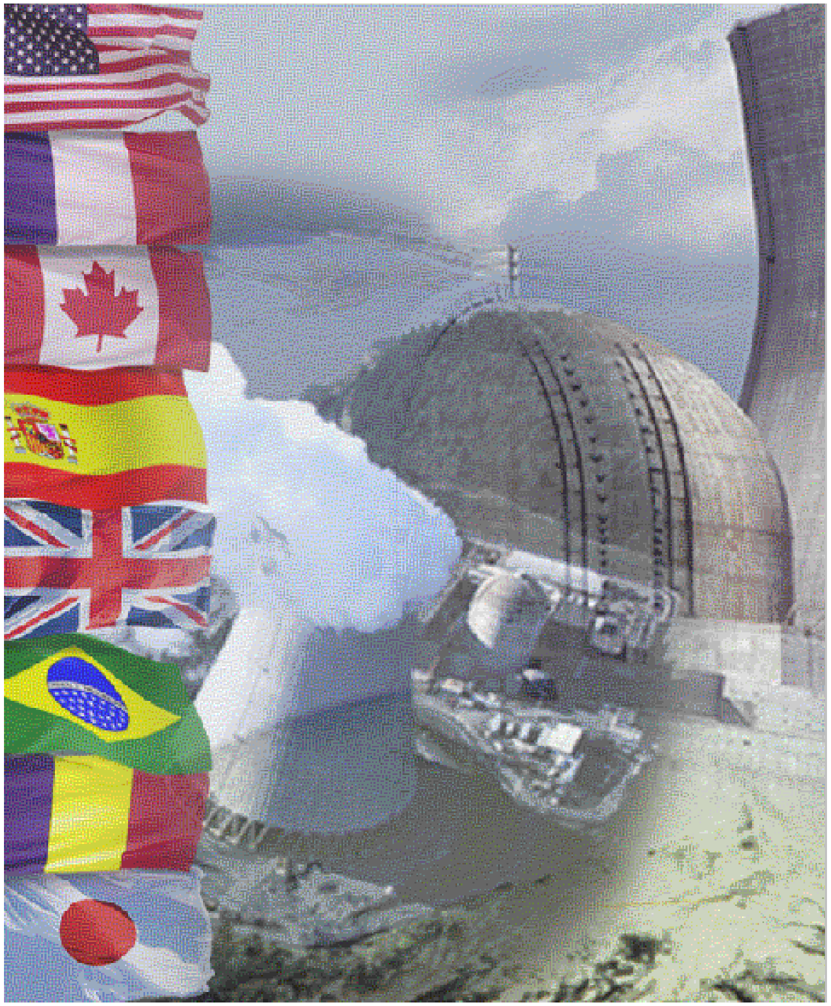


Inspection of Reactor Vessel Closure Head Nozzles

ASME CC N-729

March 22, 2005

Craig Harrington, TXU Power

Alloy 600 Issue Task Group (ITG)

Materials Reliability Program

Where we have been

- **MRP-75 issued in late 2002**
  - 1st industry inspection regime for RV closure heads
  - Reactive to inspection findings
  - Key assumptions rendered invalid by inspection results at North Anna-2
- **New strategy for a non-reactive, comprehensive response**
  - Performed a detailed Failure Modes and Effects Analysis
  - Deterministic and probabilistic evaluation of plant safety in terms of loss of pressure boundary structural integrity
  - Probabilistically evaluated the probability of leakage
- **MRP-110 and supporting reports totaling ~1200 pages of material, presented and submitted to the NRC Staff in April 2004.**
- **MRP-111 reviewed available knowledge regarding Alloy 690 and its weld metals, Alloys 52 and 152**

Where we have been

- **MRP-117 – Inspection and Evaluation Guidance development began.**
  - Establish inspection requirements to ensure continuing compliance with Safety Assessment assumptions
  - Re-inspection interval assumes flaw initiation has already occurred
    - Volumetric / surface examination assumed to just miss initiated flaws not yet propagated to a detectable size.
    - Susceptibility to crack initiation no longer the arbiter of re-inspection intervals,
    - Deterministic crack propagation analysis at the nominal local temperature define re-inspection.
- **NRC Commissioners directive in the summer of 2004**
  - MRP-117 translated into an ASME Code Case.
  - Presented to ASME Task Group Alloy 600 - August 2004
  - MRP-117 presented to NRC Staff - September 2004
  - Only known unresolved comments are those from the NRC Staff
    - Each was responded - February ASME Code meeting
    - Reviewed in detail in Task Group Alloy 600.

Agenda

- Review Deterministic Calculations that support CC N729
- NRC Questions
  - Inspection Frequency
    - A600 cold heads or A690 heads
    - After PWSCC has been identified
    - Increasing the re-inspection frequency to RIY=3.0 via surface exams.
  - NDE per Section V, Article 14, "low rigor" requirements
  - Sample expansion
    - Following identification of a new flaw under -2430
    - Rounded indications on j-groove welds need to be further pursued if there are other indications of potential leakage.
  - Inspection Coverage of BMV and NDE
  - Inspection zone above the root of the J-groove weld.
  - Implementation of Appendix A

Deterministic Crack Growth Analyses

- MRP-55 CGR correlations used - 75th percentile, with factor of 2 applied for OD connected circumferential flaws (severe environment effect)
- Stress Intensity Factors for envelope stress plane used to compute crack growth from 30° to ASME Section XI allowable crack length (~ 300°)
- Analyses performed for steepest angle (worst case) nozzles in Plants A - D
- Analyses run for various head temperatures using standard activation energy (31 kcal/mole) temperature adjustment on crack growth law
- Results indicate shortest time to failure > 9 RIY (EFPY at 600ºF)

EPRI

Deterministic Crack Growth Analyses
(Growth Time from 30º to 300º Circ Crack)

TEMPERATURE °F	UPHILL (EFPH)	UPHILL (EFPY)	DOWNHILL (EFPH)	DOWNHILL (EFPY)
580	258177	29.47	322569	36.82
590	199476	22.77	249227	28.45
600	154874	17.68	193501	22.09
602	147314	16.82	184056	21.01
605	136709	15.61	170805	19.50

Plant A - 38° Nozzle

TEMPERATURE °F	UPHILL (EFPH)	UPHILL (EFPY)	DOWNHILL (EFPH)	DOWNHILL (EFPY)
580	903711	103.16	158317	18.07
590	698237	79.71	122321	13.96
600	521114	61.89	94970	10.84
602	515652	58.86	90335	10.31
605	478529	54.63	83831	9.57

Plant B 43.5° Nozzle

Deterministic Crack Growth Analyses
(Growth Time from 30º to 300º Circ Crack)

TEMPERATURE °F	UPHILL (EFPH)	UPHILL (EFPY)	DOWNHILL (EFPH)	DOWNHILL (EFPY)
580	no growth	no growth	135981	15.52
590	no growth	no growth	105563	11.99
600	no growth	no growth	81572	9.31
602	no growth	no growth	77590	8.86
605	no growth	no growth	72004	8.22

Plant C – 48.8° Nozzle

TEMPERATURE °F	UPHILL (EFPH)	UPHILL (EFPY)	DOWNHILL (EFPH)	DOWNHILL (EFPY)
580	279167	31.87	273879	31.26
590	215694	24.62	211608	24.16
600	167465	19.12	164293	18.75
602	159291	18.18	156274	17.84
605	147823	16.87	145023	16.56

Plant D – 49.7° Nozzle

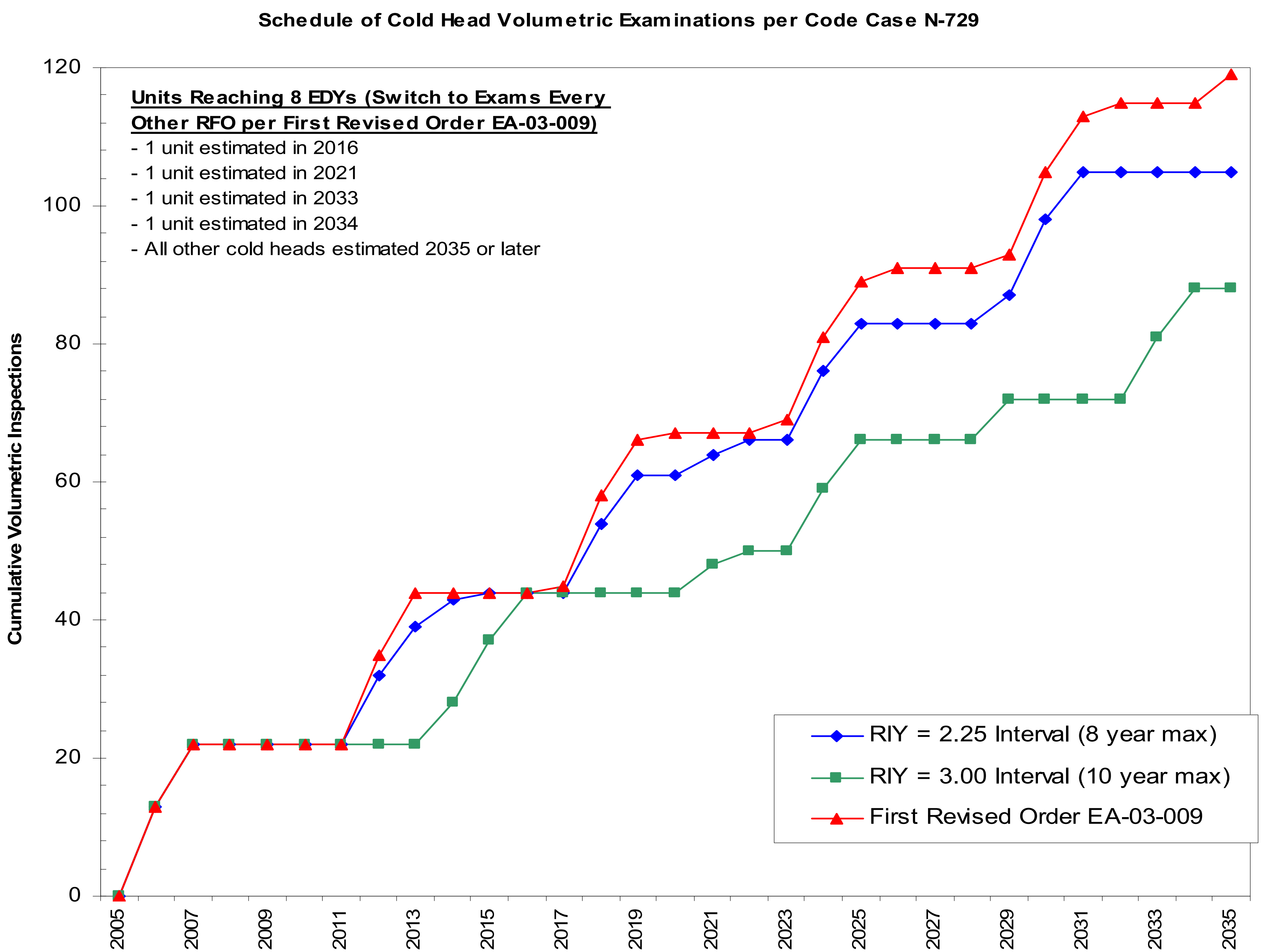
Summary of MRP Nozzle Ejection Evaluations

(excerpt Table 6-1 from MRP-110)

- Plants Analyzed
  - MRP-105: B&W, W 2-loop, W 4-loop, CE
  - MRP-104: W and CE
  - MRP-103: B&W
- Deterministic Results for Circumferential Crack Growth Time
  - MRP-105: Shortest time to failure > 9 RIY (through-wall circumferential flaw)
  - MRP-104: 17 RIY (through-wall circumferential flaw)
  - MRP-103: 7.5 RIY (part-depth circ flaw that then becomes through-wall)
- Thus, deterministic analyses bound the re-inspection interval by a factor of about 3

NRC Questions: Inspection Frequency

- NDE Inspection frequency of 10 years for either A600 low susceptibility heads or A690 heads.
  - Every 4 RFOs or 7 years, whichever occurs first, would be more appropriate.
- Footnote 5 would allow a reinspection frequency of every second outage for plants which have experienced PWSCC cracking.
- Crediting of surface examinations for increasing the reinspection frequency to RIY=3.0.
  - The Order reinspection frequency already takes into account the "annulus leakage assessment." The additional crediting of an acceptable surface exam in Footnote 6 of Table 1 is not justified since the surface exam essentially accomplishes the same thing as the "leakage assessment."


Schedule of Cold Head Volumetric Examinations per Code Case N-729
Units Reaching 8 EDYs (Switch to Exams Every Other RFO per First Revised Order EA-03-009)
- 1 unit estimated in 2016
- 1 unit estimated in 2021
- 1 unit estimated in 2033
- 1 unit estimated in 2034
- All other cold heads estimated 2035 or later
Cumulative Volumetric Inspections
RIY = 2.25 Interval (8 year max)
RIY = 3.00 Interval (10 year max)
First Revised Order EA-03-009

Alloy 690 Re-Inspection Frequency Technical Basis (MRP-111)

- Lab testing and plant experience strongly support the re-inspection frequency of 10 calendar years
- Material improvement factor of at least 26
  – much greater than the factor implied by the Code Case for resistant materials
  – Operating time has been shown by plant experience and laboratory testing to be a key parameter for determining the likelihood of cracking
  – The 10-year interval corresponds to less than 1 year of equivalent degradation time for the original head materials.

Alloy 690 Field Experience (MRP-111)

- In service for over 15 calendar years with no reported indications
- Cumulative number of EFPYs of service for the domestic Alloy 690 SG tubes is about 2.1 million tube-EFPYs (corresponds to about 3.3 million tube-EDYs)
- Over 1000 other Alloy 690/52/152 components are currently in service in the U.S., with some in service for nearly 14 calendar years.
  - Cumulative number of EFPYs of service is about 2800 part-EFPYs, corresponding to about 7600 part-EDYs given a temperature normalization to 600°F.
  - Thick-walled Alloy 690/52/152 includes about 222 replacement components operating at pressurizer temperatures for up to almost 15 years.
    - Equivalent to more than 50 years experience at the highest reported temperatures for reactor vessel upper heads.
  - Alloy 690/52/152 heads in Europe includes at least 47 heads and up to about 11 years of operation.
    - EDF has inspected the CRDM nozzles in three of these heads using NDE without any indications of stress corrosion cracking.

Alloy 690 Inspections

	Estimated Number of Volumetric Examinations (Years 11 to 25 after first head replacement)														
	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025	2026	2027
Exams per Code Case N-729	**5**	**2**	**8**	**9**	**4**	**4**	**5**	**7**	**1**	**3**	**4**	**9**	**8**	**4**	**5**
Exams per First Revised Order EA-03-009*	**5**	**3**	**14**	**7**	**11**	**5**	**5**	**4**	**14**	**7**	**11**	**5**	**5**	**4**	**14**

*every 4 cycles or 7 years, whichever occurs first

Footnote 5: Every Other RFO for Plants with PWSCC

- RIY=2.25 will control RVHs operating at higher temperatures with previously repaired PWSCC.
  - Higher temperature heads - the RIY parameter dictates a single cycle frequency.
- Lower temperature heads with previously repaired PWSCC flaws, this note imposes a limitation of two refueling outages
- In addition to ensuring safety, these inspection frequencies ensure a low probability of leakage.

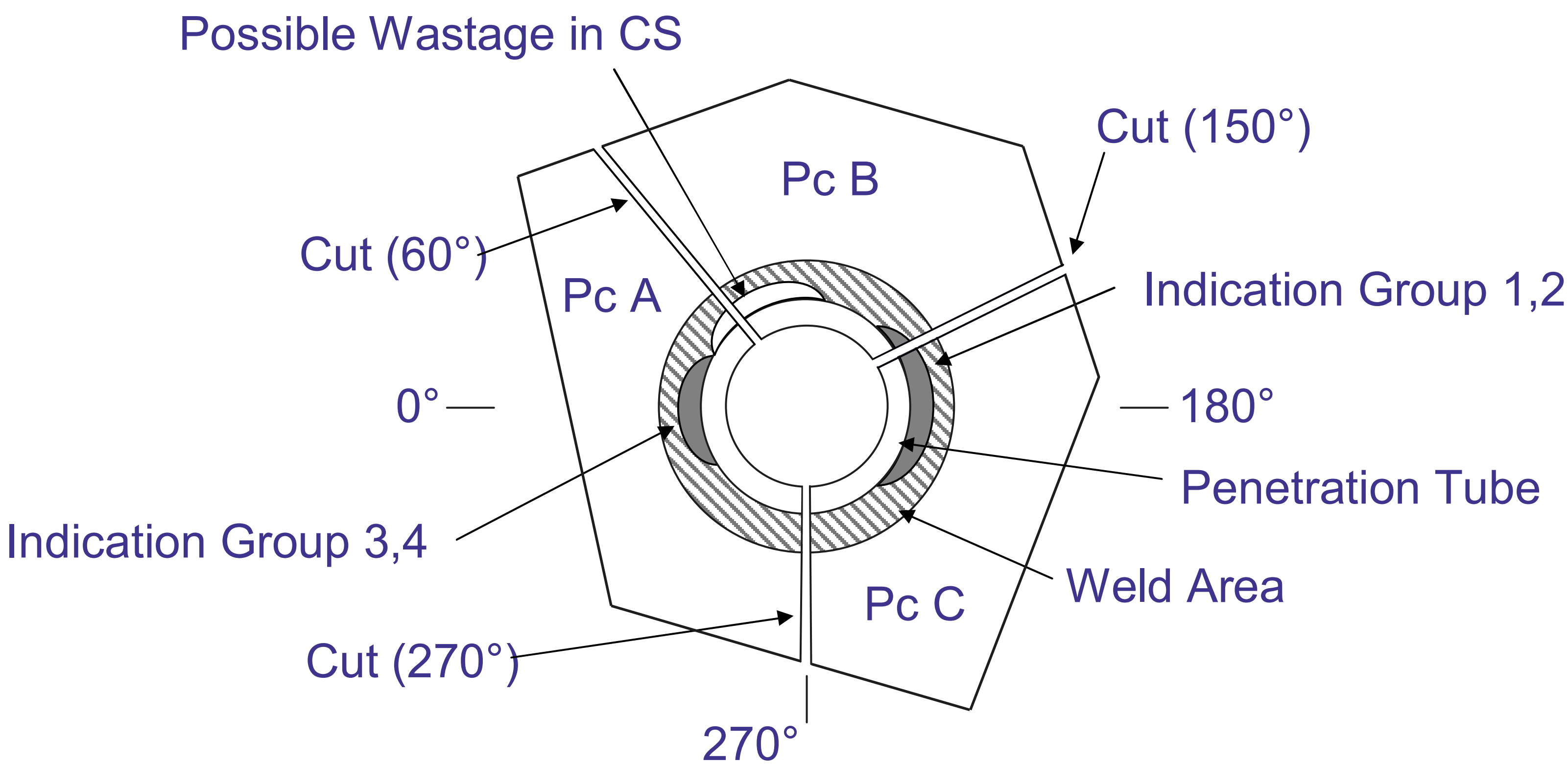
Increasing Re-inspection Interval for J-Groove Weld Examination

- Weld cracking could lead to leakage into the annulus on the nozzle OD, but not directly to nozzle ejection.
- Wetted surface exams of the welds better characterize a head.
  - Code case requires more frequent volumetric/surface examinations when J-groove welds are not inspected.
  - Performing weld surface examinations provides additional assurance that cracks have not initiated, is more proactive, and thus, warrants a longer re-inspection interval
- PFM analysis demonstrates that both inspection regimes are risk neutral (both leakage and nozzle ejection).
- Thus, in addition to ensuring safety, these inspection methods and frequencies ensure a low probability of leakage.

Leakage Assessment of the Annulus

- Leak Path Detection Technique has been "used" to meet the NRC order requirements for an "assessment . . . to determine if leakage has occurred into the annulus . ."
- Systematic demonstration of the techniques through a protocol using blind mockups has not been completed
- Used as an adjunct to the normal UT examination and any conditions revealed by the leak path should be investigated.

Destructive Examination of NA Reactor Vessel Head CRDM Penetration #54

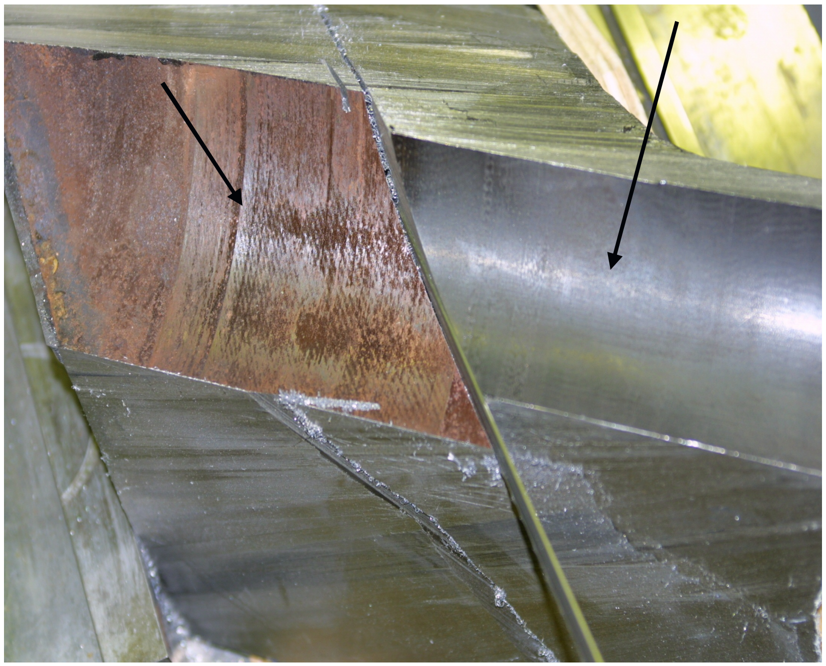


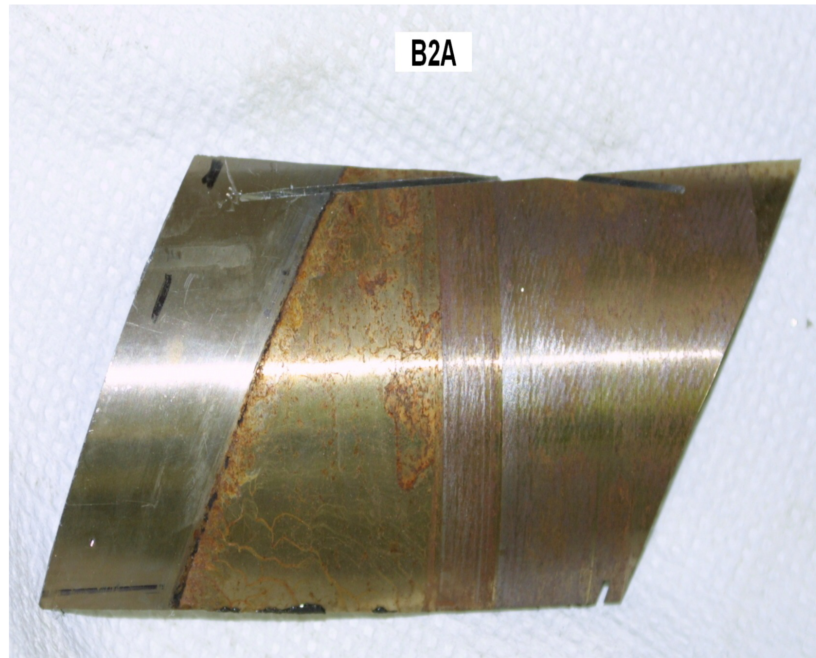
As-Sectioned Pieces A, B & C

Destructive Examination of NA Reactor Vessel Head CRDM Penetration #54

Carbon Steel Surface in the Annulus

ID Surface of Penetration Tube





Piece B during Cutting Operation, Part of Penetration Removed

Piece B Separated Penetration OD Face at the Annulus

NRC Questions: NDE Qualifications

- NDE per Section V, Article 14, "low rigor" requirements. The requirements of Section XI, App. VIII, must be cited. If necessary, a new Supplement to App. VIII will have to be developed. Article 14 has many shortcomings.

- Answer:
  - Use of Section V Article 14 provides for a demonstration of NDE and thus more robust inspection methods than the Order
    - Order is silent on NDE qualification requirements

Attributes of MRP NDE Demonstration

- Realistic mockups with realistic geometries containing flaws that represent the range of flaw conditions known or projected to exist. The ultrasonic and eddy current responses of the mockup flaws have been benchmarked against real PWSCC in real VHPs.
- Real PWSCC from field removed samples are included in the demonstration process to assess detection performance.
- Blind demonstrations with a large number of flaws, often exceeding 30.
- Structured demonstration protocol.
  - Definitive procedures are required to be presented for demonstrations that capture the logic of decision making- flaw detection and sizing.
  - Each step of the decision process is monitored and questioned by the administrators during the demonstration to ensure that the decisions made by the vendor are based on logic described in the procedure.

Attributes of MRP NDE Demonstration (cont'd)

- Thorough documentation of demonstration results including description of procedures essential variables.
  - Documentation addresses flaw detection efficiency, sizing accuracy, flaw location accuracy, and false call performance
  - This enables licensees to monitor inspections to ensure that demonstrated procedures are applied. It also provides a mechanism to identify when procedures have changed to the point that they no longer represent the system previously demonstrated.
- Monitoring and feedback of field experience to ensure that geometric conditions and flaw characteristics are adequately addressed the demonstration process.

NRC Questions: Sample Expansion

- Sample expansion following identification of a new flaw under -2430, "Additional Examinations." -2430 would not require sample expansion if a new flaw is determined to be acceptable for continued service. This may be acceptable only if the flaw is conclusively determined not to be from PWSCC. If a new flaw is found to be, or assumed to be from PWSCC, there is no basis to believe that other "new" PWSCC flaws of unacceptable dimensions are not present in other penetrations.
- Rounded indications on j-groove welds need to be further pursued if there are other indications of potential leakage. The Code case would not require further investigation of "acceptable" rounded indications. The intent is not to pursue any and all rounded indications.

Sample Expansion (if the flaw is PWSCC)

- Previous Outage
  - Find acceptable flaw and leave it in service
- Current Outage (Previous + 1 RFO)
  - Inspect nozzle with previously acceptable flaw
  - Find new flaw in same nozzle
    - No expansion is required if new flaw is acceptable
    - Expansion is required if new flaw is unacceptable

- Re-inspection intervals already account for NDE threshold and probabilities of detection and set frequency appropriately
- Assuming an unacceptable flaw where there was no flaw in the previous cycle is overly conservative

Rounded Indications with potential leakage

- Per the Code Case, acceptable rounded indications not associated with other evidence of leakage do not require investigation
  - If leakage is identified for a nozzle, then the Code Case requires that a volumetric/surface examination be performed on that nozzle in order to characterize the flaws that caused the leakage.
- Repairs performed must eliminate from the pressure boundary any unacceptable defects, including any leak-path flaws that originate on the surface of the J-groove weld. Therefore, the Code Case addresses the technical concern raised by this comment for confirmed leaks.
- Indications within the J-groove weld itself are not a direct safety concern.

NRC Questions: Inspection Coverage & Volume

- Footnote (7) - The BMV must cover 100% of the nozzle head intersection, not "essentially 100." There have been very few licensees not able to meet the full 100%. Any outliers can submit a relief request.
- Same general concern as No. 3 above, but regarding NDE coverage.
- 2" vs. 1-1/2" inspection zone above the root of the J-groove weld.

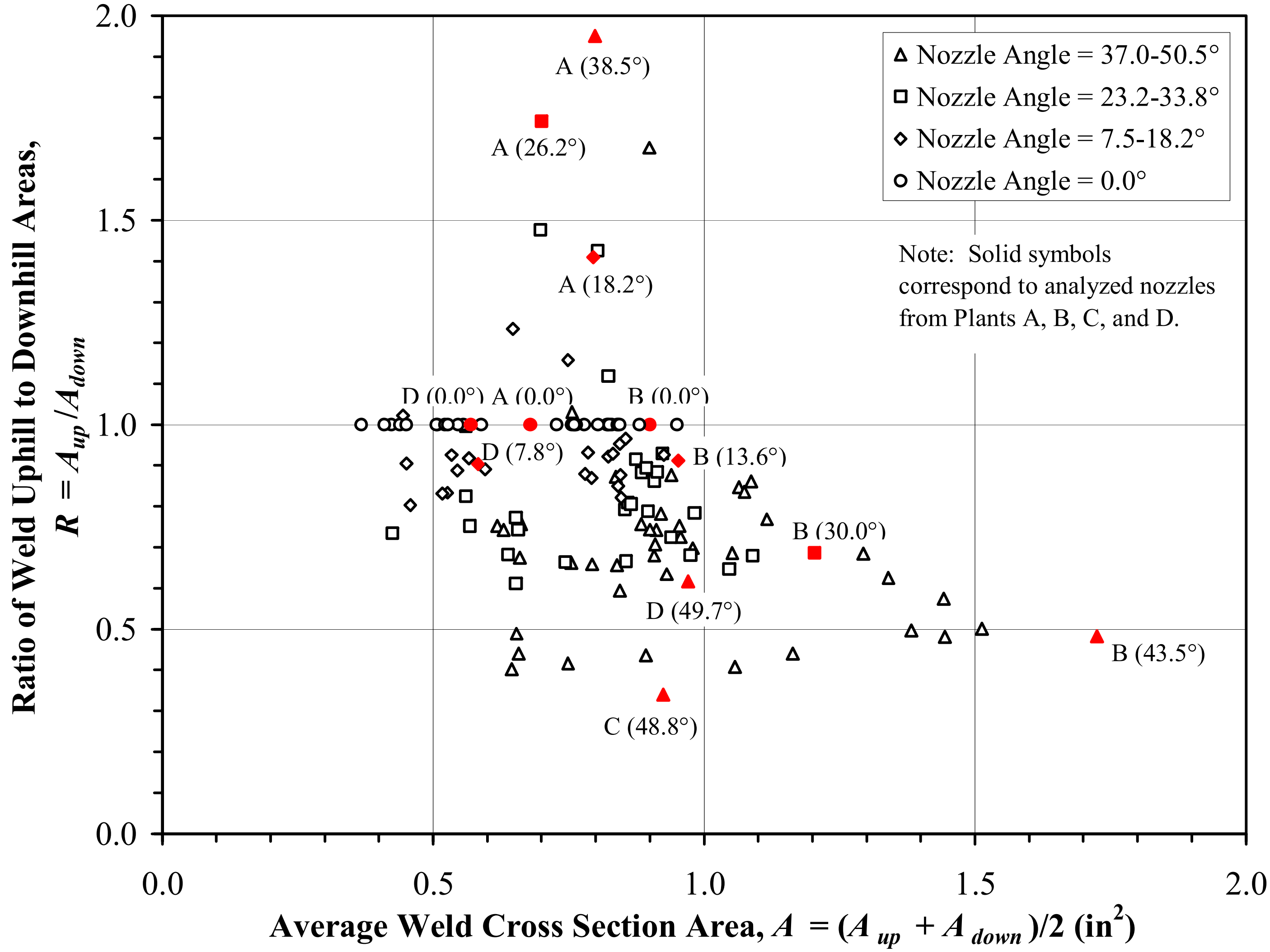
Visual and Volumetric Coverage Adequacy

- The surface/volumetric and visual examination coverage requirements of the Code Case are appropriate to ensure safety and plant defense in depth.
- The visual leak detection examinations provide two principal elements of protection.
  - First, acts as a backup examination to the required periodic surface/volumetric examinations
  - Second, the visual examination provides protection against significant boric acid wastage of the low alloy steel head material.
- The volumetric examinations provide protection against nozzle ejection and core damage based on PFM calculations previously reviewed with NRC.
  - Assuming 90% coverage of individual nozzles with 95% of aggregate

Exam Volume Based on Characteristic Plants

- Plant A – B&W plant
  - nozzle angles ranging from 0° to 38°
  - nozzle yield strengths ranging from 36.8 to 50 ksi
- Plant B – Westinghouse 2-loop plant
  - nozzle angles ranging from 0° to 43.5°
  - nozzle yield strength of 58 ksi
- Plant C – Westinghouse 4-loop plant
  - nozzle angles ranging from 0° to 48.8°
  - nozzle yield strength of 63 ksi
- Plant D – large CE plant
  - CEDM nozzles
    - angles ranging from 0° to 49.7°
    - nozzle yield strengths ranging from 52.5 to 59 ksi
  - ICI nozzles
    - 55.3° nozzle angle
    - yield strength = 39.5 ksi

Weld Parameters of Characteristic Plants



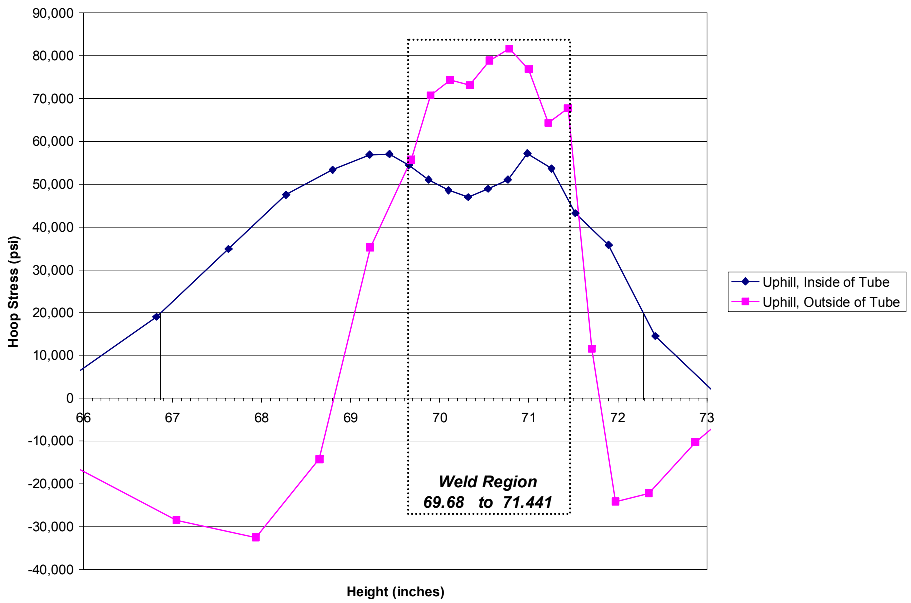
Characteristic Plants and the PWR Fleet

- Characteristic plants & nozzles selected for analysis bound nozzle angles and weld geometry factors that influence residual stresses
  - 51 of the 69 U.S. PWRs weld geometries have been evaluated
  - Analyses span expected range of nozzle yield strengths
- Therefore, examination zone definition based on these stresses is judged to be applicable to all U.S. PWRs
- MRP-117 requires that all plants
  - Verify that their specific RVCH penetration designs are bounded by the MRP-95 examination zone

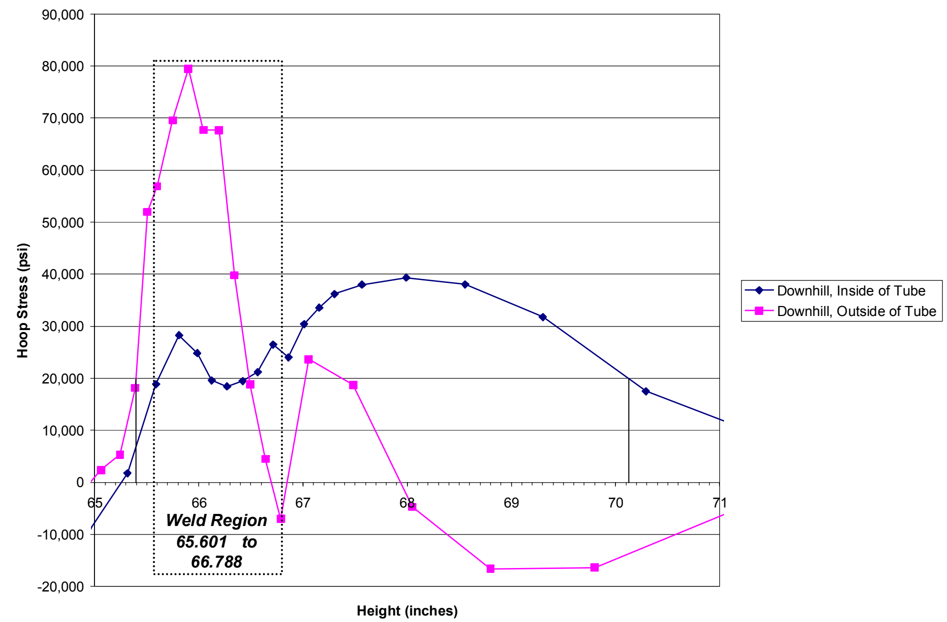
    OR
  - Develop appropriate site-specific examination zone

Typical Nozzle Stress Distributions

Uphill Side of Nozzle



Downhill Side of Nozzle



Summary of Nozzle Stresses at Edge of Exam Volume (Above Weld)

Plant	Nozzle Angle-Azimuth	Inspection Zone Dist. from Weld (inches)	Stresses at Edge of Inspection Zone Above Weld (ksi)			
			ID-Hoop	OD-Hoop	ID-Axial	OD-Axial
A	38-Downhill	5.65	8	1.4	1.8	3.1
	38-Sidehill	3.29	-3.1	-1.3	1.0	-0.1
	38-Uphill	1.00	14.2	-20.1	4.2	-7.6
A	26-Downhill	4.39	6.9	3.6	2.0	3.8
	26-Sidehill	2.93	0.0	3.1	2.3	3.7
	26-Uphill	1.50	5.4	-5.8	1.7	0.0
A	18-Downhill	3.37	4.6	0.4	4.2	1.2
	18-Sidehill	2.43	1.7	-0.2	5.5	0.1
	18-Uphill	1.50	3.9	-2.7	4.7	-2.3
A	0-All	1.50	7.0	-1.6	12.3	-7.8
B	43-Downhill	4.66	8.1	1.2	2.9	9.6
	43-Sidehill	2.80	1.1	0.6	-2.1	-4.8
	43-Uphill	1.00	15.8	-14.3	4.6	-7.0
B	30-Downhill	3.75	6.3	0.9	3.4	5.7
	30-Sidehill	2.62	2.5	2.4	-0.2	-1.3
	30-Uphill	1.50	1.3	-4.0	1.0	-3.6
B	13-Downhill	2.47	1.4	-1.4	7.7	1.6
	13-Sidehill	1.98	1.7	-1.9	7.4	-4.6
	13-Uphill	1.50	1.3	-4.4	6.3	-4.7
B	0-All	1.50	6.8	-3.9	14.4	-10.3
C	48-Downhill	5.15	13.7	-2.4	10.9	13.6
	48-Sidehill	3.04	-2.5	7.2	-1.0	0.4
	48-Uphill	1.00	11.5	-6.5	2.3	-7.4
D	49-Downhill	6.31	11.1	0.3	2.0	4.5
	49-Sidehill	3.59	-1.7	2.6	-2.1	1.3
	49-Uphill	1.00	15.5	-23.3	4.5	-12.4
D	8-Downhill	2.11	4.3	-2.0	10.6	-6.7
	8-Sidehill	1.81	4.1	-2.2	10.6	-6.3
	8-Uphill	1.50	6.0	-0.7	10.7	-7.3
D	55-Downhill(ICI)	9.88	20.2	1.7	2.2	4.6
	55-Sidehill(ICI)	5.51	5.4	13.9	-2.2	5.2
	55-Uphill(ICI)	1.50	19.1	-3.5	-1.9	-3.2

NRC Questions: Appendix A

- Although the MRP may not be able to address this issue, the staff disagrees with Footnote (10) and the implementation of App. A. App. A is essentially an alternative to the Code Case. The staff believes if licensees have to implement App. A as a opposed to the Code Case, there shouldn't be many instances, and these instances should be handled via relief requests.

- Answer –
  - Appendix A is not an alternative to the WHOLE code case.
  - Provide specific rules to evaluate inspection coverage when difficulties are encountered inspecting one or more nozzles