An update on Risk Based Inspection: Bringing focus on external corrosion under insulation, stress corrosion cracking and other damage mechanisms

October 19, 2012

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Presentation agenda

Introduction - Risk Based Inspection (RBI)
- Work steps for developing an RBI program
  - Data collection including:
    - Equipment and inspection history review
    - Process study
    - Field verification
    - Design data
  - Corrosion study - identifying damage mechanisms
  - Criticality analysis
  - Prioritized inspection planning
- Focus - CUI and cracking damage mechanisms
- The RBMI project at Port Neches
- KPI’s and measurable metrics
- Significant findings
- Conclusions and path forward
What is RBI?

Risk Based Inspection (RBI) is “a risk assessment and management process that is focused on loss of containment of pressurized equipment in processing facilities, due to material deterioration. These risks are managed primarily through equipment inspection.”

API RECOMMENDED PRACTICE 580
SECOND EDITION, NOVEMBER 2009
What Risk are We Discussing?

As is presented in the RBMI Introduction of Basic Training, the risk that is managed through Risk Based Inspection is a subset of the overall risk associated with a piece of equipment. There are many items not considered such as improper design, operating outside of “integrity operating windows”, IOW, or even items that mitigate risk such as deluge systems, or automatic shutdowns.

The risk managed through RBMI is the risk associated with loss of containment through inspectable causes.
The Risk Definition

Probability of Failure \(\times\) Consequence of Failure

- Equipment Type
- Deterioration of the Equipment
- Uncertainty in the Equipment Condition
- Loss of Containment
- Process Safety
- Environmental Impact
- Production Loss
- Maintenance Costs

\[ \text{Risk} = \text{Impact (\$) per Year} \]
Criticality Rating Matrix

Risk can be shown as a number in dollars per year or as a point on an XY plot with probability and consequence axes, or a location on a two dimensional matrix.

Consequence Ranking

A - Catastrophic
B - Very Serious
C - Serious
D - Significant
E - Minor

Probability Ranking

1 - Very High
2 - High
3 - Moderate
4 - Low
5 - Very Low

Risk can be shown as a number in dollars per year or as a point on an XY plot with probability and consequence axes, or a location on a two dimensional matrix.
Creating the Cumulative Risk Curve

Risk can be shown as a number in dollars per year or as a point on an XY plot with probability and consequence axes, or a location on a two-dimensional matrix.
Work steps for developing an RBI program

1. Identify Equipment
2. Equipment History
3. Corrosion Study/Screening Inspections
4. Design Data
5. Process Study
6. Field Verification/Visual Inspection
7. Data Collection
8. Criticality Analysis
9. Inspection Planning
10. Inspection Activities
11. Evaluate Results
12. Non Conformances
13. Update Criticality
14. Report Results
15. Update Inspection Plans
16. Report Results
Storage Tank

Asset

Components

Roof

Shell

Items

Connection
Nozzle
Bleeder
Thermowell
Etc.

Bottom
Heat Exchanger

Asset

Components

Items

Shell

Channel

Bundle

Connection
Nozzle
Bleeder
Thermowell
Etc.
RBMI Implementation Steps

1. Identify Equipment
   - Equipment History
   - Corrosion Study/Screening Inspections
   - Design Data
   - Process Study
   - Field Verification/Visual Inspection

2. Data Collection

3. Criticality Analysis

4. Inspection Planning

5. Inspection Activities
   - Evaluate Results
     - Non Conformances
     - Update Criticality
     - Report Results
     - Update Inspection Plans
Data Collection
Corrosion Study & Environmental Cracking

- The process for identifying and quantifying the types of degradation occurring in equipment
- Determine design basis, original wall thickness, toxic percentages, flammable and explosive end points, piping systems and circuits defined, inventory, representative fluid, fluid initial phase etc.
- The Corrosion Study and Environmental Cracking Analysis are linked to the component
- Understand how the equipment will fail
  - Subject Matter Expert (SME/Corrosion Engineer) will identify likely failure mechanisms and expected rates
  - Inspection data will be reviewed to confirm predictions
- Used to establish appropriate Inspection Plans
  - Inspection planning will add methods to cover “un-inspected” mechanisms
Data Collection Sources

- Process Flow Diagrams or Block Flow Diagrams
- Piping & Instrumentation Diagrams
- Heat and materials balances
- DCS, process historian or field instrumentation (for operating conditions)
- Electronic equipment data base
- Master equipment files
- Manufacturer’s equipment data sheet (U-1 Report)
- Inspection and test records
- Equipment Nameplate/Field Verification
- As-built drawings
- Maintenance records (equipment repair, re-rating, replacement, failure reports, etc.)
RBMI Implementation Steps

1. Identify Equipment
2. Equipment History
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5. Process Study
6. Field Verification/Visual Inspection
7. Data Collection
8. Criticality Analysis
9. Inspection Planning
10. Inspection Activities
11. Evaluate Results
12. Non Conformances
13. Update Criticality
14. Report Results
15. Update Inspection Plans
Corrosion Study
Typical Contents

- Introduction
- Process Description
- Potential Corrosion and Damage
- Prevention of Corrosion
- Material Selection and Failure Mechanisms
- Performed on simplified process flow diagrams (PFD’s).
- Establishes the basis on which the corrosion rates, environmental cracking, and other damage mechanisms were determined.
- Can include corrosion control manual defining corrosion loops along with integrity operating windows
Corrosion Study: Marked Up PFD

**EXAMPLE PFD LEGEND: MATERIALS, CORROSION RATES, AND DAMAGE MECHANISMS**

<table>
<thead>
<tr>
<th>Material</th>
<th>Color</th>
<th>Color Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Carbon Steel</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1 Cr - ½ Mo</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1 ½ Cr - ½ Mo</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2 ½ Cr - 1 Mo</td>
<td></td>
<td></td>
</tr>
<tr>
<td>5 Cr - ½ Mo</td>
<td></td>
<td></td>
</tr>
<tr>
<td>9 Cr - 1 Mo</td>
<td></td>
<td></td>
</tr>
<tr>
<td>12 Cr</td>
<td></td>
<td></td>
</tr>
<tr>
<td>304 ss</td>
<td></td>
<td></td>
</tr>
<tr>
<td>316 ss</td>
<td></td>
<td></td>
</tr>
<tr>
<td>317 ss</td>
<td></td>
<td></td>
</tr>
<tr>
<td>321 / 347 ss</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Monel, Brass, 70-30 Cu-Ni</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Alloy 20Cb-3, 2205 Duplex</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Inco 625/800, HP-45N6</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Other (see desc.)</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

C = Corrosion Probe
CI = Chemical Injection

**EXAMPLE PFD: SECTION OF MARKED UP PFD**

Purple indicates presence of an environmental cracking or other damage mechanism.
Probability for Fixed Equipment External Corrosion

- Capture Additional Data **Required** for Evaluation:
  - Operating temperature
  - Insulated
  - Number / effectiveness of External Inspections
  - Area humidity

- Calculate or estimate the external corrosion rate
- Identify “external age”
- Calculate fractional wall loss (wall loss/initial wall)
- Look up corrosion factor
- Calculate external corrosion probability category
- CUI model:
  - “Insulated” and susceptible to external corrosion
  - Operating Temperature is between 0 and 350 deg F (-18 to 177 C)

**Optional** Information:
- Coating type under insulation
- Type of Insulation
- Insulation condition
- Circuit Complexity
- External Wetting
External Corrosion
CUI Corrosion Rate by Temperature and Humidity

Corrosion Rate (MPY) vs. Operating Temperature (F)

- High: (.36 mm/yr)
- Medium: (.18 mm/yr)
- Low: (.09 mm/yr)
External Corrosion
Actual CUI Data vs Predictions

![Graph showing Actual CUI Data vs Predictions. The x-axis represents temperature in F, ranging from 0 to 350. The y-axis represents corrosion rate in in/Yr, ranging from 0 to 0.03. The graph includes data points at various temperatures, with a trend line indicating a peak corrosion rate around 360 mm/yr at 180°F (177°C)].
Probability of Failure – External Corrosion

- Operating Temperature
- Humidity
- Number of external inspections
- Inspection confidence
- External years in service (a)
- Initial wall thickness (t)
- Adjusted external corrosion rate (r)
- Initial external corrosion rate
- Operating temperature (F)
- Humidity
- Corrosion factor (1-1000+)
- Corrosion factor
- Probability category
- Probability category (1-4)
- External corrosion probability category (1-5)
- Estimated remaining wall
- Estimated minimum thickness
- Wall ratio*

* Wall ratios of 1 or less need to be reviewed separately to determine if the equipment has remaining life.

< 0.005 inches per year (0.13 mm/yr)
A CUI Finding:

For example, to find CUI

Table 40 – Note 4 from RBM Inspection Strategies for Piping / CUI / by Profile RT or CUI Visual

The external visual inspection counts the number of potential inspection locations. As a minimum, Location Categories for circuits subject to CUI should include barrier penetrations larger than 10” diameter and smaller penetrations that are not properly sealed, termination of insulation, damaged insulation, bottom of vertical runs, and low points of horizontal runs.

- RBI focuses the right inspection strategy to reveal the damage mechanism driving the risk
Environmental Cracking Mechanisms Potential Factor

- Severe cracking mechanisms
  - Chloride SCC
  - Carbonate cracking
  - HF cracking (HIC, SOHIC)
  - Caustic SC
  - Polythionic Acid SCC

- Non-Severe cracking mechanisms
  - Wet H2S cracking (HIC, SOHIC)
  - Amine SCC
  - all others

- Cracking model is most sensitive when damage found at last inspection
- Option to calculate with higher severity if the mechanism is not severe
- Inspection Confidence, key especially if it is Medium or High and no damage found
Probability of Failure – Environmental Cracking

- Initial Cracking Potential
- Damage Found at Last Inspection
- Number of cracking Inspections
- Inspection Confidence
- Date of Last Inspection
- Analysis Date
- Cracking Years in Service

- Adjusted Cracking Potential
- Cracking Potential Factor (CPF)
- Cracking Type
- Adjusted Years (AY)
- Cracking Damage Factor

- Probability of Failure Category (1-4)

<table>
<thead>
<tr>
<th>Cracking Damage Factor</th>
<th>Probability Category</th>
</tr>
</thead>
<tbody>
<tr>
<td>1-9</td>
<td>4</td>
</tr>
<tr>
<td>10-99</td>
<td>3</td>
</tr>
<tr>
<td>100-999</td>
<td>2</td>
</tr>
<tr>
<td>1000+</td>
<td>1</td>
</tr>
</tbody>
</table>
Other damage mechanisms

- Brittle Fracture
- Carburization
- Creep
- Erosion
- Graphitization
- Hot Hydrogen Attack
- Hydrogen Embrittlement
- Blistering
- Coating Failure
- Manufacturing Defects
- Mechanical Failure – Floating Roof
- NH3 Cracking
- Pontoon Failure
- Liquid Metal Embrittlement
- Lining Failure
- Mechanical Fatigue
- Phase Change Embrittlement
- Thermal Fatigue
- Temper Embrittlement
- External CSCC
- Wet H2S
Overview of Safety Consequences

Pressure Vessel Safety Consequences

- Inert
  - Consequence: E or Burst

- Reactive
  - Pool spread model
    - Pool Size Area
      - Consequence

- Flammable
  - EPA Models
    - Distance to Injury
      - Injury Area

- Toxic
  - EPA Models
    - Distance to Injury
      - Injury Area
Required Data for Consequence Analysis

- **Fluid**
  - Rep. fluid, operating temperature, operating pressure
  - Initial state (gas or liquid)
  - Toxic fluid and percent

- **Available Inventory**
  - Default inventory for liquid = 40,000 lbs (18,144 kg)
  - Default inventory for gas = 10,000 lbs (4536 kg)
  - Check inventories of large vessels

- **Mitigation**
  - Detection & Isolation time (Duration)
  - Diked Area for liquids
Safety Consequence of Failure

- Initial State
- Operating Pressure
- Toxic Percentage
- Equipment Type
- Isolation Time
- Detection Time
- Inventory

- Toxic Fluid
- Rep. Fluid

- Diked Area

- Affected Area

- Release Rate

- Leak Size

- Release Duration

- Leak Quantity

- Safety Consequence Category (A-E)

<table>
<thead>
<tr>
<th>Category</th>
<th>Affected Area (ft²)</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>&gt;5,000,000 (450,000 m²)</td>
</tr>
<tr>
<td>B</td>
<td>500,000 – 5,000,000 (45,000 – 450,000 m²)</td>
</tr>
<tr>
<td>C</td>
<td>50,000 – 500,000 (4,500 – 45,000 m²)</td>
</tr>
<tr>
<td>D</td>
<td>5,000 – 50,000 (450 – 4,500 m²)</td>
</tr>
<tr>
<td>E</td>
<td>&lt; 5,000 (&lt; 450 m²)</td>
</tr>
</tbody>
</table>
Seven user inputs are available:
Final State – Shell and Channel

1. What is the final state of the fluid that starts out in the Shell?

2. What is the final state of the fluid that starts out in the Bundle?
Flammable Leak Type

Choose from the following list:

- Flammable leak could cause a catastrophic loss of containment or violent chemical reaction
- Flammable HC leak into a utility system
- Utility leak into a HC system
- N/A

NOTE – the consequence will be calculated based on the above choice, NOT the representative fluid!
# Flammable Safety Consequences

<table>
<thead>
<tr>
<th>Category</th>
<th>Flammable</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>A</strong></td>
<td>Tube leak could cause a catastrophic loss of containment or violent chemical reaction</td>
</tr>
<tr>
<td><strong>B</strong></td>
<td>Major Flammable HC vapor leak into a utility system (Leak rate $\geq 100$ lb/min (45.4 kg/min))</td>
</tr>
<tr>
<td><strong>C</strong></td>
<td>Major Flammable HC liquid leak into a utility system (Leak rate $\geq 100$ lb/min (45.4 kg/min)) Minor Flammable HC vapor leak into a utility system (Leak rate $&lt; 100$ lb/min (45.4 kg/min))</td>
</tr>
<tr>
<td><strong>D</strong></td>
<td>Minor Flammable HC liquid leak into a utility system (Leak rate $&lt; 100$ lb/min (45.4 kg/min)) Major utility leak into a HC system (Leak rate $\geq 100$ lb/min (45.4 kg/min))</td>
</tr>
<tr>
<td><strong>E</strong></td>
<td>Minor utility leak into a HC system (Leak rate $&lt; 100$ lb/min (45.4 kg/min))</td>
</tr>
</tbody>
</table>
Toxic Leak Type

- Choose from the following list:
  - Toxic leak could cause a catastrophic loss of containment or violent chemical reaction
  - Toxic leak into a utility
  - Toxic leak into process system
  - Leak into a toxic system
  - N/A

- NOTE – the consequence will be calculated based on the above choice, but it checks to be sure a toxic can leak where you say it will!
# Toxic (or Toxic Mix) Leak Type

<table>
<thead>
<tr>
<th>Category</th>
<th>Description</th>
</tr>
</thead>
</table>
| **A**    | Tube leak could cause a catastrophic loss of containment or violent chemical reaction  
Major toxic leak into a utility system  
(Toxic Leak rate $\geq 5$ lb/min (2.3 kg/min)) |
| **B**    | Minor toxic leak into a utility system  
(Toxic Leak rate $< 5$ lb/min (2.3 kg/min))  
(Minor component of mixed process stream is non water-soluble toxic)  
Major toxic leak into a process system  
(Toxic Leak rate $\geq 5$ lb/min (2.3 kg/min)) |
| **C**    | Minor toxic leak into a process system  
(Toxic Leak rate $< 5$ lb/min (2.3 kg/min)) |
| **D**    | Leak into a toxic system |
| **E**    | |
Product Leak Consequence

- Account for loss of product quality, assumes you can’t recover or re-work it
- Simply multiplies
  - Leak Rate*Unit Value*Leak Duration
  - Result in $
Time to Detect Leak

- UNITS are in YEARS!
- To convert to years, divide hours by 8760
- Rules of Thumb
  - Slow leaks (less than 10 lbs/min (4.5 kg/min)) from process to process, use one-half the time between internal inspection of tubes
  - HC into utilities, with HC monitors, use 24 hours
  - HC into utilities, no HC monitors, use one week
  - Slow leaks of utilities into product, use one-half the time between internal inspection of tubes
- This also impacts hole size -> leak rate!
HX Tube – Unit Value

- Input estimate of $/lb ($/Kg) for loss of product
- Consult process engineers for estimates
Impact of Product Leak Inputs

- Bottom line – this could easily dominate the other types of consequence, if the others are low
Chloride Stress Corrosion Cracking (CSSC)

External Chloride Stress Corrosion Cracking (ECSSC), this damage mechanism can occur in austenitic and duplex stainless steels when insulated equipment is exposed to a combination of an aqueous chloride environment and either an applied or residual tensile stress.

The type of unit that the equipment is in or near can also affect CUI rates. For instance, units that process HCl have been seen to suffer higher CUI and general atmospheric corrosion rates. Reductions in fugitive emissions within these units will likely reduce this effect. Acidic conditions increase the likelihood of ECSCC, while alkaline conditions decrease the susceptibility. While 5 ppm chloride content is sometimes used as a lower limit for chloride SCC, there is no generally accepted threshold of chlorides to avoid Chloride SCC, particularly when chlorides can concentrate, as they do in the insulation.
Environmental affects

An aqueous chloride environment is a necessary condition. Missing or damaged jacketing and caulking are the most common reasons for water ingress into the insulation.

Wet insulation is more likely in plants located in coastal regions where there is a high humidity factor. Coastal regions not only have a high humidity factor but are more likely to have chloride contamination from sea salt in the air. Therefore, both the corrosion rates of carbon steels and the likelihood of ECSCC of stainless steels increase in coastal regions.

Equipment located down wind of cooling towers are exposed to water mist that can saturate insulation. Often times, this mist contains elevated chloride levels from cooling water treatment chemicals, further increasing CUI and ECSCC potentials.
Temperature affects

Failures are generally observed at metal temperatures between 140 - 350°F. However, since process temperatures are known better than equipment temperatures, the potential for ECSCC is considered in the temperature range of 120 - 400°F for 300 series stainless steels. This does not mean that ECSCC can not occur at higher temperatures. Cracking has been observed at process temperatures as high 550°F, but likely cracked at lower temperatures due to cyclic service.

This temperature range also causes the chlorides to concentrate via a wet/dry percolation effect thereby causing the cracking to occur at lower temperatures as seen in here.
Susceptible locations

Areas adjacent to penetrations in the insulation are likely damage sites. These include:

- Nozzles
- Platform supports
- Vacuum stiffening rings
- Piping support clamps

Weep holes in top head reinforcing pads can allow water and chlorides to get behind the repad and concentrate, allowing the cracking to progress undetected. Wax plugs, grease or short lengths of instrument tubing bent in a “goose neck” should be installed in the weep holes to prevent future water ingress. Similarly, ear type of lifting lugs can create a water trap. Since only the sides and bottom of the lug are welded, water can get behind the lug from the top head surface. Lugs should be removed after the vessel is installed.

In short, any locations of water ingress or collection points that can concentrate chlorides is a potential crack location.
Susceptible locations

A stripper column pipe support clip to the 3/8” SA-240 304 stainless shell developed ECSCC.
The top column was a high 1A criticality consequence/probability of failure rating. The column was placed in service in 1968. The cracking was found during the planned 50% ECSCC inspection. The cracking was located on the top 14” feed inlet piping support. This was a remote location, difficult to access.

Weep hole where ECSCC was found behind the repad.

ECSCC damage, black arrows point to crack indications
Prevention of CUI and ECSCC

• Plug weep holes with grease or wax plugs to prevent water ingress. Or, install short lengths of instrument tubing bent in a “goose neck” so that leaks into the repad area do not go un-noticed. Note: DO NOT install metal plugs into weep holes, they must not be able to hold pressure.

• Remove lifting lugs and other protrusions through the insulation if possible. If a protrusion is needed, try to design such that it angles downward to naturally shed water.

• Use of immersion grade coatings, or thermal sprayed aluminum coatings to protect the stainless or carbon steel equipment.

• European users use heavy duty aluminum foil to wrap piping and vessels to provide sacrificial corrosion protection and barrier.
Pictures of high risk with CUI and CSCC as damage mechanism

Performance Products Manufacturing Team

(RBM recommended CUI inspections) –
Corrosion under insulation... make that label.
RBMI Inspection Planning

- Based on Equipment Type & Risk Category
- Link to identified failure modes
- Create a dynamic inspection plan
  - Methods, location, extent and frequency
- Evaluate condition monitoring confidence
  - Inspected and “represented” items
- Recommend reducing / deleting inspections
- Recommend increasing / changing inspections
Developing a Risk Based Inspection Program:

EQT-3
Fixed Equipment

PURPOSE
This Equipment Technology defines best practices for maintaining the integrity and reliability of fixed equipment and includes strategy rules and guidance to determine acceptance criteria for tasks.

SCOPE
Applies to fixed equipment:
- Pressure vessels and exchangers as defined by API 510 Pressure Vessel Inspection Code.
- Piping as defined by API 570 Piping Inspection Code.
- Boilers and Fired Heaters as defined by API 573 Inspection of Fired Heaters and Boilers not including heaters operating under vacuum or using solid fuel.
- Relief devices (pressure relief valves, rupture disks, flame arresters, pressure and vacuum relief valves) as defined by API 576 Inspection of Pressure-Relieving Devices.
- Atmospheric Storage Tanks as defined by API 653 Tank Inspection, Repair, Alteration, and Reconstruction.

BACKGROUND
Equipment Plans define the tasks to maintain the integrity and reliability of equipment based on the Criticality Rating of the equipment and the failure modes that could be present. If the criticality for an equipment item is not known, the Equipment Plan is based on industry recognized practices.
Developing a Risk Based Inspection Program:

**Develop Equipment Plan**

**Note:** The following steps address the equipment-specific details required in RBMI Manual Chapter WF4, *Develop Equipment Plan* to develop an Equipment Plan.

The following tables provide sample Equipment Plans:

- **Table 8 - Sample Pressure Vessel Equipment Plan**
- **Table 9 - Sample Exchanger Equipment Plan**
- **Table 10 - Sample Piping Circuit Equipment Plan**
- **Table 11 - Sample Boiler Equipment Plan**
- **Table 12 - Sample Relief Valve Equipment Plan**
- **Table 13 - Sample Tank Equipment Plan**

**Identify Expected Failure Modes**

*(Responsibility – Subject Matter Expert)*

Identify expected failure modes depending on the type of equipment using the following as suggestions:

- Improper assembly
- In-service deterioration of components such as bolts, flange, and gaskets
- Wall Loss from corrosion, erosion or wear
- Cracking
- Blistering
- Creep
- Change in material or mechanical properties such as embrittlement, carburization, and brittle fracture
- Fouling or plugging
- Relief at wrong pressure
- Damaged Internals
Developing a Risk Based Inspection Program:

Select Tasks (Responsibility - Assigned Person)
Select tasks to maintain the integrity and reliability of the equipment item based on the expected failure modes and criticality rating using the attached strategy rules.

Pressure Vessels and Exchangers Strategy Rules
Use the following strategy rules to select tasks for pressure vessels and exchangers:
Table 14 – Minimum Tasks for Pressure Vessel & Exchanger
Table 15 - Pressure Vessel & Exchanger / Visible External Deterioration / by External Visual
Table 16 - Pressure Vessel & Exchanger / Internal Corrosion / by Internal Visual
Table 17 - Pressure Vessel & Exchanger / Internal Corrosion / by External UT
Table 18 - Pressure Vessel & Exchanger / Internal Corrosion / by External UT Without Internal Visual
Table 19 - Pressure Vessel & Exchanger / Erosion / by Internal Visual
Table 20 - Pressure Vessel & Exchanger / Erosion / by External UT
Table 21 - Air Cooled Exchanger / Internal Corrosion / by Partial Internal Visual
Table 22 - Air Cooled Exchanger Header Box / Internal Corrosion / by External UT
Table 23 – Exchanger Tubes (Air Cooled Exchangers) and Tube Bundle (S&T Exchangers)/ Corrosion and Environmental Cracking / by Tube Inspection
Table 24 – Double Pipe Exchanger / Internal Corrosion / by Profile RT
Table 25 - Pressure Vessel & Exchanger / CUI / by CUI Inspection
Table 26 – Pressure Vessel & Exchanger / Environmental Cracking / by MT or PT
Table 27 – Pressure Vessel & Exchanger / Environmental Cracking / by External UT Shear Wave
Table 28 - Glass or Polymer Lined Pressure Vessel / Deterioration of Lining / by Internal Visual and Internal Thickness Reading
Table 29 - Glass Lined Pressure Vessel / Deterioration of Glass Lining / by Spark Testing
Table 30 - Jacketed Vessel / Corrosion in Jacketing Area / by Partial Internal Visual in Jacketed Area
Table 31 - Jacketed Vessel / Corrosion in Jacketing Area / by External and Internal UT with Partial Internal Visual of Jacket Area
Table 32 - Jacketed Vessel / Corrosion in Jacketing Area / by External and Internal UT with No Partial Internal Visual
Inspection Priority Categories (IPC)

- IPCs are calculated in the Criticality module for each defined damage mechanism.
  For example, a **High** criticality pressure vessel, may have a **High** IPC for Internal Corrosion, but have a **Low** IPC for External Corrosion.

- Tasks are recommended in the Inspection Planning Module are based on the IPC for each damage mechanism, the strategy rules and equipment/component type.

Note: The only exception is External Visual Inspections which are planned based upon the combined criticality rating.
Developing a Risk Based Inspection Program:

- All Consequence A & B Bundles require eddy current/IRIS inspection regardless of leak direction.
- Only those bundles of lower consequence which leak process to utility need to be eddy current/IRIS inspected.
Developing a Risk Based Inspection Program:

Table 27 – Pressure Vessel & Exchanger / Environmental Cracking / by External UT Shear Wave

<table>
<thead>
<tr>
<th>Internal Criticality Rating Based on Failure Mode&lt;sup&gt;6&lt;/sup&gt;</th>
<th>Low</th>
<th>Medium</th>
<th>Medium-High</th>
<th>High</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Baseline&lt;sup&gt;1,2&lt;/sup&gt; Number of Locations&lt;sup&gt;3,7&lt;/sup&gt;</strong></td>
<td>10%&lt;sup&gt;7&lt;/sup&gt;</td>
<td>25%</td>
<td>50%</td>
<td>100%</td>
</tr>
<tr>
<td><strong>Follow-up Total Number of Locations&lt;sup&gt;4&lt;/sup&gt;</strong></td>
<td>25%</td>
<td>50%</td>
<td>100%</td>
<td>100%</td>
</tr>
<tr>
<td>Maximum Interval (Yr.), or 1/2 remaining life</td>
<td>15</td>
<td>10</td>
<td>10</td>
<td>5</td>
</tr>
<tr>
<td>Inspection Confidence&lt;sup&gt;5&lt;/sup&gt;</td>
<td>Low</td>
<td>Low</td>
<td>Medium</td>
<td>High</td>
</tr>
</tbody>
</table>

- Heat exchanger bundles can be grouped, and representative inspection results from one heat exchanger can be used if the group of heat exchangers are in the same service (process environment), do not have a High Risk rating, are constructed of the same materials, and the corrosion rates are comparable.

- Inspections are not required for bundles with a Low Risk rating.

- 25% of the Medium Risk bundles in the group must be inspected.

- 50% of the Medium-High bundles in the group must be inspected.

- High Risk bundles cannot be grouped for internal inspections.
Definition of Risk Based Inspection:

Table 40 - Piping / CUI / by Profile RT or CUI Visual

<table>
<thead>
<tr>
<th>Probability Ranking</th>
<th>Consequence Ranking</th>
<th>Baseline Criticality Rating Based on Failure Mode</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Low</td>
</tr>
<tr>
<td>Baseline</td>
<td></td>
<td></td>
</tr>
<tr>
<td>NInlet Ring Circuits</td>
<td>Gly/lowup visual paddens</td>
<td>10%</td>
</tr>
<tr>
<td>NInlet Locations per circuit</td>
<td>Gly/lowup visual paddens</td>
<td>10%</td>
</tr>
<tr>
<td>Followup</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total NInlet Ring Circuits within same temperature range</td>
<td>Gly/lowup visual paddens</td>
<td>25%</td>
</tr>
<tr>
<td>Total NInlet Locations per circuit</td>
<td>Gly/lowup visual paddens</td>
<td>25%</td>
</tr>
</tbody>
</table>

NOTES for Table 40: (see general notes on page 54)
1. The purpose of the CUI piping inspection program is to identify serious deterioration to the external surfaces of the piping. When significant deterioration is found as a result of the inspection program, the piping should be restored to essentially like-new condition by repair or replacement.
The RBI project at Port Neches

Objectives

• Community safety, personnel safety, and environmental protection while simultaneously improving equipment integrity and reliability

• Carefully defined steps to improve plant performance

• Systematic application of risk based inspection to all equipment types

• Optimize inspection, test and maintenance work

• Eliminate unplanned equipment downtime

• Continuously improving equipment reliability

• Improved performance metrics

• Reduced costs
The RBI project at Port Neches

Scope

• 11,000 equipment items including fixed vessels, relief devices, piping circuits across multiple process units.
• Thirty-two month implementation schedule included data collection, reviewing inspection histories, corrosion studies, criticality analyses and inspection planning.
• Prioritized NDE inspections began as each inspection planning review session was completed for each process unit.
• These inspections revealed significant findings fairly quickly.
Work steps for developing an RBI program

1. **Identify Equipment**
   - Equipment History
   - Corrosion Study/Screening Inspections
   - Design Data
   - Process Study
   - Field Verification/Visual Inspection

2. **Data Collection**
   - Criticality Analysis
   - Inspection Planning
   - Inspection Activities
   - Evaluate Results
   - Update Criticality
   - Report Results
   - Update Inspection Plans

3. **Risk Distribution**

   Weep hole where ECSCC was found behind the repad.

<table>
<thead>
<tr>
<th>Risk Distribution</th>
</tr>
</thead>
<tbody>
<tr>
<td>31 1 13 1 4 11 2</td>
</tr>
<tr>
<td>23 2 9 1 4 5 4</td>
</tr>
<tr>
<td>15 3 6 1 3 3 2</td>
</tr>
<tr>
<td>19 4 4 0 2 10 3</td>
</tr>
<tr>
<td>12 5 4 0 2 4 2</td>
</tr>
<tr>
<td>E D C B A</td>
</tr>
<tr>
<td>100 36 3 15 33 13</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Risk Distribution</th>
</tr>
</thead>
<tbody>
<tr>
<td>27 1 13 1 4 8 1</td>
</tr>
<tr>
<td>24 2 9 1 4 6 4</td>
</tr>
<tr>
<td>16 3 6 1 3 4 2</td>
</tr>
<tr>
<td>20 4 4 0 2 11 3</td>
</tr>
<tr>
<td>13 5 4 0 2 4 3</td>
</tr>
<tr>
<td>E D C B A</td>
</tr>
<tr>
<td>100 36 3 15 33 13</td>
</tr>
</tbody>
</table>
Definition of Risk Based Inspection:

**Cumulative Risk - Safety and Production Loss**

- **Inspectable Risk**
  - Exchanger Channel 50%

- **Combined Risk Distribution**
  - Totals as a percentage
  - As Found: 13, 1, 4, 11, 2
  - As Is: 9, 1, 4, 5, 4
  - 2, 6, 1, 3, 3, 2
  - 4, 0, 2, 10, 3
  - 4, 0, 2, 4, 2

- **Component Number**
RBI
inspecting the right things using the right inspection methods

Significant Findings (CI-SCC)

Table 2: Pressure Vessel & Exchanger / Environmental Cracking / by External UT Shear Wave

External Corrosion Risk Distribution
Totals as a percentage

<table>
<thead>
<tr>
<th>A</th>
<th>B</th>
<th>C</th>
<th>D</th>
<th>E</th>
</tr>
</thead>
<tbody>
<tr>
<td>13</td>
<td>1</td>
<td>4</td>
<td>11</td>
<td>2</td>
</tr>
<tr>
<td>9</td>
<td>1</td>
<td>4</td>
<td>5</td>
<td>4</td>
</tr>
<tr>
<td>6</td>
<td>1</td>
<td>3</td>
<td>3</td>
<td>2</td>
</tr>
<tr>
<td>4</td>
<td>0</td>
<td>2</td>
<td>10</td>
<td>3</td>
</tr>
<tr>
<td>4</td>
<td>0</td>
<td>2</td>
<td>4</td>
<td>2</td>
</tr>
</tbody>
</table>

Image of a裂缝 (SCC)
Definition of Cumulative Risk in RBMI:
The RBI project at Port Neches

Conclusion:

• Huntsman’s Port Neches facility has achieved significant improvements in reliability leading to a 96.7 percent asset mechanical reliability.

• The significant findings in CUI and Chloride Stress Corrosion Cracking as a result of the RBMI study, have delivered significant value to Huntsman’s Port Neches facility in lost production avoidance.