MRP-227, Revision 1 Requests for Additional Information

Kyle Amberge
EPRI-Materials Reliability Program

Tim Wells
Southern Nuclear

Joshua McKinley
Westinghouse

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Background

- MRP-227, Revision 1 transmitted to NRC 12/21/2015 (ML15358A046)
- Formal RAIs from staff received by letter dated 5/15/2017 (ML17079A027)
- Preliminary responses discussed in three meetings
  - July 12-13, 2017 (ML17159A432)
  - September 6, 2017 (ML17248A542)
  - October 5, 2017 (ML17278A034)
- Industry responses transmitted in two letters:
  - MRP 2017-027 on October 16, 2017 (ML17305A056)
  - MRP 2018-003 on January 30, 2018

Purpose

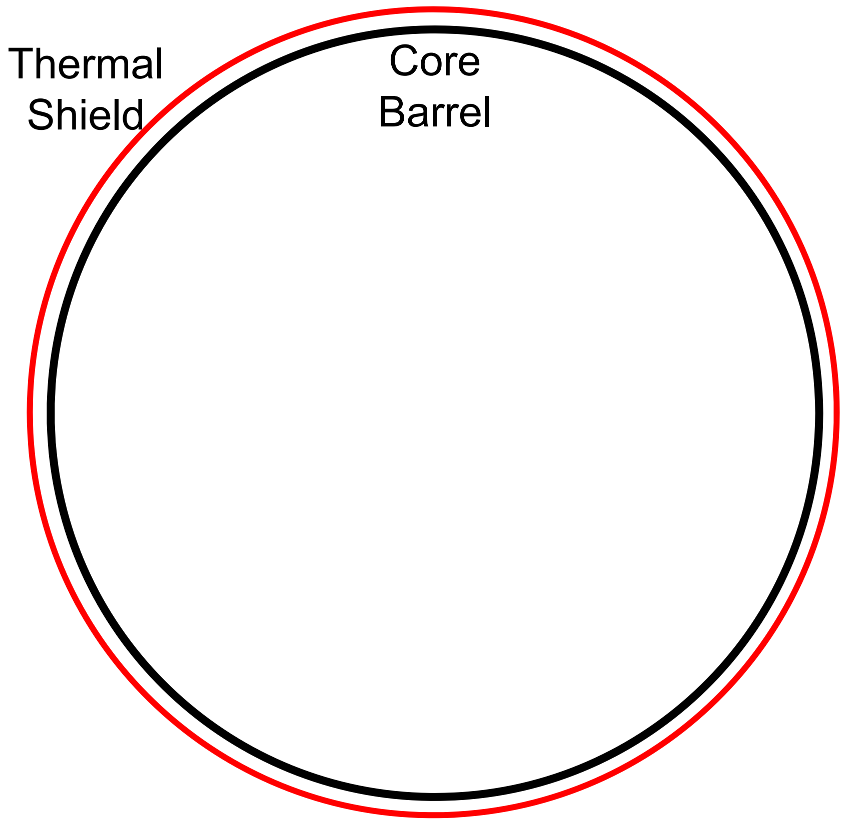
- Additional informal questions provided on February 5, 2018
- Primary focus on clarifications for RAI 5 and RAI 10
- Presentation provides preliminary responses to these additional questions for further discussion

Industry Concerns about Barrel Weld Coverage

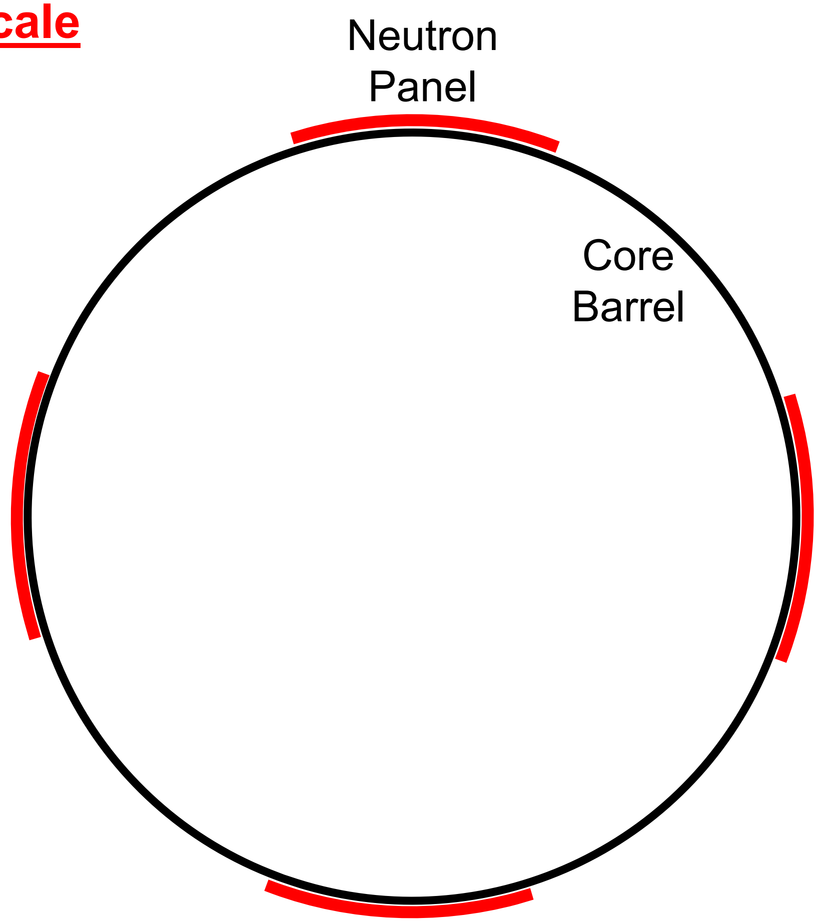
- Full coverage of lower barrel welds will require disassembly
  - Baffle-former assembly or core shroud completely covers ID
  - Neutron panels cover 40-50 percent of barrel OD (bolted on, no gap)
  - Thermal shields limit OD accessibility and increase difficulty
- Basic assumption in MRP-227 development was component disassembly should be avoided unless absolutely warranted
  - RAI 4-8 on MRP-227, Rev. 0 (MRP 2010-066, ML103160381)
  - Driver should be a safety need
- Disassembly carries serious risks:
  - Personnel safety and dose during disassembly, inspection, and re-assembly (ALARA)
  - Mechanical disassembly and reassembly would have to be performed remotely
  - Potential for damage to the assembly sections
  - Potential for loose parts and debris
  - Inability to re-weld structures
  - Potential need to modify the internals' design (due to accommodating the above)

Sketch of Thermal Shield and Neutron Panel Layout

Not to Scale



Thermal Shield Configuration



Neutron Panel Configuration

Industry Response to Observed Degradation

- Observation of cracking degradation in the PWR core barrel welds would lead to several responses
  - Notification of the industry through emergent issue vehicles
  - Notification of the industry and NRC through EPRI under MRP-227 NEI 03-08 requirement on reporting
  - Evaluation of the extent of condition (both at the affected plant and at other plants)
  - Flaw tolerance evaluations in accordance with WCAP-17096-NP-A
  - Determination of the need for interim guidance and revisions to the MRP-227 I&E guidelines
- Industry has demonstrated how it will respond to new operating experience in the 2016 baffle-former bolt clustering experience

Relevance of BWR Experience to PWRs

- BWR cracking experience has been extensive
  – Core shroud cracking first observed in 1992
  – Circumferential cracking required installation of tie rods at several plants by 1994
  – Vertical weld cracking observed by 1996
  – Cracks grow slowly and have allowed a 10-year inspection interval
  – Number of flaws observed has increased and dimensions changed
    - May be due to improving inspection techniques and tighter inspection requirements
    - Changes in inspection technique may also be a factor (VT to UT)
  – Investigations have shown flaws initiating from locations where construction supports were welded and later removed

Relevance of BWR Experience to PWRs (cont.)

- PWR cracking experience
  - Core barrel cracking only observed at two US sites
    - Cracking early in life due to thermal shield design issues
    - Fatigue cracks in base metal (well away from CB welds) due to flow-induced vibration
    - Source of fatigue resolved by making design changes to the barrel
    - Cracks left in place with blunting-holes drilled at ends and monitored (periodic visual exams over past 30+ years)
  - Cracking of baffle-former-bolting (BFBs) by IASCC
  - Limited cracking observed in other PWR primary system components
    - Majority due to off-normal chemistry incidents in high flow regions
    - Most due to severe cold work
- Difference between PWRs and BWRs is due to the differences in water chemistry and electrochemical potential
  - Plants must maintain water chemistry control per chemistry handbooks
    - *BWRVIP-190 Revision 1: BWR Vessel and Internals Project, BWR Water Chemistry Guidelines-2014 Revision.* EPRI, Palo Alto, CA: 2014. 3002002623.
    - *Pressurized Water Reactor Primary Water Chemistry Guidelines: Volume 1, Revision 7.* EPRI, Palo Alto, CA: 2014. 3002000505.

Core Barrel Weld MRP-227 Inspection Experience

- Westinghouse and CE UFW (SCC only):
  - At least 11 inspections have been conducted, which have achieved 100% reported coverage of the weld. These have each been of one side of the core barrel with a mix of inspections from the OD and inspections from the ID. No relevant indications.
- Westinghouse LFW and CE LGW (SCC only):
  - At least 9 inspections have been conducted, which have achieved greater than 75% reported coverage of the weld. Six of these achieved greater than 90% and three reported 100% coverage. These have all been conducted from the OD of the core barrel. No relevant indications.
- Westinghouse and CE UGW (SCC only):
  - At least 9 inspections have been conducted, which have achieved 100% reported coverage of the weld. These have each been of one side of the core barrel with a mix of inspections from the OD and inspections from the ID. No relevant indications.
- Westinghouse LGW and CE MGW (core beltline welds fluence, IASCC):
  - At least 9 inspections have been conducted, which have achieved greater than 55% reported coverage of the weld. Seven of these achieved greater than 75% coverage. These have all been conducted from the OD of the barrel. No relevant indications.

Comparison of BWR and PWR Parameters Affecting SCC

- SCC and IASCC dependent on three factors:
  – Mechanical loading
  – Susceptible material
  – Corrosive environment
- BWRs and PWRs have many similarities
  – Sources and magnitudes of stress are going to be similar
  – Material types used in the internals are the same and from same vintage
  – Coolant provides an aqueous environment with the potential for SCC
- Several *significant* differences exist between BWRs and PWRs
  – Peak temperature and dose are higher in PWRs
  – BWR normal water chemistry has a much higher electrochemical potential (ECP) as compared to PWR coolant
  – Less than optimal early-life BWR chemistry control may have resulted in more deleterious species present in the coolant

Impact of High ECP Operation

- Early life BWR operation resulted in accelerated SCC degradation
  - Operation with oxidizing environment (high ECP) leads to accelerated initiation and growth (min. 5x difference in growth from NWC to HWC)
  - Early life impurity levels may have contributed to SCC
  - Started in the most susceptible locations, including areas of high cold work or residual stress and sensitized material
- Introduction of HWC and noble metal chemistry in BWRs
  - Significantly reduce the cracking propensity
  - Does not heal existing cracks
- PWRs have operated with a lower susceptibility environment from day one of operation
  - Hydrogen added to the coolant to scavenge oxygen = low ECP
  - Boiling not part of primary water = concentrating species not possible

Conclusions about BWR and PWR Comparison

- The significant differences between BWRs and PWRs should be considered when evaluating BWR experience relative to PWR internals
- PWRs use the same materials and have some design similarities but little degradation has been observed
  - Comparisons between BWR and PWR experience must consider the significant differences in water chemistry
  - Low ECP of PWR primary coolant suppresses degradation
  - Early life operation with oxidizing environments led to much more cracking in BWR internals components
- Industry responded to degradation observed in BWRs with increasing inspections and improved inspection techniques
  - Observation of degradation in PWR components would elicit the same
  - Current visual inspections are appropriate given the lack of cracking
  - Coverage would be increased if cracking is observed

Additional Question 1 (February 5 Questions)

Question 1:

- Response to Request for Additional Information (RAI) 5 in part discussed functionality considerations in support of the reduced sample size for the core barrel welds. Specifically, a core barrel weld could completely fracture allowing the core to drop, and the reactor could still be safely shut down. However, MRP-191 failure modes, effects and criticality analysis (FMECA) categorizes the core barrel welds as high consequence of failure, because failure of these welds could preclude safe shutdown. Please discuss the apparent inconsistency between the RAI 5 response and the MRP-191 FMECA results.

Response to Question 1

- Apparent inconsistency stems from two aspects of the original FMECA from 2005:
  - FMECA combined the economic and safety consequences into one category labeled “Likelihood of Damage” (See MRP-191, Table 6-3)
  - Rev. 0 expert panel assigned a conservative “Likelihood of Failure” of medium
    - Multiple degradation mechanisms
    - Little experience with EVT-1 level core barrel weld inspections
- Industry is currently revising MRP-191 FMECA for SLR
  - Consequence now divided into both safety and economic
  - Results account for new data and experience
    - Acceptance criteria have examined stress, dose, and crack growth
    - MRP-227-A inspections performed on multiple plants and welds with no relevant conditions detected to date
  - Updated Rev.2 report will be published in mid-2018

Comparison of FMECA Results - Westinghouse

MRP-191, Revision 1 FMECA Ranking and Categorization Table for the Westinghouse Core Barrel Welds

Assembly	Subassembly	Component	Material	Screened-in Degradation Mechanisms	Likelihood of Failure L, M, H	Likelihood of Damage L, M, H	FMECA Group	Category
Lower internals assembly	**Core barrel**	Lower core barrel (includes LGW, LFW, MAW, and LAW)	304 SS	1A, 2, 6	M	H	3	C
		Upper core barrel (includes UFW, UGW, and UAW)	304 SS	1A, 6	M	H	3	C

MRP-191, Revision 2 (SLR) FMECA Ranking and Categorization Table for the Westinghouse Core Barrel Welds

Assembly	Subassembly	Component	Material	Screened-in Degradation Mechanisms	Likelihood of Failure	Safety Consequence	Economic Consequence	Safety FMECA Group	Economic FMECA Group	Safety Category	Economic Category
Lower Internals Assembly	**Core barrel**	Lower core barrel axial welds (includes middle axial weld (MAW) and lower axial weld (LAW))	304 SS	Weld, IASCC, Fatigue, IE, VS	L	L	M	1	1	A	A
		Lower core barrel girth welds (includes lower girth weld (LGW) and lower flange weld (LFW))	304 SS	Weld, IASCC, Fatigue, IE, VS	L	M	H	1	2	B	B
		Upper core barrel axial welds (includes upper axial weld (UAW))	304 SS	Weld, Fatigue	L	L	M	1	1	A	A
		Upper core barrel girth welds (includes upper flange weld (UFW) and upper girth weld (UGW))	304 SS	Weld, Fatigue	L	M	H	1	2	B	B

Comparison of FMECA Results - CE

MRP-191, Rev. 1 FMECA Ranking and Categorization Table for the CE Core Support Barrel Welds

Assembly/ Subassembly	Component	Material	Screened-in Degradation Mechanisms	Likelihood of Failure L, M, H	Likelihood of Damage L, M, H	FMECA Group	Category
Core Support Barrel Assembly	Upper cylinder (includes UFW, UGW, and UAW)	304 SS	1A	L	H	2	B
	Lower cylinder (includes MGW, LGW/LFW, MAW, LAW, and CSBFW)	304 SS	1A, 2, 6	M	H	3	C

MRP-191, Rev. 2 (SLR) FMECA Ranking and Categorization Table for the CE Core Support Barrel Welds

Assembly	Component	Material	Screened-in Degradation Mechanisms	Likelihood of Failure	Safety Consequence	Economic Consequence	Safety FMECA Group	Economic FMECA Group	Safety Category	Economic Category
Core Support Barrel assembly	Upper cylinder girth welds (Upper Flange Weld, Upper Girth Weld)	304 SS	Weld, IASCC, Fatigue, IE	L	M	H	1	2	B	B
	Upper cylinder axial welds (Upper Axial Weld)	304 SS	Weld, IASCC, Fatigue, IE	L	L	M	1	1	A	A
	Lower cylinder girth welds (Middle Girth Weld, Lower Girth Weld /Lower Flange Weld)	304 SS	Weld, IASCC, Fatigue, IE	L	M	H	1	2	B	B
	Lower cylinder axial welds (Middle Axial Weld, Lower Axial Weld)	304 SS	Weld, IASCC, Fatigue, IE	L	L	M	1	1	A	A

Conclusions from MRP-191 Revision 2 for SLR

- FMECA ranking and categorization results for Rev. 2 consistent with the technical basis provided in the response to RAI 5 (MRP 2018-003)
- Likelihood of Failure reduced to Low
  - Extensive operating experience from MRP-227-A inspections
  - Significantly improved understanding of stress in the core barrel and its welds
- Separation of safety and economic consequences:
  - Safety consequence is medium – core shutdown is still maintained
  - Economic consequence is high – may result in costly repairs or replacement
- Note that core barrel welds were separated into girth welds and axial welds because of the significant differences
  - Axial weld operating stress and safety significance are much lower

Additional Question 2 (February 5 Questions)

Question 2:

- RAI 5, Tables 1-3, what is the probability of detection for each crack size?   How do you get >25% probability when inspecting a 25% sample with only one crack present? (Maybe provide an example of one of these calculations).

Response to Question 2

- "Probability of Detection" (POD) refers to two things:
  - Probability that a particular EVT-1 inspection will detect a crack of a certain size
  - Probability of detecting one or more cracks of a specific size in a typical core barrel weld length
- Inspection POD
  - Implicitly included in the response to RAI 5 in minimum detectable crack size assumptions (0.25" in the response) and treatment
  - Cracks below 0.25" assumed to have POD of zero (conservative)
  - Cracks 0.25" and longer assumed to have POD of 100%
  - Expected to be close to the real probability of detection for longer cracks
  - MRP-228 inspection standard EVT-1 requirements maximize POD
    - Demonstration, cleanliness, travel speed, angle, distance, and lighting requirements.
  - POD vendor and inspection system specific, thus not included in calculations

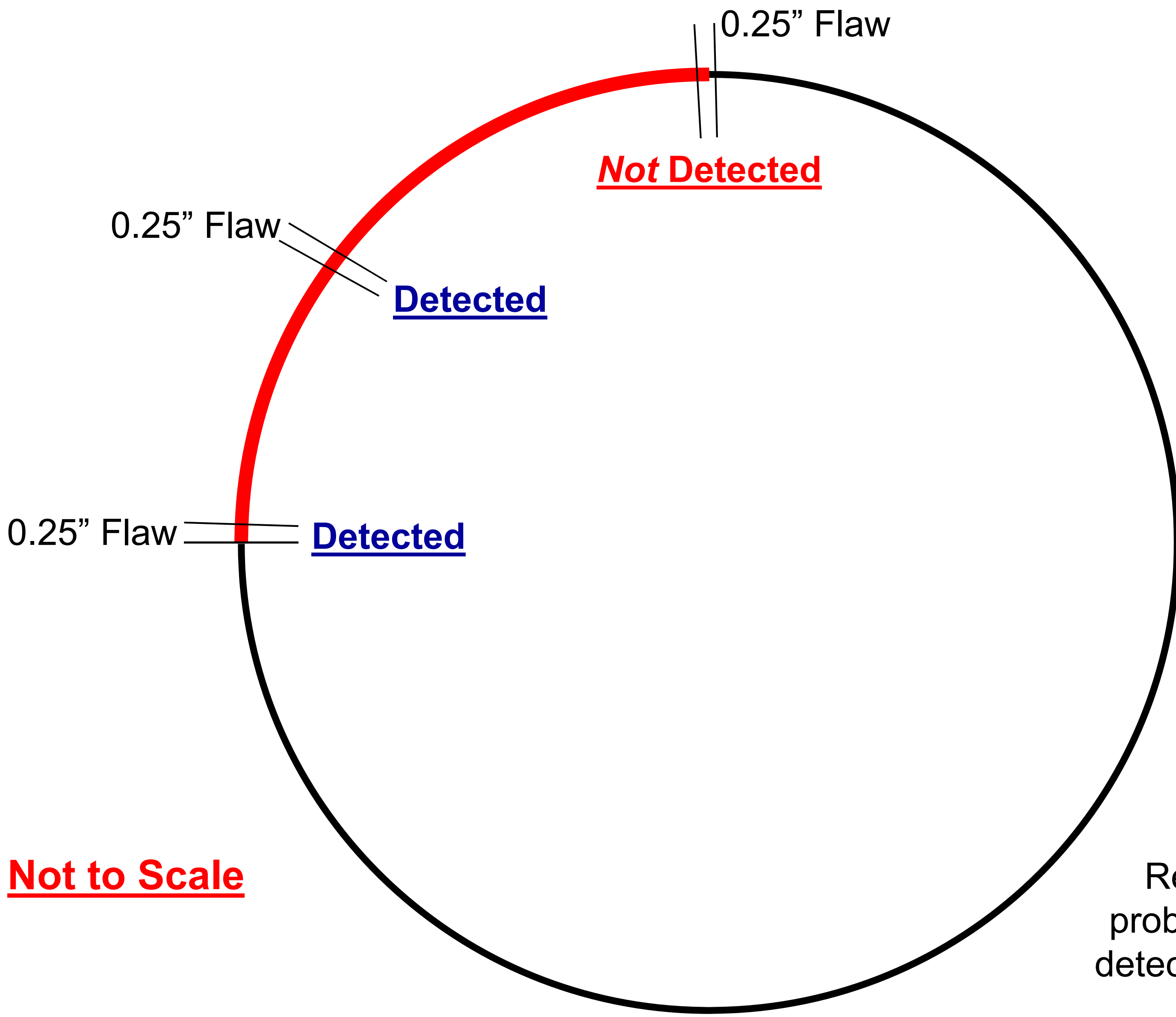
Response to Question 2 (cont.)

- Main subject of RAI 5 response in MRP 2018-003 is probability of detecting a crack of a certain length
- Probability dependent on crack length
  - Due to finite weld length, crack size, and minimum detectable size
  - *"Assumed crack size has a slight effect on the probability of detection, with larger cracks having a higher probability than smaller cracks. In this calculation, the increase in probability comes from the potential to detect the end of a crack that extends into the uninspected portion of the weld." (MRP 2018-003, Page 7)*

Crack Detection Probability

- Probability of detecting a crack of certain length for 25% coverage is not precisely 25%
  - Due to finite length and minimum detectable crack size
  - 0.25” of crack length or greater intersecting inspection will be detected
  - Less than 0.25” will not be detected
- 0.25” crack case:
  - Probability = *inspection coverage (25%) – 0.25”/weld length* = 24.9%
  - Crack at very end of inspected area assumed to be missed
- Larger crack
  - 0.25” or more of the crack must intersect the inspection.
  - Inspected length effectively increased by the crack length minus the minimum detectable size
- 2” crack case
  - Increases inspection coverage effectively by 1.75”
  - Probability = *inspection coverage (25%)+(crack length-0.25”)/weld length-0.25”/weld length = 25.3%*

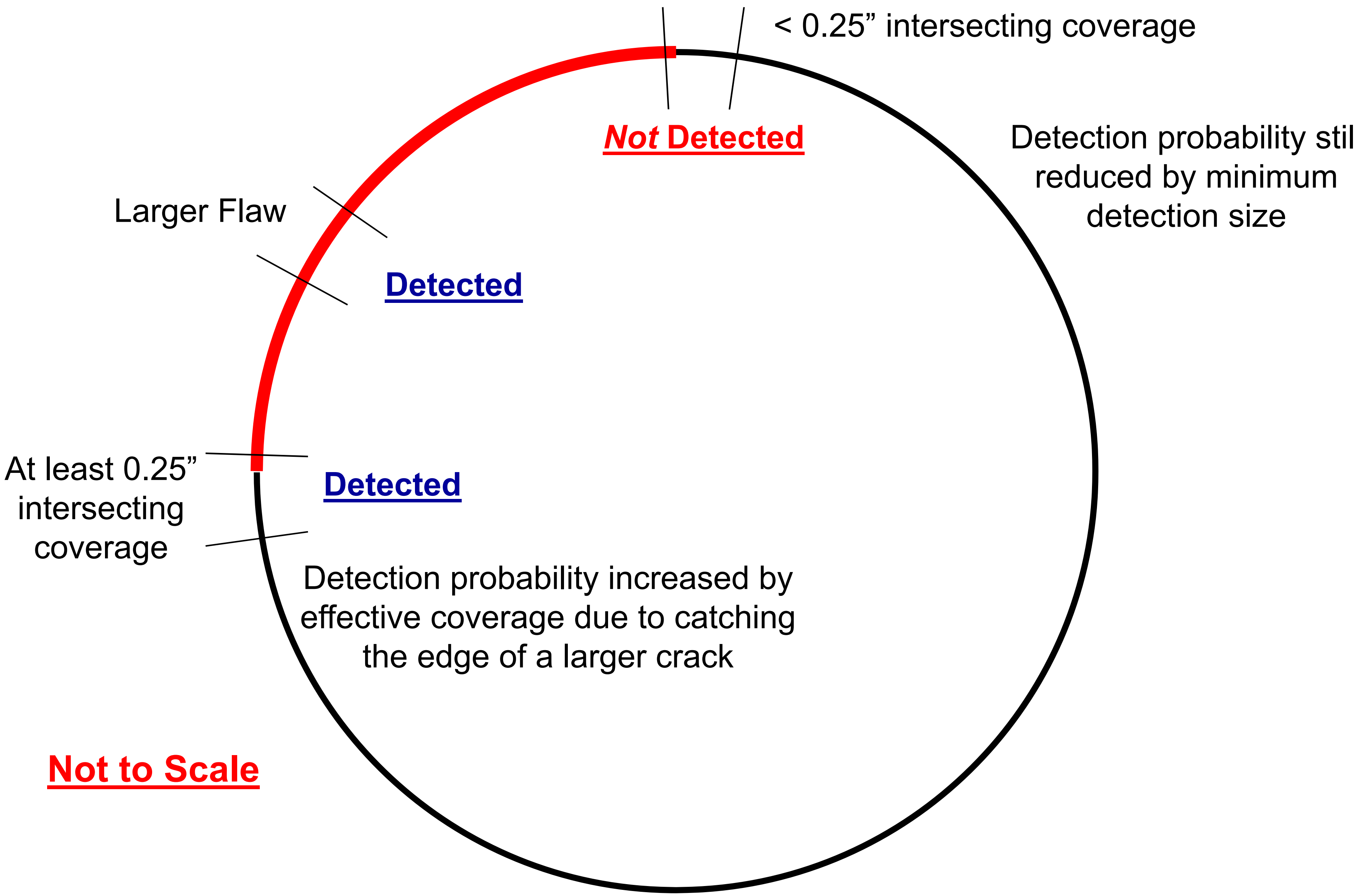
Visual Representation of Inspection with 0.25” Crack



Not to Scale

Reduces detection probability by minimum detection size (to 24.9%)

Visual Representation of Inspection with Larger Crack



Additional Question 3 (February 5 Questions)

Question 3:

- RAI-5—Response from the Material Reliability Program (related to the functionality of the core barrel under a faulted condition) states in part the following—Page 11 of LTR-AMLR-17-9, Rev.2:
  - "Testing was conducted to measure the effect of various abnormal conditions on the ability to insert the control rods and the time to scram. One of these tests investigated the effect of a full core drop type accident.
  - The testing performed ... also tested the effect of significant fuel deflections (i.e., the center of the fuel assembly was deflected laterally while the top and bottom were pinned) and determined that effect on scram time was acceptable. This provides evidence that the small 'bend' in the control rod insertion path that could be caused by a tilted core barrel would not have an impact on the ability to insert the control rods for core shutdown."
- The staff requests industry discuss the following:
  - During the scenario addressed above, how many control rod assemblies are allowed to encounter the small "bend" in the control rod insertion path due to a tilted core barrel?
  - Is the deflection due to small "bend" observed (in the testing) in the control rod insertion path bounded by the safety margin established in a plant loss-of-coolant-accident accident analyses for each Combustion Engineering and Westinghouse unit?
  - Provide a brief summary on how the full core drop test was conducted.

Description of CRDM Drop Testing

- Third part addressed first to support other questions
- Control rod drop testing evaluated how deflections at various points in drive line could impact insertion times
- Test setup:
  - Simulated control rod drive mechanism (CRDM) and related driveline components
  - Full size prototypic 17x17 standard guide tube assembly
  - Full size prototypic 17x17 fuel assembly
  - Fuel assembly submerged in water and guide tube wetted
  - Drop times tuned to match drop times achieved during full-flow loop drop tests
  - Drop times confirmed as repeatable within less than ±1%

Description of CRDM Drop Testing (cont.)

- Relevant test 1:
  - Assessed impact that a core drop would have on rod insertion times
  - Simulated vertical and lateral offsets of the fuel assembly top nozzle
    - Vertical offset slightly greater than that expected for core drop condition
    - Lateral offset simulated representative of lateral offset possible between the fuel assembly top nozzle and the fuel alignment pin during the maximum vertical displacement in a core drop
  - Resulted in less than an 8% impact on rod insertion times and rods still fully insert
- Relevant test 2:
  - Assessed impact of fuel assembly deflections on rod insertion times
  - Simulated a fuel assembly lateral offset at mid span (top and bottom pinned)
  - Represented half of the core being deflected completely to one side of the core if all assemblies were in contact
  - Resulted in less than a 2% impact on rod insertion times and rods still fully insert

Response to Question 3 (cont.)

- Response to first part of question:
  - Impact on one fuel assembly and control rod assembly was simulated by the test
  - Test simulated the maximum vertical and lateral offsets
  - Offsets during a core drop due to core barrel failure could vary from location to location
  - Results of the test expected to represent all control rod locations
- Response to second part of question:
  - Although other fuel designs were not explicitly tested, 17x17 test adequately represents all fuel designs
    - Deflections applied were significant relative to the total available gap across the core
    - Impact on rod insertion times negligible even for significant deflection
    - Rods were still fully inserted

Additional Question 4 (February 5 Questions)

Question 4:

- The response to RAI 10, which concerns the adequacy of a 25% sample inspection of the deep beam welds, provides a markup of Table 5-2 showing the expansion to the remaining deep beam welds if cracking is found in the initial sample. The markup shows this expansion inspection must be completed by the end of the next refueling outage.
- Why not require the expansion be completed during the same refueling outage during which the cracking was found in the initial sample, consistent with the approach for the core barrel welds?

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Response to Question 4

- Based on component redundancy and function
  - Multiple beams support each fuel assembly
  - Each beam is kept in place by more than one weld
  - Failure of an entire weld would not result in loss of functionality
- Compared to a core barrel weld, this is quite different
- Additionally, insertion and removal of fuel each outage provides an element of regular monitoring
  - Fuel loading and unloading operations are expected to detect a loss of functionality
- Adds the side benefit of flexibility in planning and implementing

Response to Question 4 (cont.)

- Current response text for RAI 10 already addresses this:

  "The function of the deep beams is to directly support the core, to keep the fuel in place and to maintain alignment for control element assembly insertion. From the standpoint of functionality, the welded array is a redundant structure. If one weld of a cross-beam fails completely, the other end of that particular beam would still be attached to another main beam. The main beams are welded at multiple locations and would require multiple weld failures to compromise function. Assurance of the continued functionality of the deep beams is also aided by the fact that the onset of the loss of structural functionality would be likely to be first detected during fuel loading or unloading conducted during each refueling outage. The fuel loading and unloading operations are expected to detect this loss of functionality as misaligned fuel assemblies or abnormal difficulty with removing or placing fuel assemblies." (MRP 2018-003, Page 28)

Summary

- Responses provided for the February 5 questions
- Results from MRP-191, Rev. 2 resolve inconsistency between RAI 5 response and 2005 original FMECA results
- Crack POD explained by finite nature of inspection
- Testing of CRDM drop times and insertability show that insertion path deflections due to core drop would not impact safe core shutdown
- Expansion requirement for deep beams differs from core barrel weld due to component differences: redundancy and function

Q&A and Open Discussion

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