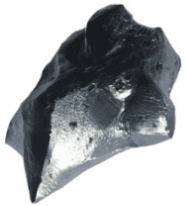
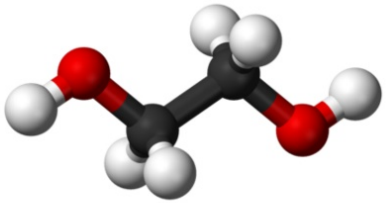
Team 7's Case Study

Glycol Desalination Plant





Root Cause Analysis

Identified Root Causes

Case Study Background

Corrosion Risk Assessment

Introduction

Mitigation

Conclusion

Team 7 - Members

Julia Tan
Wood Plc

Rachael Milne
BP

Agenda

Jorge Garcia
SGN

Oneeb Khan
Subsea7

Agenda

- Overview of the Desalination Plant and Case Study
- Mechanical and Operational Root Cause Analysis
- Identified Root Causes
- Corrosion Risk Assessment
- Mitigation Plans
- Concluding Remarks

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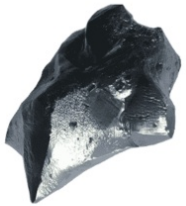

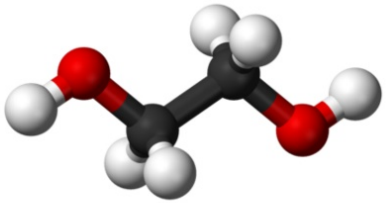

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Desalination Plant Overview

Case Study Background

- Overview of the Desalination Plant
- Leak Locations and Details
- Spool Piping Branch Details: Material and Design Operating Parameters

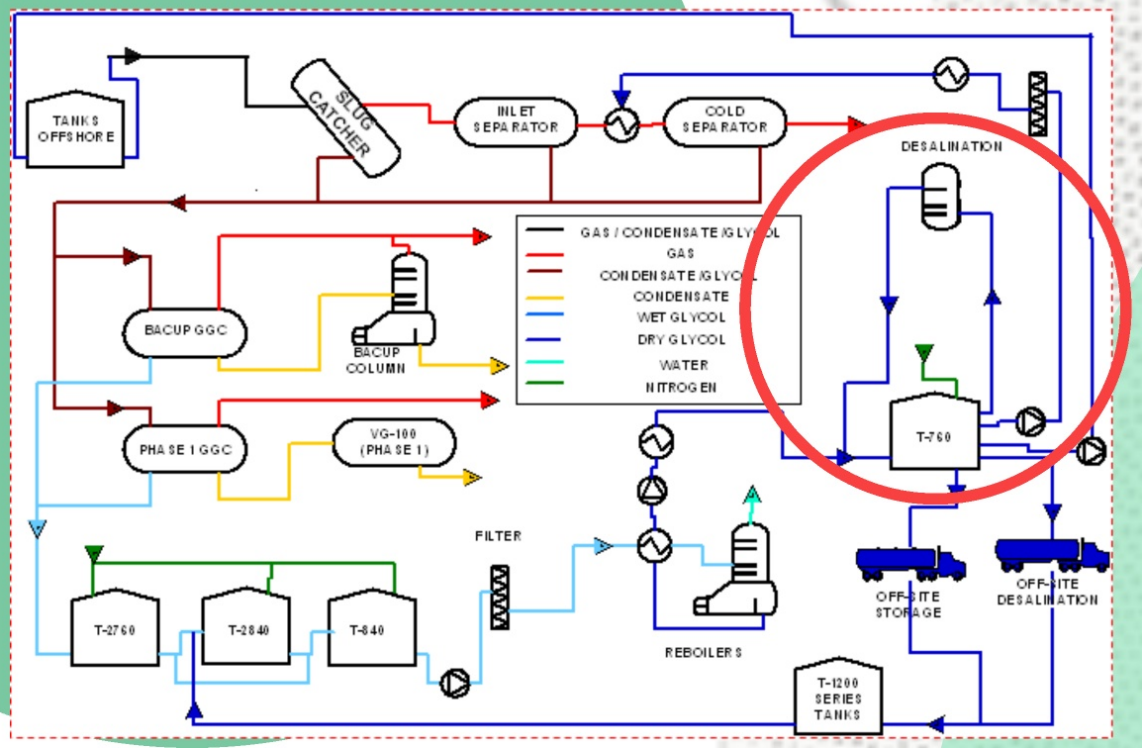
Leak Locations and Details

Spool Piping Branch Details

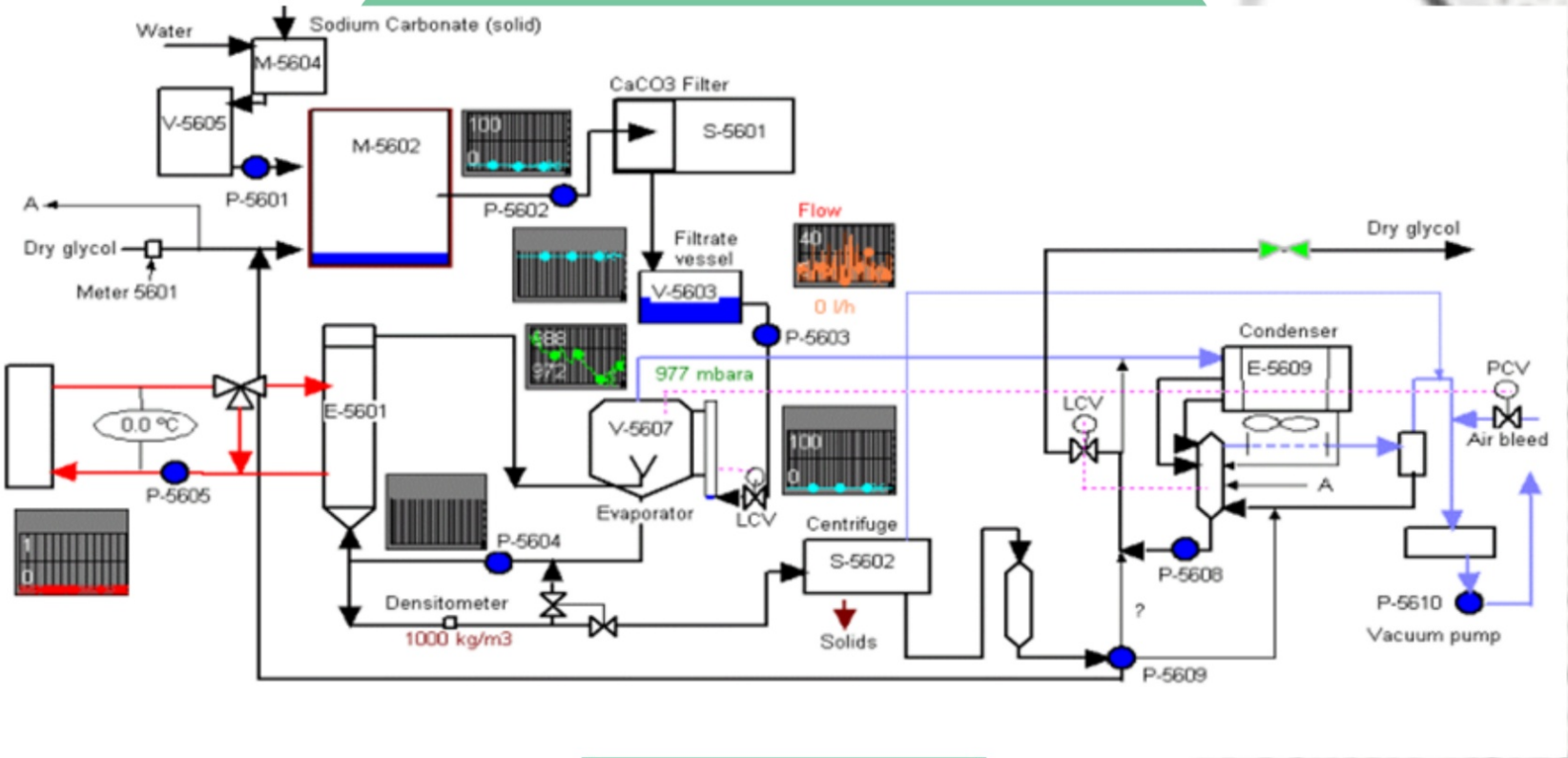
Desalination Plant Overview

Plant Schematic

- MEG used for hydrates and corrosion control of gas pipelines from three offshore fields.
- Desalination plant removes calcium ions and other salts from the MEG for reuse.
- Incoming MEG has sodium carbonate added to aid calcium carbonate precipitation for salt removal.
- Rich MEG fed into the evaporator.
- **NO LEAK POLICY.**



Desalination Plant Schematic



Desalination Plant Overview

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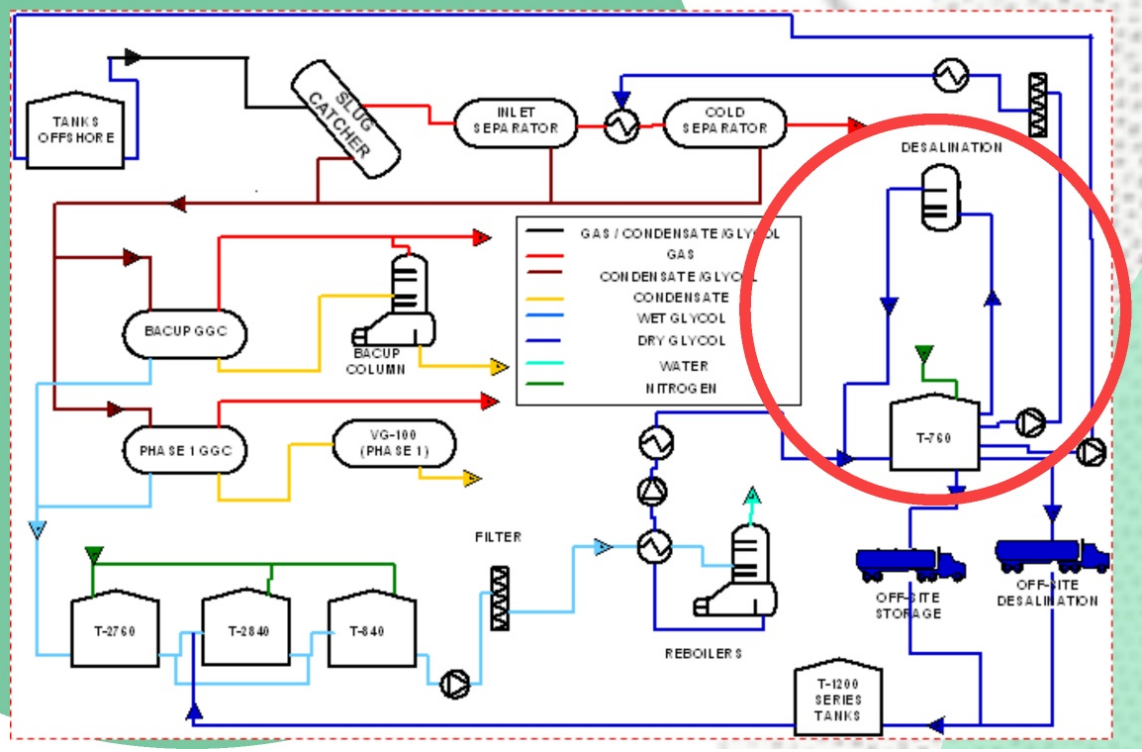


Desalination Plant Overview

Case Study Background

- Overview of the Desalination Plant
- Leak Locations and Details
- Spool Piping Branch Details: Material and Design Operating Parameters

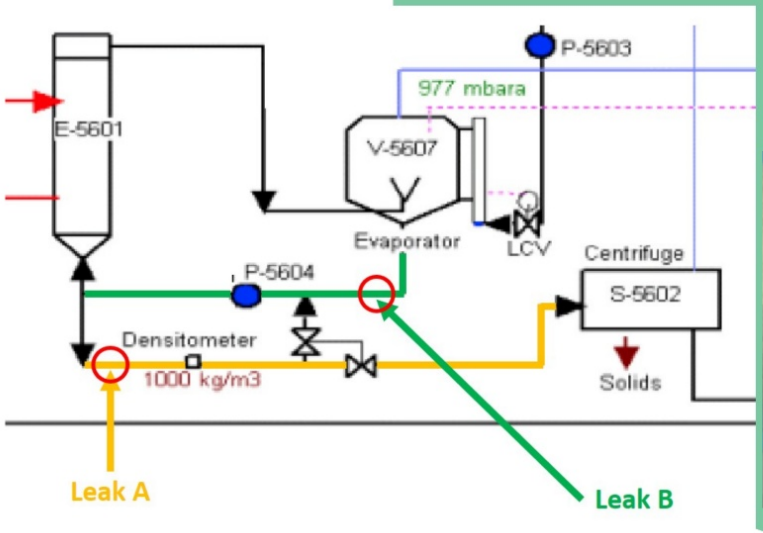
Leak Locations and Details

Spool Piping Branch Details

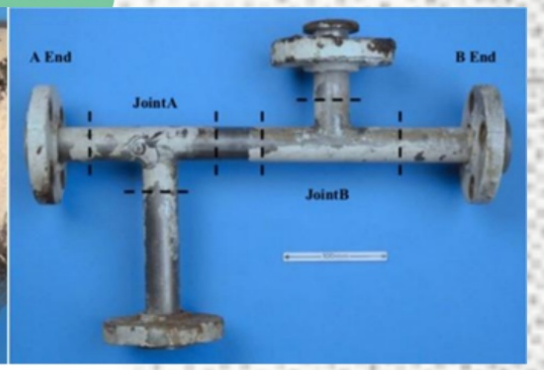
Leak Locations and Details

- Two leaks occurred in the Evaporator (V-5607) section:
  - **LEAK A**: drain off-take from the Calandria to the S-5602 Centrifuge.
  - **LEAK B**: recycle line from V-5607 to the E-5601 Calandria.
- Both leaks occurred at perpendicular branch piping welded onto the main piping.
- 1mm diameter holes occurred approximately 5mm from the toe of the branch piping welds.

LEAK A



LEAK B



Desalination Plant Overview

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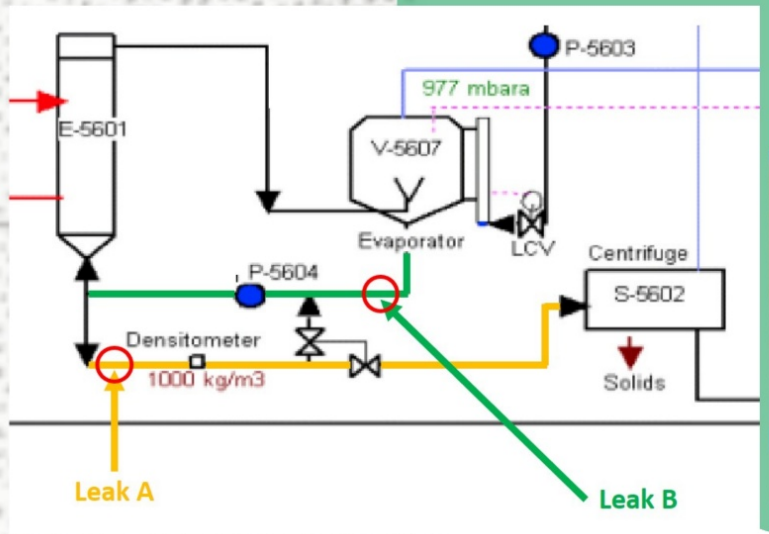
Leak Locations and Details

Spool Piping Branch Details

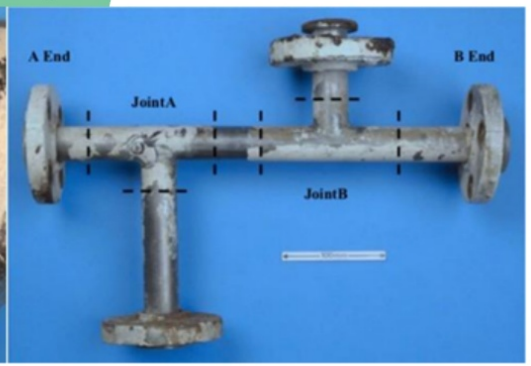
Spool Piping Branch Details: Material and Design Operating Parameters

- Titanium Grade 12 piping was selected for enhanced corrosion resistance.
- Insulated piping (Nilflame & Ulvashield).
- Operating temperature approximately 120°C (max. 135°C).
- MEG containing sodium chloride <25%.wt.
- Piping diameters: Leak A Ø33.4mm - Leak B Ø28.5mm.
- Piping thickness: 1.65mm.
- Both leaks occurred 15 years into service.

LEAK A



LEAK B



Desalination Plant Overview

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Spool Piping Branch Details

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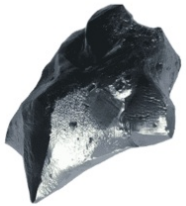

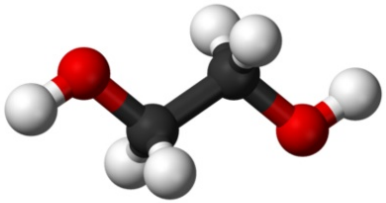

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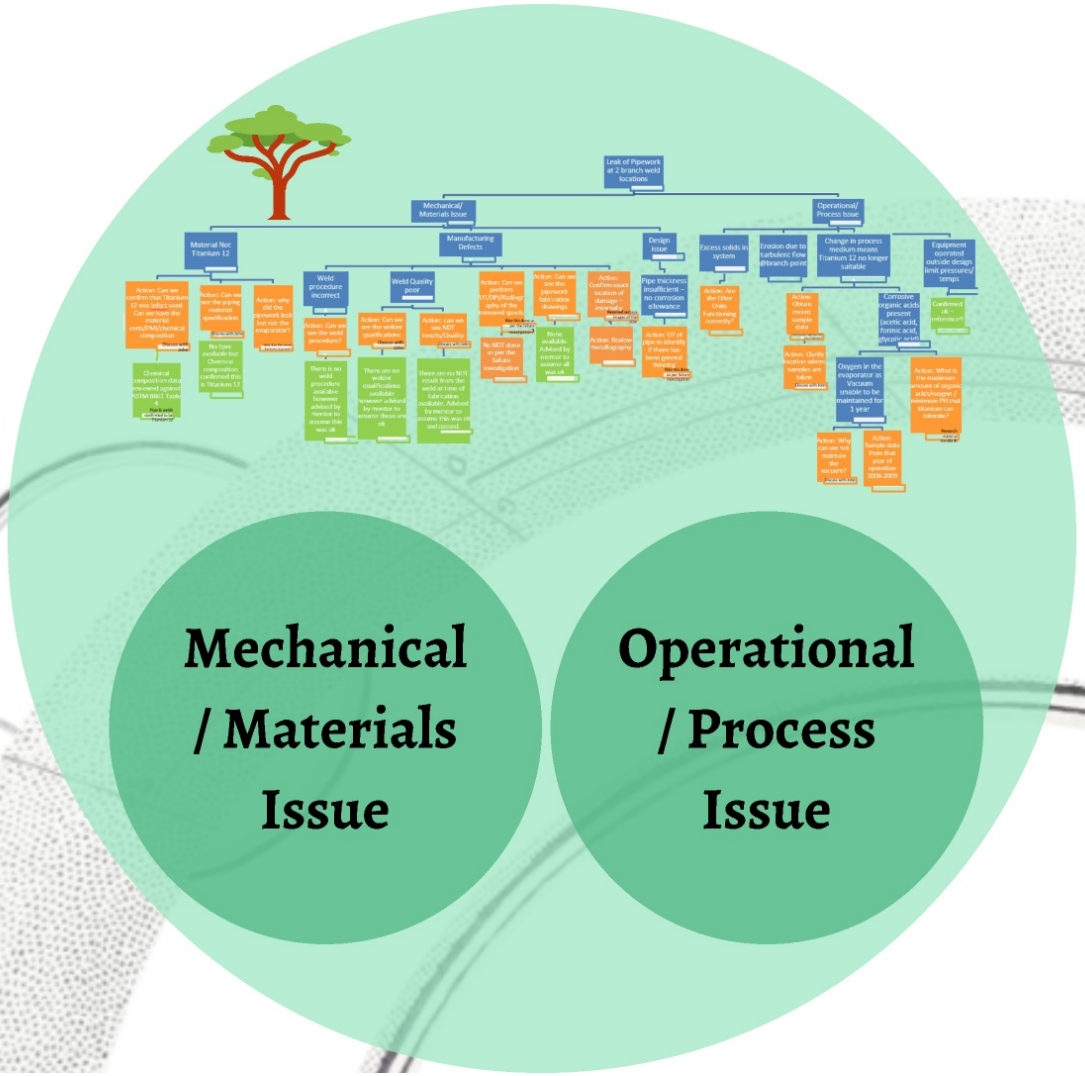
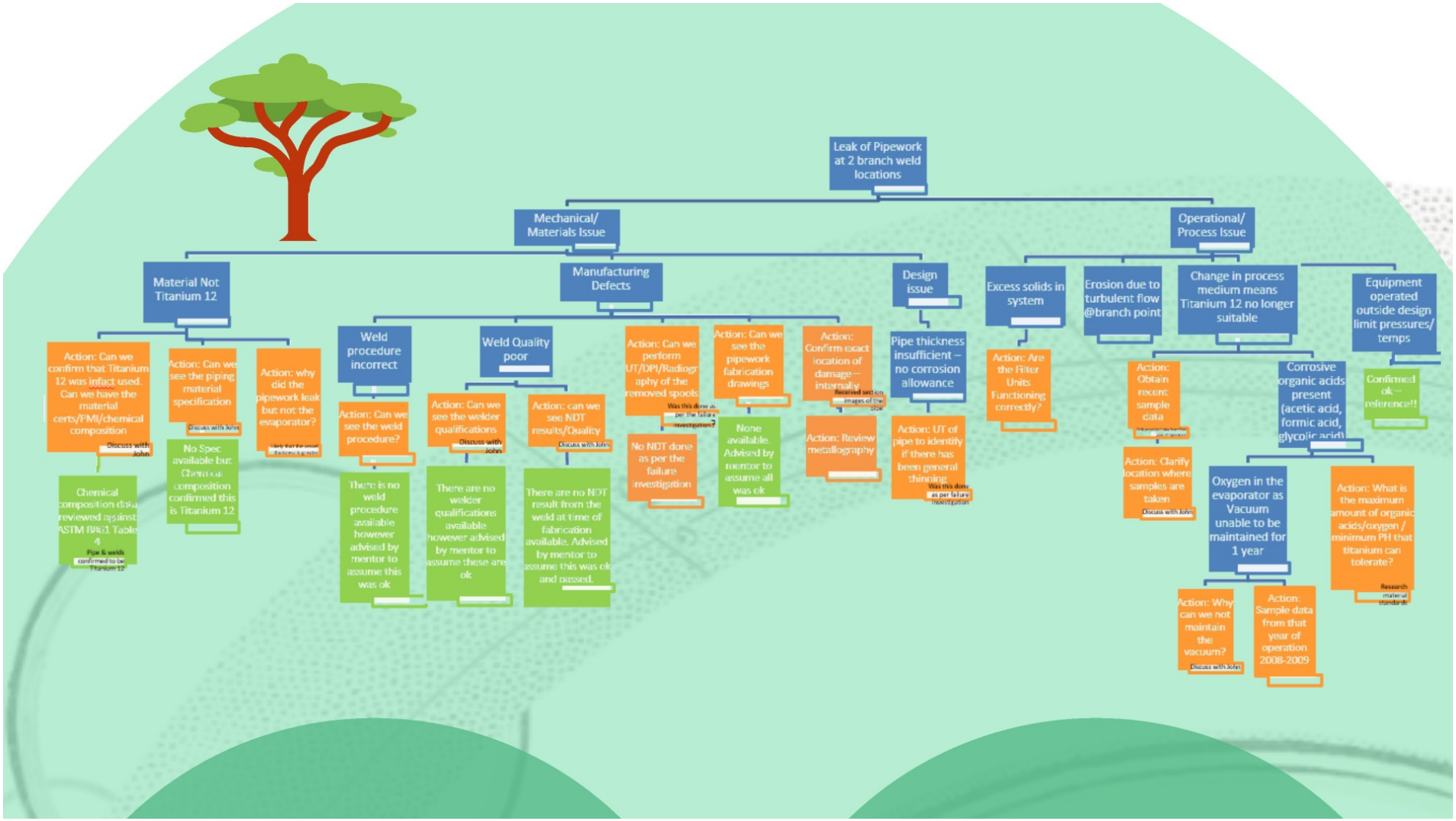
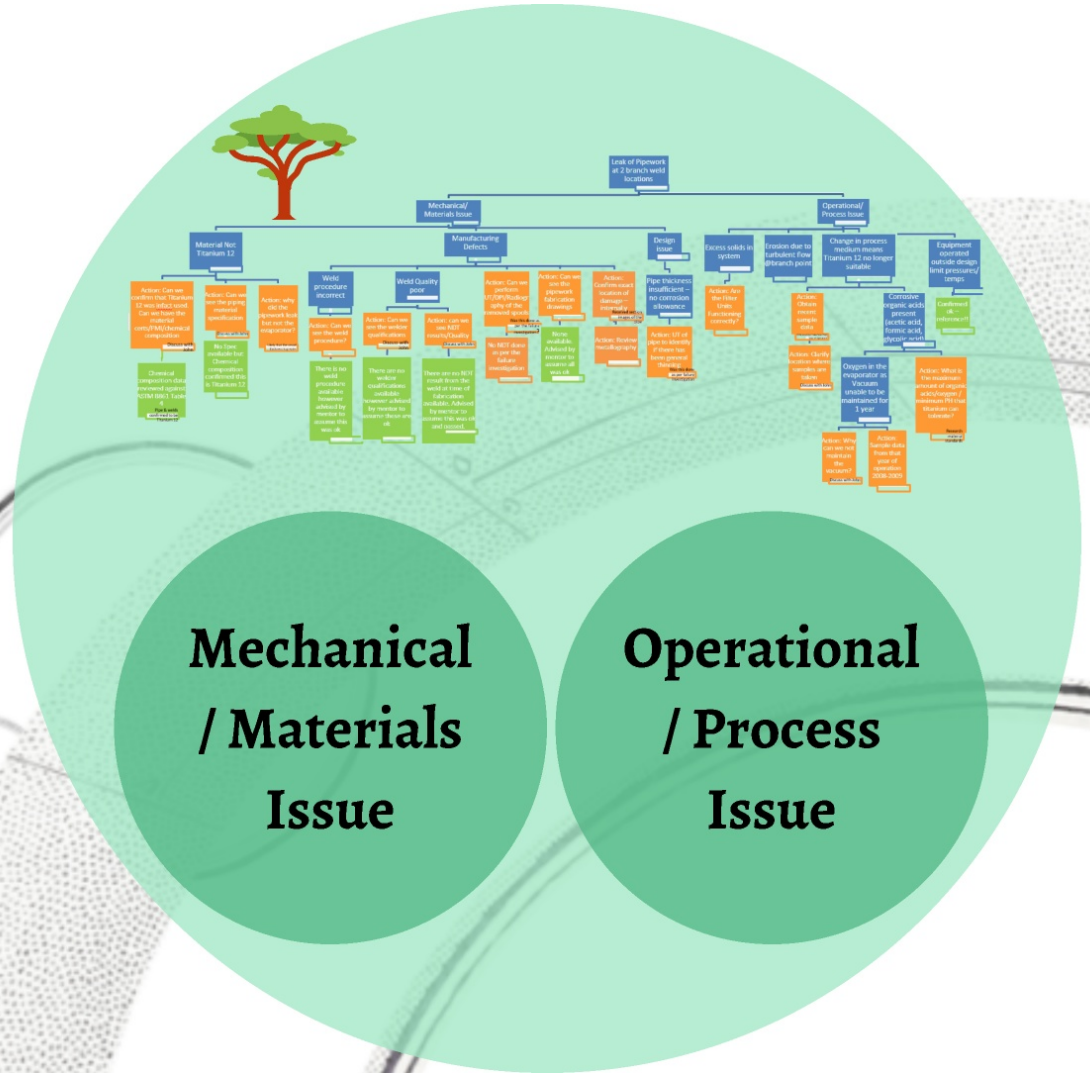

Mechanical / Materials Issue
Operational / Process Issue


Leak of Pipework at 2 branch weld locations
Mechanical/ Materials Issue
Operational/ Process Issue
Material Not Titanium 12
Manufacturing Defects
Design issue
Excess solids in system
Erosion due to turbulent flow @branch point
Change in process medium means Titanium 12 no longer suitable
Equipment operated outside design limit pressures/ temps
Action: Can we confirm that Titanium 12 was infact used. Can we have the material certs/PMI/chemical composition
Discuss with John
Action: Can we see the piping material specification
Discuss with John
Action: why did the pipework leak but not the evaporator?
Chemical composition data reviewed against ASTM B861 Table 4
Pipe & welds confirmed to be Titanium 12
No Spec available but Chemical composition confirmed this is Titanium 12
Weld procedure incorrect
Weld Quality poor
Action: Can we perform UT/DPI/Radiography of the removed spools
Action: Can we see the pipework fabrication drawings
Action: Confirm exact location of damage – internally
Pipe thickness insufficient – no corrosion allowance
Action: Are the Filter Units Functioning correctly?
Action: Obtain recent sample data
Corrosive organic acids present (acetic acid, formic acid, glycolic acid)
Confirmed ok – reference!!
Action: Can we see the weld procedure?
Action: Can we see the welder qualifications
Discuss with John
Action: can we see NDT results/Quality
Discuss with John
Was this done as per the failure investigation?
No NDT done as per the failure investigation
None available. Advised by mentor to assume all was ok
Received section images of the pipe
Action: Review metallography
Action: UT of pipe to identify if there has been general thinning
Was this done as per failure investigation
Action: Clarify location where samples are taken
Discuss with John
Oxygen in the evaporator as Vacuum unable to be maintained for 1 year
Action: What is the maximum amount of organic acids/oxygen / minimum PH that titanium can tolerate?
Research material standards
There: is no weld procedure available however advised by mentor to assume this was ok
There are no welder qualifications available however advised by mentor to assume these are ok
There are no NDT result from the weld at time of fabrication available. Advised by mentor to assume this was ok and passed.
Action: Why can we not maintain the vacuum?
Discuss with John
Action: Sample data from that year of operation 2008-2009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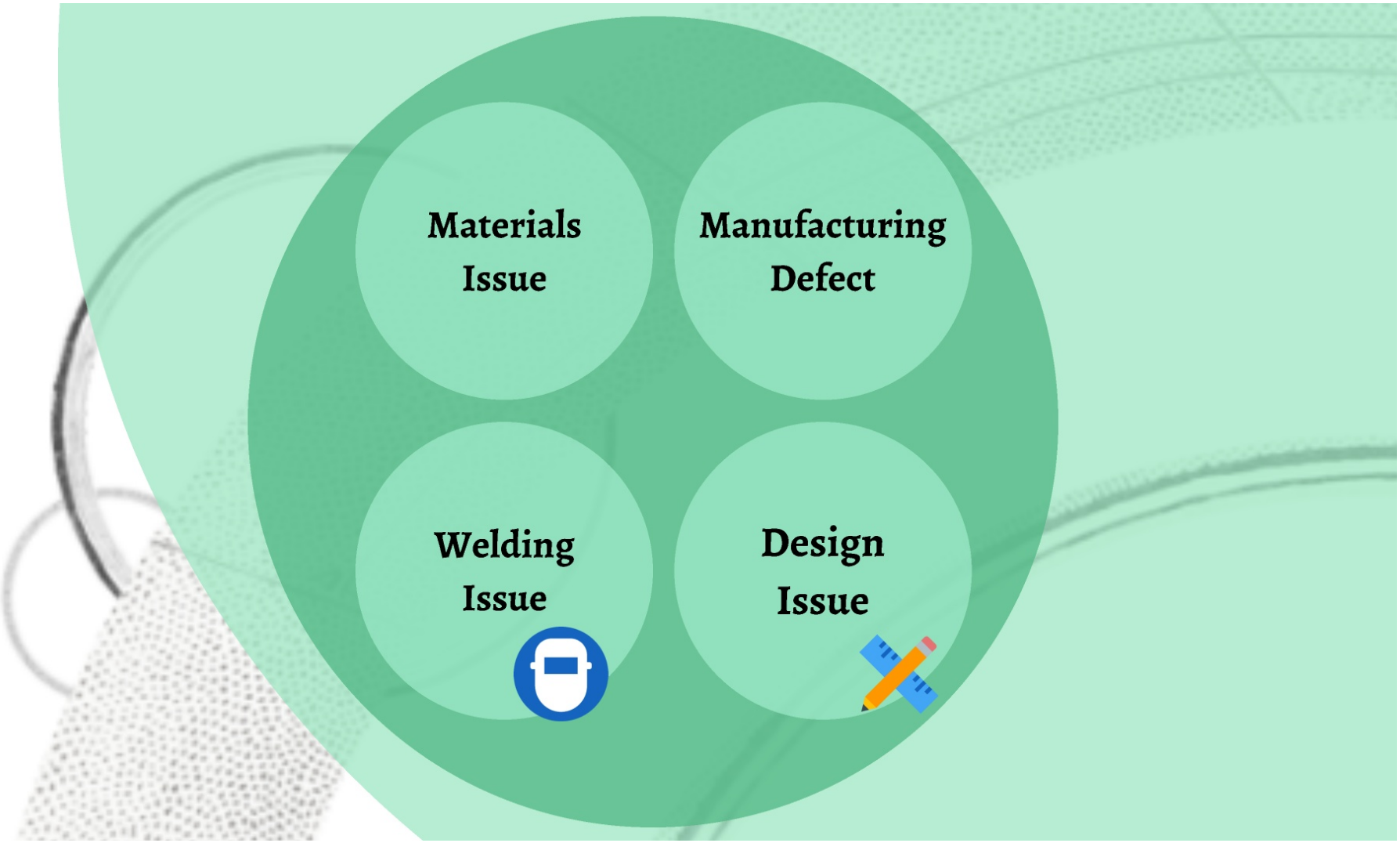
Materials Issue
Manufacturing Defect
Welding Issue
Design Issue

Materials Issue

Can we confirm piping is Titanium 12?

Considered and Discounted

Evidence Requested

- Material Specification
- Chemical composition
- PMI
- Material Certifications

Evidence Response

- Chemical composition

Proved that material was Titanium 12 as per ASTM B861 Table 4

Titanium 12 within design parameters for the purposes

Materials Issue

Can we confirm piping is Titanium 12?

Considered and Discounted

Evidence Requested

- Material Specification
- Chemical composition
- PMI
- Material Certifications

Specification and sample	Element, Wt%									
	C	Al	Fe	H	Mo	N	Ni	O	V	Ti
ASTM Grade 12*	0.08	NS	0.30	0.015	0.2 -0.4	0.03	0.6 -0.9	0.25	NS	Balance
Main pipe	0.012	<0.01	0.08	0.0068	0.29	0.016	0.75	0.18	<0.01	Balance
Weld	0.021	0.02	0.11	0.0058	0.29	0.014	0.75	0.16	<0.01	Balance
Branch	0.009	0.02	0.13	0.0058	0.29	0.013	0.77	0.16	<0.01	Balance

Evidence Response

- Chemical composition

Proved that material was Titanium 12 as per ASTM B861 Table 4

Titanium 12 within design parameters for the purposes

Materials Issue

Can we confirm piping is Titanium 12?

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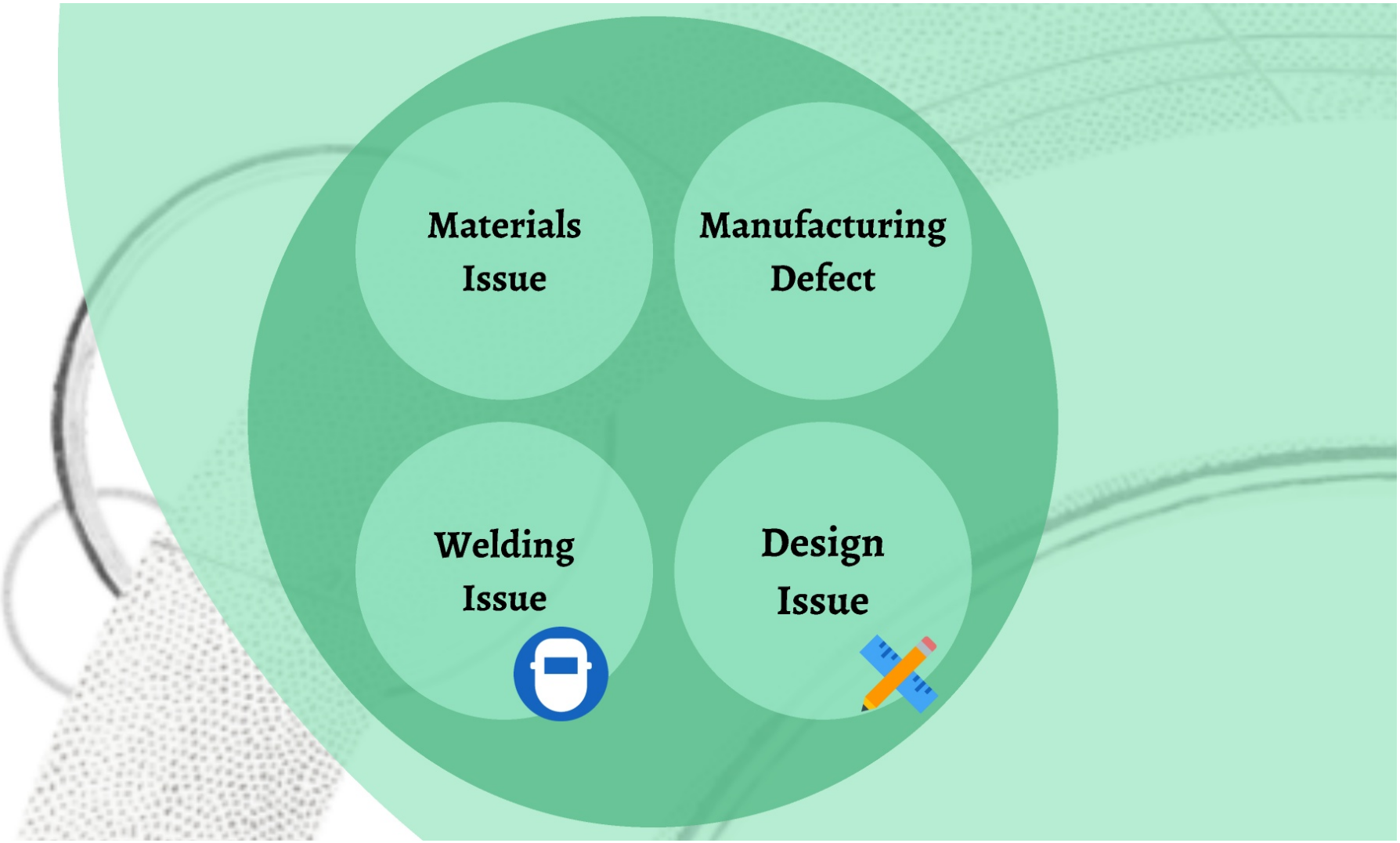
Branch	0.009	0.02	0.13	0.0058	0.29	0.013	0.77	0.16	<0.01	Balance

TABLE 4 Permissible Variations in Product Analysis

Element	Product Analysis Limits, Permissible Variation	
	max or Range, %	in Product Analysis
Aluminum	0.5 to 2.5	±0.20
Aluminum	2.5 to 6.75	±0.40
Carbon	0.10	+0.02
Chromium	0.1 to 0.2	±0.02
Chromium	5.5 to 6.5	±0.30
Hydrogen	0.02	+0.002
Iron	0.80	+0.15
Iron	1.2 to 1.8	±0.20
Molybdenum	0.2 to 0.4	±0.03
Molybdenum	1.5 to 4.5	±0.20
Molybdenum	14.0 to 16.0	±0.50
Nickel	0.3 to 0.9	±0.05
Niobium	2.2 to 3.2	±0.15
Niobium	>30	±0.50
Nitrogen	0.05	+0.02
Oxygen	0.30	+0.03
Oxygen	0.31 to 0.40	±0.04
Palladium	0.01 to 0.02	±0.002
Palladium	0.04 to 0.08	±0.005
Palladium	0.12 to 0.25	±0.02
Ruthenium	0.02 to 0.04	±0.005
Ruthenium	0.04 to 0.06	±0.005
Ruthenium	0.08 to 0.14	±0.01
Silicon	0.06 to 0.40	±0.02
Vanadium	2.0 to 4.5	±0.15
Vanadium	7.5 to 8.5	±0.40
Zirconium	3.5 to 4.5	±0.20
Residuals[A] (each)	0.15	+0.02

[A] A residual is an element in a metal or alloy in small quantities inherent to the manufacturing process but not added intentionally.


Materials Issue
Manufacturing Defect
Welding Issue
Design Issue

Manufacturing Defect

Confirm exact location of the damage internally

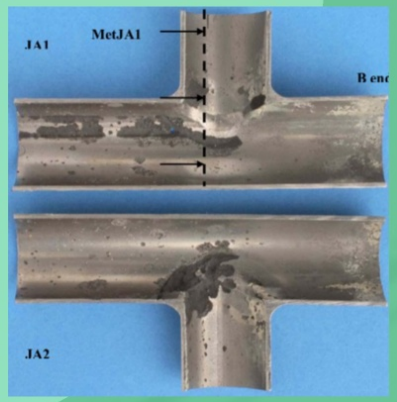
Evidence Requested

- Section of the failed pipe

Considered and discounted

Conclusions

- Pits seen uniformly across the pipe
- Most severe damage at the HAZ of the branch weld and the seam weld



Conclusions

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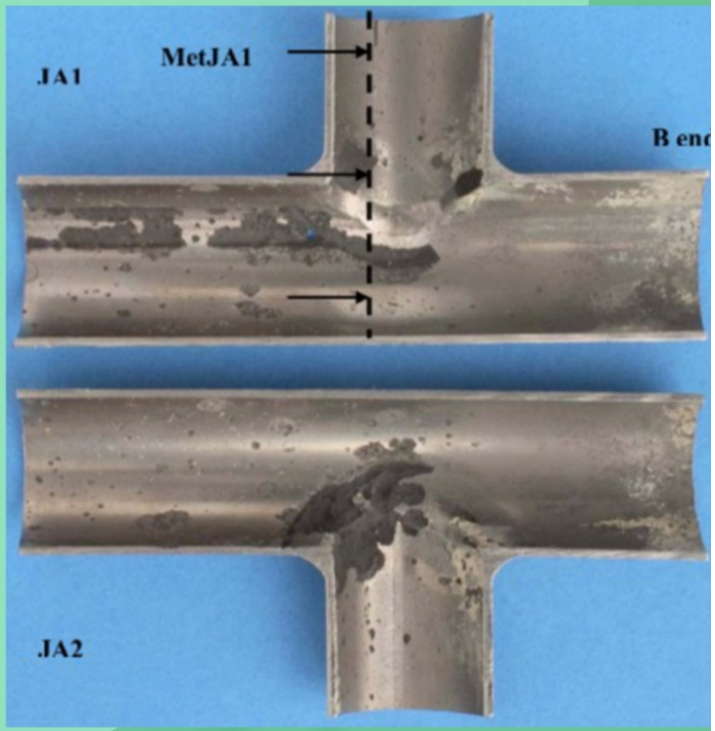
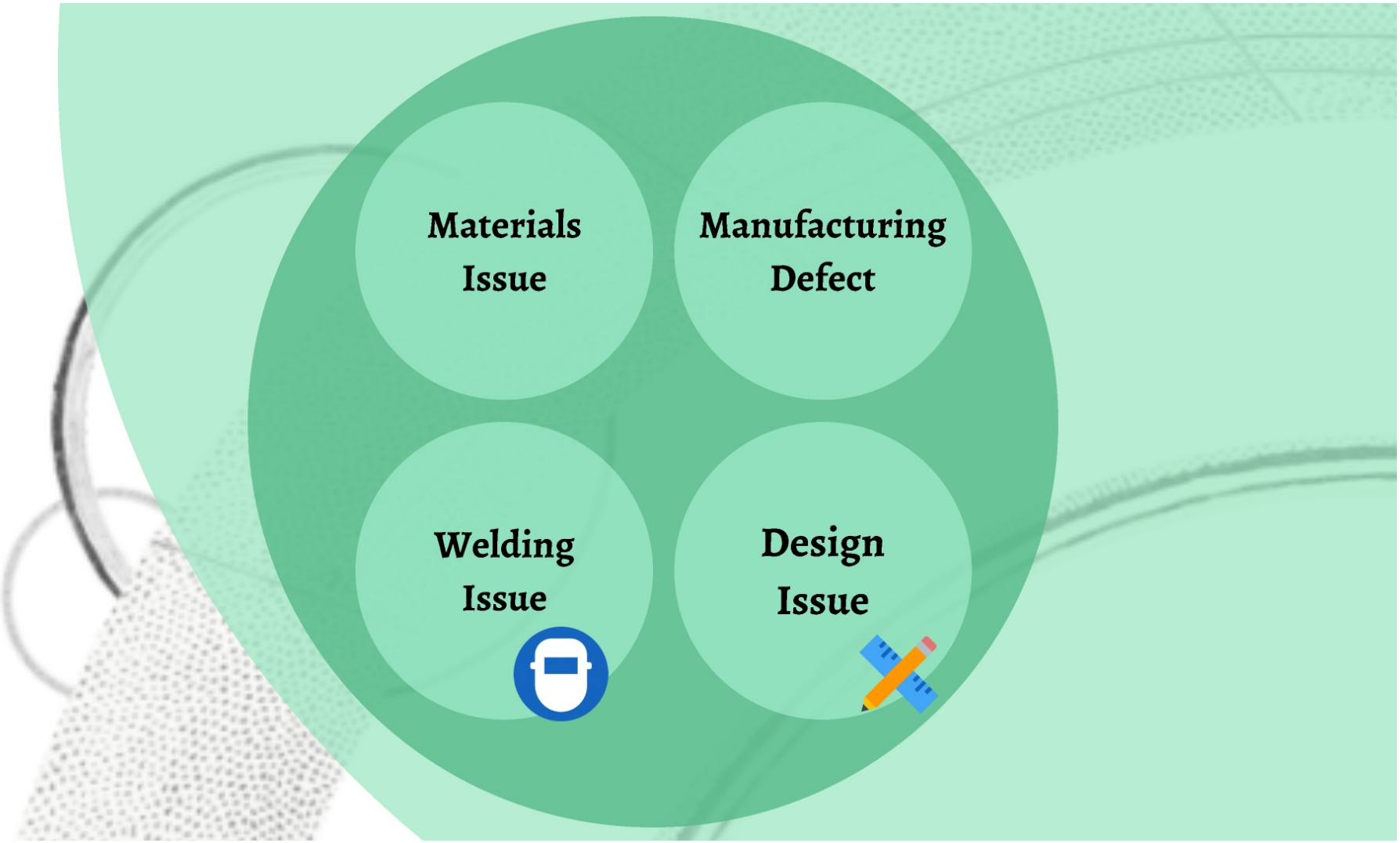
- Most severe damage at the HAZ of the branch weld and the seam weld




Materials Issue
Manufacturing Defect
Welding Issue
Design Issue

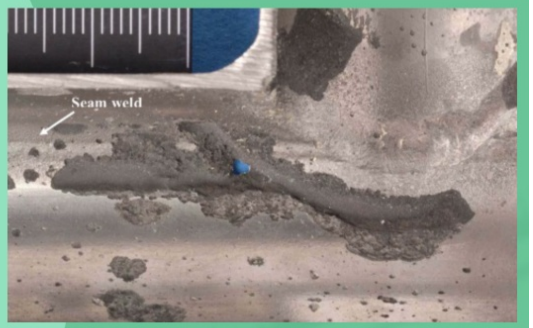
Welding Issue

Potential Issues:

- Incorrect welding procedure (WPS)
- Poor weld quality

Evidence Request

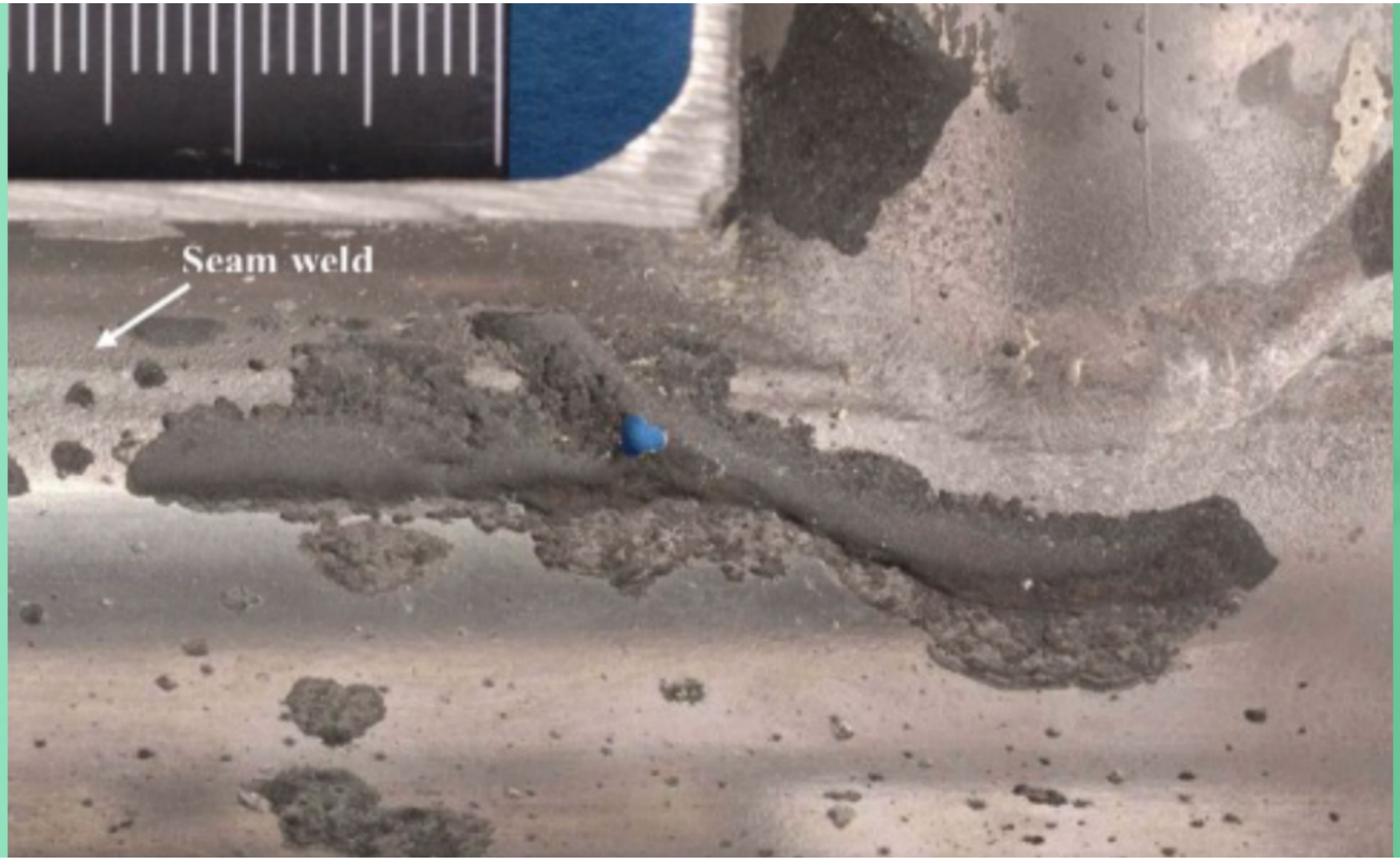
- Copy of original WPS
- Copy of original welder qualifications
- NDT reports from original manufacture

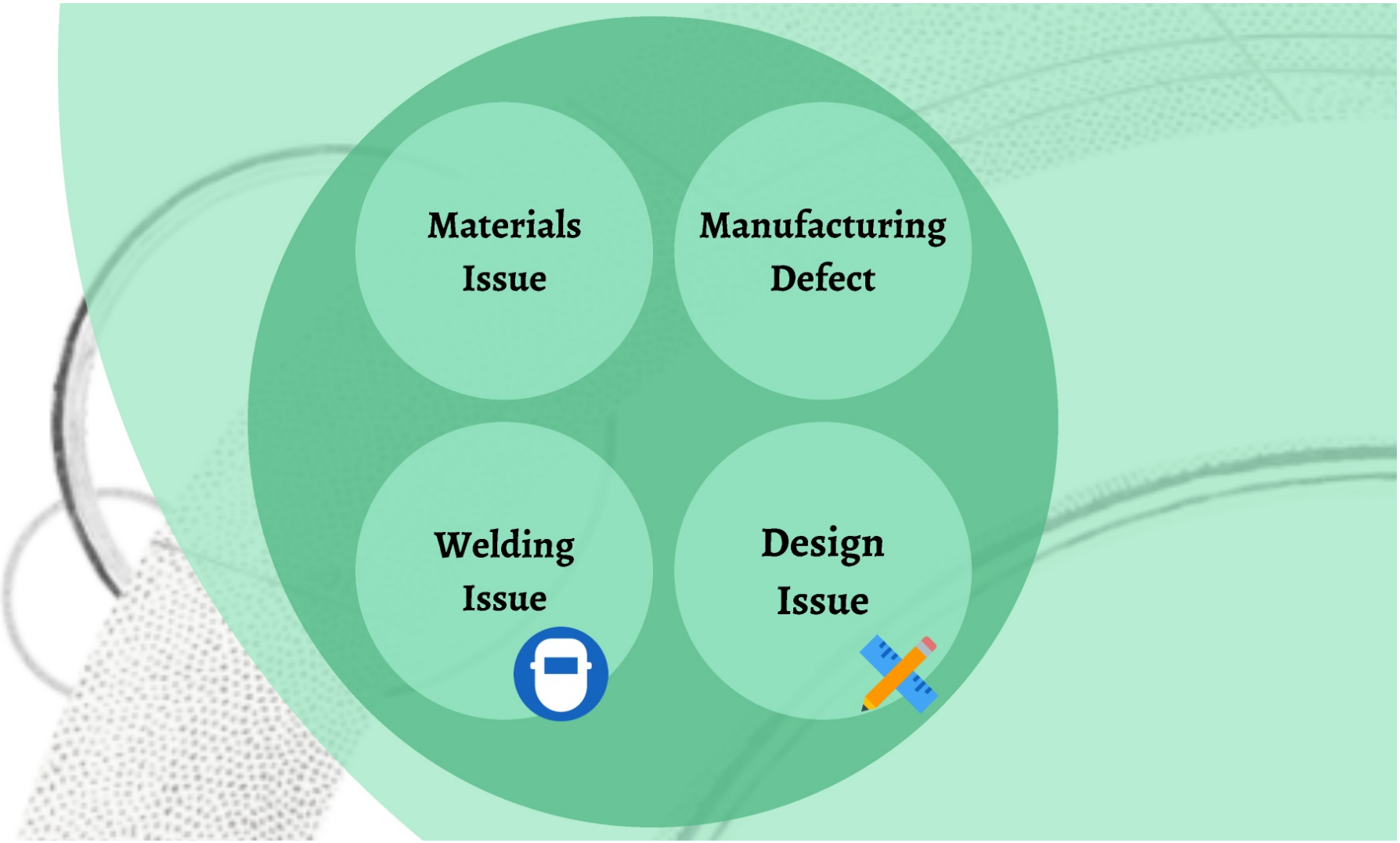


Evidence Response

- No original weld details available
- Advised to assume that this was good and to standard

Considered and discounted


Seam weld


Materials Issue
Manufacturing Defect
Welding Issue
Design Issue

Design Issue

Considered and discounted

Potential Issues

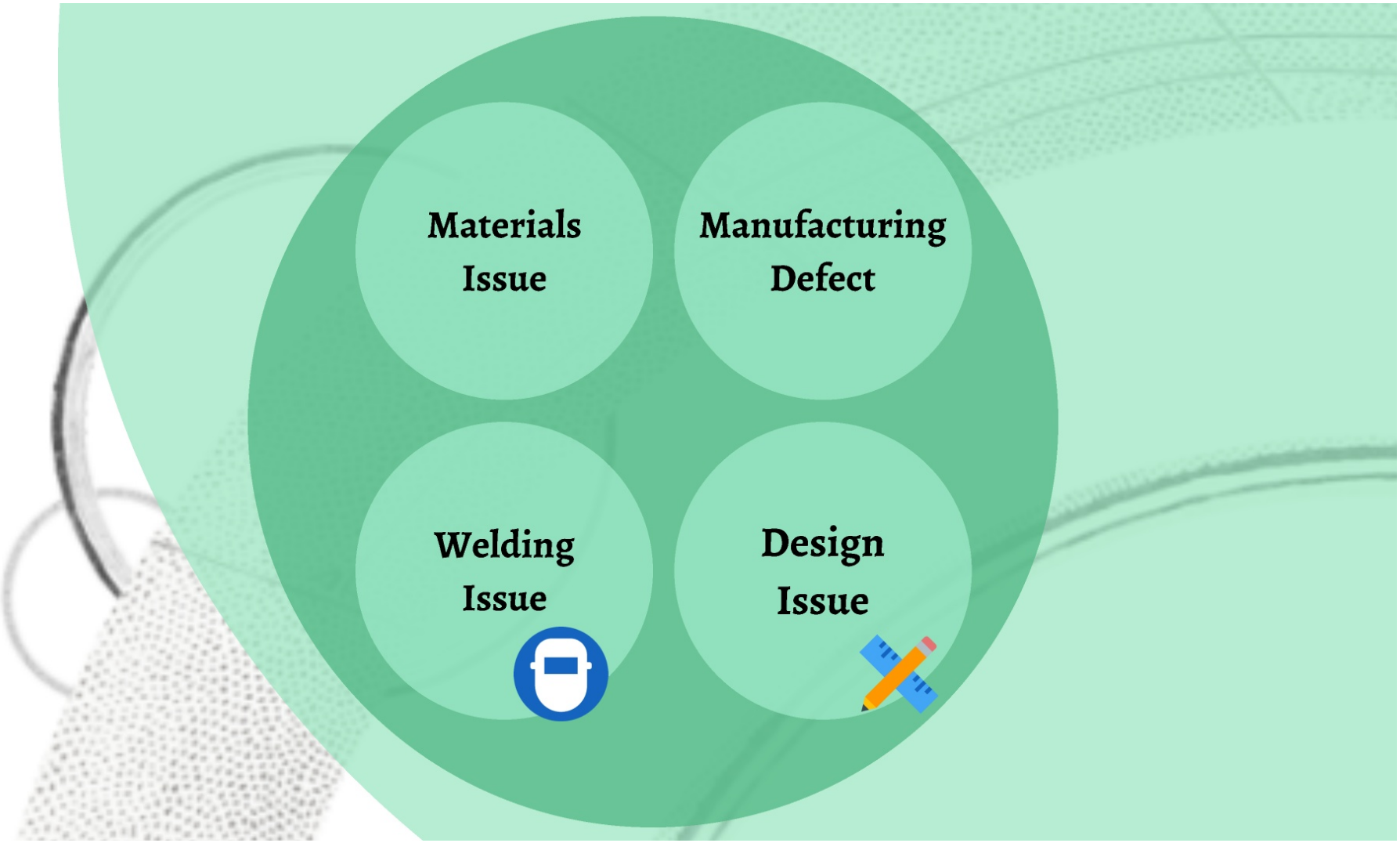
- Wall thickness incorrect
- Why did the pipework leak but not the vessel

Evidence Requested

- Fabrication Drawings

Evidence Response & Conclusions

- Pipe thickness ok as per ASME B31.3 design code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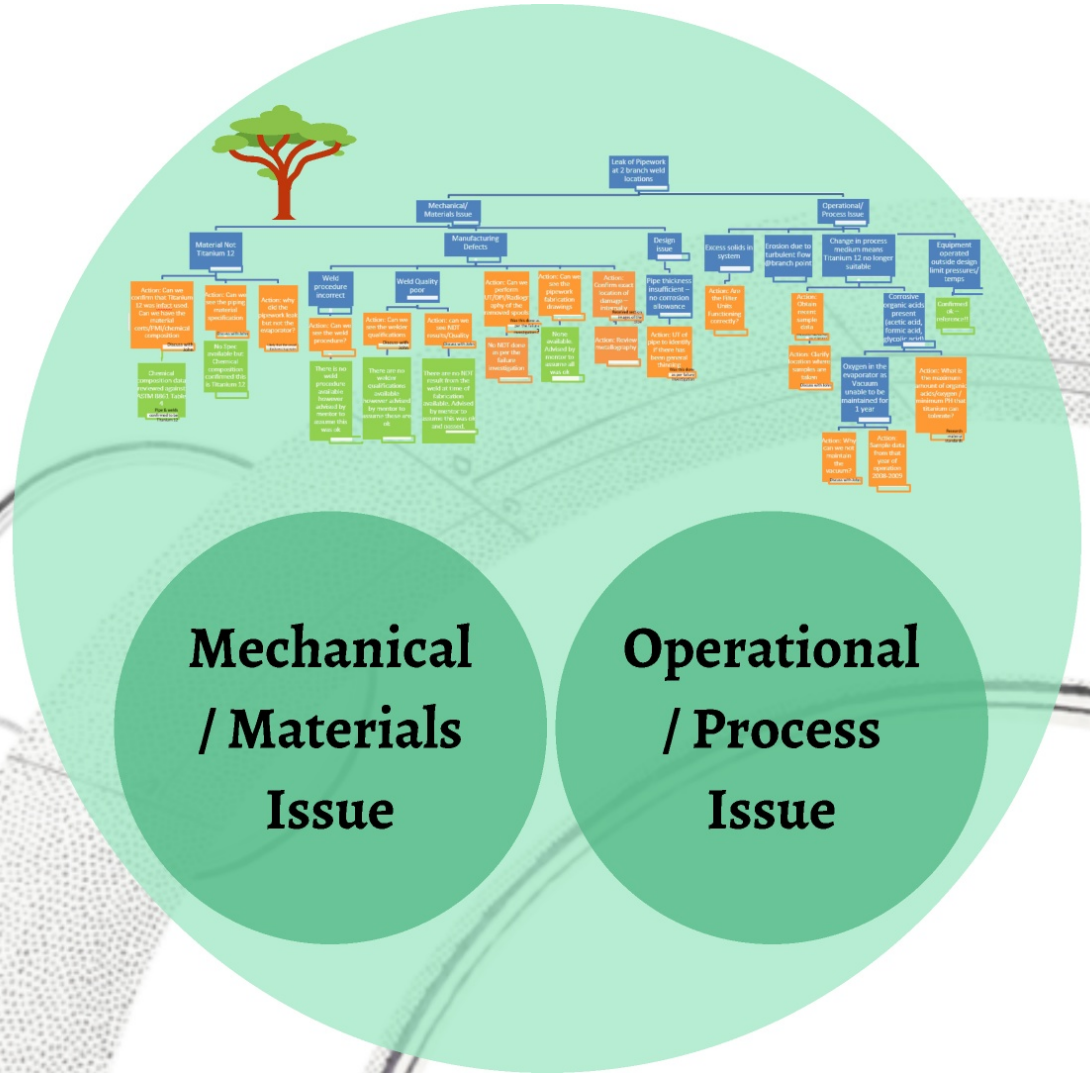
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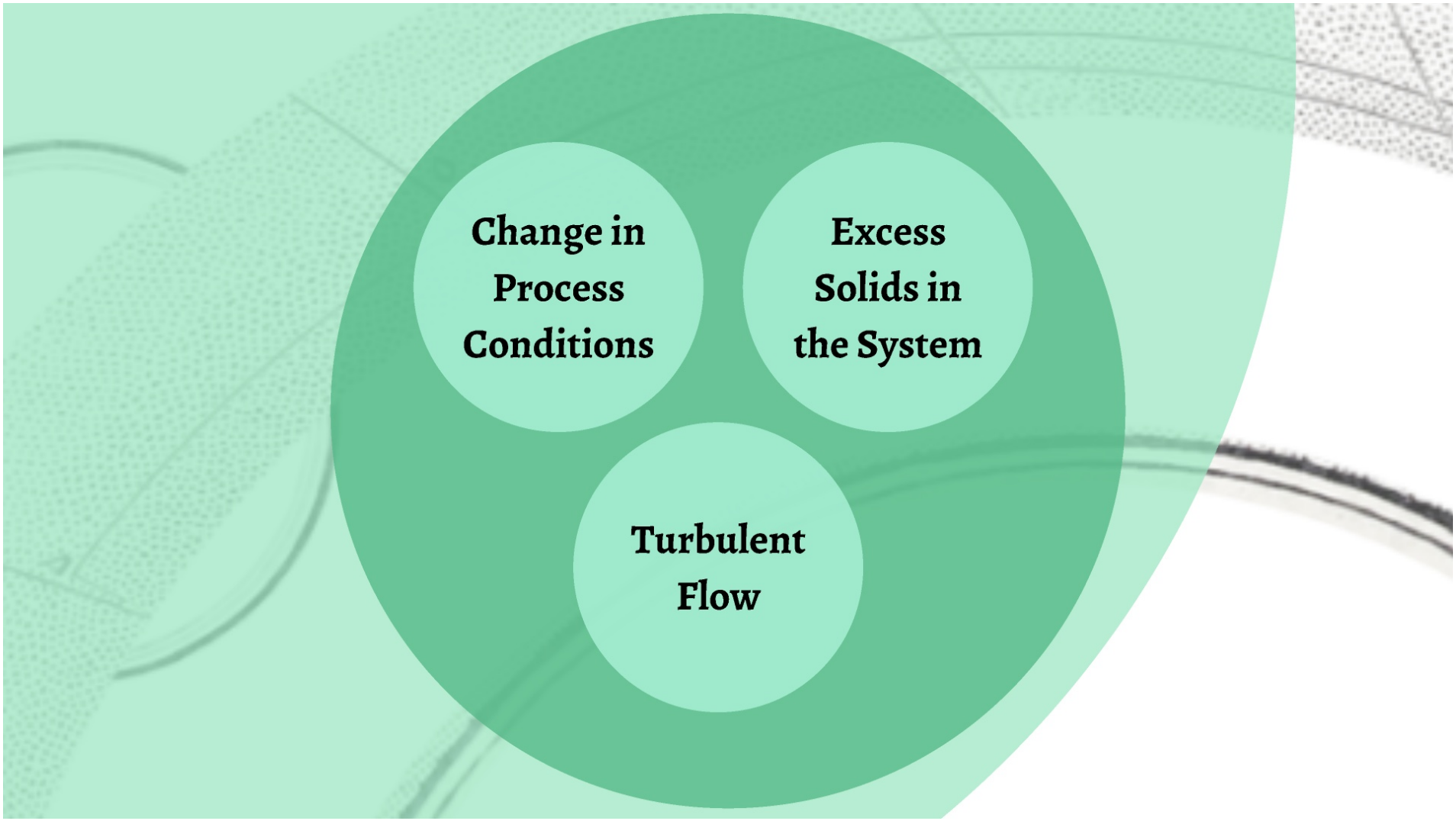
Operational / Process Issue


Change in Process Conditions
Excess Solids in the System
Turbulent Flow

Possible Issues

- Change in process medium, temperature, pressure... could mean that titanium 12 is no longer suitable

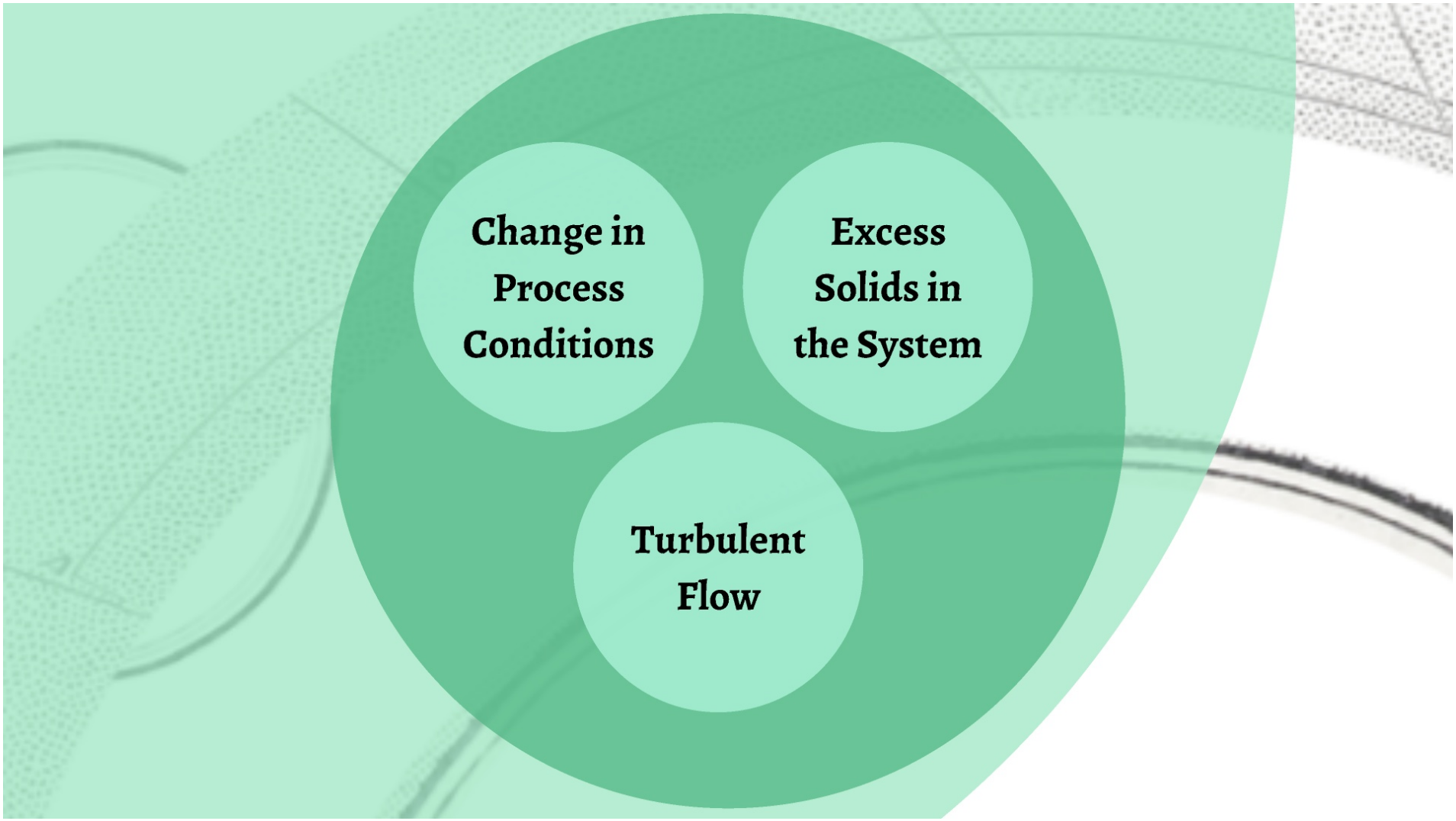
Evidence Requested

- Operating information (PI data)
- Sample information

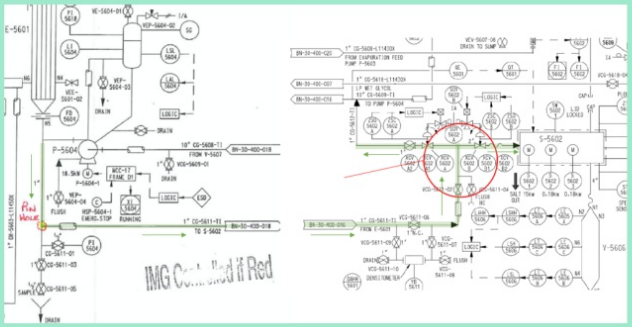
Evidence Response & Conclusions

- Sample info provided from 1995/1996 - no recent sample info available
- Oxygen in the evaporator as Vacuum unable to be maintained for 1 year
- Corrosive organic acids present (acetic acid, formic acid, glycolic acid)

Potential Root Cause - Corrosive Acids now present


Change in Process Conditions
Excess Solids in the System
Turbulent Flow

Potential for solid particles to cause erosion at the branch location



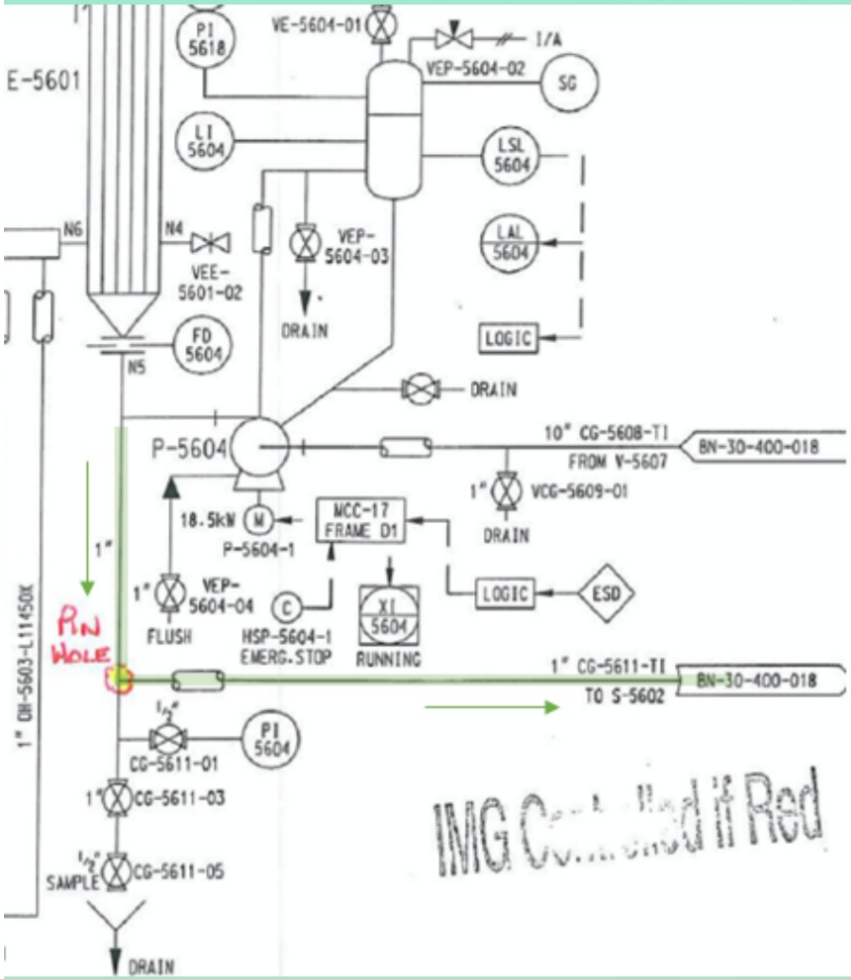
Possible Issues

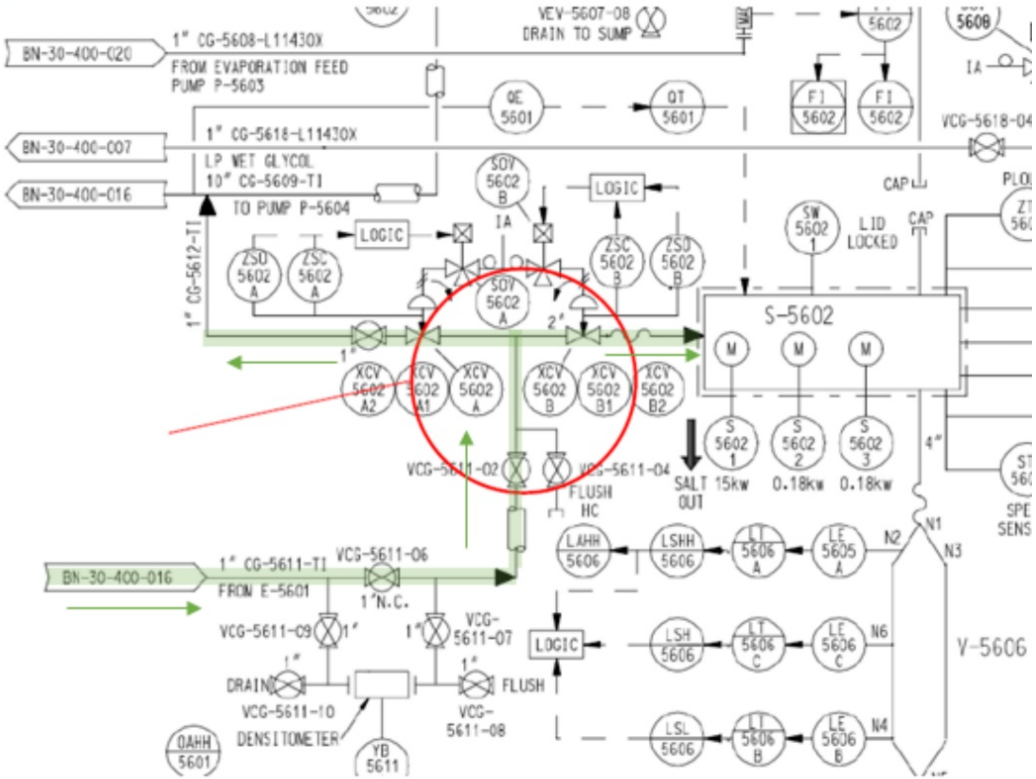
- Increased solids in the system
- Filters not functioning correctly

Evidence Requested

- Sample information
- Maintenance/Inspection history for the filters

Potential Root Cause


E-5601
PI 5618
VE-5604-01
I/A
VEP-5604-02
SG
LI 5604
LSL 5604
LAL 5604
N6
N4
VEE-5601-02
VEP-5604-03
DRAIN
FD 5604
N5
LOGIC
DRAIN
P-5604
10" CG-5608-TI
FROM V-5607
BN-30-400-018
1" VCG-5609-01
DRAIN
18.5kW
M
P-5604-1
MCC-17 FRAME D1
1" VEP-5604-04
FLUSH
HSP-5604-1 EMERG.STOP
XI 5604
RUNNING
LOGIC
ESD
PIN HOLE
1" CG-5611-TI
TO S-5602
BN-30-400-018
1" DN-5603-L11450X
1/2" CG-5611-01
PI 5604
1" CG-5611-03
1/2" SAMPLE CG-5611-05
DRAIN


BN-30-400-020
1" CG-5608-L11430X
FROM EVAPORATION FEED PUMP P-5603
VEV-5607-08 DRAIN TO SUMP
QE 5601
QT 5601
FI 5602
FI 5602
5608
IA
VCG-5618-04
BN-30-400-007
1" CG-5618-L11430X
LP WET GLYCOL
BN-30-400-016
10" CG-5609-TI
TO PUMP P-5604
LOGIC
SOV 5602 B
SOV 5602 A
ZSO 5602 A
ZSC 5602 A
ZSC 5602 B
ZSO 5602 B
SW 5602 1
LID LOCKED
CAP
1" CG-5612-TI
S-5602
XCV 5602 A2
XCV 5602 A1
XCV 5602 A
XCV 5602 B
XCV 5602 B1
XCV 5602 B2
VCG-5611-02
VCG-5611-04
FLUSH HC
SALT OUT
S 5602 1 15kw
S 5602 2 0.18kw
S 5602 3 0.18kw
LAHH 5606
LSHH 5606
LT 5606 A
LE 5605 A
N1
N2
N3
BN-30-400-016
1" CG-5611-TI
FROM E-5601
VCG-5611-06
1" N.C.
VCG-5611-09
VCG-5611-07
DRAIN
FLUSH
VCG-5611-10
DENSITOMETER
VCG-5611-08
YB 5611
OAHH 5601
LSH 5606
LT 5606 C
LE 5606 C
N6
LSL 5606
LT 5606 B
LE 5606 B
N4
V-5606

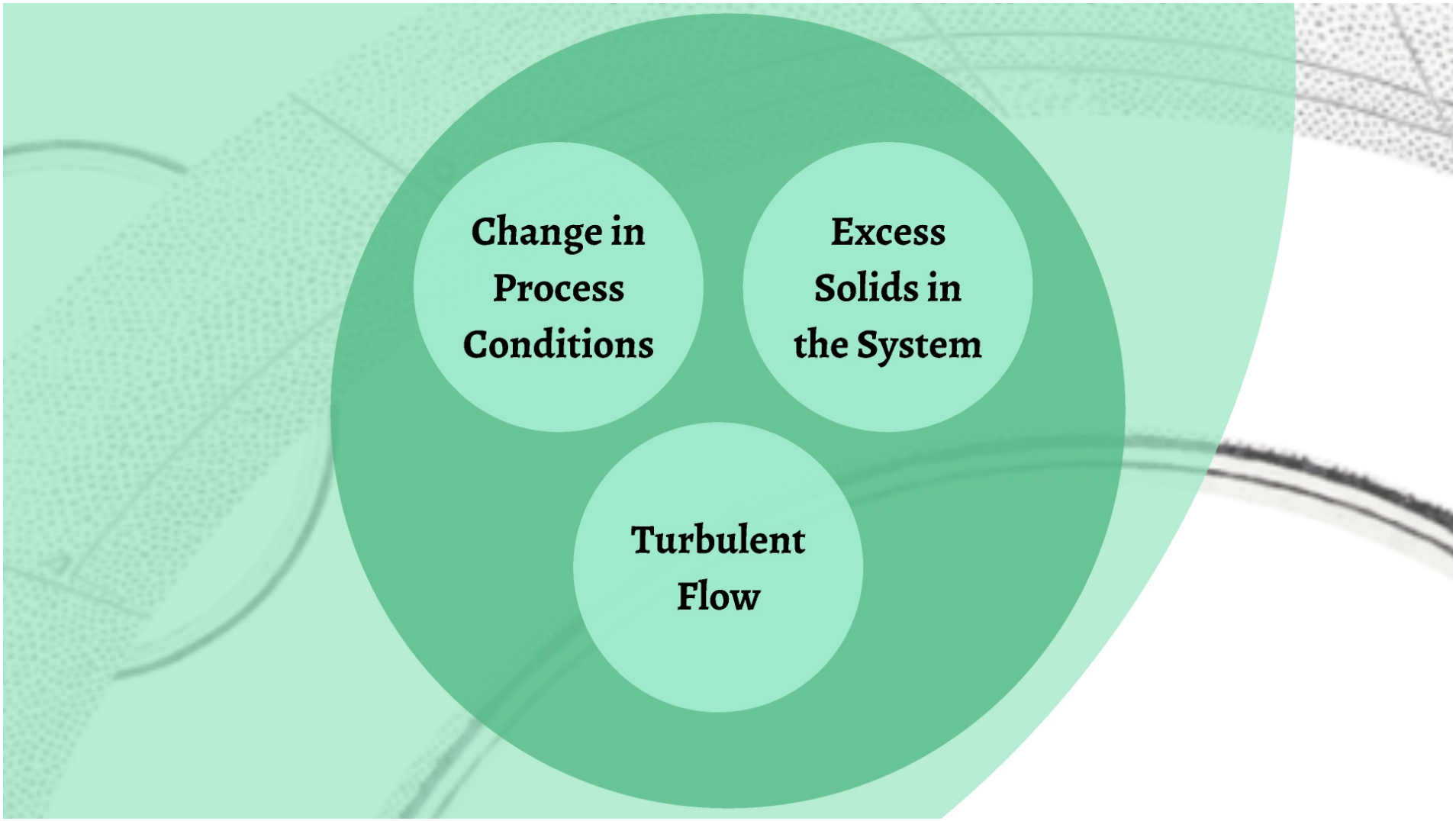
Possible Issues

- Increased solids in the system
- Filters not functioning correctly

Evidence Requested

- Sample information
- Maintenance/Inspection history for the filters

Potential Root Cause


Change in Process Conditions
Excess Solids in the System
Turbulent Flow

Possible Issues

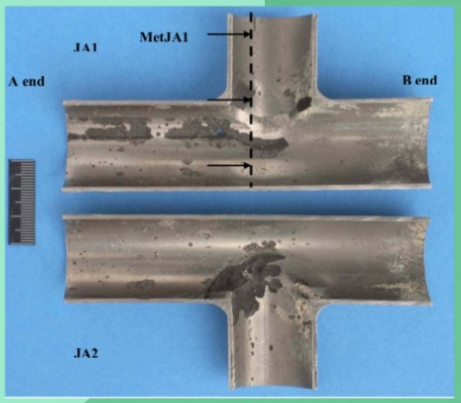
- Turbulent flow around the branch connections
- Cavitation

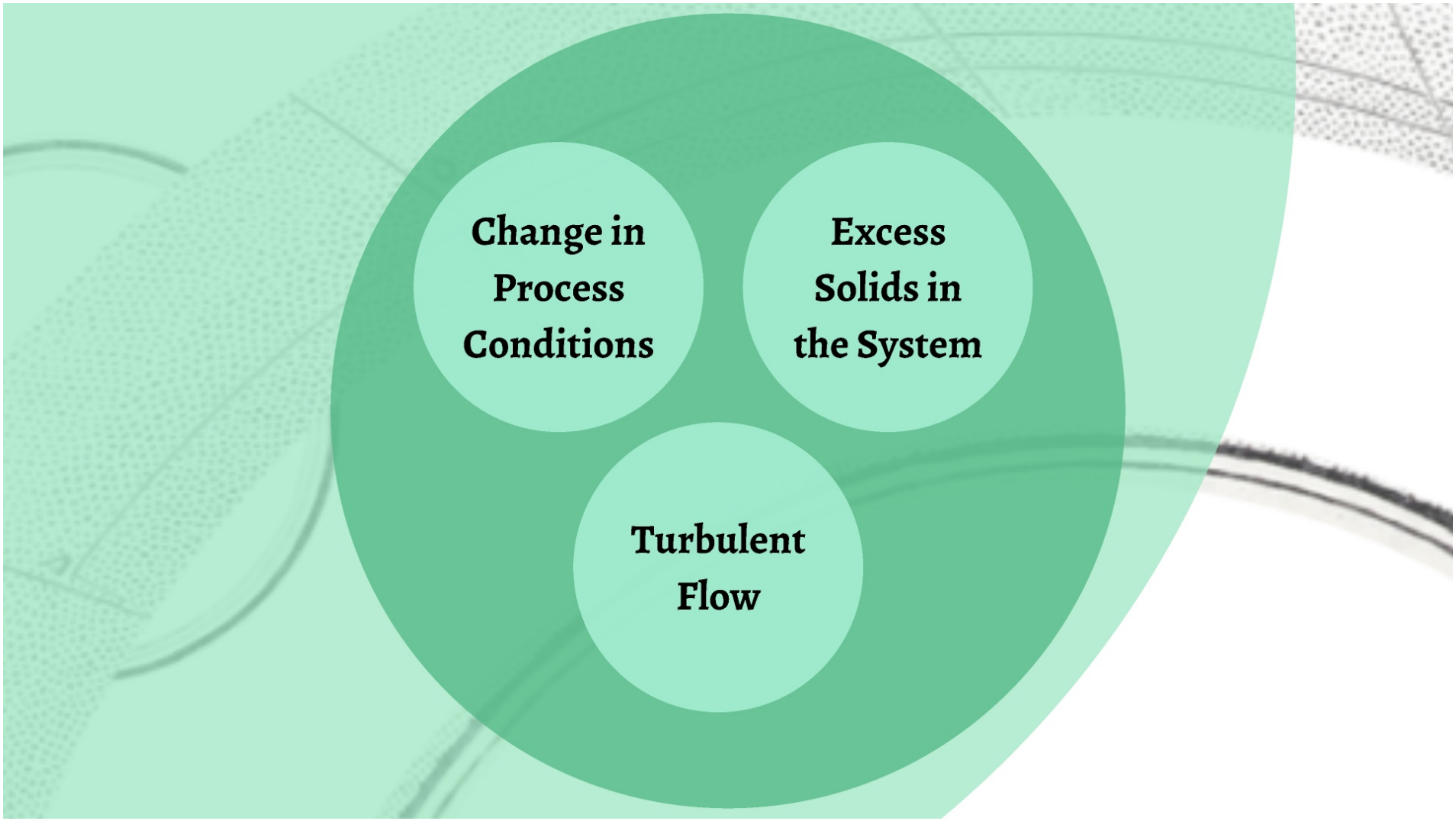
?

Potential Root Cause

Research & Conclusions

- Cavitation can occur where bubbles implode on the material to create the pits

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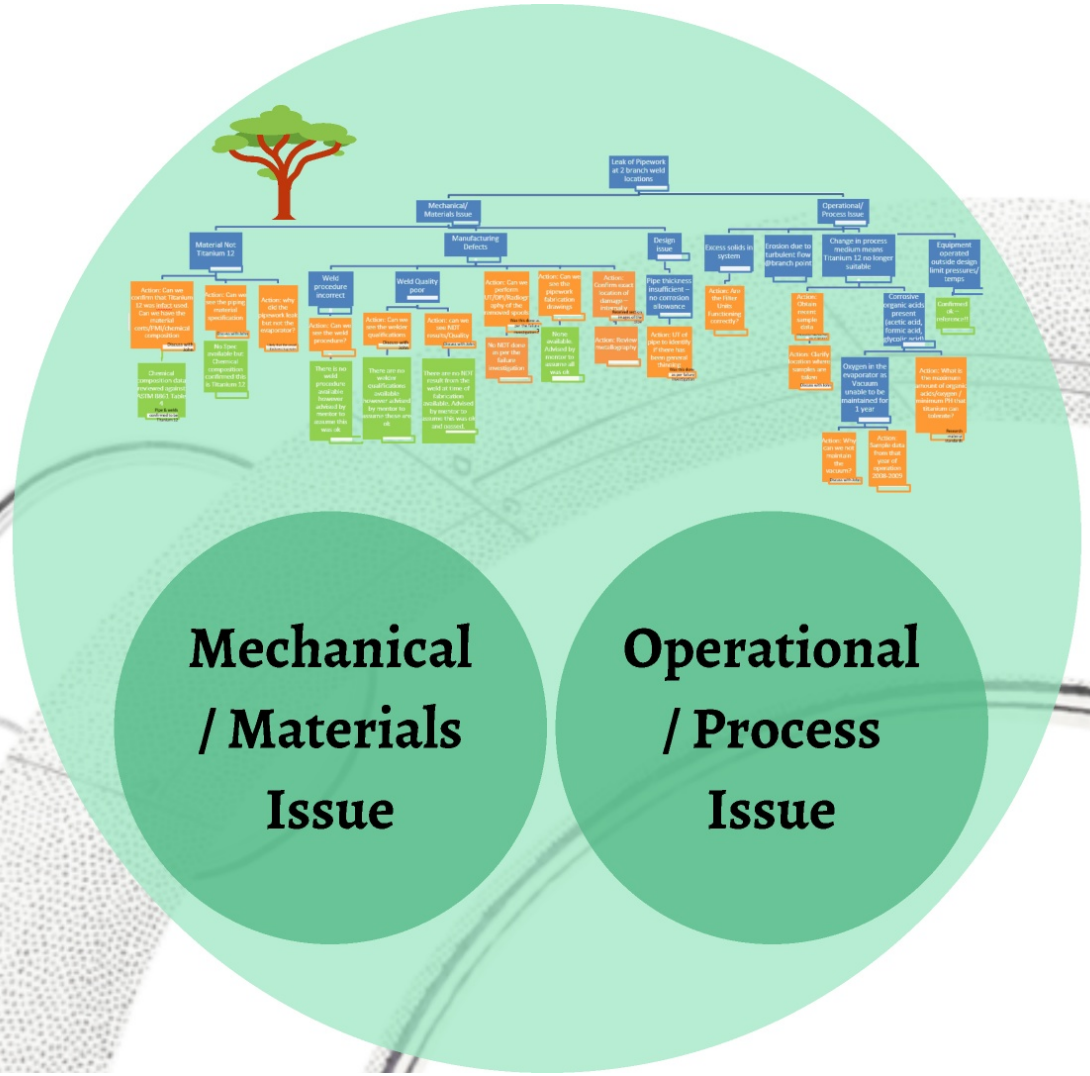
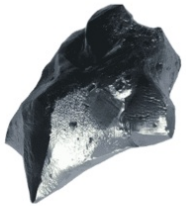
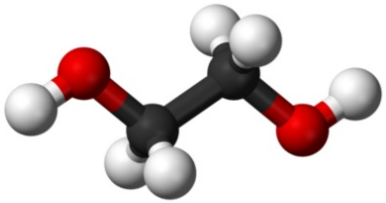

Mechanical / Materials Issue
Operational / Process Issue

Team 7's Case Study

Glycol Desalination Plant





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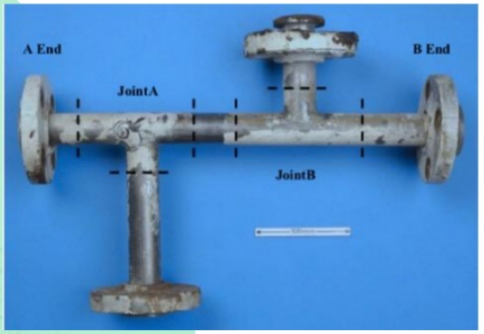
Identified Main Root Cause For Titanium 12: Stress Corrosion Cracking

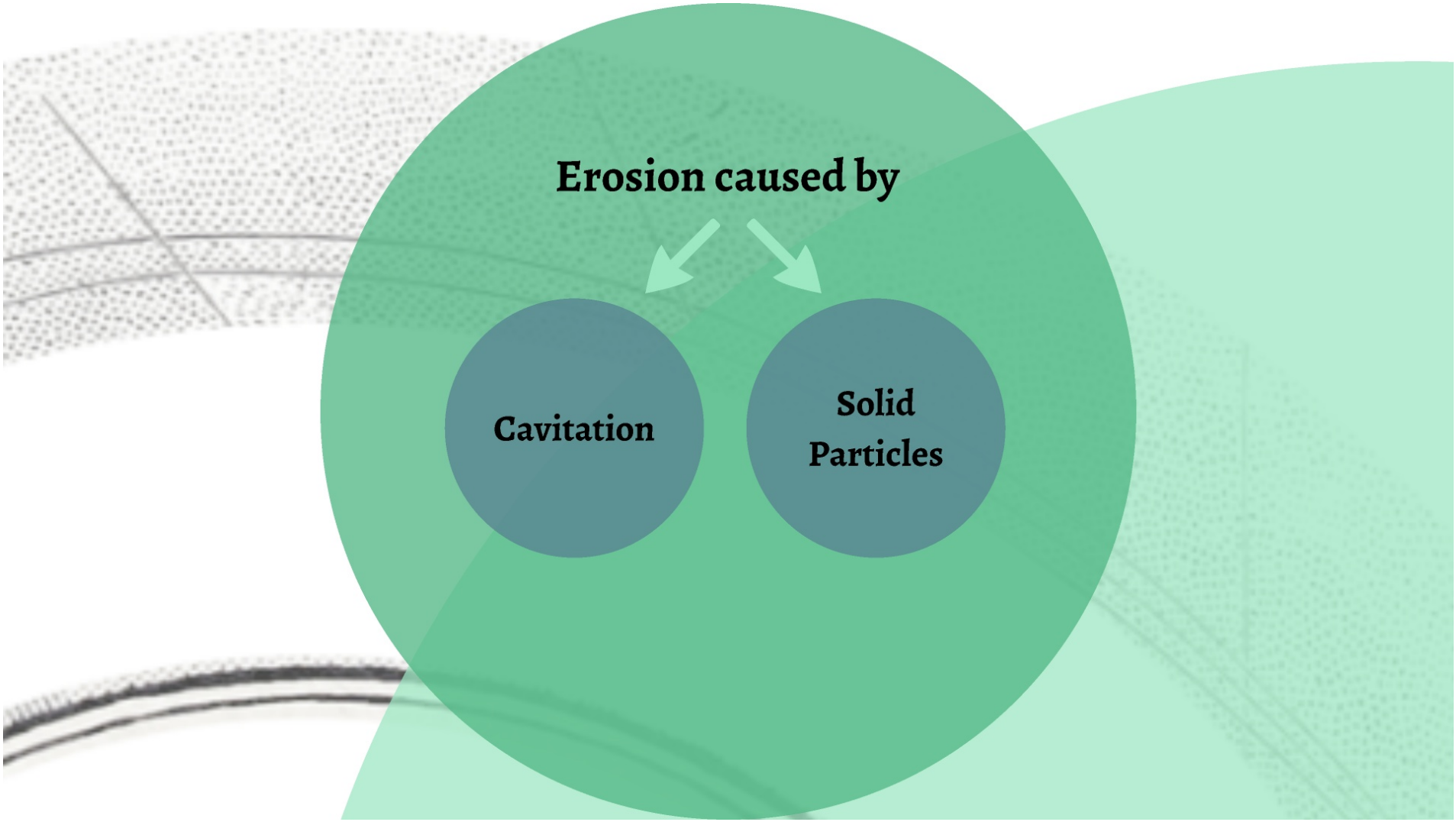
Damage Initiated by Erosion

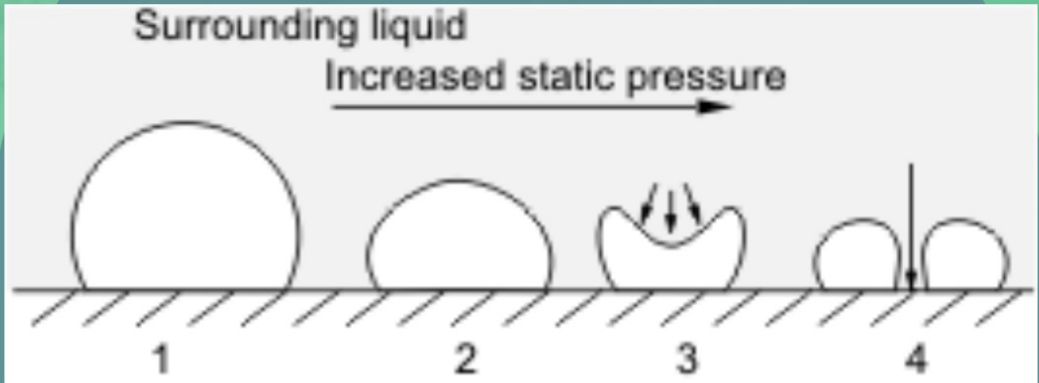
Corrosion - Presence of Organic Acids

Transgranular Susceptibility

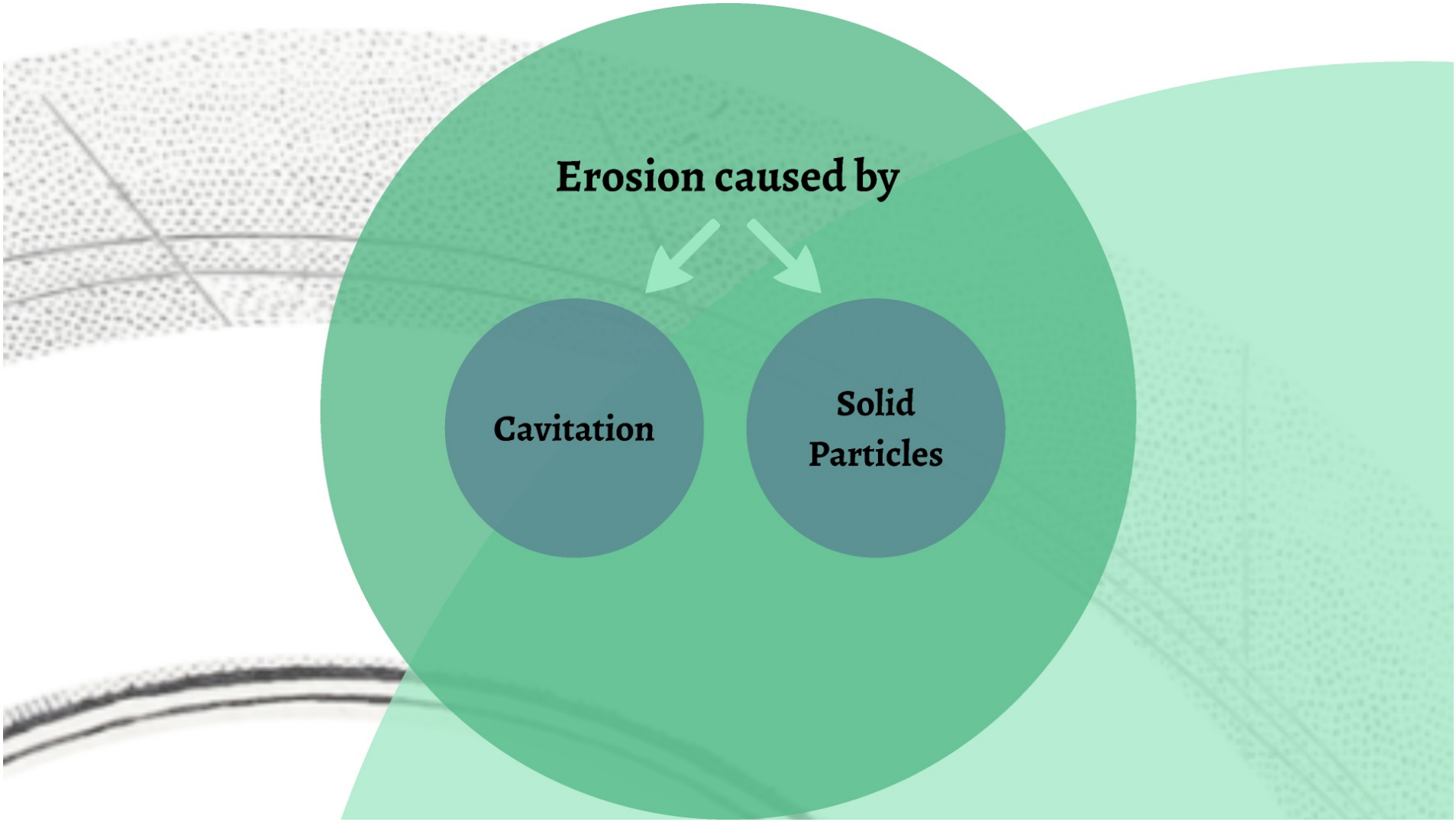
Residual Stress




Erosion caused by
Cavitation
Solid Particles



Cavitation bubble imploding close to a fixed surface generating a jet (4) of the surrounding liquid.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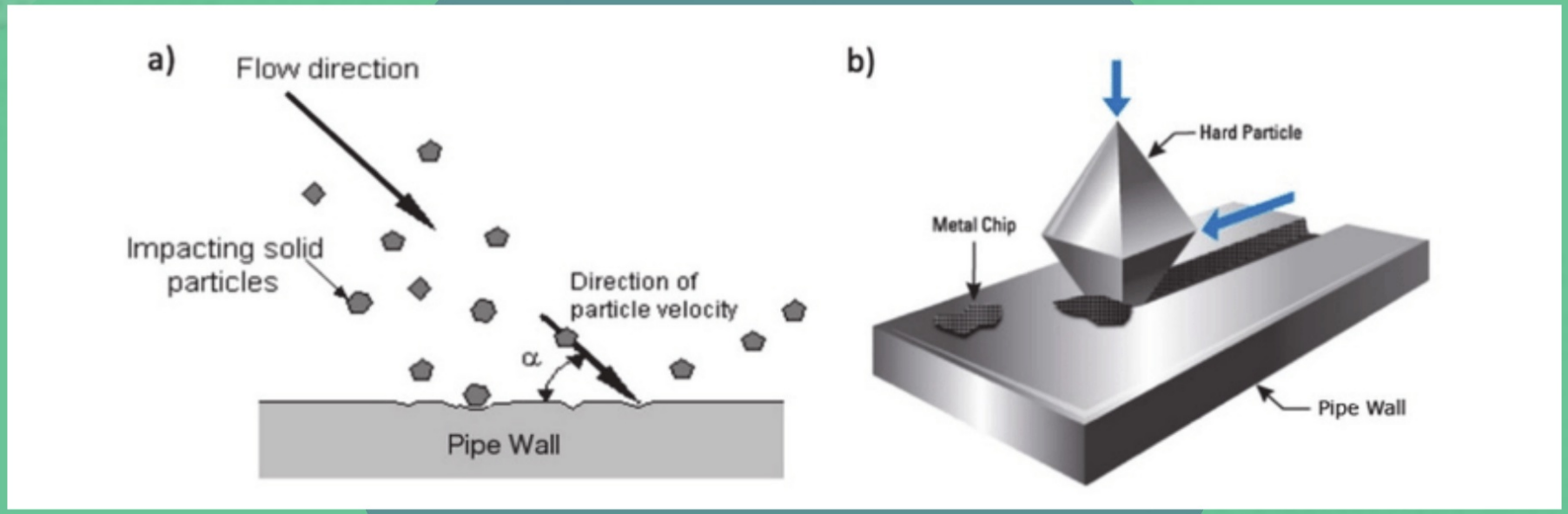
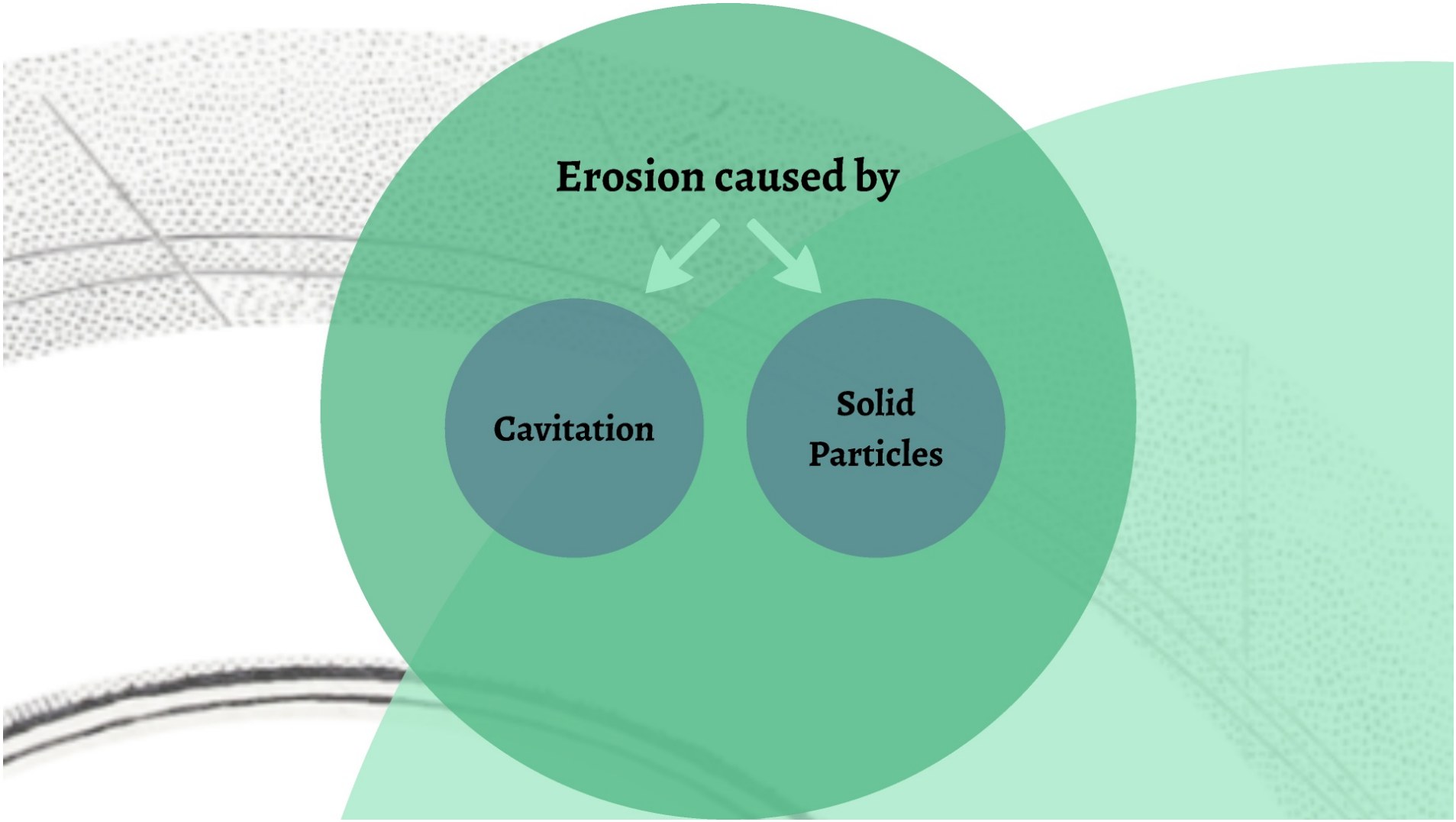

a)
Flow direction
Impacting solid particles
Direction of particle velocity
α
Pipe Wall
b)
Hard Particle
Metal Chip
Pipe Wall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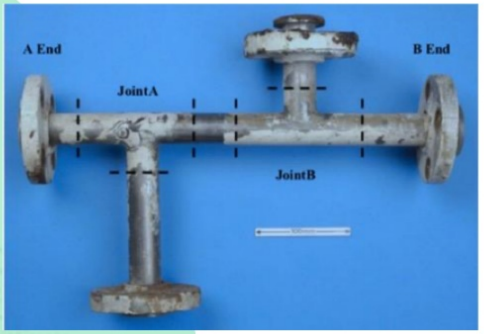

Titanium 12 & Organic Acids

Calculated concentration of acids in sample:

Acetic acid	700ppm	53.4%
Formic Acid	500ppm	38.2%
Propanic Acid	100ppm	7.6%
Glycolic Acid	<5ppm	0.4%
Oxalic Acid	<5ppm	0.4%

Corrosion rates for Titanium 12 alloy :

	Concentration %	Temperature °F(°C)	Corrosion rate mpy (mm/y)
Formic acid, non-aerated	10	212 (100)	>50 (>1.27)
	25	212 (100)	96 (2.44)
	50	Boiling	126 (3.20)
	90	212 (100)	118 (3.00)

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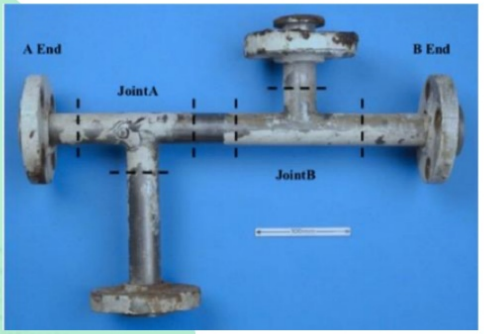
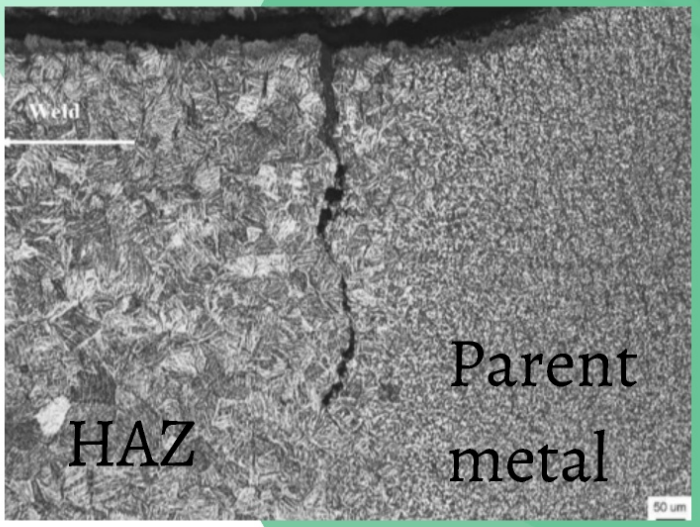
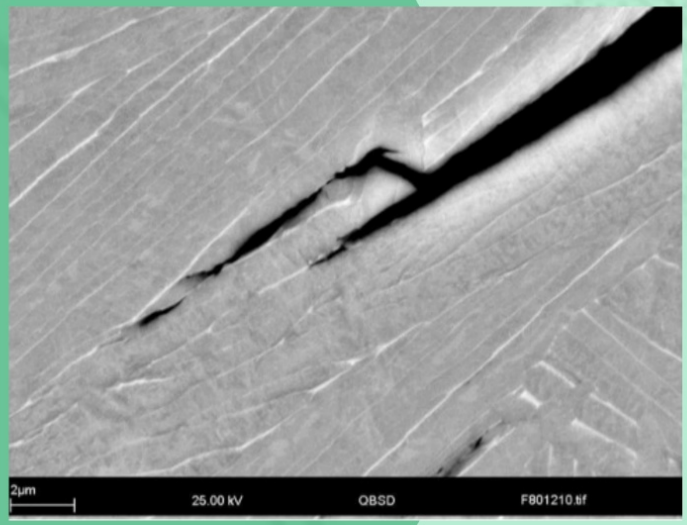
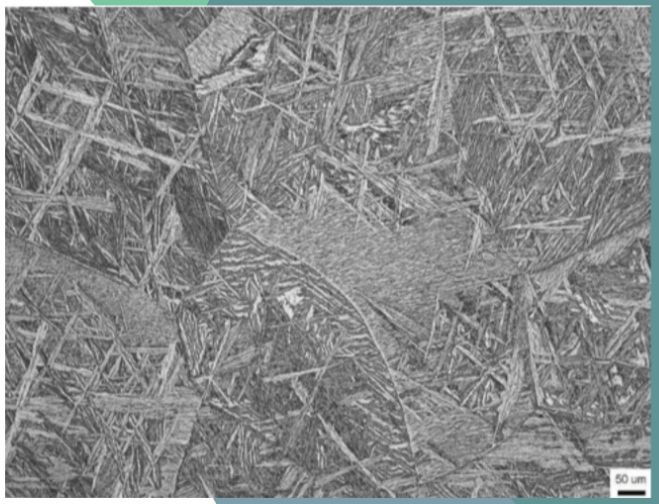


Macrostructure & Cleavage Cracking

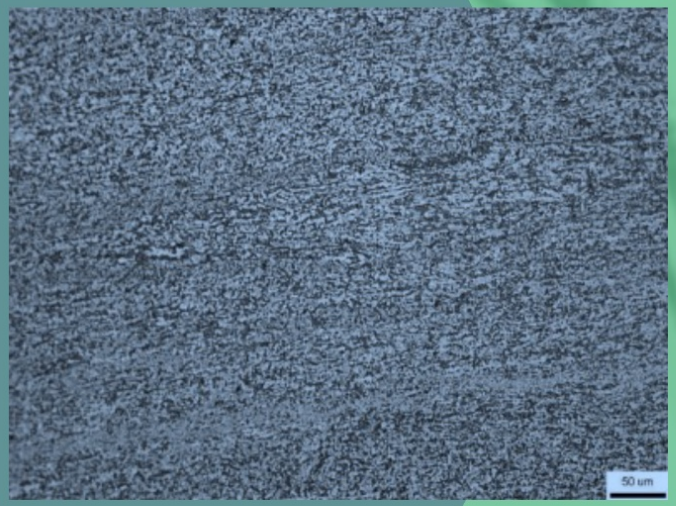




Microstructure

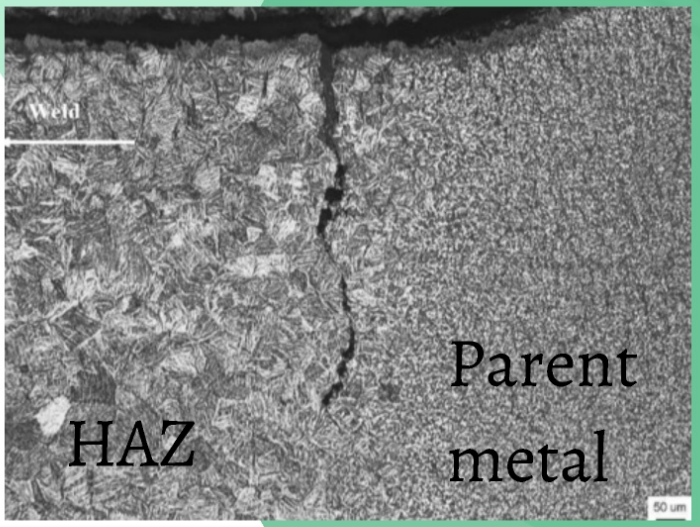


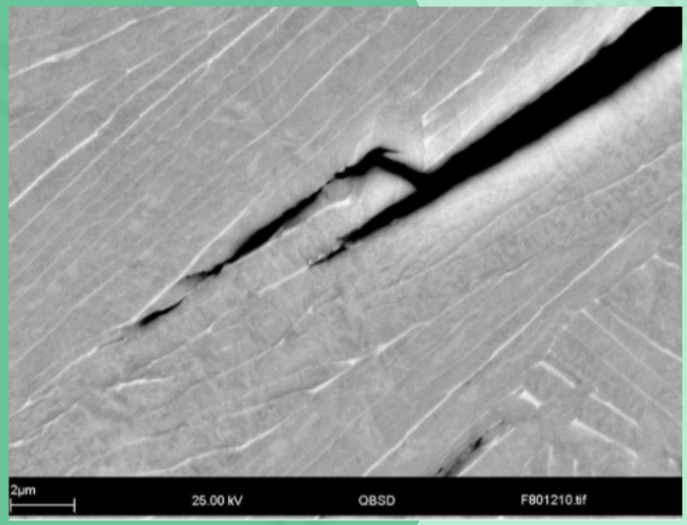
Martensitic



Equiaxed Grains

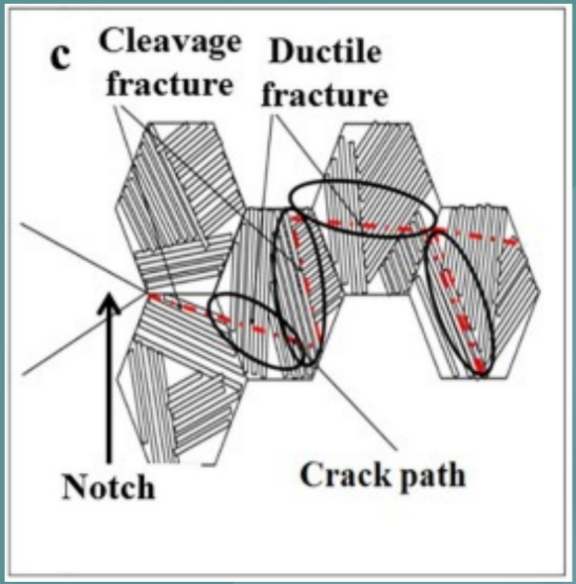
Macrostructure & Cleavage Cracking





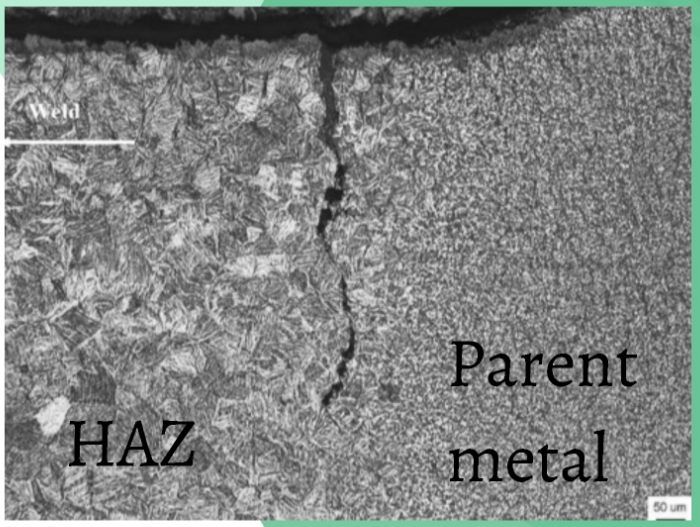
Microstructure

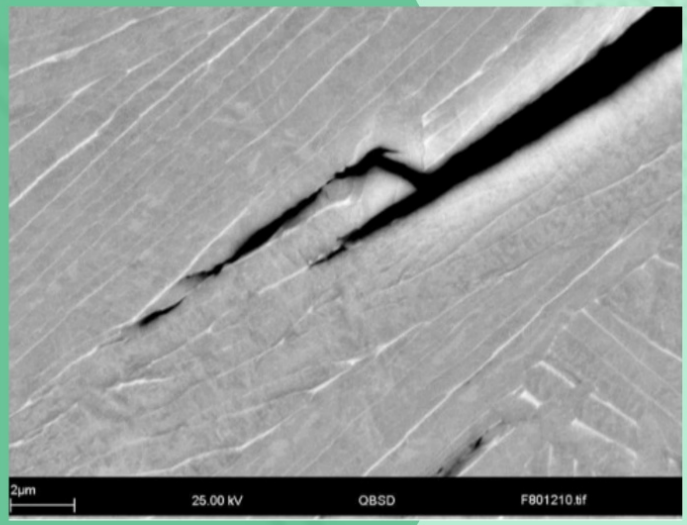
Cleavage Cracking



- Increases at lower temperature and higher strain rate
- Could be accelerated by operational cyclic stresses

Macrostructure & Cleavage Cracking





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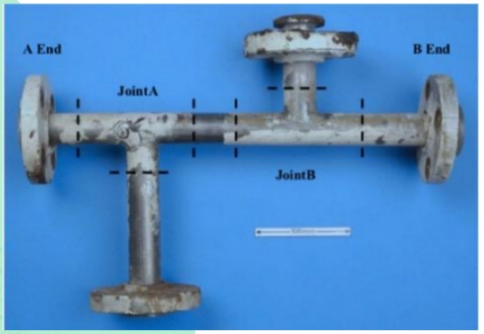

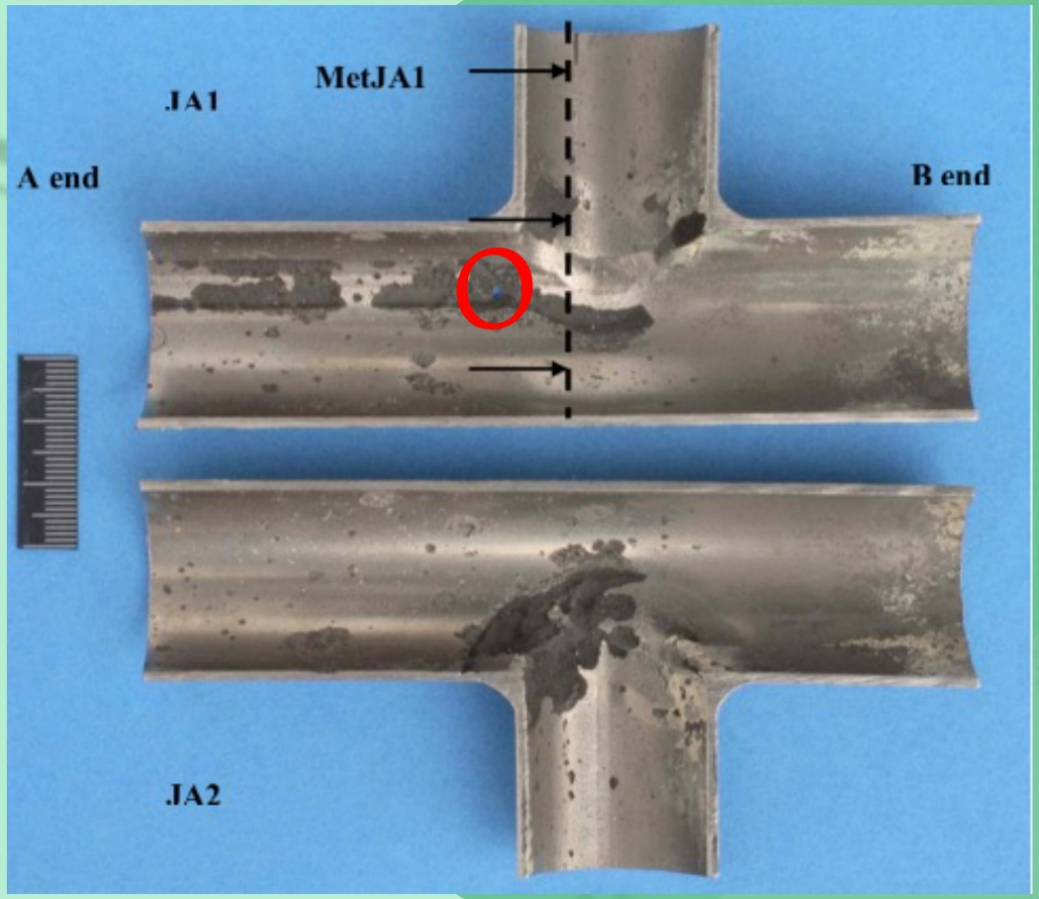

- Residual stress might remain
- Operational cyclic stresses + Residual stresses = Work hardening of weld area

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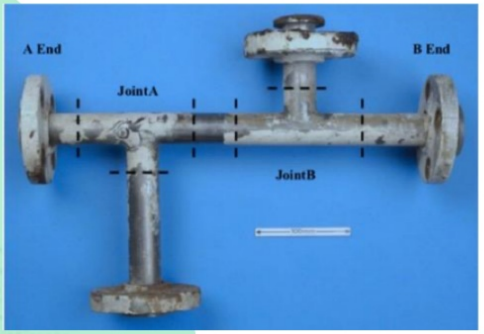
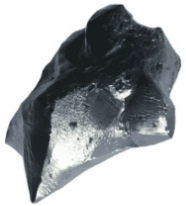
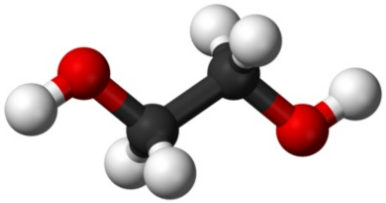


Team 7's Case Study

Glycol Desalination Plant





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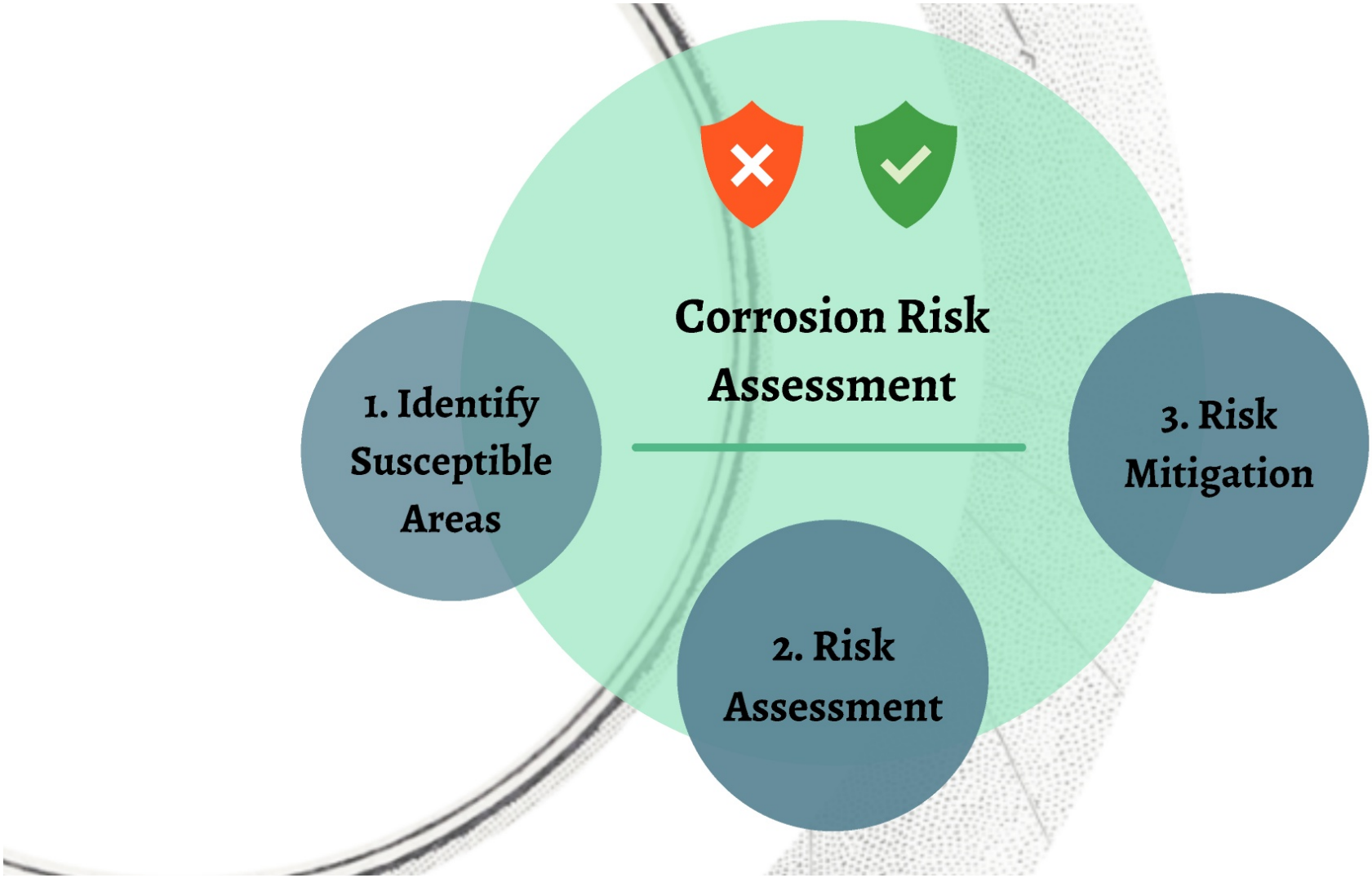

Corrosion Risk Assessment
1. Identify Susceptible Areas
2. Risk Assessment
3. Risk Mitigation

Susceptible areas

S

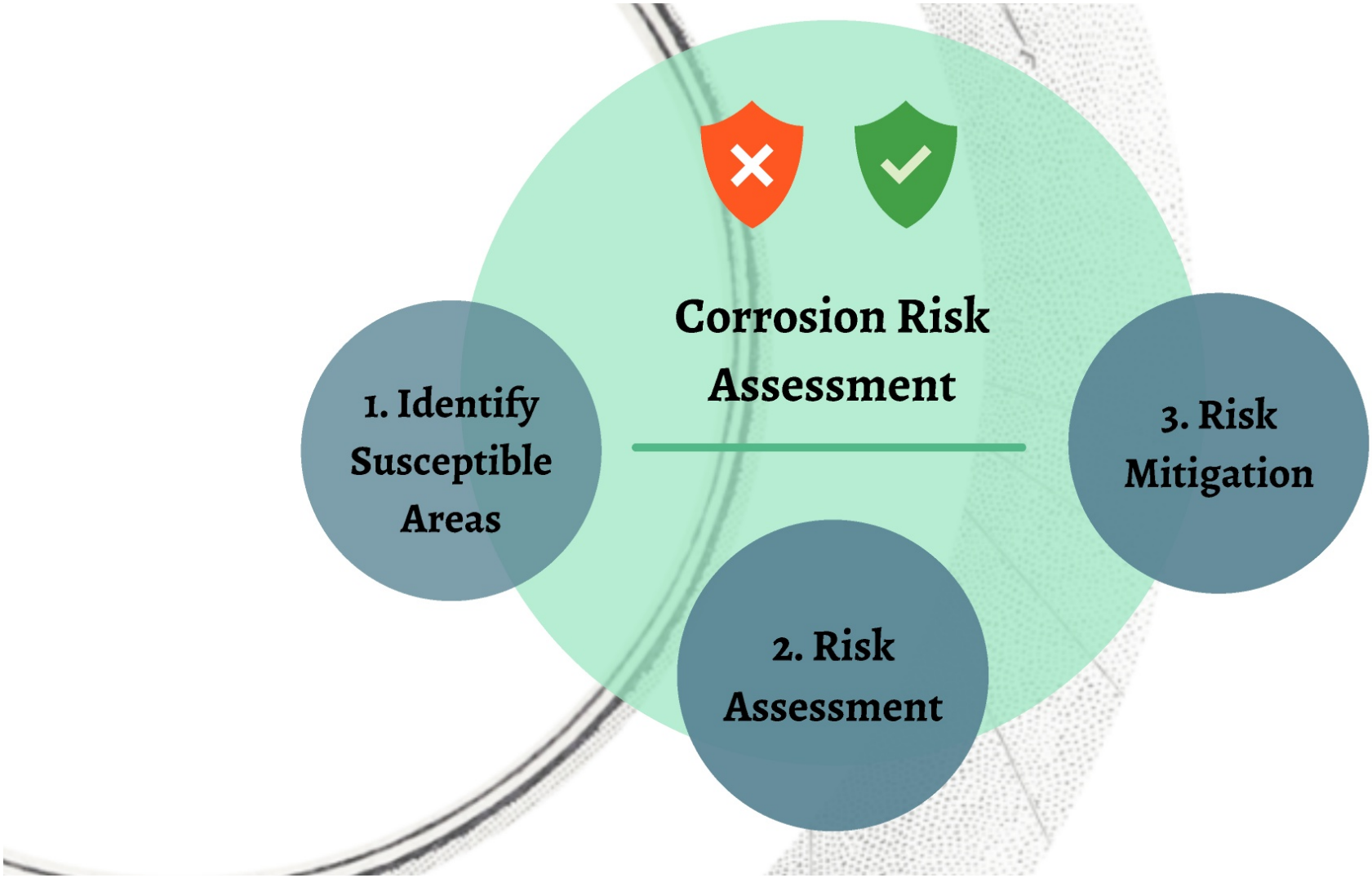
High aerosol content
Slightly combustible
Swallowing
Ingestion
Irritation to eyes
Skin
Respiratory problems
Acids
High temperature

P

Plant shutdown
Efficiency
Optimization
Economic losses

E

Aquatic organism
Terrestrial organism
Pollution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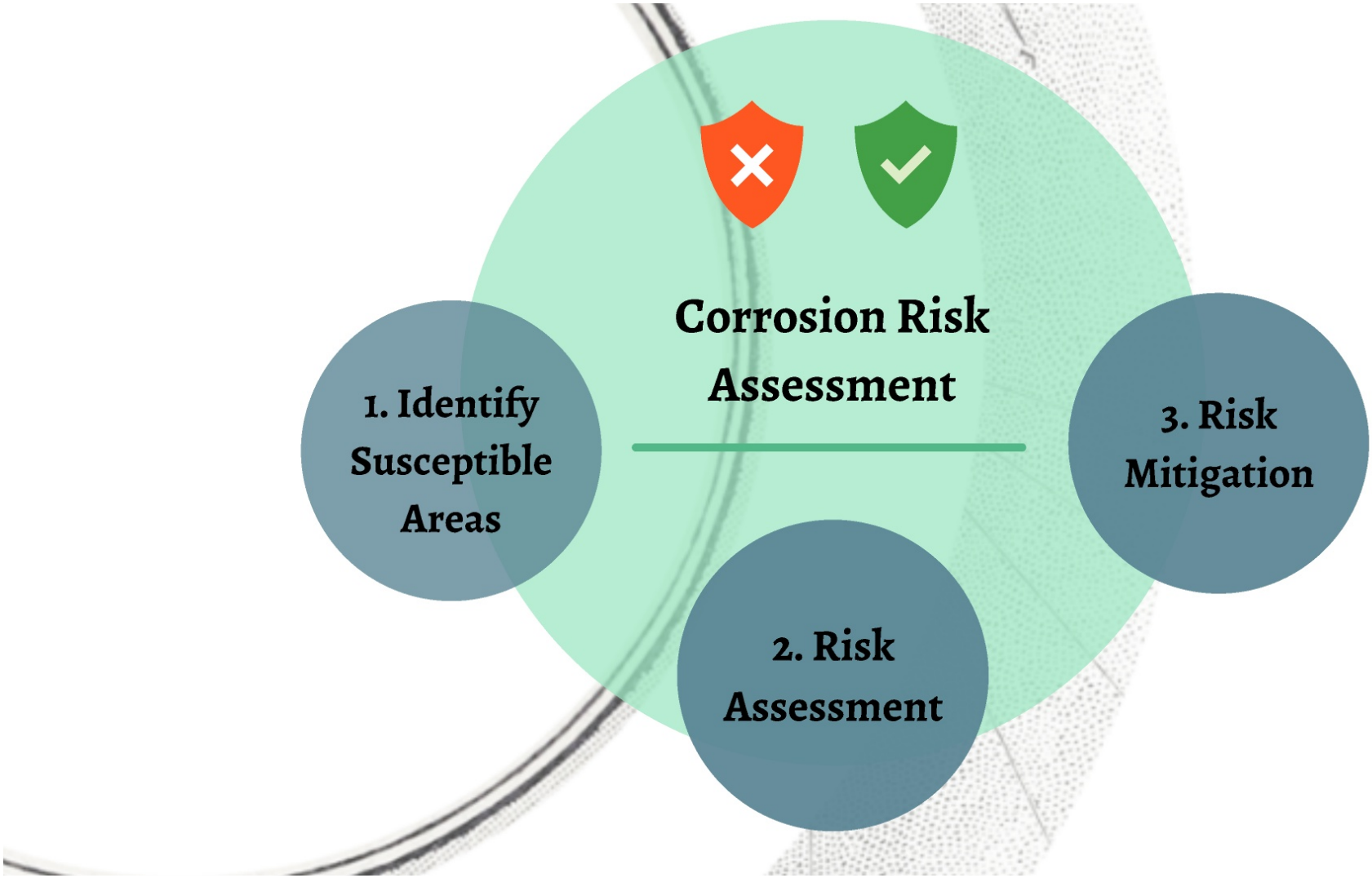
Likelihood / Impact	Rare - 1	Unlikely - 2	Possible - 3	Likely - 4	Highly likely - 5
Negligible - 1	1	2	3	4	5
Minimal - 2	2	4	6	8	10
Medium - 3	3	6	9	12	15
High - 4	4	8	12	16	20
Major - 5	5	10	15	20	25

RISK = Impact x Likelihood

Class of Impact	Safety	Production	Environment
Negligible – 1	No (or very slight injury)	No disruption	No residual impact
Minimal – 2	Minor Injury	Brief disruption to production	Minor impact
Medium – 3	Major Injury	Partial short-term shutdown	Localised but major impact
High – 4	1 fatality	Undefined shutdown	Sever impact
Major – 5	>1 fatality	Substantial plant loss	Extreme impact

Likelihood	Generic Qualitative	Energy Institute
Rare – 1	Never heard of in the industry	>20 years
Unlikely – 2	Known possibility	10-20 years
Possible – 3	Has happened in the organisation or more than once per year in the industry	5-10 years
Likely – 4	Has happened at the location or more than once per year in the Organisation	2 to 5 years
Highly Likely – 5	Has happened more than once at the location	< 2 years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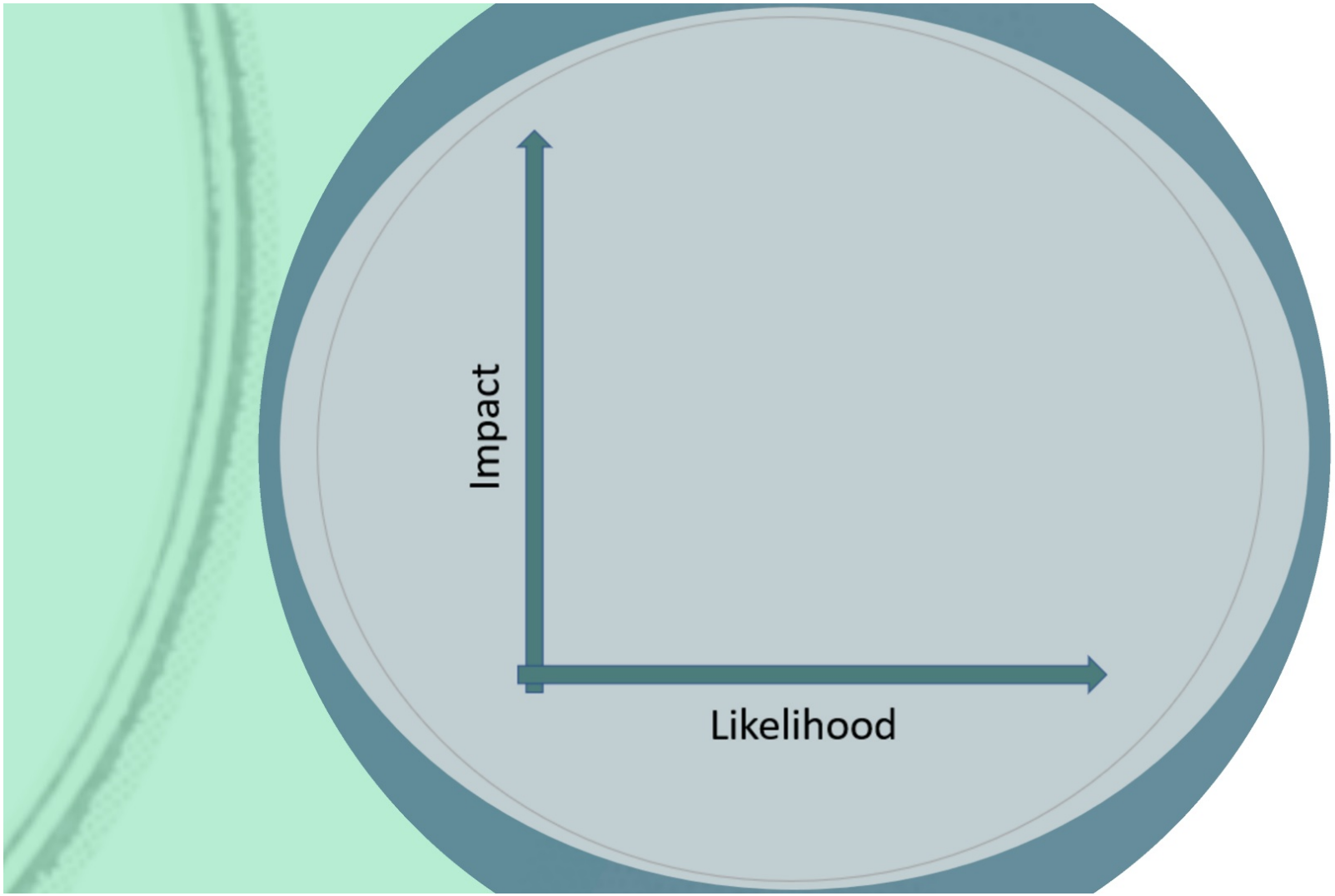
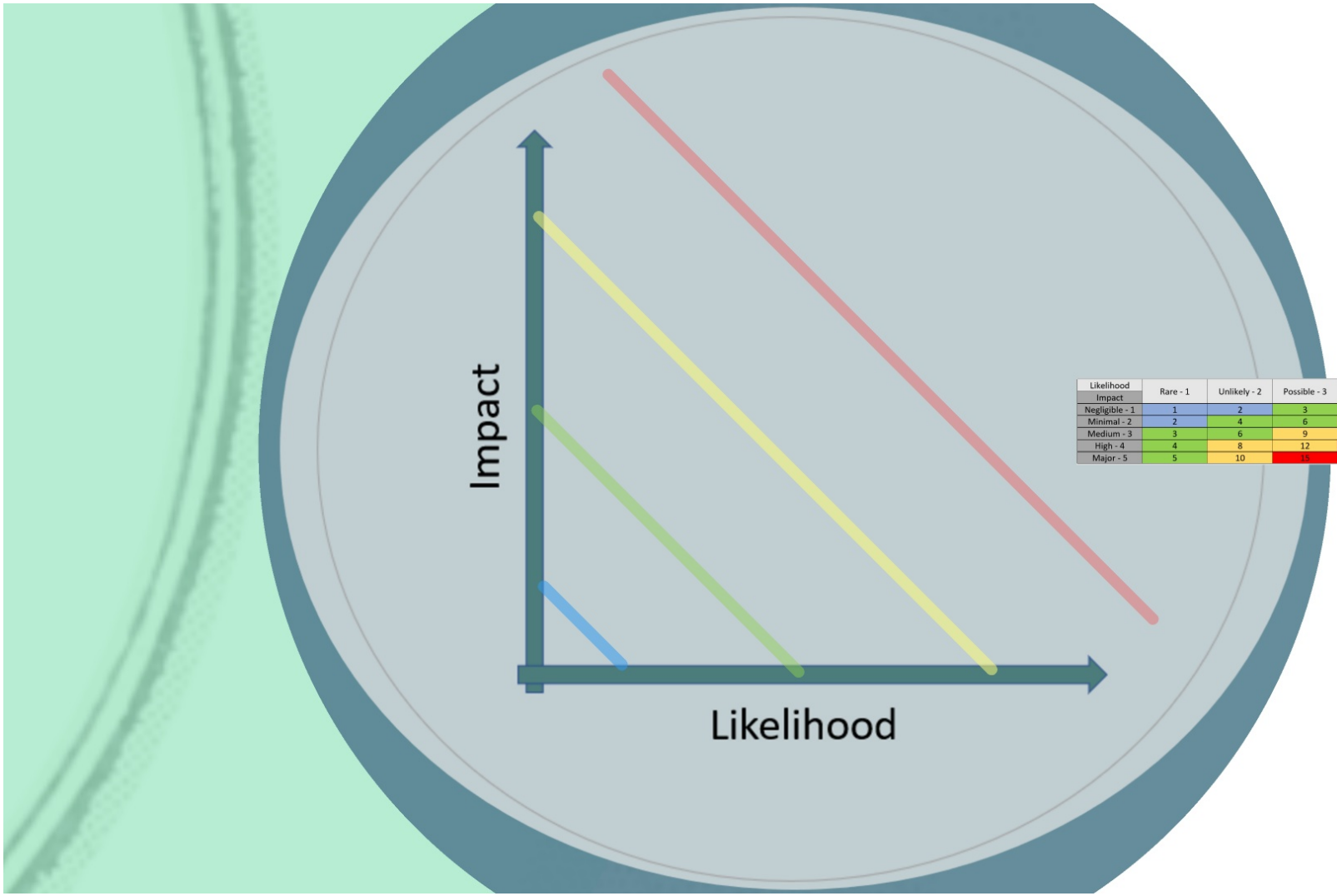

Impact
Likelihood



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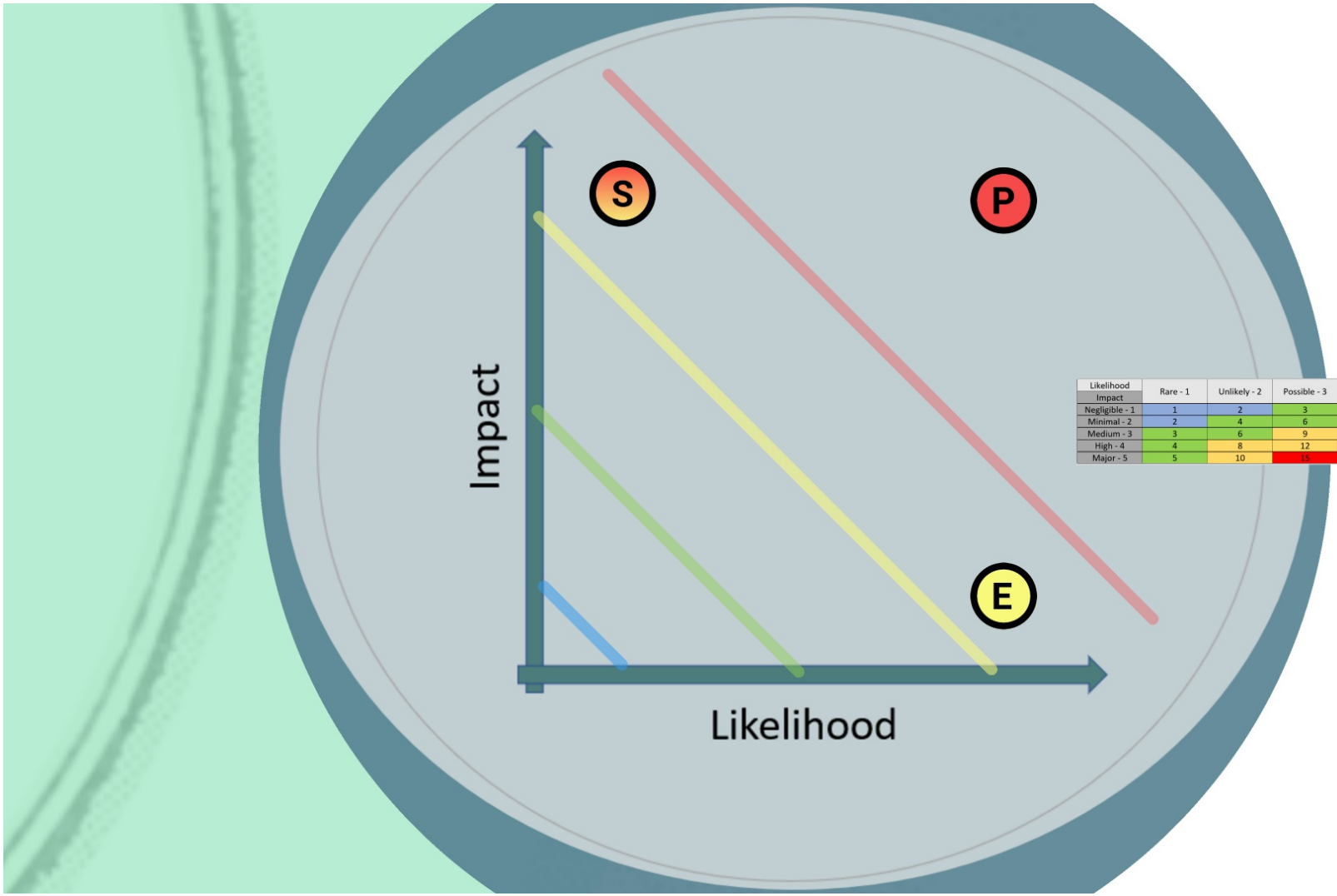

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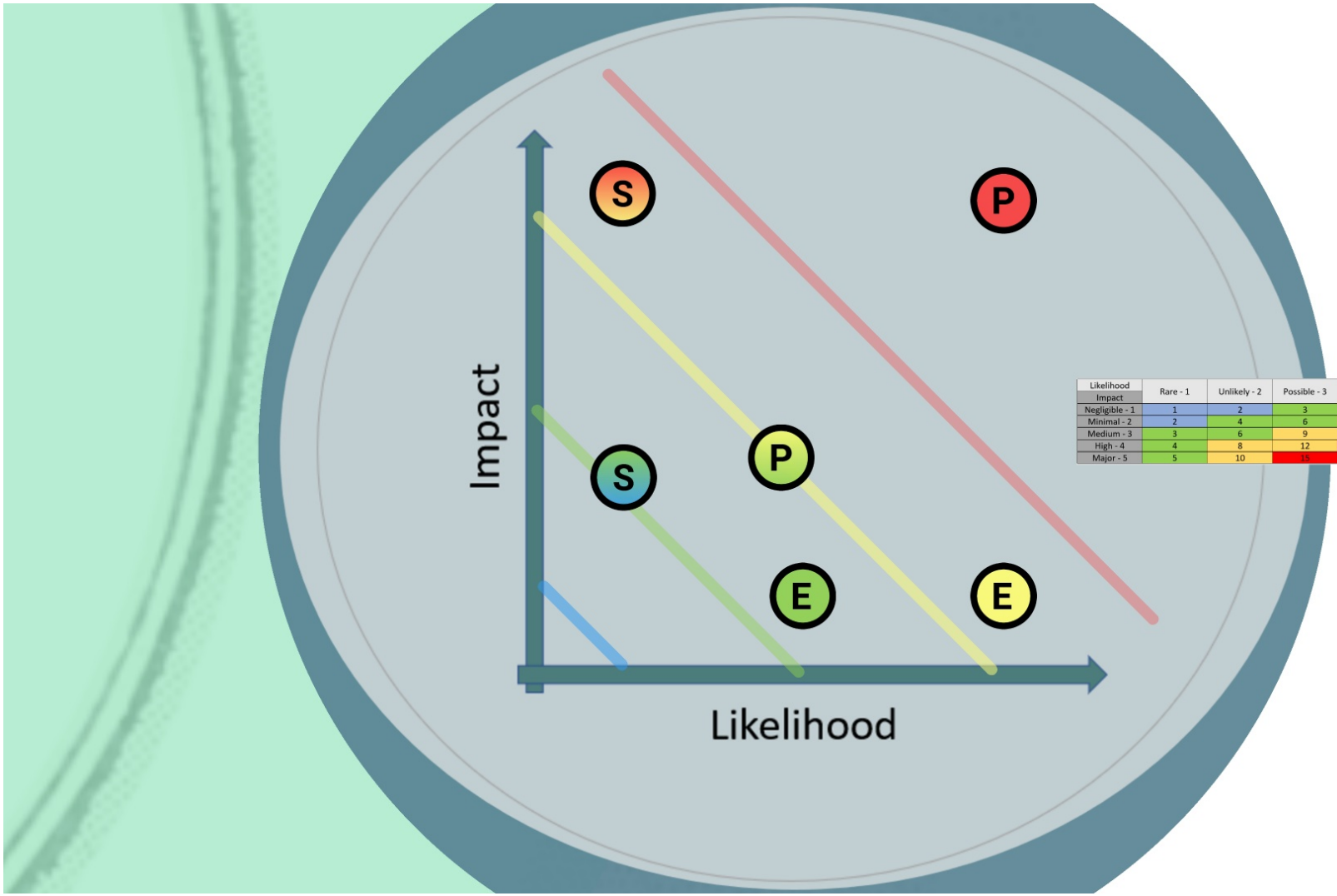

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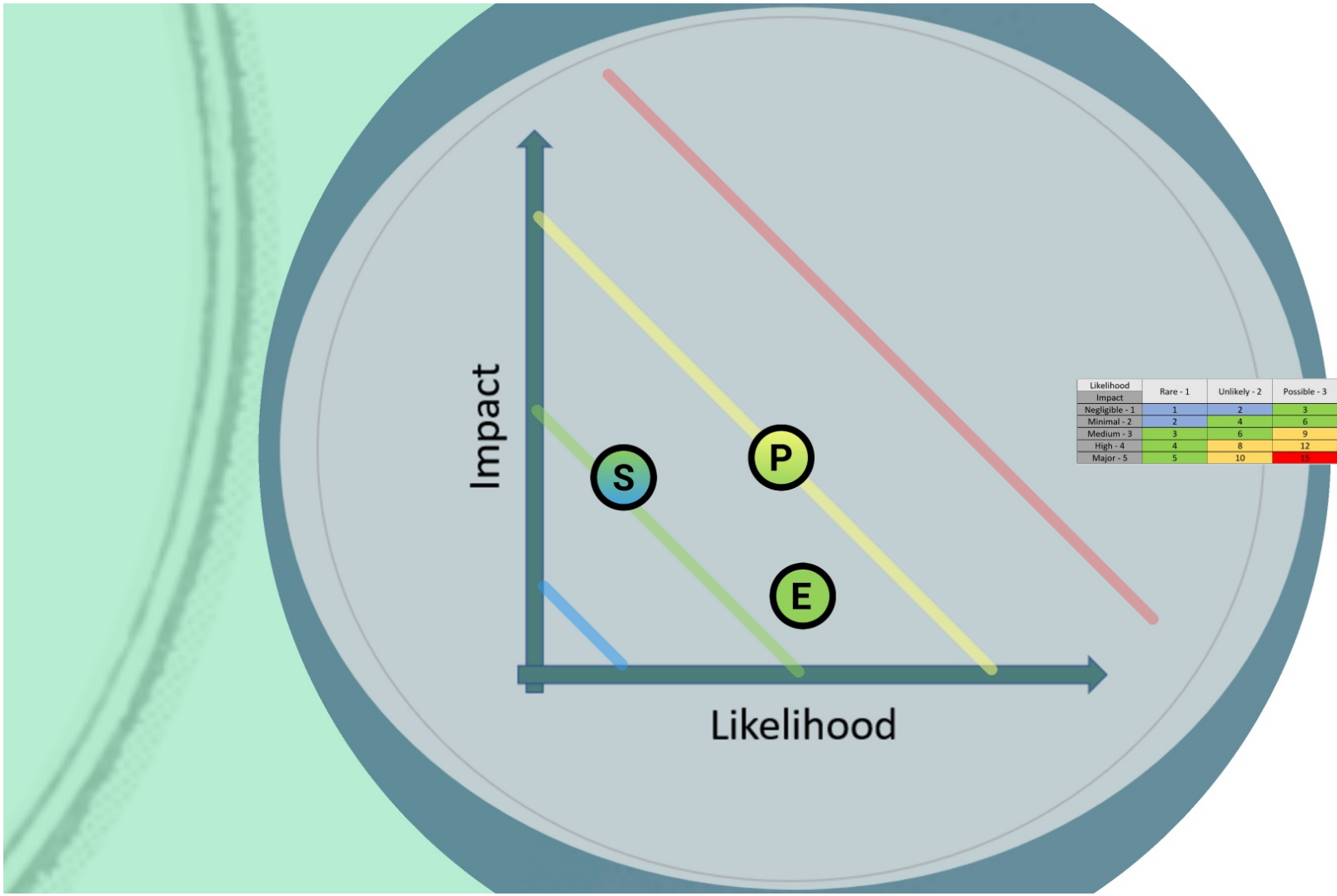

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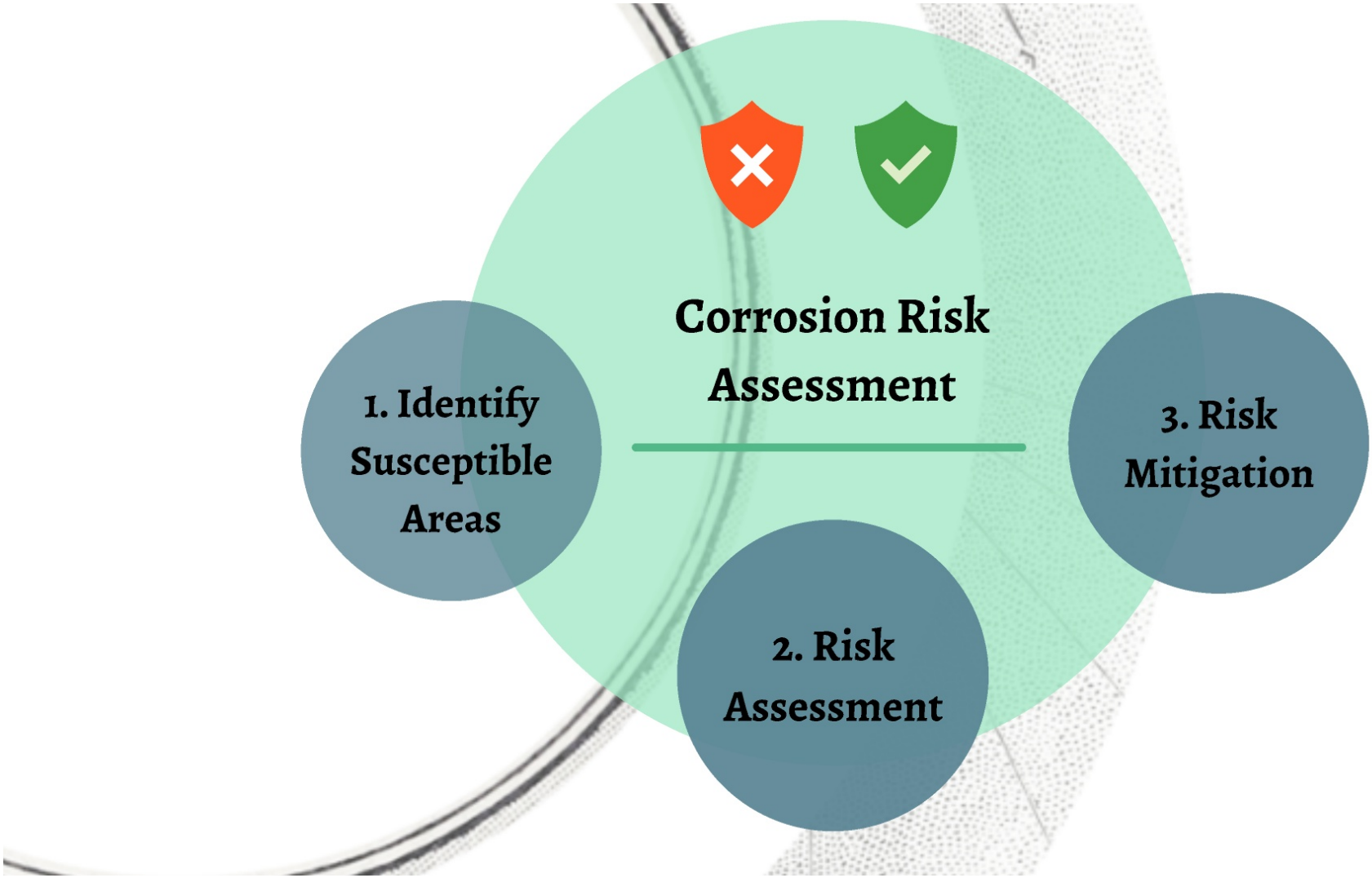
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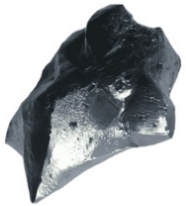

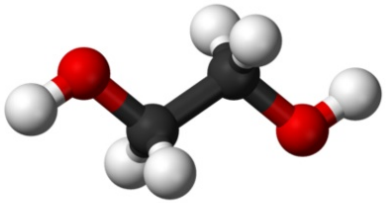

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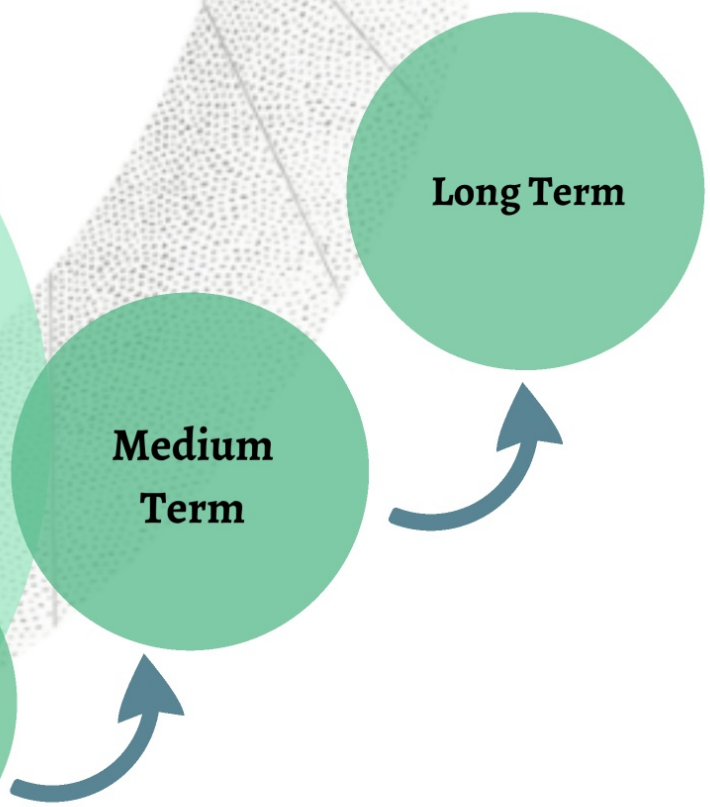


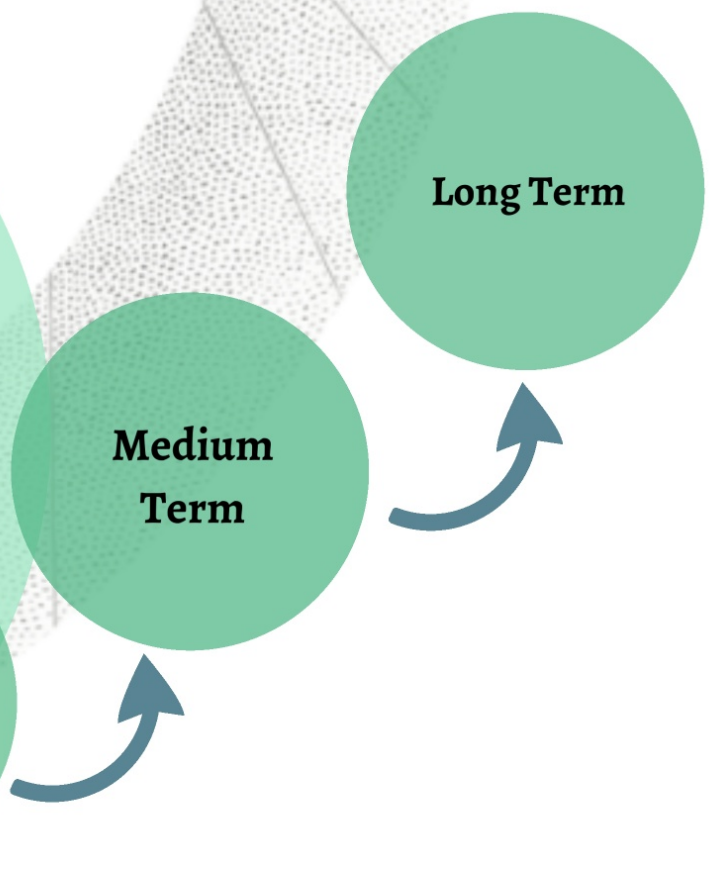
Short Term

Follow the non-leaking policy
Partial shutdown at off-peak time
Fully replace pieces (like per like)
Investigation of spools
Filters
Operational rounds

- Specify the use of correct PPE

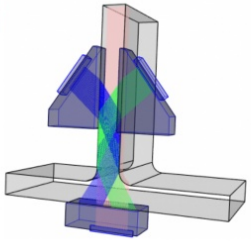
Investigation and identify more susceptible areas

Mitigation Plan

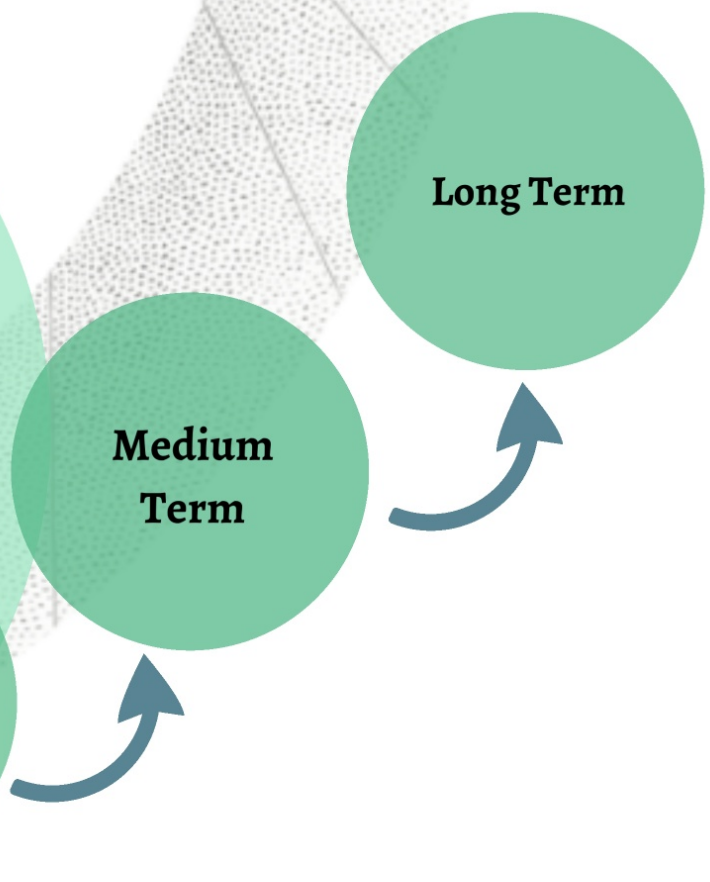


Medium term

Create new policies/procedures
Set up a proactive approach
Data collection
Samples
NDTs (Pitting - UT)
Installation of titanium coupons
Repair more susceptible areas



Mitigation Plan

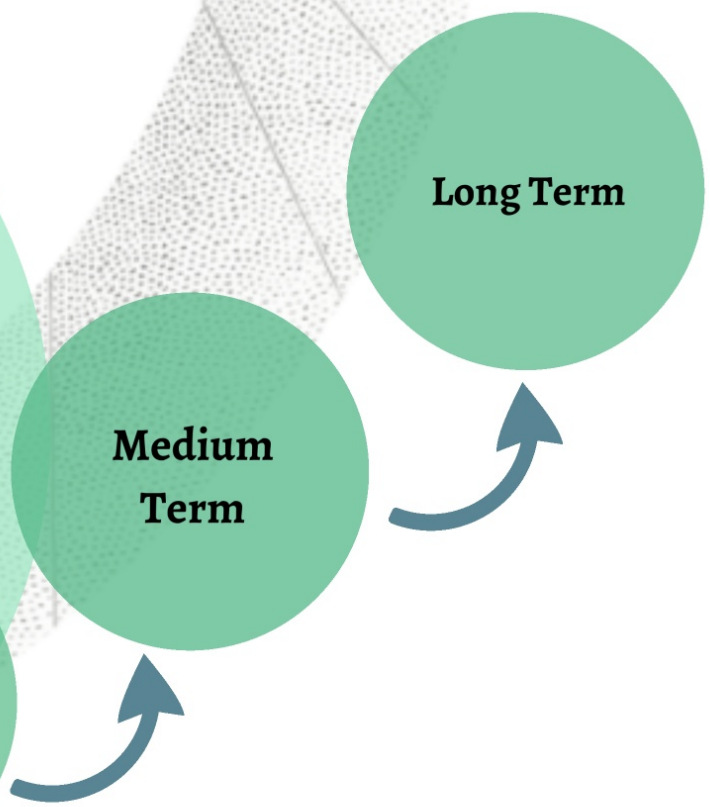


Long term

Bypasses for maintenance
Oxygen scavengers
Installation of corrosion inhibitors
Corrosion probes
Alternative manufacturing method like forged tees

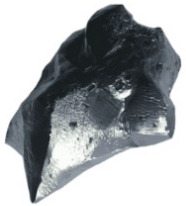
- Microstructure/grain
- Thickness
- Titanium 12
- Documentation (WPSs, NDTs, Design, life expectancy)

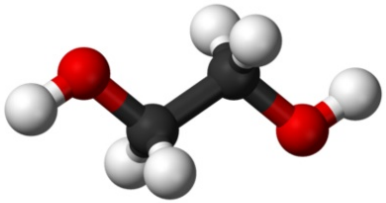
Mitigation Plan



Team 7's Case Study

Glycol Desalination Plant





Root Cause Analysis

Identified Root Causes

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- Loss of protective titanium oxide layer at the branches.
- Corrosion of the exposed material due to organic acids.
- Grain boundaries within the HAZ susceptible to chemical corrosion attack.
- Crack propagation at the grain boundaries.

Conclusion Continued

Conclusion Continued

To mitigate against the root causes of the leaks:

- Investigate, maintain and improve the filter design.
- Investigate the loss of the vacuum.
- Re-design at-risk pipework sections in the evaporator spools.

SAFE, RELIABLE AND COMPLIANT PLANT OPERATION

Conclusion Continued

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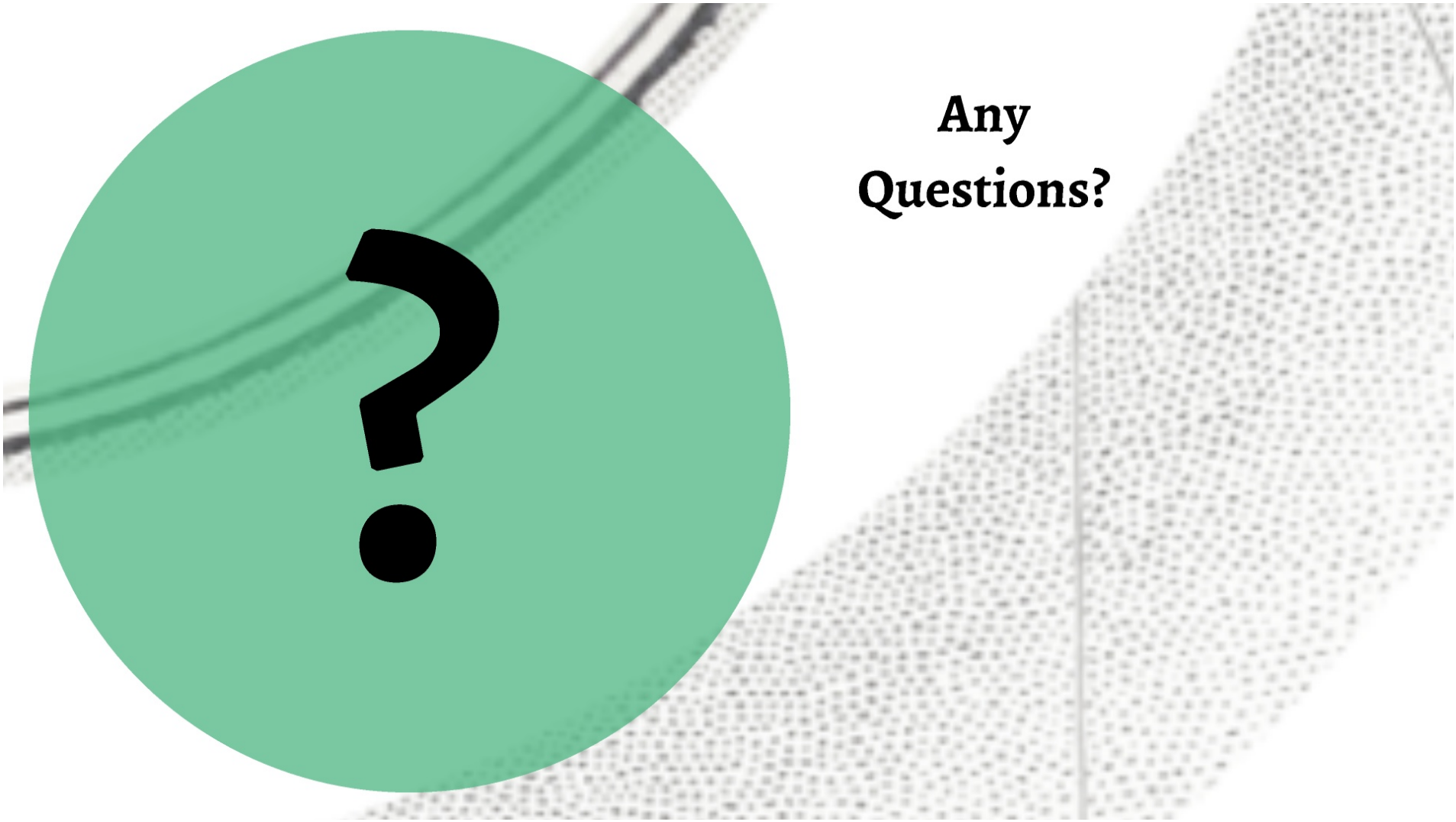
Any Questions

SAFE, RELIABLE AND COMPLIANT PLANT OPERATION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Conclusion Continued

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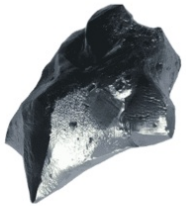

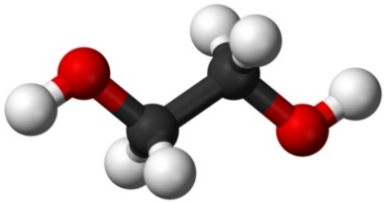

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