Performance of Five Australian X70 Transmission Pipelines in High-Pressure Hydrogen Gas

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APA
Australia's energy infrastructure partner

Jemena

GPA

Outline

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Background &
Industry Relevance

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Material Performance

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Conclusions

Background & Industry Relevance

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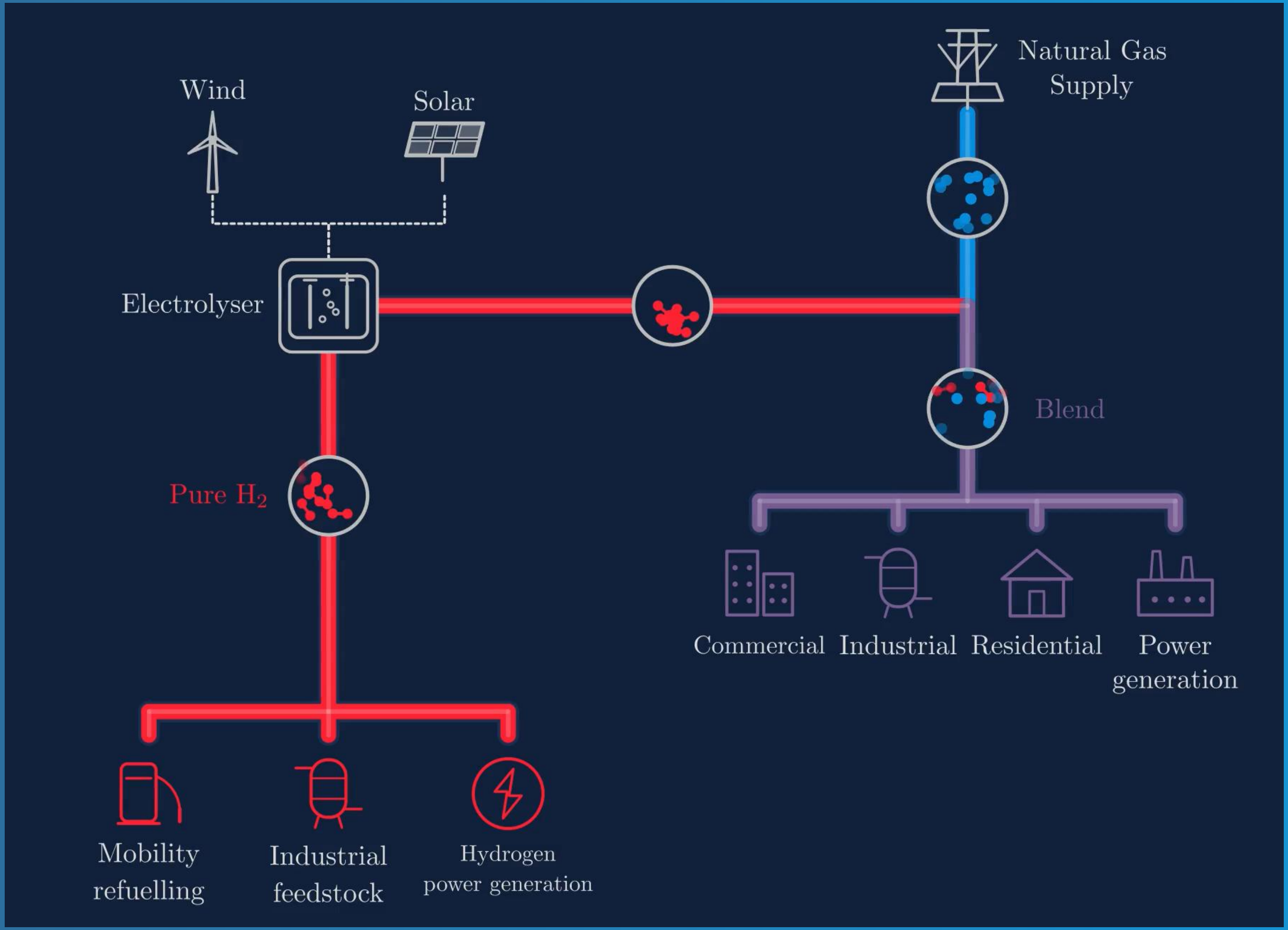
Future Role of Hydrogen Transmission

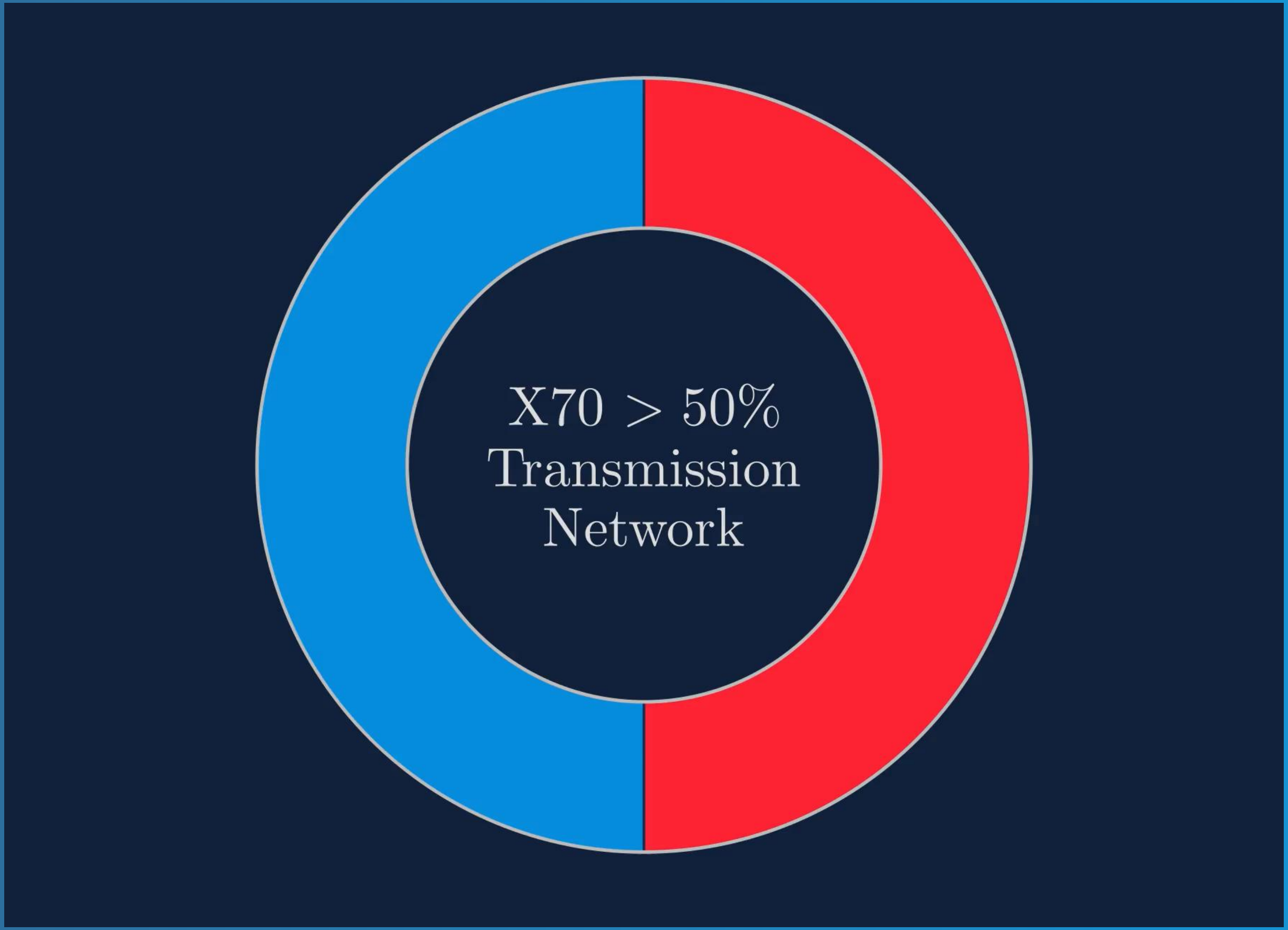
- Prospective hydrogen suppliers and industrial users are seeking transportation services on existing pipelines
- Operators want to know pipeline compatibility with hydrogen transportation for long-term asset planning and valuation
- Operators are considering the delivery of
  - Pure H_2
  - Blended H_2



Background & Industry Relevance

Importance of Grade X70 in the Network

- >50% of Jemena and APA's transmission network is made of X70 steels
- Knowledge gaps exists on material performance of X70 steels in H_2 service
- High-strength materials are generally considered more susceptible to hydrogen embrittlement
- APA and Jemena contracted H_2 material testing services to address this gap
- Tested X70 steels of different
  - Vintages
  - Origins
  - Microstructures



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Bradley J Davis
ROSEN Australia

Hydrogen's Impact on Pipeline Defects

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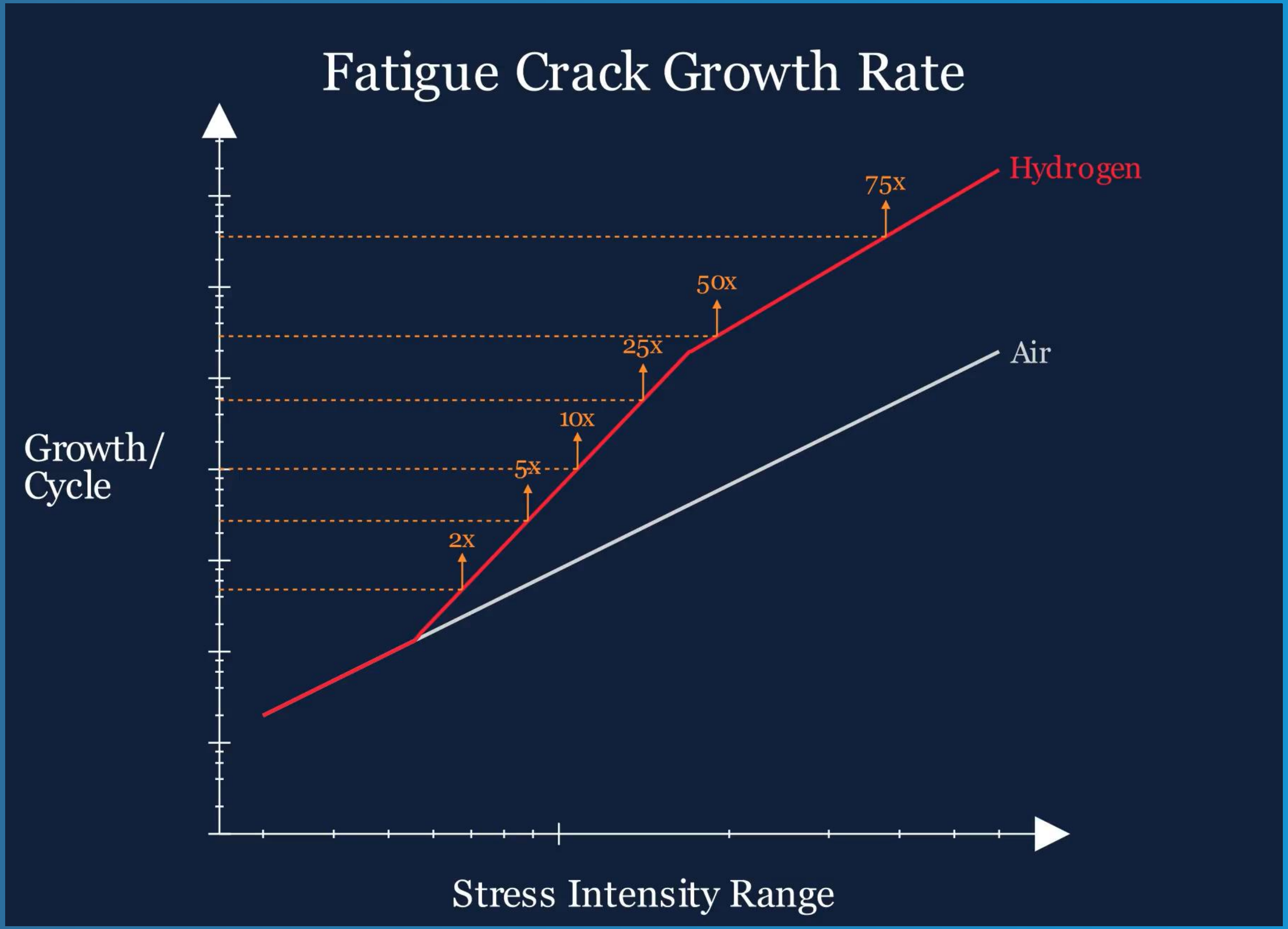
- Hydrogen transport presents new challenges
- Focusing on defect tolerance, there are two key considerations:
  1) Accelerated fatigue crack growth



Hydrogen's Impact on Pipeline Defects

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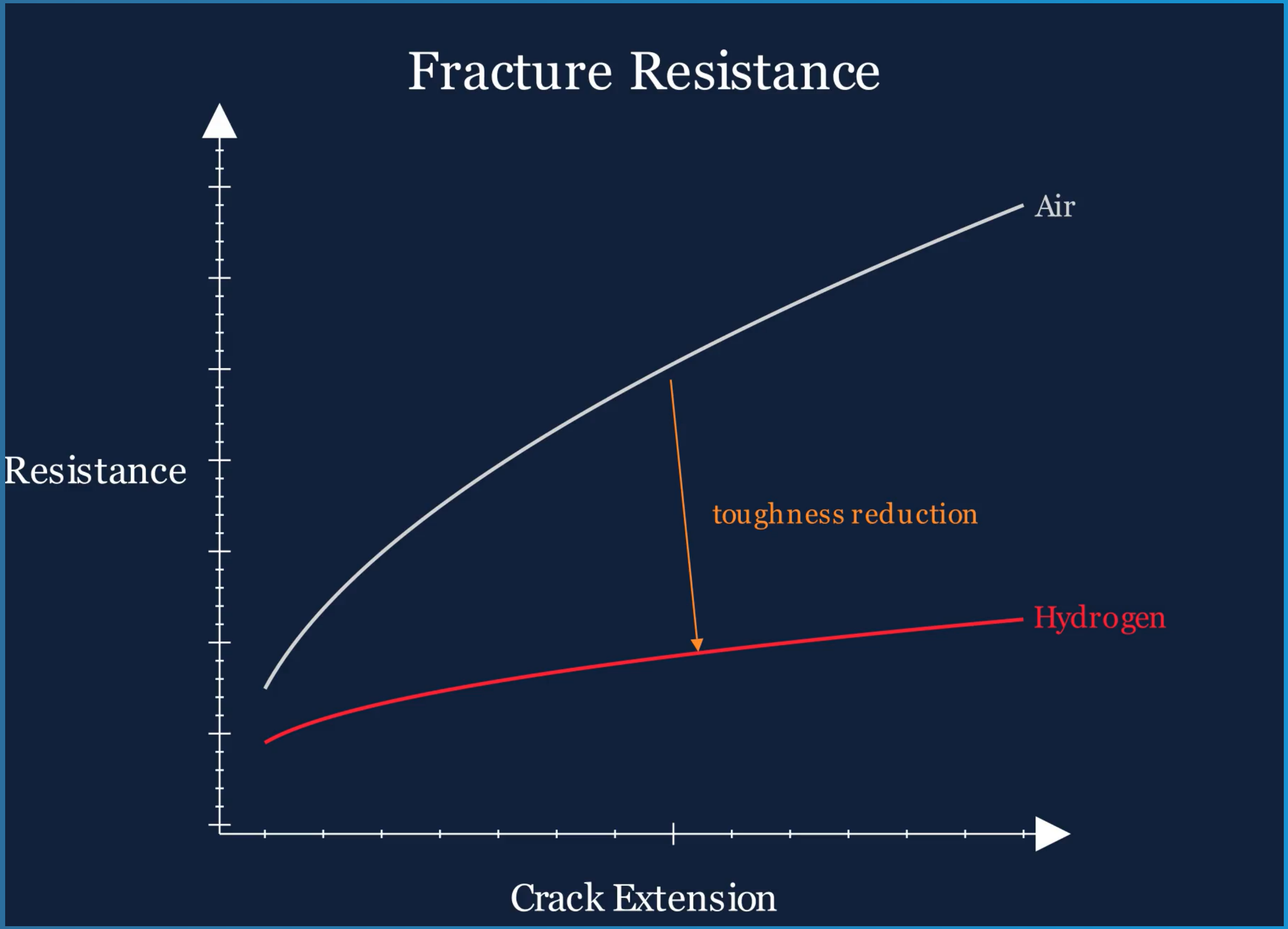
- Hydrogen transport presents new challenges
- Focusing on defect tolerance, there are two key considerations:
  1) Accelerated fatigue crack growth
  2) Reduced fracture resistance
- Hydrogen reduces the allowable defect size and the service time for it to be reached
- There are integrity management solutions



Hydrogen's Impact on Pipeline Defects

Consider an existing crack-like defect in the pipe

Hydrogen’s Impact on Pipeline Defects

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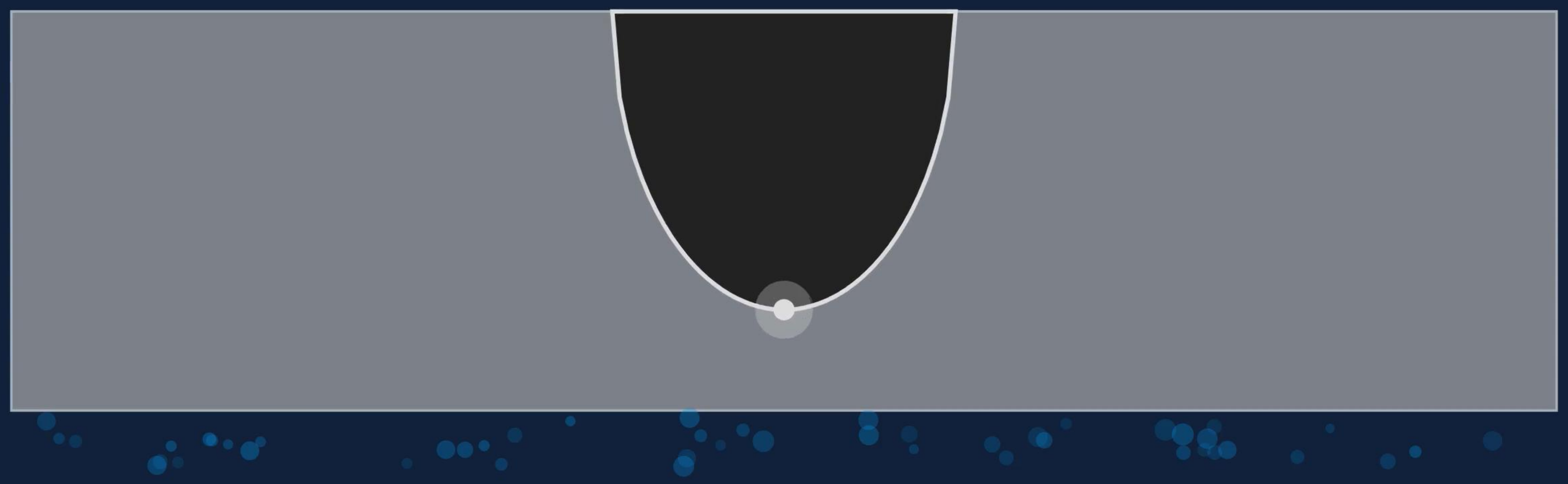
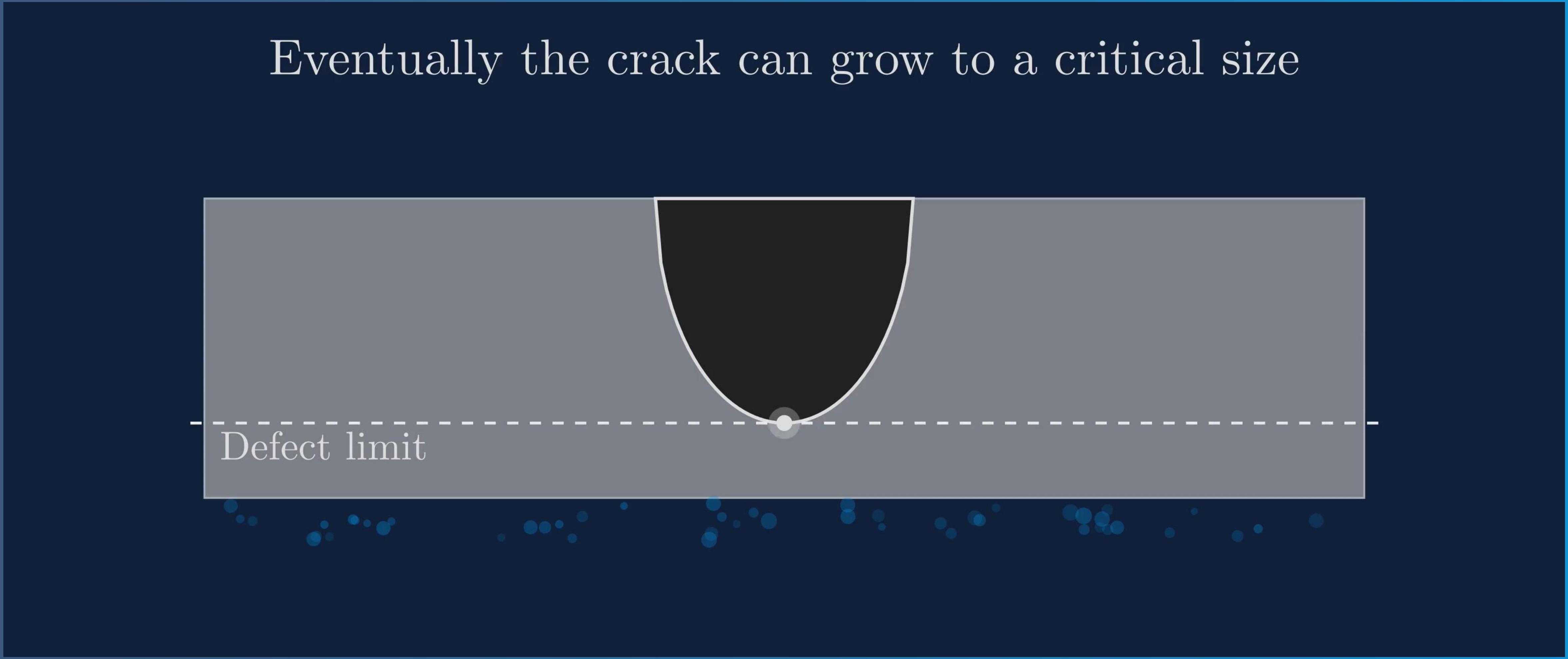
The crack can grow through mechanisms such as fatigue



Hydrogen's Impact on Pipeline Defects



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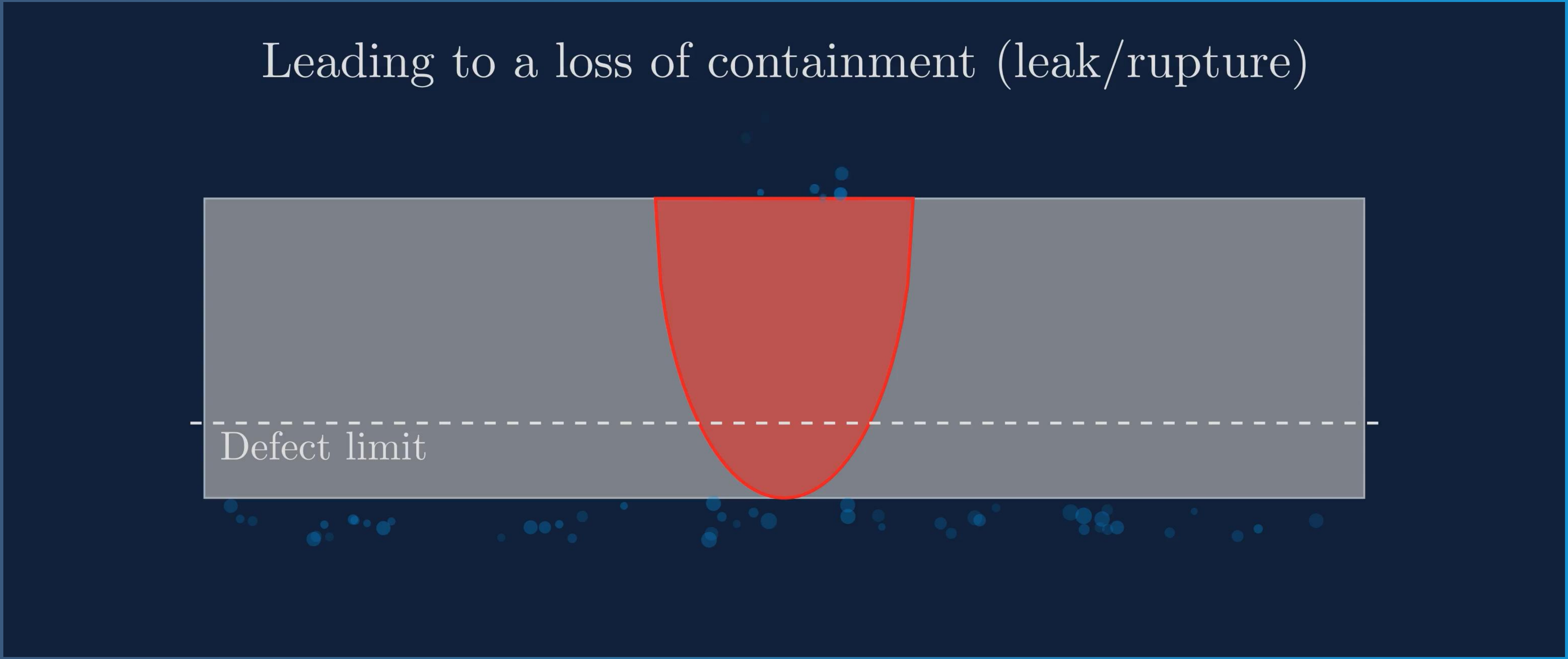

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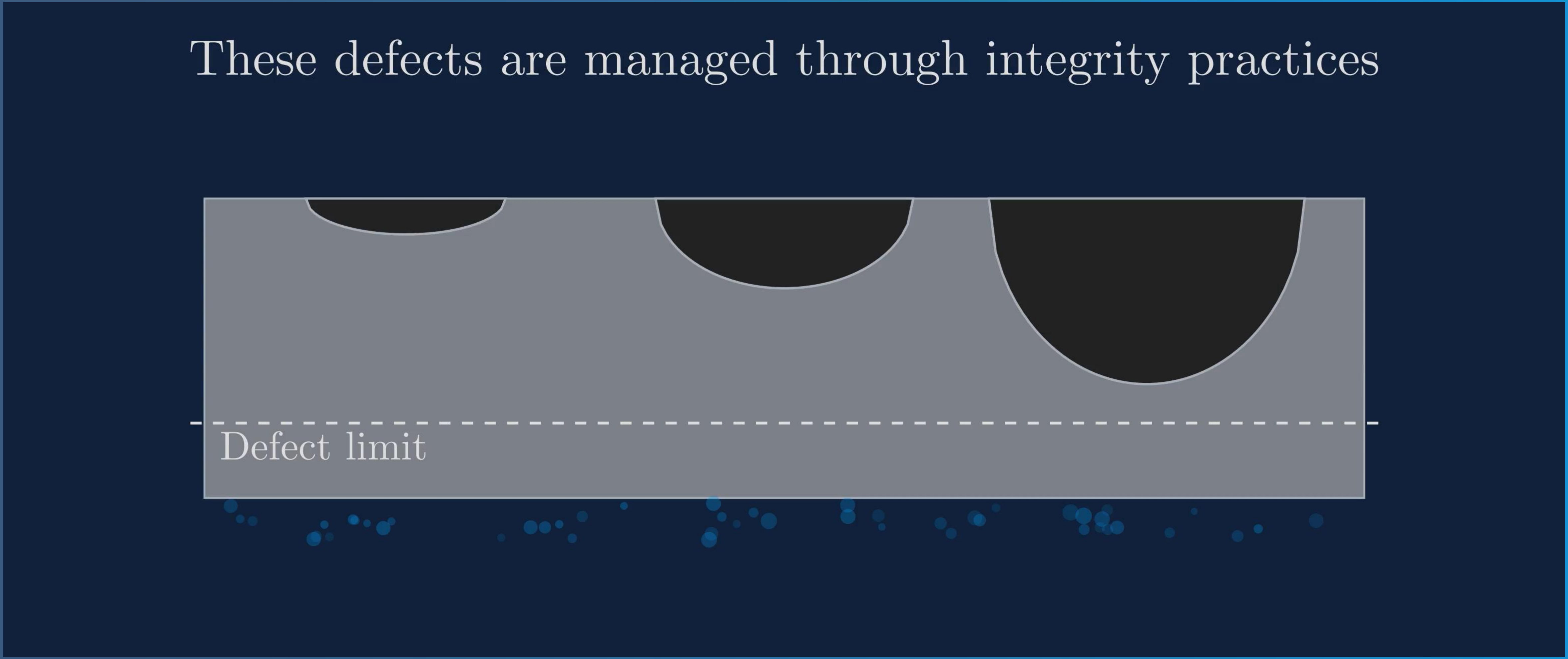
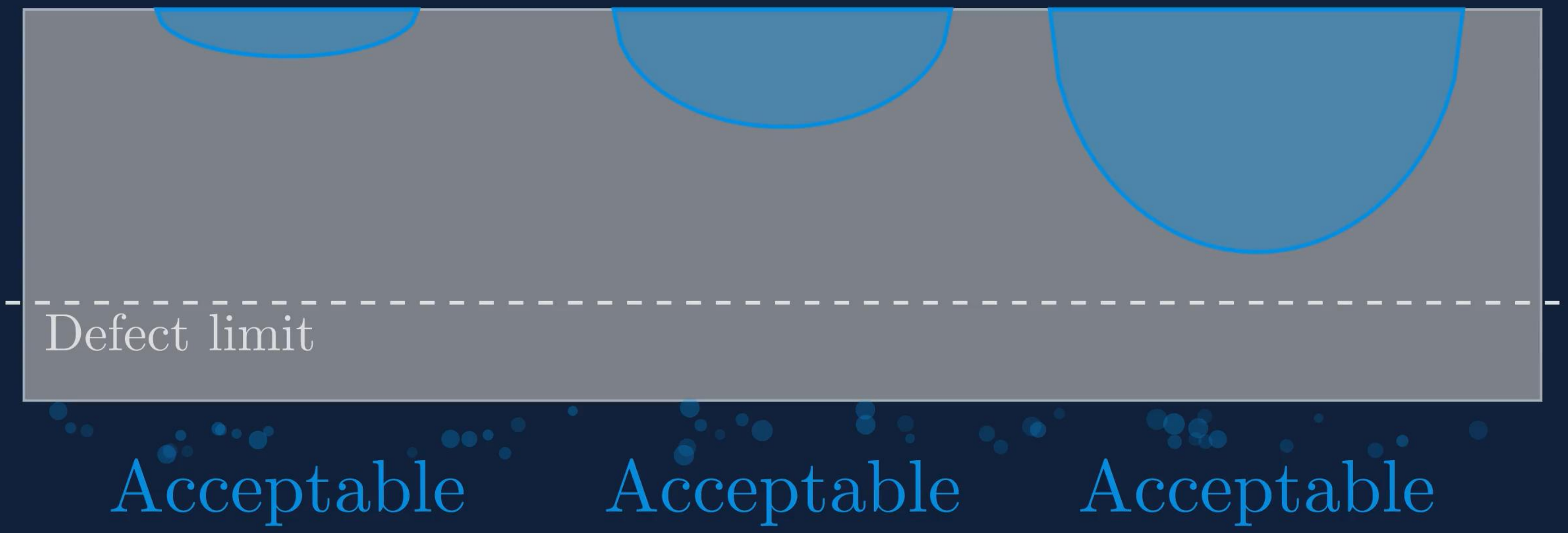


Hydrogen's Impact on Pipeline Defects

These defects are managed through integrity practices



Hydrogen’s Impact on Pipeline Defects

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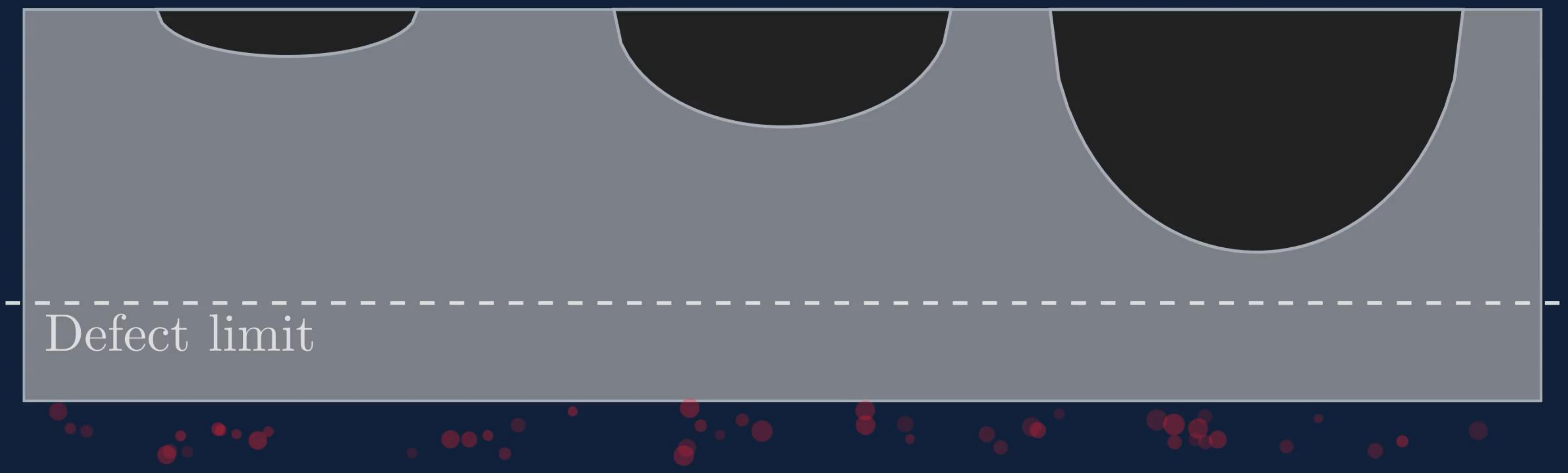
Switching to hydrogen service,
requires a reassessment of the defect population



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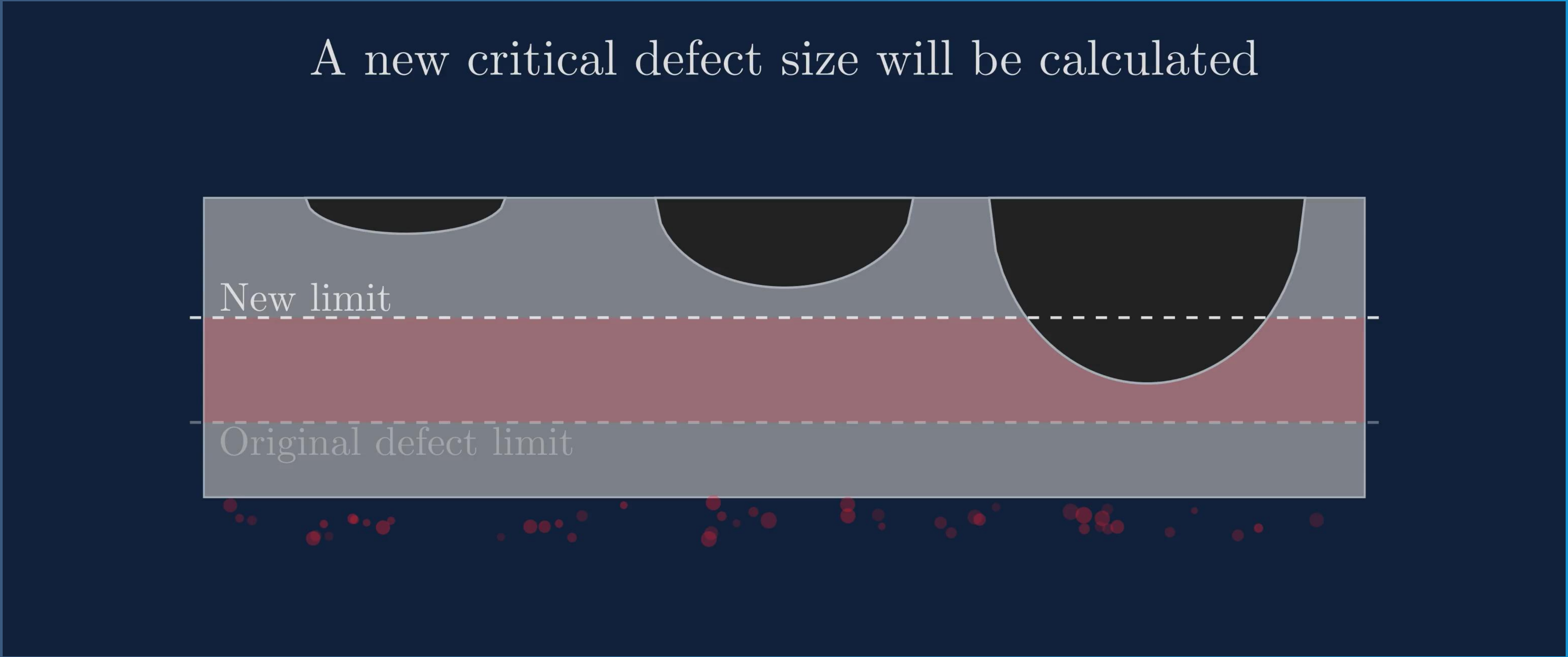

Hydrogen's Impact on Pipeline Defects

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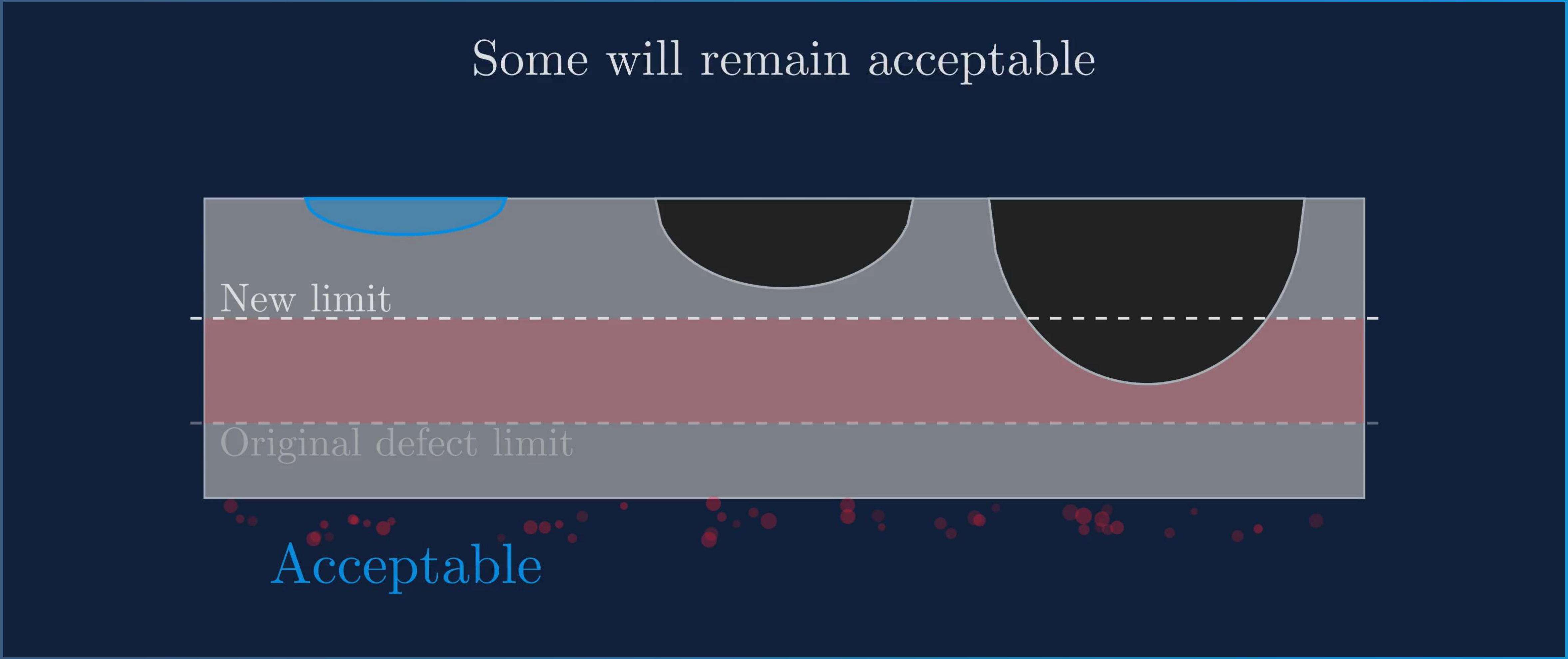

Hydrogen's Impact on Pipeline Defects

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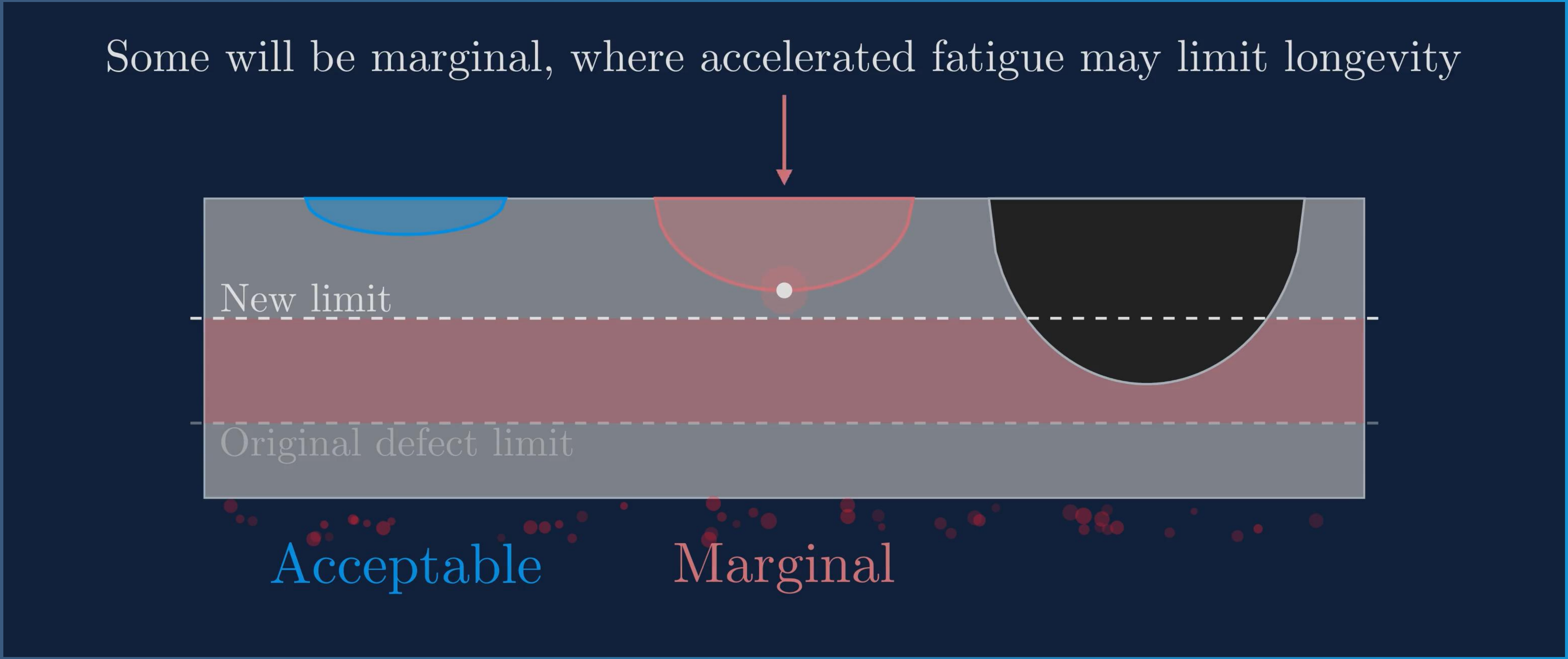

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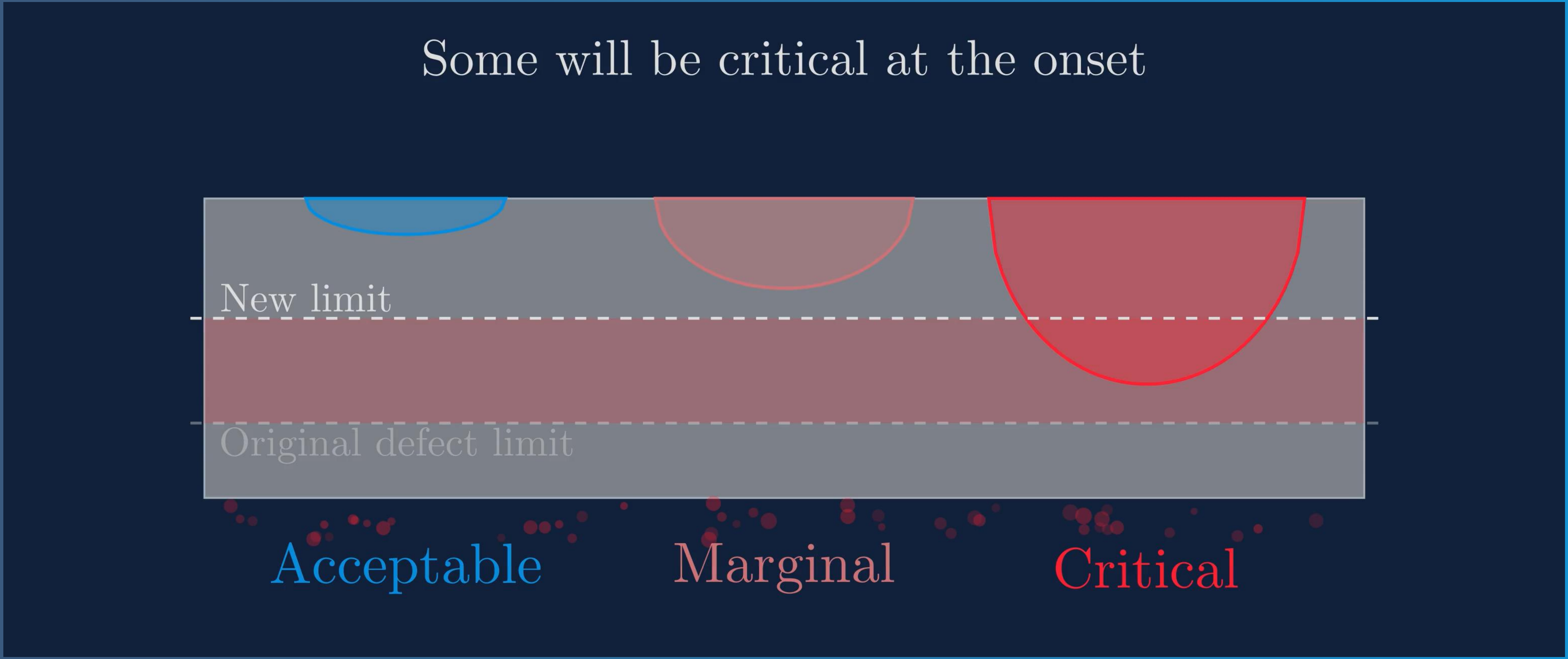

Integrity Management Solutions

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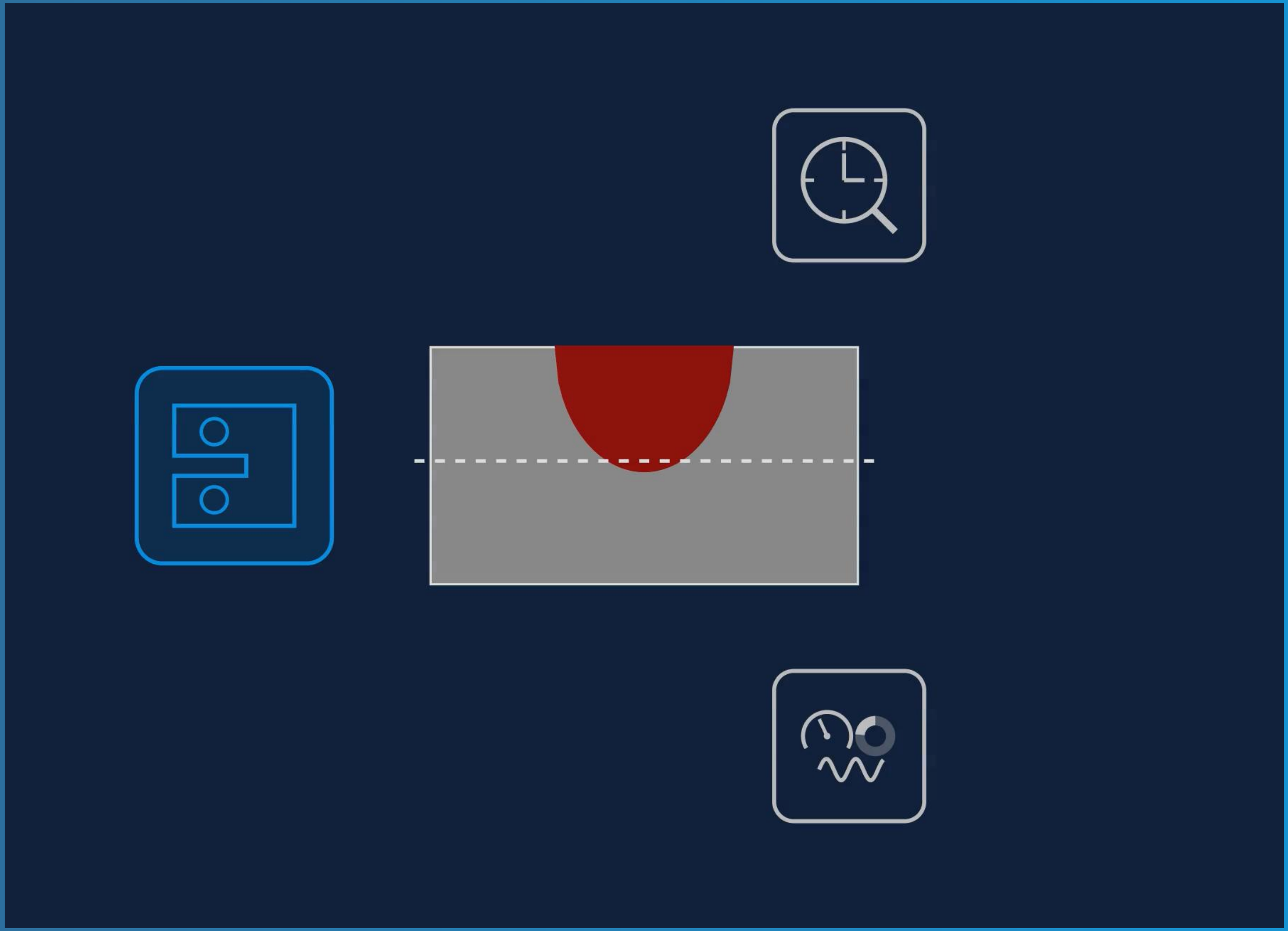
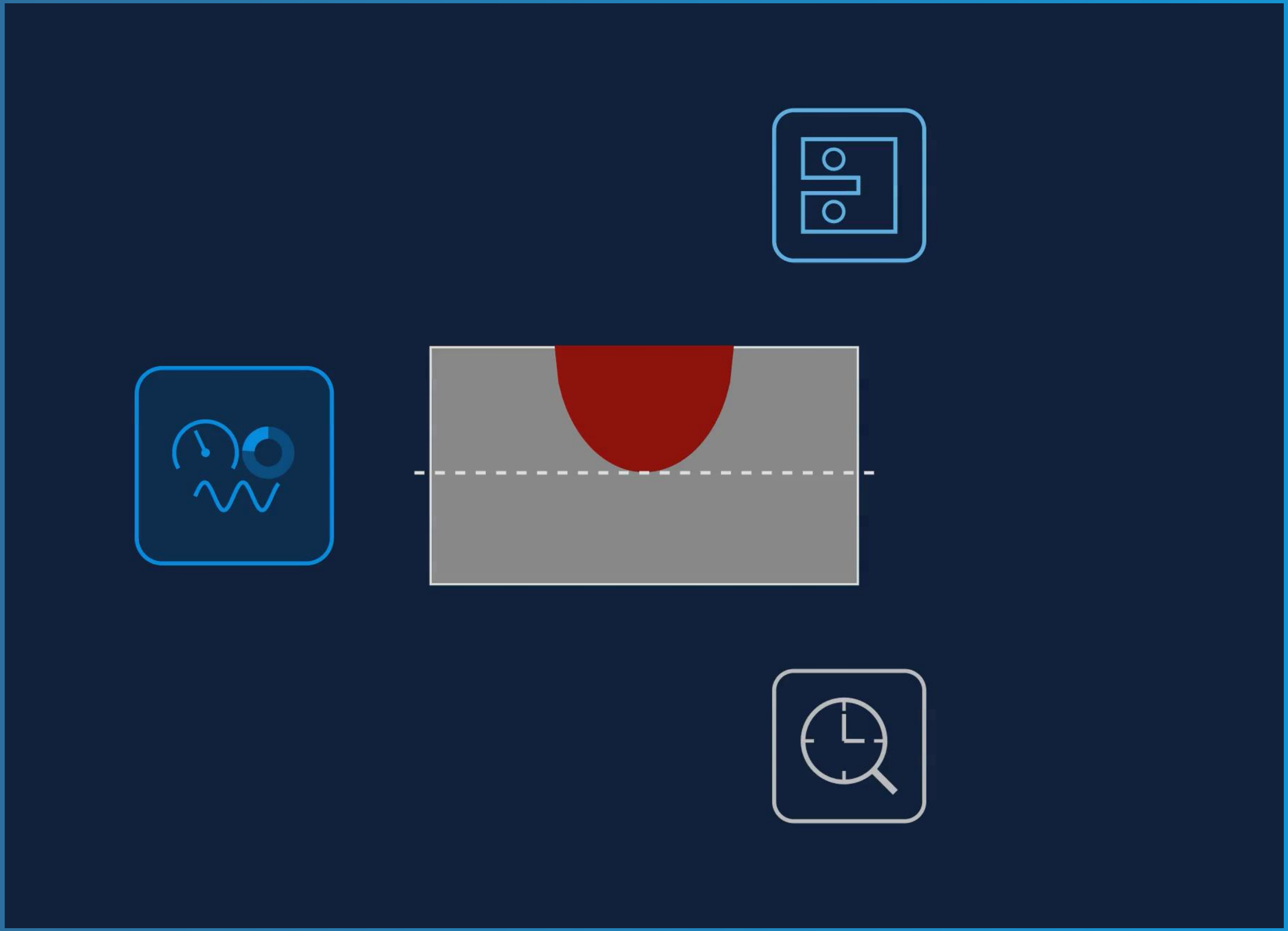
- Measure Material Performance in Intended H_2 Service Conditions
  - Either blended or pure service
  - Test base metal, girth, and seam welds
  - Used for integrity management planning
  - Avoids using overly conservative design assumptions



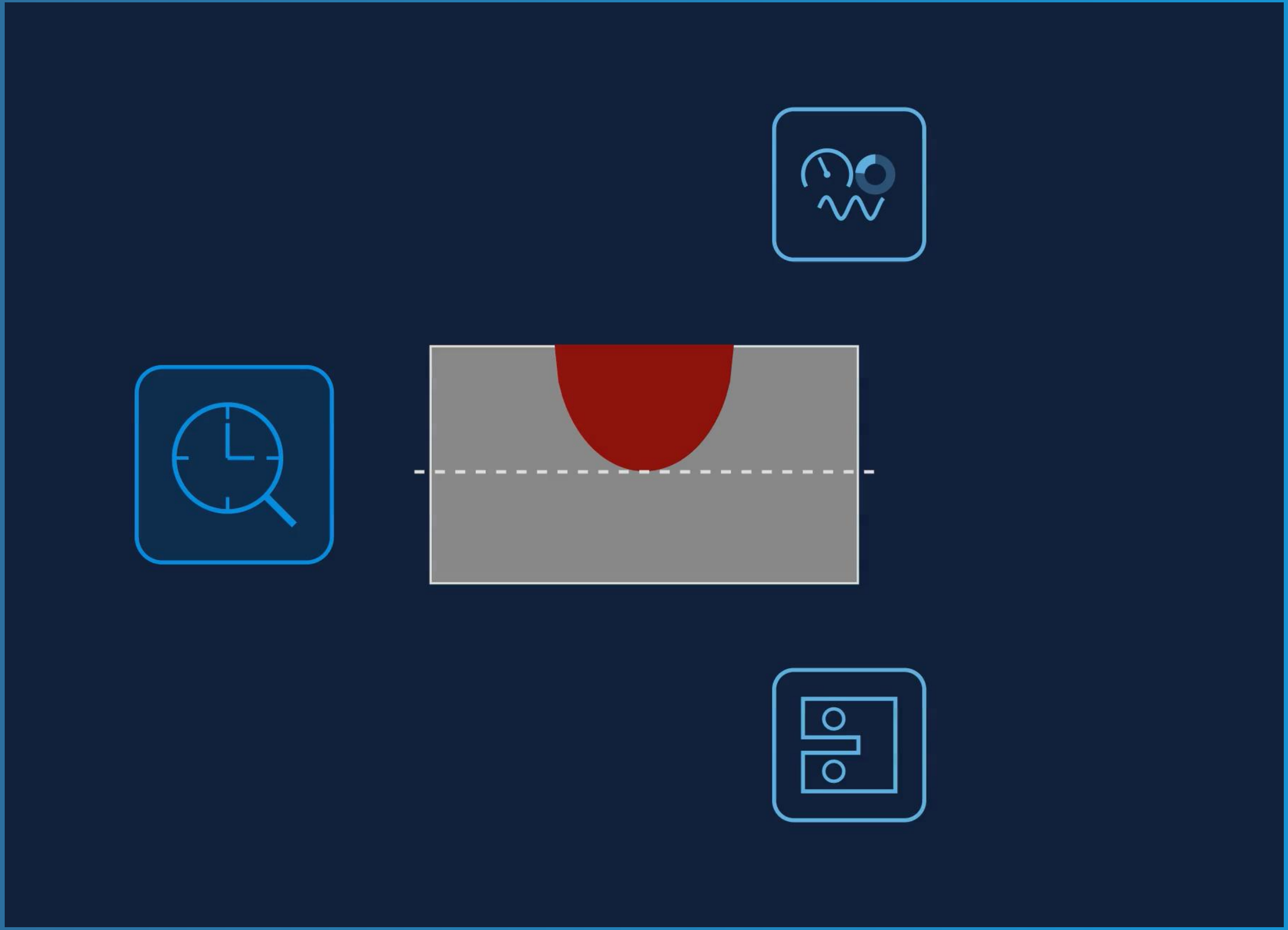
Integrity Management Solutions

- Define Safe Operating Envelope
  - Adjust operating pressure
  - Manage fatigue cycling



Integrity Management Solutions

- Revise Integrity Management Plan
  - Review ILI intervals and technology
  - Decide on necessary repairs and replacements
  - Perform change of service Safety Management Study (SMS)



Integrity Management Solutions

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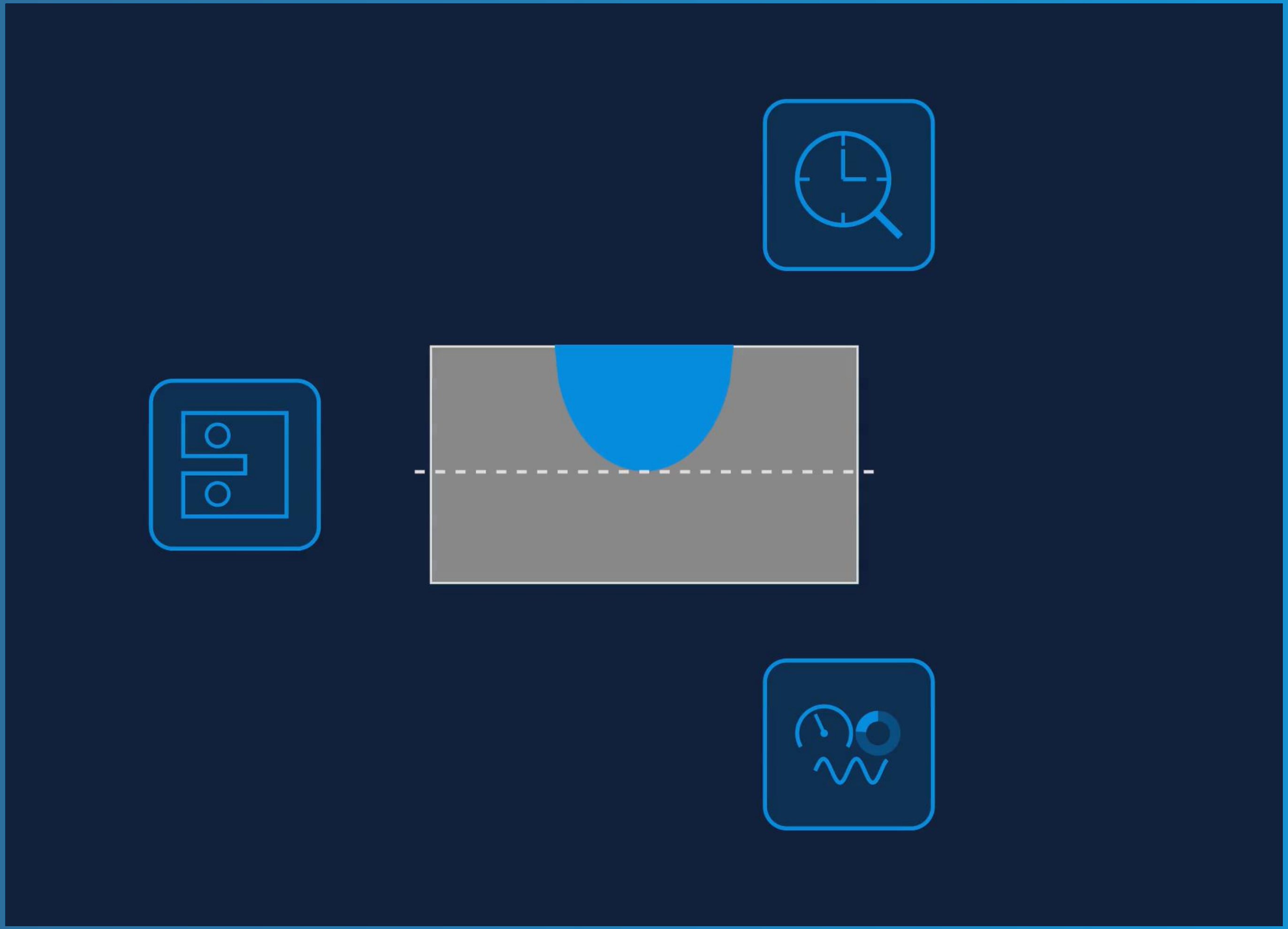
With all controls defects can be managed



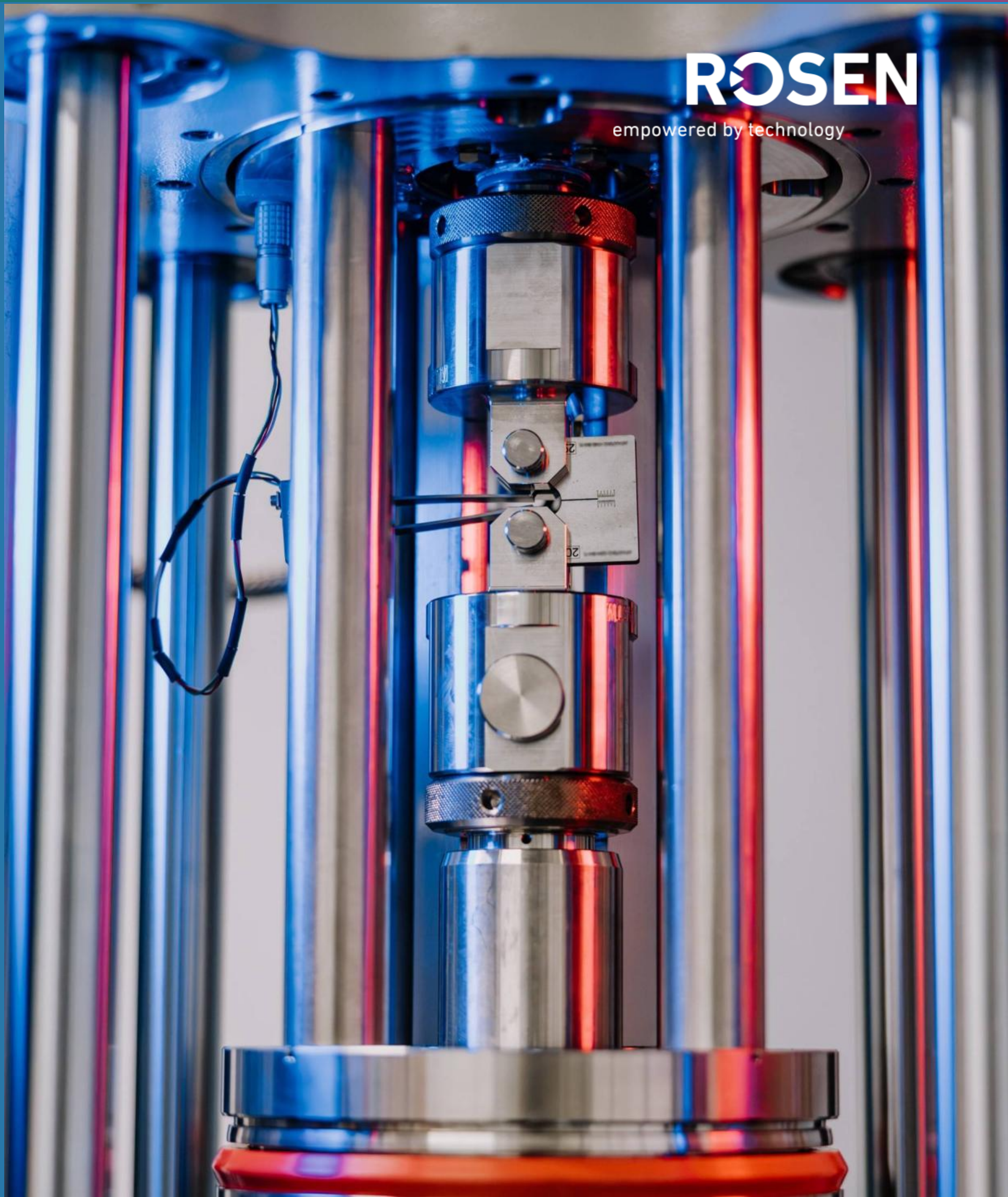
Testing Overview

X70 Pipe Properties

- DN300 to DN450
- Vintages 1990s to 2010s

Fracture Toughness (J–R) Tests

- >120 tests (tensile, fracture, fatigue)
- Specialised equipment capable of testing material in an ultra-pure H_2 environment
- Parent material with an axial crack
- Baseline in air at atmospheric pressure
- Hydrogen partial pressures from 1.5 to 15 MPa
  - N_2 + H_2 Mix at 10 MPa
  - Extensive purging to achieve O_2 < 0.5 ppm



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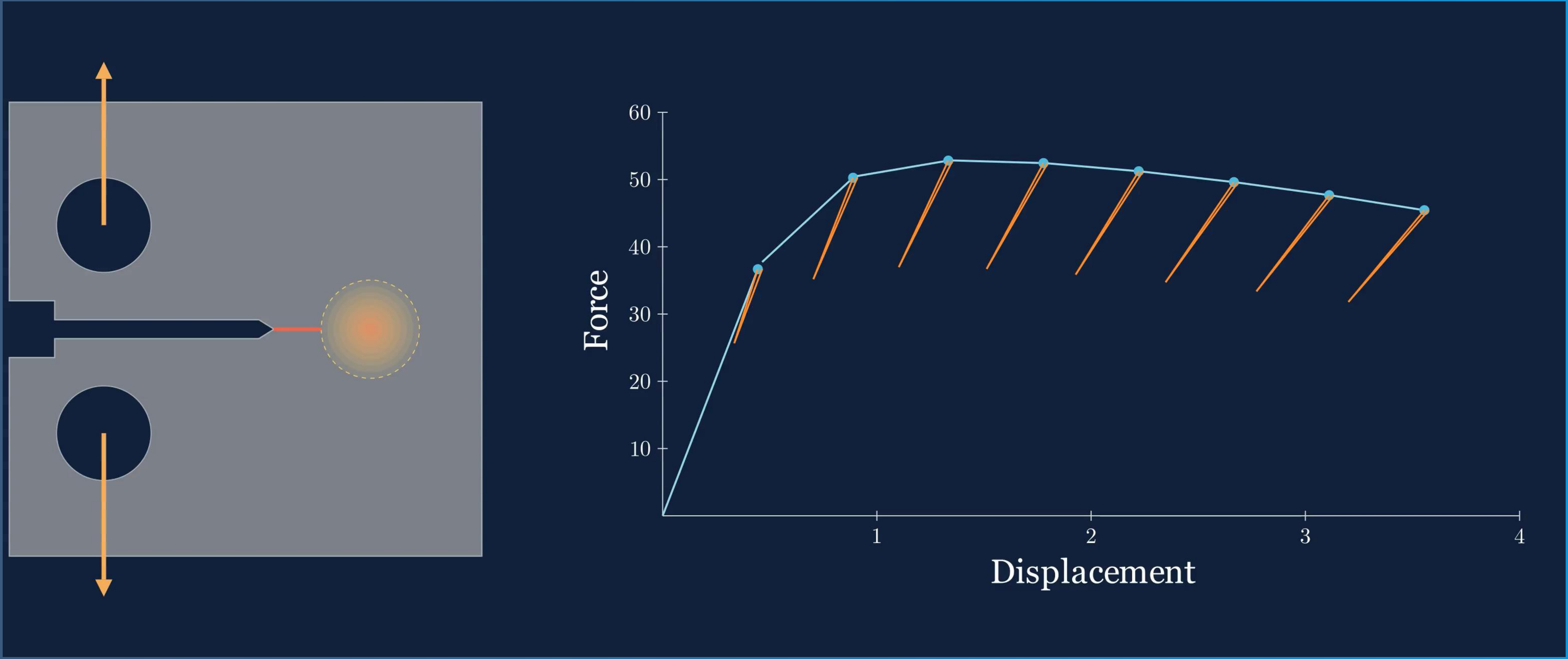
Measuring Fracture Resistance



Measuring Fracture Resistance

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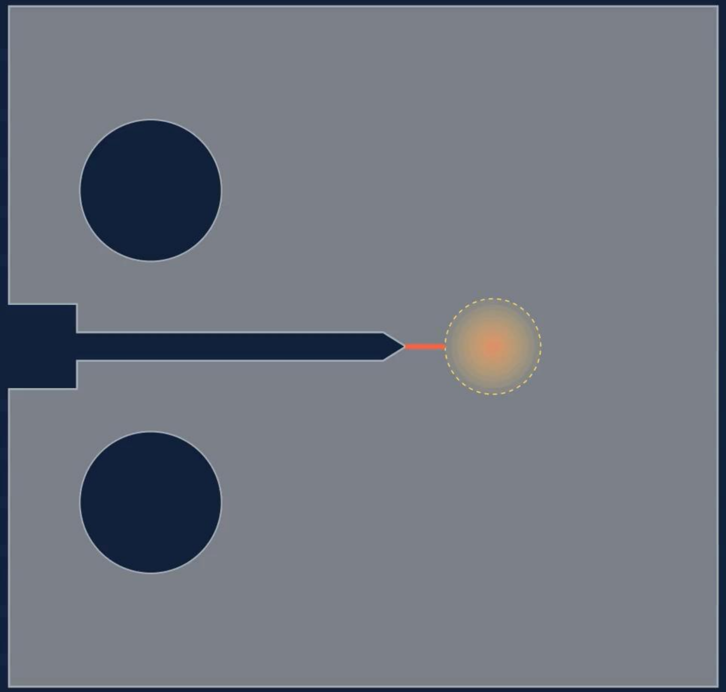

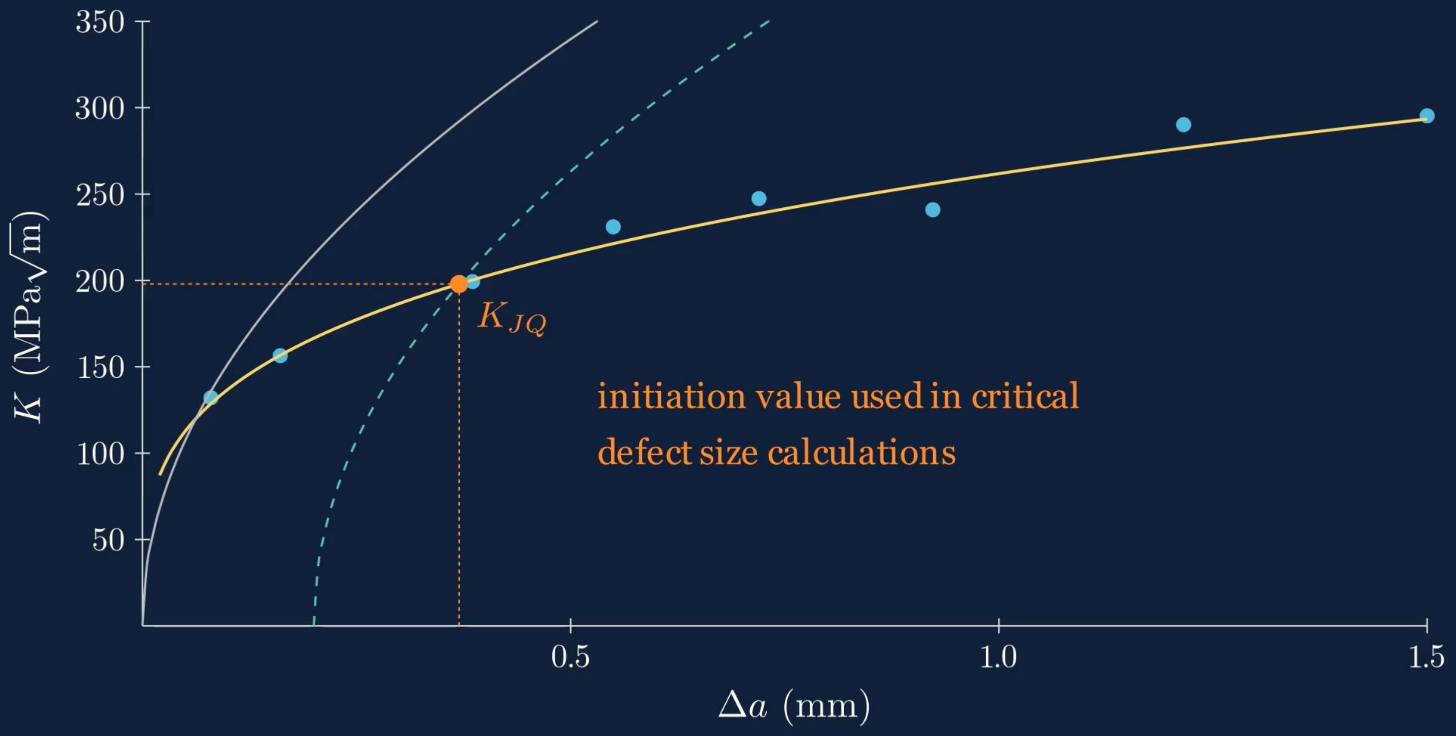

Test Results

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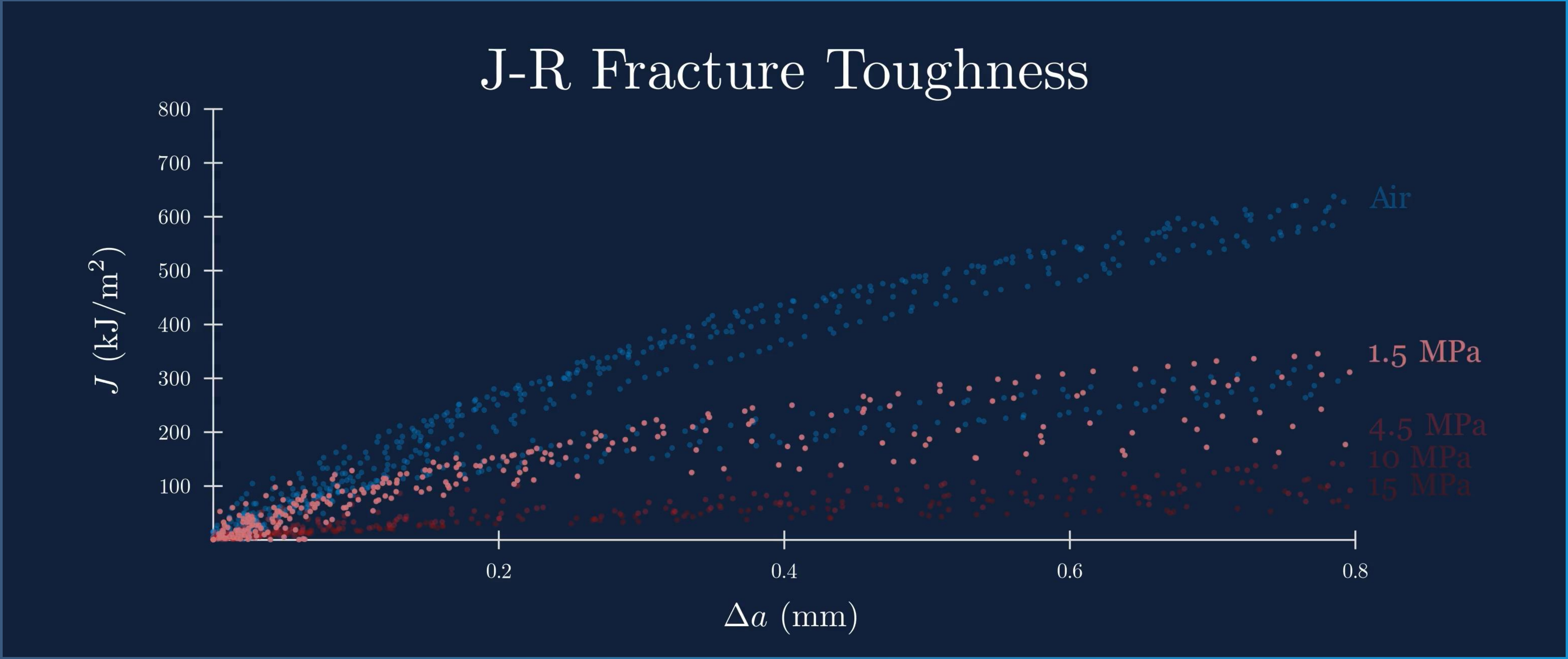
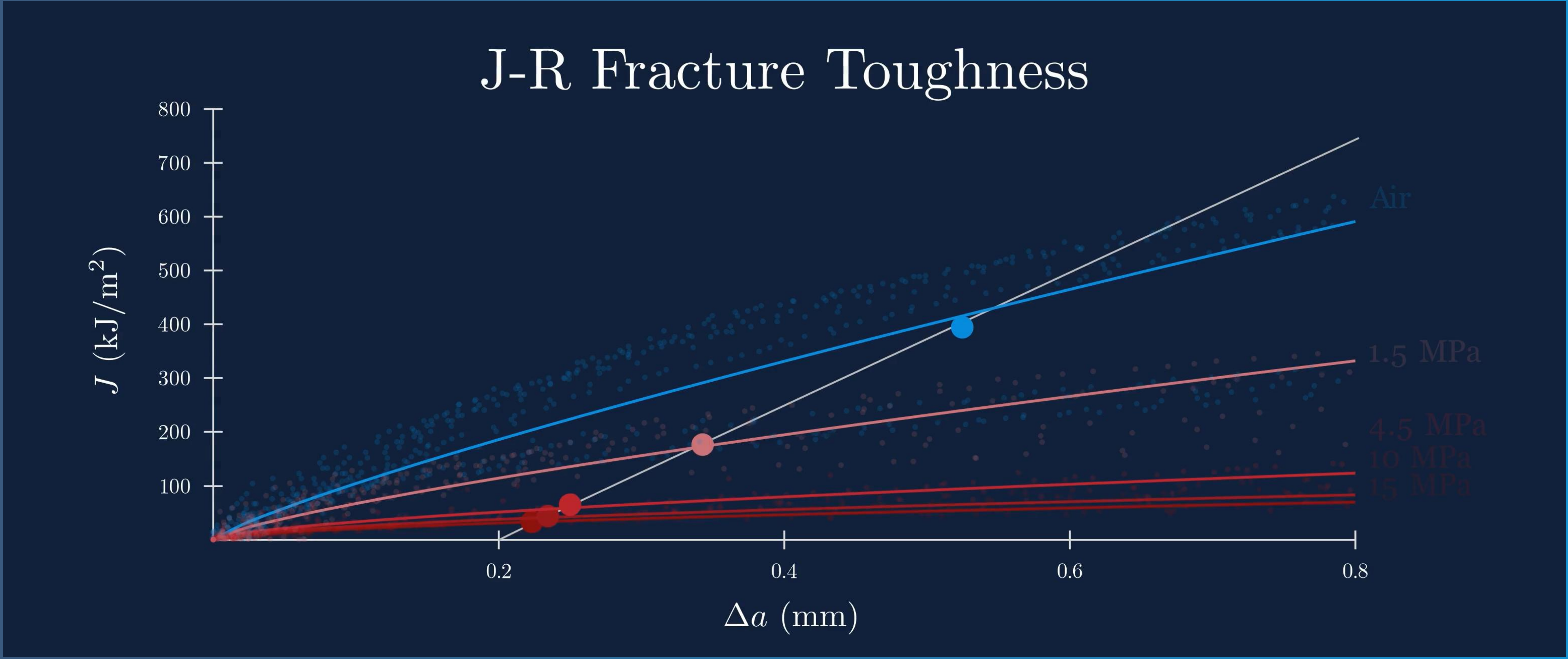


Test Results



Test Results

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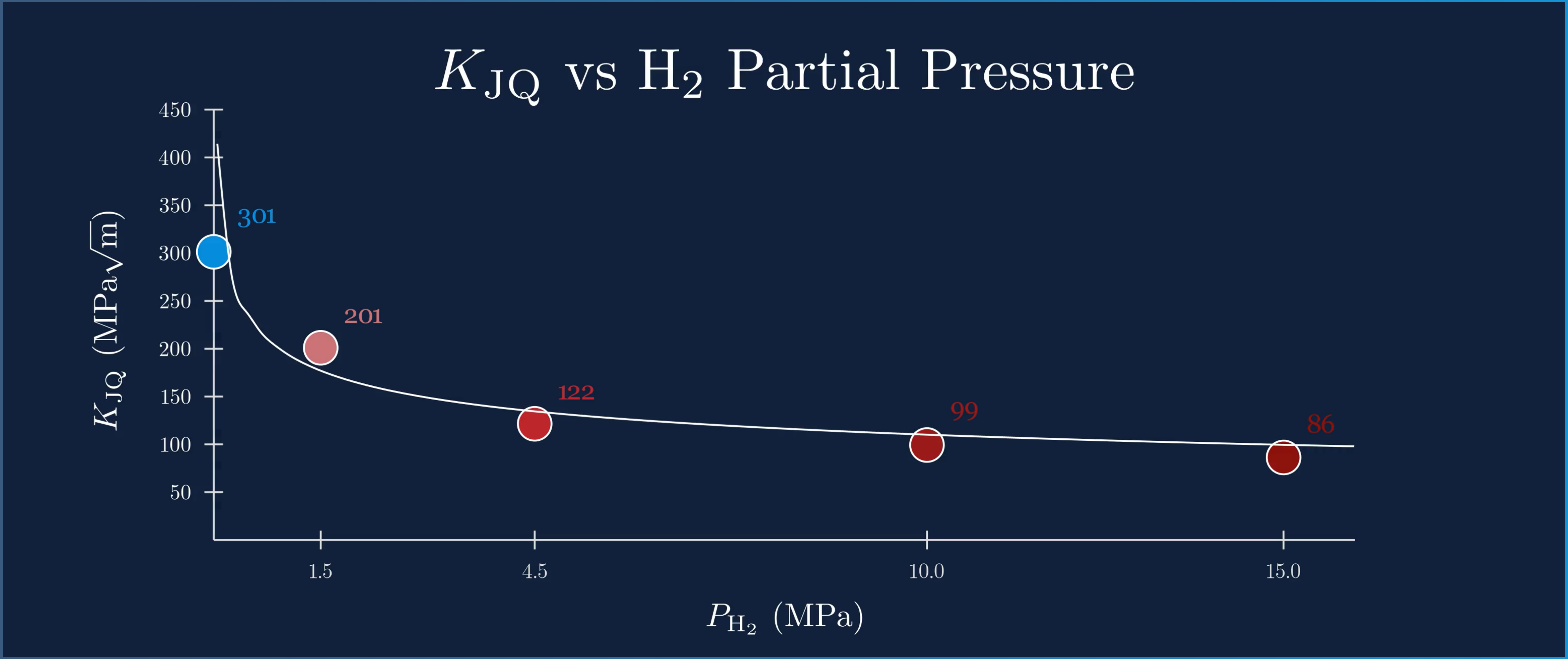

Case Study

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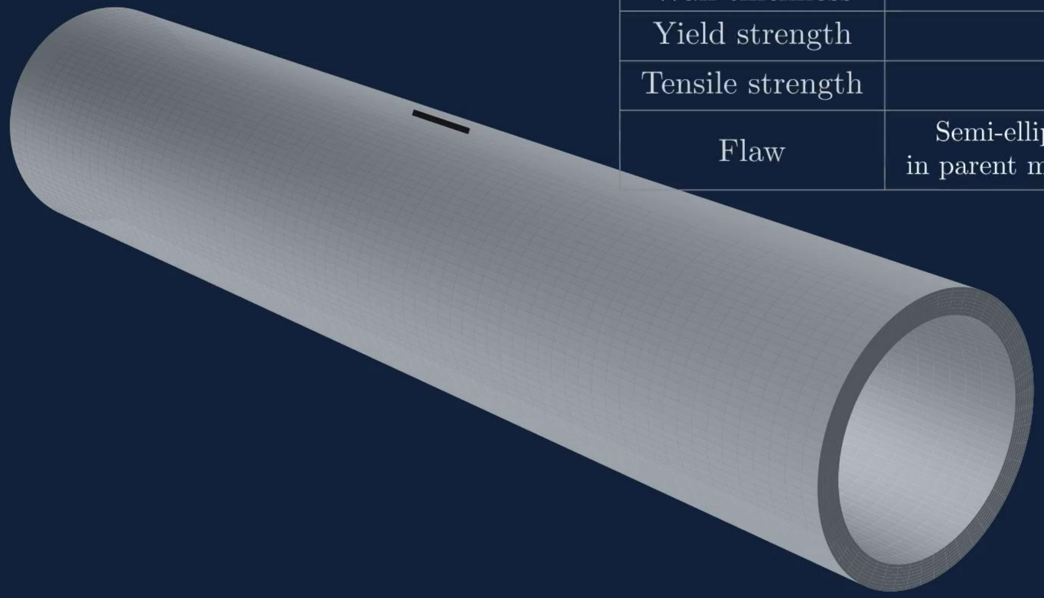
API-579-1 ASME-FFS-1



Study parameters

Parameter	Value
Outer diameter	DN450
Wall thickness	10 mm
Yield strength	475 MPa
Tensile strength	570 MPa
Flaw	Semi-elliptical crack-like flaw in parent material, axial direction

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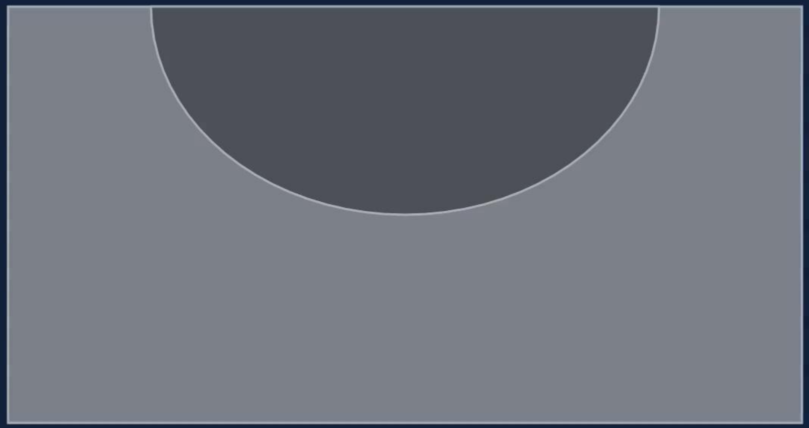
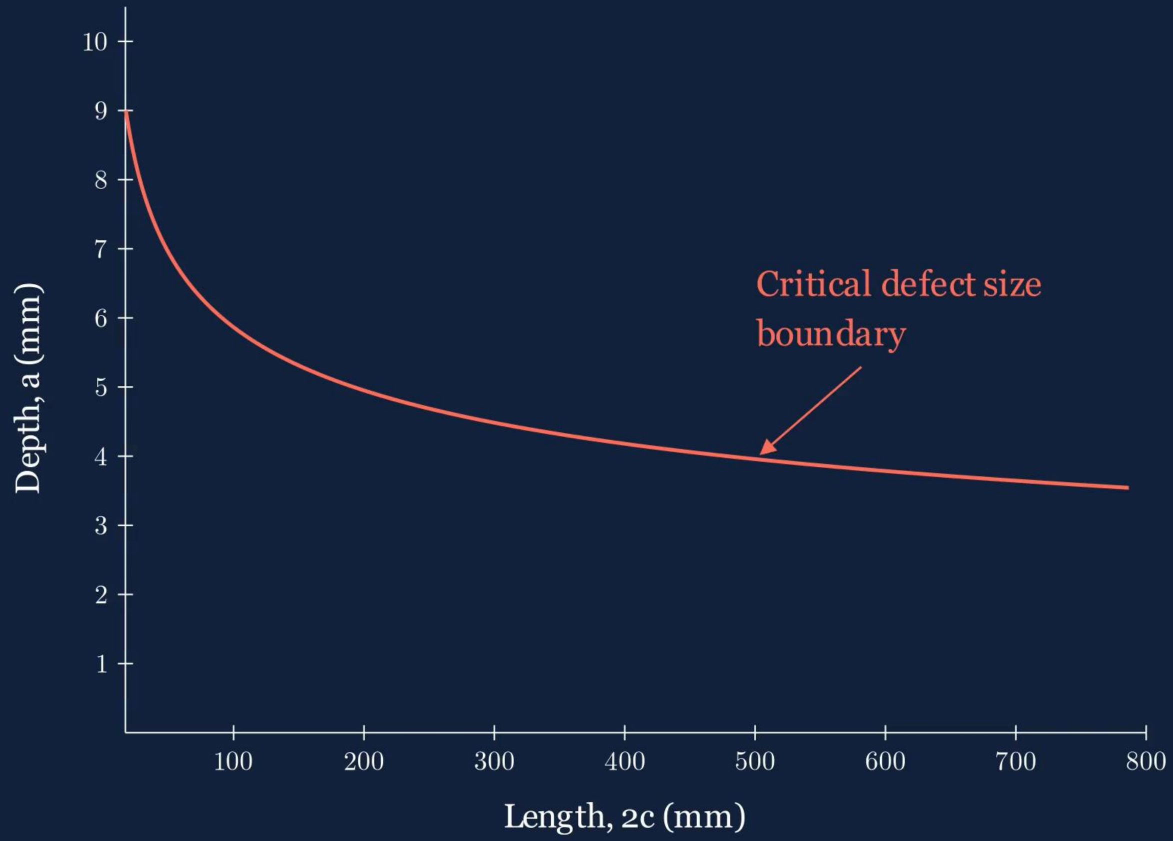
Pipe wall cross-section

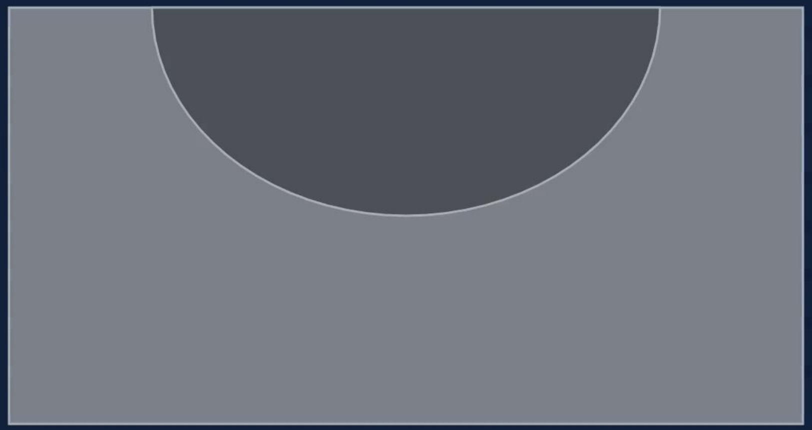


Critical defect size

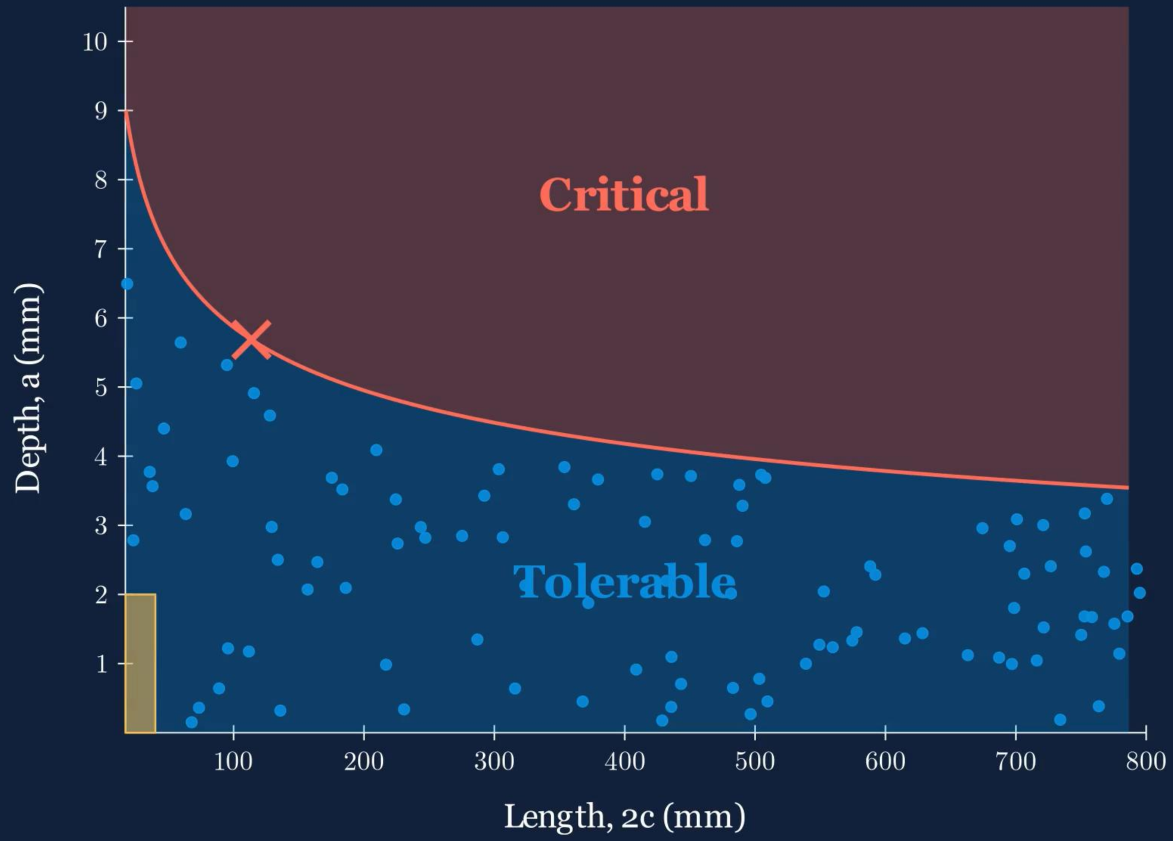


Case Study

Pipe wall cross-section



Critical defect size



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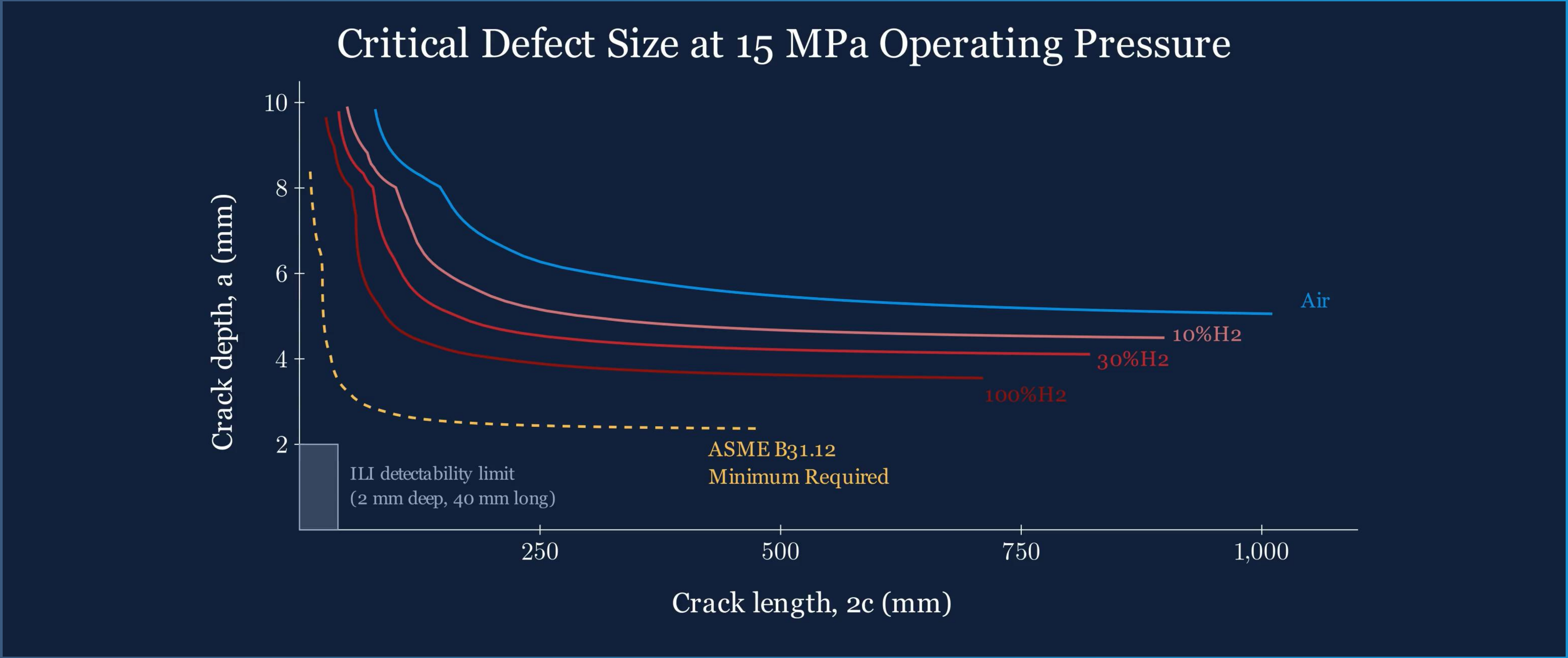

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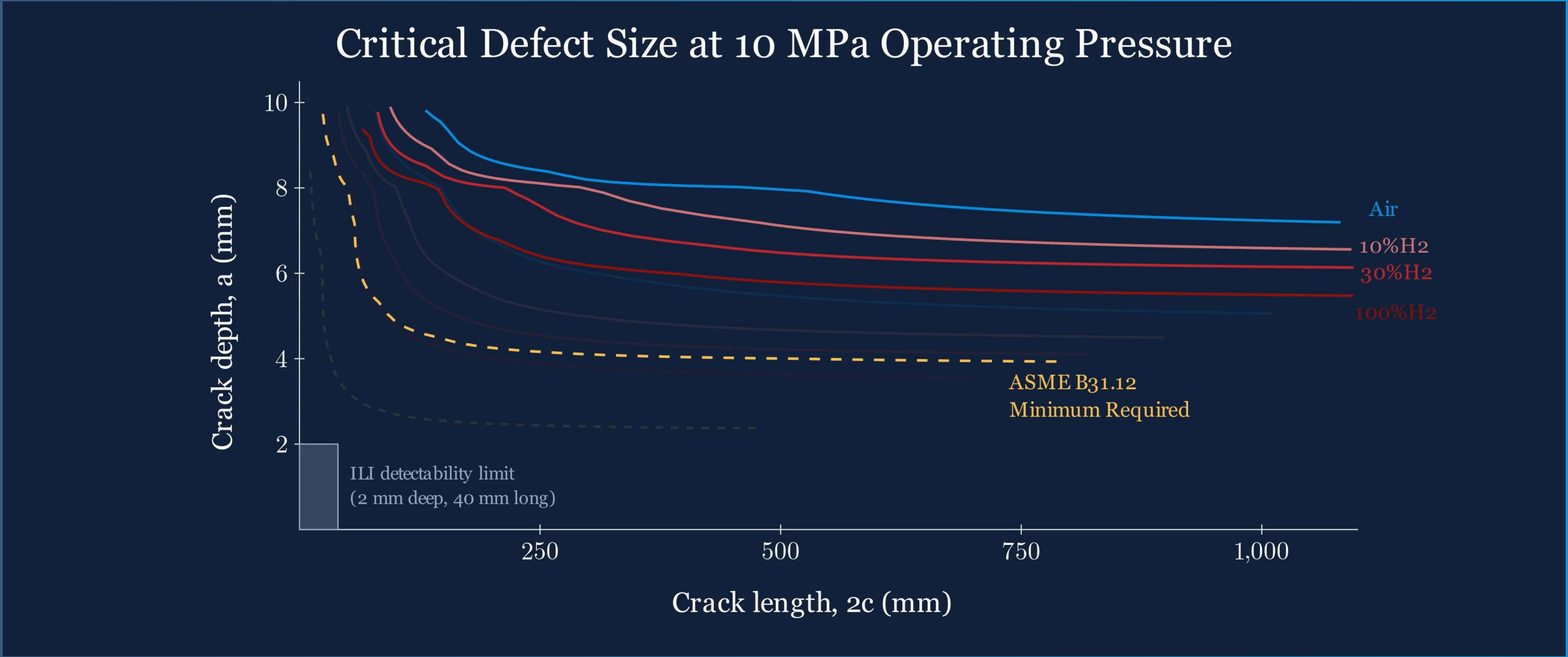
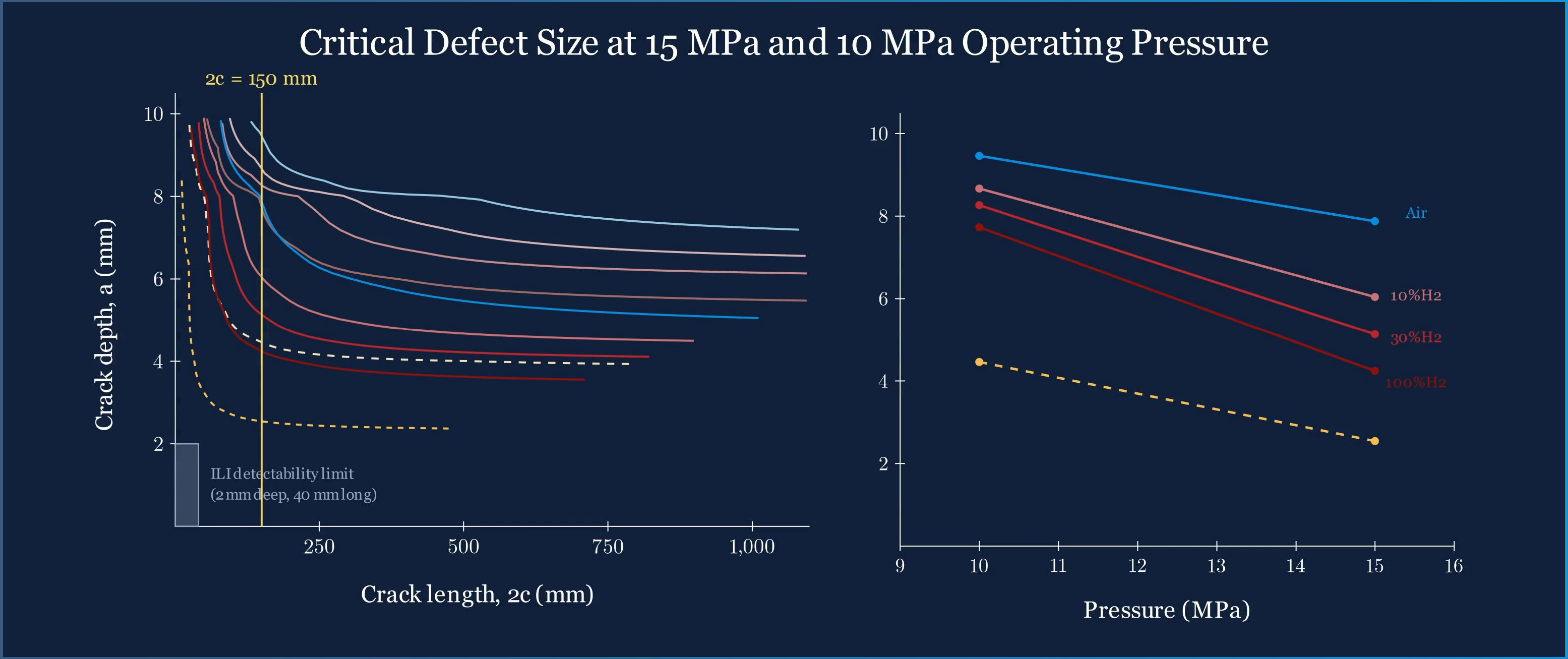


Case Study



Critical Defect Size at 15 MPa and 10 MPa Operating Pressure
2c = 150 mm
Crack depth, a (mm)
10
8
6
4
2
ILI detectability limit
(2 mm deep, 40 mm long)
250
500
750
1,000
Crack length, 2c (mm)
10
8
6
4
2
Air
10%H2
30%H2
100%H2
9
10
11
12
13
14
15
16
Pressure (MPa)

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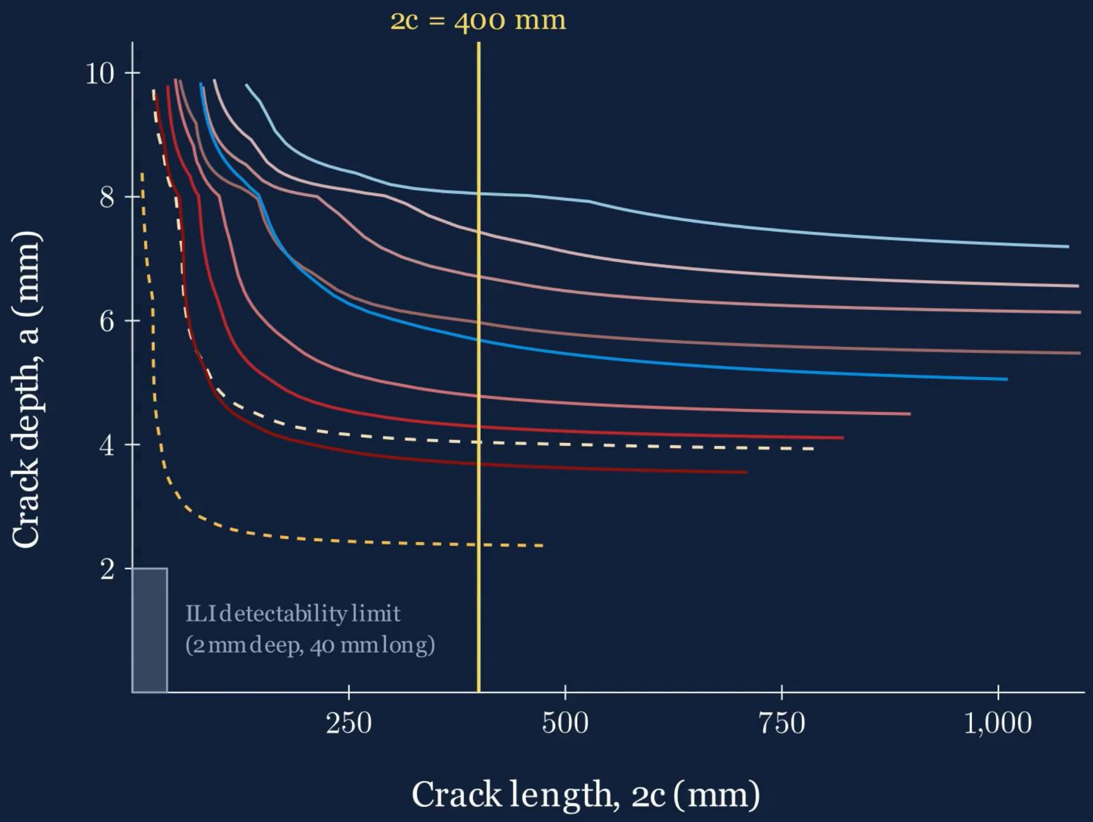
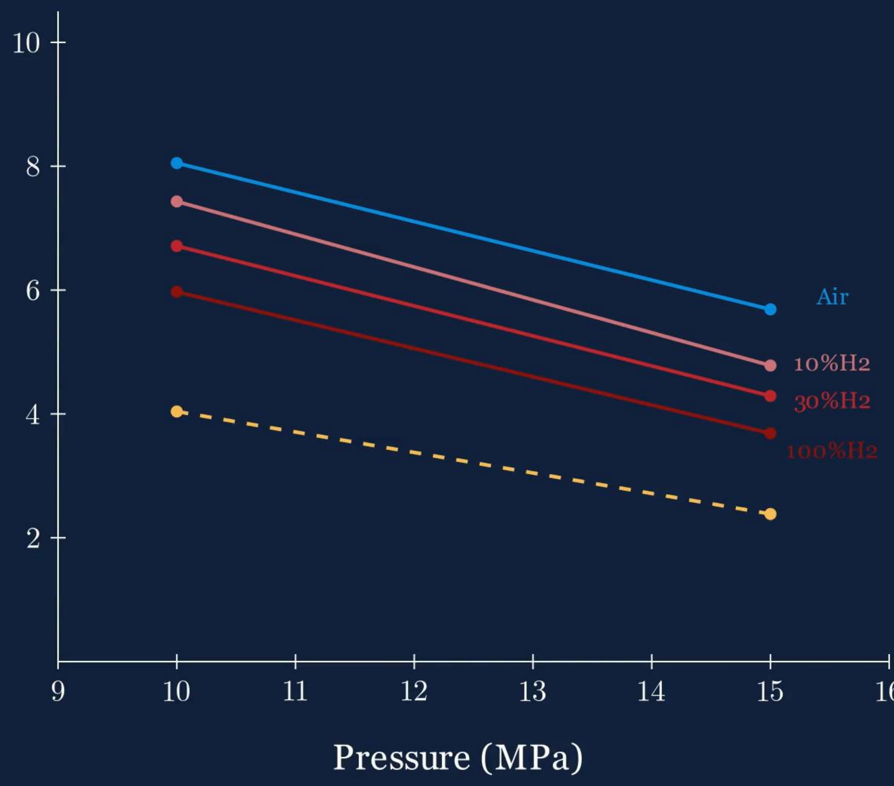
Critical Defect Size at 15 MPa and 10 MPa Operating Pressure





Discussion & Conclusions

- H_2 reduces fracture resistance
  - Performance improves with decreasing partial pressure
  - Reduction in tolerable defect sizes
- Fracture properties of grade X70 pipe are compatible for hydrogen service
  - Revised integrity plan may be required
  - Critical defects are still detectible by crack ILI tools
- Results are in-line with lower grades steels tested in FFCRC program

- Ongoing H_2 testing and research
  - Definition of the fracture initiation point
  - Role of impurities
  - Fatigue crack growth rate studies
- Correlate lab test data with full-scale results
- JTM 2027
  - Detailed microstructure evaluations
  - Girth and seam weld results

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