ASME Code Inspection Relaxations

Applications and Performance Monitoring

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U.S.NRC
United States Nuclear Regulatory Commission
Protecting People and the Environment

Topics

- PFM aspects staff focused on
  - PFM acceptance criteria
  - Audit of the PROMISE PFM computer code
  - Sensitivity studies
  - Criteria for plant-specific applications

- Performance monitoring
  - Statistically determined inspection sample size

- Plant-specific applications
  - Pressurizer (PZR) and steam generator (SG) vessel welds and nozzles
  - Single/two-unit plant submittals and fleet submittals

RIMA

Precedents for PFM with adequate performance monitoring (vessels)

- Elimination of BWR vessel circumferential weld examinations
  - PFM → BWRVIP-05 and BWRVIP-329-A (based on FAVOR analyses)
  - Performance monitoring → axial/longitudinal welds still being examined
- 20-year ISI extension of PWR vessel weld examinations
  - PFM → WCAP-16168-A (based on FAVOR analyses)
  - Performance monitoring → coordinated fleet inspections that ensure regular stream of monitoring data
- Reduction of BWR vessel nozzle inspections (Code Case N-702-1)
  - PFM → BWRVIP-108 and BWRVIP-241 (based on VIPERNOZ)
  - Performance monitoring → 25% of nozzles still being inspected

PFM aspects staff focused on

Acceptance criteria

- 1×10^{-6} failures/yr, consistent with the basis during the development of 10 CFR 50.61a, in which reactor pressure vessel (RPV) TWCF was conservatively assumed to be equivalent to an increase in CDF.
  - Conservative because in reality an increase in RPV TWCF does not mean an equivalent increase in CDF
  - Details are in NUREG-1806, “Technical Basis for Revision of the Pressurized Thermal Shock (PTS) Screening Limit in the PTS Rule (10 CFR 50.61)”
  - Used for the PFM analyses in:
    - EPRI reports 3002014590, 3002015906 for SGs
    - EPRI report 3002015905 for PZR
  - While PZRs and SGs are safety significant, they are not as safety significant as the RPV; therefore, staff finds 1×10^{-6} failures/yr appropriate.

PFM aspects staff focused on

Audit of the PROMISE computer code

- PROMISE stands for **Pr**obabilistic **O**pti**m**ization of **I**n**s**p**e**ction
- 2.5-day audit (ML20258A002); objective was for staff to understand how PFM principles were being applied, were they consistent with guidance
- Referred to RG 1.245 (guidance for PFM submittals)
  - Inputs/models (probabilistic models, e.g., mean and standard deviation of distributed variables, but also non-probabilistic models, e.g., FEA, stress intensity factor solutions, ISI & exam coverage)
  - Uncertainties
  - Convergence
  - Software V&V
  - Sensitivity studies

PFM aspects staff focused on

Audit of the PROMISE computer code (continued)

Key observations

- Software V&V was adequate
- Uncertainties adequately addressed
- Initial flaw distribution model was adequate
- ISI and examination coverage adequately modeled
- Performed adequate sensitivity studies

PFM aspects staff focused on

PROMISE audit – V&V and Uncertainties

- Software V&V
  - Followed ASME NQA standards and 10 CFR 50 Appendix B guidance
  - Software V&V plan and V&V reports generated
    - Plan contained testing of the various parts of the software, and that testing results were adequate and reflected in the reports

- Uncertainties
  - Mean and standard deviation values of random variables (i.e., those with a probability distribution rather than a single value) were consistent with previously accepted values.

crack depth	crack length
fracture toughness	crack growth rate
crack growth threshold	

RIMA

PFM aspects staff focused on

PROMISE audit – Initial Flaw Distribution, ISI & Exam Coverage

- Based on the Pressure Vessel Research User's Facility (PVRUF) unused RPV
  - Developed from NDE of fabrication flaws in the vessel weld
  - Consists primarily of small-surface breaking flaws
  - Used in the BWRVIP-05-based submittals
- Staff ensured that ISI and examination coverage (of the weld volume) were modeled since these are key aspects of ASME Code, Section XI, examinations.
  - ISI model: implemented through a probability of detection (POD) curve at times of inspections
  - Examination coverage model: implemented by allowing modeled postulated flaw to grow for a number of realizations proportional to coverage missed

PFM aspects staff focused on

PROMISE audit - Sensitivity studies

From RG 1.245:

2.11. Sensitivity Studies

In most cases, the applicant should perform sensitivity studies to understand how analysis assumptions impact the results of the overall analysis, to show why some assumptions may or may not impact the results, and to understand new and complex codes, models, or phenomena, especially if there are large perceived uncharacterized uncertainties. The applicant should assess its PFM software and analysis to determine the sensitivity studies category shown in Table C-10. The applicant should follow the guidelines in Table C-10 to document the details of sensitivity studies. If the combination of PFM software and analysis belongs to category SS-1 in Table C-10, the staff does not recommend performing sensitivity studies.

Staff ensured that sensitivity studies (SS) were performed for the critical parameters of stress and fracture toughness.

- SS on stress up to more than 2 times base case stress levels, and on fracture toughness up less than half of base case fracture toughness were performed and showed that acceptance criteria of $1\text{x}10^{-6}$ failures/yr was met.

PFM aspects staff focused on

Criteria for plant-specific applications

- EPRI reports were based representative/conservative geometric configurations, transients/cycles based on survey of PWRs

- Thus, the need for criteria for the following parameters in plant-specific applications:
  - Geometry
  - Materials
  - Loading conditions (thus stress) and cycles

PFM aspects staff focused on

Criteria for plant-specific applications (continued)

SGs

EPRI Report 3002014590

EPRI Report 3002015906

PZRs

EPRI Report 3002015905

Staff also evaluates plant-specific inspection history: number of ISIs and examination volume coverage.

Performance monitoring

Supports RIDM in three primary ways

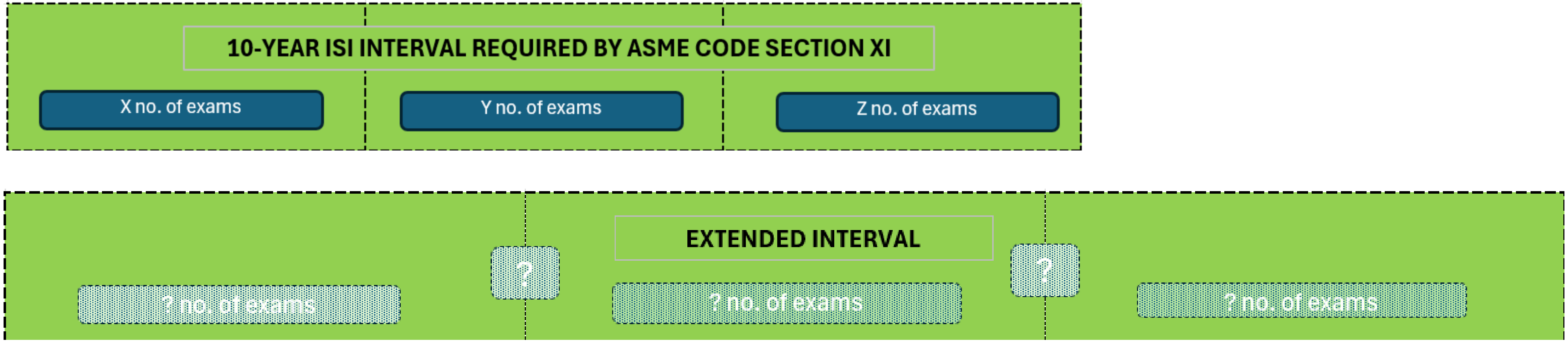
- Direct evidence of presence and/or extent of degradation
- Validation/confirmation of continued adequacy of analyses
- Timely method to detect novel/unexpected degradation

What about the other 3 aspects of RIDM: safety margins, defense-in-depth, and compliance with regulations?

- Safety margins and defense-in-depth: primarily have to do with design; design parameters (material properties and operating characteristics) and multiple means to accomplish safety functions are not changing
- Compliance with regulations: licensees seek an alternative to ASME Code requirements pursuant to 10 CFR 50.55a(z)(1)—evaluated by staff

Performance monitoring (continued)

Illustration of interval extension



- Performance monitoring is built into the ASME Code Section XI ISI interval.
- Fewer inspections with interval extension. The question is: what inspection sample size is acceptable?

Performance monitoring (continued)

Statistically determined sample

- Quantitative sampling calculation can be derived from statistical calculation (next two slides)
  - Binomial distribution
  - Monte carlo analysis

- At the conceptual level, the objective is to determine the sample size (in our case # of inspections) from a population of like objects that gives x% probability of “success” outcome (detection of degradation/cracking), assuming a certain p% of the population has characteristic for "success" outcome (degraded/cracked).

- Staff described details in *Rudland, David L. and Widrevitz, Dan,* ***PVP2023-105203****, “Statistical Approach to Developing a Performance Monitoring Program”*

Performance monitoring (continued)

Binomial distribution

- The binomial distribution is frequently used to model the number of successes in a sample of size “n” drawn with replacement from a population of a certain size
- Can be used to find # of inspections needed to find a crack
- Independent of population size

$$f(k,n,p) = \binom{n}{k} p^k (1-p)^{n-k}$$

$$\binom{n}{k} = \frac{n!}{k!\,(n-k)!}$$

k= number of successes (cracks found)
n=number of trials (inspections)
p= probability of success on an individual trial (% of population cracked)
If k=0 then this is the probability of no successes is:

$$f(n,p) = (1-p)^n$$

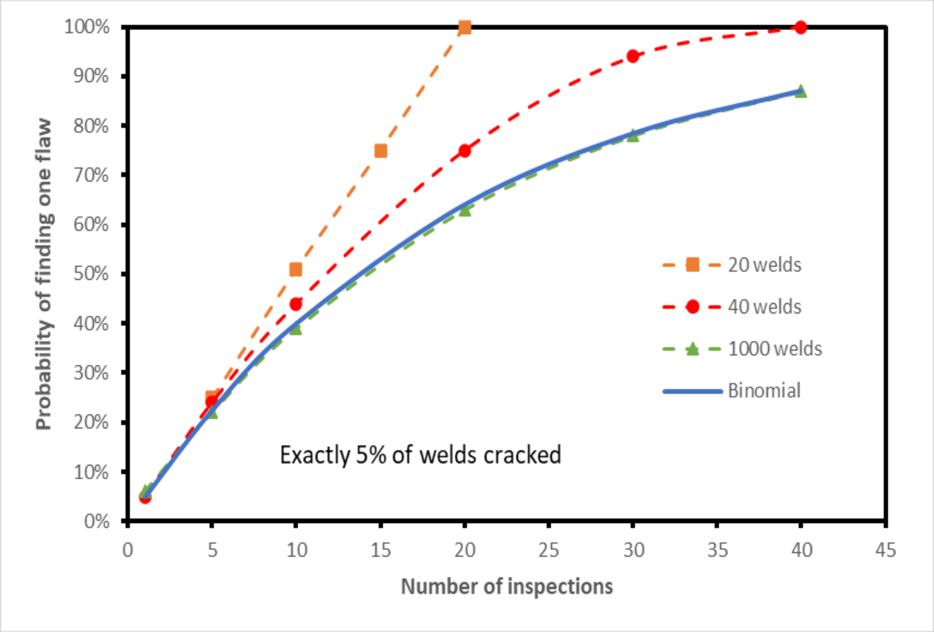
and therefore, the probability of at least one success is:

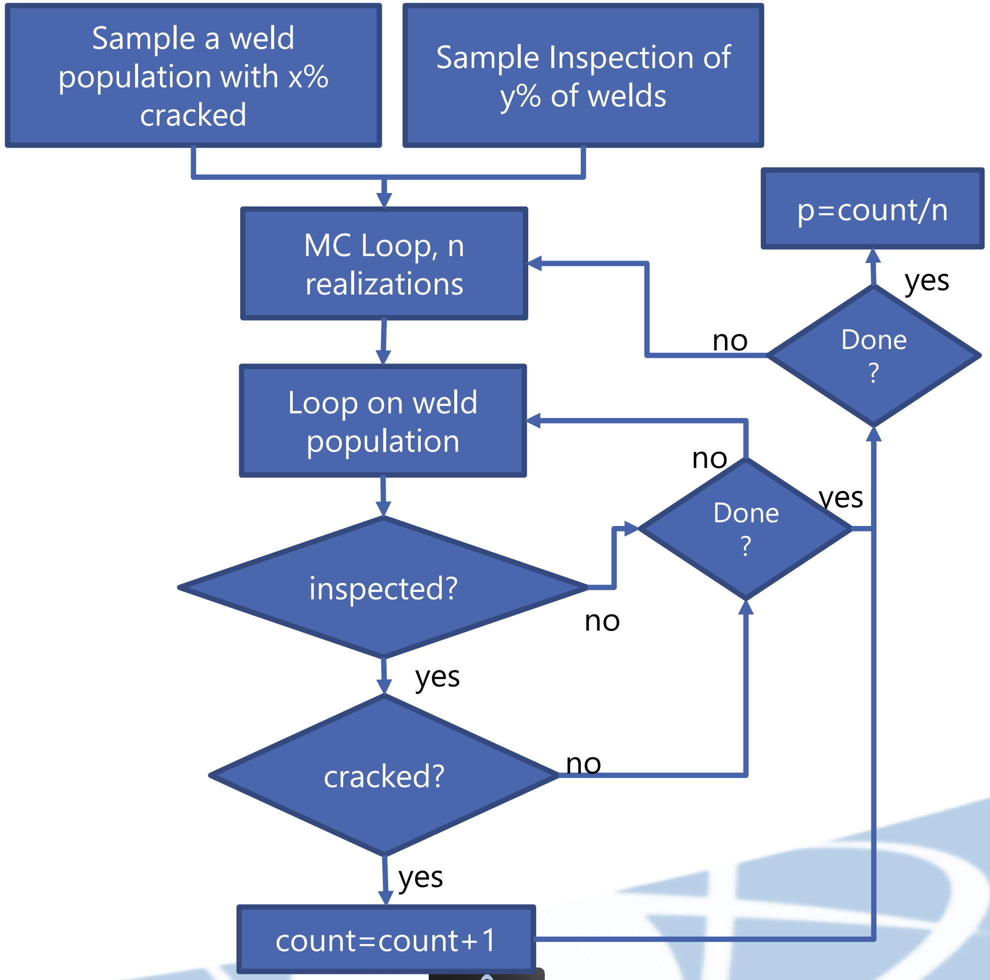
$$1 - f(n,p)$$

Performance monitoring (continued)

Monte carlo (MC) analysis

- Same concept can be applied with an MC analysis
- More general, allows maximum flexibility in the analysis
- Binomial response can be recreated
- Works for better for small populations

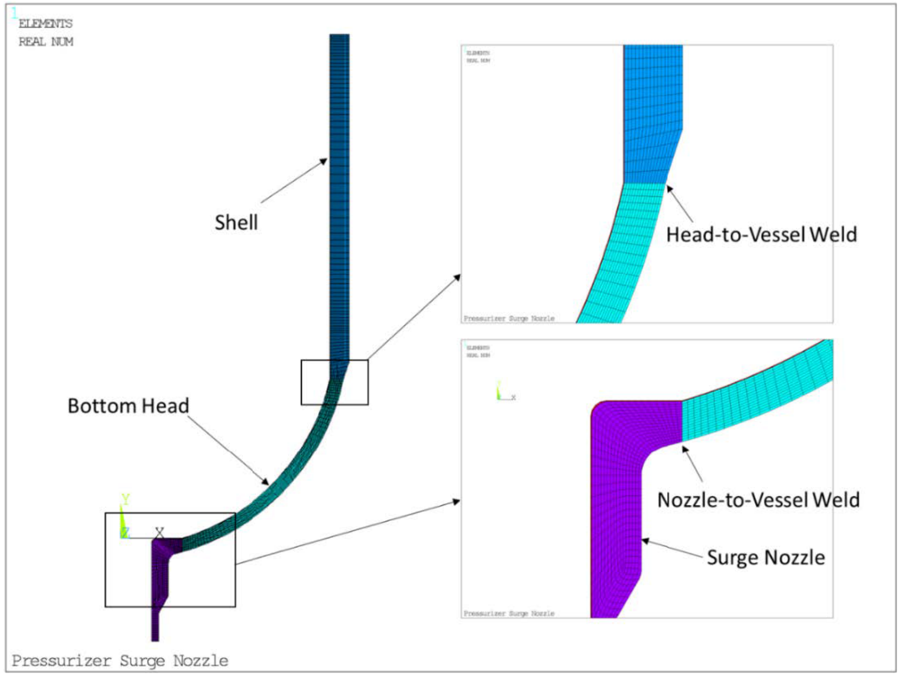


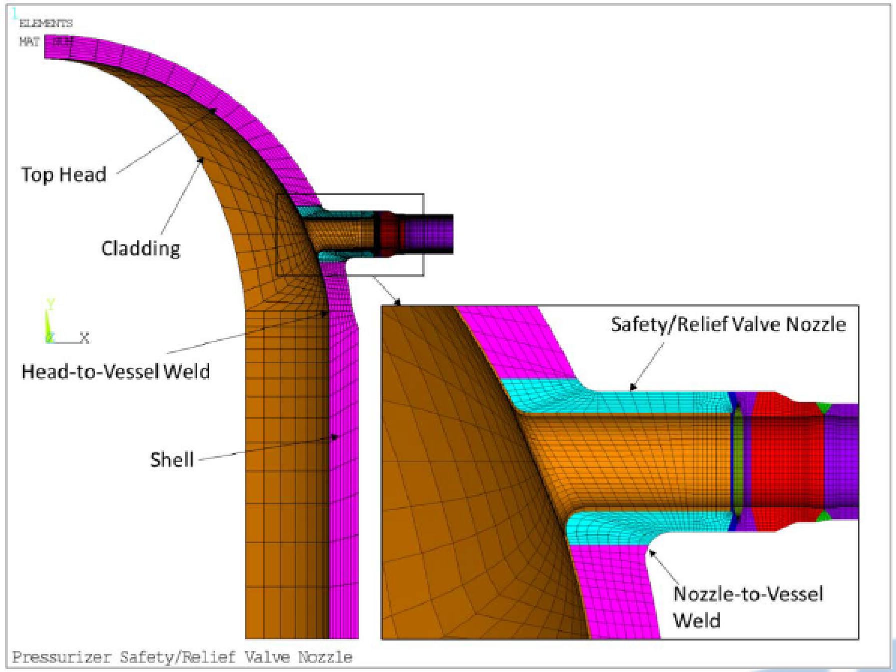


Performance monitoring (continued)

Should the statistics be applied at weld level or whole component level?

Weld level



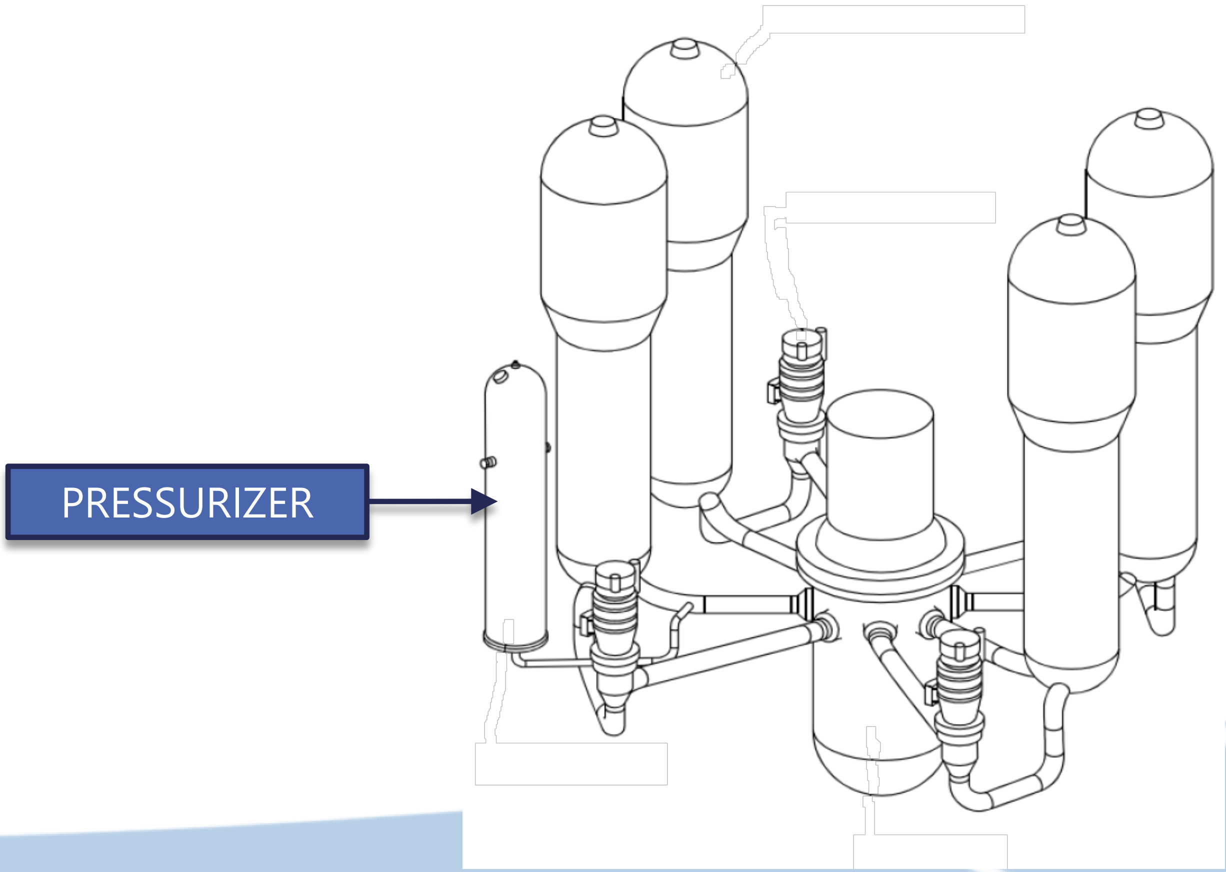


RIMA

Performance monitoring (continued)

Should the statistics be applied at weld level or whole component level?

Component level: inspection of the whole component means inspecting the suite of welds required to be inspected for that component (PZR in our example).



Performance monitoring (continued)

Example of statistical calculation for PZRs (1 of 2)

Objective:

Determine inspection sample size for performance monitoring of PZRs

Population size = 61 PZRs (61 PWRs in US, one PZR ea)

5% of population is degraded/cracked

90% probability of detecting at least one crack in the population

BINOMIAL/MONTE CARLO

25% of population of PZRs

Performance monitoring (continued)

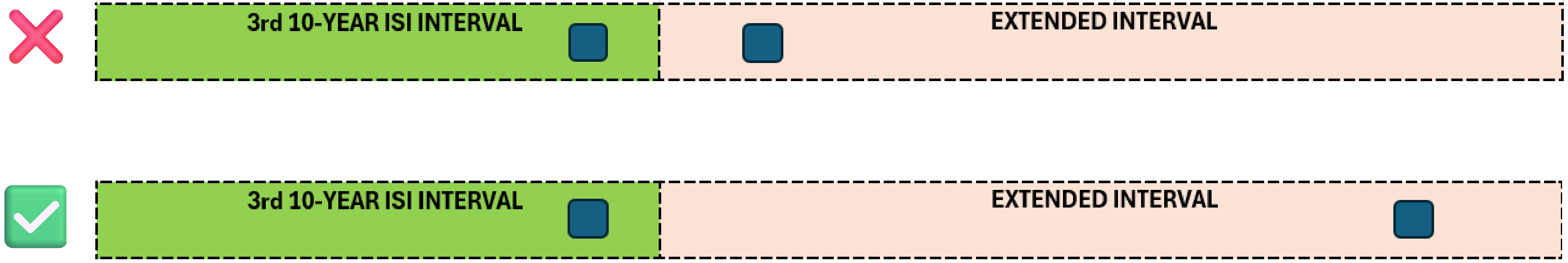
Example of statistical calculation for PZRs (2 of 2)

- Submittal with 1 unit requesting three 10-year intervals
  - 3 PZR inspections required by ASME Code
  - 25% sample = 1 PZR for performance monitoring sample (rounded up)

- Submittal with 10 units requesting three 10-year intervals
  - 30 PZR inspections required by ASME Code
  - 25% sample = 8 PZRs for performance monitoring sample (rounded up)

Performance monitoring (continued)

Timing of inspections



- Inspections performed later during the requested extended interval more impactful (but time from last inspection can't be too long).
- Later inspections have more chance of detecting degradation (if present) than earlier inspections since the degradation has had time to develop to a level that is detectable.

Plant-specific applications

Submittals using the EPRI reports as technical basis

- Applications (i.e., submittals) have been coming pursuant to 10 CFR 50.55a(z)(1) requesting to extend ISI intervals, referring to the EPRI reports as technical basis.

- Staff approach on evaluating these:
  - PFM consistent with the technical basis reports, especially that the submittal meets the plant-specific criteria covered earlier
    - EPRI reports 3002014590 and 3002015906 for SGs
    - EPRI report 3002015905 for PZRs
  - Performance monitoring is adequate

Plant-specific applications (continued)

Single or two-unit plant submittals

- These submittals are for one or two-unit plants proposing to extend the ASME Code required 10-year ISI interval to up to three 10-year ISI intervals.

- They refer to the EPRI reports for the PFM the technical basis and provide an adequate performance monitoring plan.

Plant-specific applications (continued)

Fleet submittals

- These submittals are for more multiple plants (thus for multiple units) proposing to extend the ASME Code required 10-year ISI interval to up to three 10-year ISI intervals; tech basis for PFM also the EPRI reports.

- Proposed performance monitoring gets interesting since now you have different alignment of ISI intervals of the various plants.

Plant-specific applications (continued)

Fleet submittals

Plant \ Year	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030	2031	2032	2033	2034	2035	2036	2037	2038	2039	2040	2041	2042	2043	2044	2045	2046
V 1	3rd Interval			4th Interval								4th Interval		5th Interval				X[1]							6th Interval - ASME Code PZR Requirements Resume							12/5/2043			
V 2	3rd Interval			4th Interval								4th Interval				5th Interval							X[1]		6th Interval - ASME Code PZR Requirements Resume							12/5/2043			
W 2	5th Interval											6th Interval							7/31/2030																
X 1	4th Interval									5th Interval										X[1]	6th Interval									6/12/2041					
X 2	3rd Interval		4th Interval										5th Interval								X[1]			6th Interval								3/3/2043			
y 1, 2, 3	4th Interval		5th Interval										6th Interval									#													
Z 1	3rd Interval					4th Interval						4th Interval					5th Interval			X			X				6th Interval - ASME Code PZR Requirements Resume								10/24/2046

LEGEND	
	Inspection Interval prior to Alternative RA-22-0257
X	Scheduled Performance Monitoring Exam
	Deferral Period per RA-22-0257
	Subsequent Inspection Interval: Reverts Back to ASME Code Requirements
	Current License Period End Date
#	Current License Period End Date: Unit 1 - 2/6/2033; Unit 2 - 10/6/2033; Unit 3 - 7/19/2034

Proposed Performance Monitoring Sample

Plant-specific applications (continued)

Fleet submittals

Calculation of total ASME Code required PZR inspections

Site	# of units	# of ISI intervals	ASME Code Required PZRs = units × intervals
[redacted]	2	2	4
	2	2	4
	1	2	2
	3	1	3
	1	1	1
Total			14

Using statistics, sample size needed is 0.25 x 14 = 4 PZRs (rounded up)

Calculation of PZR equivalents

Unit	# of Section XI exams	# of performance monitoring exams	PZR Equivalents = PM exams / required exams
[redacted] 1	10	2	0.2
2	10	2	0.2
1	10	2	0.2
2	10	2	0.2
	10	2	0.2
Total			1.0

Total no. of PZRs in proposed monitoring sample is = 1.0 (from above) + 3 (from prev slide) = 4

Example of how the staff confirms that the proposed sample size for performance monitoring is adequate.

Guidance?

- There have been fifteen or so submittals for PZRs and SGs since the first submittals.
- Similar approach taken for other components. Examples:
  - Heat exchanger vessels
  - Reactor closure head studs, but with DFM as technical basis instead of PFM
- These clearly bring up the question, is the staff developing guidance?

Questions?