# Bundle Risk Based Inspection Assessment Using API 581 Case Study

by

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and

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# Presenters

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# Presentation Overview

Introduction

API 581 Document Status

Heat Exchanger Bundle RBI Methodology

- Probability of Failure
- Impact of Inspection (Inspection Effectiveness)
- Consequence of Failure
- Risk Analysis and Inspection Planning

Crude Unit Case Study

- Crude Overhead/Raw Crude Exchangers
- FCC Slurry/Desalted Crude Exchangers
- Kerosene Product Cooler

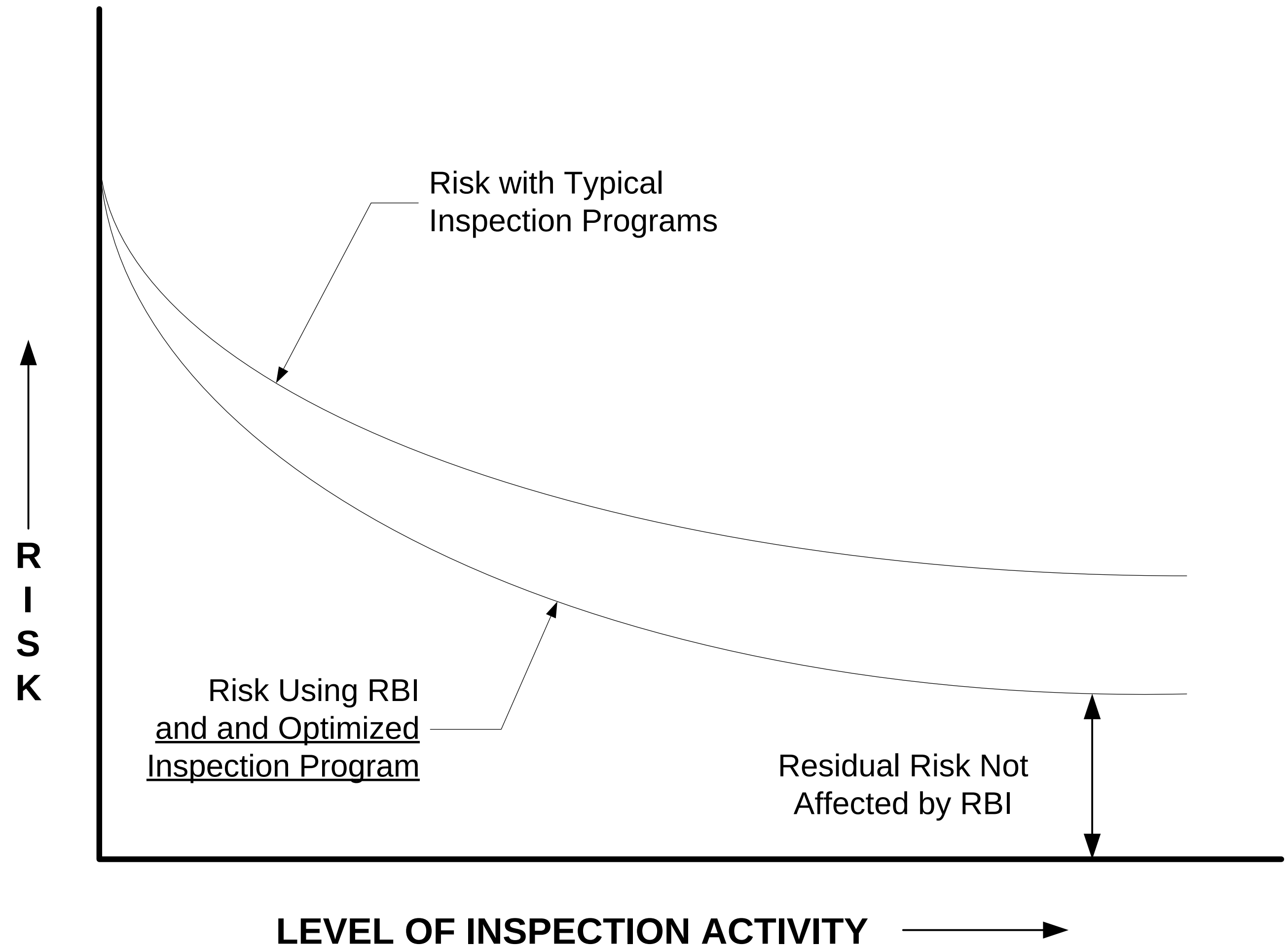
Lessons Learned

Summary

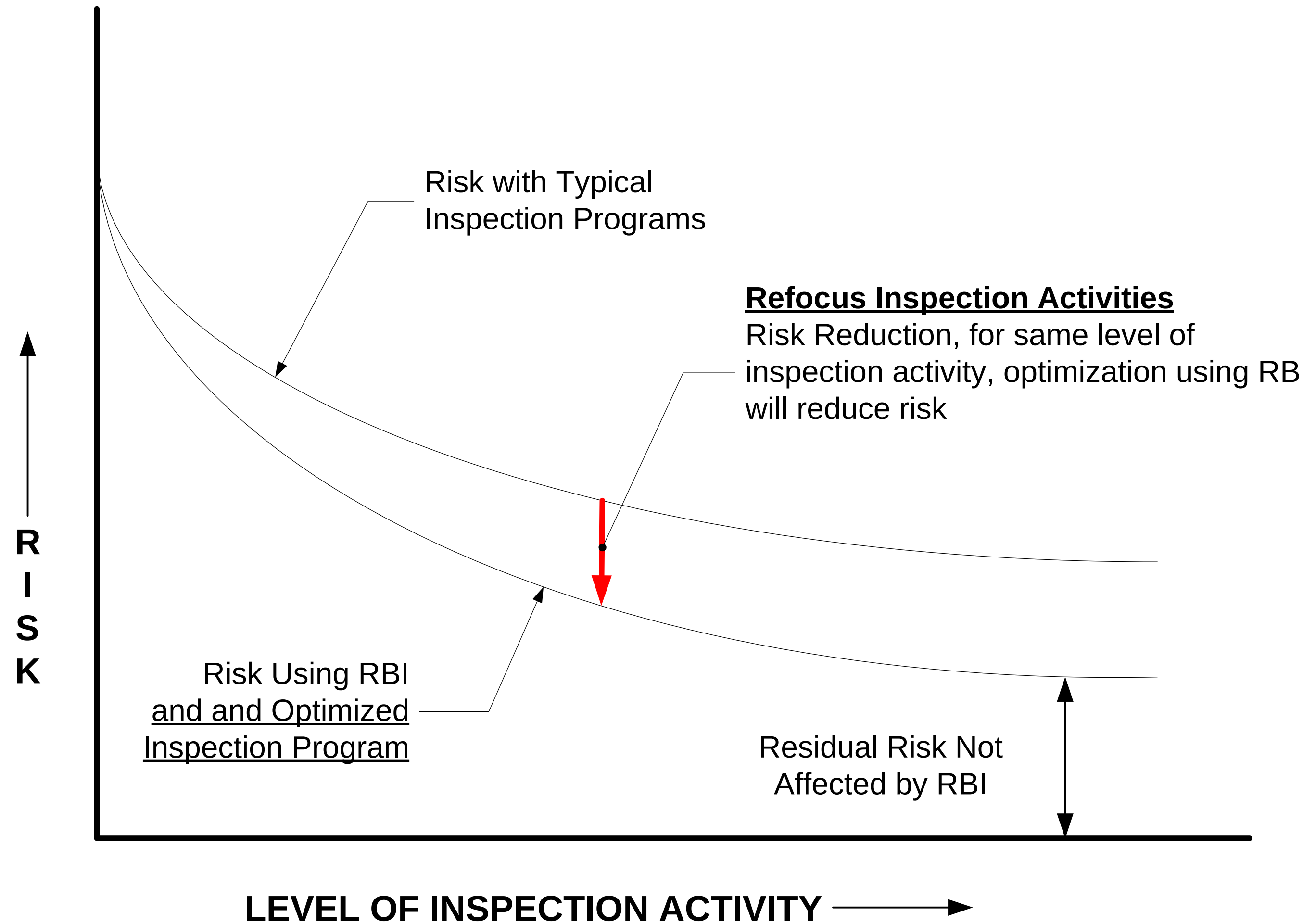
# Introduction

- The API Risk-Based Inspection (API RBI) methodology may be used to manage the overall risk of a plant by focusing inspection efforts on the equipment with the highest risk
- API RBI provides the basis for making informed decisions on inspection frequency, the extent of inspection, and the most suitable type of Non-Destructive Examination (NDE)
- In most processing plants, a large percent of the total unit risk will be concentrated in a relatively small percent of the equipment items
- These potential high-risk components may require greater attention, perhaps through a revised inspection plan
- The cost of increased inspection effort may sometimes be offset by reducing excessive inspection efforts in the areas identified as having lower risk

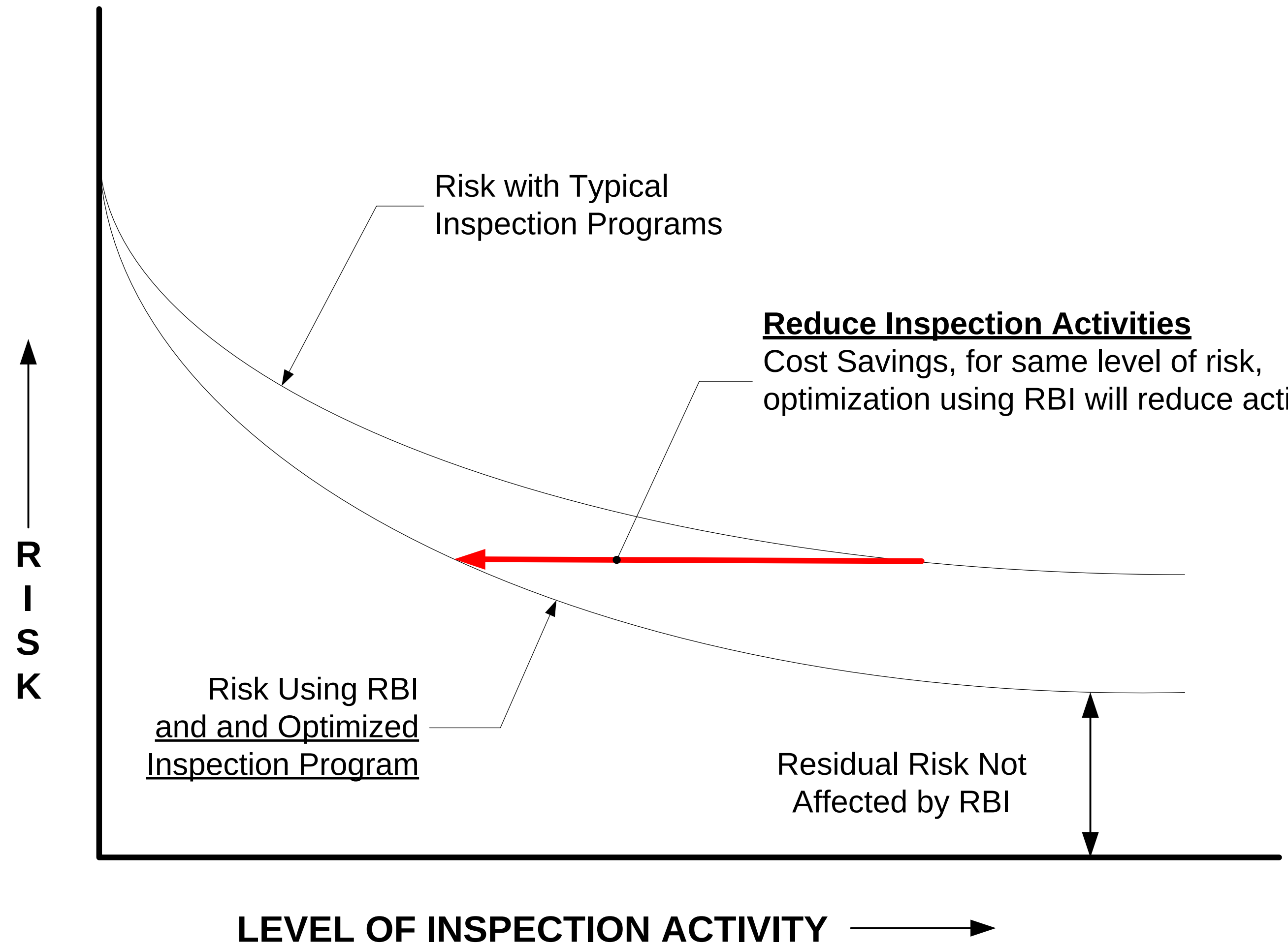
# Introduction



# Introduction



# Introduction



# API RBI Document Status

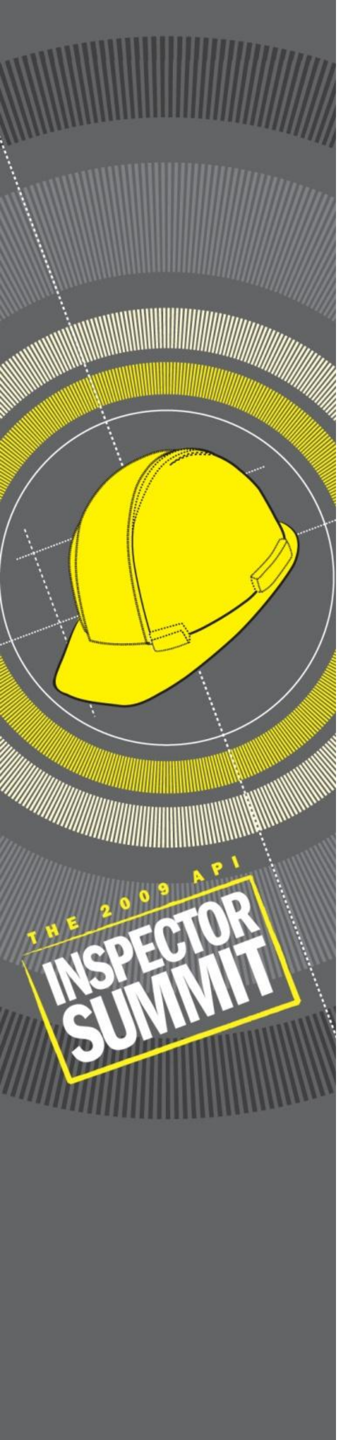
- API RBI was initiated as a Joint Industry Project in 1992, two publications produced
  - API 580 *Risk-Based Inspection* (2nd Edition May, 2002)
    - Introduces the principles and presents minimum general guidelines for RBI
    - 3rd Edition targeted for late 2008
  - API 581 *Base Resource Document – Risk-Based Inspection* (1st Edition May, 2000)
    - Provides quantitative RBI methods for inspection planning
- API 581 *API RBI Technology* (2nd Edition published September, 2008) significantly revised to a new three part document
  - Part 1: Inspection Planning Using API RBI Technology
  - Part 2: Determination of Probability of Failure in an API RBI Assessment
  - Part 3: Consequence Analysis in an API RBI Assessment

# API RBI Document Status

- Part 1 - Inspection Planning Using API RBI Technology
  - Calculation of Risk as a combination of POF and COF
  - Inspection Planning using time stamping
  - Presentation of results, Risk Matrix (area and financial) – introduce user specified POF and COF category ranges
  - Risk Calculations for Vessels, Piping, Tanks, Bundles and PRDs
- Part 2 - Determination of Probability of Failure in an API RBI Assessment
  - POF calculation
  - Part 2, Annex A - Management Score Audit Tool
  - Part 2, Annex B - Corrosion Rate Determination
- Part 3 - Consequence Modeling in API RBI
  - COF calculation
    - Level 1 modeler with step-by-step “canned” procedure
    - Level 2 modeler providing rigorous procedure
    - Tank model consequence calculation

# API RBI Document Status

- Major improvements in API RP 581 2nd Edition
  - Step-by-Step procedures similar of API 579-1/ASME FFS-1 2007 *Fitness-For-Service* and ASME Section VIII, Div 2, 2007 to demonstrate the technology, to fully illustrate calculation procedures, and to stimulate peer review
  - Focus is now on inspection planning, concept of time-based risk provided, algorithm for inspection planning utilizing user specified risk targets
  - Improved damage calculations, introduction of $t_{min}$ calculation
  - Multi-level consequence models
  - Inclusion of RBI models for atmospheric tanks, heat exchanger bundles and pressure relief devices




# Heat Exchanger Bundle RBI Methodology

- Bundle failure definition – Tube Leak
- Condition based inspection programs
  - Are limited since failure data for a particular bundle usually does not exist
  - Not enough data to be statistically significant
- API RBI relies on failure database with matching criteria to obtain statistical "cut-set"
- Probability of Failure (POF) as a function of time is determined as follows:
  - Specific bundle failure history, if enough data to determine MTTF or Weibull parameters
  - Filtering on Local and Corporate Failure Libraries to obtain Weibull curve of matching bundles (Weibayes analysis)

# Heat Exchanger Bundle RBI Methodology

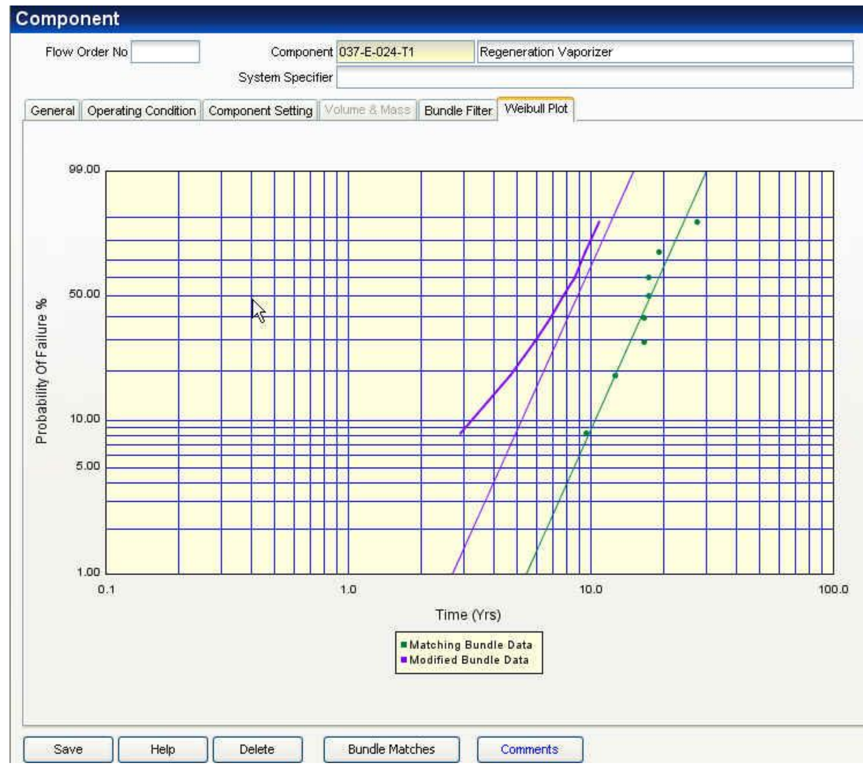
**Matching Bundles**

| # | Component | Component Description | Exchanger ... | TEMA Type | Shell Side Fluid Category | Shellside Proc |
|---|---|---|---|---|---|---|
| 1 | 037-E-024-T1 | Regeneration Vaporizer | Vaporizer | BKU | Olefins (Propylene/Butyle | Selective Hydrogenatior |
| 2 | 014-E-053-T2 | Propane Vaporizer | Vaporizer | AEU | LPG (Propane/Butane) | Cumene |
| 3 | 041-E-021A-T1 | Propane Dryer Regenerator | Vaporizer | Brown Fintube | LPG (Propane/Butane) | Sat Gas Plant |
| 4 | 041-E-021A-T2 | Propane Dryer Regenerator | Vaporizer | Brown Fintube | LPG (Propane/Butane) | Sat Gas Plant |
| 5 | 041-E-021A-T3 | Propane Dryer Regenerator | Vaporizer | Brown Fintube | LPG (Propane/Butane) | Sat Gas Plant |
| 6 | 041-E-021B-T1 | Propane Dryer Regenerator | Vaporizer | Brown Fintube | LPG (Propane/Butane) | Sat Gas Plant |
| 7 | 041-E-021B-T2 | Propane Dryer Regenerator | Vaporizer | Brown Fintube | LPG (Propane/Butane) | Sat Gas Plant |
| 8 | 041-E-021B-T3 | Propane Dryer Regenerator | Vaporizer | Brown Fintube | LPG (Propane/Butane) | Sat Gas Plant |
| 9 | 041-E-021C-T1 | Propane Dryer Regenerator | Vaporizer | Brown Fintube | LPG (Propane/Butane) | Sat Gas Plant |
| 10 | 041-E-021C-T2 | Propane Dryer Regenerator | Vaporizer | Brown Fintube | LPG (Propane/Butane) | Sat Gas Plant |
| 11 | 041-E-021C-T3 | Propane Dryer Regenerator | Vaporizer | Brown Fintube | LPG (Propane/Butane) | Sat Gas Plant |
| 12 | 041-E-021D-T1 | Propane Dryer Regenerator | Vaporizer | Brown Fintube | LPG (Propane/Butane) | Sat Gas Plant |
| 13 | 041-E-021D-T2 | Propane Dryer Regenerator | Vaporizer | Brown Fintube | LPG (Propane/Butane) | Sat Gas Plant |
| 14 | 041-E-021D-T3 | Propane Dryer Regenerator | Vaporizer | Brown Fintube | LPG (Propane/Butane) | Sat Gas Plant |

- Obtain a matching set of bundles by filtering on failure libraries
  - Exchanger Type
  - TEMA Type
  - Tube Metallurgy
  - TS and SS Fluid Categories
  - Operating conditions, Temps, Pressures, Velocities, etc.
  - Process Unit
  - Controlling Damage Mechanism
  - Fluid Damage Modifiers ($H_2S$, Sulfidation, Caustic, etc.)
  - Many, many others

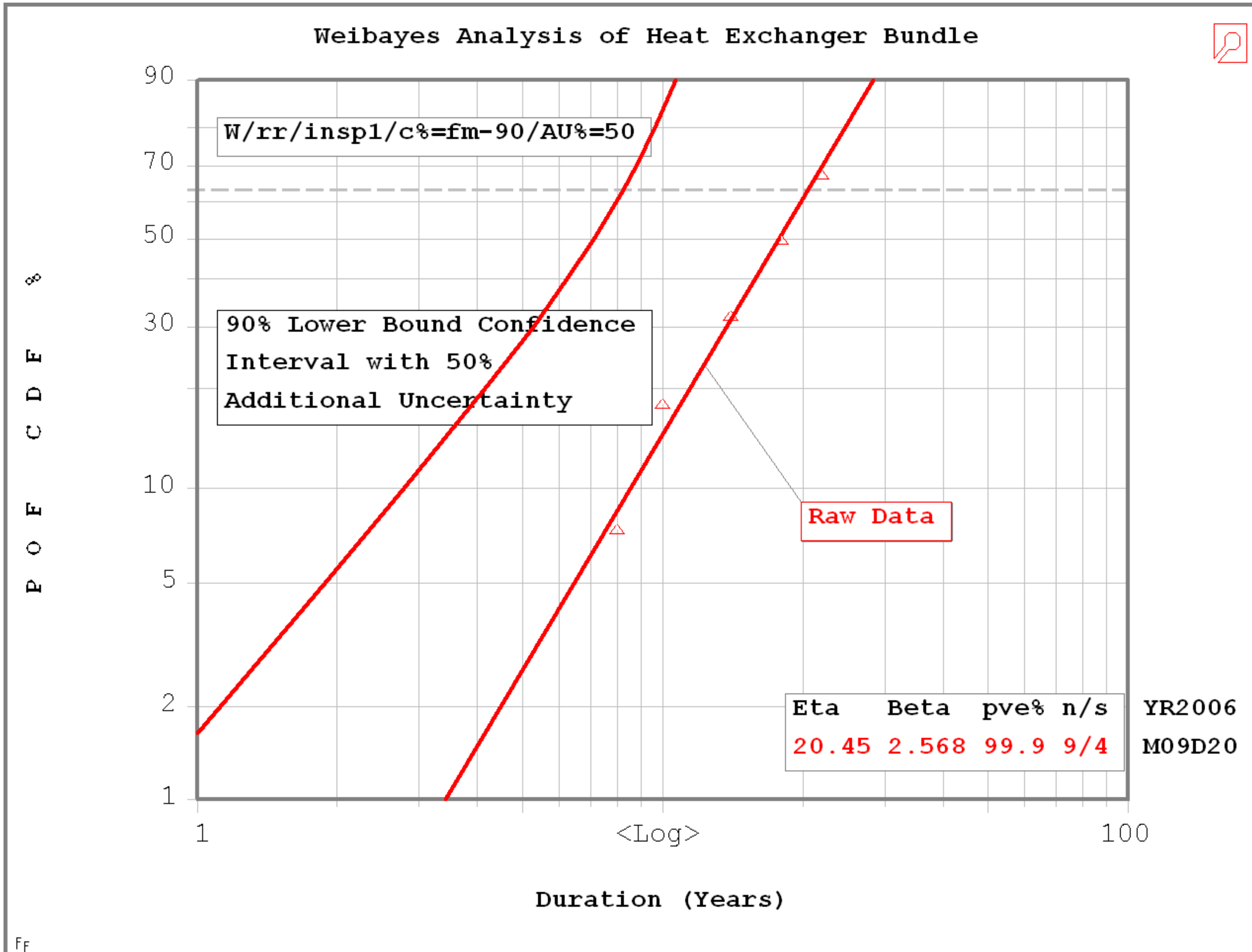
# Heat Exchanger Bundle RBI Methodology

- Weibull plot based on filtered set of similar bundles
  - Goodness of fit test
  - If poor fit, redo filter/cut set
  - Ability to review matching bundle set
  - Eliminate outlier bundles as necessary to make the fit more appropriate
  - Inspection History effects amount of uncertainty (shift to the left)

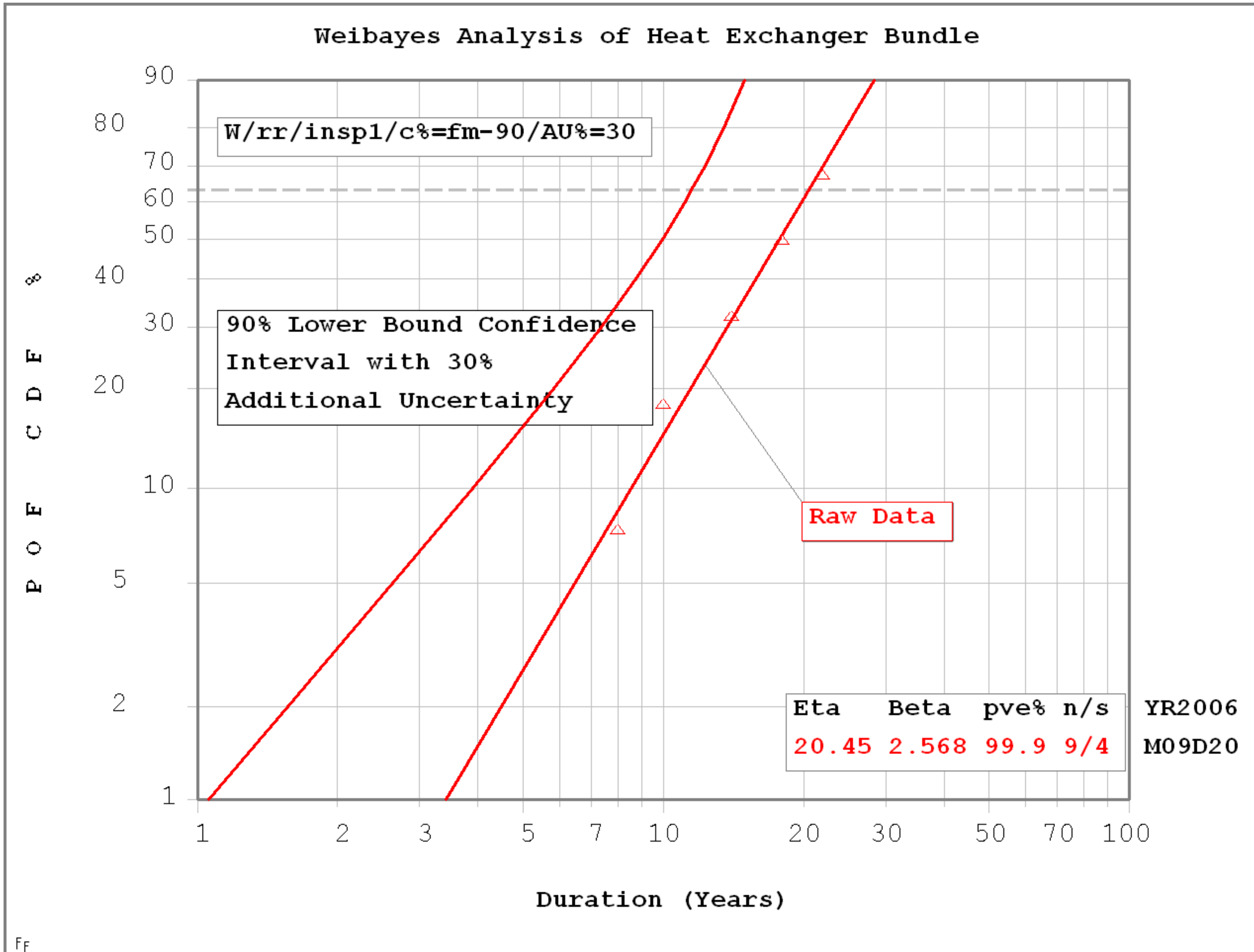


# Heat Exchanger Bundle RBI Methodology

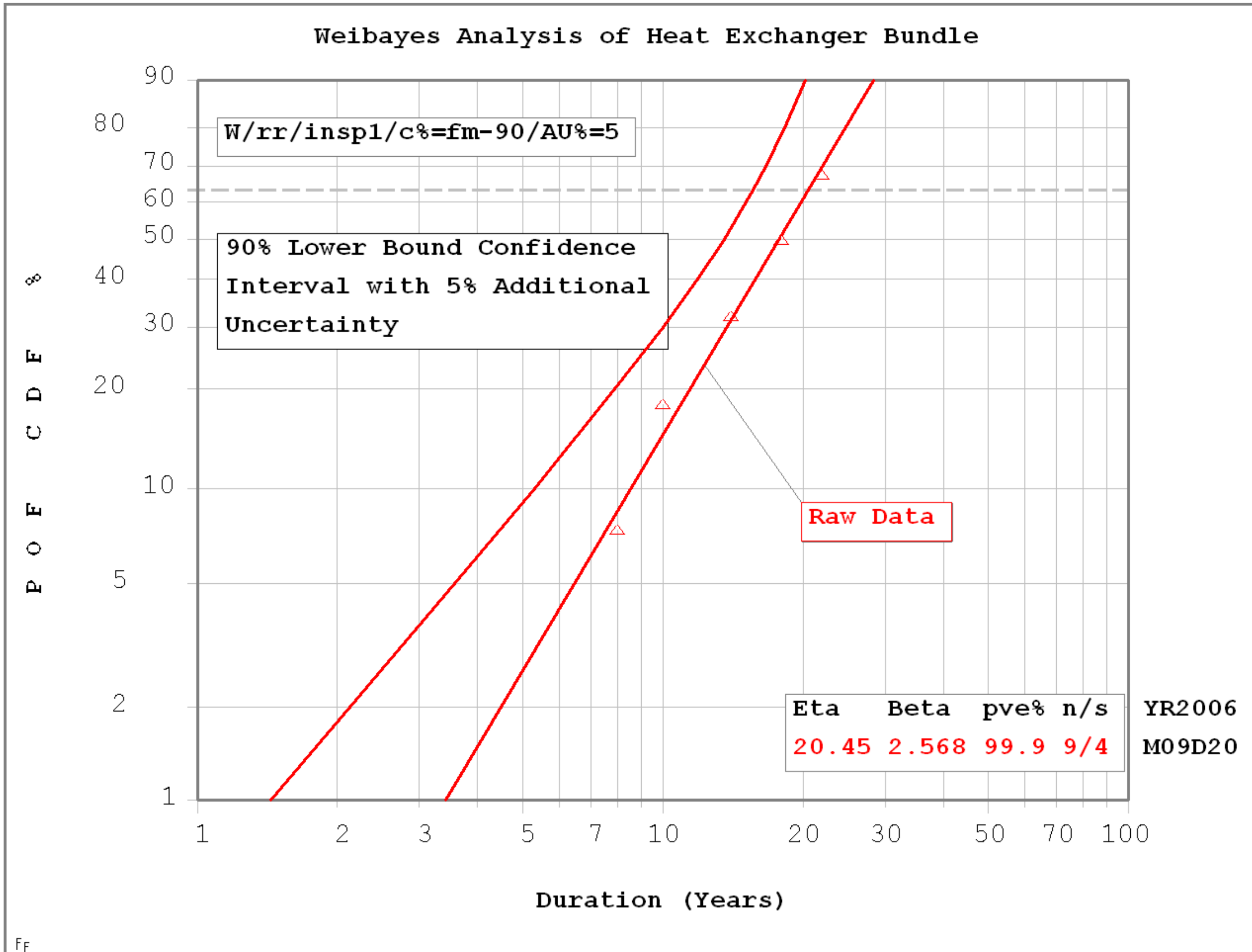
- Inspection effectiveness
- Use uncertainty on Weibull plot based on level of inspection
- Better inspections reduce uncertainty, shifting Weibull curve to the right
  - An inspection provides two things:
    - Reduction in uncertainty resulting in the use of a different failure rate curve, e.g. moving from a 50% AU curve (no inspection history) to a curve 5% AU curve (Highly Effective Inspection)
    - Knowledge of the actual condition of the bundle; this may result in a shift of the raw data failure rate curve to the right or to the left. The current condition of the bundle could either be quantified by remaining wall thickness data or by an estimate of the remaining life.



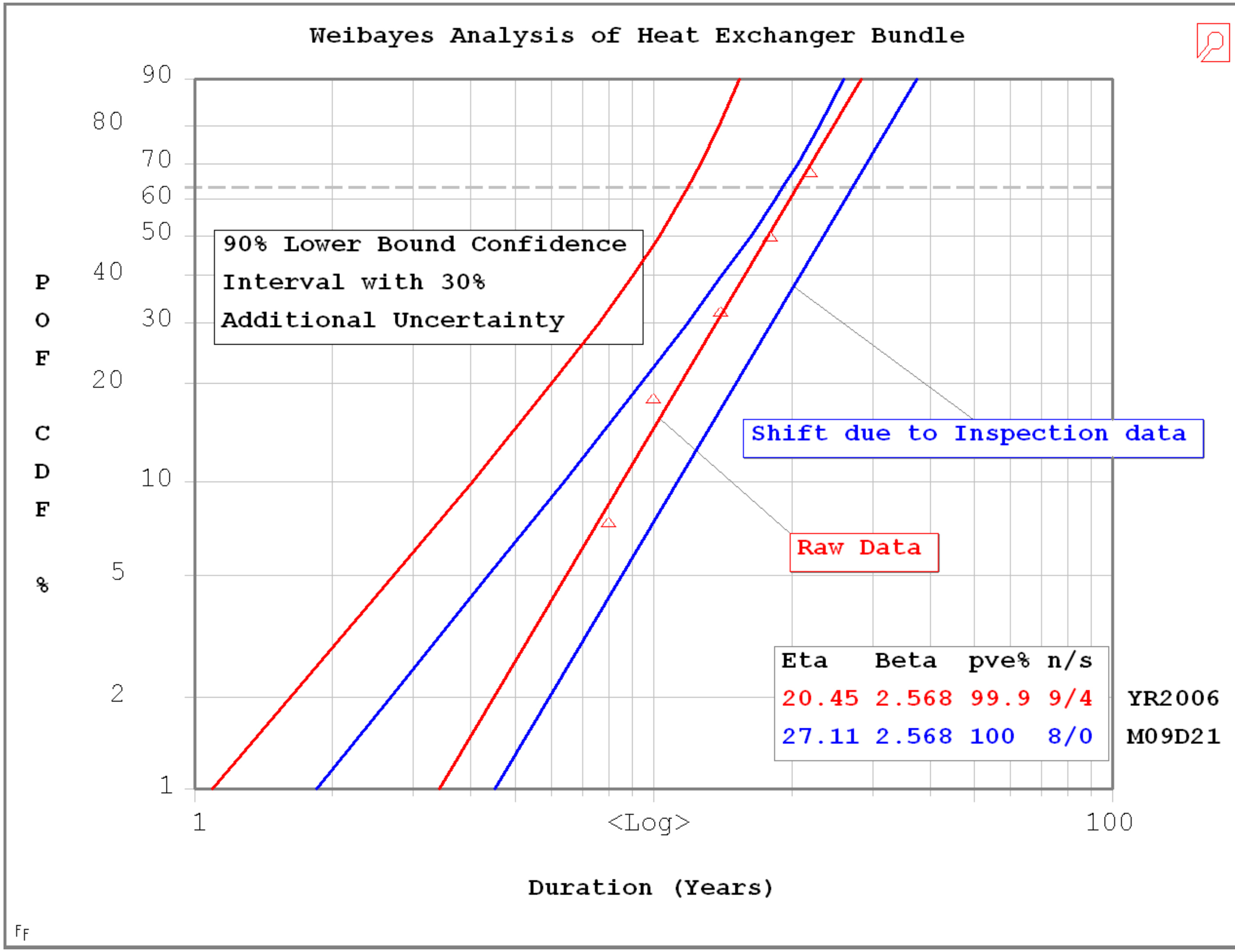
Weibayes Analysis of Heat Exchanger Bundle
W/rr/insp1/c%=fm-90/AU%=50
90% Lower Bound Confidence
Interval with 50%
Additional Uncertainty
Raw Data
Eta Beta pve% n/s
20.45 2.568 99.9 9/4
YR2006
M09D20
POF CDF %
90
70
50
30
10
5
2
1
1
<Log>
100
Duration (Years)



Weibayes Analysis of Heat Exchanger Bundle
W/rr/insp1/c%=fm-90/AU%=30
90% Lower Bound Confidence
Interval with 30%
Additional Uncertainty
Raw Data
POF CDF %
Duration (Years)
Eta Beta pve% n/s
20.45 2.568 99.9 9/4
YR2006
M09D20



Weibayes Analysis of Heat Exchanger Bundle
W/rr/insp1/c%=fm-90/AU%=5
90% Lower Bound Confidence Interval with 5% Additional Uncertainty
Raw Data
P O F C D F %
90
80
70
60
50
40
30
20
10
5
2
1
1
2
3
5
7
10
20
30
50
70
100
Duration (Years)
Eta Beta pve% n/s
20.45 2.568 99.9 9/4
YR2006
M09D20


Weibayes Analysis of Heat Exchanger Bundle
90
80
70
60
50
40
30
20
10
5
2
1
P O F C D F %
90% Lower Bound Confidence
Interval with 30%
Additional Uncertainty
Shift due to Inspection data
Raw Data
Eta Beta pve% n/s
20.45 2.568 99.9 9/4
27.11 2.568 100 8/0
YR2006
M09D21
1
<Log>
100
Duration (Years)

# Heat Exchanger Bundle RBI Methodology

- Consequence of Failure (COF)
  - Lost Production
  - Maintenance and Inspection Costs
  - Environmental Cost (e.g leaks to cooling tower)

$$COF = Cost_{prod} \times \frac{Rate_{red}}{100} \times Sddays + Cost_{env} + Cost_{sd}$$

# Heat Exchanger Bundle RBI Methodology

- Bundle inspection planning involves recommending the level of inspection required to reduce risk to an acceptable value at the plan date
- Inspection effectiveness is graded A through E, with A providing the greatest certainty of finding damage mechanisms that are active

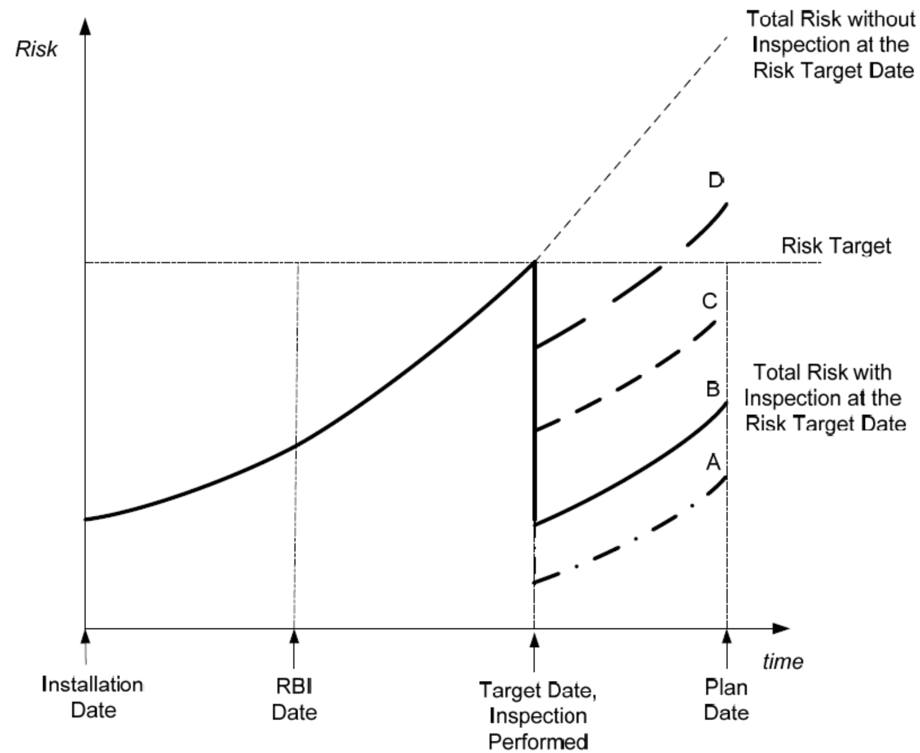



**Figure 7 – Case 1: Inspection Planning When the Risk Target is Exceeded Between the RBI Date and the Plan Date**

# Heat Exchanger Bundle RBI Methodology

- For many applications, the user's risk target has already been exceeded at the time the RBI analysis is performed
- Inspection is recommended immediately

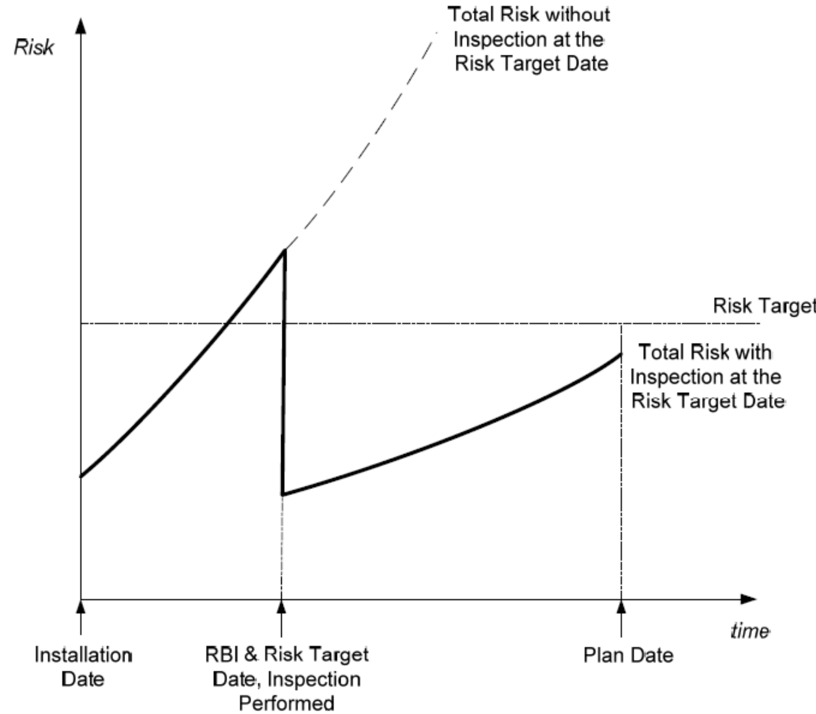



Figure 8 – Case 2: Inspection Planning When the Risk Target has been Exceeded Prior to the RBI Date

# Heat Exchanger Bundle RBI Methodology

- When the risk is determined to be acceptable at the plan date, inspection is not required

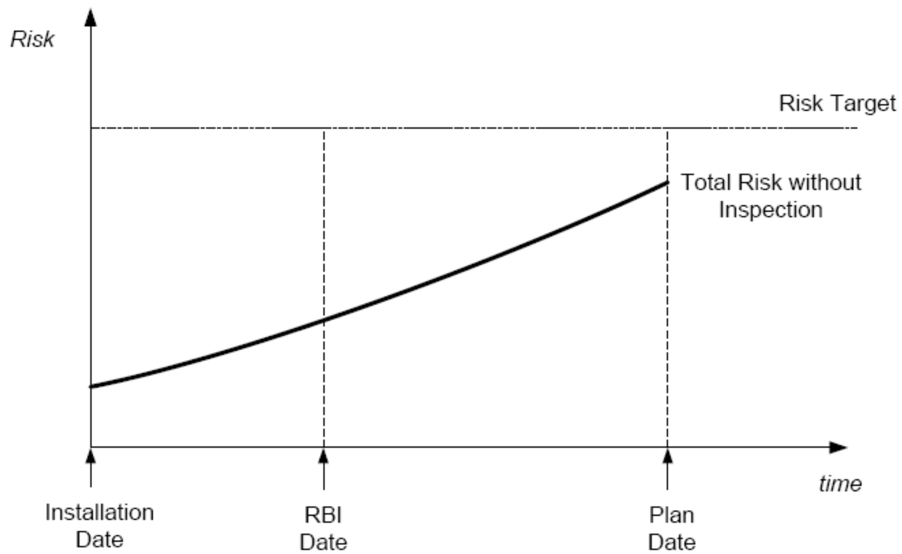
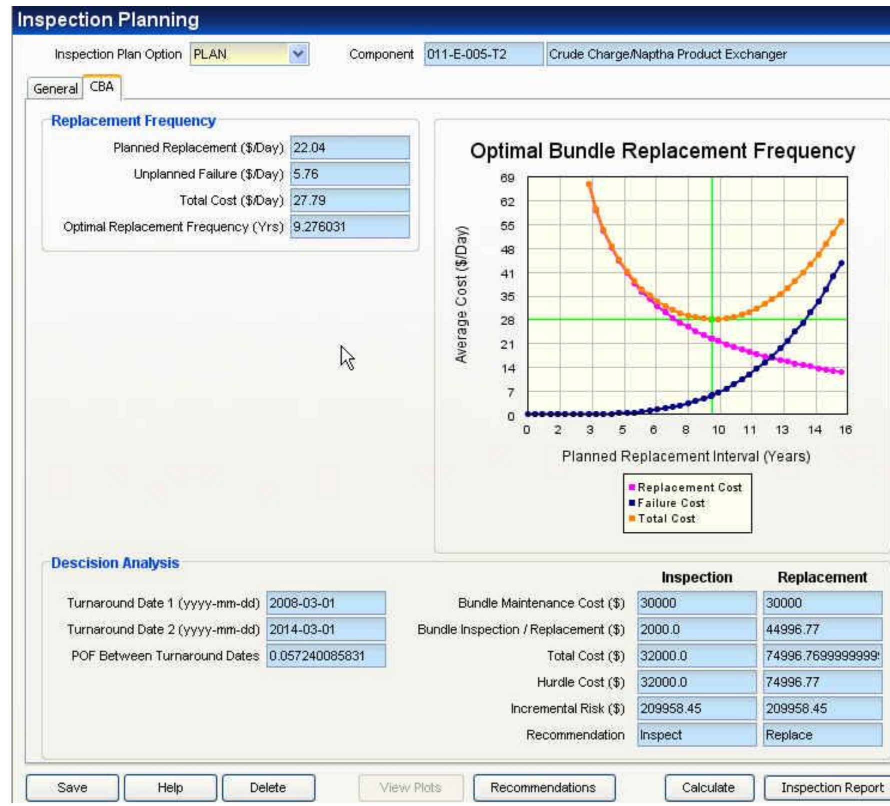



**Figure 9 – Case 3: Inspection Planning When Risk Target is Not Exceeded Prior to the Plan Date**

# Heat Exchanger Bundle RBI Methodology

- Cost benefit analysis
  - Provides economic basis for inspection and replacement decisions
  - Calculates the optimal bundle replacement frequency by comparing bundle replacement costs to costs associated with unplanned failures
  - Determines probability of failure at next turnaround given no failure at current turnaround



# Crude Unit – Case Study

- ConocoPhillips Lake Charles Refinery
- CoP Heat Exchanger Reliability Program Charter
  - Develop, implement and maintain system and methods to monitor, track and improve heat exchanger reliability
  - Use reliability and statistical methods as well as "Life Cycle" cost assessments in inspection, repair and replacement decisions
  - Implement API RBI new bundle module
  - Include fouling data??
  - Revise Mechanical Integrity program to assure that program remains evergreen

# Crude Unit – Case Study

- ConocoPhillips Lake Charles Refinery
- Crude Unit
  - Processes 56.5 MBPD of sweet crude
- RBI Analysis Conducted in 2008
  - 30 exchanger bundles
    - 6 Crude Overhead (4 CW, 2 Raw Crude)
    - 3 Raw Crude Preheat
    - 12 Desalted Crude Preheat
    - 5 Product Coolers
    - 4 Miscellaneous (Desalter water, Jacket water coolers)

# Crude Unit – Case Study

- Risk Target
  - Difficult to arrive at value to use
  - Calibration tool on model
  - Used one day's production losses as initial starting point for analysis
- Cost Benefit Analysis
  - Compared cost of inspection and replacement to reduction in risk
  - Hurdle rate of 100% used for decision to act
- Inspection Effectiveness
  - API 581 currently provides no guidelines
  - Concentrated on general corrosion mechanisms
  - Following table used in analysis

## Effectiveness Of Inspection for Exchanger Tubes

| Inspection Effectiveness Category | **Cracking**<br><br>**For Susceptible Tube Bundles:** | **ID & OD Corrosion / Erosion**<br><br>**For Susceptible Tube Bundles:** |
|---|---|---|
| A | 25 - 50 % ET or RFET<br>and 100% visual inspection of tubes | 25 - 50% ET or RFET<br>and 100% visual inspection of tubes<br><br>**OR**<br><br>25 - 50% IRIS UT<br>and 100% visual inspection of tubes |
| B | 10 – 24% ET or RFET<br>and 100% visual inspection of tubes | 100% visual inspection of tubes with 25% of the tubes callipered on both ID & OD |
| C | 5 – 9% ET or RFET<br>and 100% visual inspection of tubes | 100% visual inspection of tubes with 10% of the tubes callipered on both ID & OD |
| D | None | None |
| E | None | None |

**Assumptions:**

- All inspections are done with the required access to the tubes.
- Susceptible tube bundles are those bundles suspect as having the applicable damage mechanism as defined by knowledgeable persons.
- Tube bundles are cleaned, free of scale, deposits, pluggage or debris and allow appropriate probes to enter the tubes freely without resistance. Cleaning for IRIS testing is considerably more robust and is also critical to satisfactory performance.
- Carbon Steel tube bundles in cooling water service with no coating on the water side should have two or more tube samples removed for corrosion analysis, regardless of which inspections done.

# Crude Unit – Case Study

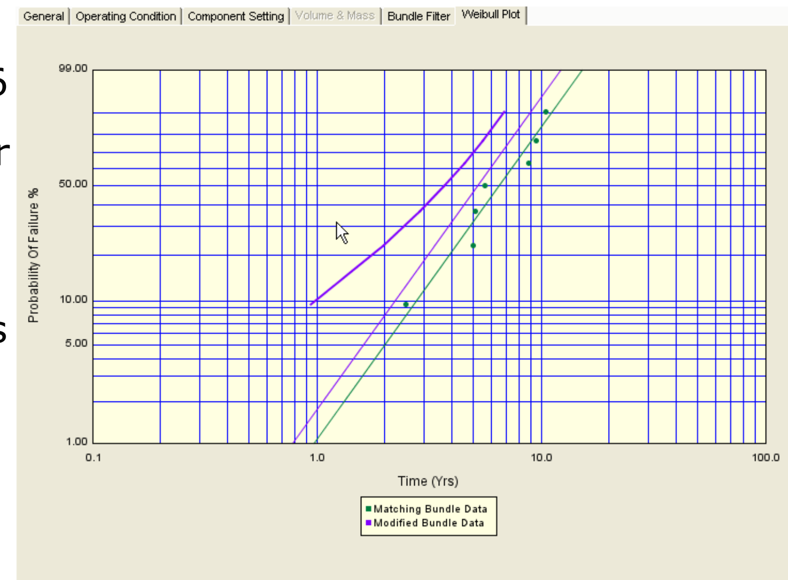
- Consequence Factors
  - Most exchangers could be bypassed without shutting down, crude rate reductions between 15% to 30% of capacity
  - CROH versus raw crude required total shutdown
  - 5 day turnaround time typical to isolate remove, repair, re-install and start-up unit (oil to oil)
  - Assumed $400,000/day production costs
  - Default value of $25,000 for maintenance

# Crude Unit – Case Study

- Summary of Results
  - Crude unit bundles present extraordinary risk due to production losses incurred to repair leaks
  - RBI used to improve reliability
  - Many exchanger inspection intervals governed by fouling
  - Recommendations to inspect 16 of 30 bundles
  - Target high risk bundles using RFEC or IRIS inspection techniques (A and B levels of inspection)
  - Cost benefit analysis (CBA) justifies increased inspection, more frequent bundle replacement, as well as upgrades in metallurgy

# Crude Unit – Case Study

- Crude Overhead/Raw Crude Exchangers
  - Original Installations 1978
  - 2 exchangers, current bundles new in 1991, 1996
  - CS tubes, 40 inch diameter x 16 foot long
  - Past inspection history showed 7 previous bundles failures, ranging from 2.5 to 10.5 years
  - Failure mechanism, OD corrosion/erosion  and pitting
  - Weibull parameters, $\beta$=2.2, $\eta$=7.7 (MTTF=6.8 years)

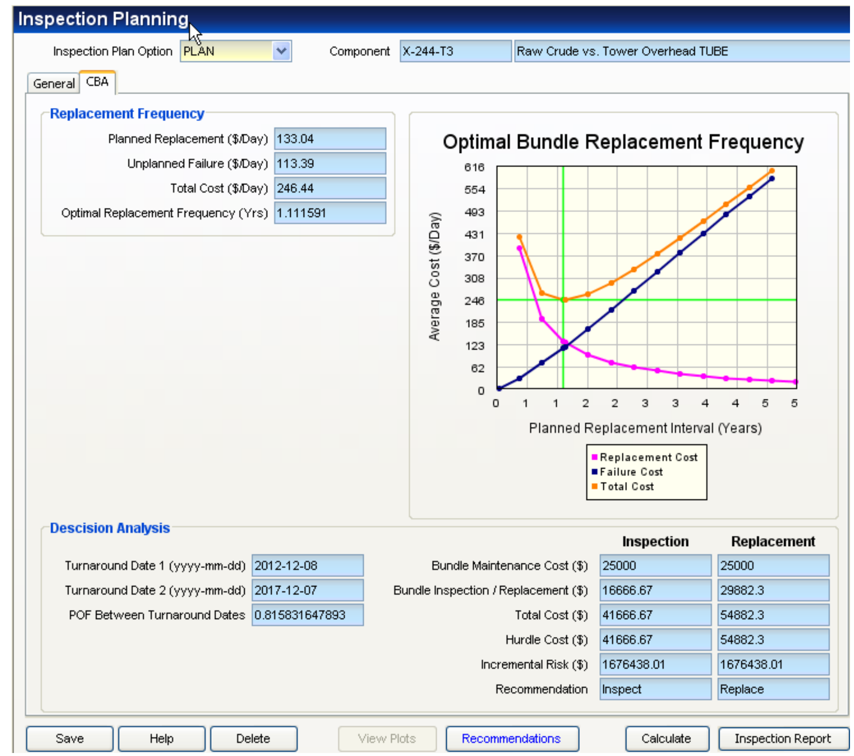


# Crude Unit – Case Study

- Crude Overhead/Raw Crude Exchangers
  - Exchangers could not be bypassed
  - Requires total shutdown for 5 days to repair
  - Exchangers require cleaning every shutdown
  - Consequence of Failure = $2.1 MM
  - Target POF with a risk target of $400,000 is 0.19
  - Both exchangers had previously plugged tubes in 1999 and 2004 shutdown (8 years in-service), previous inspection only included visual with random UT or Elliot gauging ("C" level inspection)
  - Calculated POF at RBI date (12/2008)
    - X-243 (installed 03/1996) =0.98
    - X-244 (installed 11/1991) =0.999
  - RBI recommended "A" level inspection for 2009 TA

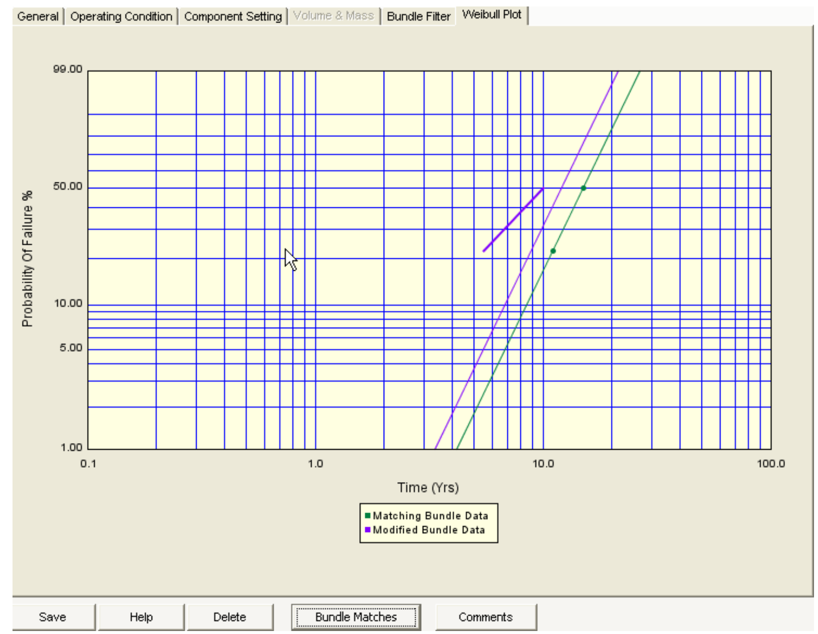
# Crude Unit – Case Study

- Crude Overhead/Raw Crude Exchangers
  - Cost Benefit Analysis (CBA)
    - Inspection Cost = $42,000
    - Replacement Cost = $55,000
    - Incremental Risk = $1.67 MM
    - CBA ratio for inspection action is 20, for replacement action is 15.5
    - Optimal Bundle Replacement Frequency = 1.1 years
    - Candidate for upgraded metallurgy?



# Crude Unit – Case Study

- FCC Slurry/Desalted Crude Exchangers
  - 3 exchangers
  - 1 original installation 1978, 2 installed 1991
  - Current bundles new in 5/81 and 11/99 (2)
  - 5 Cr tubes, 44 inch diameter x 16 foot long
  - Past inspection history, 2 previous bundle failures at 11 and 15 years
  - Failure mechanism, tube bowing and pulling out of tubesheet (plugging)
  - Weibull parameters, $\beta=3.3$, $\eta=16.9$ (MTTF=15.1 years)



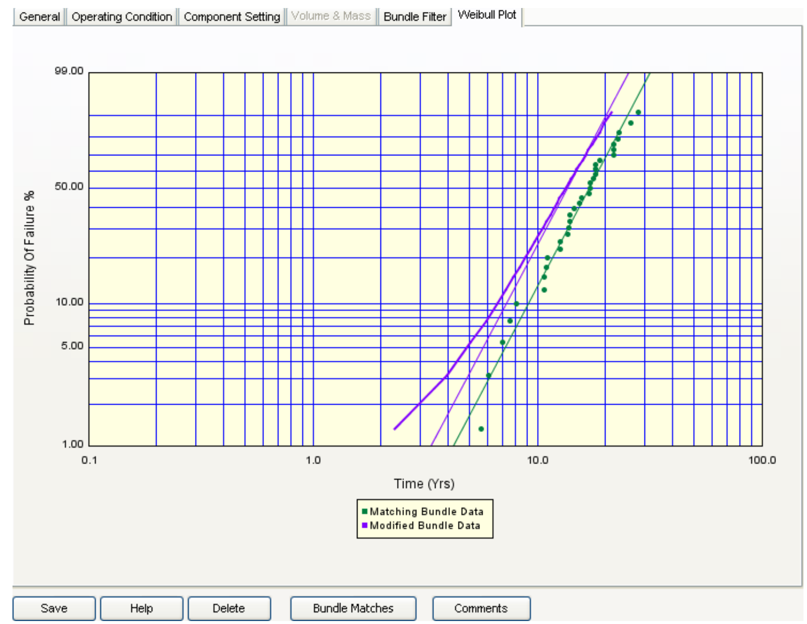
# Crude Unit – Case Study

- FCC Slurry/Desalted Crude Exchangers
  - Exchangers could be bypassed with 30% reduction in crude unit rates
  - Requires 5 days to repair
  - Exchangers requires cleaning during runs, approximately every 2 to 3 years
  - Consequence of Failure = $740,000
  - Target POF with a risk target of $400,000 is 0.54
  - Previous inspections only included visual with Random UT and Elliot gauging ("C" level inspection), revealed little if any wall loss, shifted Weibull curve to the right
  - Calculated POF at RBI date (12/2008)
    - X-247 (installed 11/1999) =0.01
    - X-248 (installed 11/1999) =0.02
    - X-249 (installed 05/1981) =0.33
  - RBI recommended no inspection based on risk target
  - However, CBA ratio for inspection action is 2 to 3

# Crude Unit – Case Study

- Diesel Product Cooler
  - Original installation 1951
  - Current bundle new in 06/2001
  - CS tubes, 32 inch diameter x 16 foot long
  - Past inspection history showed switch from Admiralty to CS in 1989 (CS lasted ≈11 years)
  - Failure mechanism, corrosion
  - Used Failure database and found 67 bundle matches
  - Weibull parameters, $\beta=3.0$, $\eta=19.2$

    (MTTF=17.2 years)



# Crude Unit – Case Study

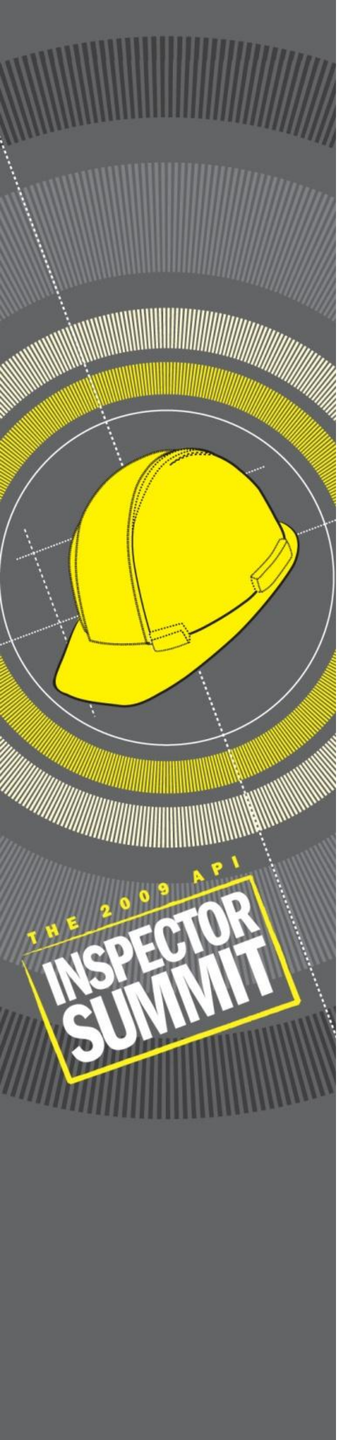
- Diesel Product Cooler
  - Exchanger could be bypassed with 30% reduction in crude unit rates
  - Requires 5 days to repair
  - Consequence of Failure = $620,000
  - Target POF with a risk target of $400,000 is 0.64
  - One previous inspection in 2004 only included visual with Random UT and Elliot gauging (“C” level inspection), revealed little if any wall loss
  - Calculated POF was at RBI date (12/2008) was 0.078
  - Calculated POF was at future TA date (12/2017) was 0.68
  - RBI recommended “B” level inspection based on risk target
  - CBA ratio for inspection action is 3.5

# Lessons Learned

- Bundles that cannot be bypassed on units with high production margins will require much more rigorous inspection to improve unit reliability Exchanger could be bypassed with 30% reduction in crude unit rates
- Initial response of users of methodology may be negative based on increased amount of inspection and replacement recommendations
- Analysis results need to be reviewed by the RBI team to make sure recommendations pass the common sense test
- Need to consider fouling cleaning frequencies
- Make sure statistical failure distribution for bundle being evaluated is specific to governing damage mechanism

# Summary

- The bundles recommended for inspection using API RBI approach matched the common sense "gut feel" inspection currently in place Initial response of users of methodology may be negative based on increased amount of inspection and replacement recommendations
- However, the API RBI method for bundles provides the justification needed to increase the extent and level of sophistication of the inspection techniques being used
- The API method can be used to provide economic based decisions on bundle replacement frequency and metallurgical upgrades
- The API RBI Method is used properly will assist in making true "Life Cycle" decisions, reliability will be increased, unplanned shutdowns will be reduced




# Questions??

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