Development of the Risk-Based Inspection Techniques and Pilot Plant Activities

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Abstract

Risk-Based techniques have been developed for commercial nuclear power plants for the last eight years by a team working through the ASME Center for Research and Technology Development (CRTD). System boundaries and success criteria is defined using the Probabilistic Risk Analysis or Probabilistic Safety Analysis developed to meet the Individual Plant Evaluation. Final ranking of components is by a plant expert panel similar to the one developed for the Maintenance Rule. Components are identified as being high risk-significant or low risk-significant. Maintenance and resources are focused on those components that have the highest risk-significance. The techniques have been developed and applied at a number of pilot plants. Results from the first risk-based inspection pilot plant indicates safety due to pipe failure can be doubled while the inspection reduced to about 80% when compared with current inspection programs. The reduction in inspection reduces the person-rem exposure resulting in further increases in safety. These techniques have been documented in publications by the ASME CRTD which are referenced.

Introduction

Risk-Based In-Service Inspection (ISI) methods have been under development within the ASME Center for Research and Technology Development for about eight years. A series of documents have been written by a multi-disciplinary ASME research task force and published by the ASME. These documents define a four-part process for managing the inspection and testing of nuclear power plant components.

Risk-Based Process

The four major elements of the process are:

1. Definition of system boundaries and success criteria using a plant probabilistic risk assessment (PRA) or probabilistic safety assessment (PSA) that has been developed to meet the Individual Plant Examination (IPE) and Maintenance Rule requirements of the U.S. Nuclear Regulatory Commission,

2. Ranking of components or piping segments by a plant expert panel that makes the final selection of where to focus ISI resources by considering risk importance measures, consequences of failures, and other deterministic measures,

3. Determination of effective ISI programs that define when and how to appropriately inspect or test the two categories of more-safety-significant or less-safety-significant components, and,

4. Performing the ISI program to verify component reliability and then updating the risk rankings based on the inspection or test results.

RBI Pilot Studies

Pilot tests of the risk-based ISI methodology have been accomplished. A major study has been completed at Millstone-3 Power Station by Northeast Utilities with support from the Westinghouse Owners Group (WOG) and Westinghouse. The results from this effort have been forwarded to the U.S. Nuclear Regulatory Commission via the Nuclear Energy Institute (NEI) as a Westinghouse Owners Group topical report, WCAP-14572 (1996). This work adapted the ASME research methods in order to accomplish this full scale study.

A project is underway to perform a verification and validation (V&V) of the risk-based process through industry and NRC participation in an ASME research project. This verification and validation project uses Virginia Power's Surry plant for the evaluation. The use of Surry is significant because of the extensive initial risk-based ISI work performed there under previous research efforts: a favorable comparison of those previous results with those produced by the enhanced process is anticipated to assist the acceptance of the process by the NRC for generic industry use.

Millstone-3 was selected for the pilot study because of the support of the WOG and Westinghouse. Surry was selected for the V&V effort because of the previous research efforts performed there. Although it was not a consideration in the selection process, the fact is that both of the studies were conducted on Pressurized Water Reactors (PWRs). The technique has not been tried on a Boiling Water Reactor (BWR) type plant. Recently, an application study has been initiated at the Browns Ferry Boiling Water Reactor Plant to addresses plant type differences.

Application Study of RBI at a BWR

Basic differences between PWRs and BWRs that would affect the risk-based process exist in several areas:

-Some of the more safety-significant systems on a BWR (RCIC for instance) are currently exempted from Section XI requirements based on size; therefore, scope is different.

-BWRs have a PSA Core Damage Frequency that can be as much as an order of magnitude less than a PWR. The amount of CDF attributable to piping failures could be such a small number as to be considered below the cut-off point for significance.

-BWR chemistry and pressure have potential impact on Structural Reliability and Risk Analysis.

-BWRs are subject to different significant failure mechanisms than PWRs; for instance, IGSCC.

Another basic difference that affects BWRs is the applicability of Generic Letter 88-01, which defines requirements for IGSCC programs. A risk-based selection technique could potentially optimize the inspections performed under these programs.

The Browns Ferry project will assist industry in the validation of the ASME Research risk-based in-service inspection approach on a BWR. Currently, the NRC is developing a draft Standard Review Plan and Regulatory Guide to be submitted for public comment. A pilot application of the technique at a BWR will provide valuable insight to assure the SRP and Regulatory Guide are applicable to all the major reactor types. The ASME is also seeking individuals that will help support this project.

The project is being performed with a team from ASME Research, Tennessee Valley Authority, and other industry participants. This team would apply the current ASME Research Risk-Based In-Service Inspection approach to a BWR plant and compare the results to the previous pilot studies. Comparisons would be made along the way and any technical issues would be resolved during the course of the project. The project started in July 1997 and is scheduled to be completed in mid-1998.

Benefits of the BWR RBI Program

Risk-based inspection program development has benefits for the industry, BWR owners, the owners of the plant being studied (Tennessee Valley Authority in this case.), the NRC, and the Code writing Body. These benefits are as follows:

a. Industry
   - Assure applicability of the approach to all major reactor types.
   - Provide a better understanding of the risk-based ISI technology.
   - Increase success of risk-based in-service inspections.

b. BWR owners

- Provide a documented basis for potential optimization of the inspection process mandated by Generic Letter 88-01

c. Tennessee Valley Authority
   - Provide a risk-based ISI program for the plant based upon an updated IPE model.
   - Lead to earlier consideration for program approval.

d. ASME Code
   - Provide support for Code changes.

e. NRC
   - Provide insights to the applicability to all major reactor types of the techniques outlined in their draft SRP and Regulatory Guide.
   - Provide insights to the potential optimization of the inspection process mandated by Generic Letter 88-01 for inclusion in their draft SRP and Regulatory Guide.

e. All parties
   - Provide a mechanism to resolve issues in a nonregulatory setting (ASME Research-CRTD) as they occur during the process (i.e., reduce review cycle time).

Results of the RBI Pilot Studies

The Risk-Based ISI project at Millstone-3 has been completed using the ASME Research methodology described in WCAP-14572. A total of 120 elements have been selected for some type of examination under the Risk-Based ISI program as compared to 753 welds now scheduled under the current ASME Section XI program, representing an 84% reduction in the raw number of examinations to be performed. In addition, examination of the current ASME Code locations addresses 44% of the Core Damage Frequency attributable to piping, while examination of the Risk-Based elements addresses 98%, representing a 122% improvement. Although total Core Damage Frequency attributable to piping is a small fraction of the total plant CDF, safety is enhanced with fewer examinations being performed. While the Surry pilot has not been completed, it is estimated that the number of Risk-Based examinations will be approximately 40% of the number now scheduled under the current Section XI program.

In economic analysis, these pilots represent a direct cost savings of 60-84% of the current costs of examination per outage. Additionally, Millstone-3 estimated an exposure savings of 15 man-rem each outage. Other indirect cost savings are expected from items such as reduction in costs associated with evaluating flaw indications which may not really exist (i.e., false calls).

These results indicate that a risk-based program can be successful in greatly reducing costs, both dollars and exposure, while improving safety; however, they have only been done on PWR nuclear steam supply systems. Validation of the process on a BWR in the

Browns Ferry Application also has the potential to provide a path for optimization of the inspection process mandated by Generic Letter 88-01, and as such makes this a worthwhile project.

The objective of the program is to further validate the ASME Research Risk-Based In-Service Inspection approach when applied at a Boiling Water Reactor.

Advantages of the Quantitative RBI Approach

The ASME technique is call quantitative because the failure probability of each pipe segment is quantified. The advantages of the ASME Research Risk-Based In-Service Inspection quantitative approach when compared with the less effective qualitative approaches are as follows:

- Provide a quantitative approach to measure risk reduction
- Provide risk trade off--active components can be inspected or operation changes can be made to take the place of inspections
- End the subjective percentage of components inspection criteria
- Probabilistic Fracture Mechanics Calculations for inspection and frequency evaluation
- Augment the generic data and plant specific sources
- Project failure probability into the future to evaluate conditions that have not occurred.
- Allows capability to include aging in the calculations.

The quantitative approach to risk-based inspection should be as efficient and should be no more costly than the qualitative approaches which do not offer the advantages.

Conclusions

Techniques have been develop that focus scarce resources on components that most affect risk. Risk-based approaches focus maintenance activities on components where failures can occur and have high consequences at plants. Results indicate that safety can be increased and inspection of piping components can be decreased. These techniques have been developed by teams working with the ASME Center for Research and Technology Development. The results of this work is published in documents which have been referenced.

References

American Society of Mechanical Engineers, *Risk-Based Inspection - Development of Guidelines, Volume 1, General Document,* CRTD-Vol. 20-1, ASME Research Task Force on Risk-Based Inspection Guidelines, Washington, D.C., 1991.

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COPIES OF OVER HEADS

Risk-Based Inspection at Surry and Millstone

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October 1, 1997

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Agenda

- Risk-Based Technique
- Pilot Study at Millstone and Results
- Surry Verification and Validation Project
- Browns Ferry Application Study
- Codes Cases Status

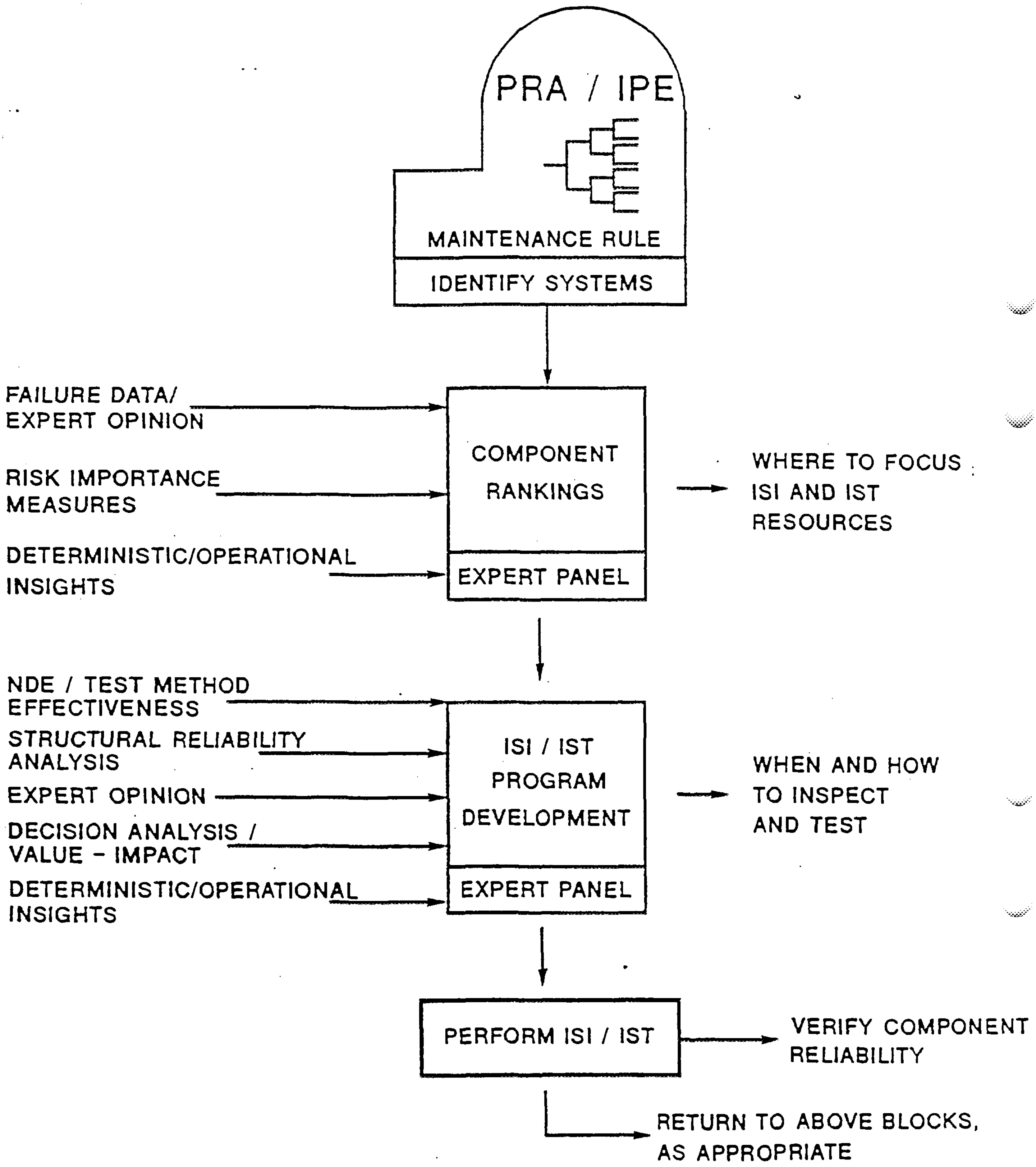
Acronyms

- RBI - Risk-Based Inspection
- RII - Risk-Informed Inspection
- RBT - Risk-Based Testing
- SRRA - Structural Reliability Risk Analysis
- PRAISE - Piping Reliability Analysis Including Seismic Evaluation
- WinPRAISE - a Windows Version of PRAISE
- IGSCC - Intergranular Stress Corrosion Cracking
- PFM - Probabilistic Fracture Mechanics

What is the ASME CRTD?

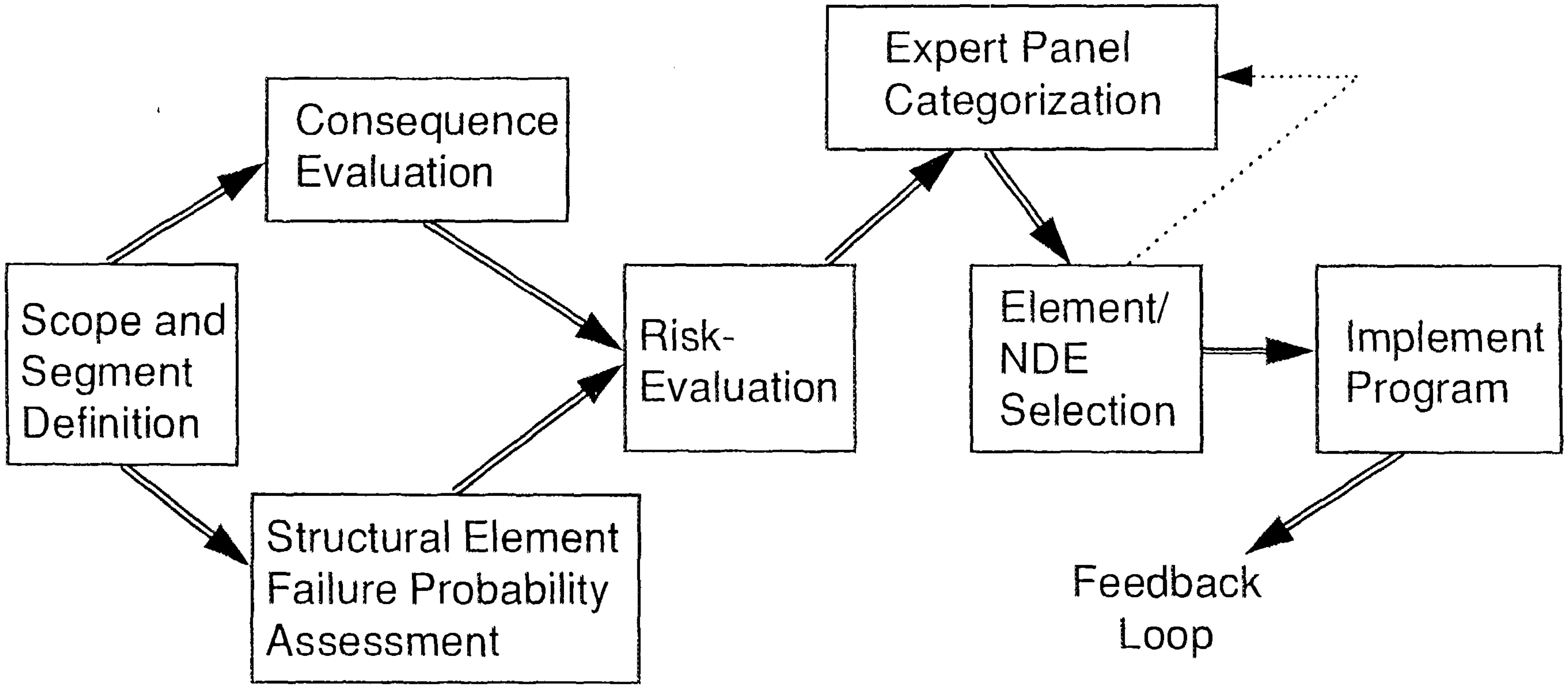
- Center for Research and Technology Development
- Research since 1909. (Developed and Maintain Steam Tables)
- Develop Projects to Resolve Public Needs
- Work is Done by Members
- Bring Industry, Academy, Government Together
- Publish Results.

FIGURE 1
ASME RISK - BASED INSERVICE INSPECTION
AND TESTING PROCESS



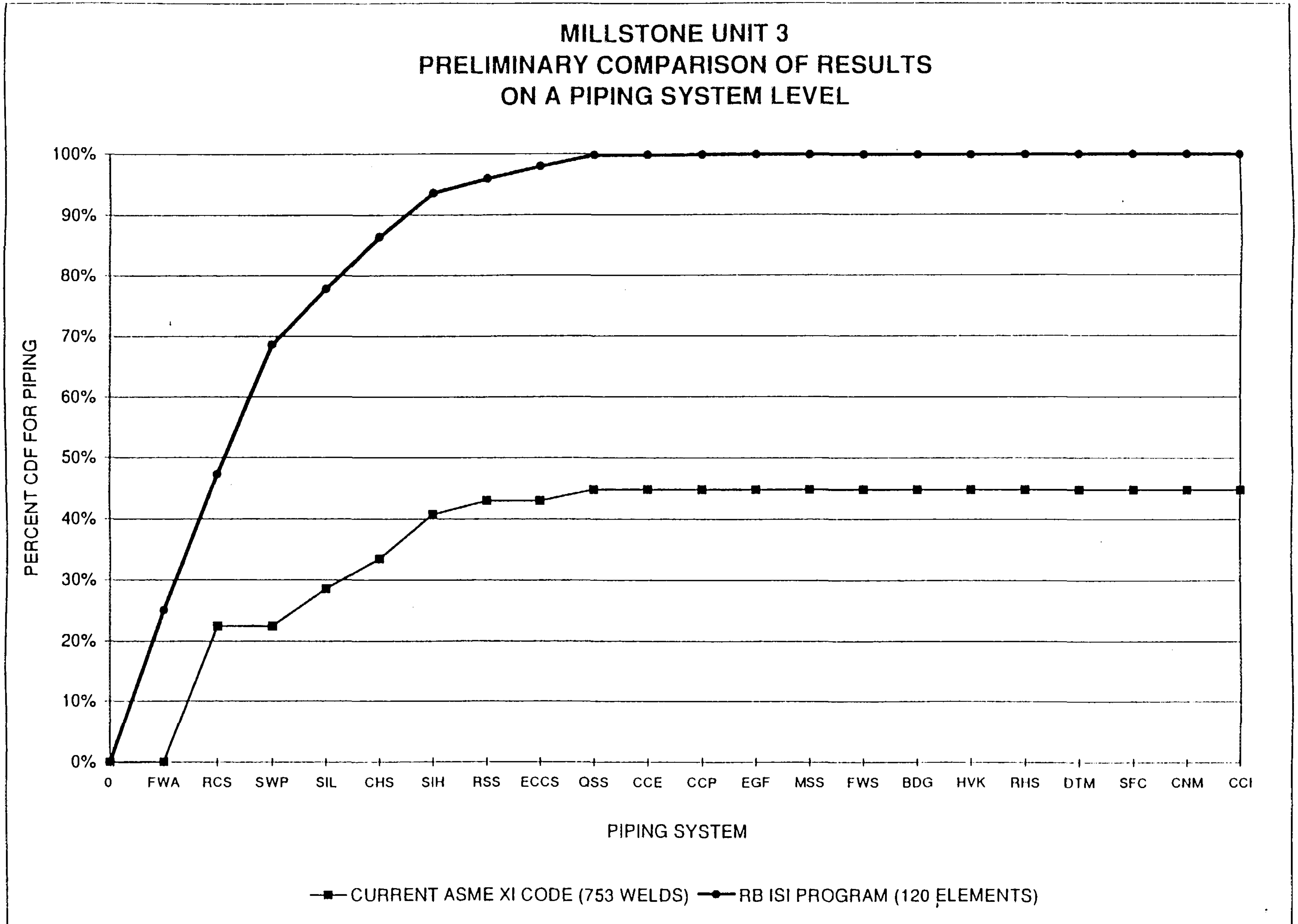
ISI - INSERVICE INSPECTION
IST - INSERVICE TESTING
NDE - NON-DESTRUCTIVE EXAMINATION

Overall Risk-Informed ISI Process



Millstone RBI Results

- Current ASME Section XI Program
  - 753 Welds
  - 44% of Risk Due to Piping Failure
- RBI Program
  - 120 Elements
  - 98% of the Risk due to Piping Failure
- 84% Reduction in Inspection and Double the Safety Improvement



MILLSTONE UNIT 3
PRELIMINARY COMPARISON OF RESULTS
ON A PIPING SYSTEM LEVEL
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
PERCENT CDF FOR PIPING
0
FWA
RCS
SWP
SIL
CHS
SIH
RSS
ECCS
QSS
CCE
CCP
EGF
MSS
FWS
BDG
HVK
RHS
DTM
SFC
CNM
CCI
PIPING SYSTEM
CURRENT ASME XI CODE (753 WELDS)
RB ISI PROGRAM (120 ELEMENTS)

Preliminary Results for Surry V&V RBI

- Example in the Reactor Coolant System (RCS)
  - Total number of welds is about 537
  - Current ASME XI Program - 162 Welds
- RCS Preliminary RBI Program
  - 53 to 62 Welds would be in the Program

Prodigal Computer Program for Flaw Distribution

- Created by Rolls-Royce & Assoc.
- Flaw Distribution for Failure Probability
- Based on Expert on Judgment
- Flaw Distribution based on Weld Build Specification
- Benchmarked Against United Kingdom Ducting (Pipe)

Indirect Effects Summary

For Surry

- Many indirect effects from flooding, pipe whip and jet impingement were identified (more than for Millstone 3)

- Several pipe segments in systems not in risk-informed ISI scope were added to program due to indirect effects

Perdue Statistical Model Inputs

- Requires following inputs
  - Number of welds in segment
  - Prob of flaw (a/t>.10) @ 25 years (from SRRA)
  - Conditional leak rate given flaw in remaining 15 years (per year) (from SRRA)
  - Sample size
- Target Leak Rate (per year per weld)
- Confidence level - 95%

Overview of Risk Model Currently Under Study

	A	B	C	D	H	L	P	T
1	Consumer Risk Model							
2								
3	Segment # / Loop #		RCS 4/B	(User Input)				
4	Number of Welds		8	(User Input)				
5	Prob. of Flaw @ yr 25/weld		6.50E-03	(User Input)				
6	Probability of Detection		0.65	(User Input)				
7	Cond. Prob. of Leak / yr/weld		3.00E-06	(User Input)				
8	Double Sampling Plans		For 1 and 2 welds in each sample. Accept #=0 & Cum Reject #=2. POD= input					
9	Single Sampling Plan		Accept #=0.Reject #=1. Assumes Prob.of Detect=100%(unlike double plans)					
10	Single Sample Size		2	(User Input), make sample <"Number of Welds"				
11	Target Leak rate /yr/weld		1.00E-06	(User Input)				
12	Target Leak rate /yr/Lot		0.000008	(Calculated)				
13								
14	Consumer Risk Table		RCS 4/B					
15	A	B	C	D	H	L	P	T
16	No. of Flaws (k)	Implied Leak/yr/Lot	Binomial Probability of k Flaws	Pre-ISI (i.e., No ISI) Probability of k or less Flaws	Double Sample (each sample=1) Prob. of k or less Flaws	Double Sample (each sample=2) Prob. of k or less Flaws	Single Sample (POD=1) Prob. of k or less Flaws	Single Sample (POD in Cell C6) Prob. of k or less Flaws
17	0	0	0.94917	0.94917	0.94918	0.94925	0.96163	0.957239
18	1	0.000003	0.04968	0.99885	0.99887	0.99894	0.99938	0.99920
19	2	0.000006	0.00114	0.99998	0.99999	0.99999	0.99999	0.999992
20	3	0.000009	0.00001	1.00000	1.00000	1.00000	1.00000	1.00000
21	4	0.000012	0.00000	1.00000	1.00000	1.00000	1.00000	1.00000
22	5	0.000015	0.00000	1.00000	1.00000	1.00000	1.00000	1.00000
23	Col. Total		1.00000					
24								
25	Consumer Risk (prob. leak rate/yr/lot > target)			0.00002	0.00001	0.00001	0.00001	8.43E-06
26								

Chart7

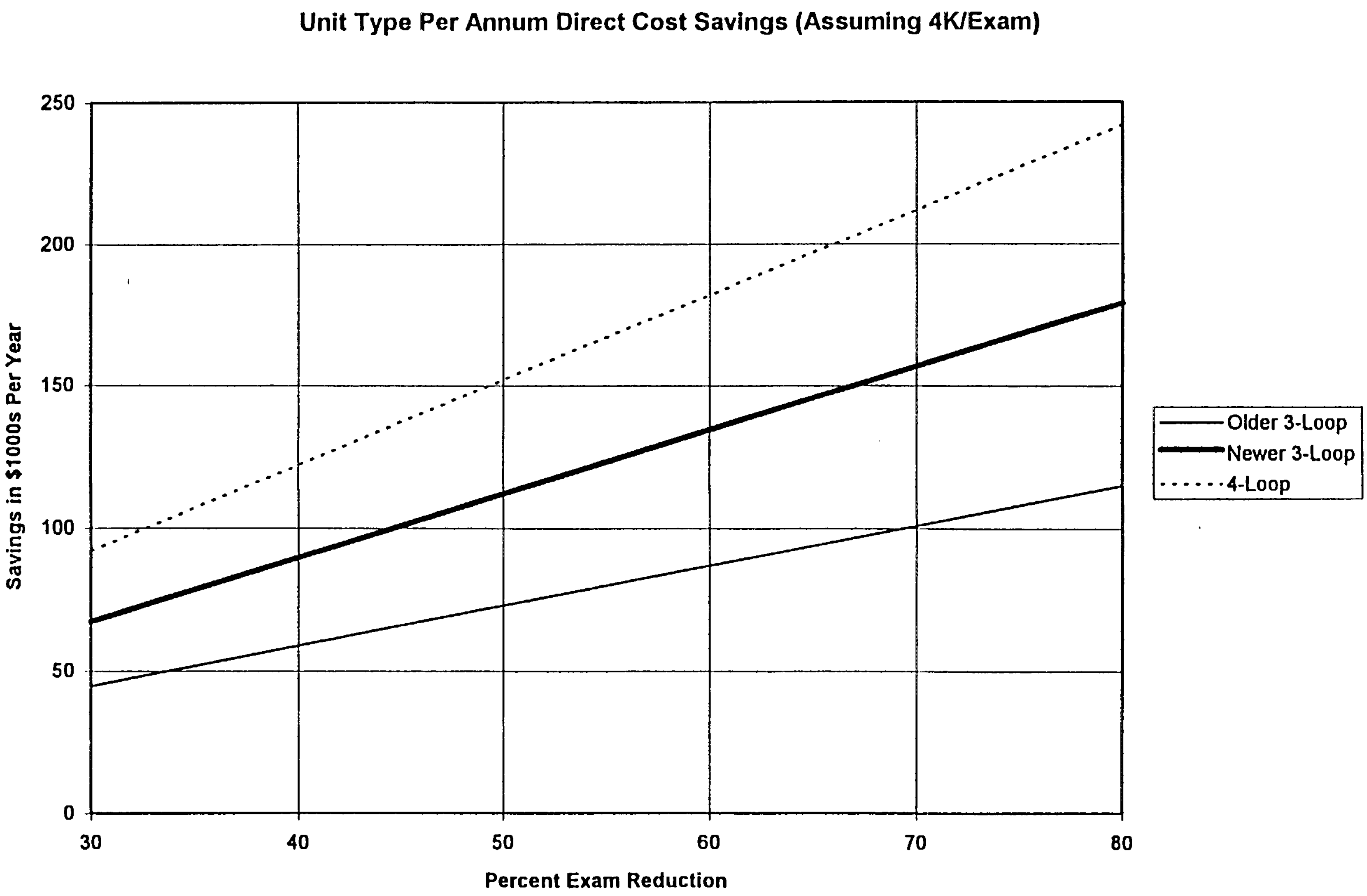
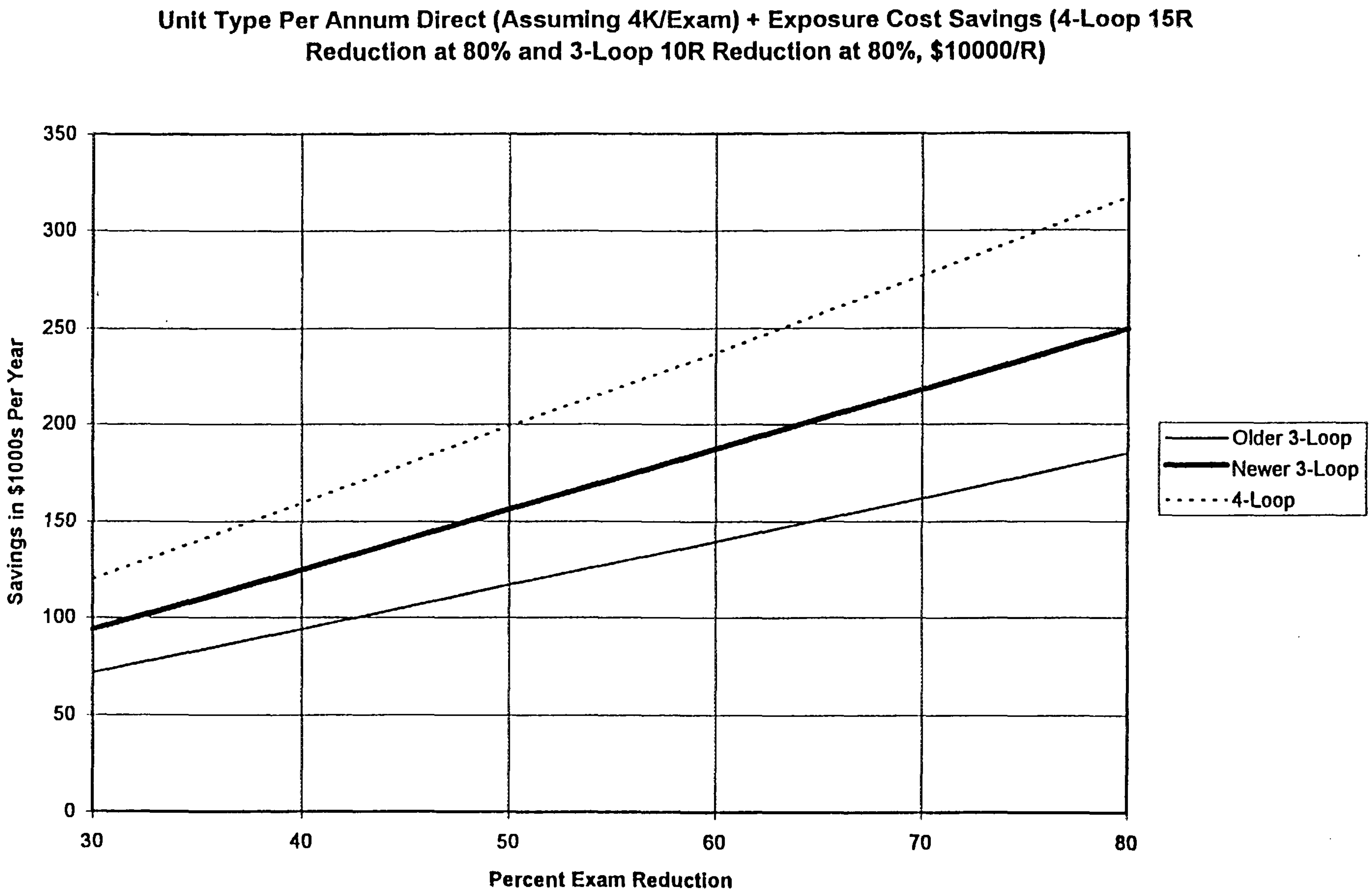

Unit Type Per Annum Direct Cost Savings (Assuming 4K/Exam)
Savings in $1000s Per Year
250
200
150
100
50
0
30
40
50
60
70
80
Percent Exam Reduction
Older 3-Loop
Newer 3-Loop
4-Loop

Chart8



Unit Type Per Annum Direct (Assuming 4K/Exam) + Exposure Cost Savings (4-Loop 15R Reduction at 80% and 3-Loop 10R Reduction at 80%, $10000/R)
350
300
250
200
150
100
50
0
Savings in $1000s Per Year
30
40
50
60
70
80
Percent Exam Reduction
Older 3-Loop
Newer 3-Loop
4-Loop

Browns Ferry RII Project Started

- BWR Application of RII
- IGSCC Augmented Program Risk
- Fully Quantitative Analysis
  - Modified Version of PRAISE
  - Menu Input, Maintain all Properties
- Determine Efficient Implementation Time
- Complete by Mid-1998
- Seeking Sponsors

Advantages of Quantitative RII and Mechanistic Models

- Augment Expert Opinion
- Make up for Lack of Data
- Future Predictions
- Alternate Insp. Accuracy (POD) and Freq.
- Leak and Break Probability over Plant Life
- Crack Trajectory Plots
- Aging Effects and Material Prop. Changes
- Risk and Delta Risk Calculation

Code Cases on Risk-Based Inspection - Schedule

- Case N-577, Risk-Informed Requirements for Class 1, 2, and 3 Piping, (Method A) - ASME Approach
- Case N-578, Risk-Informed Requirements for Class 1, 2, and 3 Piping, (Method B)
- Approved by Board on Nuclear Codes and Standards
- To be Issued for Public Comment and Published

New Issues Related to Risk-Based Techniques

- Browns Ferry BWR RBI
- Ad Hoc Committee on Risk-Based Design
- ASME-NRC Ad Hoc Committee on PRA Scope
- Ad Hoc Committee on Nuclear Air and Gas Treatment

Conclusions

- RBI and RBT Techniques have been Developed
- Pilot Studies Indicate that Safety can be Increased and Money Focused
- Regulatory in US is Appears to be Moving Toward Risk-Informed Regulation
- Risk-Based Techniques are Being Applied to Design, Decision Analysis