Boiler Tubing Failure Reduction

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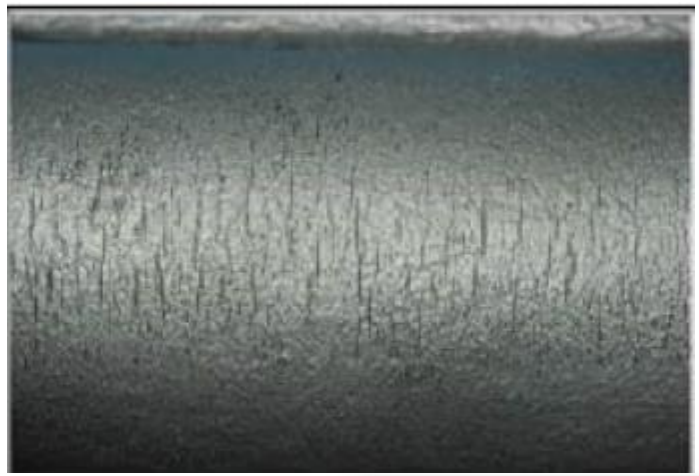
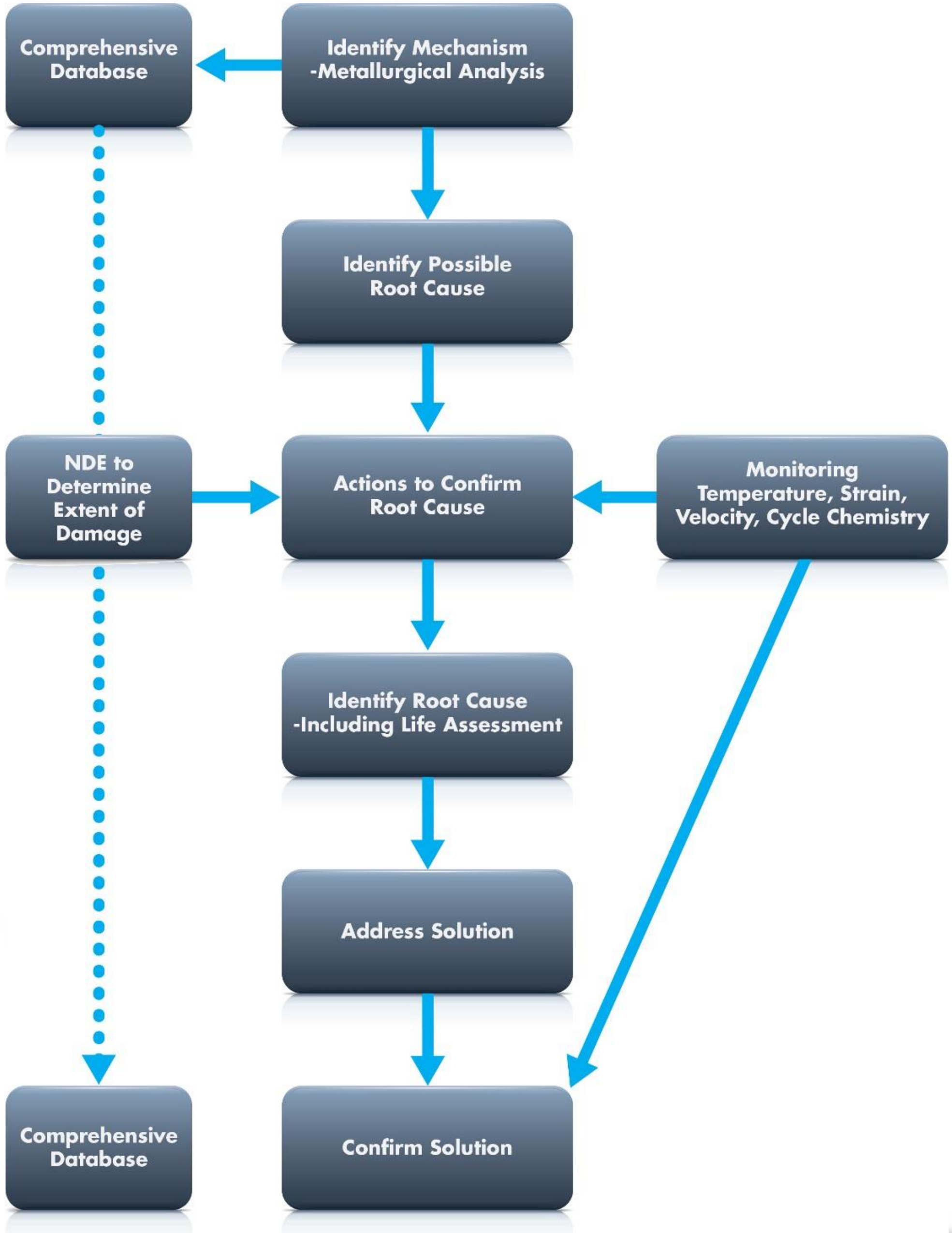
Boiler Tube Failures




Comprehensive Database
Identify Mechanism -Metallurgical Analysis
Identify Possible Root Cause
NDE to Determine Extent of Damage
Actions to Confirm Root Cause
Monitoring Temperature, Strain, Velocity, Cycle Chemistry
Identify Root Cause -Including Life Assessment
Address Solution
Comprehensive Database
Confirm Solution

Metallurgical Analysis

• A determination of the mode of damage responsible for the failure is an essential component of the root cause analysis, although in most cases it is *not* sufficient for identifying the root cause of failure.

• For critical boiler pressure parts, and tubing in particular, Metallurgical Analysis is the primary tool for determining the active damage mechanism, or mechanisms.

• An erroneous or incomplete analysis is worse than no analysis at all, since it will prompt inappropriate responses that do not address the basic cause of failure - and BTFs will continue

Elements of a Successful Metallurgical Analysis

- A sample containing the failure of interest or containing evidence of the damage responsible for the failure

- Accurate background information

- A laboratory equipped to conduct all non-destructive and destructive tests required to fully characterize the metallurgical condition of the Sample

- Materials specialists who can formulate a test program to accurately reveal the metallurgical condition of the sample, who can execute that program, and who then can correctly interpret the information obtained from the tests
  - Expertise in ferrous metallurgy, with broad experience in non-ferrous
  - A basic understanding of the design and operation of boilers and pressure parts
  - A basic understanding of manufacturing/construction processes as they apply to boiler tubing

Tube Sampling

- Photo documentation of failed area
- Drawing/sketch showing failure location in the boiler
- Labeling of the tube(s) in-situ (flow direction, hot side)
- Removal of the tube(s) via mechanical means
- Data snap shot of operations, water chemistry, excursions.

Boiler Tube Sample Form

(to be completed prior to forwarding sample for analysis)

please remember to mark flow direction and hot side of tube

Sample No. ___ of ___

Plant: ___

Unit: ___

Sample analysis needed as a result of:

___ a failure
___ for chemical cleaning purposes
___ condition assessment
___ internal deposit analysis
___ other

Boiler Manufacturer: ___ Unit Size (MW): ___

Total Hours of Operation: ___

Design Conditions Pressure (psig): ___ Temperature (F): ___ Steaming Rate (lbs/hr): ___

Operating Conditions Pressure (psig): ___ Temperature (F): ___ Steaming Rate (lbs/hr): ___

Steam Drum Pressure (psig): ___

*Outlet Conditions (i.e. finishing superheater tube → finishing superheater outlet header)

*Please provide thermocouple data of actual and/or similar tubes, if available.

When was the last chemical cleaning performed:

Date: ___ Hours of Operation Since: ___

Water Treatment Program:

Feedwater:

Evaporator:

Feedwater Components Materials of Construction: ___ (e.g. carbon steel, copper)

Tube(s) removed from: Type & Orientation (e.g. low temp, horizontal, etc.) (Provide drawings, if possible.)

___ Superheater
___ Reheater
___ Economizer
___ Waterwall
___ Other

Location: Furnace ___ Penthouse ___

Element No. ___ from the: ___ north wall ___ south wall ___ east wall ___ west wall

Tube Row ___ from the: ___ leading edge ___ top tube

Tube Elevation: ___

Material: ___

Diameter: ___

Wall Thickness: ___

*Specify nominal or min wall

Failure Mechanisms
Water Touched Tubes

- Corrosion Fatigue
- Flyash Erosion
- Hydrogen Damage
- Acid Phosphate Corrosion
- Caustic Gouging
- Waterwall Fireside Corrosion
- Thermal Fatigue (Waterwalls, Economizer Inlet Headers)
- Thermal-Mechanical and Vibrational Fatigue
- Flow-Accelerated Corrosion
- Sootblower Erosion
- Short-term Overheating
- Low Temperature Creep
- Pitting
- Coal Particle Erosion
- Acid Dewpoint Corrosion

Failure Mechanisms
Steam-Touched Tubes

- Longterm Overheating/Creep
- SH/RH Fireside Corrosion
- Dissimilar Metal Weld Failures
- Short-term Overheating
- Stress Corrosion Cracking
- Explosive Cleaning Damage
- Thermal-Mechanical and Vibrational Fatigue
- Rubbing/Fretting
- Pitting
- Graphitization
- Chemical Cleaning Damage
- Maintenance Damage
- Material Flaws
- Welding/Repair Defects

Cycle Chemistry

Cycle Chemistry (CC) is one of the most important factors of availability and performance or boilers and HRSG's

- influences about 50% of the boiler tube failures (BTF)
- influences about 70% of the HRSG tube failures (HTF)
- influences/controls every one of the main damage mechanisms in the steam turbine except liquid droplet erosion
- has a major influence on condenser tube and feedwater heater tube failures.

Identifying Failure Mechanisms

Laboratory Metallurgical Analysis

- Visual examination and photo-documentation
- NDE, where appropriate
- Chemical analysis
- Dimensional measurements
- Hardness Evaluation and/or Mechanical Properties Testing (RT or Elevated Temperature)
- Metallography
- Fractography/EDS Analysis
- Characterization of Internal and/or External Oxide/Deposit (EDS/XRD)

Identifying Failure Mechanisms

- Visual examination and photo-documentation - A preliminary diagnosis of the mechanism can often be made based on visual examination of the macroscopic damage features; this will determine the number and location of specimens removed for destructive analysis.

- Photo-documentation will record distinctive features of the damage prior to sample cutting and can indicate location of specimens removed for destructive analysis.

- Dimensional Measurements can:
  - ❑ Identify location and magnitude of wall loss
  - ❑ Identify degree of service-induced swelling, which is a measure of accumulated creep damage

Sample No.	Original ID (inch)	Measured ID (inch)	Apparent Swelling (%) at ID Surface	Amount of Life Expended
2	1.84	1.975	7.3	End of Life
3	1.84	1.920	4.3	>80%

Identifying Failure Mechanisms

Metallography

- Microstructure
- Microstructural degradation (spheroidization,

graphitization) or transformation

- Damage type, extent, and morphology (cracking/fracture path, rupture features, corrosion, pitting, cavitation)
- Appearance and thickness of internal and external oxides/scales/deposits

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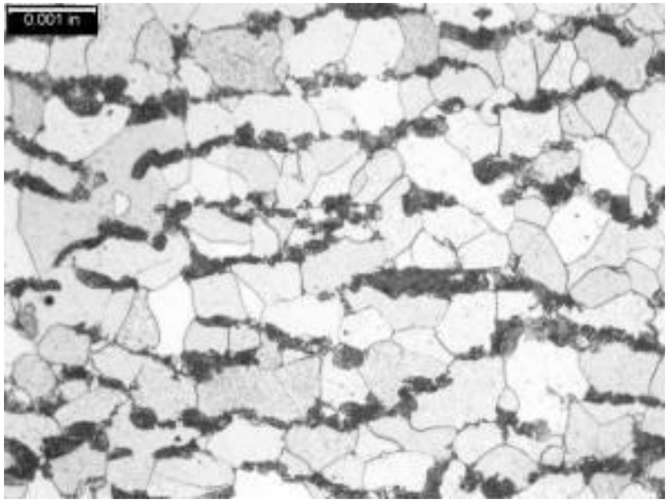
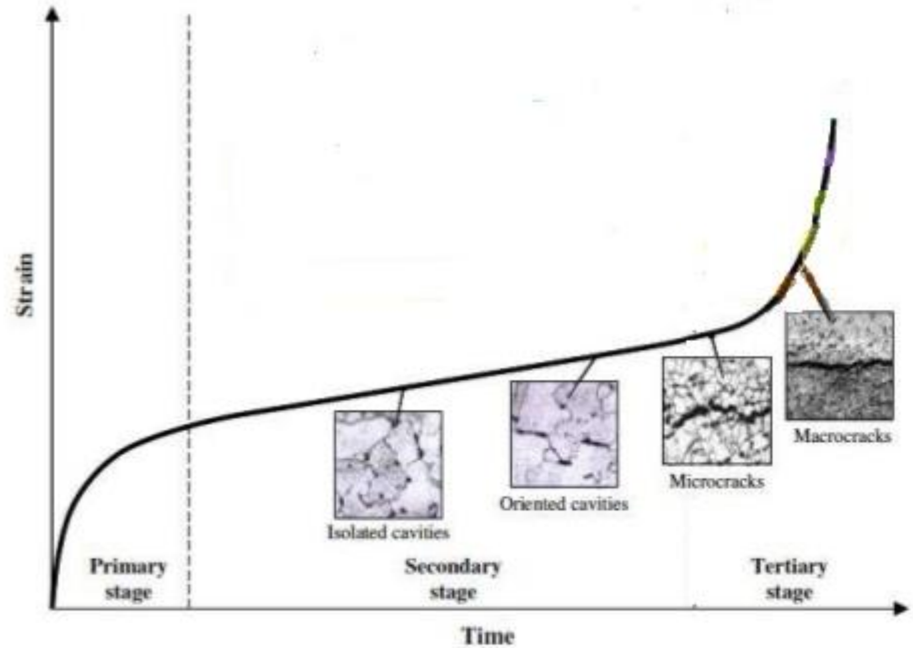
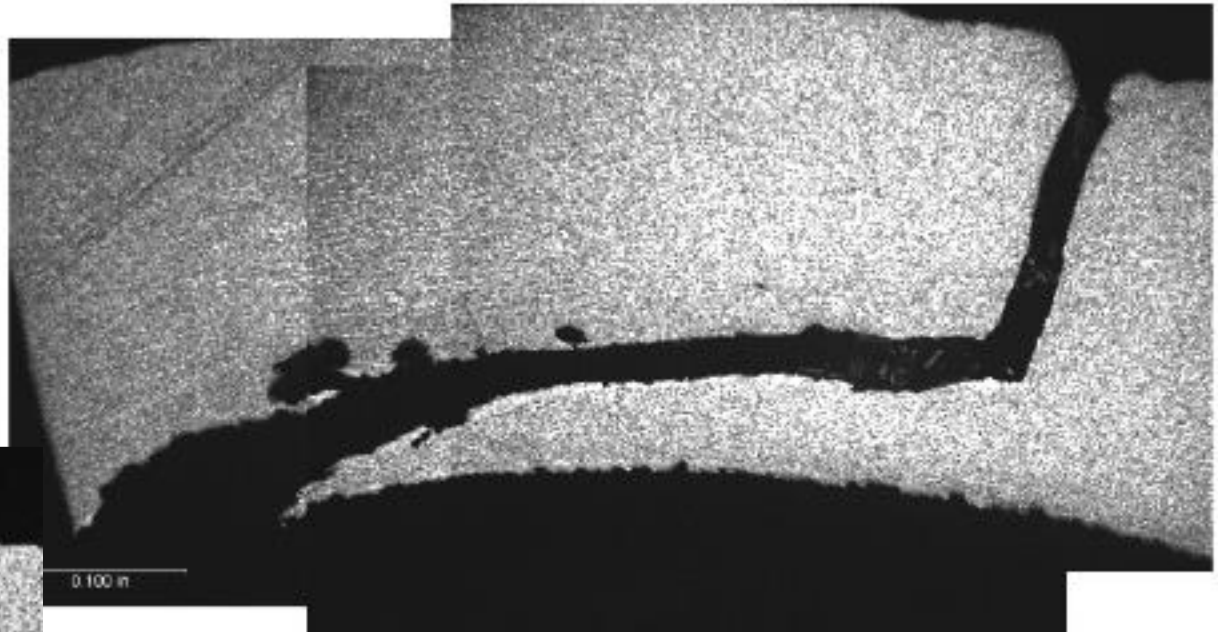


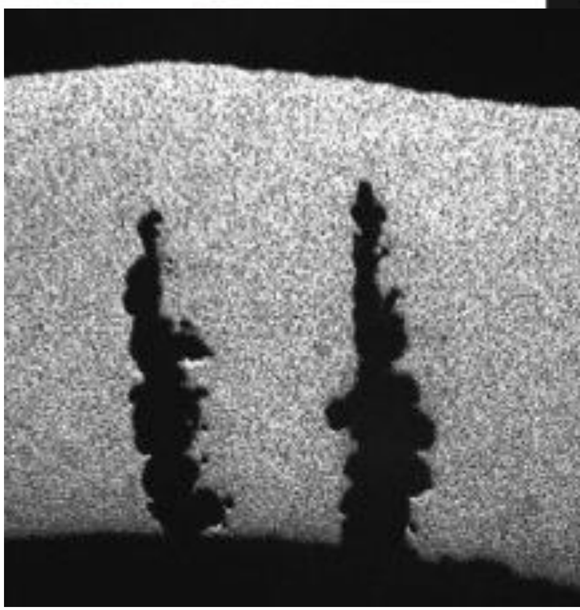


Carbon Steel Graphitization

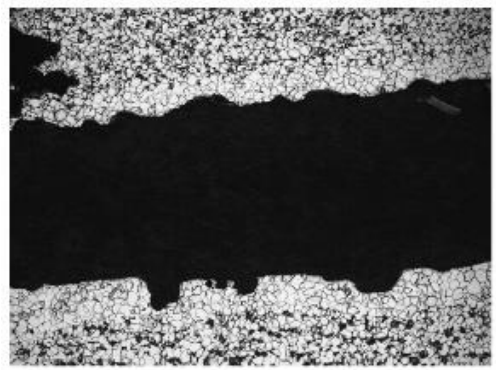
Alloy Steel Creep

Metallography-Damage Extent and Morphology

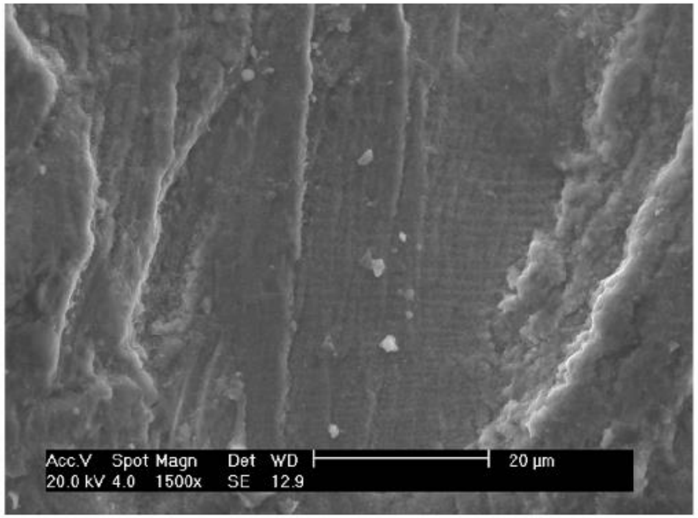




Manufacturing Lap

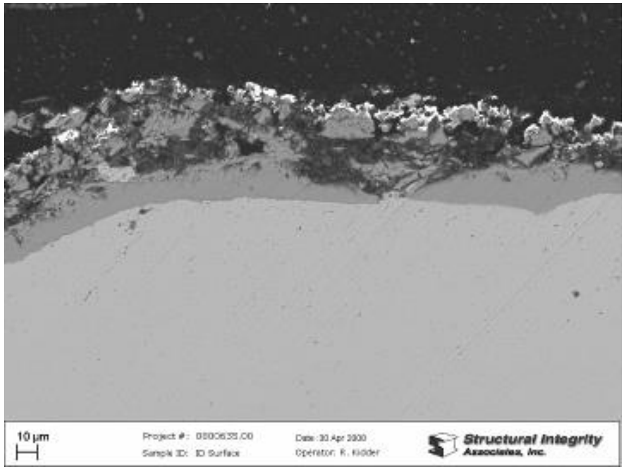


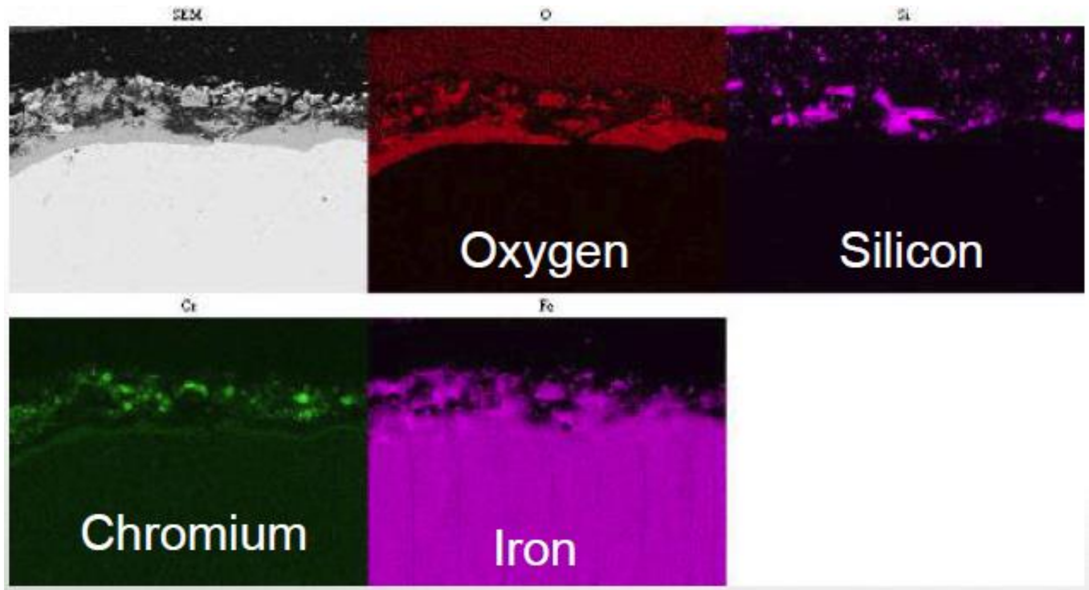
"Thumb-nail" shaped fatigue crack initiating at attachment weld on OD surface of tube.



Fatigue striations indicating high cycle fatigue. Arrow indicates area of fatigue striations and the direction of propagation.

Characterization of Internal and/or External Oxides/Deposits





Compositional Analysis

– Does the material meet specifications?

- Are elements critical to service at low end/high end of permissible range (e.g., Cr, Mo, Cb, N, Al)

– Equally important, are non-specified elements present at levels that would affect material performance adversely

- Low strength stainless steel (low nitrogen)
- Low temperature creep crack growth (high nitrogen and surface-active tramps, such as arsenic, tin, antimony)
- Poor rupture ductility in welds and BM (high surface-active tramps)

Case Histories – Damage Mechanisms with Similar Characteristics

	Hydrogen Damage	Caustic Gouging	Acid Phosphate Corrosion
Failure Characteristics	• Gouged area • Thick deposits • Thick-edged rupture, often a window rupture, brittle appearance	• Gouged area • Thick, adherent deposits • Thin-edged rupture or pinhole leak, ductile appearance	• Gouged area • Thick, loose deposits • Thin-edged rupture or pinhole leak, ductile appearance
Deposit Characteristics	• Multilayer scale, often lost during rupture	• Caustic (sodium) concentrates in deposit at base of gouge • Crystals of sodium ferroate and/or sodium ferroite	• Acid phosphate chemicals (phosphorus) concentrate in deposit at base of gouge • Two or three distinct layers with the inner layer being white/gray and speckled with red
Microstructural Characteristics	• Intergranular fissures emanating from ID surface of tube • Decarburization of the pearlite	• No microstructural changes	• No microstructural changes

Take-Aways

- You don’t have to live with Boiler or HRSG Tube Failures
- Attack problem from a systematic, continuous improvement approach
- Don’t assume what caused the failure, may failures look the same but have a completely different mechanism. Metallography and deposit analysis are necessary to determine the correct mechanism
- Water Chemistry!
- All met labs are not created equal

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