PILGRIM NUCLEAR POWER STATION REGULATORY CONFERENCE

Safety Relief Valve SRV-3A

July 8, 2015

Entergy Representatives

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OPENING REMARKS

John Dent

Site Vice President

Pilgrim Nuclear Power Station

Agenda

INTRODUCTION

Dave Noyes

Director, Regulatory & Performance Improvement

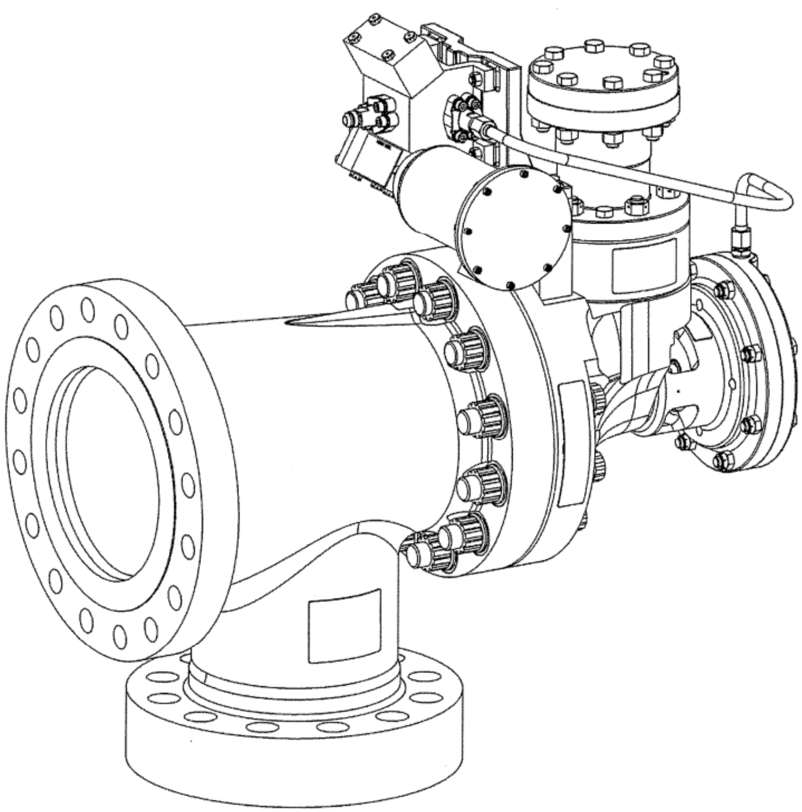
Pilgrim Nuclear Power Station

Introduction

- **We are extracting all of the learnings from this event**
  - Detailed root cause evaluation is underway; identified gaps in:
    - Equipment performance monitoring
    - Operability evaluation and corrective action rigor
    - Post trip review performance
  - We are sharing those learnings with the fleet
- **Improvements have been made in addressing conditions in the Corrective Action Program (CAP) since 2013**
  - Continued improvements in CAP implementation ongoing

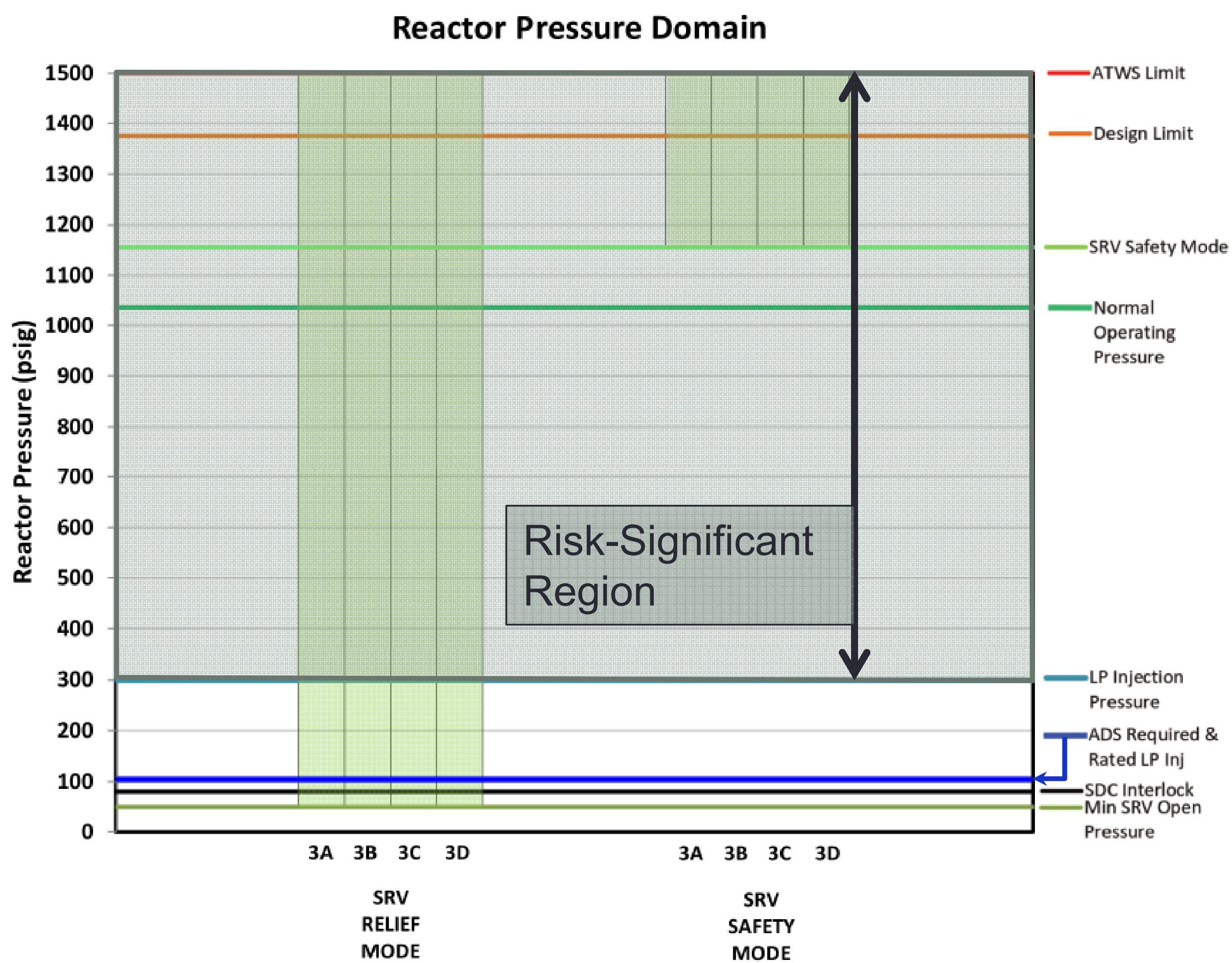
Pilgrim performance is different in 2015 versus 2013

3-Stage Target Rock Safety Relief Valve (SRV)



4 Safety Relief Valves

Full Range of SRV Operation



Pilgrim Approach and Methodology

- **Best available (including new) information is derived using:**
  - NRC's bounding analysis
  - Plant-specific PRA model
  - Actual in-plant experience in light of physical inspection of SRVs
  - Results from component inspections at National Technical Systems (NTS) (formerly Wyle Labs) **(New Information)**
  - Analytical Work **(New Information)**

- **Result after considering all plant-specific risk inputs is very low safety significance**

PILGRIM SRV PERFORMANCE HISTORY

John Macdonald

Senior Manager, Operations

Pilgrim Nuclear Power Station

Key Events

May 2011 3-Stage Target Rock SRVs installed during RFO 18

- New model SRVs included all known corrective measures for main stem/piston loosening (identified in IN 2003-01 and GE SIL 646)

Feb 8, 2013 Cooldown following loss of offsite power and scram - winter storm **Nemo**

- Attempted use of SRV-3A to reduce reactor pressure on three occasions; response from tailpipe acoustic monitor was not as expected (114 psig, 101 psig, and 98 psig)

May 2013	SRV-3A Pilot Assembly replaced due to Intergranular Stress Corrosion Cracking of Bellows identified in 10 CFR Part 21 during RFO 19; SRV-3A cycled
Aug 22, 2013	SRV-3A manually opened twice (923 psig and 823 psig) and reclosed during plant shutdown
Oct 14, 2013	SRV-3A manually opened once (1080 psig) and reclosed during plant shutdown

Jan 27, 2015 Cooldown following partial loss of offsite power - winter storm **Juno**

- Two attempts to use SRV-3C to reduce reactor pressure (220 psig and 260 psig)

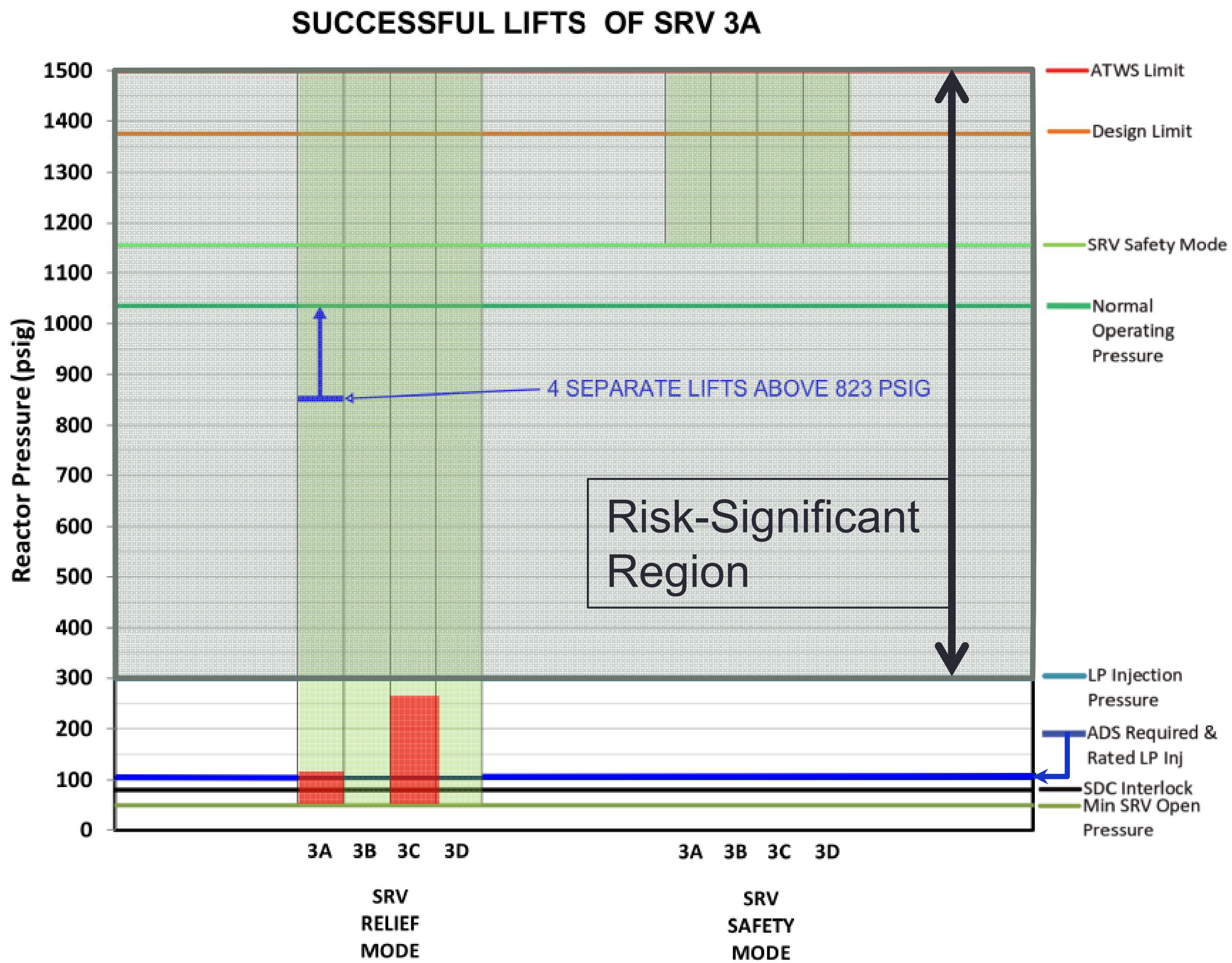
Feb 2015 SRV-3A and SRV-3C replaced prior to restart from winter storm Juno forced outage

Mar 16, 2015 Target Rock issues 10 CFR Part 21 interim report based on Pilgrim SRV performance

May 2015 3-Stage SRVs replaced with 2-Stage model during RFO 20

Limited Range of Known Impact

- **Extent of Condition**



Key Events and Timeline

Conclusions:

- At all times maintained multiple methods of reactor pressure control
- At all times had at least 2 SRVs available for pressure relief
- 2 SRVs (SRV-3B & -3D) opened and closed reliably on multiple demands when called upon across **the entire** pressure range
- All SRVs consistently opened at high pressure
- SRV-3A opened 4 times at high pressure after failing to open at low pressure during winter storm Nemo – 2013
- All SRVs consistently reclosed under all conditions
- SRV-3B & -3D responded as expected more than 100 times

Pressure control via SRVs available at all times across the entire pressure range

DELTA CORE DAMAGE FREQUENCY DIFFERENCES

Dave Noyes
Director, Regulatory & Performance Improvement
Pilgrim Nuclear Power Station

What is different?

- NRC Staff conclusions driving the low-to-moderate safety significance
  - Common Cause Factor (CCF) consistently applies to failure-to-open (FTO) for all SRVs (assumed 1 in 6 FTO probability)
  - Failure-to-close (FTC) is credible (10X FTC probability)
  - SRV failure probabilities increase across the full reactor pressure vessel (RPV) pressure spectrum (10X FTO factor)
- Pilgrim conclusions driving the very low safety significance
  - SRV-3B & -3D performance affirmed by inspection and analysis supports a lower CCF rate
  - Based on valve performance and maintenance practices, use of a nominal FTC probability is appropriate
  - All SRVs exhibited functionality at high RPV pressure
  - Based on operating history, a 2X nominal FTO probability is conservative and is based on Bayesian methodology
- Pilgrim will present the inspection and testing results and the impact this has on the risk assessment

New information provides plant-specific best information

SRV INSPECTION / ANALYSIS RESULTS

Thomas White
Manager, Design Engineering
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Pilgrim Nuclear Power Station

SRV-3A & -3C

- SRV-3A (2013) & SRV-3C (2015) failed-to-open on demand at relatively low reactor pressure
- Both valves removed from service in February 2015 and replaced
- Comparison of valves:
  - Similar conditions found on both SRV-3A & SRV-3C
  - Physical inspection of SRV-3B (SN8) & SRV-3D (SN7) revealed only minor degradation (wear) that would not have impacted valve operation

SRV-3A & -3C physical conditions distinctly different from SRV-3B & -3D

3-Stage Target Rock SRV Testing

- Testing of all 4 SRVs at NTS
  - All valves were removed during RFO-20 (April 2015)
  - SRV-3A & -3C with approximately 60 days in-service
  - SRV-3B & -3D with approximately 2-years in-service
  - As-found main stage test at 50 psig instead of safety mode setpoint
  - Successful lifts without high pressure pre-conditioning
- Valves were disassembled and inspected
  - Dimensional checks on individual parts
  - Observed by Entergy, Target Rock, Lucius Pitkin (LPI), and NRC
- Inspection and test results support Pilgrim position on reliable SRV performance for the 4 SRVs, particularly SRV-3B & -3D

SRV-3B & -3D maintained full functionality

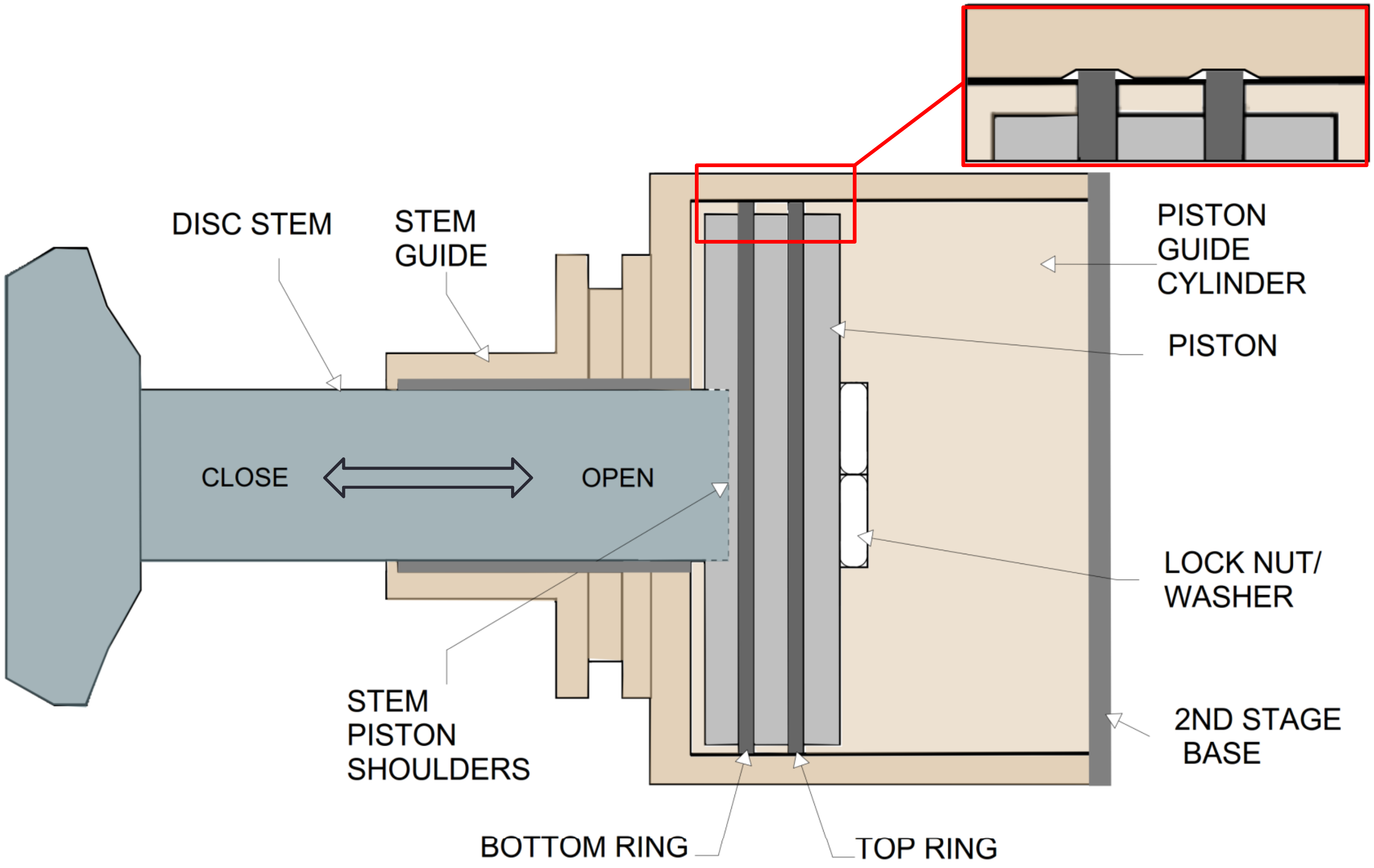
Target Rock Part 21

- New 3-Stage SRV Model 0867F has unique combination of internal features (used in Pilgrim 2011 – 2015)
  - Largest available throat diameter
  - Largest total steam drive flow to piston
  - Highest opening speed
  - Cause Analysis
    - Disc/piston experiences largest test stand impact force resulting in piston becoming de-torqued and de-shouldered
    - Vibration and/or pressure pulsations cause detrimental wear on some steam supply systems
  - Design changes to be determined by analysis and testing

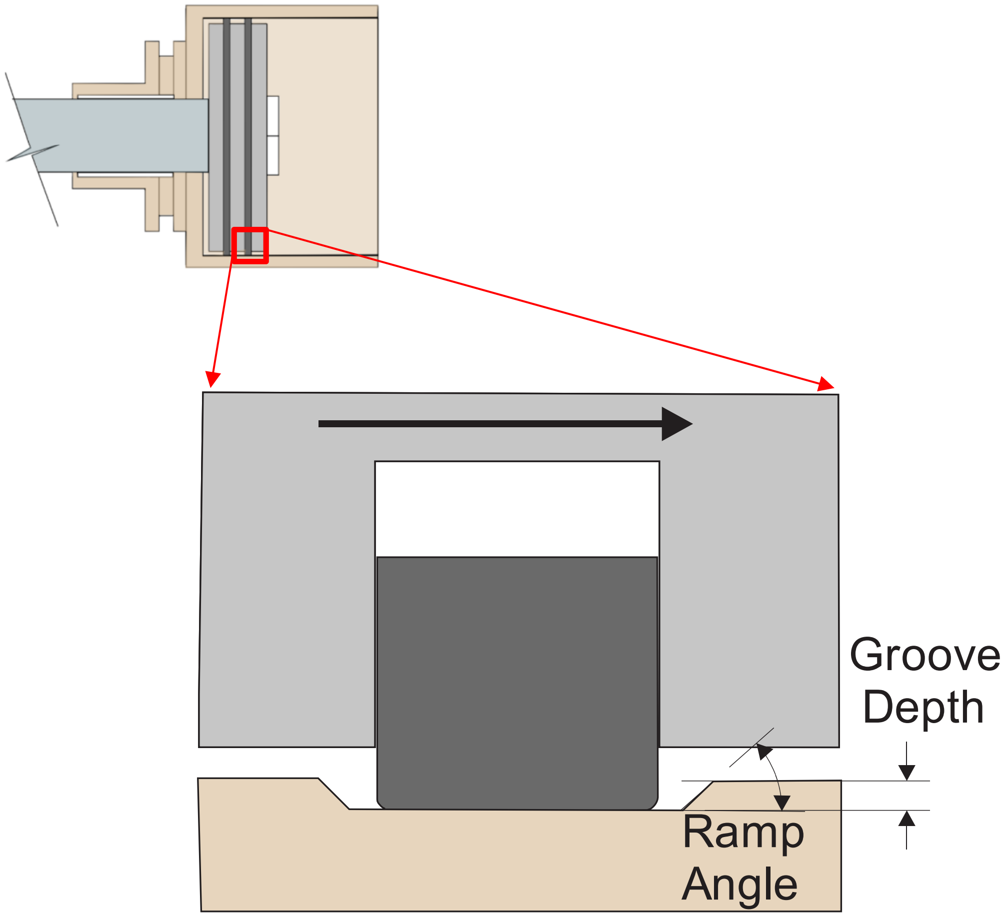
10 CFR Part 21 analysis is consistent with Pilgrim's analysis and experience

Main Stage Internal Parts

Example of Ring/Guide Wear



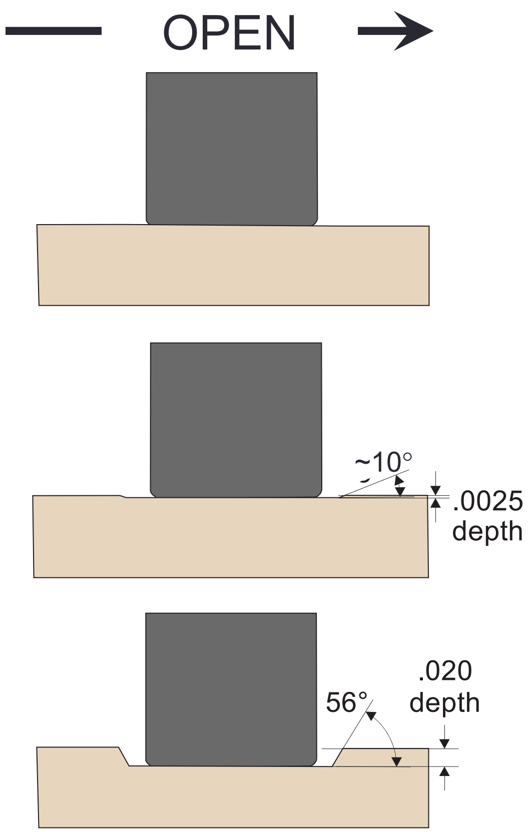
SRV Analysis Model



- Calculates the Piston Delta Pressure (DP) required to climb up the ramp
- Required Piston DP increases as angle increases
- Required Piston DP increases as friction coefficient increases

Required Piston DP is dependent on ramp angle and friction coefficient

SRV Assessment of Stroke



SRV-3B – New information

- Inspection revealed no measureable wear and guide damage
- Target Rock declared guide reusable

SRV-3D – New information

- Inspection revealed shallow wear groove and ramp angle
- Shallow ramp easily climbed by piston ring

SRV-3A and -3C

- Both did not open at low pressures (98 to 260 psig), but both opened at higher system pressures

New Information for SRV-3B & -3D

- Both opened at NTS at 50 psig; meeting the valve design specification
- Internal inspections explain why the valves operated per the design

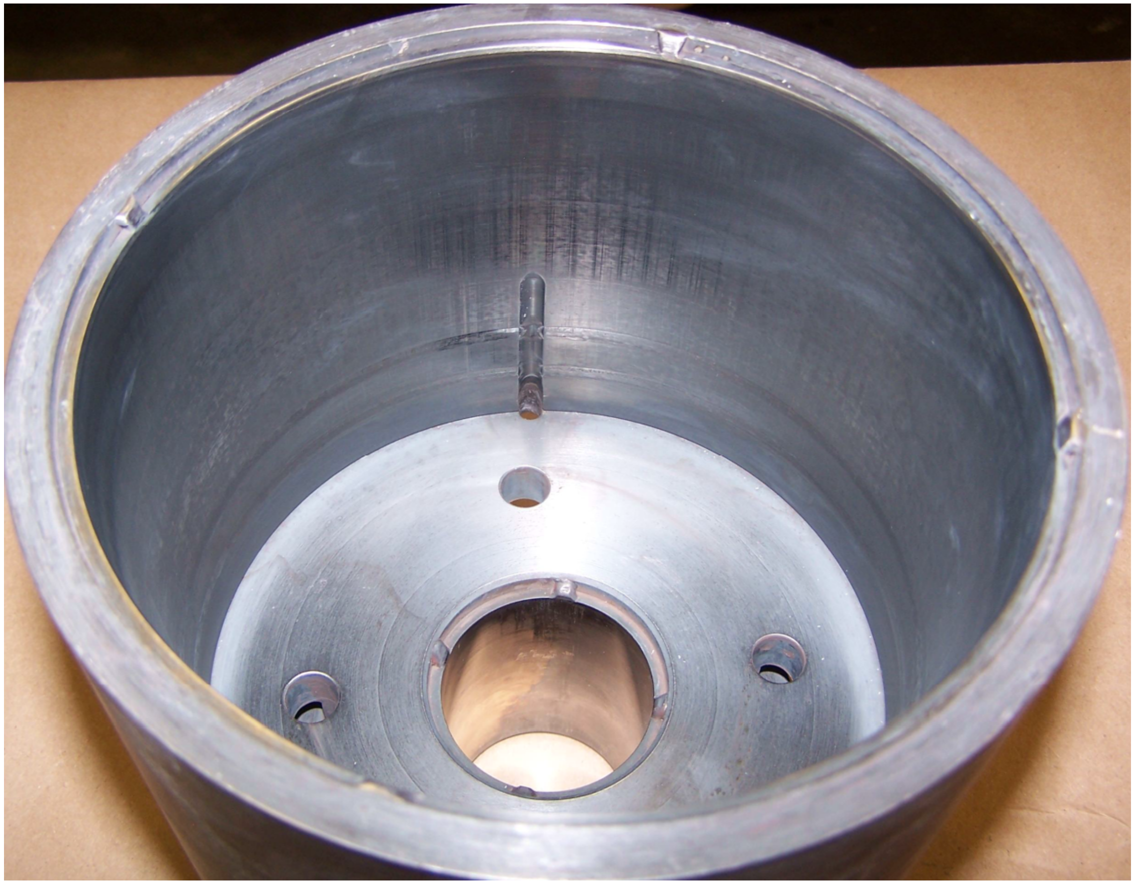
SRV-3B and -3D operated at all pressures – SRV-3A and -3C had reduced operating range due to ramp angle

Inspection Results

Condition Affected Part	SRV-3B (SN8)	SRV-3D (SN7)	SRV-3A (SN4)	SRV-3C (SN9)
Demand Cycles	**50+**	**50+**	**8 (2 PWTs)**	**3 (1 PWT)**
Grooves Worn in Guide	**NO**	**Minor wear from piston contact Max Depth 0.0025 inches**	**Deep Ring Grooves Max Depth 0.020 inches**	**Deep Ring Grooves Max Depth 0.018 inches**
Max Ramp Angle	**Not Applicable**	**~10°**	**~39°**	**~56°**
Gap from Piston to Disc Shoulder	**3-4 mils**	**3-4 mils**	**Large Gap 13-16 mils**	**Large Gap Not Measured**
Piston	OK	Shoulder not ⊥	Wear on OD Threads Galled	Wear on OD and Threads Galled
Rings	Normal Wear	Normal Wear	Fretting Wear	Fretting Wear
Disc / Stem	Shoulder not ⊥ Disc length short	Shoulder not ⊥ Disc length short	Threads Galled Disc machined off Pitch damage	Threads Galled Severe thread pitch damage

SRV-3A & -3C physical conditions distinctly different from SRV-3B & -3D

SRV-3B Guide

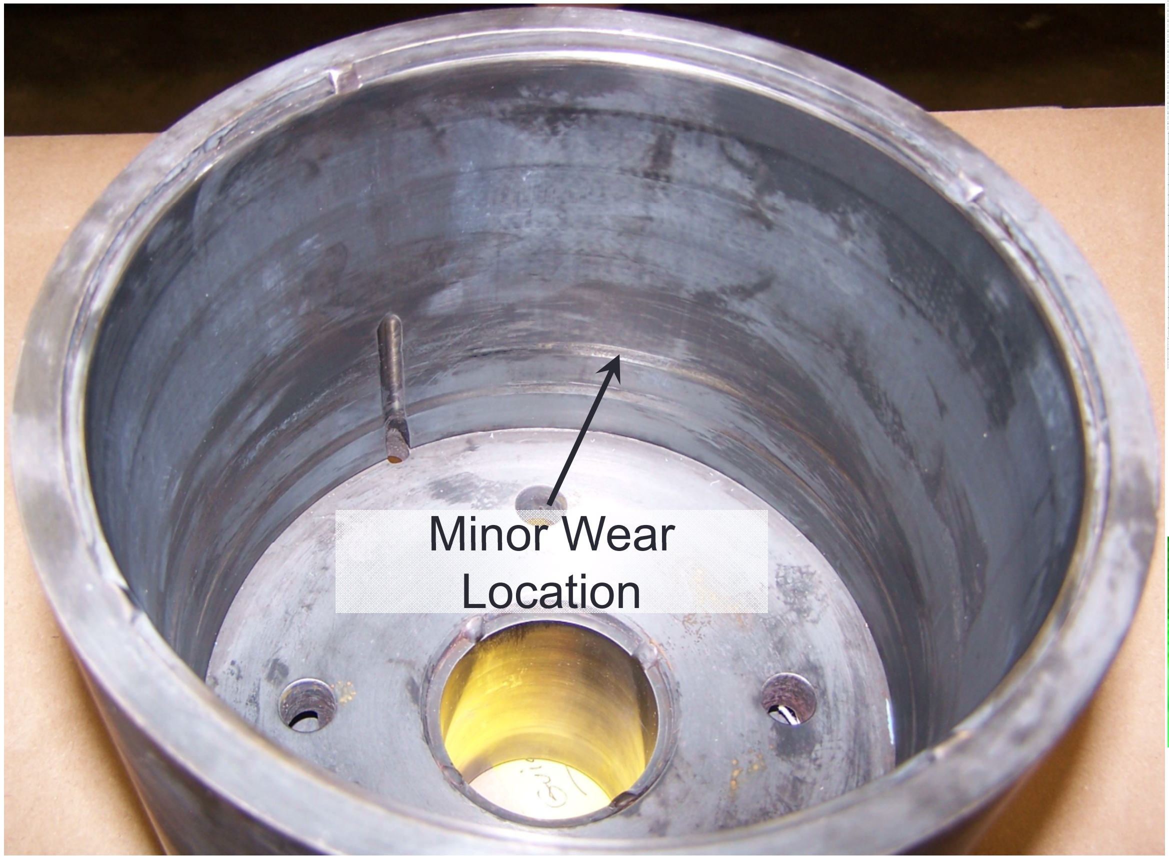


No Guide Damage
No Grooves
Guide is re-useable

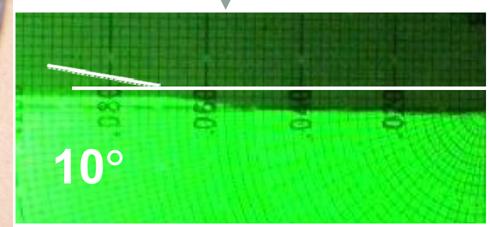
Ring shadows on Guide surface are caused by heatup

SRV-3B opening and closing unaffected - No wear

SRV-3D Guide



Magnified Impression of Localized Wear in Guide on SRV-3D Max Localized Depth 0.0025 Inches

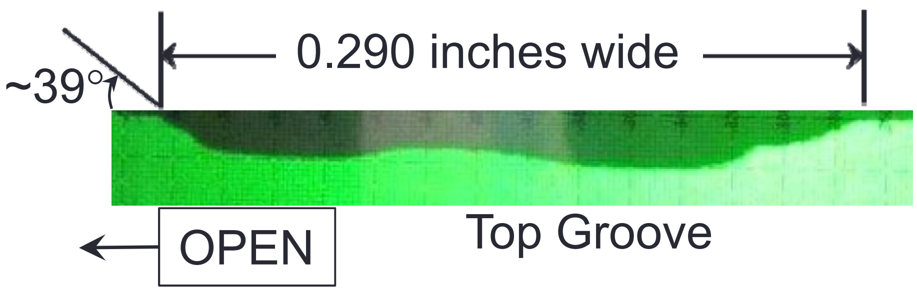


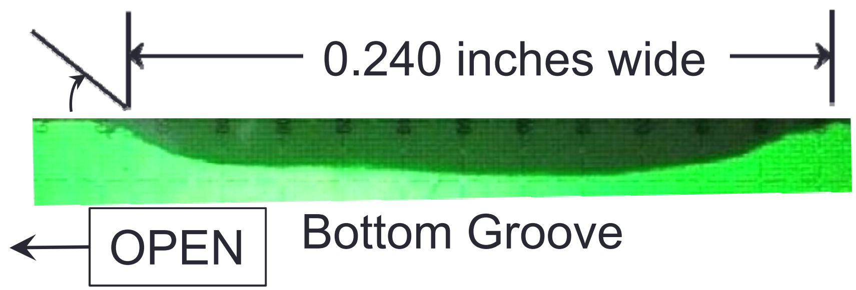
OPEN

SRV-3D opening and closing unaffected by very minor wear

SRV-3A Guide

Magnified Impression from top and bottom ring grooves located at 1200 position
Max Depth 0.020 inches
8 times deeper than SRV-3D
Shallower ramp angle than SRV-3C





SRV-3B & -3D comparatively little or no Guide wear

SRV-3C Guide

Magnified Impression from Bottom Ring Groove located at 0530 position
Max Depth 0.018 inches
7 times deeper than SRV-3D
Steeper ramp angle than SRV-3A

OPEN   Bottom Groove

SRV-3B & -3D comparatively little or no Guide wear

Kalsi Engineering Results

- Valve modeling to assess opening/closing performance (using as-found conditions)
- Force balance analysis takes into account:
  - Differential pressures
  - Coefficient of friction between internal parts
  - Spring force
  - Parts geometry
    - Threads
    - Stem and piston shoulders
    - Effective ramp angle of grooves
- Third-Party Review Performed by MPR and LPI

Comprehensive modelling of all critical parameters affecting SRV operation

Kalsi Engineering Conclusions

Opening Analysis

- SRV-3A & -3C minimum opening pressure estimated by analysis
- Minimum opening pressures:

SRV/Opening Pressure	Effective Ramp Angle
3A: Est. >200 psig	~39°
3C: Est. >300–400 psig	~56°
3B: Actual <50 psig	None
3D: Actual <50 psig	~10°

SRV-3A & -3C – Reduced ability at low pressure
SRV-3B & -3D – No loss of capability

Kalsi Engineering Conclusions

Closing Analysis

- Based on design, approximately two times more closing force available than opening force
- Ability to close was not compromised
- As-found conditions identified in Hatch and Browns Ferry 2-stage SRVs that failed to close in-service were evaluated (Ref. IN 2003-01, GE SIL 646, Browns Ferry Licensee Event Report, Hatch and Browns Ferry Root Cause Analysis)
- Pilgrim piston tilting limited by existing thread and shoulder clearances on all SRVs

Closing capability not compromised for any valve

New Information – Summary/Conclusions

- Additional Inspections, Testing, and Modelling/Analyses Support Minimal Loss of SRV Functional Capability
  - CCF
    - Significant physical differences between SRV-3A/-3C and SRV-3B/-3D
    - This explains the performance differences at low pressure
    - SRV-3A & -3C functioned at high pressure
    - Differences should be reflected in the CCF
  - FTC:
    - New data demonstrates failure mode baseline probability is unaffected
    - All SRVs demonstrated closing capability at all pressures
  - FTO:
    - Testing and inspections of SRV-3B & -3D demonstrates failure mode baseline probability is unaffected
    - Both SRVs demonstrated opening capability at all pressures

New information provides best available information for risk assessments

Entergy

PILGRIM PERSPECTIVE ON NRC STAFF BOUNDING ANALYSIS

Dave Noyes

Director, Regulatory & Performance Improvement

Pilgrim Nuclear Power Station

PRA Key Assumptions Comparison and Reconciliation – MLOCA

Run Title	PNPS (CDF)	NRC (CDF)	Factor Difference	Comment
Delta Core Damage Frequency (CDF)	**1.83E-08**	**1.34E-06**	~ 100	Result: 2 orders of magnitude difference
MLOCA Base Case	2.08E-07	1.19E-07	~ 1 **Close agreement**	Similar Success criteria of 1 out of 4 SRV required to open
MLOCA Conditional	2.27E-07	1.46E-06	~ 10 **Large difference in CCF**	NRC CCF = 1.74E-01 PNPS CCF = 1.39E-03 SPAR model kept CCF group of 4 valves PNPS separated CCF group into 2 valves (SRV-3B & -3D)

Major difference is how CCF is treated

Pilgrim Perspective – MLOCA

Run Title	PNPS (CDF)	NRC (CDF)	Factor Difference	Comment
Delta CDF	1.83E-08	**1.34E-06**	~ 100 **Large difference in CCF**	NRC CCF = 1.74E-01 PNPS CCF = 1.39E-03
Delta CDF **(New)**	**1.30E-07**		~ 10	PNPS CCF = **1.0E-02**

- **Not credible to postulate a 1-in-6 chance that all SRV's will fail to open**
  - Valves SRV-3B & -3D opened and closed more than 100 times
  - Disassembly of valves SRV-3B & -3D revealed minimal physical degradation which would not have prevented operation of valves over entire pressure range
  - Given the actual performance of SRV-3B & -3D (operated ~ 100 times), inspection results, and analysis we have assigned a conditional CCF value of 1.0E-02

CCF is overly conservative without consideration of plant-specific information

CCF Sensitivity - MLOCA

- SPAR CCF is 2 orders of magnitude greater than Pilgrim's
  - NRC treats all 4 SRVs as a CCF group of 4; Application of SPAR CCF generates a 1.74E-01 value which assumes loss of function of 2 or more valves (upper bounding condition)
  - Initial Pilgrim PRA analysis treated SRV-3B & -3D as a CCF group of 2 based on actual performance, inspection, and analysis; this generated a 1.39E-03 value (lower bounding condition)
  - Best-available information compels consideration of actual performance
  - Given actual performance of SRV-3B & -3D (operated ~ 100 times), inspection results and analysis we assigned conditional CCF value of 1.0E-02
  - A CCF value of 1.0E-02 is conservative considering the performance of SRV-3B & -3D combined with functionality of SRV-3A & -3C at high pressure
    - SRV-3A & -3C degraded performance only at pressures below risk-significant range
  - **This yields a Pilgrim Delta CDF for all MLOCA events of approximately 1.30E-07**

PRA Key Assumptions Comparison and Reconciliation – Non-MLOCA

Run Title	Pilgrim (CDF)	NRC (CDF)	Factor Difference	Comment
Delta CDF	**3.60E-07 (2X FTO)**	**2.20E-06 (10X FTO & 10X FTC)**	**~ 10**	**2X FTO most appropriate treatment** **No evidence supporting a 10X FTC**
Non MLOCA Base	2.89E-06	2.08E-05	~ 10	SPAR generally more conservative
Conditional (2X FTO)	**3.25E-06**			Conservative application of 2X FTO in accordance with data contained in NUREG/CR-7037 and the methodology for Bayesian updating in NEI 99-02
Conditional (FTO 10X & FTC 10X)	See Comment	**2.30E-05**		Overly conservative – no observed failure mechanism that would tend to increase FTC rate; not realistic to use FTC with 10X multiplier

2X FTO most appropriate and any FTC increase is not credible

Pilgrim Perspective – Non-MLOCA

Run Title	Pilgrim (CDF)	NRC (CDF)	Factor Difference	Comment
Delta CDF	**3.60E-07** **(2X FTO)**	**2.20E-06** **(10X FTO & 10X FTC)**	~ 10	2X FTO most appropriate treatment No evidence supporting a 10X FTC

- **Overly conservative to assume a 10X increase in probability of FTO**
  - Applying a 10X FTO to all SRVs is overly conservative (Note that the resultant FTO probability of 2.77E-02 would predict ~ 3 instances of SRV FTO during event when 100 demands were experienced)
  - Conservative application of 2X FTO in accordance with data contained in NUREG/CR-7037 and the methodology for Bayesian updating in NEI 99-02

- **Not credible to postulate a 10X increase in probability of FTC**
  - RASP Handbook: The expected higher failure probability estimate can be assessed using engineering judgment through expert elicitation; In some cases, the estimate may be derived through prior operating experience of the component
  - No industry history of FTC for valves modified and maintained in accordance with IN and GE SIL
  - Kalsi Engineering review of disassembled SRVs affirmed no projected FTC above nominal probability

Differences due to overly conservative FTO/FTC assumptions

Delta CDF Comparison

Run Title	Pilgrim (CDF)	NRC (CDF)	Factor Difference	Comment
Total Delta	**4.90E-07**	**3.54E-06**	~10	Differences in application of best-available plant-specific information
Delta CDF MLOCA	**1.30E-07**	**1.34E-06**	~10	CCF application difference
Delta CDF Non MLOCA	**3.60E-07**	**2.20E-06**	~10	FTO/FTC application

Differences due to overly conservative assumptions

OPERATIONAL RISK MITIGATING FACTORS

John Macdonald
Senior Manager, Operations
Pilgrim Nuclear Power Station

Operational Risk Mitigating Factors

- EOP-01, RPV Control, provides options for high pressure injection into RPV (High Pressure Coolant Injection [HPCI], Reactor Core Isolation Cooling [RCIC], Feedwater, Control Rod Drive, and Standby Liquid Control)
- EOP-01, RPV Control, provides alternate depressurization systems: HPCI, RCIC, Main Steam line drains, Reactor Water Clean-Up in letdown mode
- Our procedures and training direct operators to initiate emergency depressurization when RPV level approaches top of active fuel versus at the minimum steam cooling reactor water level
- Availability of diverse shutdown methods demonstrated

CONCLUSIONS

Dave Noyes

Director, Regulatory & Performance Improvement

Pilgrim Nuclear Power Station

Conclusions

- **Public health and safety always protected, with margin**
- **Our initial conclusions on risk were based on empirical data regarding performance of the SRVs in the plant**
  - We performed testing, detailed inspections, and expert analysis
  - These validated the experience of the SRVs in the plant
- **Updated plant-specific PRA evaluation provides best available determination of actual risk, based on:**
  - SRV-3B & -3D were distinctly different from SRV-3A & -3C
  - Two SRVs (SRV-3B & -3D) always worked
  - Narrow range of scenarios of concern with operation for SRV-3A & -3C
    - Functional at high pressure
  - Increased FTC probability is not a credible concern for Pilgrim
    - Twice as much closing force
    - Appropriate to remove the 10X factor
  - 2X FTO is appropriate
- **Result: Risk is of very low safety significance**

Appendix M Analysis - Summary

Number	Subject	Pilgrim Position
4.2.1.1	Defense in depth	Other mitigating strategies remained available; alternative pressure control and high pressure injection
4.2.1.2	Reduction in safety margin quantified	**Very small; SRV-3B & -3D remained operable at all times; Increased FTC probability of any valves not credible; 2X FTO is appropriate**
4.2.1.3	Extent of PD impact on other equipment	None
4.2.1.4	Degree of degradation	**2 valves FTO at low pressure below the risk-significant region**
4.2.1.5	Period of fault exposure time	12 months
4.2.1.6	Likelihood of success of licensee's recovery actions	Other mitigating strategies remained available; alternative pressure control and high pressure injection

CLOSING COMMENTS

John Dent

Site Vice President

Pilgrim Nuclear Power Station

QUESTIONS AND DISCUSSION