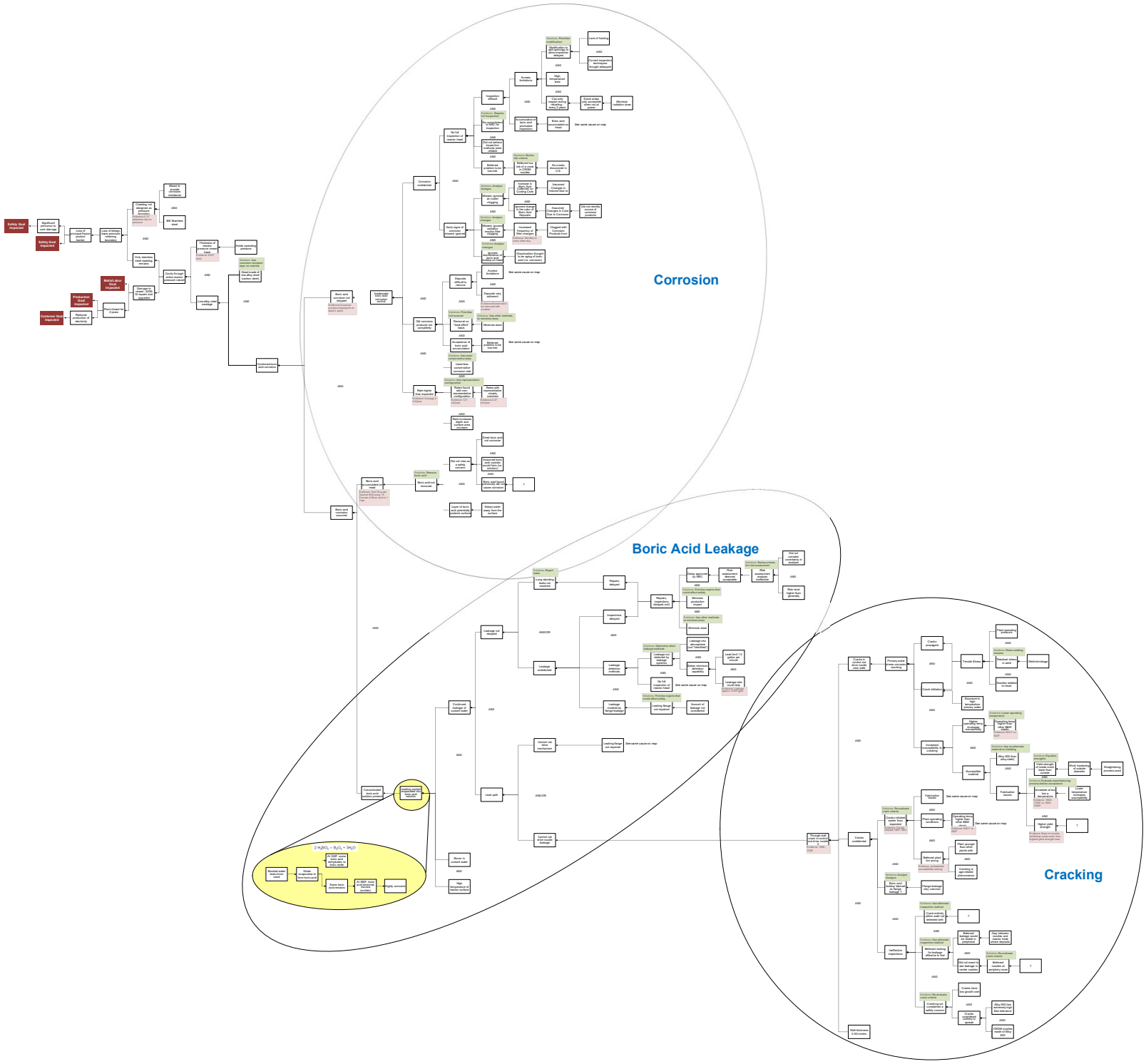
Corrosion
Boric Acid Leakage
Cracking
Safety Goal Impacted
Significant consequence core damage
Safety Goal Impacted
Loss of primary pressure boundary
Loss of design basis pressure retaining boundary
Cladding not designed as pressure boundary
Evidence: 1/2 of cladding not for pressure
Steel is ferritic material
304 Stainless steel
Only stainless steel is design basis
Early through entire reactor vessel wall
Damage to cladding, SI spurs and upgrades
Material Goal Impacted
Production Goal Impacted
Plant closed for 2 years
Safety Goal Impacted
Reduce production of electricity
Thickness of reactor pressure vessel head
Evidence: 6.25" thick
Low-alloy steel (carbon steel)
Stainless steel cladded carbon steel
Solutions: Use stainless cladded carbon steel
Head made of low alloy steel (carbon steel)
Continued from acid corrosion
Boric acid corrosion not detected
Evidence: Corrosion process ongoing for at least 2 years
Inadequate boric acid corrosion control
Corrosion underway
Not inspected to ASME for inspection
Evidence: Reactor not inspected to ASME for inspection
Inspection difficult
Access limitations
High temperature area
Solutions: Prioritize modification
Modification to make inspection area more inspection adequate
Lack of loading
Current inspection techniques thought adequate
Concrete shielding is "shielding" in every 2 years
Some areas inaccessible when not at power
Stainless radiation dose
Preservation boric acid deposition
Boric acid accumulation on head
See same cause on map
Not all surfaces inspected
Evidence: Not all surfaces inspected
Relevant problem locations
Relevant low risk of a pipe rupture in nozzles
Solutions: Revise risk criteria
Nozzle cracks discovered in U.S.
Early signs of issues, ignored
Solutions: Analyze changes
Relevant ignored air cooler changing
Ignored change of Boric Acid Concentration
Ignored in "Boric Acid Corrosion Control Cooling Coils"
Assumed Changes in Volume Due to
Ignored change of Boric Acid Concentration
Assumed Changes in Volume Due to Carbonate
Did not identify corrosion product
Solutions: Analyze changes
Relevant ignored radiation monitor changing
Increased radiation levels
Clogged with Corrosion Products from
Evidence: Identify in every other day
Solutions: Analyze changes
Ignored in "Boric Acid Corrosion Control"
Preservation through to the aging of boric acid (no corrosion)
See same cause on map
Deposits difficult to remove
Access limitations
Deposits very substantial
Not accessible to be removed with cleaning
Solutions: Prioritize substantial
Removal on "hard-to-reach" locations
Solutions: Use other methods to remove dross
Dross on steel
Accumulation of corrosion products
Solutions: Use other methods to remove dross
Relevant Boron Dross towards
See same cause on map
Solutions: Use more conservative criteria
Used less conservative (average) rate of corrosion
Solutions: Use representative configuration
Rates found in representative configuration
Evidence: 0.127 inches/year
Rates with crevices, crevice assumed
Evidence: 0.41 inches/year
Rate higher than expected
Evidence: Average 0.4 inches
Rate on nozzle angle and nozzle material
Dried boric acid not corrosive
Did not view as a active corrosion
Assumed boric acid crystals (not boric acid solution)
Boric acid form cancer corrosion
?
Solutions: Remove boric acid
Boric acid not removed
Boric acid and corrosion removed
Evidence: Due Date per Procedure Boric Acid in Core
Layer of boric acid and corrosion products solidified
Always water underneath layer
Boric acid corrosion resumed
Solutions: Prioritize modification
Modification to make inspection area more inspection adequate
Lack of loading
Current inspection techniques thought adequate
Leakage not stopped
Leakage not detected
Long standing leaks not repaired
Solutions: Repair leaks
Repairs delayed
Repairs, diagnostic analysis pulls
Delay approved by NRC
Risk assessment deemed conservative
Risk assessment analysis conservative
Solutions: Review criteria, risk assessment
Did not consider conservative analysis
Risk level higher than generally
Solutions: Prioritize repairs that could affect safety
Minimize radiation exposure
Solutions: Use other methods to minimize dose
Minimize dose
Inspections delayed
Leakage detection methods
Solutions: Determine other leakage locations
Leakage not detected by current system
Leakage not detected by system
Leakage too alternative use "sensitive"
Relax minimum leakage capability
Leak level 1/4 gallon per minute
Leakage rate 1/4 gallon
Evidence: 1 gallon approx 0.1 inches
See same cause on map
Re-full inspection of reactor head
Leakage modified by Barge-Hydrogen
Solutions: Prioritize repairs that could affect safety
Leaking Barge not repaired
Amount of leakage not considered
Leakage rate modified
Leakage not stopped
Leakage rate
Control rod drive mechanisms
Leaking Barge not repaired
See same cause on map
Control rod drive mechanism leakage
Control rod drive mechanisms
Leak path
Continued leakage of control rodes
Boron in control rodes
High temperature of nozzle surface
Concentrated boric acid solution present
Leaking control rod drive mechanism
$2\,H_3BO_3 = B_2O_3 + 3H_2O$
Required water treats boron cause
Water evaporated to form borboxylic
Same boric acid solution
H SEP, same H SEP, same Chlorine excellent
Highly corrosive
Through-wall cracks, leak-before-and-drop-outside
Evidence: 1000, 1000
Cracks in reactor vessel nozzle welds
Primary water stress corrosion cracking
Cracks propagate
Tensile Stress
Plant operating pressure
Residual stress in weld
Residual stress
Weld shrinkage
Crack initiation
Nozzles welded to head
Exposed to high temperature primary water
Higher than 550 F, leads to increase susceptibility
Solutions: Lower operating temperature
Preparing New Alloy 690 or other SBIR
Evidence: 550 F, 600 F
Increased susceptibility to cracking
Sensitized material
Solutions: Use alternate material or cladding
Alloy 600 Zero susceptibility
Fabrication issues
Solutions: Review manufacturing process before experiment
Annealed at low temperature
Evidence: 1000 F, 1000 F, 1000 F, 1000 F
Lower temperature increase susceptibility
Solutions: Review welding cracks
Crack leadtimes shorter
Shrinkage process occurred
Higher than strength
?
Solutions: Prevent welding cracks better than original plant strength level
See same cause on map
Fabrication issues
Plant operating conditions
Operating less than 550 F after SBIR
Evidence: 550 F, 550 F, 550 F, 550 F
See same cause on map
Cracks
Solutions: Reevaluate crack criteria
Cracks initiated under Boric Acid Corrosion
Evidence: Cracking, 1000 F, 1000 F, 1000 F
Relieved plant for piping
Evidence: probability susceptibility reduce
Plant younger than other plants with
Cracking is age-related phenomenon
Boric acid leakage, Hydrogen leakage
Barrier leakage not considered
Solutions: Analyze changes
Ineffective inspections
Solutions: Use alternate inspection method
Crack entering plates weld on Stainless steel
?
Solutions: Use alternate inspection method
Relieved looking for leakage, ineffective to find
Relieve up leakage results in peripheral
Gap between nozzles and control rod drive elements
Did not assume see leakage in nozzle welded
Relieved number at peripheral
?
Solutions: Reevaluate crack criteria
Cracks in reactor vessel nozzle welds cracking
Cracks have grown cold
Cracks considered cracking spread
Alloy 600 has extremely high flow fatigue
CRDM nozzles made of Alloy 600
Wall thickness 0.50 inches