PUBLIC

TREATMENT OF RISK IMPACT ASSESSMENTS IN EXELON'S RI-ISI EVALUATIONS

Dockets
50-454 50-237
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OBJECTIVES

- Clarify Exelon approach to risk impact assessment
  - Takes no exceptions to EPRI Topical Report
  - Applies EPRI methodology which has not been reviewed by NRC in previous submittals
- Clarify application of risk impact methodology
- Explain update of pipe failure data
- Present conclusions on Exelon submittals
- Discuss RAI responses

EXELON RI-ISI
RISK IMPACT ASSESSMENT
METHODOLOGY

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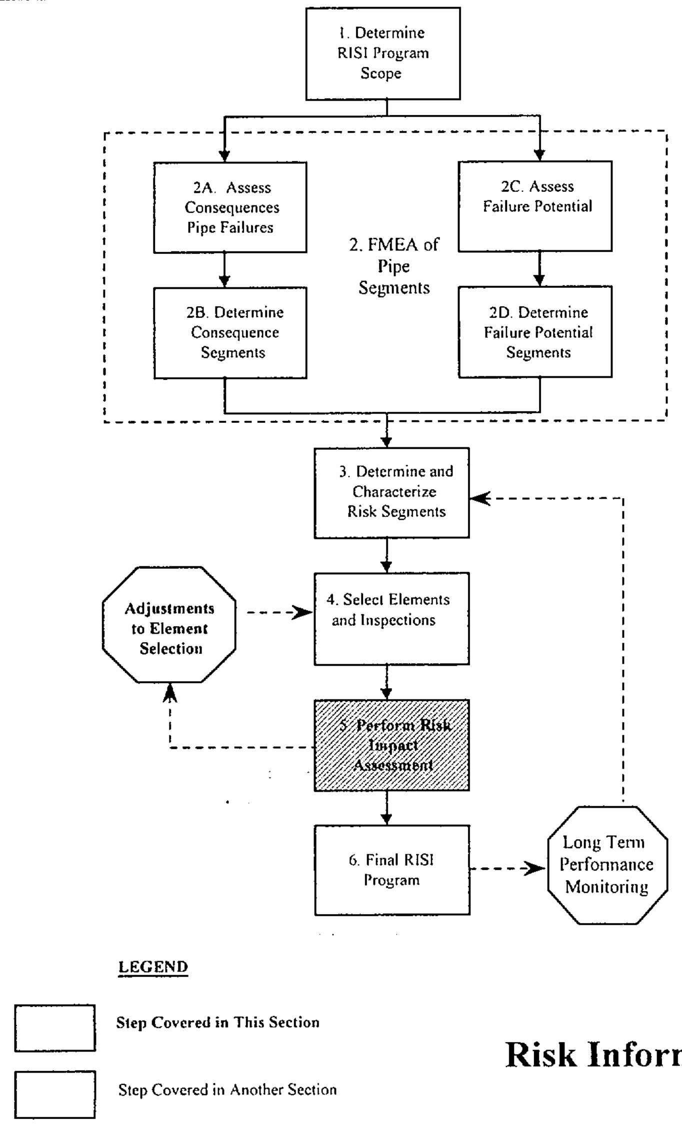
EPRI RI-ISI METHODOLOGY



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EVOLUTION OF EPRI RI-ISI RISK IMPACT ASSESSMENT

- Original EPRI RI-ISI method used by pilot plants did not include step for risk impacts of ISI program changes
- Risk impacts addressed in each pilot via RAI responses on a case by case basis
- EPRI added an explicit step to perform risk impact assessment in Topical Report TR-112657, Rev. B
- NRC SER approved the EPRI risk impact methodology
- NRC has approved only 2 relief requests since the SER prior to the Exelon RI-ISI submittals

EPRI TR PROCEDURE FOR RISK IMPACT ASSESSMENT

- Requires qualitative evaluation of risk impacts in each risk segment
  - addition of exams
  - redistribution of exams
  - removal of exams
  - enhancements to the inspection effectiveness ("inspection for cause")
- Concludes risk impact of changes in Low Risk segments is insignificant based on bounding estimates in EPRI TR
- Concludes a quantitative risk impact assessment is needed only when net exams removed from Medium or High risk segment
- Presents 3 alternate methods for quantitative risk impact assessment

EPRI METHODS FOR QUANTITATIVE ASSESSMENTS

(Ref. EPRI TR 112657, Sect. 3.7.2)

- Conservative bounding estimates
  - 3 Options for Pipe Rupture Frequencies (DM Category)
    - 1E-4 (High), 1E-5(Medium), 1E-6(Low)
    - Other defensible source of frequencies (EPRI TR-111880)
  - No credit for inspection effectiveness
- Two options for realistically estimating inspection effectiveness
  - Simplified Method (1-POD)
  - Markov Model

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RISK IMPACT ASSESSMENT

- Performed qualitative risk impact assessments for all risk segments
- Calculated realistic quantitative risk impacts for all segments using the Markov inspection effectiveness model
- Prepared sensitivity studies to illustrate realistic inspection effectiveness compared to no inspection effectiveness
- Prepared sensitivity studies using each of the EPRI approved methods on all segments
- Conformed to the requirements of EPRI TR, NRC SER, and NRC RGs 1.174 and 1.178

EPRI METHODOLOGY ILLUSTRATED IN RI-ISI SUBMITTALS

- Previous submittals included
  - qualitative analysis of all segments
  - bounding analysis of High and Medium Risk Segments
  - realistic analysis of selected segments using the (1-POD) model
  - realistic analysis of all segments using the Markov model
  - estimates of rupture frequencies from EPRI TR 102266 and EPRI TR 111880
- Exelon submittal and RAI responses include:
  - qualitative analysis of all segments
  - realistic analysis of all segments using the Markov method; comparison of inspection effectiveness factors with (1-POD) method
  - bounding analysis of all segments as a sensitivity study
  - estimates of failure rates and rupture frequencies from EPRI TR 111880 for BWRs
  - updates of failure rates and rupture frequencies using SKI-PIPE for PWRs

APPLICATION OF MARKOV MODEL IN EXELON RI-ISI

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Risk Informed Inservice Inspection Program 10

EXELON APPLIED MARKOV BASED ON NRC APPROVAL

- NRC SER states staff "adopts the analysis of the Markov model" and "finds the [Markov] model can be used as a basis for the estimation of pipe rupture frequencies instead of the bounding pipe failure frequencies"
- NRC contractor reviews of EPRI methodology endorsed use of Markov

RISK IMPACT ASSESSMENT

- Changes in risk in a pipe segment arise from changes in pipe rupture frequency due to changes in ISI moving from Section XI to RI-ISI program:
  - New exams may be added to the segment
  - Some exams may be removed from the segment
  - Effectiveness of exams may be improved due to "inspection for cause" principle
  - ISI program has no impact on CCDP and CLERP
- The change in pipe rupture frequency is estimated in terms of a baseline rupture frequency and changes in the Inspection Effectiveness Factor
  - Inspection Effectiveness Factor is Ratio of inspected weld rupture frequency to the uninspected weld rupture frequency
- The change in risk due to ISI changes at a weld is the change in pipe rupture frequency at the weld times the CCDP for ΔCDF or CLERP for the ΔLERF

QUANTIFICATION OF RISK MODEL

Parameter	Method of Quantification
ΔCDF	Computation of Eq. (3-9) in TR-112657; Eq. (3.40) in TR-110161
$\Delta LERF$	Same Equations as CDF with CLERP instead of CCDP
i	From risk segment definition in Step 3 of RISI Procedure
N	From risk segment definition in Step 3 of RISI Procedure
n_i	From risk segment definition in Step 3 of RISI Procedure
λ_i	Estimated from service data in using methodology of TR-111880
$P_i\langle R \mid F \rangle$	Estimated from service data in using methodology of TR-111880
$I_{i,new}$	Markov model solution used to develop equation in terms of parameters that describe degradation and inspection processes as explained in TR-110161 applied to RISI program
$I_{i,old}$	Markov model solution used to develop equation in terms of parameters that describe degradation and inspection processes as explained in TR-110161 applied to Section XI program
$CCDP_i$	Evaluated in Steps 2A and 2B in RISI Procedure using plant specific PRA models and the results of the consequence analysis
$CLERP_i$	Evaluated in Steps 2A and 2B in RISI Procedure using plant specific PRA models and the results of the consequence analysis

MARKOV MODEL FOR PIPING RELIABILITY ANALYSIS

- Is an established method for time dependent reliability of repairable components
- Was used in this application to model influence of ISI exams and leak detection as strategies to repair pipe degradation to prevent ruptures
- Uses a set of four pipe states (ok, cracked, leaking, ruptured) and transition rates to model time dependent state transitions
- Produces output similar to probabilistic fracture mechanics codes
  - Time dependent state probabilities
  - Time dependent rupture frequencies (hazard rates)
  - Inspection effectiveness factors

APPLICATION OF NRC REVIEWED EQUATIONS

Model/Equation	Report Reference	Page, Table, Equation References
Equations for Calculating changes in CDF and LERF	EPRI TR-112657	Equation 3-9 on p. 3-86
Equation for Calculating CDF and LERF	EPRI TR-110161	Equation 3.40 on p. 3-34
Markov Model used for ISI amenable damage mechanisms	EPRI TR-110161	Figure 3-9 on p. 3-24 Equations (3.26) though (3.38) on pp. 3-24 to 3-27
Definition of Inspection effectiveness Factor for use in delta risk equation	EPRI TR-110161	$I = \frac{h_{40}\{\omega_{NEW}\}}{h_{40}\{\omega_{OLD}\}}$ This is similar to Equation (3.41) on p. 3-37 except that 40 year vs. steady state hazard rates are used. NEW corresponds with RI-ISI and OLD with ASME Sec. XI.
Definition of the flaw inspection repair rate, ω	EPRI TR-110161	Equation (3.23) on p. 3-18
Definition of the leak detection repair rate, μ	EPRI TR-110161	Equation (3.24) on p. 3-18
Failure rates and rupture frequencies	EPRI TR-111880	Table A-11
Plant specific documentation of all other input data needed to quantify above equations	DNPS Units 2 and 3 RI-ISI Evaluation (Tier 2 Documentation)	Section 7

MODELING IMPACT OF INSPECTION (ISI)

- The benefits of ISI are modeled by the transition in the Markov model from the flaw state to the success state to reflect the opportunity to detect flaws or cracks via ISI exams before they propagate to pipe leaks or ruptures and to repair the damaged pipe.
- Estimation of ω: the repair rate for flaws

$$\omega = \frac{P_{FI} P_{FD}}{\left(T_I + T_R\right)}$$

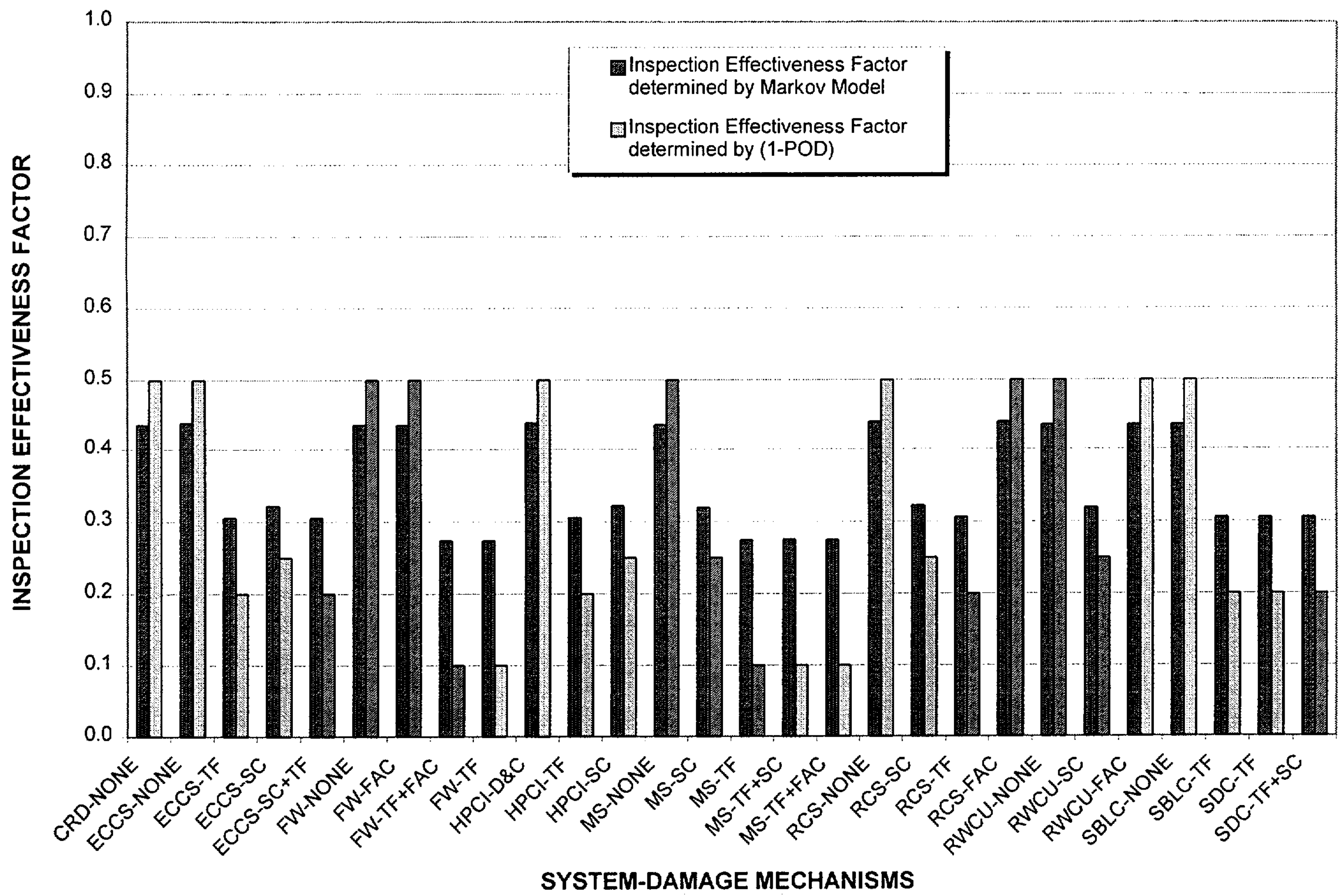
where:

- P_{FI} = 1 if the weld is inspected; 0 if it is not inspected
- P_{FD}= probability that flaw is detected given inspection ("POD")
- T_I = mean time between inspections (e.g. 10 years per ASME Section XI)
- T_R = mean time to repair the damaged pipe after detection in ISI exam

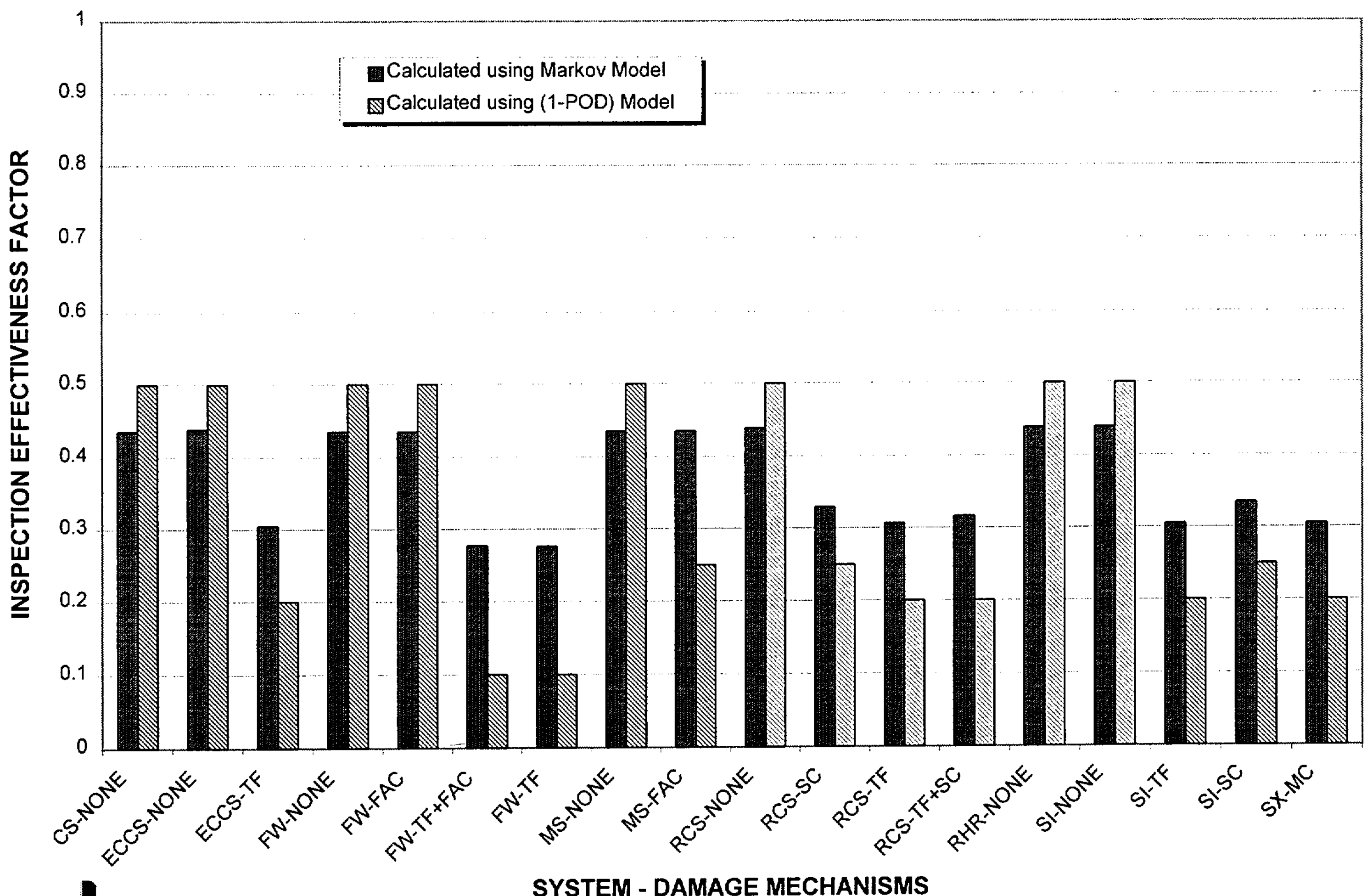
ESTIMATION OF MARKOV MODEL INPUT PARAMETERS

- Applied to each weld in scope of RISI program separately
- Crack and Leak Failure Rates and Rupture Frequency inputs
  - Estimated from service data and Bayes update methodology of EPRI TR-111880; updated for selected PWR systems and damage mechanisms; modified to account for damage mechanism synergy
- Inspection Repair Rates
  - Simple model from EPRI TR-110161 and estimates of POD modified for ISI accessibility; ISI inspection intervals, repair time
- Leak Detection Repair Rates
  - Simple model from EPRI TR-110161; estimates of detection probabilities, inspection intervals and repair time; not varied between RISI and Section XI cases

COMPARISON OF INSPECTION EFFECTIVENESS FACTORS FOR BWRS



COMPARISON OF INSPECTION EFFECTIVENESS FACTORS FOR PWRS



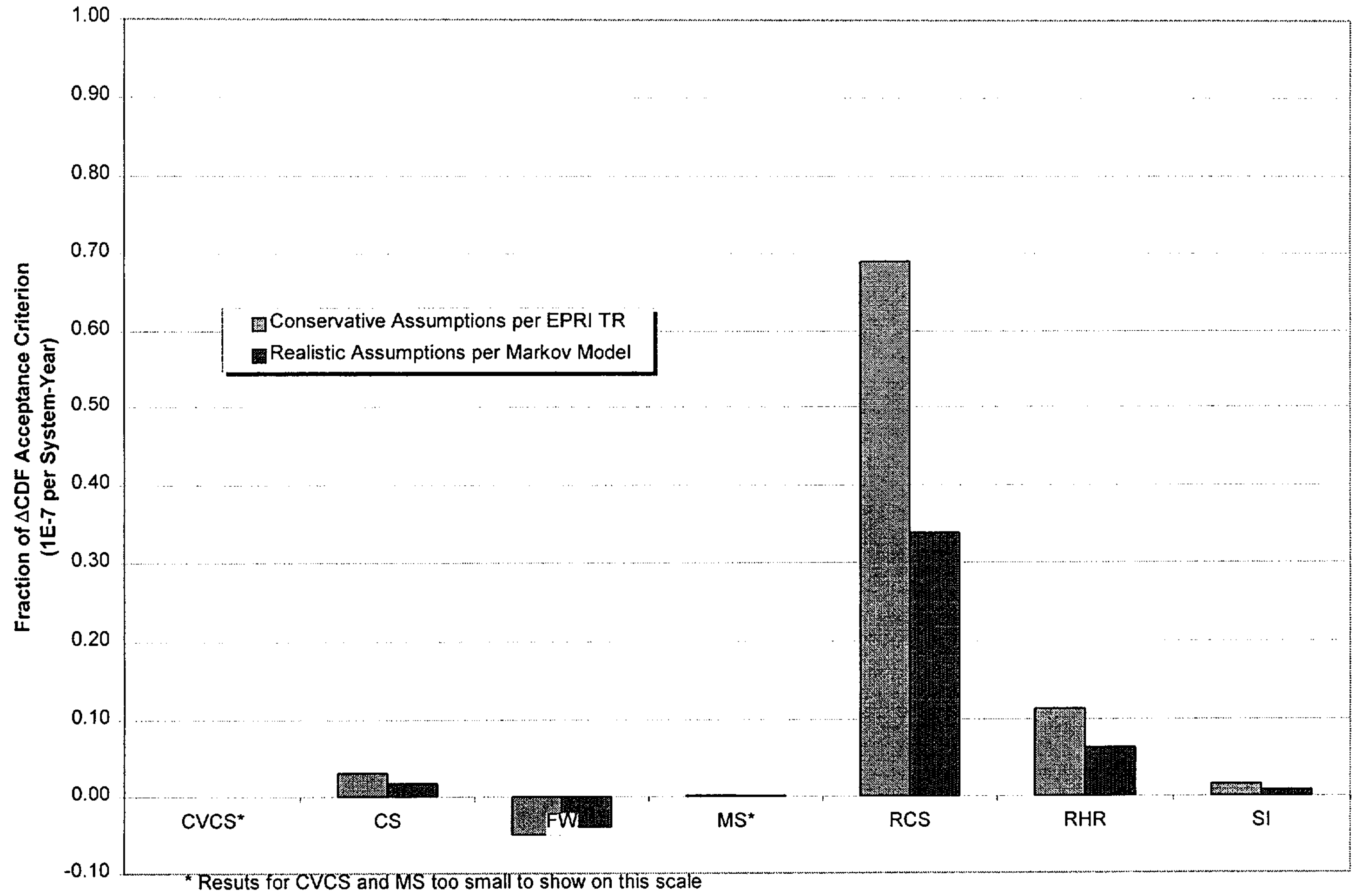
APPLICATION OF MARKOV MODEL TO EXELON RI-ISI

- Equations and methodology are identical to those described in EPRI reports reviewed by NRC
- Differences in application vs. PWR pilot plant RCS example
  - Explicitly considered crack and leak ratios
  - Updated failure rates and rupture frequencies for PWRs
  - Modified PODs to reflect limited accessibility
  - Applied Markov models to predict change in both leak and rupture frequencies
  - Applied to both delta CDF and delta LERF

BOUNDING SENSITIVITY ANALYSIS

- Used values from realistic analysis for:
  - Failure rates and rupture frequencies
  - CCDPs and CLERPs
- Took no credit for inspection effectiveness changes in RISI
- Credited added and redistributed welds; all risk change comes from net welds added or removed from each segment
- Evaluated all risk segments and case with High and Medium welds only

COMPARISON OF BOUNDING AND REALISTIC RISK IMPACTS BRAIDWOOD 1



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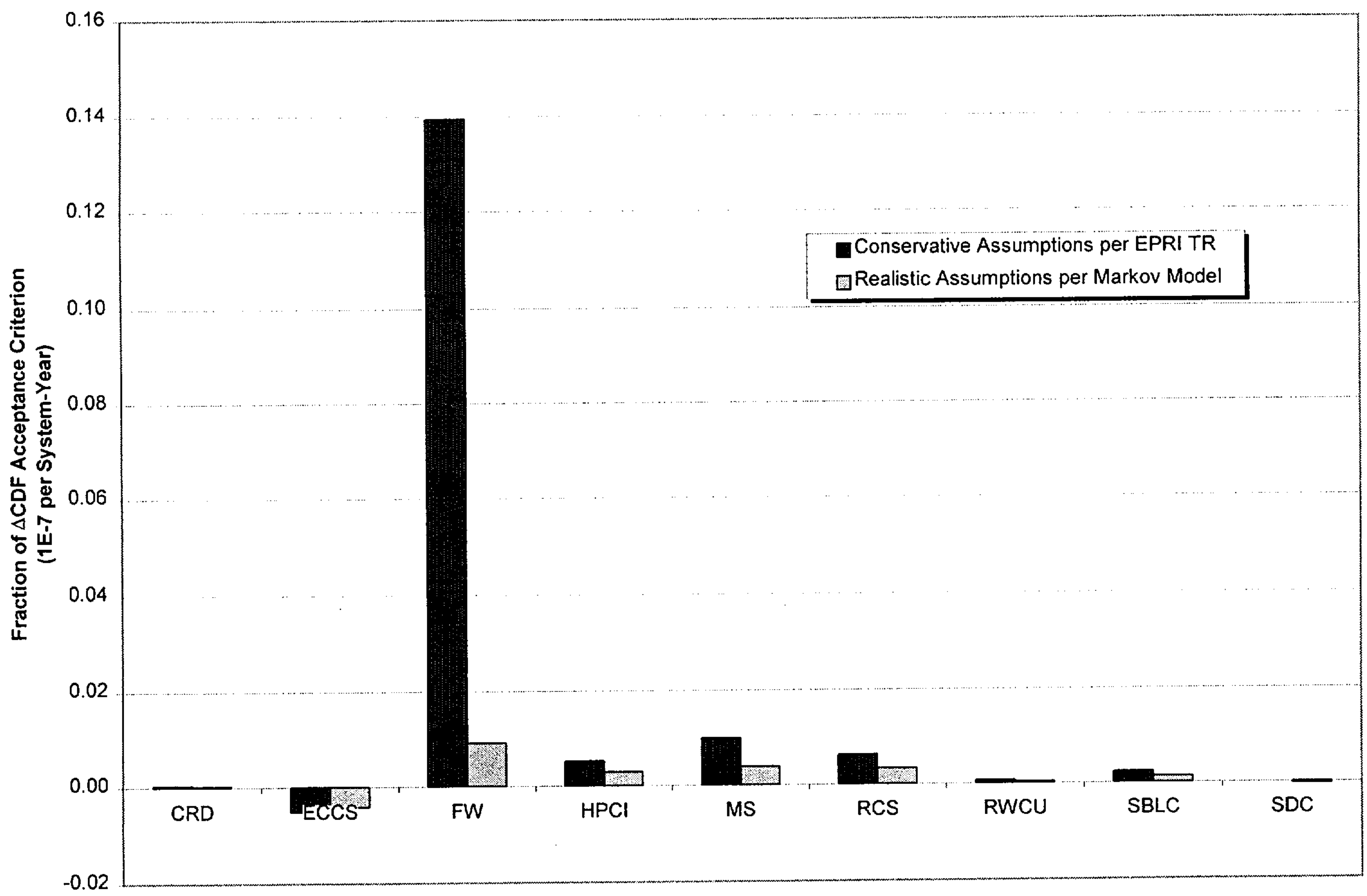
COMPARISON OF BOUNDING AND REALISTIC RISK IMPACTS DRESDEN 2



CONCLUSIONS FROM SENSITIVITY STUDY

- Risk acceptance criteria are met for all Exelon plants and systems in RI-ISI scope
  - large margins for all BWR and most PWR systems
  - small margins for PWR RCS system
- Realistic estimates provide more reasonable basis for RI-ISI evaluation
  - reasonable to expect risk reductions from inspection for cause especially for thermal fatigue susceptible segments
  - bounding analysis overstates risk importance of ISI on mitigating pipe rupture frequencies
  - risk impacts from low risk segments not necessarily dominated by high risk segments
  - enhanced consistency with other risk informed applications such as technical specification changes; enhanced capability to balance resources and risk across different risk informed applications

UPDATE OF
PIPE FAILURE DATA

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ESTIMATION OF FAILURE PROCESSES

- Estimate flaw failure rates from results of NDE inspections in pipe database; must have at least one flaw for each failure
- Estimate leak and rupture failure rates from service experience, failure rate models for different system types, and failure mechanisms
- Determine distinct rupture failure rates depending on the presence of a flaw or leak to model effects of aging
- Apply Bayes' theorem to incorporate available generic and system-failure mechanism specific experience in full quantification of uncertainties

Sources of Data

- Piping Reliability Databases
  - EPRI-97 Database
    - Based on reports by Bush, Chockie, Jamali, Fleming, et al
  - SKI-PIPE 98 Database
    - Worldwide Piping Reliability Database by Lydell
    - Basis for OECD (Office of Economic Cooperation and Development) International Piping Reliability Database

ESTIMATION OF FAILURE RATES AND RUPTURE FREQUENCIES

- For BWRs used values direct from EPRI TR-111880 Table A-11
- For PWRs used same Bayes' methodology as EPRI TR-111880 but updated to reflect:
  - More complete and more accurate and traceable account of pipe failures
  - Improved estimates of weld populations from completed RI-ISI submittals
  - Improved estimates of fractions of population susceptible to different damage mechanisms from completed RI-ISI submittals

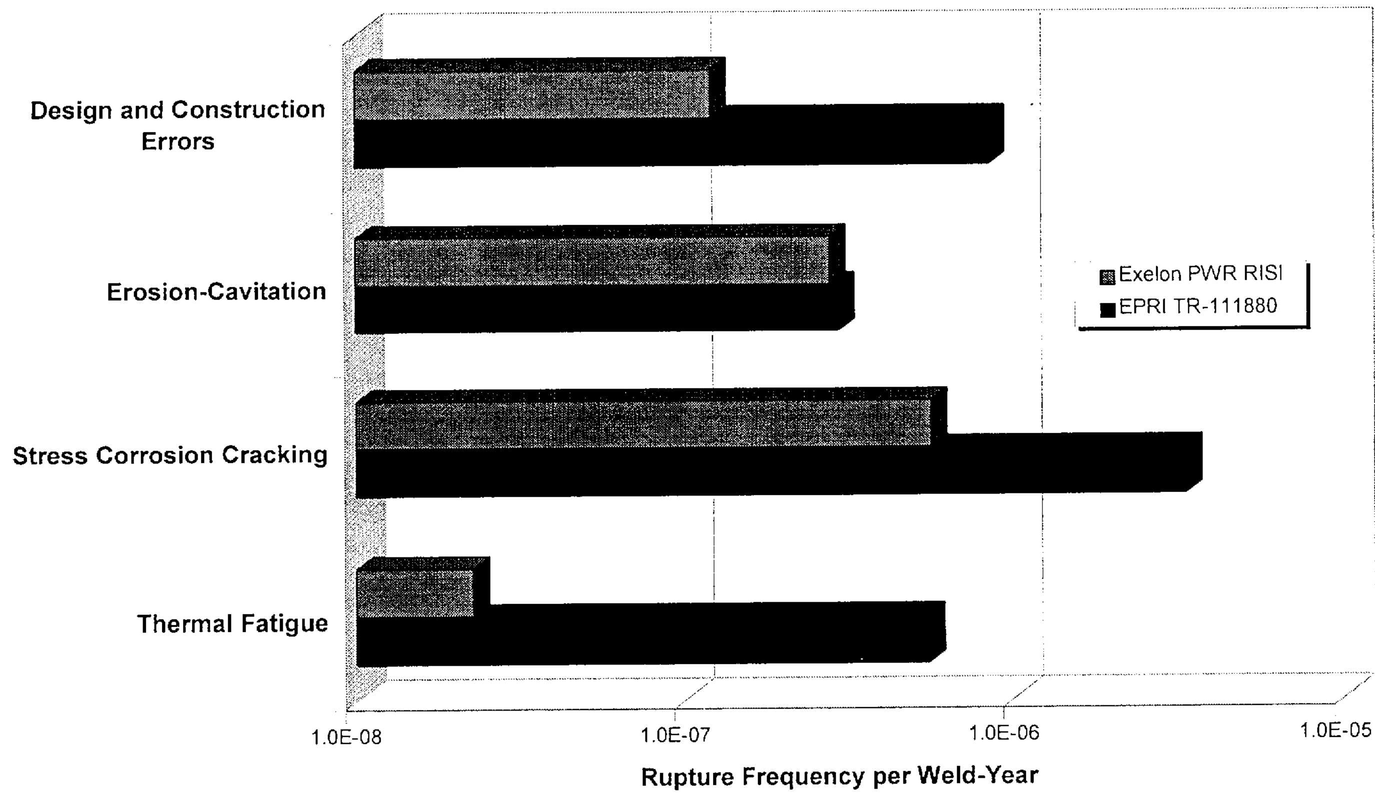
CONSIDERATIONS IN THE SELECTION OF FAILURE RATES FOR RISI

- EPRI and SKI-PIPE databases were compared following publication of EPRI TR-111880 to address weld overlay issue for BWR VIP 75
- SKI-PIPE is a superior data source for developing failure rates and rupture frequencies
- PWR data was updated with SKI-PIPE because it provides much more data available to estimate PWR weld populations and DM susceptibility fractions
- BWR data was not updated because risk assessment showed significant margins using EPRI TR-111880 data and expected changes would have been to reduce failure rates and rupture frequencies for key mechanisms

COMPARISON OF PWR FAILURE RATE ESTIMATES

Failure Rate Parameters			EPRI TR 111880	Exelon PWR RISI
Failure Data Source			SKI 96:20 as modified in EPRI TR-111880 with U.S. experience through 1995	SKI-PIPE Database described in SKI 98:30 and updated through May 2000;
Westinghouse PWR reactor years experience			905 U.S. only	2,234 U.S, Europe and Japan
Number of ISI amenable Failures in Westinghouse PWR Class 1 and 2 piping		Leaks	16	55
		Ruptures	0	0
Weld Population estimates per plant	RCS		409	364
	SI		1,211 for entire SIR system group	1,520
	RHR			420
	CVC S			744
Total Class 1 and 2 component exposure estimate			1.47×10^{6} weld-years	6.81×10^{6} weld-years
Plant data available to support weld population and damage mechanism susceptibility fraction estimates			ANO-2	ANO-2, STP-1, STP-2, Bw-1, Bw-2, By-1, By-2
Bayes Update Methodology			As described in EPRI TR-11880	Same procedure with refinements to take advantage of better data; use of Beliczey-Schulz correlation to anchor priors for conditional rupture probabilities

COMPARISON OF RUPTURE FREQUENCIES FOR RCS



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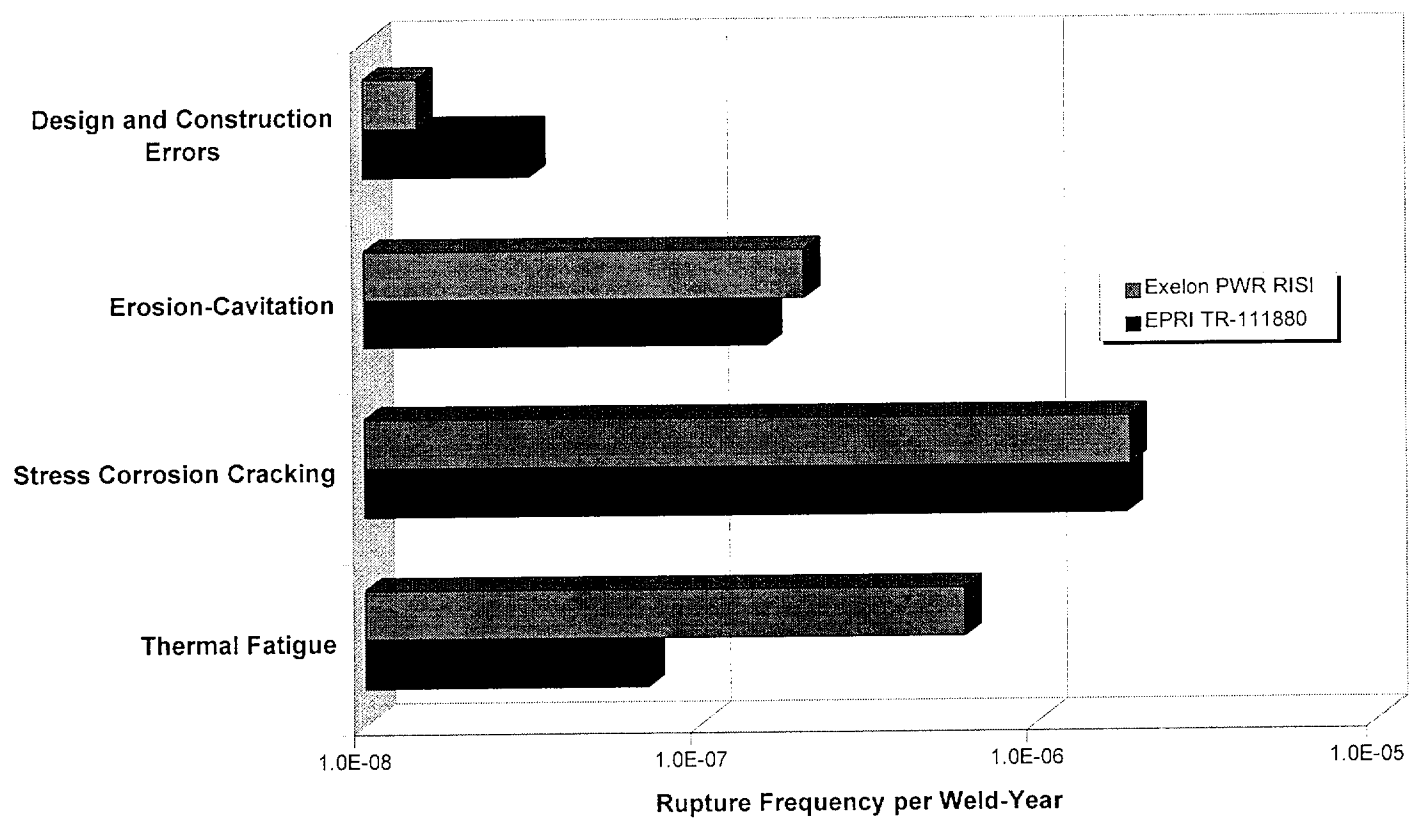
COMPARISION OF RUPTURE FREQUENCIES FOR SI SYSTEM



CONCLUSIONS FROM UPDATE OF FAILURE DATA

- EPRI TR-111880 provides reasonable and somewhat conservative basis to support BWR delta risk evaluation
- SKI-PIPE provides more realistic estimates for PWR Class 1 and 2 systems
  - Rupture frequencies for PWR RCS thermal fatigue and design and construction errors are significantly lower than EPRI TR 111880
  - Rupture frequencies for PWR SI thermal fatigue are significantly higher than EPRI TR 111880
  - Updated PWR estimates are based on enhanced estimates of weld populations and damage mechanism susceptibility fractions and correct some classification inconsistencies

OVERALL CONCLUSIONS

- Submittal takes no exceptions to EPRI TR requirements for risk impact evaluation
- Submittal realistically quantifies risk impact in accordance with the EPRI TR
- RAI response shows (1-POD) model and Markov model produce comparable inspection effectiveness factors
- RAI response shows risk impact acceptance criteria are met even with conservative bounding risk impact estimates
- Submittal provides improved estimates of failure rates and rupture frequencies for PWRs
- The submittal and RAI responses support timely NRC review