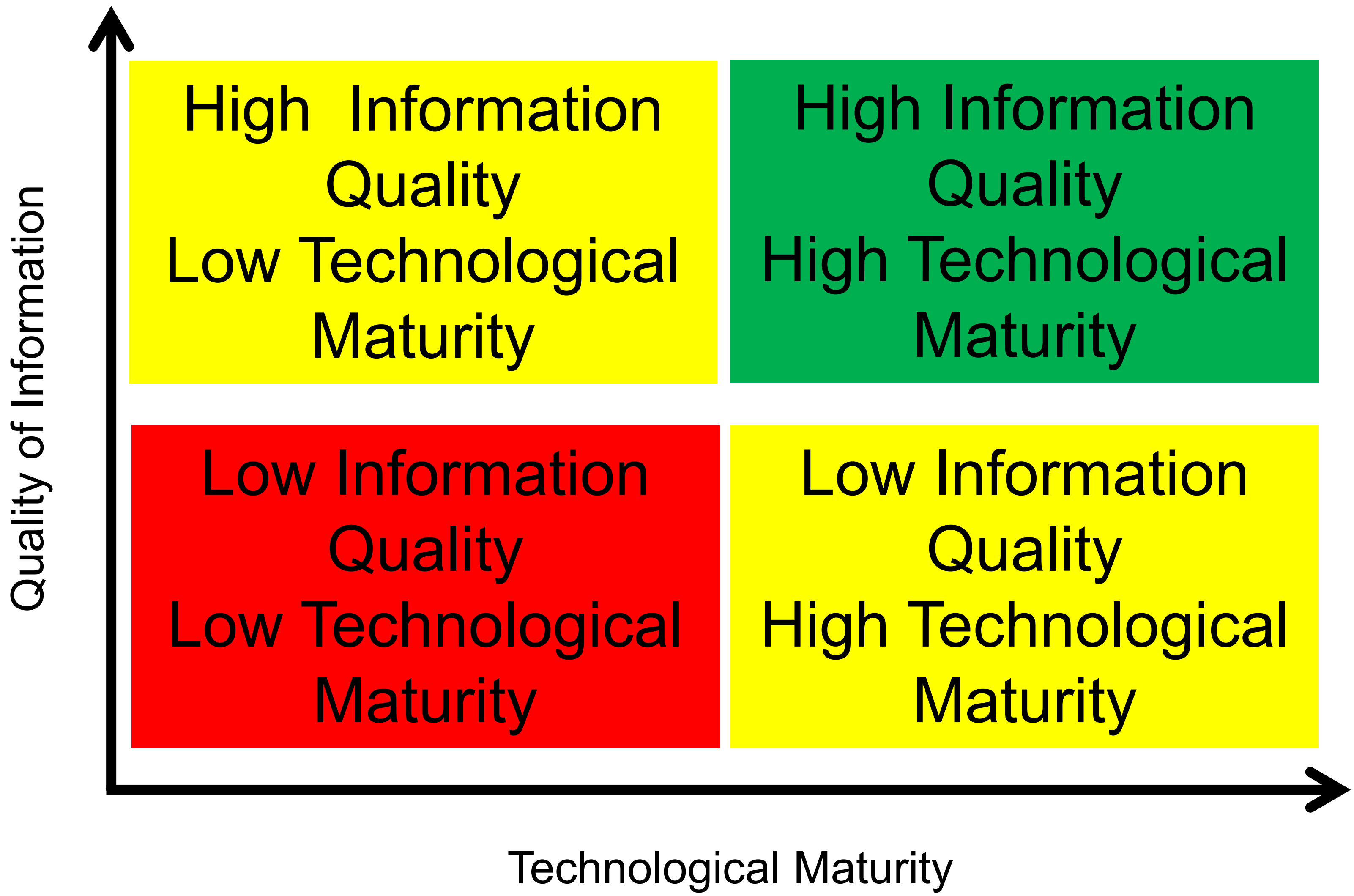
Understanding Limitations



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Inspection and Monitoring

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Challenges and Limitations

- Probability of detection
  - Threshold size, energy, etc.
  - Techniques generally confirm problems, not soundness
- Access issues
  - Radiation, dose
  - Below grade structures
  - Steel plate features

Strategic Monitoring

- Certain techniques are better suited to monitoring than others
  - E.g. Acoustic Monitoring
- Others best suited to targeted inspection
- Are there examples from other industries of monitoring strategies?
- Can our theoretical understanding of mechanisms help to create strategies?
- Is there adequate knowledge to use temporal trending of data for decision making?

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Aging Management Programs

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Lead System / Targeted Inspection

- Should be the "worst" system to ensure that the state is bounded
- Any known problems should be considered
- Environmental conditions
- Age/Loaded Age
- Perhaps more than one system
- Statistics based

- Could a degradation ranking metric be determined?
- Could a logic tree or flow chart be used?

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Frequency

- ACI 349.3R inspection frequencies:
  - 5 year for above grade, inaccessible
  - 10 year for below grade
- Should increase when:
  - A problem is detected
  - Adverse conditions are detected

- Are there examples of concrete degradation progressing more rapidly than these proposed inspection frequencies?

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A Proposed AMP

- Visual per ACI 349.3R
- Groundwater Chemistry Monitoring
- Radiation Surveys

- May not be sensitive to
  - Internal damage
  - Initiation of degradation

- How might the monitoring and detection portion of this proposed AMP be augmented?
  - Methods
  - Frequencies
  - Decision trees

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Time Limited Aging Analyses

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Radiation TLAA

- ACI 349.3R cumulative limits:
  - 1×10^{17} Neutrons/m^2
  - 10^{10} Gy
- Conservative with respect to limits from literature
- Potential coupling:
  - Thermal
  - Environmental
  - Aging
- Is better understanding of the coupled effects with radiation needed?
- Despite the lack of physics based models, is this an expected limiting factor for extended storage?

Other TLAA Possibilities

- Many degradation mechanisms are driven by chemical reactions with unique reaction kinetics
  - ASR
  - Carbonation
- Could any other mechanisms be addressed through TLAA?
  - Adequate modeling
  - Necessary data to support modeling
- Are any mechanisms likely not suitable for TLAA?

Repair Remediation and Replacement

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Repair, Remediation, and Replacement

- Corrective actions could take many forms
  - Patching
  - Partial demolition and replacement of material
  - External shoring or bracing
  - Total replacement
- Licensee decision, but NRC must be able to evaluate any corrective action in the context of the license
- How could the effectiveness of a repair be evaluated?
  - Prescriptive or methods based
  - Performance based
- Are there methods from other industries for evaluating repair quality and the contribution to performance life?

Capacity Quantification