# Nondestructive evaluation in advanced reactors

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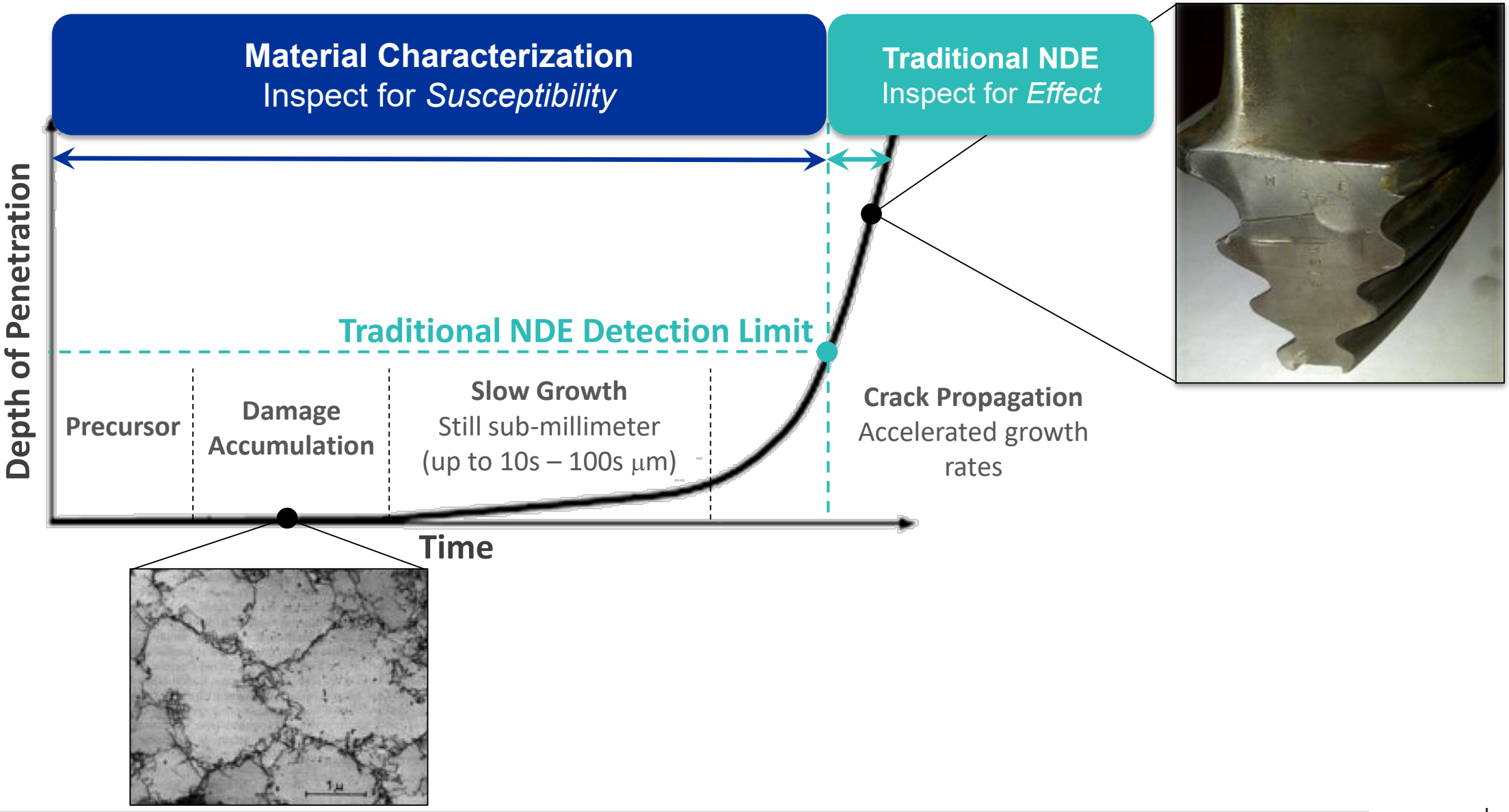
# Topics

- Necessary areas of research focus
- Relevant EPRI research in process
- Highlight:  NDE research in support of compact heat exchangers

# Necessary areas of research focus

| CHALLENGE | RESEARCH |
| --- | --- |
| **Understanding the degradation mechanisms**<br>*Knowing what to look for, and where, before plant design is finalized* | Materials and corrosion research specific to the operational temperatures, loads and coolant chemistry |
| **Optimizing O&M costs**<br>*The plants must be economically competitive* | Robotics, permanent sensors, data analytics |
| **Severe environment – during power operation**<br>*For permanently mounted sensors* | Robust sensors, coupling and connections at temperature<br>*Ultrasonic, strain, optical* |
| **Severe environment – during outages**<br>*Conditions affecting human- and robotically-delivered NDE* | • Robotics hardened for the anticipated radiation fields<br>• Minimizing human entry |
| **Access – human** | Plant design to minimize radiation fields and temperature, and to provide adequate space, where human entry will be required |
| **Access – robotic** | Plant design to enable robotic access and operations to the fullest extent possible<br>The ideal: no human entry at all (ref. high-radiation hot cell facilities) |

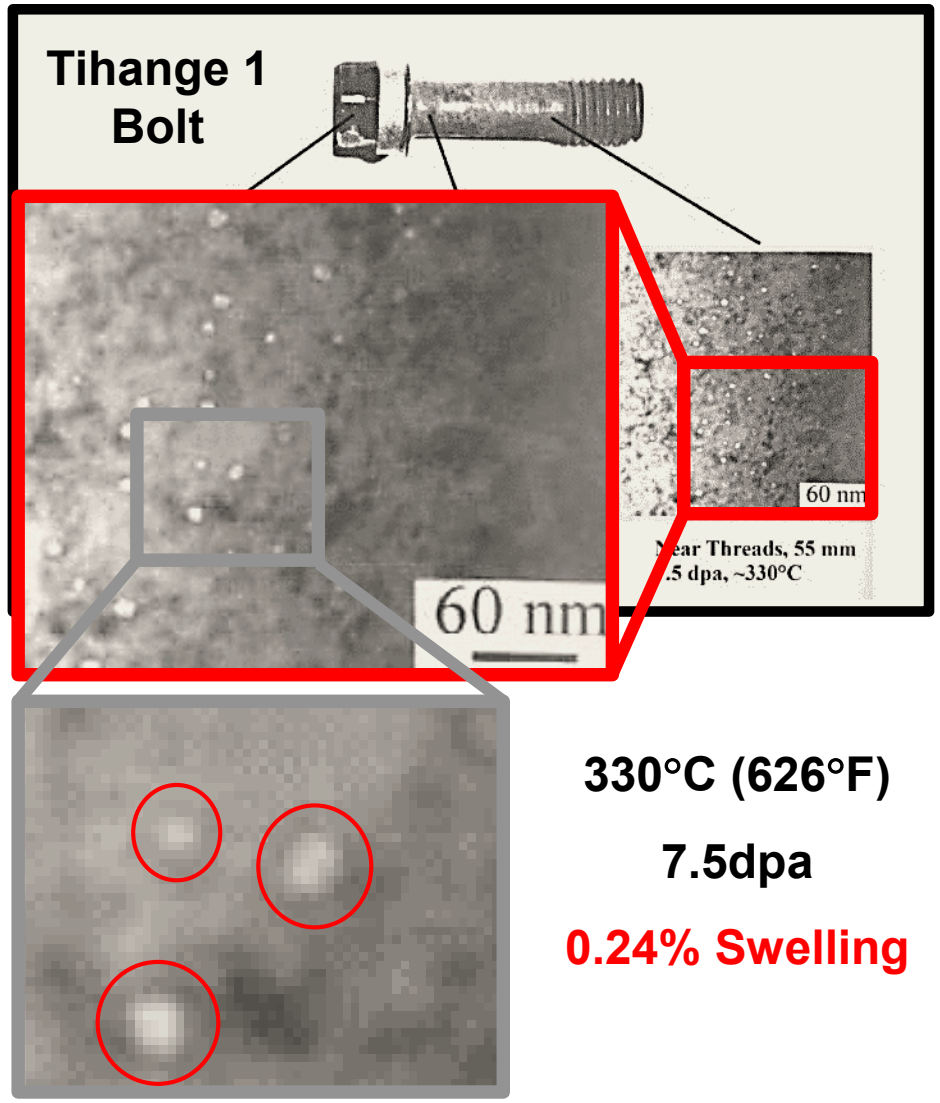
# Why Material Characterization?



# Relevant EPRI research in process

# Void Swelling

- Irradiation of austenitic stainless steel can lead to dimensional changes, distortion, and embrittlement
  - Detrimental for components that do not have a lot of dimensional tolerance
  - Small levels of differential swelling in large components could result in significant strains
- Swelling could be an end-of-life determinant for a component




**330°C (626°F)**

**7.5dpa**

**0.24% Swelling**

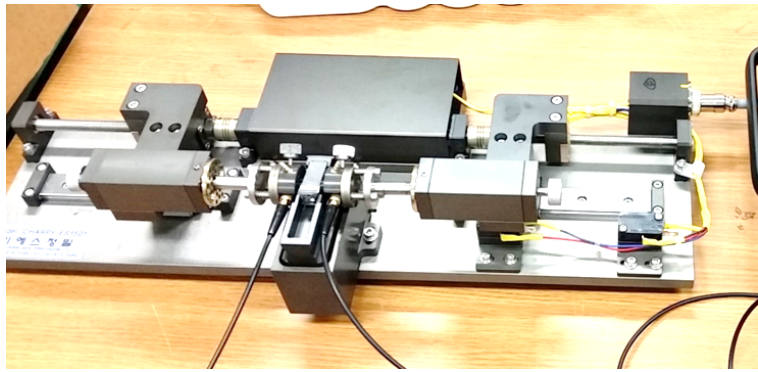
# Void Swelling: Approach

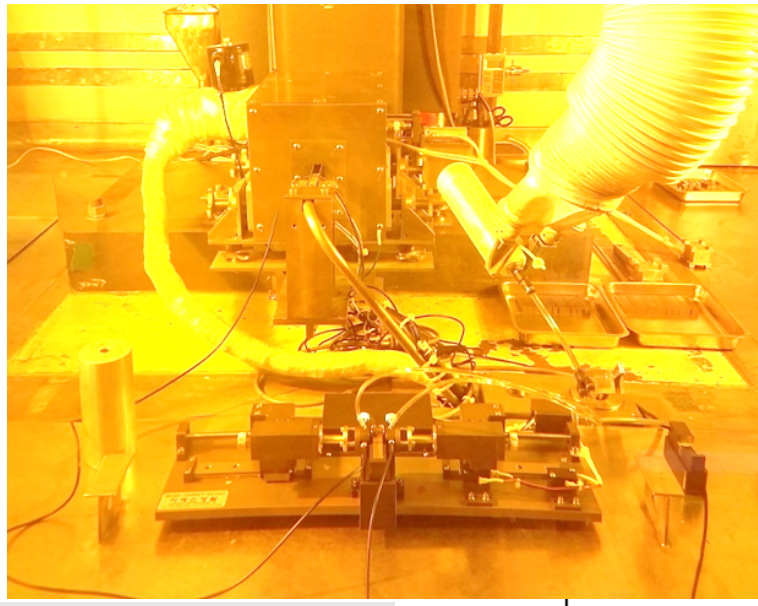
## Test samples

- EBR-II Hex Block Samples with known swelling (0-3%)
- Unirradiated blank coin specimens

## Techniques

- Nonlinear Ultrasonic Testing
  - Nonlinear parameter $\beta$
- Linear Ultrasonic Testing
  - Speed of Sound
  - Attenuation
- Four-Point Probe Resistivity





## 2019

- UT measurements

## 2020

- Resistivity measurements
- Identify and assess best NDE method
- Develop concepts for in-situ inspections

# Fracture Toughness

## Test samples

- Compact CT:  SS304, SS316, SS347, A286
- Cold work to simulate embrittlement
  - Cold work 0%, 20%, 40%, 60%, 80%


## Techniques

- Linear UT (velocity, attenuation, absorption
- Nonlinear UT
- Thermal Thermoelectric Power
- Instrumented Indentation System

## 2019

- NDE on surrogate CT samples
- Identify relevant irradiated materials

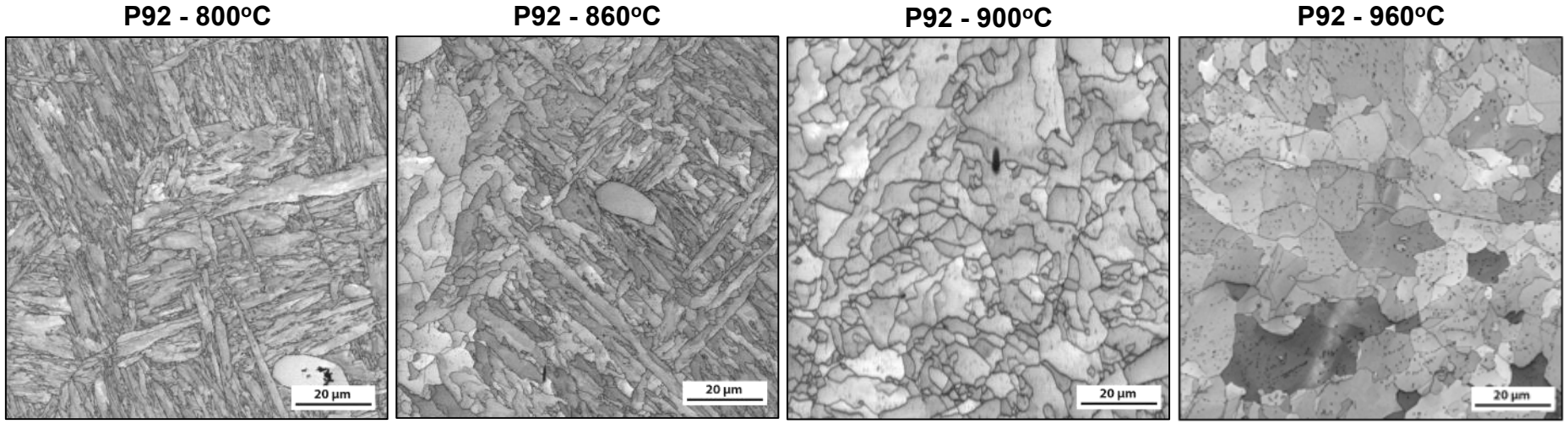
## 2020

- Destructive testing of surrogate CT samples
- NDE on irradiated materials

# Microstructure Characterization

- A significant portion of failures in grade 91 and 92 steels have been attributed to poor fabrication
- Damage susceptibility is linked to operational conditions as well as **variability of microstructure**

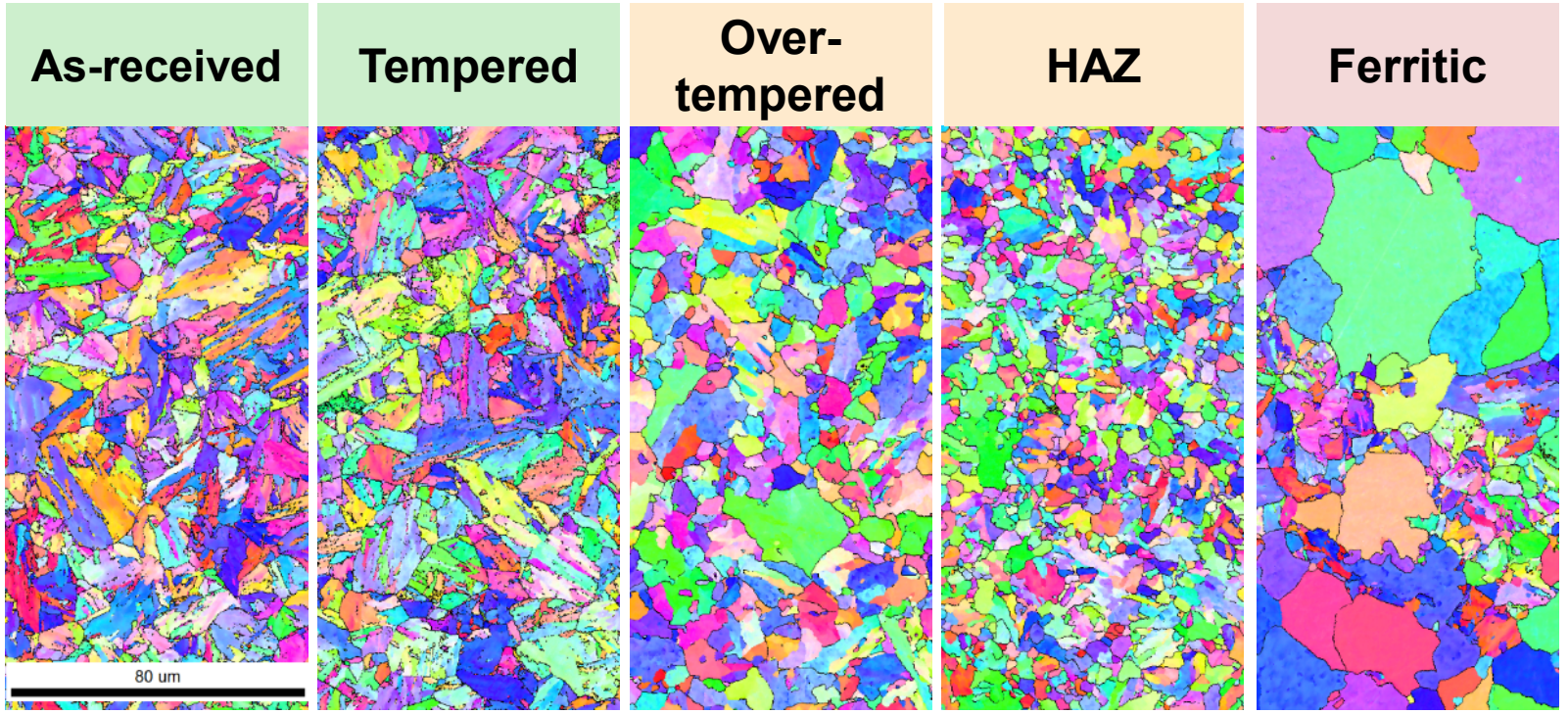
- Current NDE methods use hardness measurements
  - Difficult to obtain meaningful results
  - Ambiguous, insufficient measure of quality




# Microstructure Characterization: Test Samples

| | Quantity | OD (in) | Wall Thickness (in) | Axial Length (in) | Angular Section |
|---|---|---|---|---|---|
| Tubes | 16 | 2 | 0.165 | 12 | 360° |
| Pipe Sections | 8 | 18 | 1.5 | 9 | ~60° |

| Condition | Median Hardness |
|---|---|
| As-received | 220 |
| Normalized | 428 |
| Normalized + Tempered | 208 |
| Tempered | 207 |
| Over-tempered | 198 |
| Fully Ferritic | 147 |
| HAZ | 405 |
| HAZ + Tempered | 170 |



# Microstructure Characterization: NDE Techniques

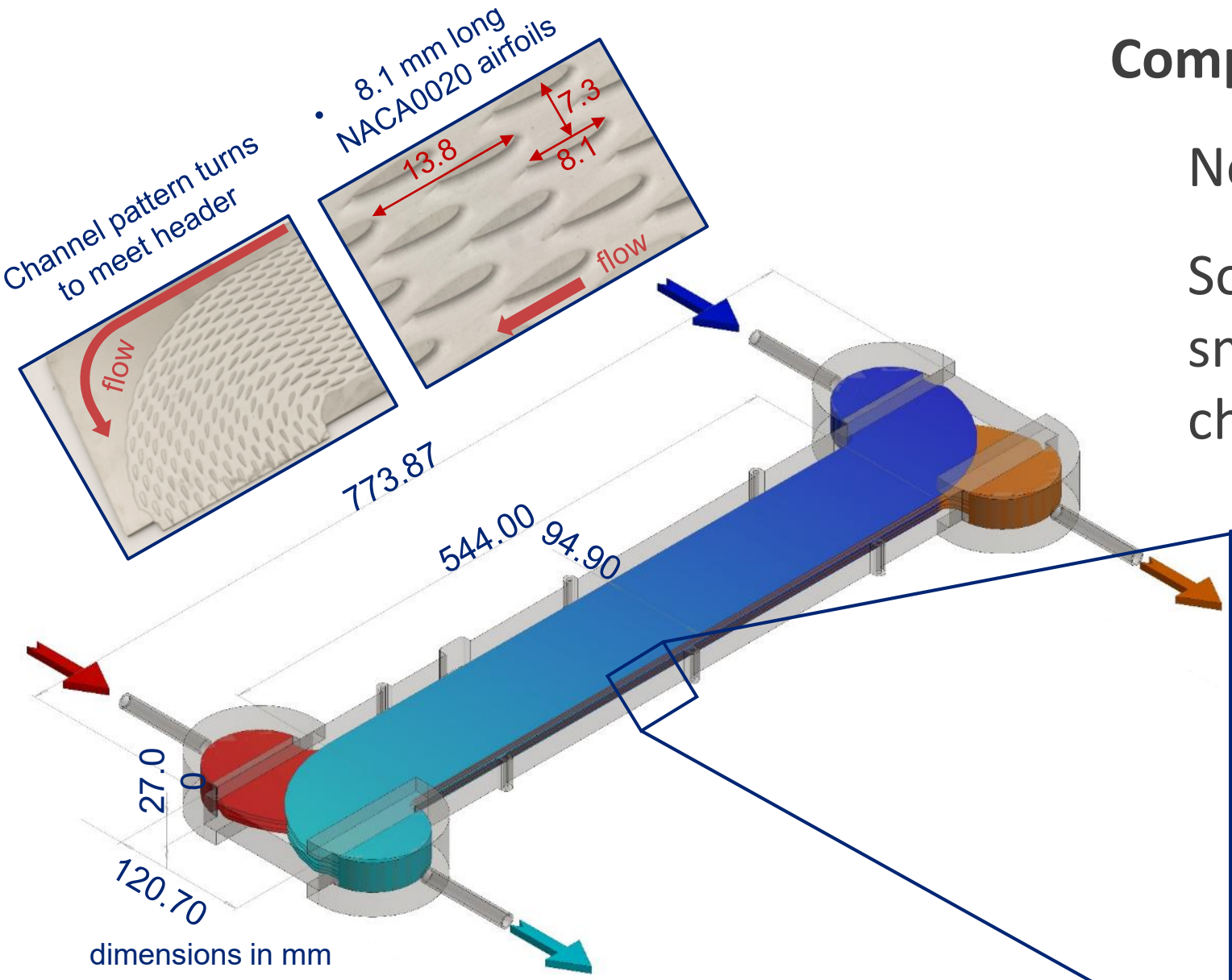
- Magnetic Methods
  - BH loops
  - Incremental permeability
  - Barkhausen noise
- Linear Ultrasound
  - Attenuation
  - Backscatter
  - Absorption
- Additional proposed techniques under review
  - Thermal properties
  - Electric properties

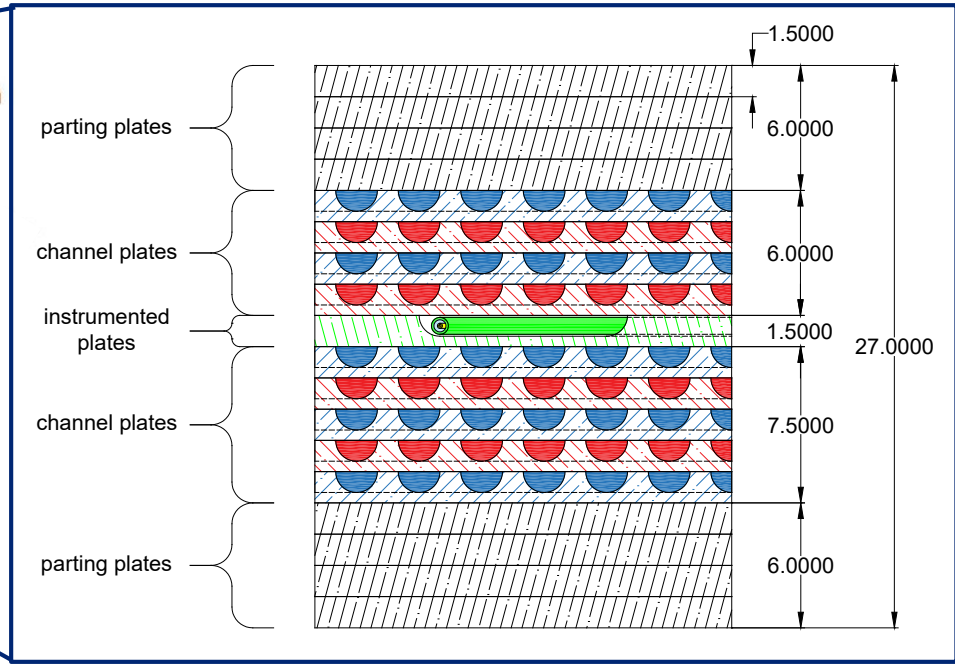
- Schedule
  - 2019
    - Magnetic & Ultrasonic NDE testing
    - Identify additional NDE techniques
  - 2020
    - Additional NDE testing

# NDE research in support of compact heat exchangers

# Compact heat exchanger (CHX)

- Not a tube-and-shell design
- Solid metal block with many small hot and cold flow channels



# NDE research is part of a DOE project directed at a Section III Code Case supporting CHX construction for advanced reactors

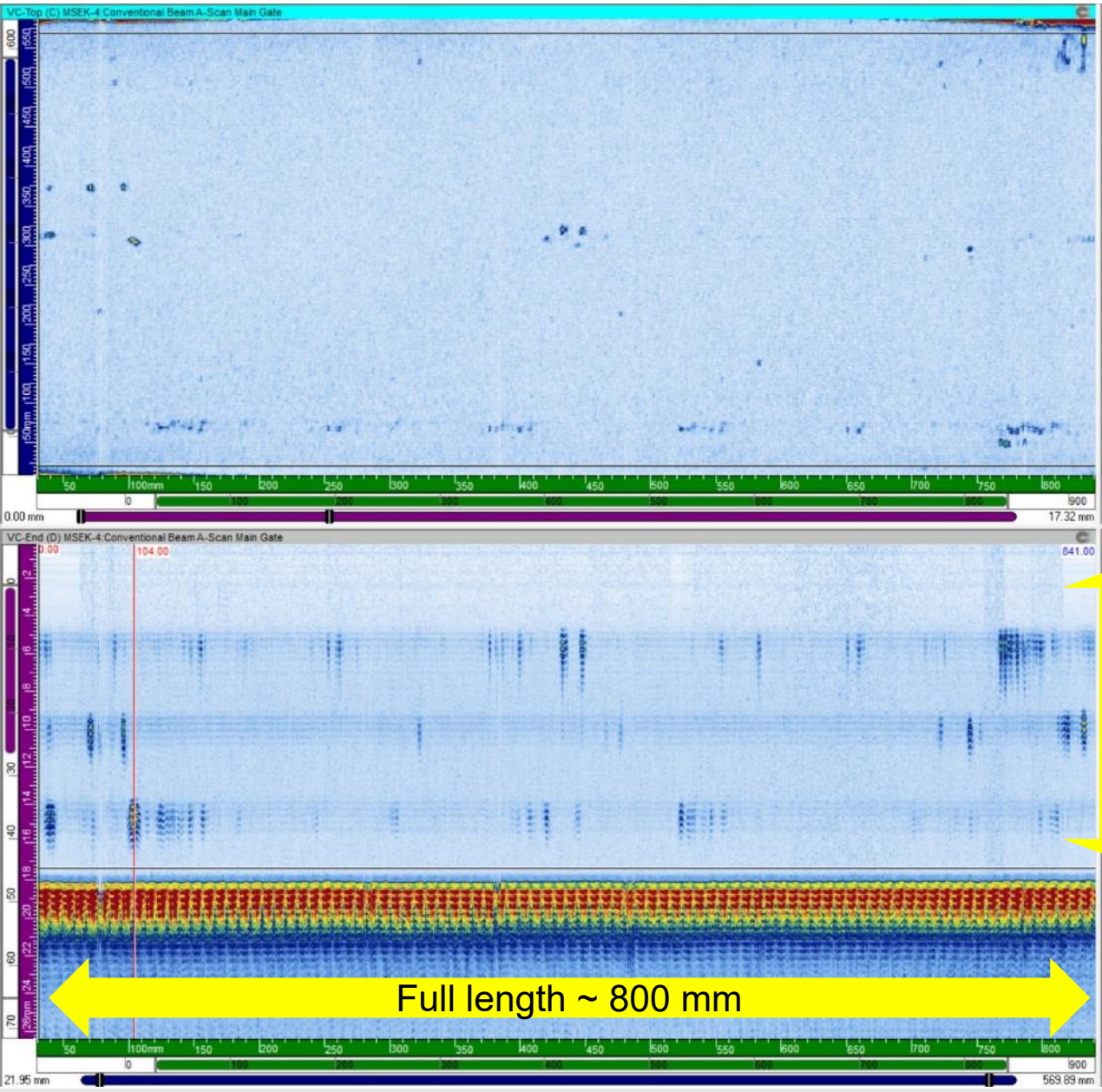
- Components
  - Diffusion-bonded block
    - Solid side walls
    - Channeled core
  - Header attachments to the block
- Scenarios
  - Construction examination – **highest priority** for the Code Case
  - Other examinations of interest to the owner/operator – in support of run/repair/replace decisions
    - Pre-service examination, after the CHX is installed
    - In-service examination (during operation or during outages)

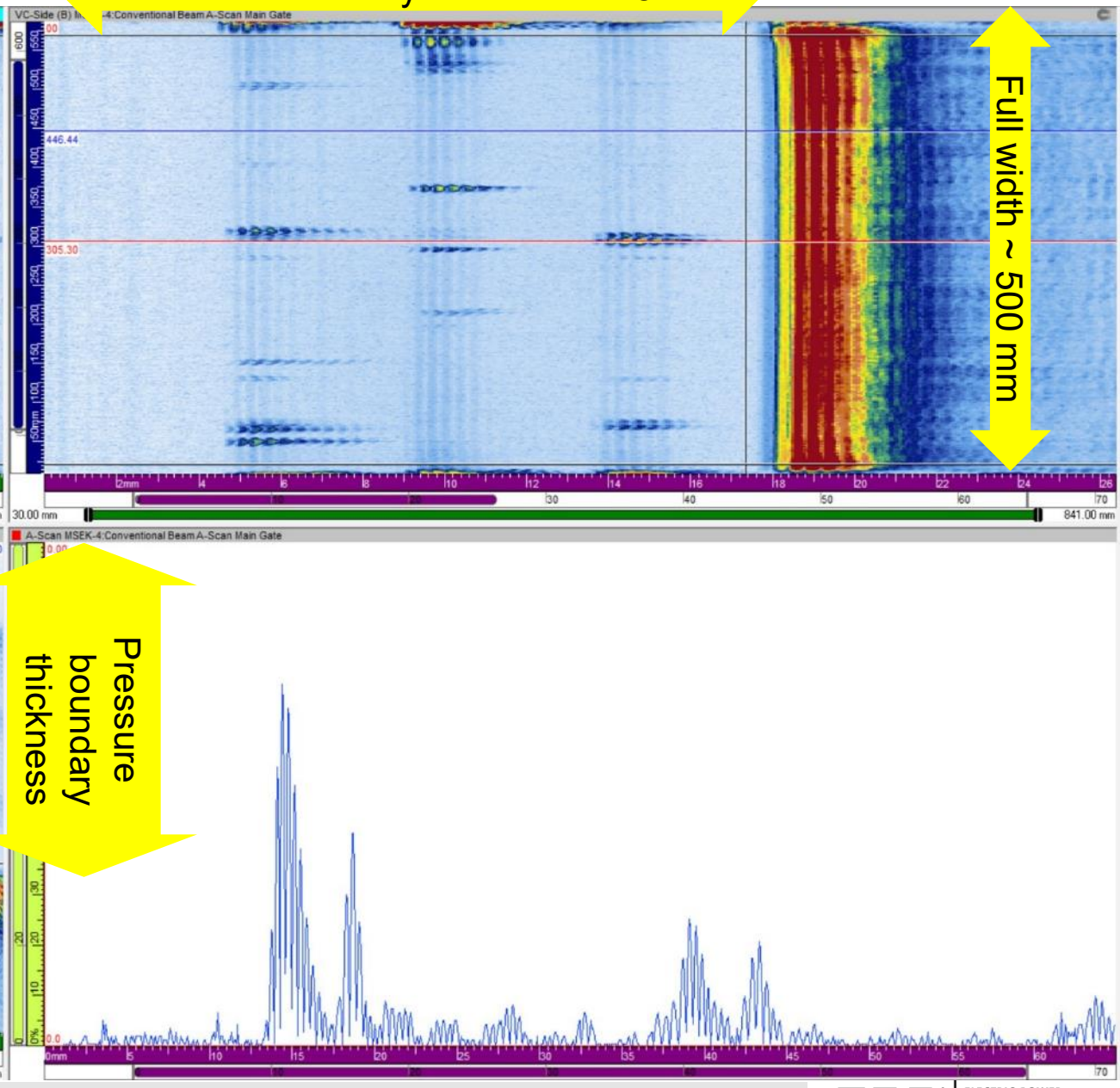
# NDE results on a failed CHX provided by UW

# Comprex CHX

# Scanning setup


# Side A – entire surface

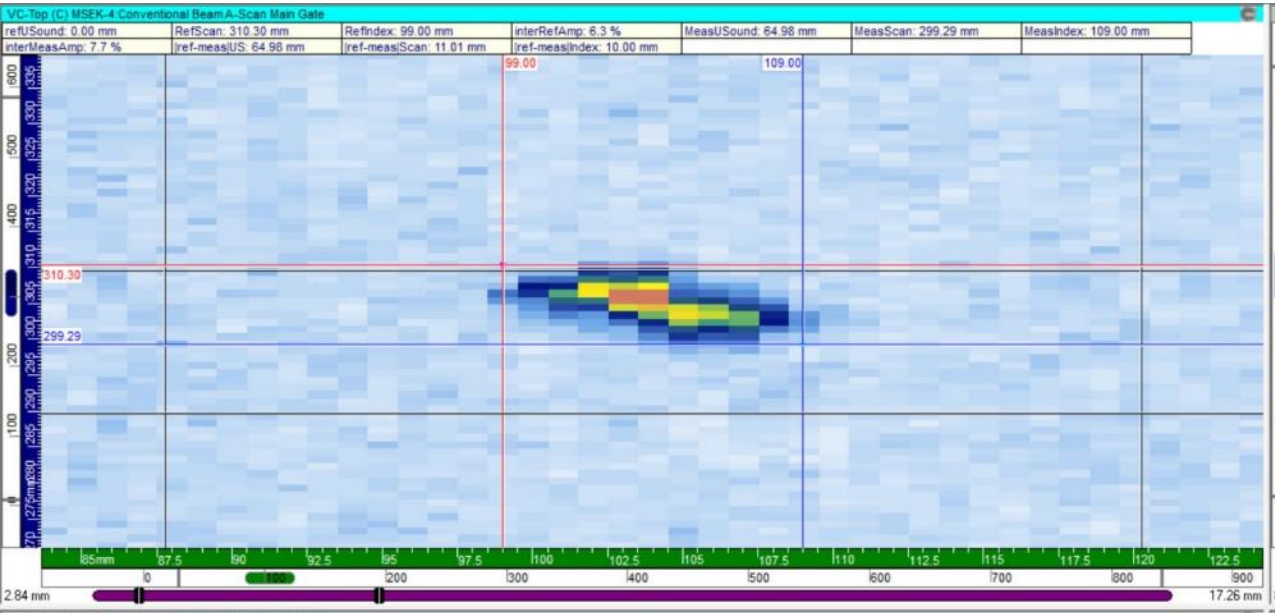


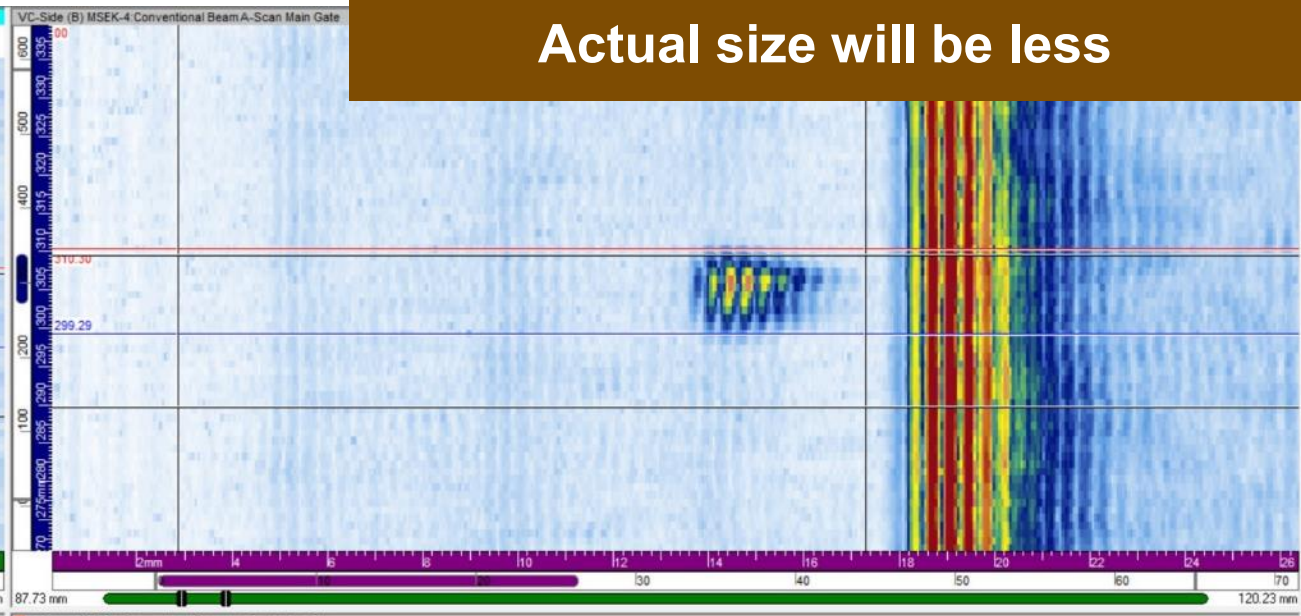



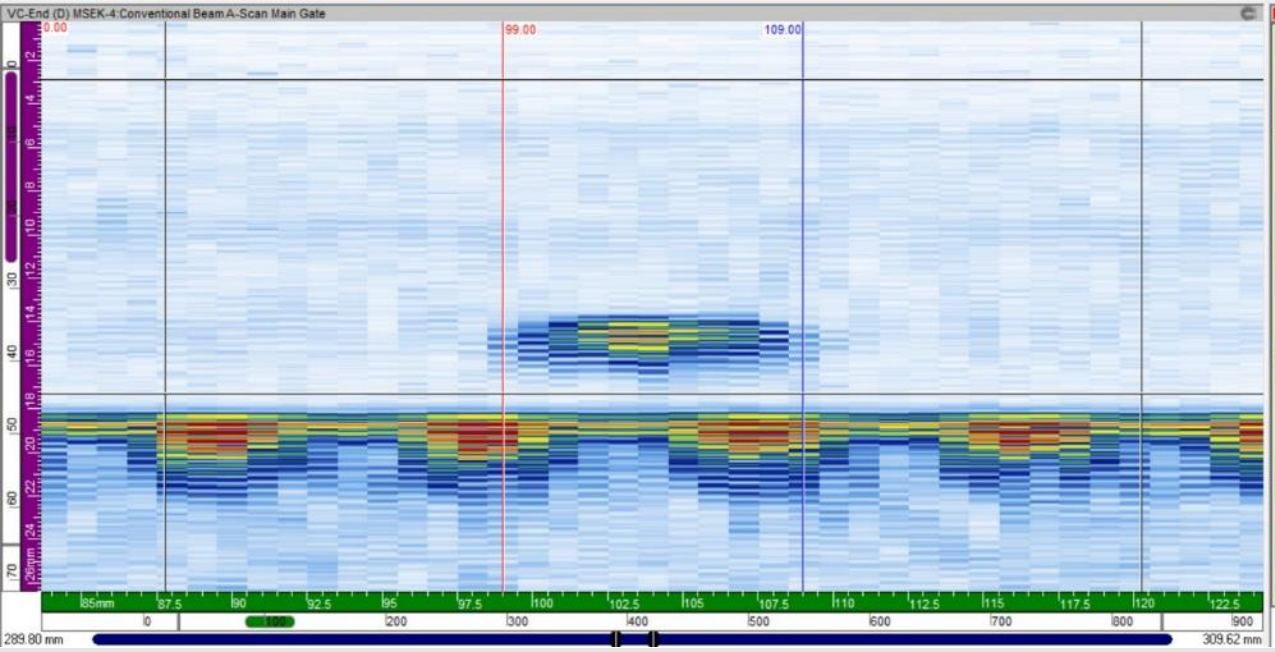
# Side A – detail of largest indication

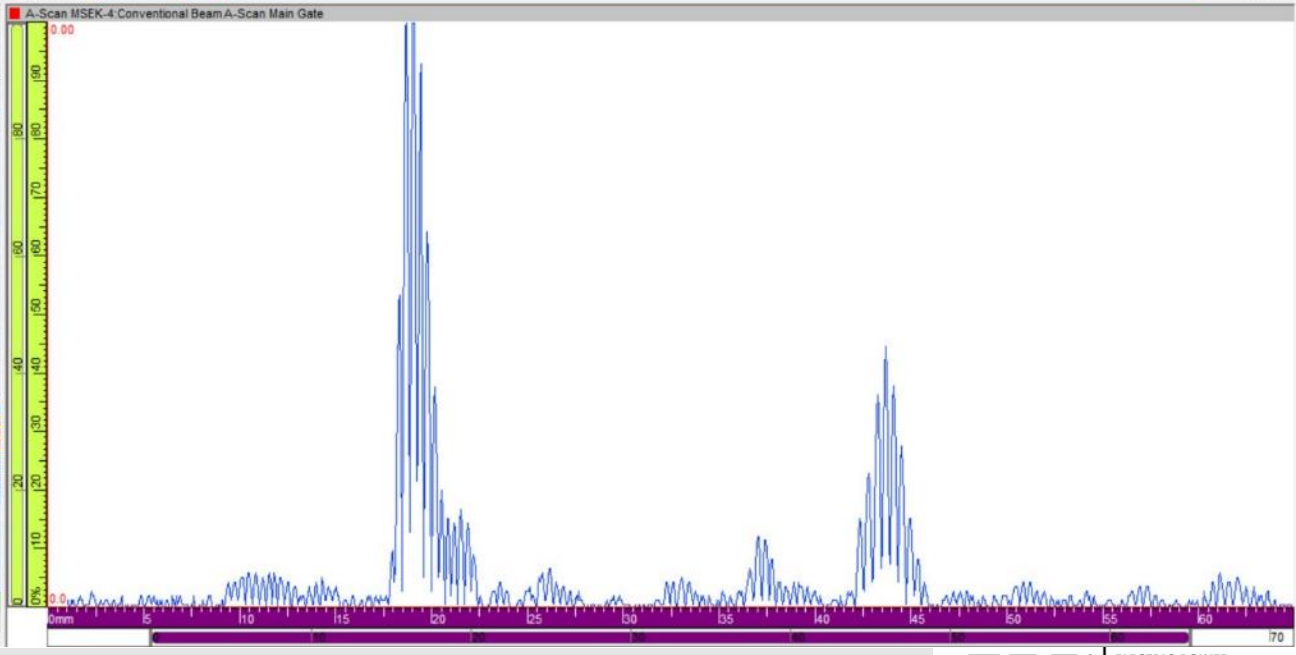
**Conservative measure 10 x 11 mm**

**Actual size will be less**

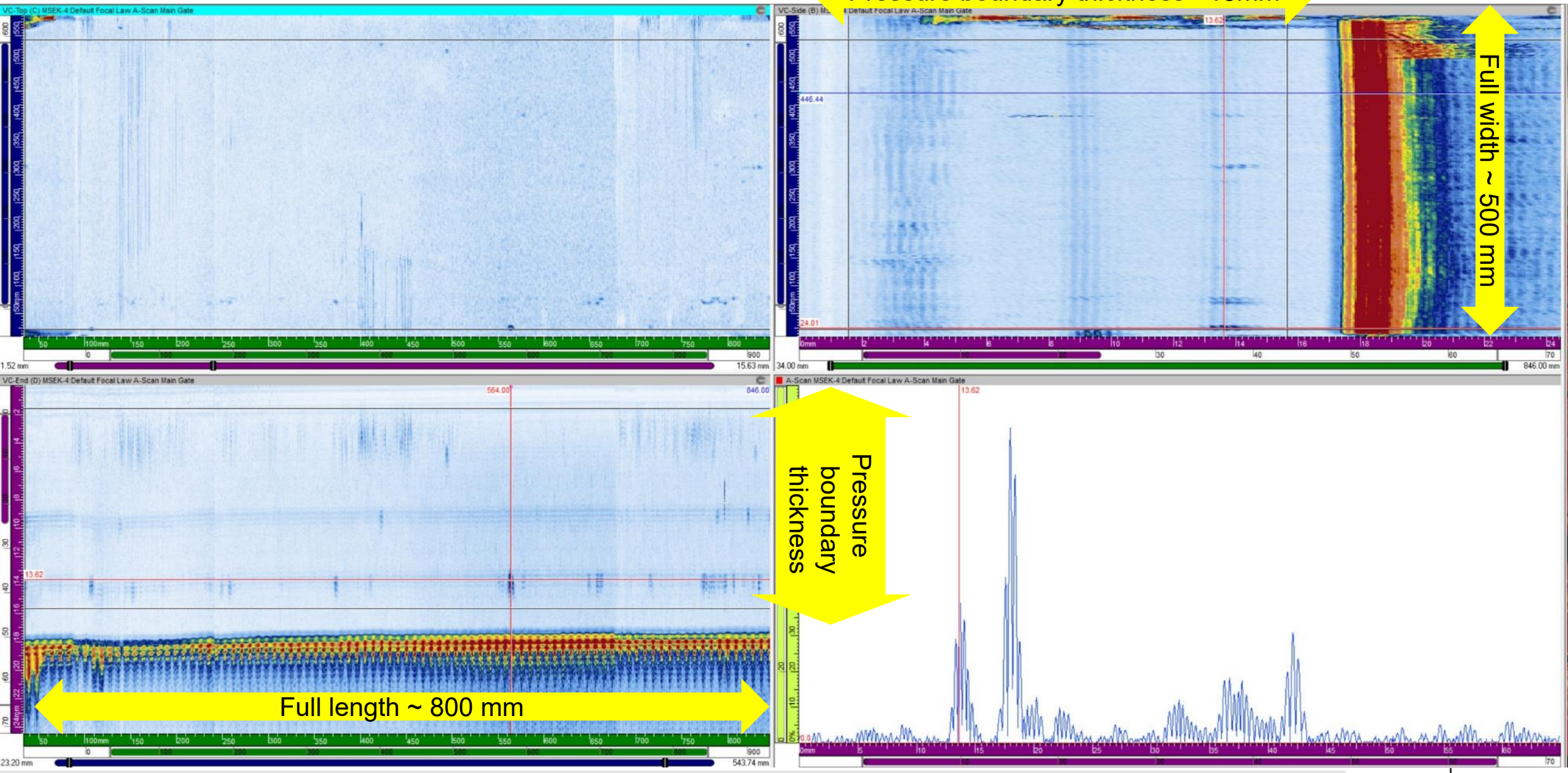


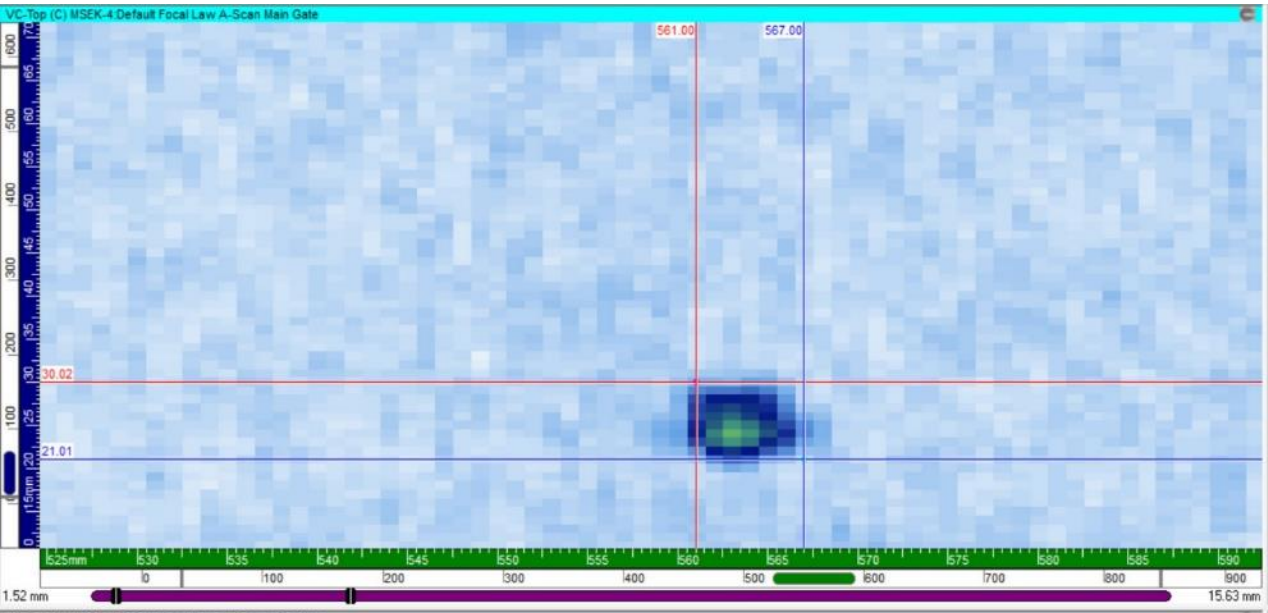
# Side B – entire surface

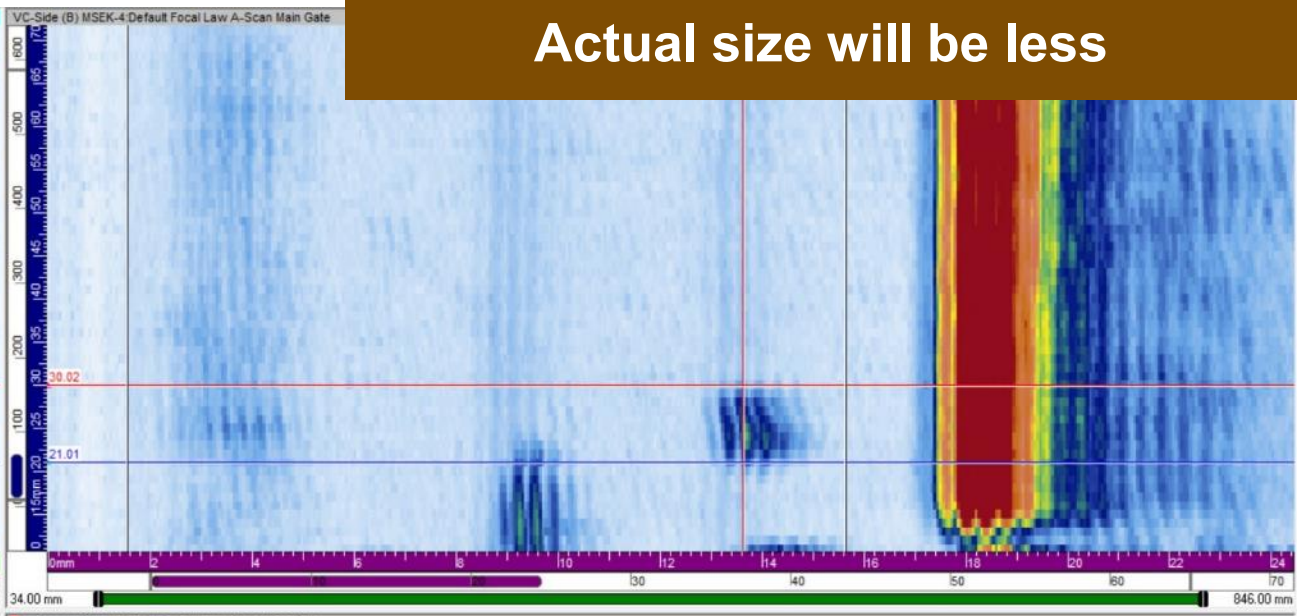


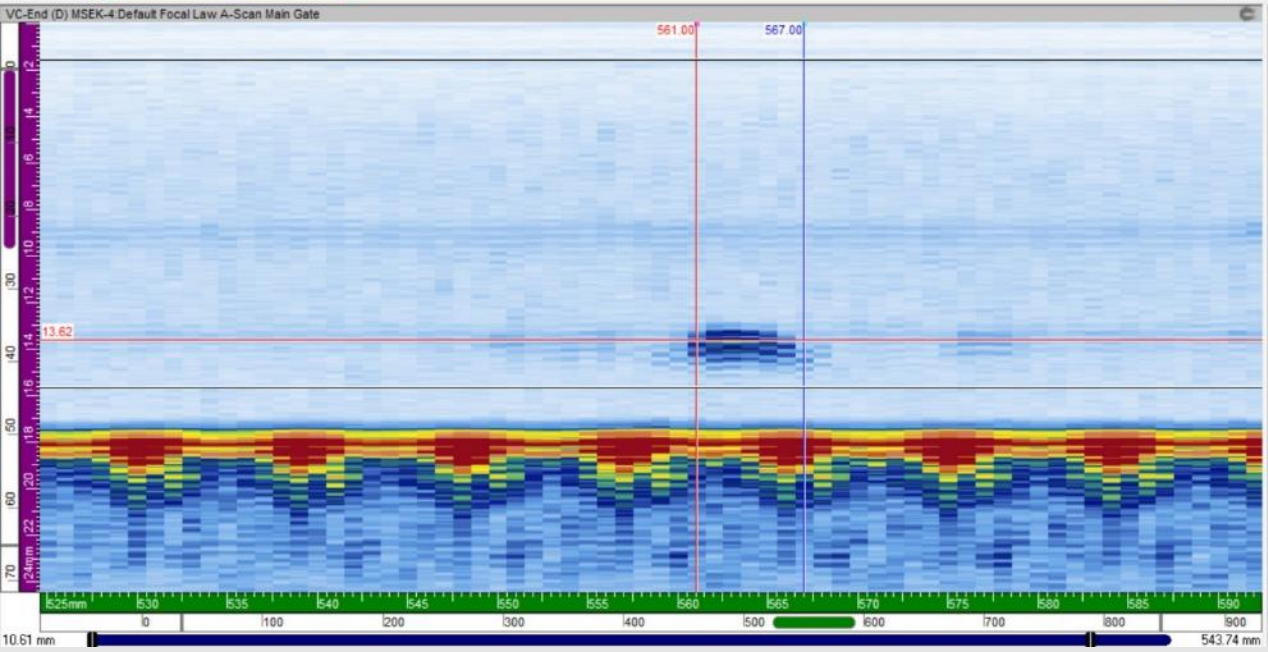
# Side B – detail of largest indication

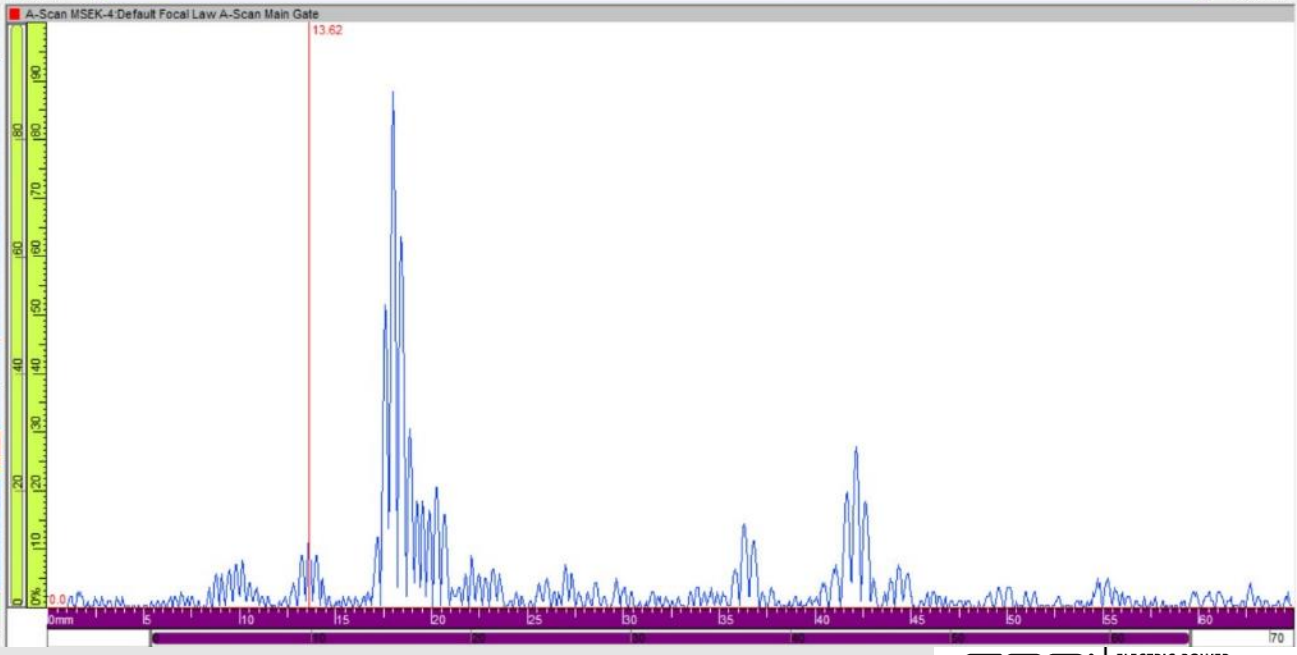
**Conservative measure 9 x 6 mm**

**Actual size will be less**



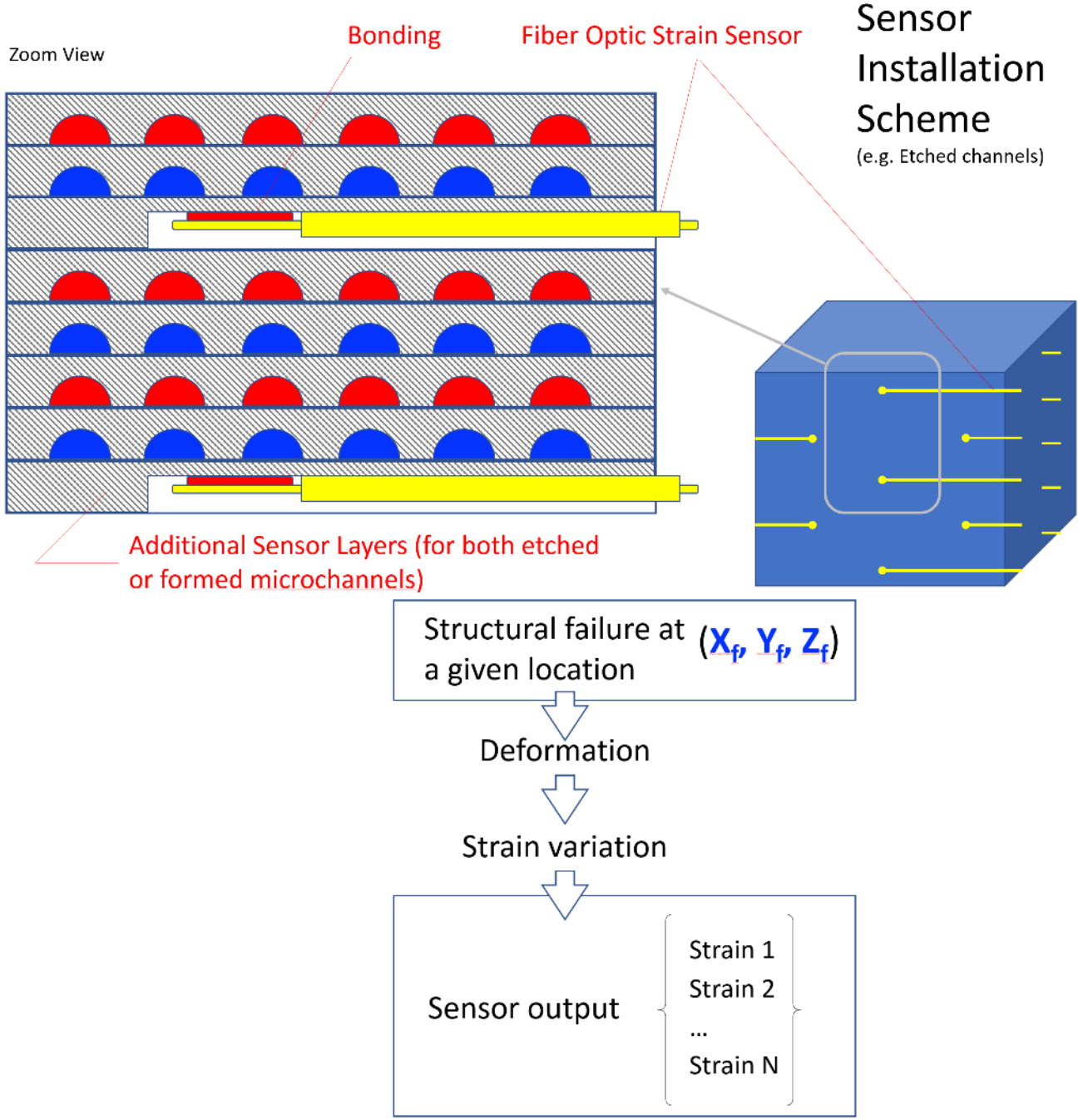



# Block interior, during service

- Strain gages, embedded
- Challenges:
  - Sensor design and bonding method
  - Accurate numerical modeling
  - Sensor location optimization
  - Algorithm design
  - Sensor calibration



# *discussion*

# Together...Shaping the Future of Electricity