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Preparing Breakers for Cold Weather with Failure Modes and Mechanisms

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Winter Weather Preparation Webinar

September 6, 2018

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Preparing Breakers for Cold Weather

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Lesson Learned

Preparing Circuit Breakers for Operation in Cold Weather

Primary Interest Groups
Generator Owners (GOs)
Generator Operators (GOPs)
Transmission Owners (TOs)
Transmission Operators (TOPs)

Problem Statement
After two sequential line faults, an entire substation and a 1,150 MW nuclear plant tripped off-line due to consecutive breaker failures during cold weather (4°F).

Details
Two sequential B-phase faults occurred on a 500 kV line, apparently due to icing. Three breakers subsequently experienced breaker failure (failure-to-trip) events, de-energizing an entire substation and tripping a large generating unit off-line. The first breaker (Breaker 1, a SF_6 breaker with hydraulic mechanism) opened properly for the first fault, but did not reclose correctly. Breaker 1 experienced a hydraulic mechanism malfunction and correctly reclosed on only two of its three phases. As a result, Breaker 1 was unable to respond to the second fault. After that, two other breakers (Breakers 2 and 3, SF_6 breakers with pneumatic trip/spring close mechanisms) were very slow to trip on B-phase. For Breakers 2 and 3, there was a failure of the center pole to clear the fault quickly enough due to cold temperatures.

Corrective Actions
For Breaker 1, a defective motor contactor was discovered and replaced and a full hydraulic service was performed on all three phases. A diagnostic service was also performed to ensure that the breaker was ready to be returned to service.

- There was no cost effective way identified to foretell or prevent the issues discovered with Breaker 1. This type of failure has not been a systemic problem at other locations. The entity is still evaluating counter-measures based on these findings and will continue to monitor the condition of this breaker using existing preventive maintenance guidelines.

For Breakers 2 and 3, the manufacturer engineered a fix consisting of additional thermostatically-controlled cabinet heaters that prevent moisture from freezing inside the pneumatic (air) control valve during cold-weather conditions. One breaker also needed repair to the trip-coil circuitry. The engineered fix and repairs were completed for both breakers. A diagnostic service was also performed to ensure that both breakers were ready to be returned to service.

- Application of the engineered short-term fix to Breakers 2 and 3 prevents future operational issues on B-phase pneumatic control valve during low-temperature conditions. The manufacturer is developing a long-term fix.

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https://www.nerc.com/pa/rrm/ea/Lessons%20Learned%20Document%20Library/LL20180702_Preparing_Circuit_Breakers_for_Operation_in_Cold_Weather.pdf

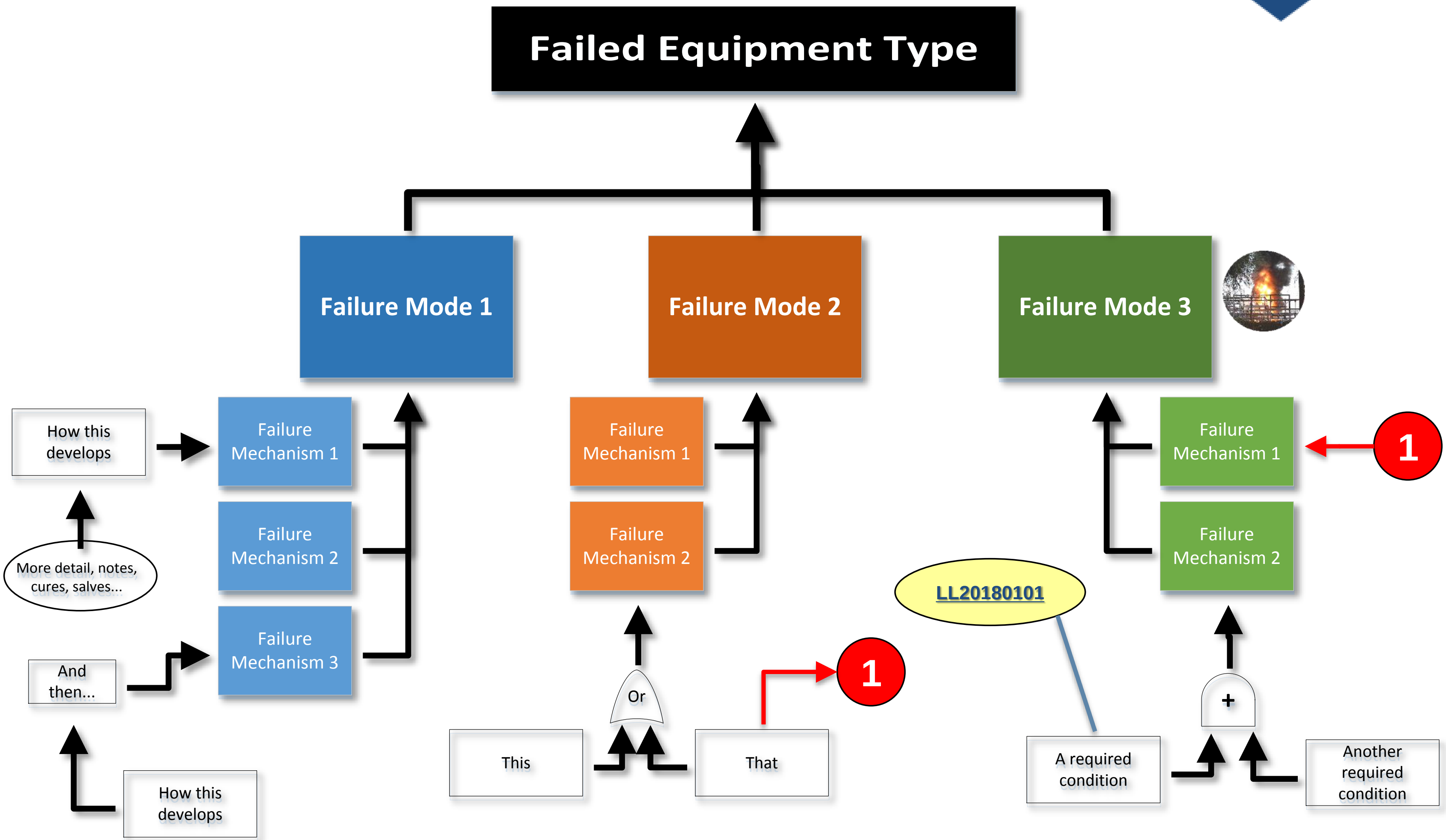
How to Find Lessons Learned

https://www.nerc.com/pa/rrm/ea/Pages/Lessons-Learned.aspx

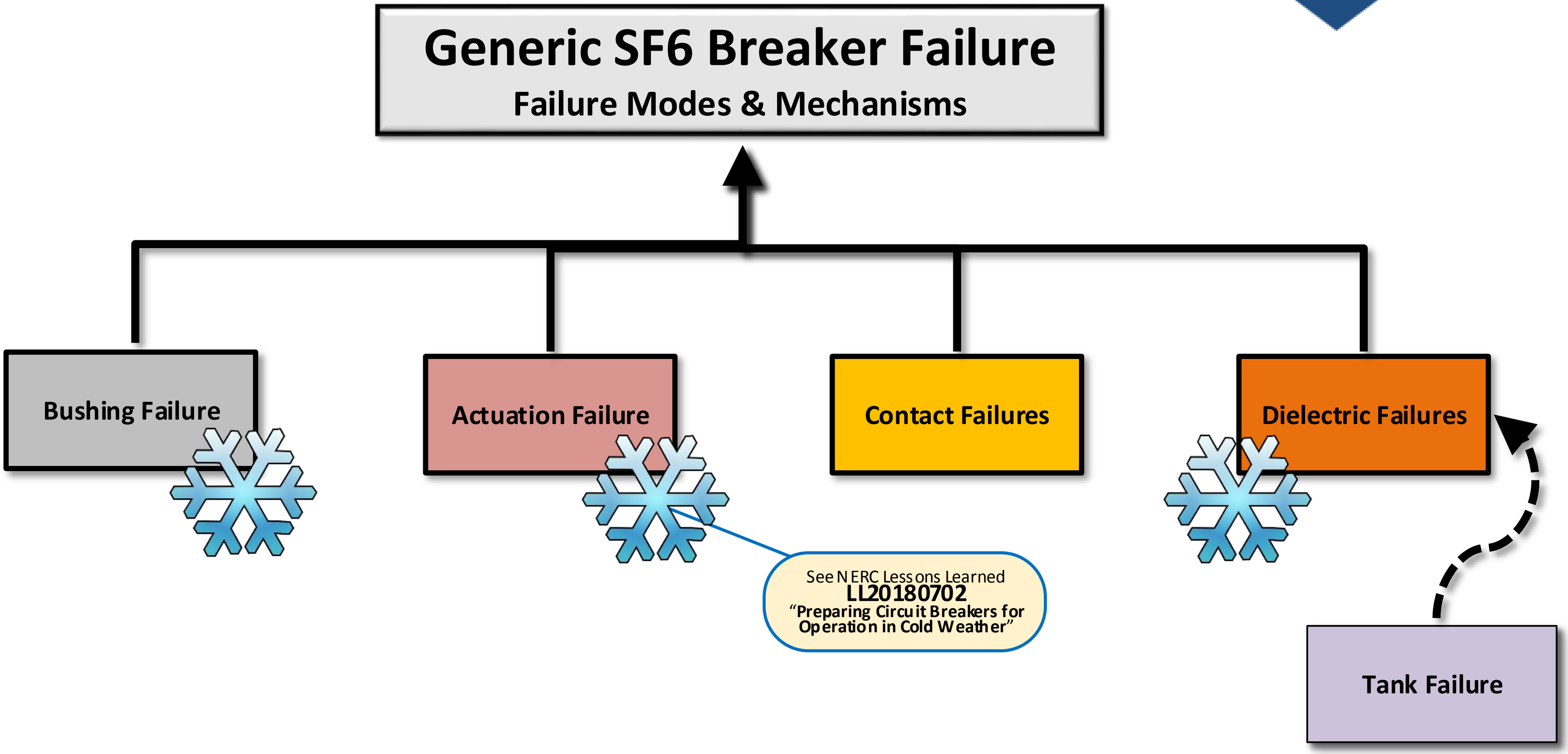
Failure Modes and Mechanisms (FMMs)

- Failure Modes are what gets your attention
- Failure Mechanisms are how the equipment gets going on the path to a failure
- Equipment Failures have logical cause-and-effect relationships behind them.
- Physical Evidence Examination and Root Cause Analysis can reveal what Failure Mechanisms were involved.
- Aging is not a ‘cause.’ It is just a catch-all term for slow moving Failure Mechanisms.
- Failure Mechanisms are detectable. Many can be stopped, or at least slowed down so they can be corrected before

Generic Failure Modes & Mechanisms Layout



SF6 Breaker Failure Modes



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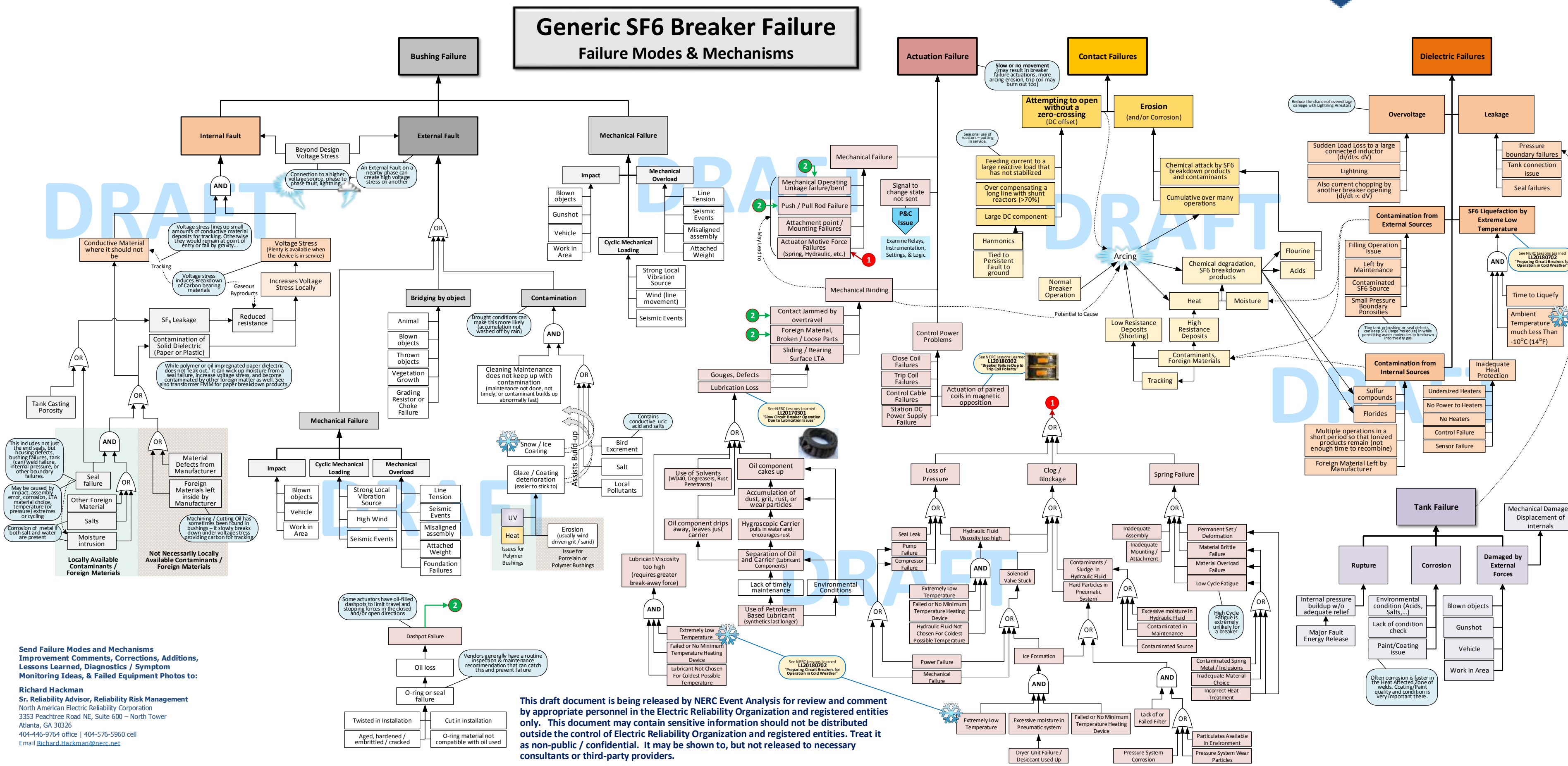

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Send Failure Modes and Mechanisms Improvement Comments, Corrections, Additions, Lessons Learned, Diagnostics / Symptom Monitoring Ideas, & Failed Equipment Photos to:

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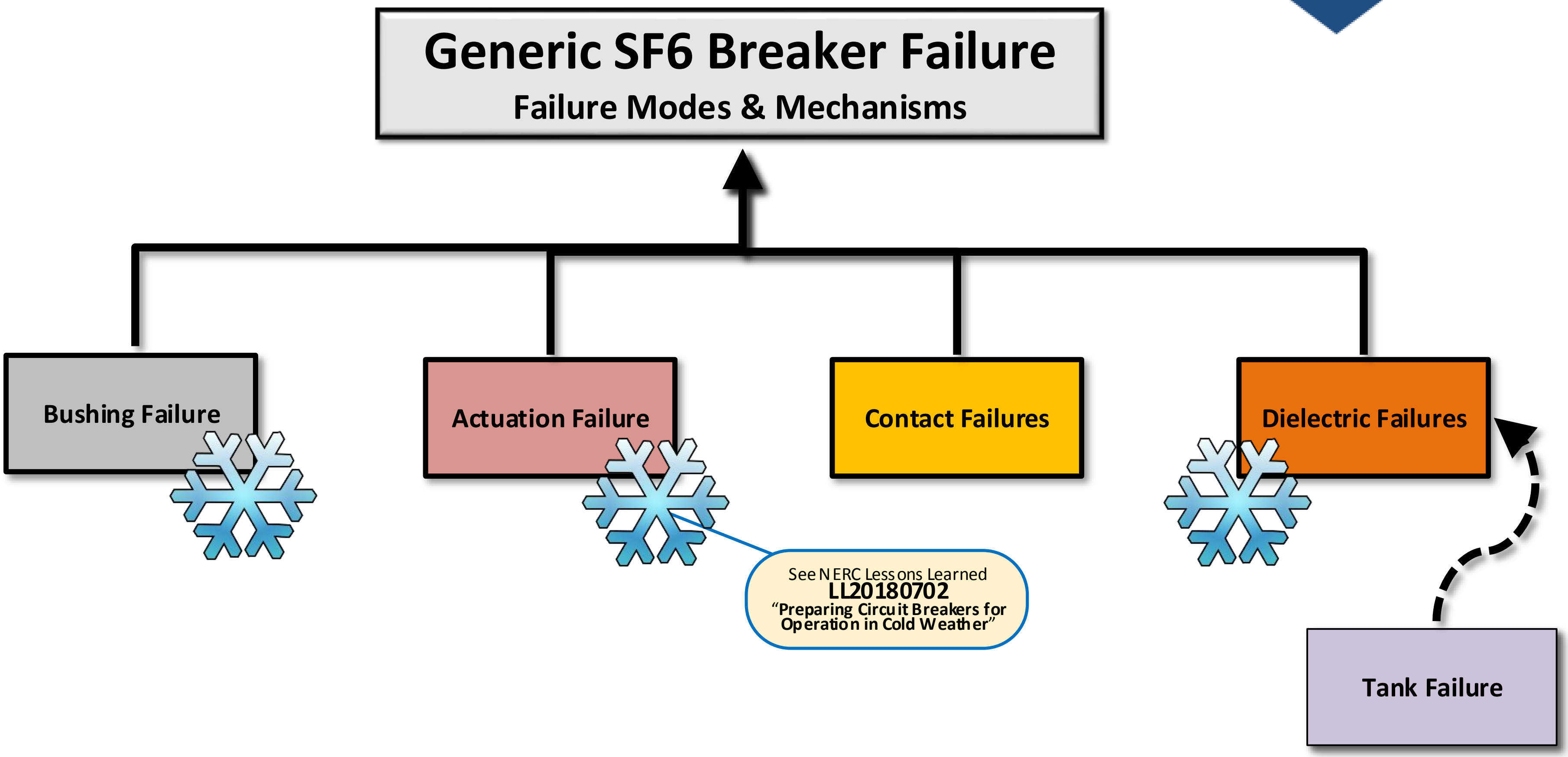
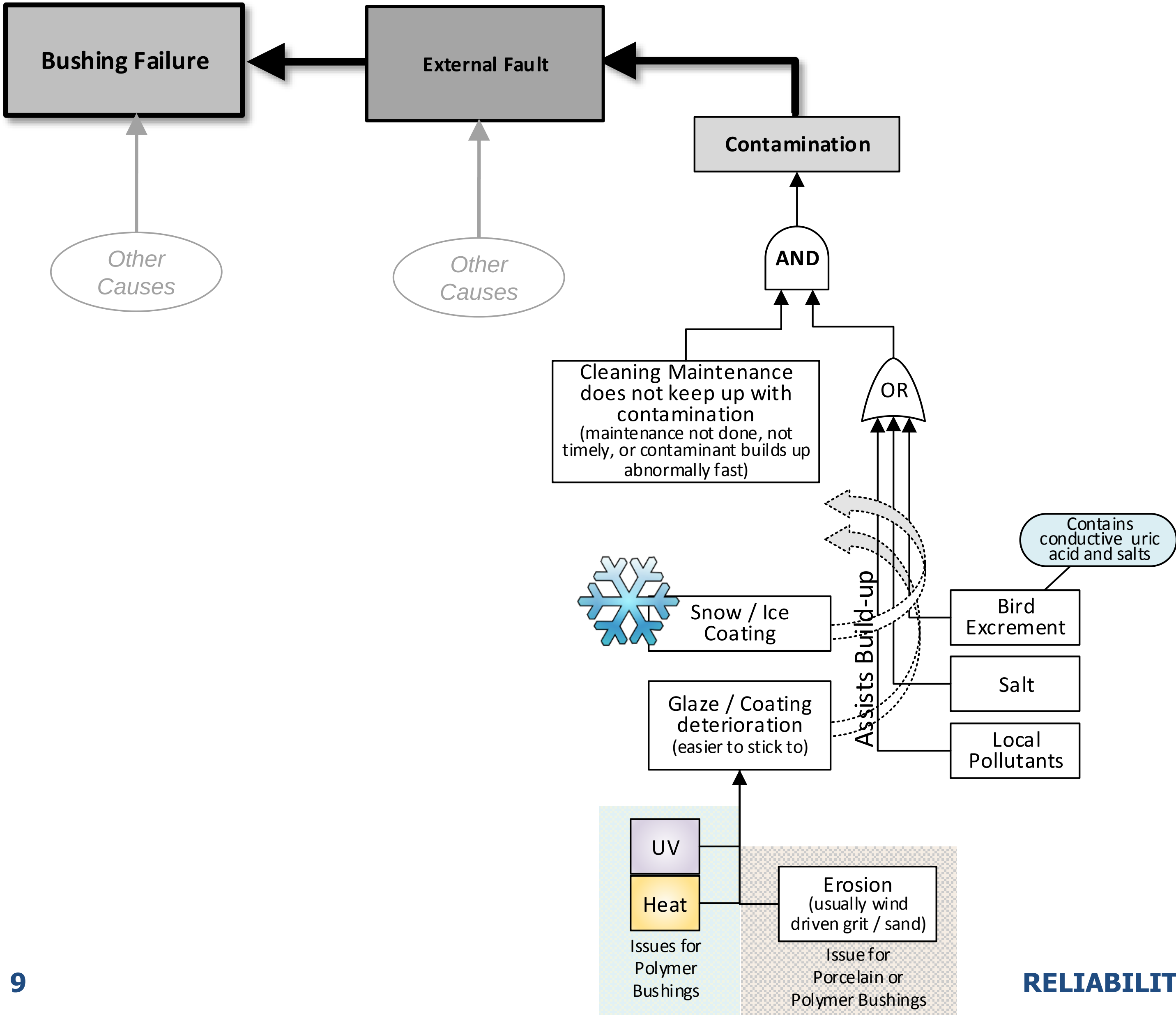


SF6 Breaker Failure Mechanisms



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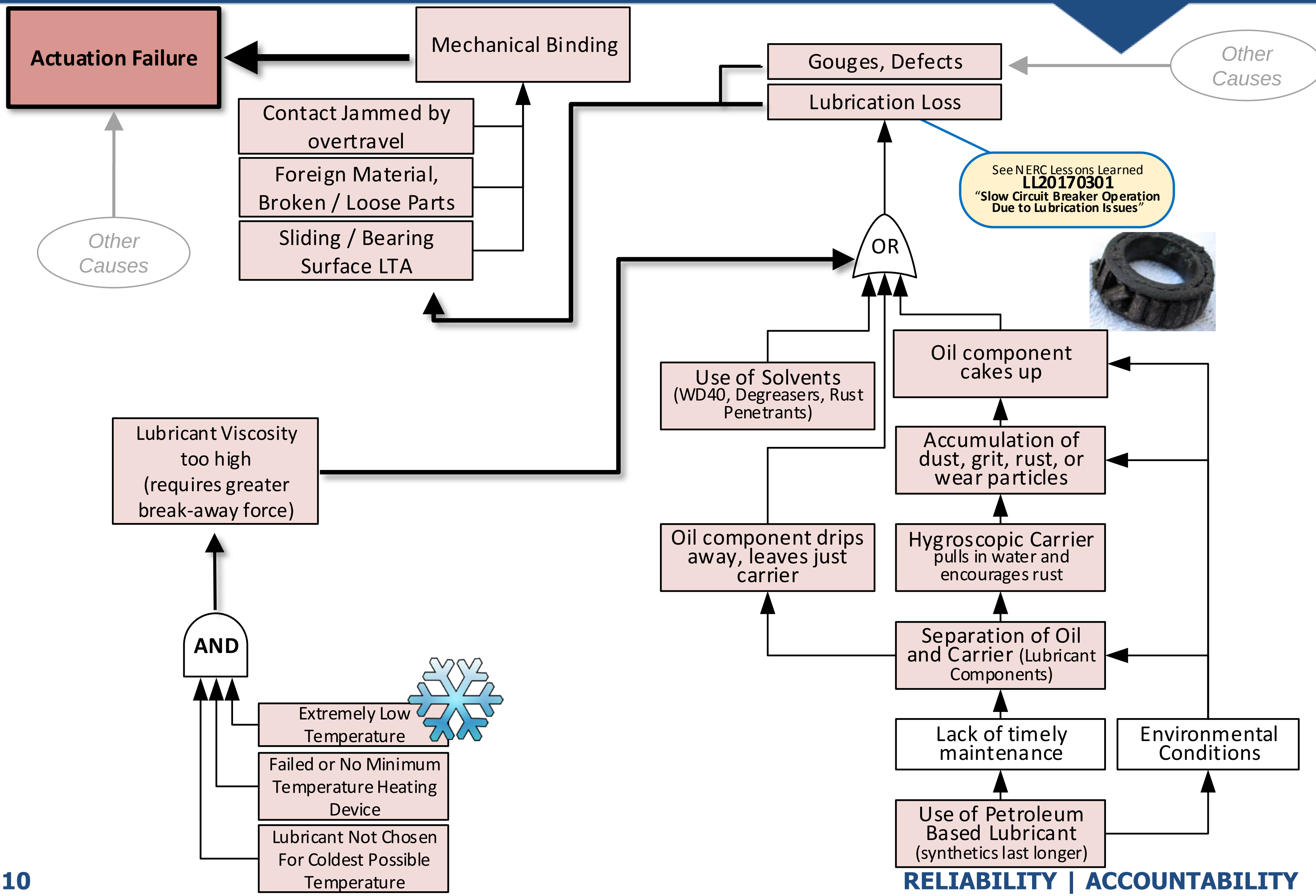

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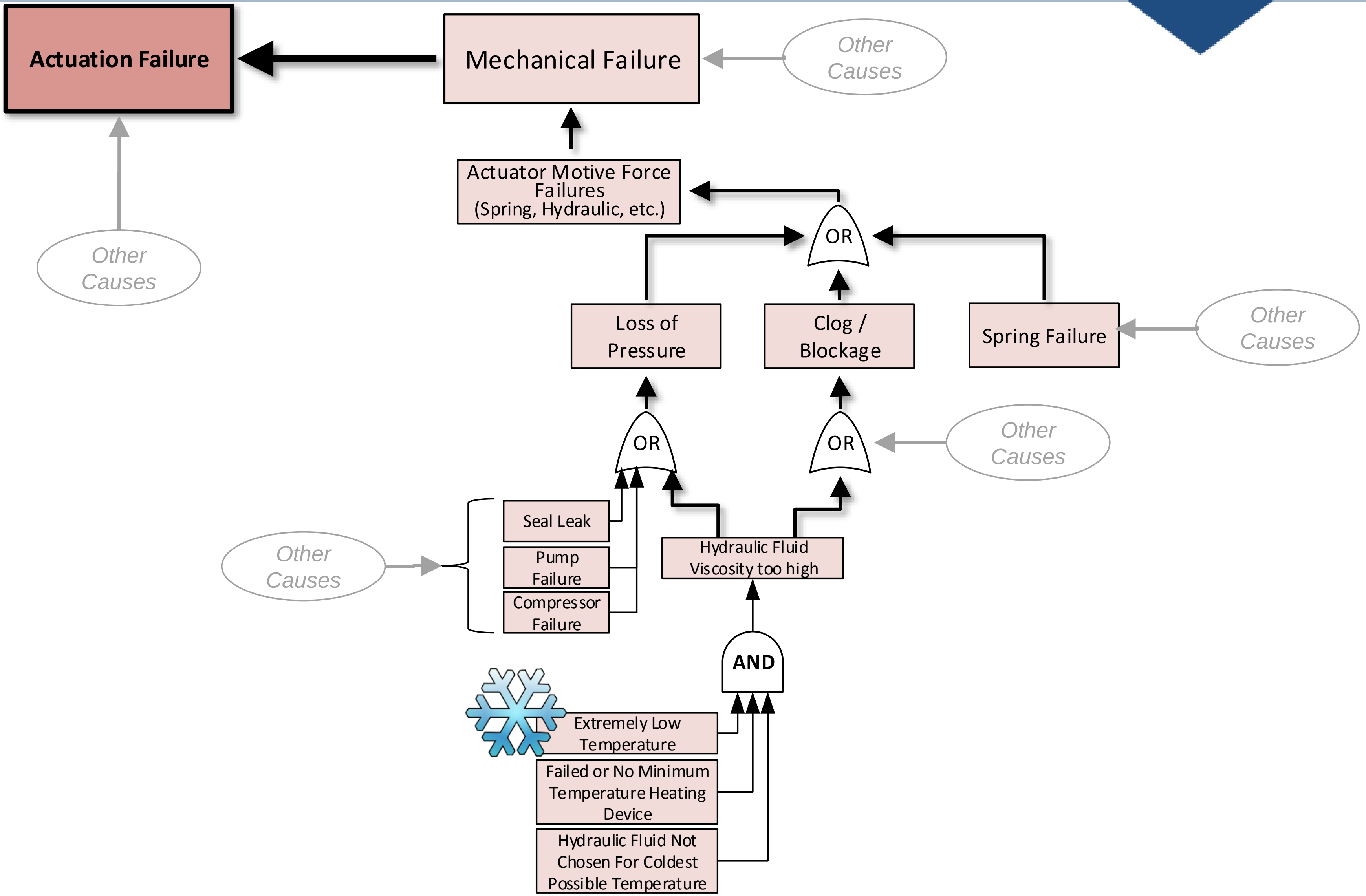

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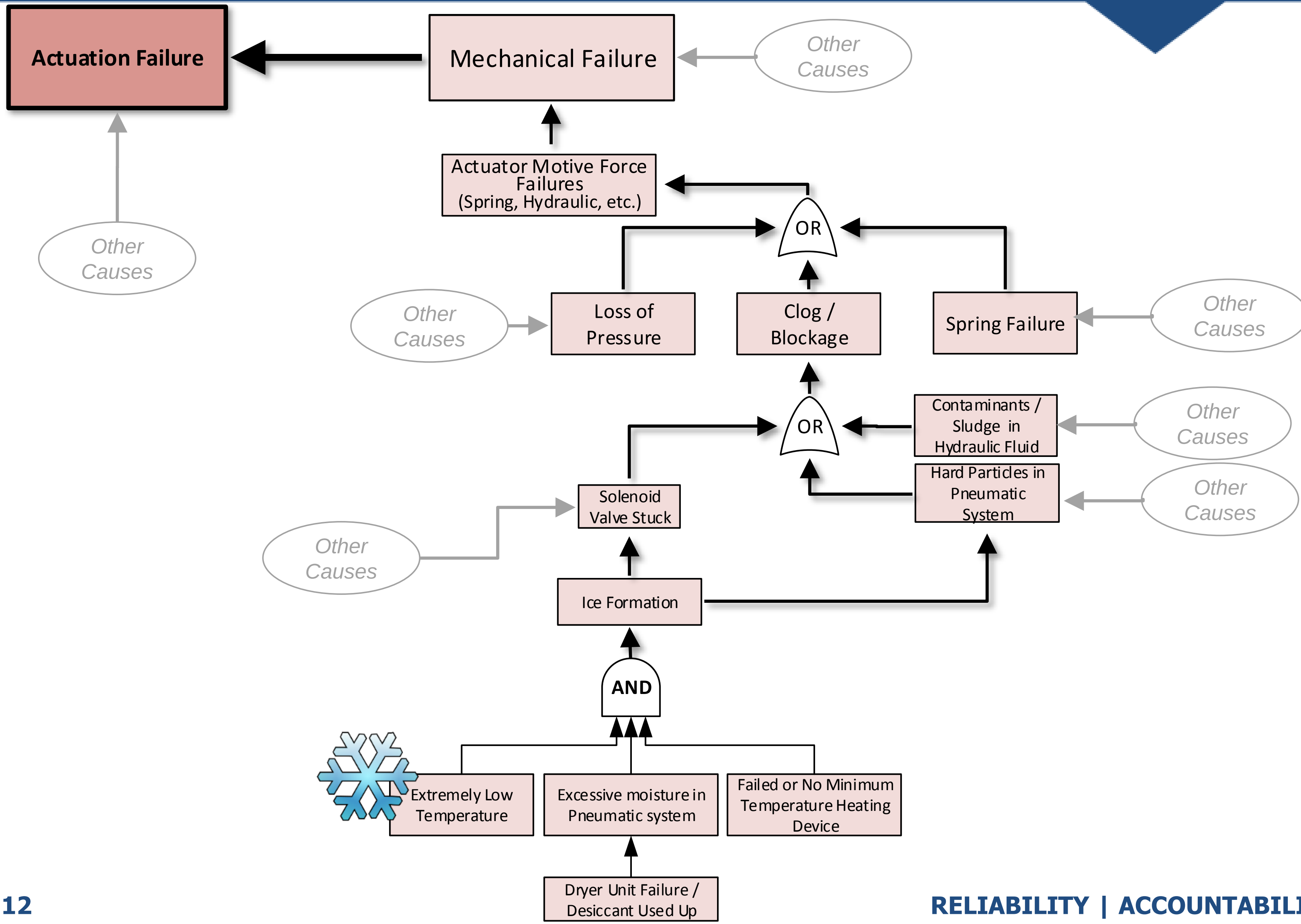

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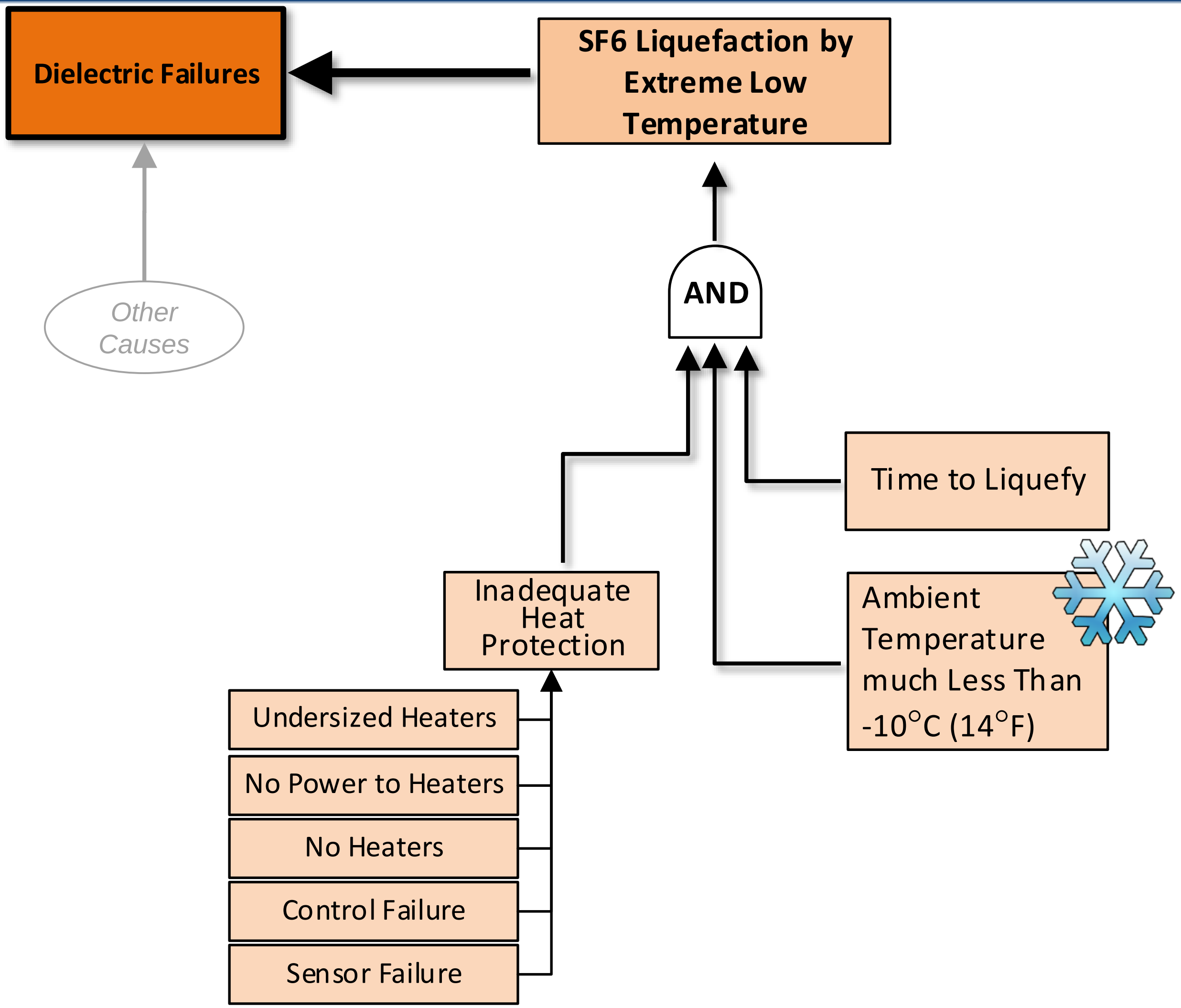

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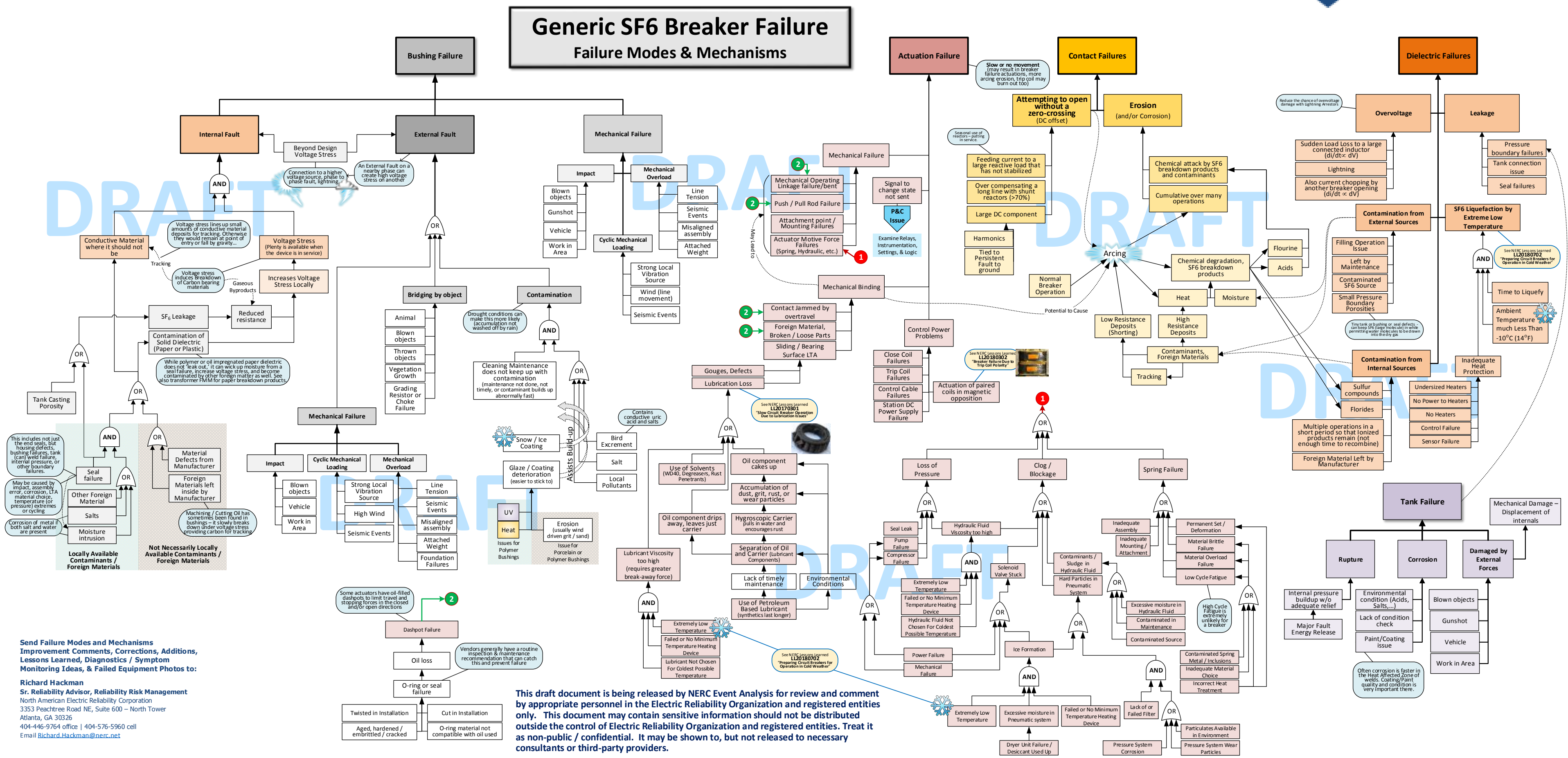
SF6 Breaker Failure Modes & Mechanisms



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- There were two additional breakers from the same manufacturer at the same substation. The same short-term fix was also applied to those breakers.

Lessons Learned

Breakers have several cold-temperature-related failure mechanisms. A good practice is to annually (prior to first frost date for the location) perform pre-cold weather checks (seal condition, lubrication, pressures, dielectric, dryers, and adequate functioning heaters or heat tracing) for cold-sensitive components.

Other Cold Weather Breaker Issues

Hydraulic

- Sections that are normally at air pressure may pull contaminants in past seals as cooling pulls a vacuum there. If contaminated with water - ice gets in the works - can plug ports.
- If oil is breaking down, sludge may form that can also harden at cold temperatures.
- Hydraulic oil becomes more viscous as it gets colder; ensure oil used is rated for conditions colder than expected.
- Seals may shrink, harden or crack and leak, losing oil and pressure.
- If the design uses belt-driven pumps, belts may embrittle/crack. Belt shrinkage may cause axles to pull into misalignment (rubbing, dragging, seizing, belt coming off, belt failure, axle bearing failure, axle seal failure).

Gas / Air pressure operated

- Extreme cold reduces pressure (Ideal Gas Law $PV = nRT$). If pressure was already close to low end of operability, the cold will take it below (the compressor should cycle on to make up for that). Reduced pressure reduces the capacity of the breaker to interrupt an arc. Extra margin is needed for extreme cold.
- Seals may shrink, harden or crack and leak, losing gas and pressure. Sections that are normally at air pressure may pull contaminants, (including moisture which can freeze) in past seals as cold pulls a vacuum there.
- Compressor belts may embrittle and crack. Belt shrinkage may cause axles to pull into misalignment (e.g., rubbing, dragging, seizing, belt coming off, belt failure, axle bearing failure, axle seal failure). Air compressors need intakes that are protected from the elements (water and dust ingestion, freezing over) and the air water separator/dryer maintained (desiccant monitoring and replacement).
- SF_6 gas condenses to liquid at temperatures encountered in northern winters (-10°F/-23.3°C to -30°F/34.4°C depending on pressure, - generally between 95 and 70psig). This requires heaters to keep the SF_6 in a gaseous state.
- Heaters (and insulation) that do not provide complete coverage of the SF_6 volume (and tubing) may allow cold pockets for SF_6 condensation.

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General/Mechanical

- Exposed mechanisms can be frozen over, requiring more force to break free and move initially.
- Differential expansion coefficients of materials can cause sliding surfaces to become tighter or seize if the outer material shrinks faster with cold than the inner surface. It is worse if lubrication is less than adequate or if grit has gotten in between surfaces.
- Lubricants thicken as they get colder. There is a viscosity limit; ensure the lubricant used is rated for more than the expected temperature range (cold and hot) since temperature records are broken in both directions eventually. If lubricant component separation occurs (reference other slow breaker LL), lubrication becomes less than adequate.

Cold weather impacts other substation, transmission, and generation equipment too. NERC Event Analysis is developing substation equipment Failure Modes and Mechanism (FMM) information that includes cold weather impacts. NERC conducts annual webinars on Winter Weather Preparedness for the industry.

Click here for: Lesson Learned Comment Form

For more Information please contact:

NERC – Lessons Learned (via email)	WECC Event Analysis
Source of Lesson Learned:	Western Electric Coordinating Council
Lesson Learned #:	20180702
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Category:	Transmission Facilities

This document is designed to convey lessons learned from NERC's various activities. It is not intended to establish new requirements under NERC's Reliability Standards or to modify the requirements in any existing Reliability Standards. Compliance will continue to be determined based on language in the NERC Reliability Standards as they may be amended from time to time. Implementation of this lesson learned is not a substitute for compliance with requirements in NERC's Reliability Standards.

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Learn more about Failure Modes & Mechanisms at: *https://vimeopro.com/nerclearning/cause-coding/video/208745179*

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Questions and Answers