PWROG
PWR Owners Group

Global Expertise • One Voice

Overview of Long-Term Core Cooling Industry Guidance

PA-ASC-1377

NRC Public Meeting
July 19, 2016

PRESSURIZED WATER REACTOR OWNERS GROUP

Meeting Purpose: Obtain NRC feedback on the PWR and BWR Owners Group (OG) project to create long-term core cooling (LTCC) guidance

PWROG PWR Owners Group

Global Expertise • One Voice

Overview of Long-Term Core Cooling Industry Guidance

PA-ASC-1377

NRC Public Meeting
July 19, 2016

Source – www.indigocarhire.co.uk

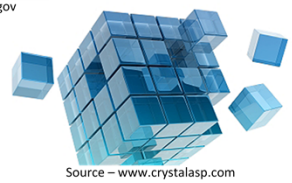
PRESSURIZED WATER REACTOR OWNERS GROUP

- The intent of the LTCC guidance is to provide methods that are considered acceptable for use in implementing requirements regarding the long-term recirculation performance of the emergency core cooling system (ECCS) after a loss-of-coolant accident (LOCA)
- It also provides guidelines for evaluating the adequacy of the ECCS during long-term recirculation, or the LTCC, phase of a postulated LOCA as required by 10 CFR 50.46/50.46c
- At this stage of the guidance development, the OGs are specifically seeking feedback on the overall framework, key definitions, and features
- Historically, regulatory guidance regarding acceptable ECCS performance demonstrations have, due to the complex physical phenomena and mathematical models required, focused on the short-term period of the event
- More recently however, evolving concerns associated with sump debris have challenged the traditional methods and simple models used to demonstrate acceptable ECCS performance during the long-term period of a LOCA
- In addition to the concerns associated with sump debris, two U.S. Nuclear Regulatory Commission letters, one dated August 1, 2005 and one dated November 23, 2005, communicated numerous concerns regarding the way in which potential BAP was addressed in PWR licensees' LTCC analyses that relied on CENPD-254-P or similar analytical models
- Draft Rule 10 CFR 50.46c also emphasizes the need for industry guidance for LTCC. Per the 50.46c Statement of Considerations (SOC) "…the applicable entity must define the demarcation between short-term and long-term ECCS performance demonstration, as well as applicable evaluation models, analytical requirements, and, if necessary, analytical limits."

This presentation focuses on the long-term core cooling guidance framework and structure

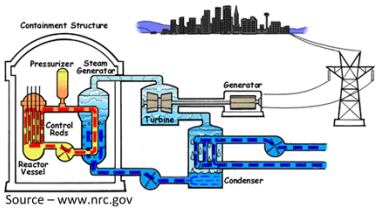
Regulatory Framework – Where does LTCC Guidance Fit?

Source – www.nrc.gov



Overview of Guidance Framework

Source – www.crystalasp.com



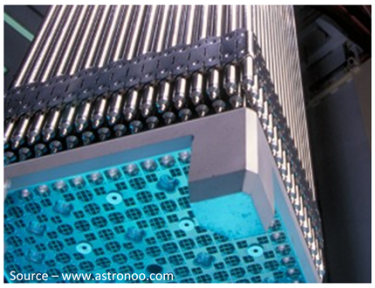
Source – www.nrc.gov

PWR LTCC Content

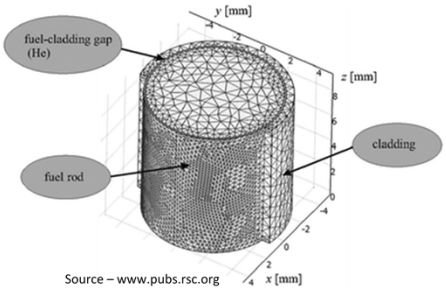
- Regulatory Framework
  - Guidance Applicability
  - 10CFR50.46/50.46c LTCC Requirements
- Overview of Guidance Framework
  - Table of Contents
  - Schedule for Completion
- PWR LTCC Content
  - LOCA Sequence
  - Performance Requirements
  - Key Considerations (i.e., definitions and features)
- Discussion on content of BWR
  - Overall relation to corresponding PWR framework and structure
  - Summary of Content
- Open Discussion
  - NRC feedback on overall approach
  - Regulatory considerations and path for NRC acceptance
  - Summary of actions and next steps

This guide applies to both PWRs and BWRs currently licensed to generate power within the United States

- Applies to reactors fueled with uranium oxide pellets within a cylindrical zirconium alloy cladding



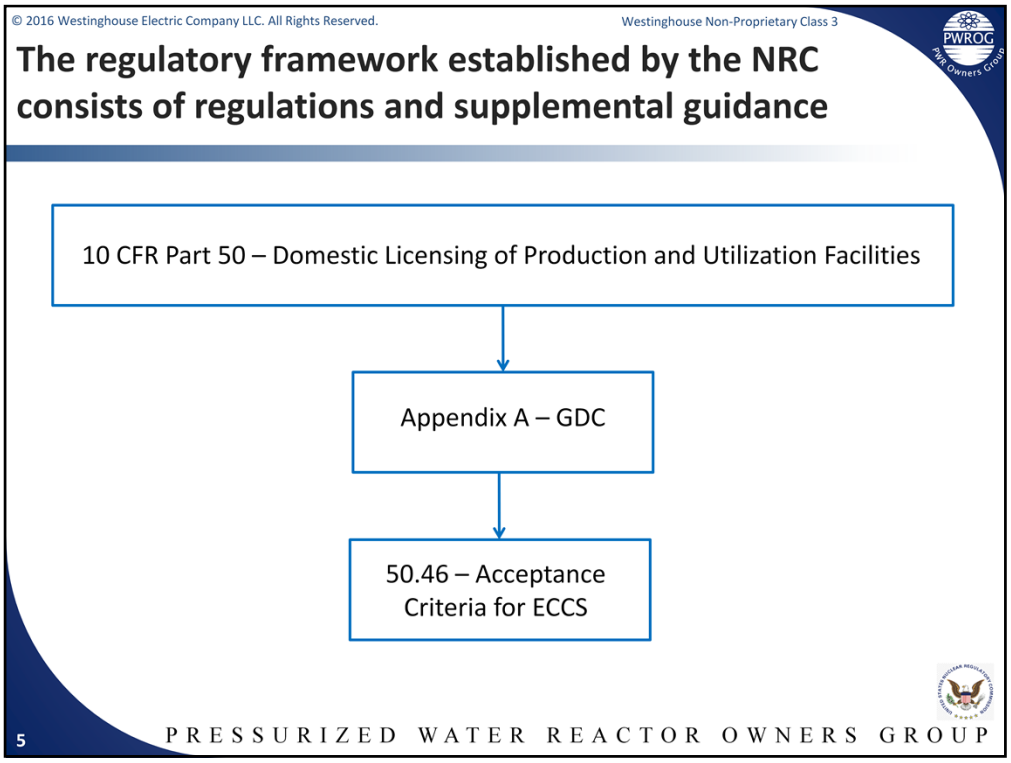
Source – www.astronoo.com



Source – www.pubs.rsc.org

- Applicable to ECCS LTCC demonstrations on a forward fit basis

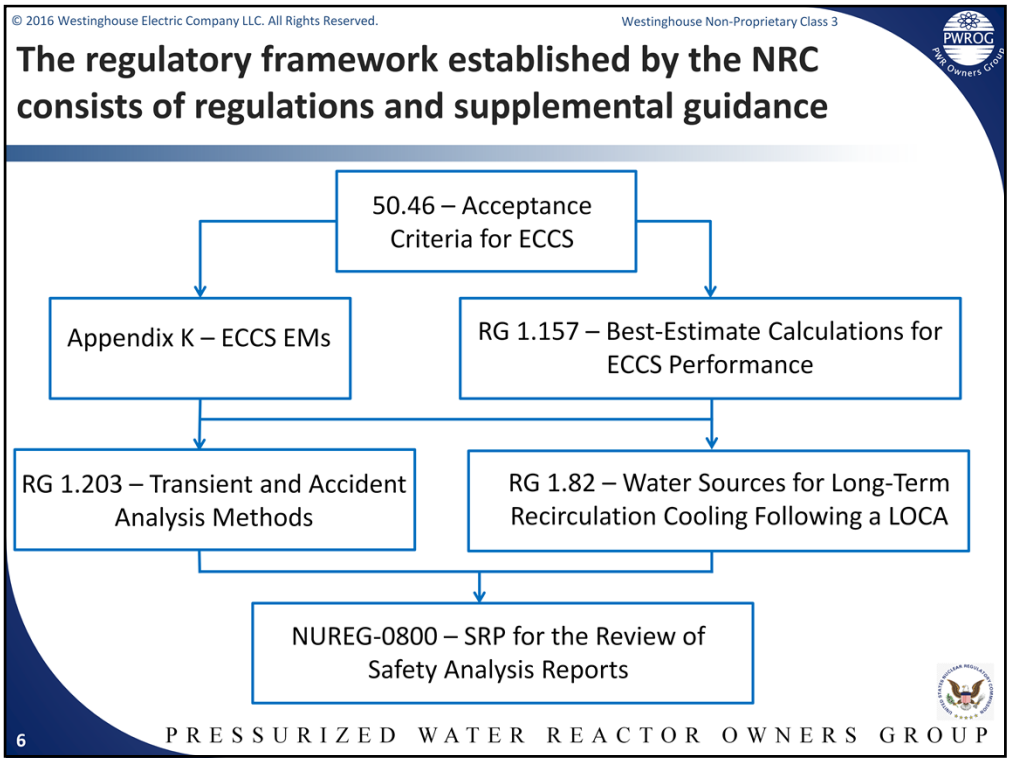
- Long-term ECCS performance requirements and methods for evaluating ECCS adequacy during LTCC using different methods or guidelines than those described herein may also be acceptable if sufficient justification is provided
- Previously performed ECCS LTCC analyses with features which may differ from this guide have been determined to be acceptable
  - Per the 50.46c SOC, “The Staff has found these approaches acceptable for decades. In the absence of a debris-induced, post-quench reheat transient, the staff has determined that: 1) currently approved analytical models and methods continue to be acceptable…”



- General Design Criteria (GDC) applicable to LTCC:
  - GDC 4, "Environmental and Dynamic Effects Design Bases," requires that systems important to safety be designed to accommodate LOCAs
  - GDC 35, "Emergency Core Cooling," requires that an ECCS system be provided to transfer heat from the reactor core following any loss of reactor coolant

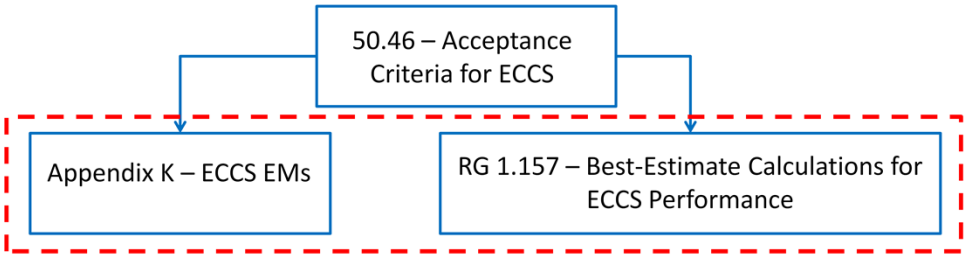
- 10 CFR 50.46(a) requires that the ECCS calculated cooling performance following postulated loss-of-coolant accidents (of different sizes, locations, and other properties sufficient to provide assurance that the most severe results are calculated)

- 10 CFR 50.46(b)(5), "Long-term cooling," requires that:
  - *After any calculated successful initial operation of the ECCS, the calculated core temperature shall be maintained at an acceptably low value and decay heat shall be removed for the extended period of time required by the long-lived radioactivity remaining in the core.*



- Appendix K – Defines required and acceptable features of the ECCS Evaluation Model (EM)
  - Bounding, Deterministic Method focused on analysis of the short-term LOCA transient
  - Many of the required features are not applicable to LTCC
- Regulatory Guide (RG) 1.157 – Describes models, correlations, data, model evaluation procedures, and methods that are acceptable to the NRC staff for meeting the requirements for a realistic calculation of ECCS performance during a LOCA
  - Requires an estimate of uncertainty to demonstrate there is a high probability that the 50.46 limits are met
  - Similar to Appendix K, the RG is focused on the short-term LOCA transient
- RG 1.203 – Describes a process for use in developing and assessing EMs that may be used to analyze transient and accident behavior
  - Evaluation Model Development and Assessment Process (EMDAP) is a generic process that can be applied to LTCC EM development
  - The LTCC Guidance is essentially completing Element 1, “Establish Requirements for EM Capability” of the EMDAP
- RG 1.82 – Provides guidelines for evaluating the adequacy of the sump or suppression pool for long-term recirculation cooling following a LOCA (GSI-191)
  - Guidance is provided for the majority of GSI-191 concerns (debris sources and generation, debris washdown, strainer performance, ex-vessel downstream)
  - Due to the publication date, guidance is lacking with regard to in-vessel concerns and LTCC
  - The LTCC Guidance will consider debris latent coolant as part of LTCC
- NUREG-0800 (Section 15.6.5) – Provides guidance for review of transient and accident analyses
  - Includes guidance for review of LTCC analysis
    - Decay Heat Removal
    - Sources of Coolant Water (GSI-191)
    - Boric Acid Precipitation Control (PWRs)
    - Operator Actions

LTCC Guidance is required for calculation of long-term ECCS performance



Specific LTCC Guidance is Required at this Level of the Framework

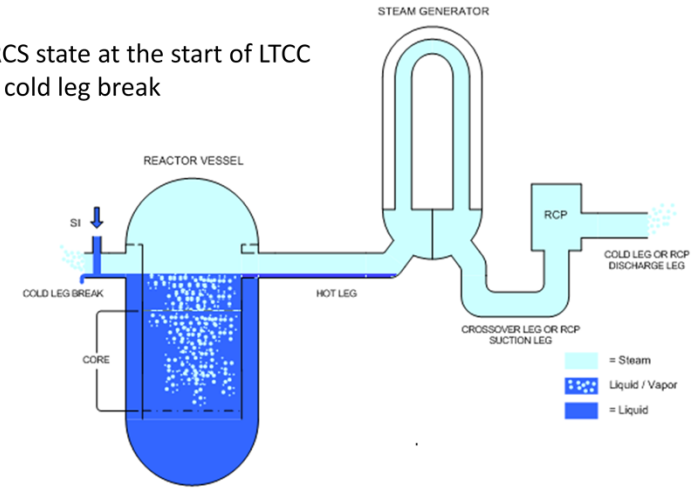
The LTCC Guidance Table of Contents is developed. BWR sections will be discussed separately.

The LTCC Guidance is scheduled to be completed in February 2017

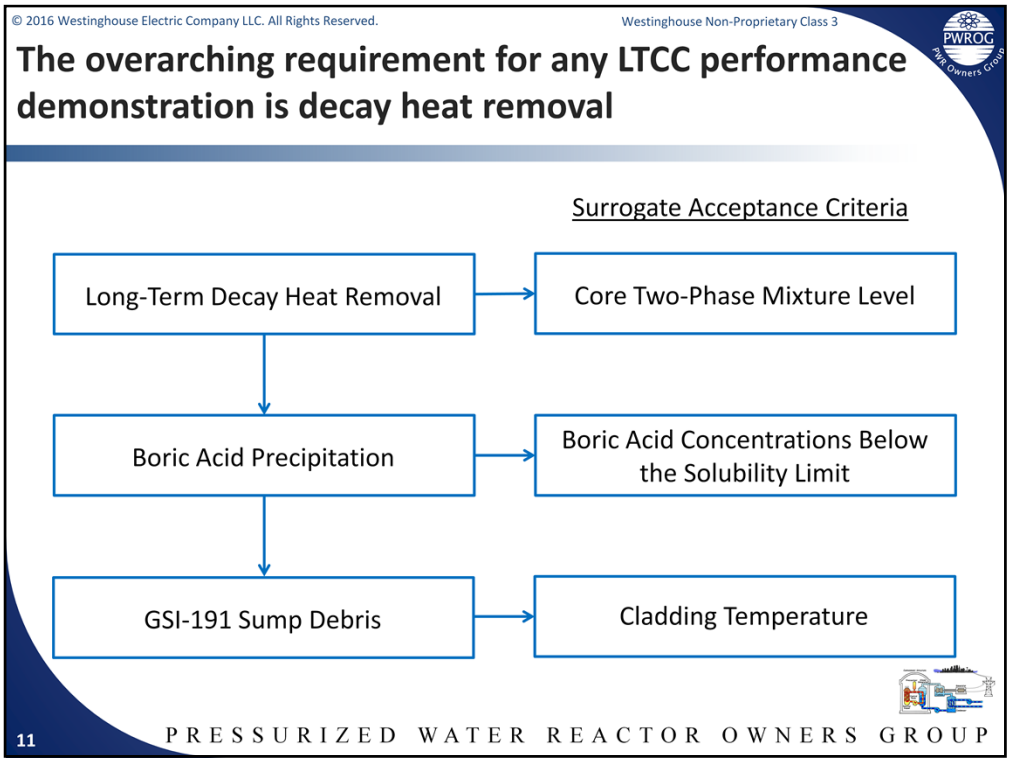
- Complete Guidance Framework – May 2016
- Hold NRC Meeting – July 2016
- Complete Draft Guidance – October 2016
- Hold LTCC Industry Workshop – November 2016
- Issue Final Guidance – February 2017

The LOCA accident sequence if typically broken into a short-term and long-term period

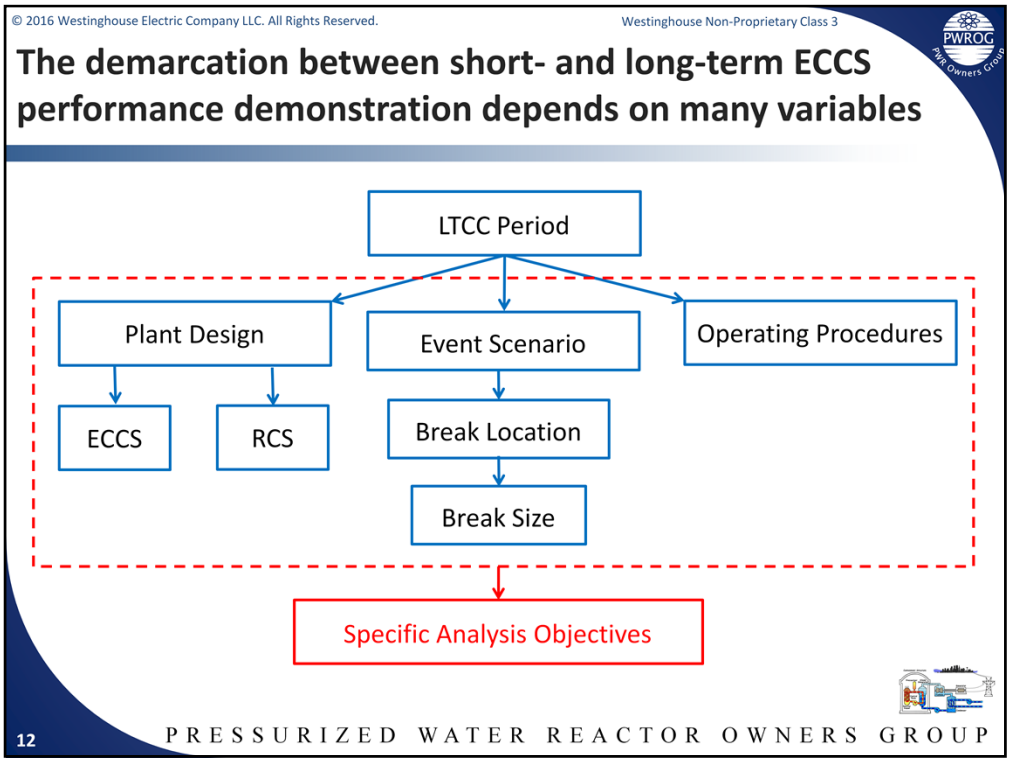
Representative RCS state at the start of LTCC following a large cold leg break



- Safety injection (SI) is initiated to mitigate the short-term consequences of the event by replenishing the reactor coolant system (RCS) liquid inventory and reducing cladding temperatures to acceptably low levels (refill and reflood phases)
- After core reflood is complete, the transition into the long-term period begins
  - ECCS continues to inject into the RCS cold legs (except for UPI plants)
  - RCS liquid inventory continues to increase
  - Operators begin actions to transfer the ECCS to sump recirculation mode
- The LTCC period is characterized by:
  - ECCS operating in sump recirculation mode
  - The arrival of sump debris to the RCS and the potential for a debris-induced post-quench heatup transient
  - Realignment or securing of ECCS equipment (operator actions)
  - After several hours, operators begin actions to mitigate the potential for boric acid precipitation (BAP)
- During the long-term period, it must be assured that core decay heat be removed by the ECCS
  - ECCS is capable of providing coolant flow to the core in excess of boil-off
  - BAP or sump debris does not lead to a condition in which the ECCS cannot maintain effective core cooling



- PWR LTCC Requirements
  - Decay Heat Removal – Overall requirement for any LTCC performance demonstration
    - Surrogate Criterion: Core two-phase mixture level - precludes further heatups which could cause additional cladding failures
  - Boric Acid Precipitation – Specific phenomena analysis to assure continued decay heat removal
    - Surrogate Criteria: Concentration of boric acid below the solubility limit associated with system conditions (temperature, pressure)
  - GSI-191 Sump Debris
    - Demonstrate continued ECCS performance (sump strainer and downstream ex-vessel)
    - Demonstrate continued decay heat removal (in-vessel debris)
      - Surrogate Criterion: Cladding temperature - precludes additional cladding failures
- Other Considerations
  - Operator Action
  - Equipment Classification
  - Recriticality
  - Heat Removal
  - Containment Integrity

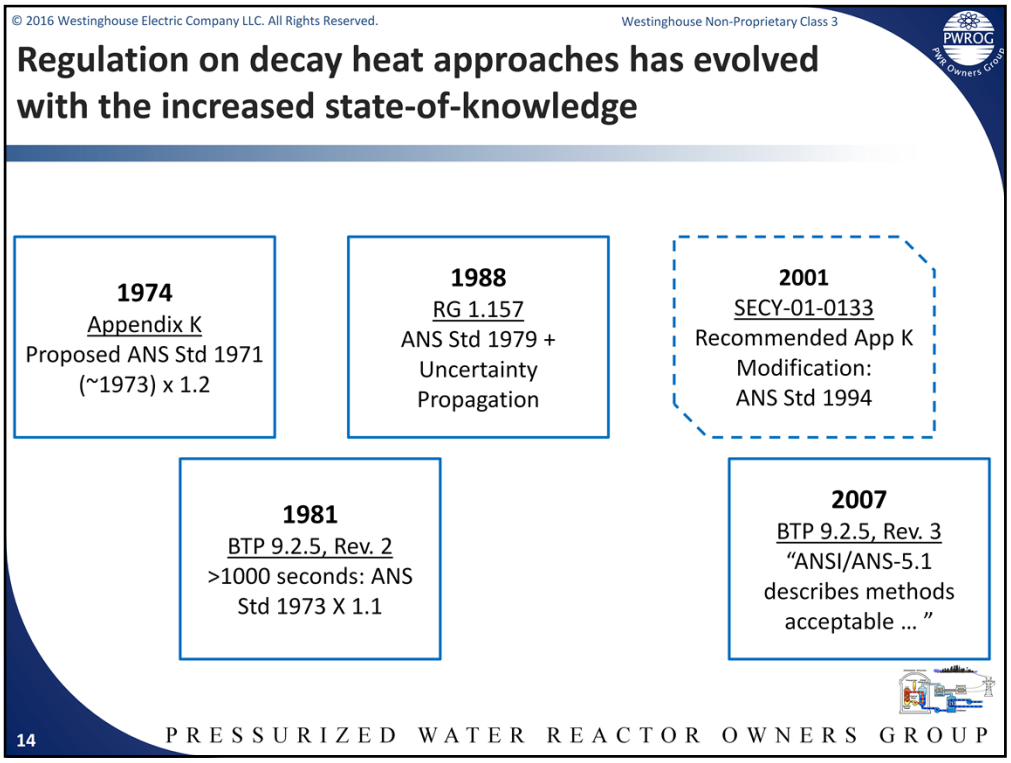


- The start and end of the LTCC period have historically been loosely defined due to the many variations between plant designs, operating procedures, and breadth of scenarios considered
- This is exemplified by the NRC's SOC for 10 CFR 50.46c, "The demarcation between short-term and long-term ECCS performance demonstration depends on many variables including reactor coolant system design, ECCS design, break size, and break location." The SOC goes on further to state, "As a result of these design dependencies, the applicable entity must define the demarcation between short-term and long-term ECCS performance demonstration, …"
- The specific analysis also needs to be considered. Different analyses will have different start and end times

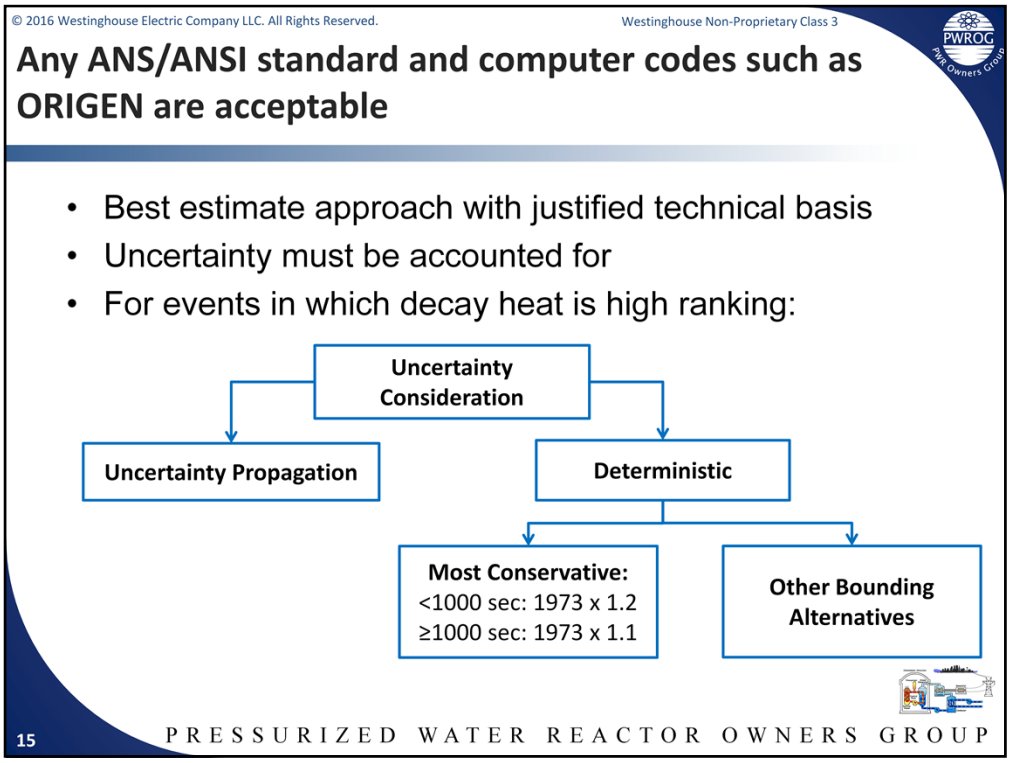
The guidance establishes a process for which a specific time period can be defined for any LTCC analysis.

1. Identify key phenomena and physical processes for the analysis
2. Determine when key phenomena appear based on plant configuration and break scenario to define the start of LTCC
3. Determine when key phenomena have been resolved to define the end of LTCC

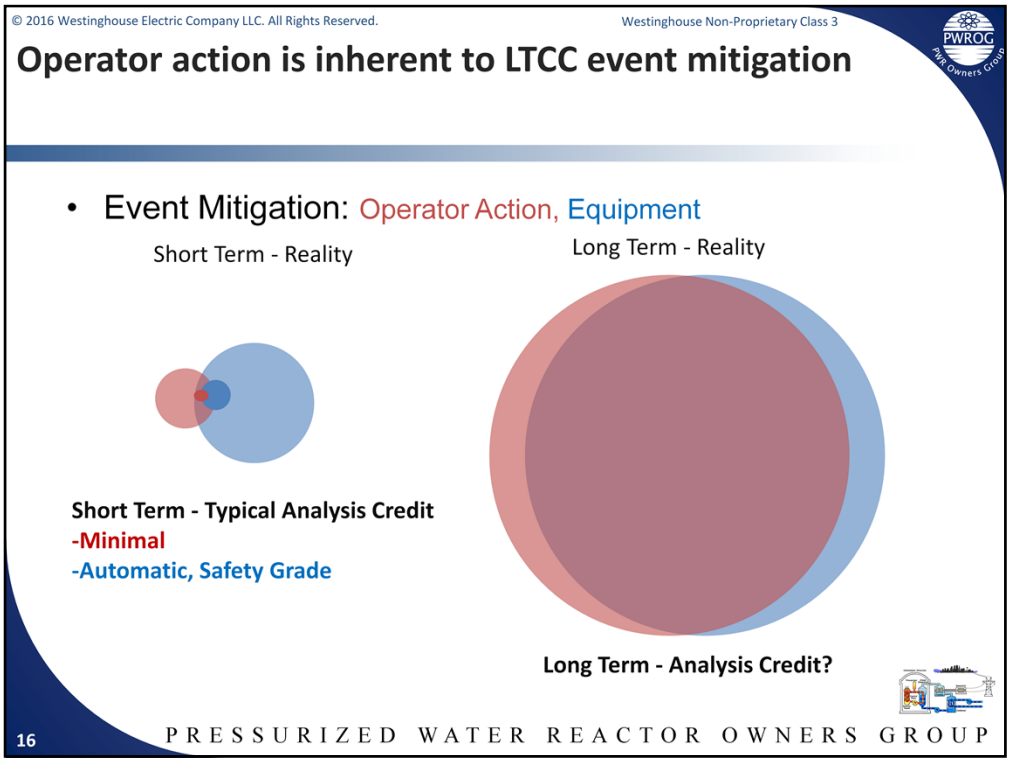
- For every LTCC analysis the major phenomena are identified and this phenomena identification is utilized to define a start and end of LTCC that is specific to each analysis
- The start of LTCC is then determined based on when the appropriate LTCC event phenomena appear, the plant configuration, and break scenario
- The start of LTCC should be considered to be an extension of the short-term analysis. This provides confidence that the full LOCA event scenario is covered.
- In a general sense, LTCC can be defined to start sometime after the core has completely quenched, all fuel rod cladding temperatures are near the saturation temperature, and the reactor vessel liquid inventory has been re-established. Around this time, operators will begin the process of switching from injection mode to long-term sump recirculation mode.
- The generalized end of LTCC can be defined as the time when all dominate phenomena and physical processes have been resolved and there is assurance that all conditions for entering RHR (or shutdown cooling mode, or DHR) can been established; or, that adequate flow can be provided indefinitely to maintain the core at acceptably low temperatures if RHR cannot be established



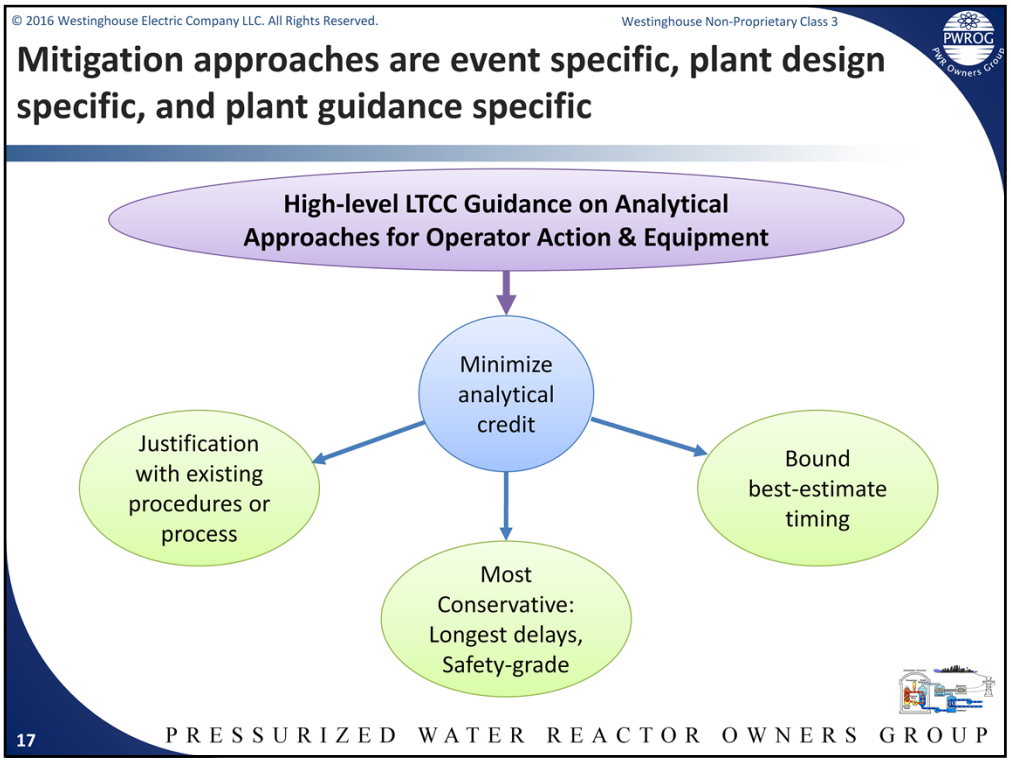
- 10 CFR 50.46
  - Appendix K requires draft 1971 ANS standard with a multiplier of 1.2
    - 20% is the maximum uncertainty in the <1000 second time frame
  - RG 1.157 allows use of ANS 1979
    - Best-estimate models are considered acceptable with demonstration of technical basis
    - ANS 1979 and future standards have uncertainty, sigma values, associated with the equation contributors
    - Many "Realistic Methods" continue to treat decay heat deterministically
- Ultimate Heat Sink analysis - Branch Technical Position (BTP) 9.2.5
  - Recognized that for longer-term analysis, the maximum uncertainty multiplier on the 1973 standard decreases to 10% after 1000 seconds
  - Latest BTP does not prescribe a specific revision of the ANS standard



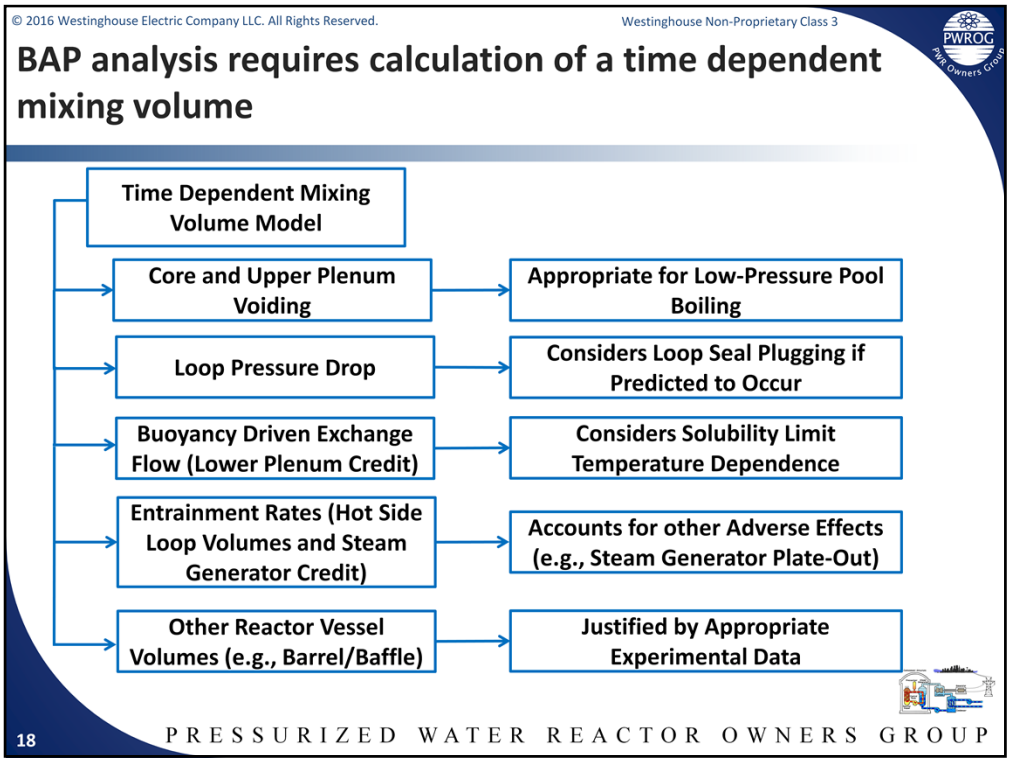
- LTCC Guidance Approach:
  - Decay heat shall include decay of fission products and actinides
  - Any ANSI/ANS-5.1 decay heat standard or acceptable code calculation, such as ORIGEN
  - Retain the consideration of uncertainty required by overall RG 1.157 guidance
    - Uncertainty propagation would treat decay heat as a sampled parameter
    - LTCC calculations are not typically “best estimate methods” with sampled inputs
      - Most conservative deterministic treatment
      - Other still bounding approaches are acceptable with appropriate justification (e.g., 2σ, infinite U^{235} operation, etc.)
    - Control rod assembly insertion may be assumed if it is expected to occur



- Short-term event
  - App. K and RG 1.157 do not place explicit restrictions
  - Typically, operator action is not credited or very limited
  - Typically, only safety-grade equipment
- Long-term event
  - Operator action is inherent to post-LOCA event management
  - Actions are governed by procedures and guidance
  - No delineation between types of equipment available to operator
  - Equipment and power restoration likely
  - Very plant and event specific



- LTCC Guidance
  - Large variation in mitigating strategies and procedures amongst PWRs → limited explicit guidance
  - Analysis credit for operator actions and non-safety grade equipment is acceptable
    - In general, should be minimized and clearly identified
    - Justification by reference to existing procedures or other processes
    - Bounding timing relative to best-estimate based timing
    - Most conservative: Longest delays and only safety grade
    - Margins can be demonstrated by comparison of bounded to best-estimate approaches
  - Consideration of operator mitigation of single failure and power availability determination



- The intend of the guidance is not to provide explicit parameters or models for LTCC analyses
- Rather, the guidance provides appropriate features and requirements that must be met when developing an analysis parameter or model
- Here, the effective mixing volume for BAP analyses is used as an example of what the guidance will provide
    - The calculation of the effective mixing volume for BAP analyses should account for time dependent quantities such as core and upper plenum voiding, two-phase mixture level, and loop pressure drop.
    - Any inclusion of lower plenum volume should consider the time delay associated with transport of boric acid from the core to the lower plenum
    - Credit from additional RCS volumes (e.g., barrel/baffle, hot side loop piping, steam generators) must be justified through comparison to appropriate experimental data or analysis
    - If credit is taken for these additional volumes, other adverse effects (e.g., steam generator plate out) must be identified and accounted for in the analysis

In summary, this product will establish consistent guidelines for addressing LTCC

- Applicable to both PWRs and BWRs currently operating in the U.S.
- Establishes the requirements and acceptable features for methods or analyses demonstrating the long-term recirculation performance of the ECCS after a LOCA
- Provides guidelines for evaluating the adequacy of the ECCS during long-term recirculation, or the LTCC phase of a postulated LOCA as required by the relevant criteria of 10 CFR 50.46/50.46c
- Industry is seeking feedback from the NRC on the overall approach

Questions?

Global Expertise • One Voice
www.pwrog.com