REINHOLD ENVIRONMENTAL Ltd.

2011 APC Round Table
& Expo Presentation

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Recent Industry Experience with Corrosion in Wet Flue Gas Desulfurization (FGD) Systems

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- **American Electric Power (AEP)**
- **Duke Energy**
- **WE Energies**
- **DNV Columbus**

Outline

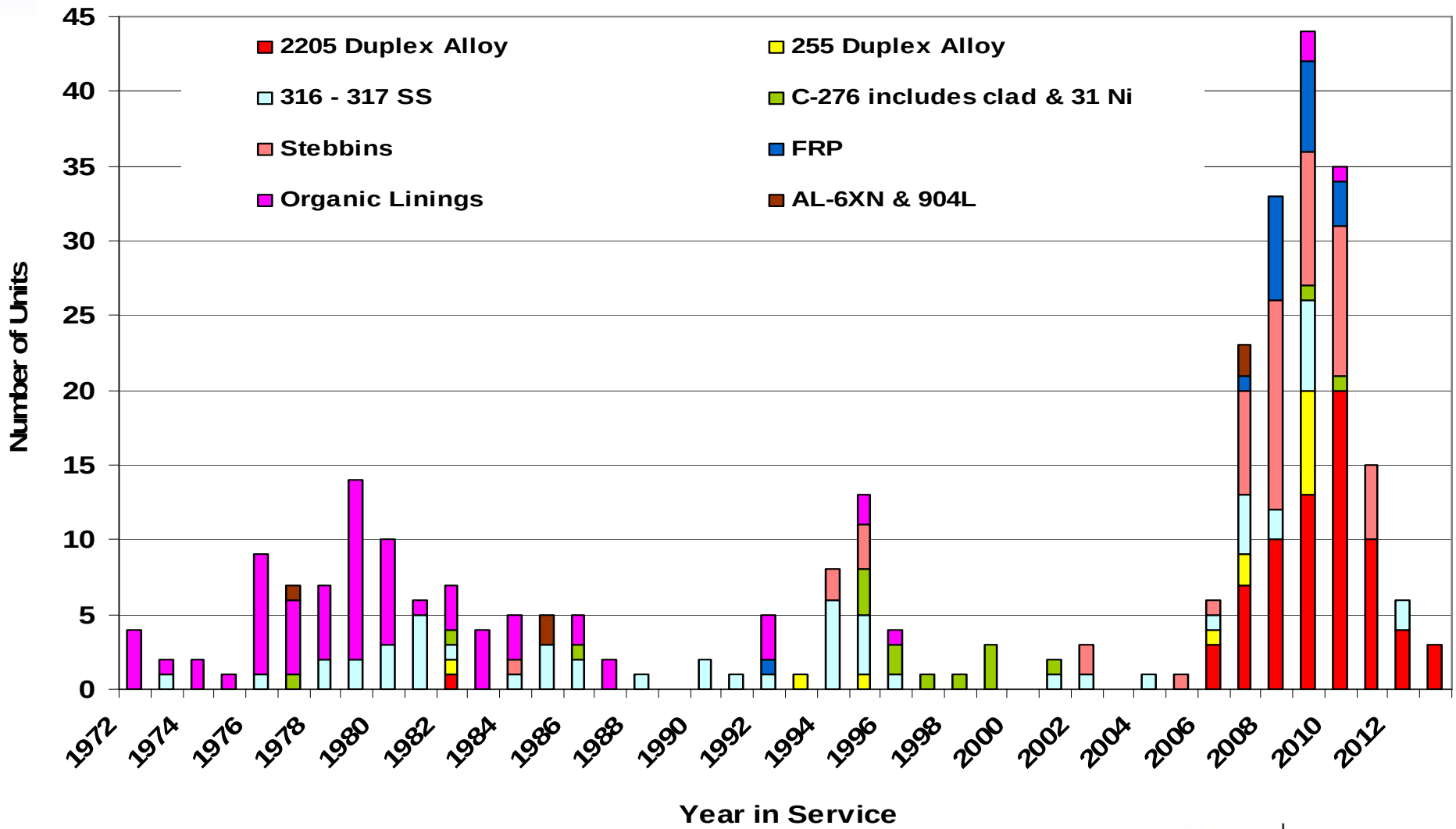
- Background on current materials of construction
- Recent industry experience with corrosion in metallic wet FGD components
- Industry actions
- EPRI response

Where we were circa 2004
EPRI Report 1011913

- In 2005, EPRI completed a survey on the material performance for 12 components in **42 FGD systems** including: ductwork, absorbers, recycle tanks, etc.
- For absorber vessels
  - **36** used stainless steel or carbon steel lined with stainless steel or nickel-based alloys with *few reported major problems*
    - Minor issues with claddings
    - Corrosion in mixing zones
  - Metallics were being considered as replacements for other organic liners or rubber

FGD Materials by Year - 347 in service by 2011

172 in service since 2006



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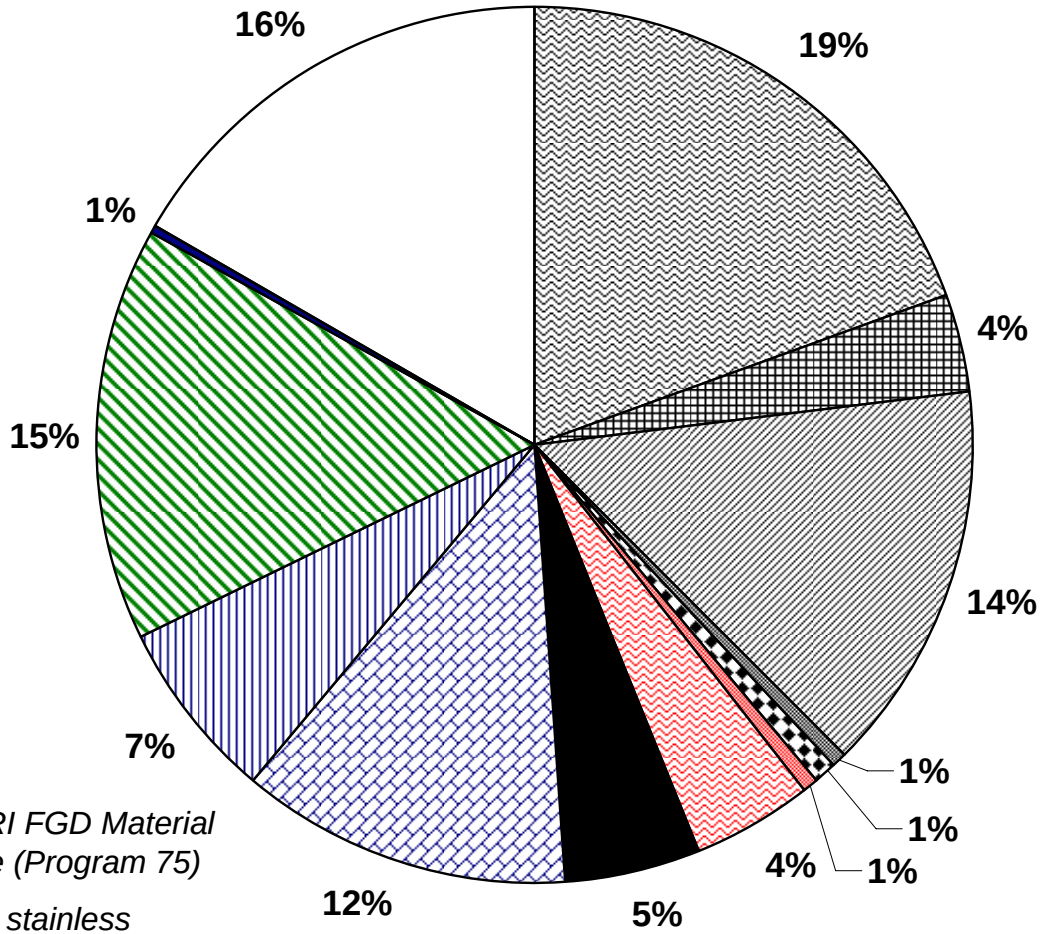
Where we were 2010

- Widespread reports of corrosion in absorber vessels of wet FGD systems constructed with duplex alloy 2205
- At the request of the EPRI Generation Council (Oct. 7-8, 2010), EPRI convened a meeting with utility members Nov. 4, 2010 in Charlotte, NC
  - 47 participants representing 15 members
  - Meeting goals
    - Review industry experience with 2205
    - Determine appropriate actions for EPRI & industry

Wet FGD Absorber Vessel Materials of Construction (363 Units in North America)



2205 Duplex
255 Duplex
316L, 317L, 317LM, 317 LMN Stainless
904L Stainless
AL6XN
31 Nickel Alloys
C-276 Nickel Alloy (includes clad & wallpaper)
Fiberglass Reinforced Plastic
Flake Glass Lined Carbon Steel
Rubber Lined Carbon Steel
Stebbins Tile Lined
Vinly Ester Resin Lined Carbon Steel
Not Reported

Source: EPRI FGD Material Database (Program 75)

Note: Not all stainless vessels have reported widespread corrosion

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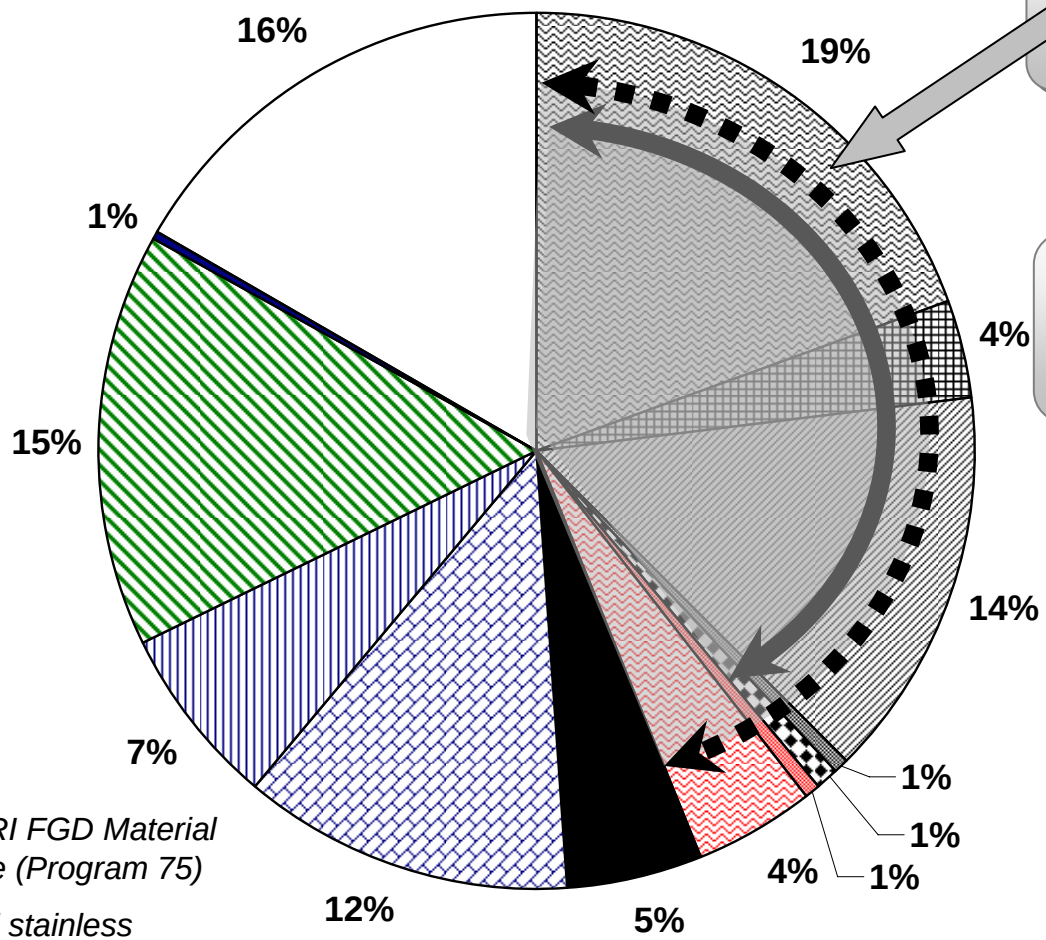
Wet FGD Absorber Vessel Materials of Construction (363 Units in North America)



All 2205 Duplex constructed after 2004

316L, 317L, 317LM, 317 LMN Stainless
904L Stainless

39% of Absorbers constructed with stainless steels

clad & wallpaper)
Fiberglass Reinforced Plastic

44% of Absorbers constructed with metallic alloys (5% Nickel-based)

Vinly Ester Resin Lined Carbon Steel
Not Reported

Source: EPRI FGD Material Database (Program 75)

Note: Not all stainless vessels have reported widespread corrosion

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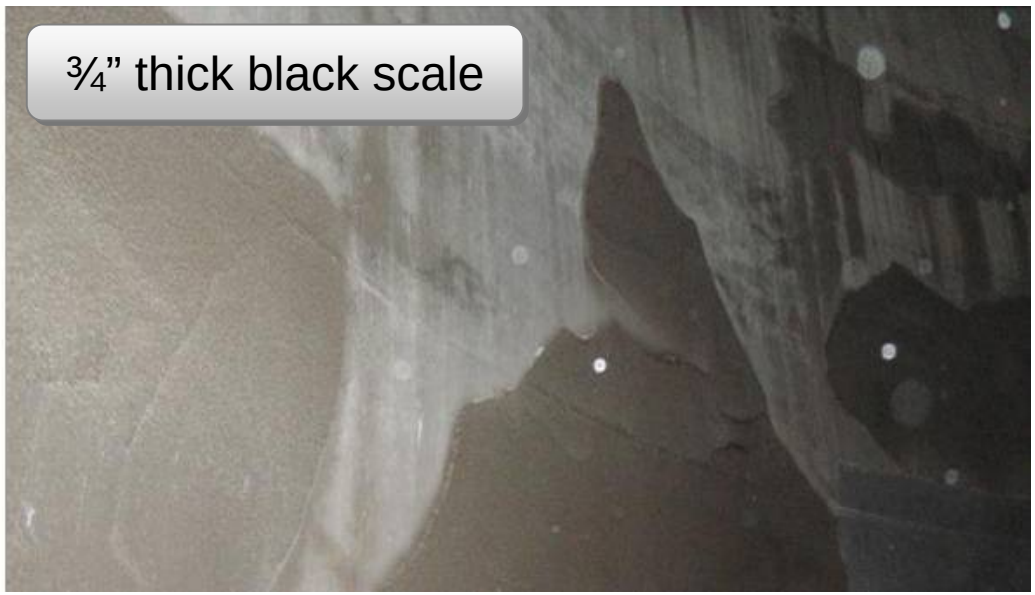
Proper inspection techniques are essential in locating corrosion

- Based on the industry experience, a draft EPRI Guideline on inspection of wet FGDs has been completed
- Before inspection, deposits and scale must be removed to assess under deposit corrosion



Proper cleaning methods are required prior to inspection

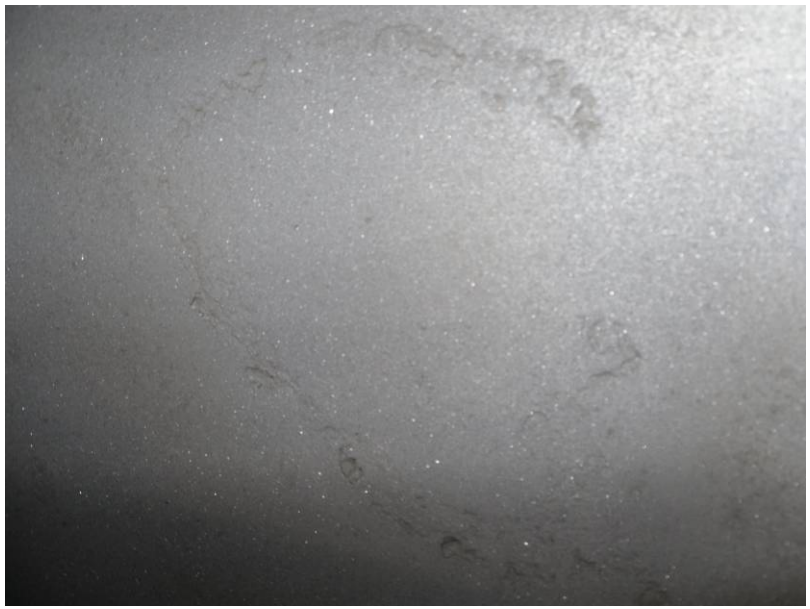
Cleaned location for partial vessel inspection

40ksi pressure wash

20ksi pressure wash

Scale removal is not enough

- Comparison of the same surface (grit blasted) under direct and indirect lighting
- Standard walkthrough could miss the corrosion



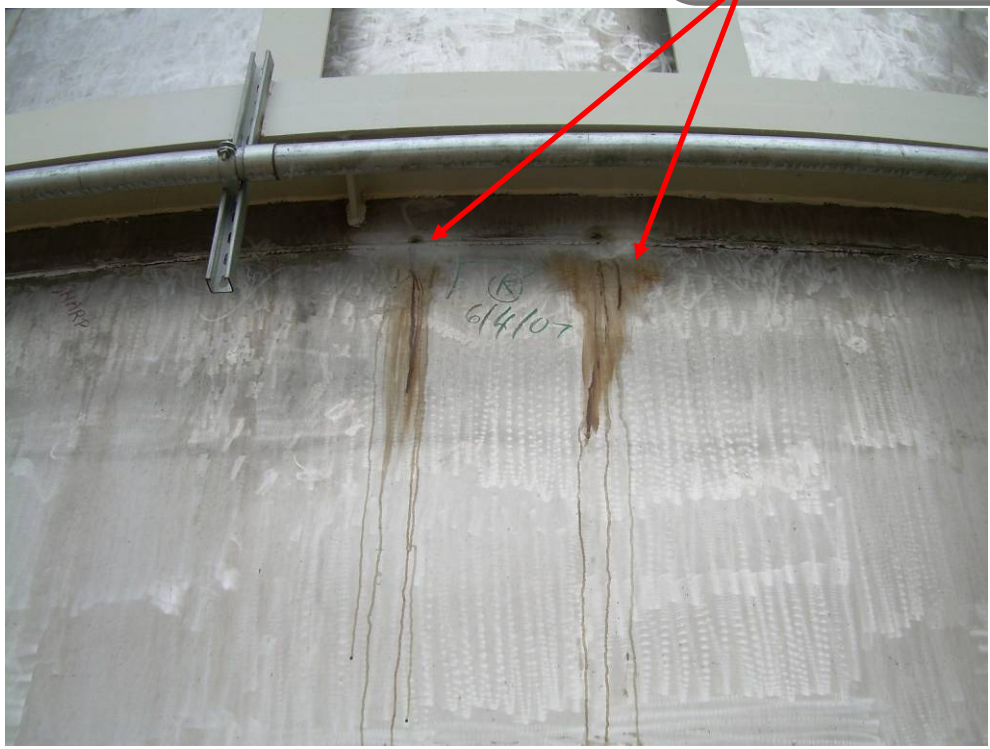
Direct lighting during typical visual inspection

Indirect lighting with LED flashlight reveals corrosion

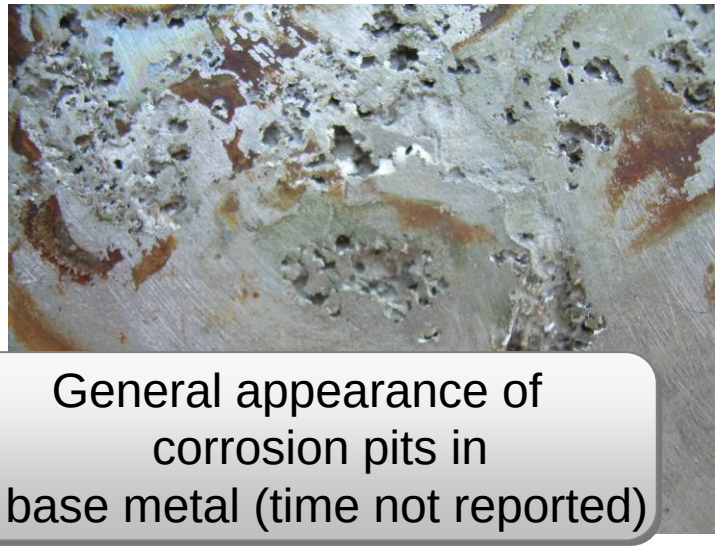
Weld metal and heat affected zones are susceptible

Corrosion in weld heat-affected zone causing through-wall failure of 11/16” (17mm) thick vessel wall (Duplex 2205)

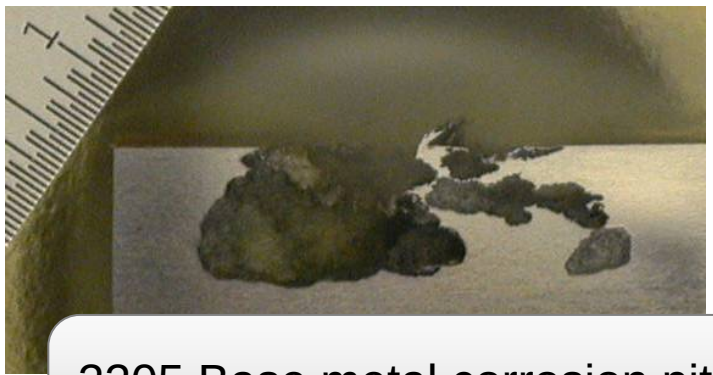
External view of through-wall HAZ leaks (11 months of service – Duplex 2205)



Base metal is susceptible



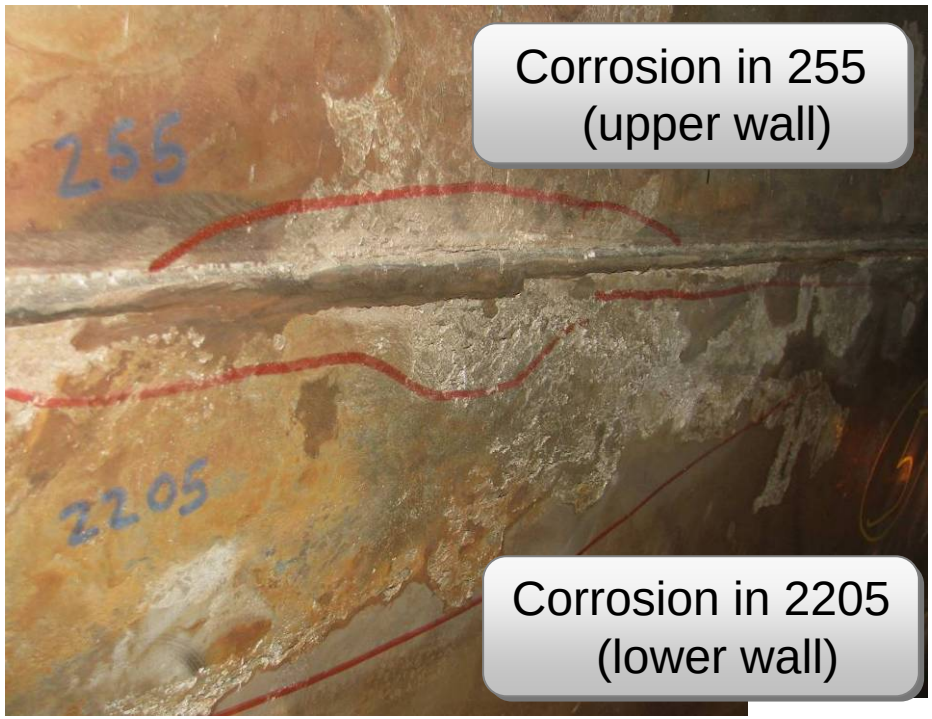
General appearance of corrosion pits in base metal (time not reported)

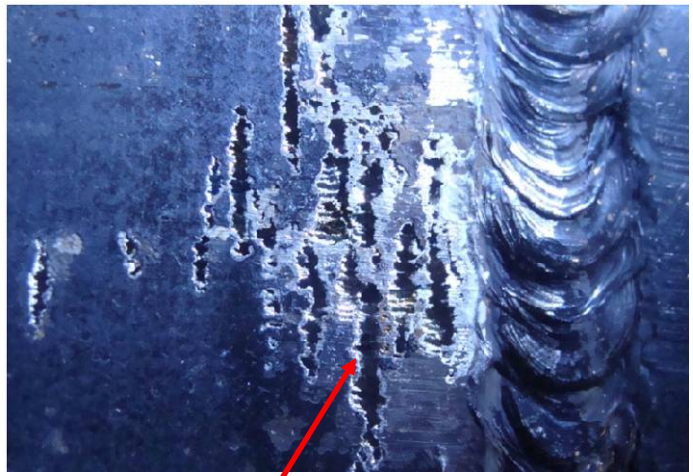


2205 Base metal corrosion pit after ~11 months of service

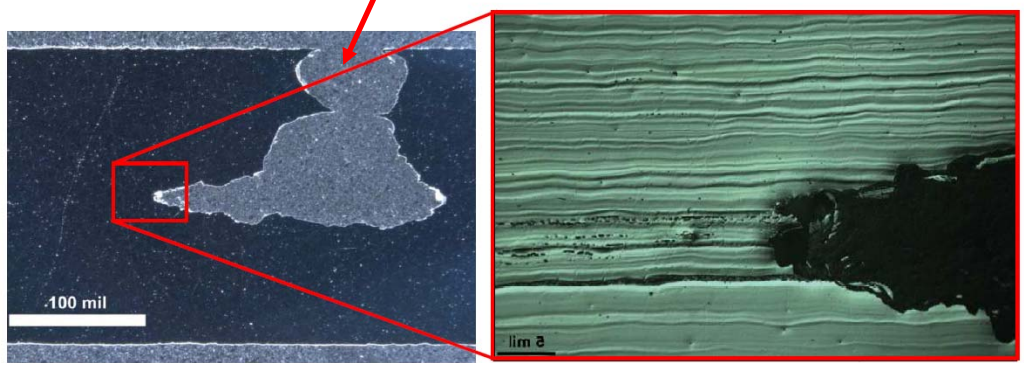
Extent of removed corrosion pits on 2205 absorber vessel walls after ~2 months of service (corrosion was ground out leaving divots)

The damage is not restricted to Alloy 2205





Significant corrosion in a 317LMN absorber vessel after <1yr. of service



- **Industry reports:**
  - Duplex: 2205, 255
  - Austenitics: 317LMN
  - Others: 6Mo alloys

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Multiple designs & components are affected

Dye penetrate reveals extensive corrosion in weld seams of spray tower

Beam support for a jet bubble reactor (JBR)

Corrosion on a Bobcat Door

Spray header corrosion

Improper/poor fabrication practices are contributing in some instances

Iron Contamination

Corrosion pattern following grinding marks on floor

Improper welding sequence may have contributed to weld metal susceptibility (final pass should be on vessel interior)

Summary of Corrosion Observations (1 of 2)

- Corrosion observations:
  - All forced oxidation wet FGDs
  - Multiple fuel types and multiple manufacturers
- Locating corrosion is only as good as your inspection techniques
  - Proper cleaning of scale and deposits
  - Serious corrosion may only be indicated with small surface features
- Corrosion is affecting:
  - Weld metal and heat-affected-zones (HAZ)
  - Base metal
  - Regions of improper fabrication techniques (grinding, contamination, etc)
  - Absorbers and Spray towers
  - Not just duplex 2205, also 255, 317LMN, and others

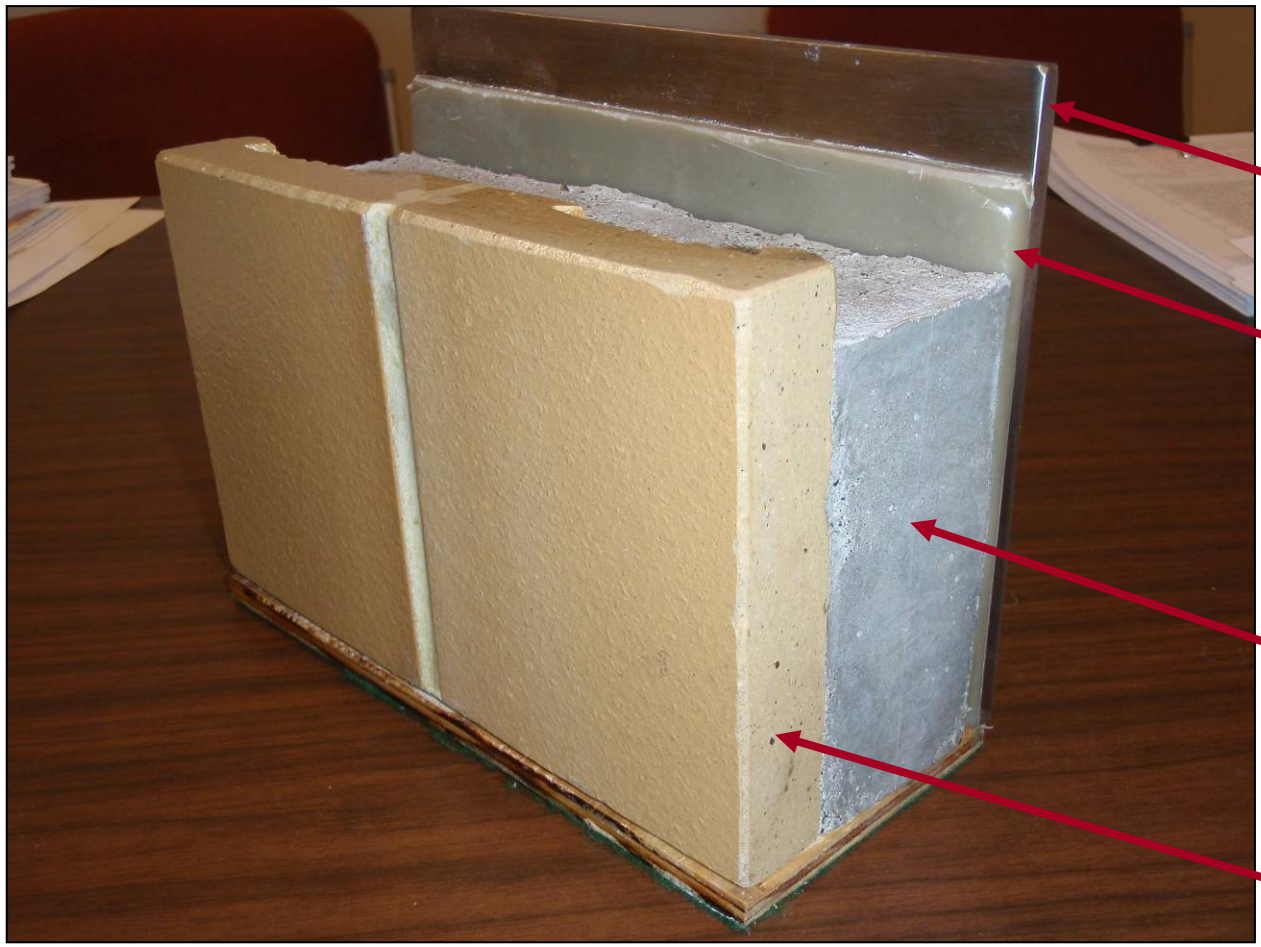
Summary of Corrosion Observations (2 of 2)

- Observed attack has been rapid and extensive
  - Pitting observed in times as short as 2 months
  - Multiple through-wall vessel leaks recorded in less than 1 year of service
  - One utility reported 65% of horizontal and 50% of vertical seam welds required repair
- Mechanisms reported:
  - Crevice corrosion (manways, doors, etc.)
  - Underdeposit pitting corrosion
  - MIC (suggested for a few cases but dismissed by others)

Mitigation strategies currently being implemented by industry

- Relining the vessel with Stebbins tile
- Weld Repair
- Coatings
- Potential Adjustment (PAP)

Stebbins Tile Mock-up for 2205 Jet Bubble Reactor Vessel



Currently considered a 'permanent' fix

Weld Repair Options in Use Today

- Installation of plate work
- Addition of external support (vessel integrity)
- Questions on weld repair
  - What filler metal?
  - How do you remove all corrosion products?
  - What about the new heat-affected-zone?
  - When do I need to repair (i.e. how do I know I've violated a minimum wall thickness?

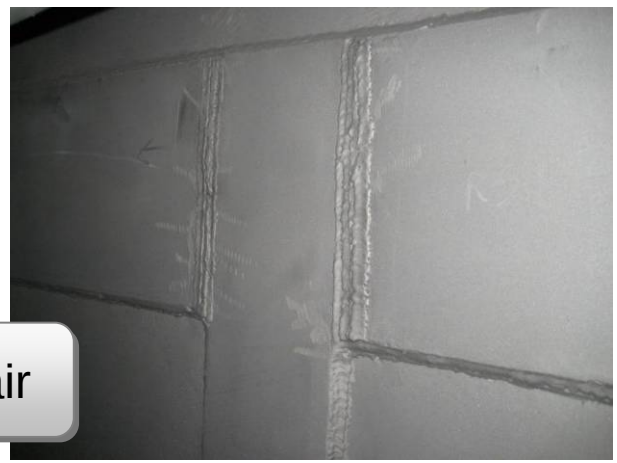
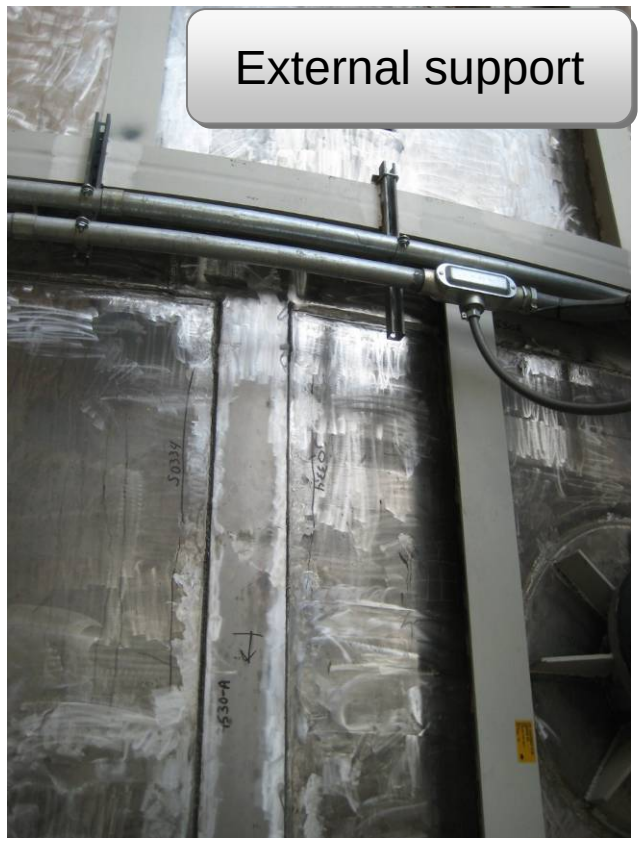


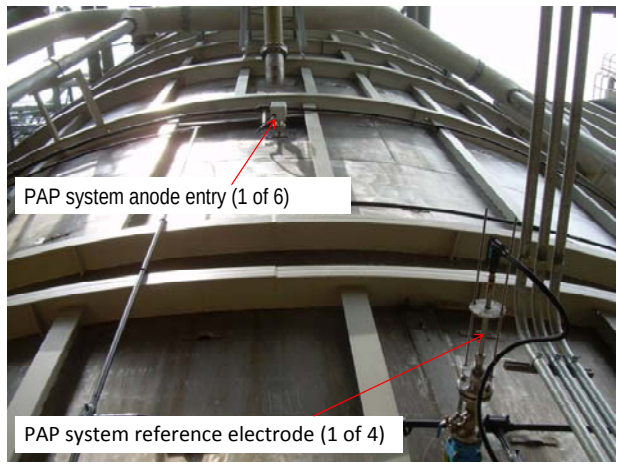
Plate work repair



External support

Potential Adjustment Protection (PAP) System

- Successful in other (older) FGD systems but not applied to 2205 duplex until 2010
- Utility application 2010 (2 units)
- Considerations:
  - Removal of corrosion prior to installation
  - Limits accessibility for inspections
  - Maintenance
- Performance (3 months, 2 units)
    - Lower than expected reference readings in lower area
    - Field testing has showed passivation
    - Field testing showed insufficient current density to fully passivate lower area of tower
    - Evaluations continue
    - Exploring the use of additional anodes

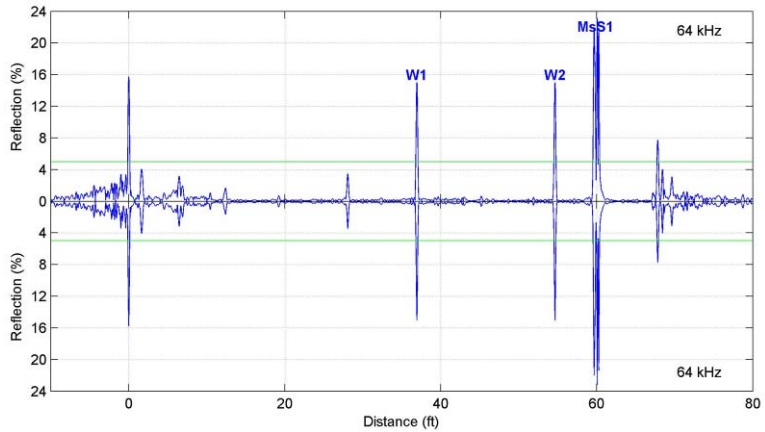


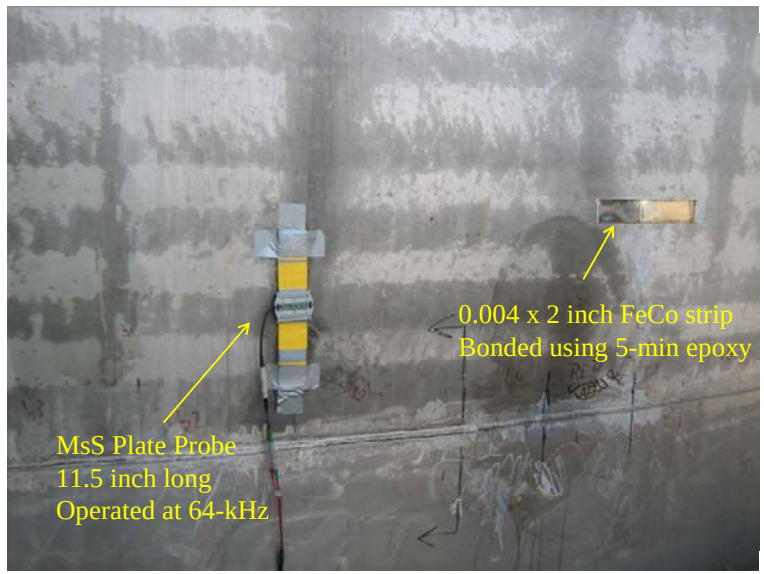
EPRI response: Corrosion in Wet Flue Gas Desulfurization (FGD) Systems

- **Supplemental project launched December 2010**
- **Project scope:**
  - Root-cause analysis for corrosion found in Alloy 2205 in wet FGD systems
  - Fabrication guidelines for the use of Alloy 2205 and other metallic alloys in wet FGD system
  - Repair guidance for metallic FGD systems and components experiencing corrosion
  - Corrosion behavior and performance of alternate materials and coatings for wet FGDs
  - Information exchange through a *Corrosion in FGD Materials Interest Group*

EPRI Studies: NDE – Guided Wave for Vessel Integrity Monitoring

- Proof-of-concept field trial
- Findings:
  - Guided waves propagate well in a 2205 FGD Vessel
  - Over 60 ft can be inspected in less than 1 minute
  - Research shows:
    - w/additional sensors
    - monitoring mode
    - a full vessel integrity inspection could be conducted in ~2.5hrs (once baseline is established)





Conclusions

- Aggressive corrosion has been noted in recently constructed wet FGD systems
- The primary alloy of construction was duplex alloy 2205, but corrosion is also effecting 317LMN, 255, and other alloys
- Various methodologies for repair and mitigation are being utilized by the industry
- EPRI has launched a supplemental project and begun a root cause analysis investigation of these issue

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