Enclosure 3

Presentation Slides to Support Westinghouse-NRC Technical Exchange Meeting on the Cobalt-60 Production Program

(Non-Proprietary)

July 2023

Westinghouse Electric Company
1000 Westinghouse Drive
Cranberry Township, PA 16066

Proprietary and Confidentiality Disclaimers

NRC – Westinghouse Technical Exchange Meeting
Cobalt-60 Production Program

July 19, 2023

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Meeting Agenda

Topic	Presenter	Start Time	Duration
Update of the Cobalt-60 program	Keith Newmyer	10:00	0:10
Executive Summary	Keith Newmyer	10:10	0:05
COBA Rodlet T/H Analysis	Alireza Mofidi	10:15	0:25
Capsule Wear and Fatigue Analysis	Eric Benacquista	10:40	0:20
Safety Analysis	Ann Marie DiLullo	11:00	0:05
Capsule Risk Assessment (PRA)	Ray Schneider	11:05	0:20
Accident Doses	Sean Kinnas	11:25	0:10
Gamma Heating	Sreela Ferguson	11:35	0:10
Spent Fuel Pool Criticality	Mike Wenner	11:45	0:10
Content and Structure of LARs	Brad Maurer	11:55	0:05
MEETING ADJOURN	- - -	12:00	

Purpose and Goals

- Provide further information to support the upcoming NRC review of Cobalt-60 LARs
  - Provide a brief update on the Cobalt-60 program
  - Discuss analysis approach for select technical areas
  - LAR structure submittal schedule
- Goal is to advance NRC understanding of analysis approaches prior to formal LAR presubmittal meetings
  - Solicit NRC staff questions and feedback
  - Identify potential follow-up actions for Westinghouse to facilitate more efficient LAR review

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Cobalt-60 Production Logistics

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Executive Summary

Westinghouse has designed and rigorously evaluated the Cobalt Burnable Absorber (COBA) to assure the design and operational integrity of the cobalt capsules to allow safe, continued operation of commercial PWRs.

- Capsule design and qualification through detailed analysis, material selection, testing, and inspection -- as discussed with NRC in December 2022
- A detailed risk assessment demonstrates a negligible impact on public health and that the stainless steel capsule provides a reliable barrier to the migration of cobalt to the RCS coolant.
- Confirmed the thermal hydraulic performance of the capsules and COBA rodlets.
- Conducted wear and fatigue analyses of the capsules, COBA rodlets, and thimble guide tubes.
- Demonstrated the applicability of current safety analysis methodology and concluded that any impacts on the analysis conclusions would be small or negligible.
- Accident dose assessments demonstrate only minor impact on LOCA dose analyses.

COBA Thermal/Hydraulic Analysis

Alireza Mofidi

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COBA Rodlet Design - Thermal Hydraulic Criteria

The following thermal-hydraulic (TH) design criteria were evaluated for the COBA rodlet design:

I. The maximum temperature of the core component rods shall not exceed the melting temperature of the material used, for Condition I and II operation.

II. There will be no surface boiling from the core component rod within the dashpot region of the fuel assembly guide thimble, for Condition I operation.

III. There will be no bulk boiling in the fuel assembly guide thimble, for Condition I operation.

IV. The sum of the bypass flows through all the different types of thimble-core component rod combinations and the instrumentation tubes in the core shall not exceed the core design limit, for Condition I and II operation.

V. The capsules shall remain seated in the rodlet during normal operation to prevent damage and blocking of flow paths inside COBA rodlet.

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In addition to above TH core component design criteria, bulk boiling shall not occur for the COBA in the hottest channel in Region 1.

All Thermal-Hydraulic Criteria for the Current COBA Rodlet Design Are Met

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COBA Rodlet Centerline Temperature

Criterion

- The acceptance criterion is that the maximum temperature of the Cobalt-59 slug shall not exceed the melting temperature of the material used for Conditions I and II operation.

Basis

- Excessive temperatures could lead to melting of the absorber material Cobalt-59 slugs.

Verification

- The melting temperature for Cobalt-59 is 2723°F. Using a conservatively bounding peaking factor (F_Q) of 2.5, 18% overpower condition and a conservative rodlet surface temperature of 660°F (assuming boiling on the rodlet surface), the maximum rodlet temperature at the center of the Cobalt-59 absorber is 2001°F, which is lower than the corresponding melting temperature. Thus, the calculations demonstrate sufficient margin and the maximum temperature of the COBA rodlet will not exceed the melting temperature for the Cobalt-59 and this criterion is satisfied.
- As noted above, these calculations were performed based on conservative assumptions. With realistic calculations, the water temperature inside the COBA rodlet will not reach the inception of boiling temperature (660 °F) and the maximum absorber temperature during normal operation is below 850 °F.

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Thimble Bypass Flow

Criterion

- The sum of the bypass flows through all the different types of thimble core component rod combinations and the instrumentation tubes in the core shall not exceed acceptable bypass flow limits. For plants which operate with Thimble Plugs Installed (TPI), this is defined as the generically allowable limit of 2 percent of total vessel flow. For plants which operate with Thimble Plugs Removed (TPR), adding COBAs shall not increase the current thimble bypass flow.

Basis

- The core bypass flow, of which the thimble flow is a portion, is not considered as contributing to the cooling of the core. Therefore, the allowance for the thimbles must be verified to assure adequate cooling of the core.

Verification

- The maximum expected thimble flow is defined as the best estimate thimble flow plus 10 percent uncertainty. The maximum expected overall thimble/instrument tube bypass increases for a plant with TPI is less than 0.1% and the bypass flow is maintained below 1.7%, thus meeting the design criterion of 2%. For a plant with TPR, the maximum expected overall thimble/instrument tube bypass decreases. The decrease is less than 0.1%, thus meeting the criterion of not increasing the current thimble bypass (for plants which operate with Thimble Plugs Removed).

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COBA Rodlet/Thimble Boiling

Criterion

- There shall be no bulk boiling in the thimble and in the region between COBA outer tube and the capsule stack.

Basis

- The effects of stress corrosion of the ZIRLO® thimbles will be minimized if the bulk temperature of the thimble coolant is less than saturation temperature.
- The impact of a dry-out condition on cooling performance of the COBA rodlet will be minimized if the bulk temperature of the coolant in the region between COBA outer tube and capsule stack is less than saturation temperature.

Verification – COBA Rodlet

- The cooling analysis of the COBA rodlet was performed using two approaches. Region 2, defined in Figure 1, between the COBA outer tube (rodlet) and the fuel assembly thimble tube was analyzed using standard thermal hydraulic methodology. However, available thermal-hydraulic codes typically used for WABA or RCCA cooling analyses were not suitable for the analysis of Region 1, defined in Figure 1, between the capsule and COBA outer tube.

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COBA Rodlet/Thimble Boiling - Verification

Region 1

- To take advantage of the conjugate heat transfer, Computational Fluid Dynamics (CFD) was used to model the flow and heat transfer characteristics of COBA rodlet/thimble two flow path configuration in relatively fine mesh detail. Boundary conditions of the CFD domain were taken from other thermal hydraulic calculations.

- The CFD model results, accurately modeling the radial heat transfer through Region 1 to Region 2, showed that no bulk boiling occurs in all flow paths of the COBA rodlet/thimble configuration. A parametric study was conducted using various operating conditions and outer tube geometries which demonstrated that the Region 1 temperatures were insensitive to different operating conditions and outer tube designs. Therefore, it is concluded that the thimble boiling criterion is met for the COBA rod.

Region 2

- A bulk boiling analysis was performed for Region 2 in the fuel assembly guide thimble tube above the dashpot region for 17x17 fuel designs. Other T-H calculations confirm that Region 2 of the COBA absorber rod will not experience bulk boiling in the thimble. This independently confirms the results of CFD calculations that were also performed for Region 2.

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Surface Boiling in Dashpot Region

Criterion

- There shall be no surface boiling from the COBA rodlet within the dashpot region of the thimble. The surface boiling criterion, which is applied to the low flow dashpot region, does not apply to the small gap and potentially low flow region between the COBA capsule and the outer tube. The COBA capsule, which has the highest temperature in this region, is made from stainless steel and thus, there is no concern with corrosion.

Basis

- Surface boiling from the COBA rodlet within the dashpot could lead to accelerated corrosion of the Zircaloy dashpot tube.

Verification

- A surface boiling analysis was performed for the COBA rodlets in the fuel assembly dashpot region. This analysis conservatively assumed the COBA rodlet to be fully inserted and considered the limiting thermal design flowrate. The results show that surface boiling in the dashpot region will not occur for the COBA rodlet.

COBA Capsule Lift Force

Criterion

- The COBA capsules shall remain seated in the rodlet during normal operation to prevent damage and blocking of flow paths inside the COBA rodlet.
- This criterion cab be achieved by a spring clip mechanism or by analysis to show that the lift forces acting on a capsules stack are sufficiently low enough.

Basis

- The Lift-off of the capsule stack during operation due to the flow rate inside the capsule/outer tube gap could lead to difficulty of harvesting the capsules and also could affect the Region 1 (Figure 1) configuration, impacting the cooling performance inside the COBA rodlet.

Verification

- The COBA capsules could lift-off and float within the COBA rodlet outer tube annulus if the weight of the capsule stack is lower than the lift force acting on the capsules. Both cold zero power and hot full power conditions were analyzed to calculate the lift force together with the buoyancy component. The resulting maximum lift force acting on the capsules was determined to be lower than the capsule stack weight. Therefore, the COBA capsules will not experience lift-off during operation and will maintain the capsule stack position inside the outer tube.

Capsule Wear and Fatigue Analysis

Eric Benacquista

Westinghouse

Objectives

- Assess the susceptibility of the COBA rodlet components to failure due to fatigue and wear due to contact with interfacing components
- Analytically, some amount of wear is inevitable. Therefore, the goal is to show that even conservative levels of wear are not a concern.

Focus on wear limits for structural integrity and harvestability

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Flow-Induced Vibration

- Detailed Computational Fluid Dynamics (CFD) analyses were performed to estimate the thermal and hydraulic environment of the COBA components.
- Local and bulk flow velocities are extracted from the CFD models to calculate random turbulence forces.
- Using Au Yang correlations and generic power spectral density curves (PSDs), random force-time histories are created at several elevations for each component (guide thimble, rodlet, and capsules).

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Conservative random turbulence forcing functions are generated with methods used conventionally for PWR components.

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Non-Linear Transient Dynamic Analysis

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- An ANSYS model representing the guide thimble, rodlet, and capsules is built using beam, mass, fluid, and contact elements.
- The model formulates intermittent contact between the capsules and rodlet and between the rodlet and guide thimble.
- Capsules are conservatively modeled as a stack without friction between them.
- The capsules and slugs are evaluated with a similar non-linear transient dynamic submodel.
- The large model is benchmarked to fuel assembly static deflection, modal response, and flow test data.

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Volumetric Wear Analysis

- The results of each model are processed for contact forces, sliding distance, and component stresses.
- Contact force and sliding distances are used in aggregate to calculate a work rate applied to each component.
- Used in combination with material wear test data and the Archard work formulation, an estimated volumetric wear is calculated for a 4.5 year life of the COBA assembly.
- This wear is used to assess the risk of component failure and irradiated slug debris during harvesting.
- Component stresses are used in high-cycle fatigue calculations.

Work is in progress to provide risk probabilities into the PRA

Safety Analysis

Ann Marie DiLullo

Westinghouse

Safety Analysis Topics

- Safety Analysis Impact
  - Conservative COBA decay heat estimate of [ ]^{a,c}
  - No significant impact on reload safety analysis checklist (RSAC) parameters
  - No impact on PCWG design parameters, core bypass flow, core pressure drop, rod drop time
  - Evaluations will be performed with any necessary plant specific considerations
  - Small or negligible impacts are expected
- LOCA / LOCA-Related Analyses
  - Large Break (LB) LOCA
  - Small Break (SB) LOCA
  - Post-LOCA Long Term Cooling (LTC)
  - GSI-191
  - LOCA M&E

Safety Analysis Topics

- Transient Analyses
- Steamline break M&E
- Steam Release for Dose – SLB, locked rotor, rod ejection
- Steam generator tube rupture
- SFP heatup on loss of cooling
- Plant cooldown analyses
- Loss of RHR cooling at midloop conditions
- FLEX operation

Probabilistic Risk Assessment (PRA)

Ray Schneider

Westinghouse

Objectives

- Confirm Plant Operation with COBAs do not pose a public risk
- Demonstrate that operation with COBA rodlets will not adversely impact plant operations

Focus on both Safety and Operational Risks

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Preliminary Risk-Informed Assessment of Risk of Plant Operation with COBAs

- An assessment of COBA design and operations indicate their insertion into the fuel assemblies:
  - Will not contribute to or cause new reactor accidents
  - Will not generate sufficient additional power to alter the progression of potential severe core damage scenarios.
  - Qualitative / Quantitative assessments confirm:
    - Added power level small
    - Added zircaloy and steel content insufficient to significantly impact post-accident hydrogen generation or its consequences
    - Cobalt content will not impact human actions associated with severe accident recovery
    - Since cobalt is not volatile, public dose impacts following potential severe core damage will be largely unchanged
- Thus, no change in core damage or large early release frequencies are expected.
  - Plant change will be in accordance with RG 1.174, Revision 3, as COBAs should be limited to a “very small risk change” and poses a negligible impact on public risk.

COBA Operation results in a negligible impact on public risk

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Assessment of Operational Risks

COBA Failure Modes Evaluated For Risk of Cobalt Release to Primary System

- Cobalt ingression into RCS coolant requires damage to capsule
- Failure Modes established based on FMEA
- Failure Modes Considered:

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Stainless Steel Capsule provides a reliable barrier preventing cobalt migration into the RCS

Assessment of Operational Risks: Preliminary Insights

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Assessment of Operational Risks: Preliminary Insights (cont.)

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Stainless Steel Capsule provides a reliable barrier preventing cobalt migration into the RCS

Capsule Failure Fault Tree

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Preliminary Estimates of Likelihood of Capsule damage <~0.1%

Accident Dose

Sean Kinnas

Westinghouse

Accident Doses

- Potential impact of COBA inserts on the Dose analyses was evaluated
- No impacts on non-fuel melt events or fuel handling accident
- WEC work to assess rod ejection impact ongoing
- LOCA Dose analysis following RG 1.183 is impacted
  - Cobalt is included with noble metal nuclide group.
  - Noble metals are non-volatile.
  - Noble metals have very low release fraction.
    - WEC work to assess release fraction ongoing.
  - Dose impacts using RG gap fraction on sample analysis showed approximately 0.5% to 1% impact.

Minor impact on LOCA dose analyses

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Gamma Heating

Sreela Ferguson

Westinghouse

Increased Gamma Heating / Irradiation of SFP Concrete Structure

- Additional activity inventory in a COBA Fuel assembly after exposure to three (3) 18-month cycles (compared to a non-COBA assembly) ~ 8 x 10^5 curies of Co-60.
- There is resultant impact on the incident gamma energy flux on the SFP walls/floor
- There is consequent increase in gamma heating / irradiation of the SFP structure
- Assessment focusses on the anticipated increase in the incident gamma energy flux on the SFP walls/floor resulting from
  - Storage of COBA Fuel assemblies in the SFP
  - Co-60 rodlet / capsule harvesting activities in the cask pit area
- Assessment is focused on the incremental impact of COBA assembly storage / Co-60 capsule harvesting on
  - Gamma heating of the SFP structure
  - Integrated dose incident on the SFP structure (storage scenarios only)

SFP Structure Gamma Heating / Radiation Degradation : Acceptance Criteria

- Acceptance criteria outlined in NUREG/CR 6927 are used to assess the impact on gamma heating and irradiation of the SFP structure:
  - During storage of COBA Fuel assemblies in the SFP
  - During Co-60 Harvesting activities
- Section 4.3.1.1, of NUREG/CR 6927 states:
  - Nuclear heating of concrete structures need not be considered if the structure is exposed to an incident energy flux $< 10^{10}$ Mev/cm^2-sec
  - The degradation of concrete due to irradiation need not be considered if the total integrated dose due to exposure to COBA Fuel assemblies remains $< 10^{10}$ rads. Due to the brief duration of harvesting procedures, this criterion is only applied to COBA assembly storage.

SFP Structure Gamma Heating: Acceptance Criteria / Approach

If the incident flux on the SFP wall / floor is estimated to be > 10^{10} MeV/cm^2-sec, resolution is achieved via the following approaches:

- For COBA Assemblies Storage Scenarios:
  - Judicious fuel management of COBA assemblies is used to remain within the criterion in NUREG/CR-6927
  - Preliminary analyses indicate that typically:
    - COBA fuel assemblies should be stored a minimum of four feet from the SFP walls
    - The contribution of the COBA rodlets to the total flux at the SFP floor is less than the criterion of 10^{10} MeV/cm^2-sec
- For COBA Assembly Harvesting Scenarios:
  - If necessary, development of a thermal profile in the concrete and acceptance criterion in Section A.4.1 of ACI 349-80 Appendix A is utilized to confirm that there are no adverse effects from the management of COBA Fuel assemblies or the COBA rodlets / Co-60 capsules during the harvesting process.
  - It is assumed that COBA rodlet harvesting activities are not permitted during refueling / core-offload scenarios

Major Takeaways – Per preliminary analyses:

- Expected restrictions on COBA fuel assembly placement in the SFP is limited to requiring a minimum distance of 4 ft from the SFP walls.
- The integrated dose on the SFP walls due to storage of COBA assemblies for the remaining life of the plant (inclusive of 40 years of life extension) will remain < 10^{10} rads

Spent Fuel Pool Criticality

Mike Wenner

Westinghouse

Spent Fuel Pool Criticality

- The evaluation of the impact to Spent Fuel Pool criticality analyses is ongoing
- Primary mechanism is fuel management changes as a result of operation with COBA
  - COBA itself is a weak absorber, bounded by other absorber impact
  - Increased traditional absorber needed due to fuel management
  - Other initiatives or updates added while updating an analysis of record, such as:
    - Fuel product changes
      - Axial absorber features
      - Increased Theoretical Density Fuel
    - Potential Uprates
  - Expectation of impact to axial burnup / moderator temperature input as a result.

Fuel Management Changes Will Likely Necessitate A Full Update To Analyses Of Record Via An LAR On An Application Specific Basis

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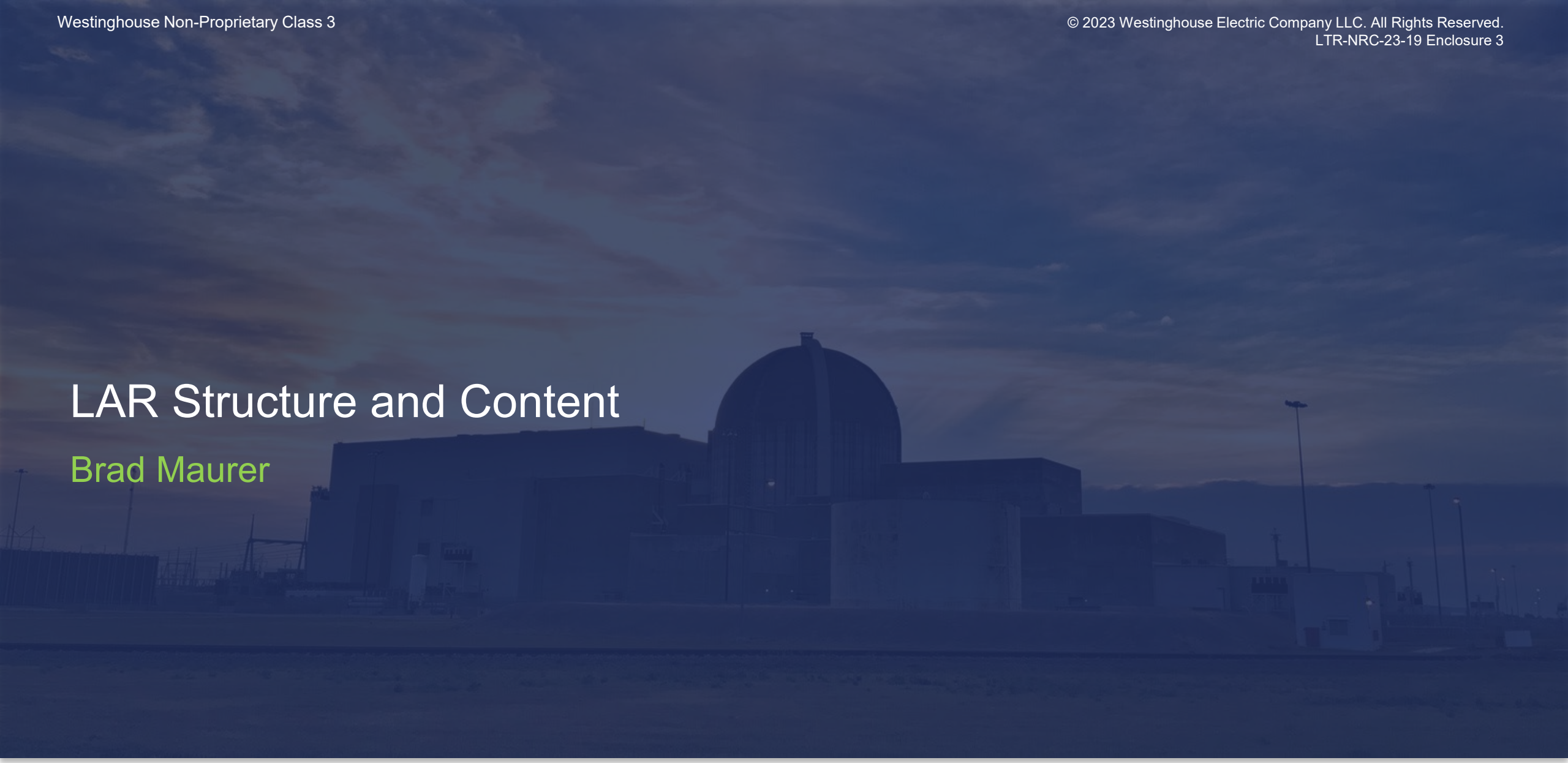


LAR Structure and Content

Brad Maurer

Westinghouse

LAR Structure and Content

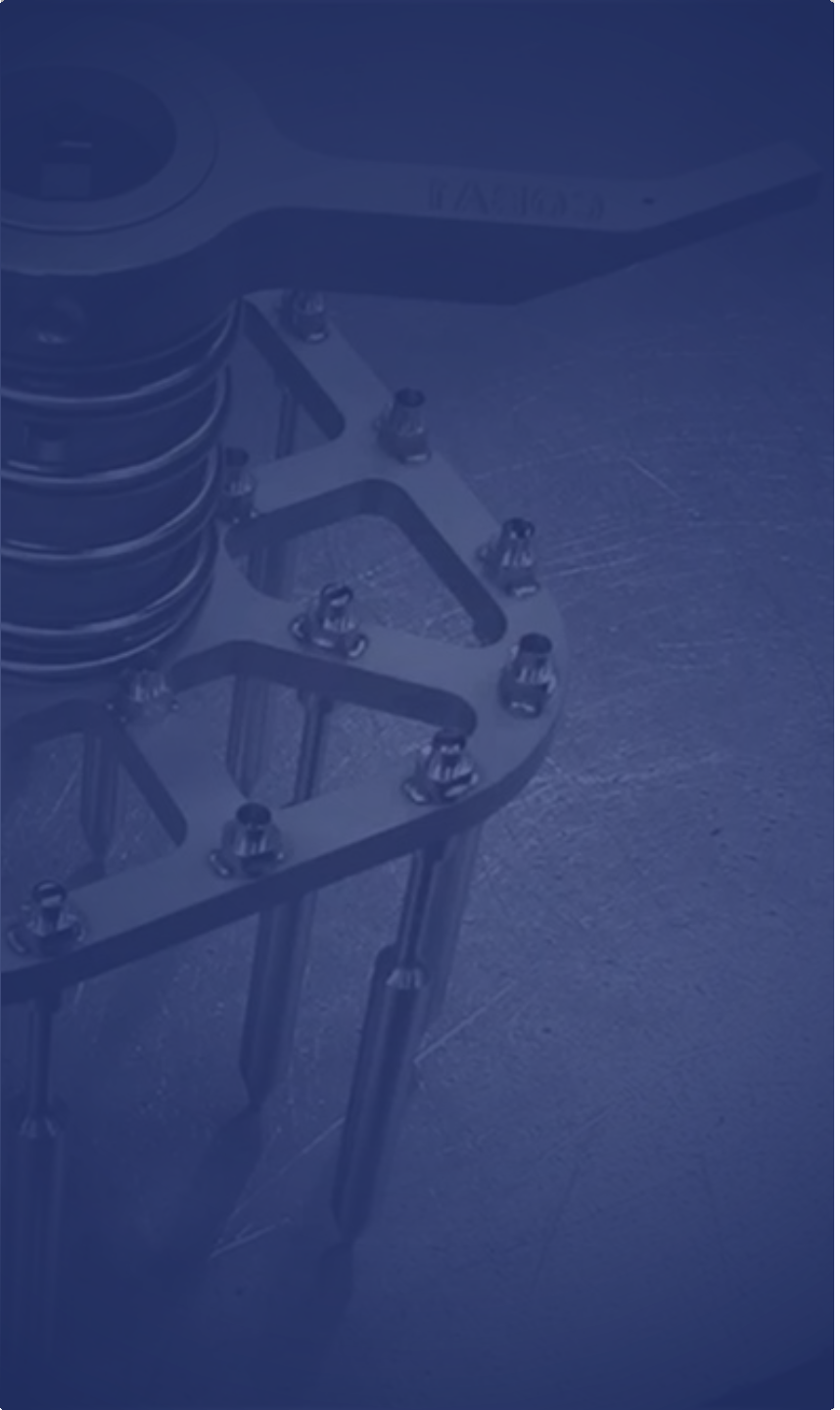
- License Amendment Request (LAR) will be submitted to address the requirements of 10 CFR Part 30 for the intentional production of byproduct material, and to make Technical Specification changes associated with reanalysis of Spent Fuel Pool criticality, as needed.
- LAR submittals will be prepared for each licensee seeking approval for the production of Cobalt-60.
- For efficiency of review, the submittals will be structured as follows:
  - License Amendment Request – significant similarity between licensees
  - Generic Technical Report –provides the bulk of the technical supporting information and would be included with each LAR submittal
  - Plant-specific information – addresses plant features and analyses specific to each plant

LAR Structure and Content

Licensee cover letter	
Enclosure 1	License Amendment Request to Support Cobalt-60 Production
	Introduction, request for approval, proposed change, background, technical analysis, regulatory analysis, environmental consideration
Attachment 1	Operating License Markups
Attachment 2	Technical Specification Markups
Attachment 3	Technical Specification Retyped Pages
Enclosures 2 & 3	Generic Description and Assessment of the Application of Cobalt Burnable Absorber (COBA) Assemblies (P/NP)
Enclosures 4 & 5	Plant-specific information in Support of Cobalt-60 Production (P/NP)
Enclosures 6 & 7	Spent Fuel Pool Criticality Safety Analysis (P/NP)
Enclosure 8	Affidavit(s)

Proposed LAR Review Schedule for Lead Plant

- Proposed LAR review schedule for lead plant
  - Pre-submittal Meeting — 2-3 months prior to LAR submittal
  - LAR / TR Submittal — Licensee dependent
  - License Amendment Issuance — 12 months after LAR submittal



Thank You

✉ Learn more about the Westinghouse and Nordion Cobalt-60 Initiative by contacting your Westinghouse account representative

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