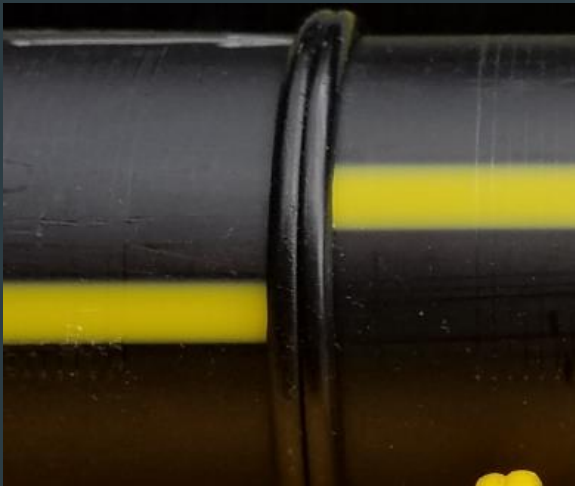




# Development of 3 Technologies for Non-Destructive Evaluation (NDE) of PE Pipe Joints



NGA Ops Conference - Spring  
April 11, 2025  
Paul Pirro



# NYSEARCH – [www.nysearch.org](http://www.nysearch.org)

- ▶ NYSEARCH is a sub-organization of NGA that conducts voluntary RD&D on behalf of 22+ gas utilities located in the United States and Canada
- ▶ NYSEARCH members define needs, identify benefits for their company, oversee the voluntary program, and work to implement R&D products into their companies
- ▶ NYSEARCH conducts research in the following areas:
  - ▶ Improved Installation, Maintenance, and Repair
  - ▶ Pipeline Integrity/Direct and Remote Assessment
  - ▶ Pipe Location and Damage Prevention
  - ▶ Low Carbon Fuels
  - ▶ Leak Detection and Methane Emissions
  - ▶ Real-time Sensing and Inspection for Distribution
  - ▶ Environment/Reducing Greenhouse Gas Emissions



# Why Develop NDE Solutions?

- ▶ Inspection of PE Pipe Joints - Butt Fusion and Electrofusion
  - ▶ State regulators have been requiring utilities to excavate, cut out and perform destructive testing on PE fusion joints identified for various reasons.
  - ▶ Until recently, the extent of a PE fusion inspection has been limited to visual observation on the exterior joint surface.
  - ▶ This created a need to develop reliable Non-Destructive Evaluation (NDE) technology solutions that could be utilized by utilities.
  - ▶ Since 2018, NYSEARCH has been leading an assortment of NDE technology projects with the goal of performing effective inspections for quality.



# 3 Types of NDE Solutions

## ▶ X-Ray Testing

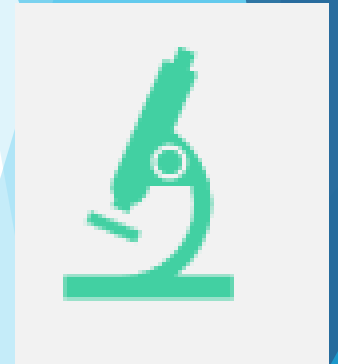
- ▶ X-ray technology works by using a form of electromagnetic radiation to capture images of the inside of objects.

## ▶ Phased Array Ultrasonic Testing

- ▶ Phased Array Ultrasonic Testing (PAUT) is an advanced form of ultrasonic testing that uses multiple ultrasonic elements or transducers to produce an array of sound waves, rather than a single wave emitted from a single transducer.
- ▶ This allows for more control and flexibility, enabling complex inspections with high precision.

## ▶ Terahertz Testing

- ▶ Terahertz (THz) testing involves the use of terahertz radiation, which falls between the microwave and infrared regions of the electromagnetic spectrum (approximately 0.1 to 10 THz), for non-destructive analysis of materials and structures.



# Who are the NDE Pioneers & Trailblazers?

- ▶ NDE Technology Leaders

- ▶ Joe Mallia - NYSEARCH
- ▶ Eclipse Scientific (Acuren)
- ▶ The Welding Institute (TWI)
- ▶ New Jersey Institute of Technology (NJIT)
- ▶ Iowa State University (ISU)
- ▶ Cogniac AI



# X-ray Technology





# X-ray Technology Review

## ► X-ray Production

- X-rays are produced in an X-ray tube. This tube contains a cathode (negative electrode) and an anode (positive electrode).
- When electricity is applied to the cathode, it emits electrons.
- These high-energy electrons travel toward the anode, where they hit a metal target, producing X-rays.

## ► Penetration

- X-rays pass through the object being imaged.
- Dense materials appear white on the image, while less dense materials appear darker.

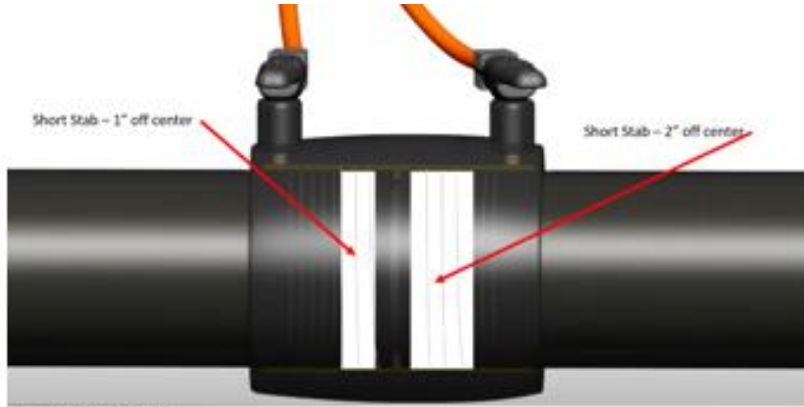


# X-rays of PE Electrofusion (EF) Joints

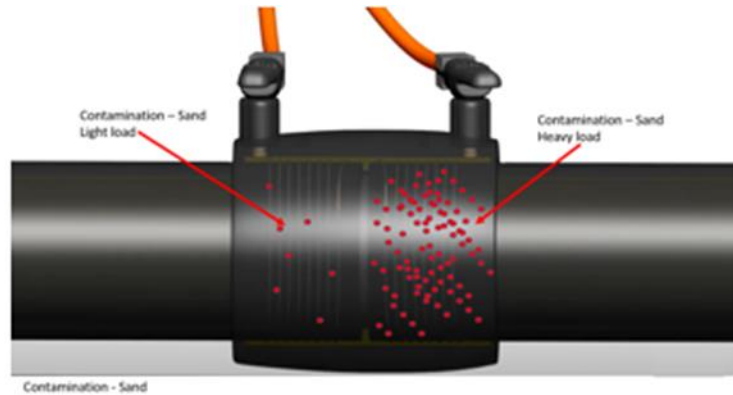
- ▶ One project delivered a new reference document that incorporates technical guidance provided by the X-ray camera manufacturer with adjustments to meet the needs of a utility operator.
  - ▶ This document aligns with relevant industry safety and compliance standards references that can be used for guidance.
- ▶ An NDE application procedure was developed to enable a non-SME to confidently use the NDE X-ray application.
  - ▶ This procedure guides users to safely set up X-ray equipment in the field, perform effective NDE inspections, and interpret results using pass/fail judgement.
- ▶ Project leaders designed test samples with embedded flaws that can be typically seen in bad PE EF joints.



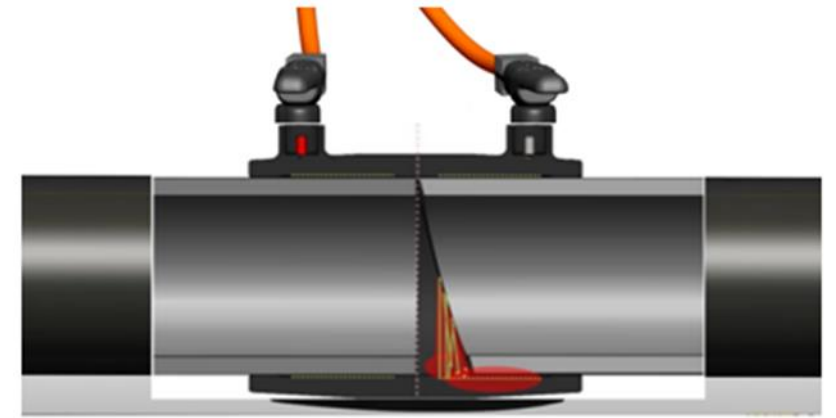
# NDE X-Ray Images of Test Sample with Embedded Flaws



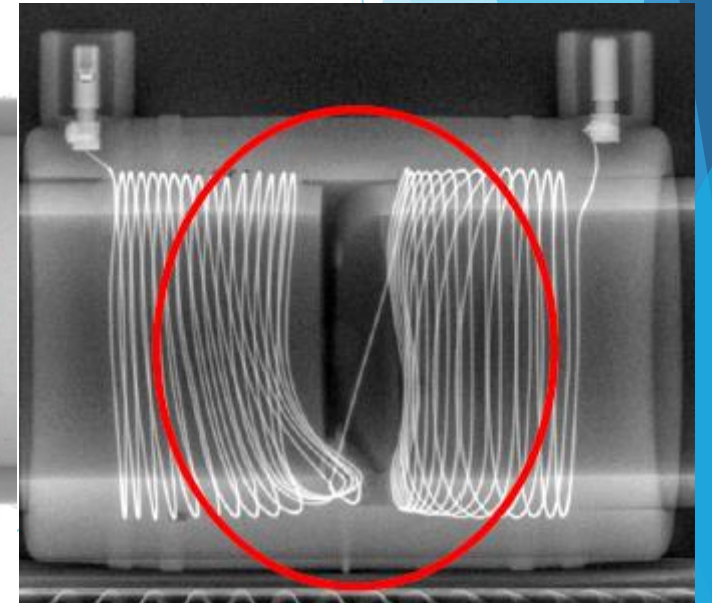
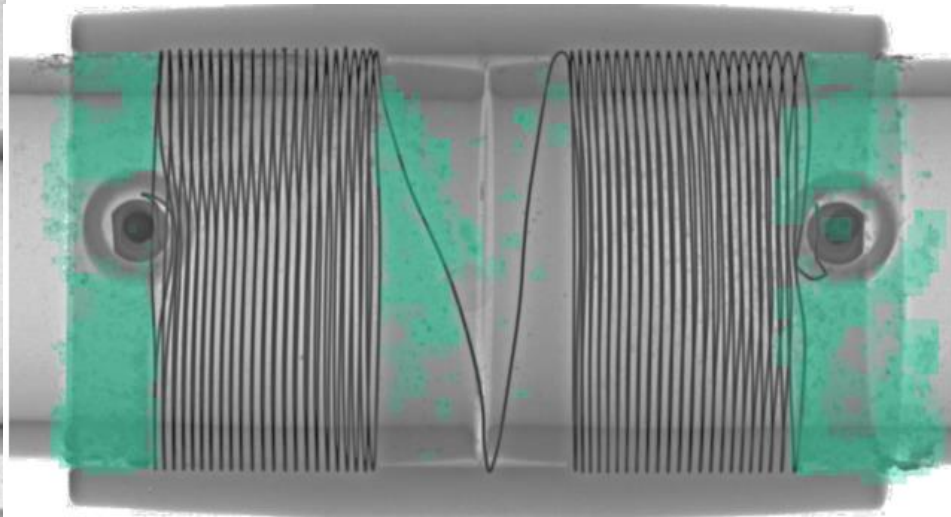
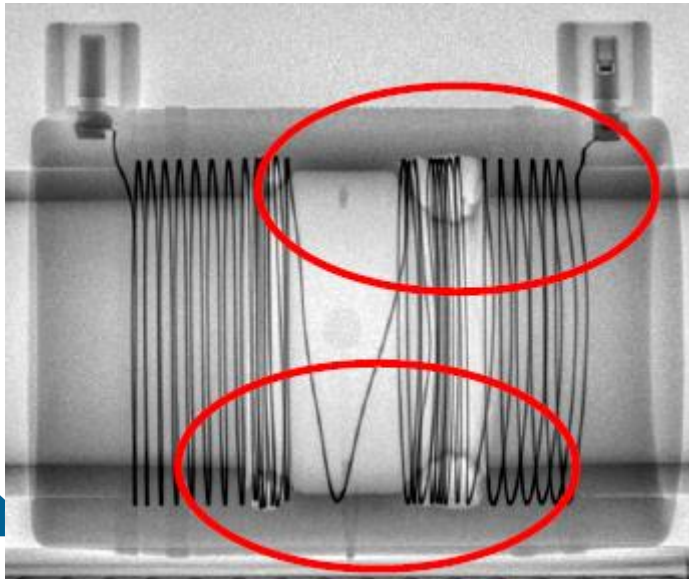
Flaw - Short stab, failure to insert PE pipe into EF coupling



Flaw - Contamination: Sand, lack of clean precautions assembling PE pipe EF coupling



Flaw - Improper pipe preparation, not square PE pipe end



# Cogniac AI Development

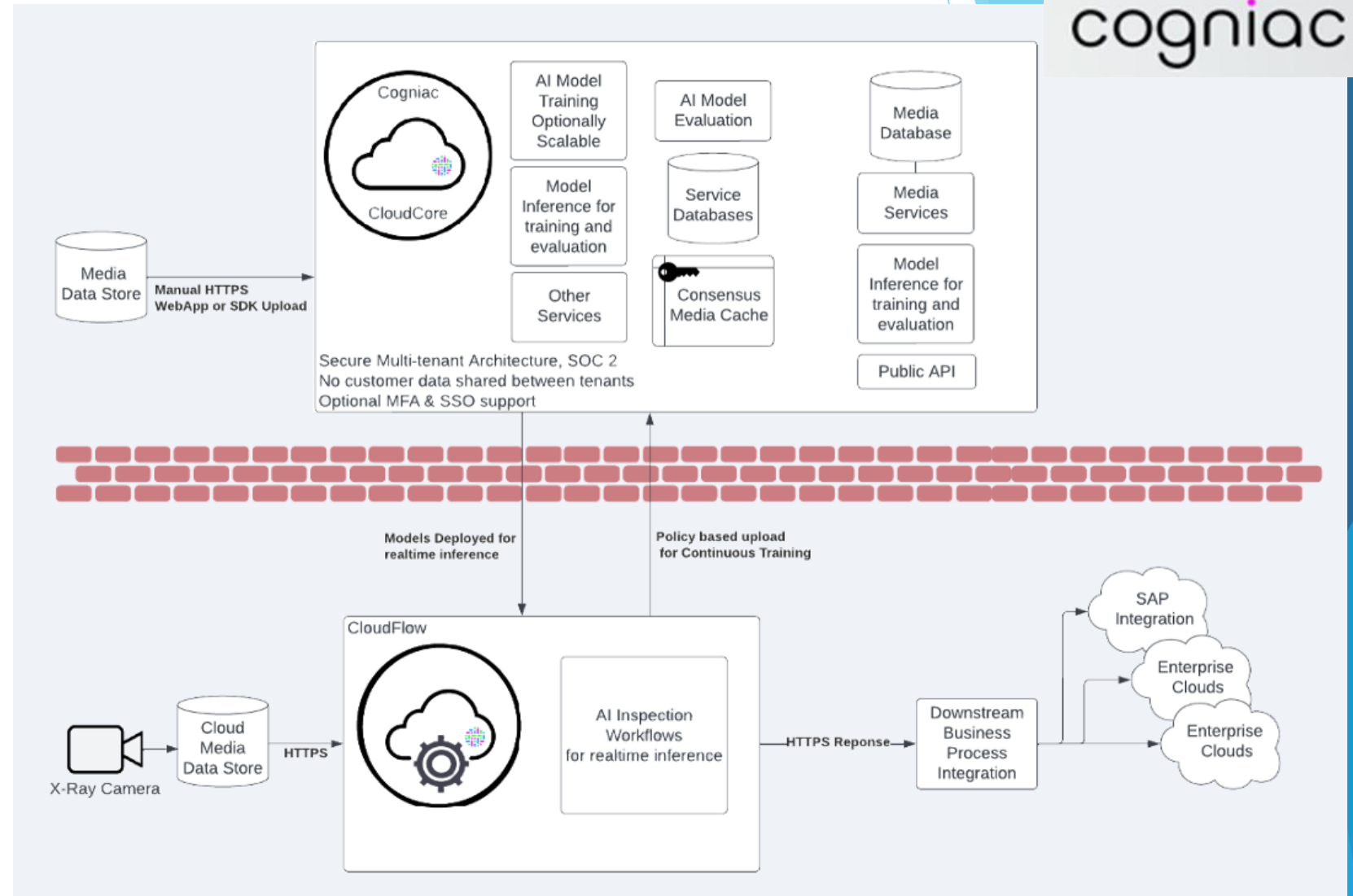
- ▶ EF joint defect samples were created at 3 utility funder laboratory locations.
- ▶ X-ray contractor prepared X-rays of each sample from 10 different angles.
- ▶ A library of over 2,200 X-ray images was transferred to Cogniac AI cloud-based system.
- ▶ Utility SMEs have been analyzing hundreds of images to identify anomalies associated with gaps due to construction errors and contamination.



# Cogniac Architecture Platform

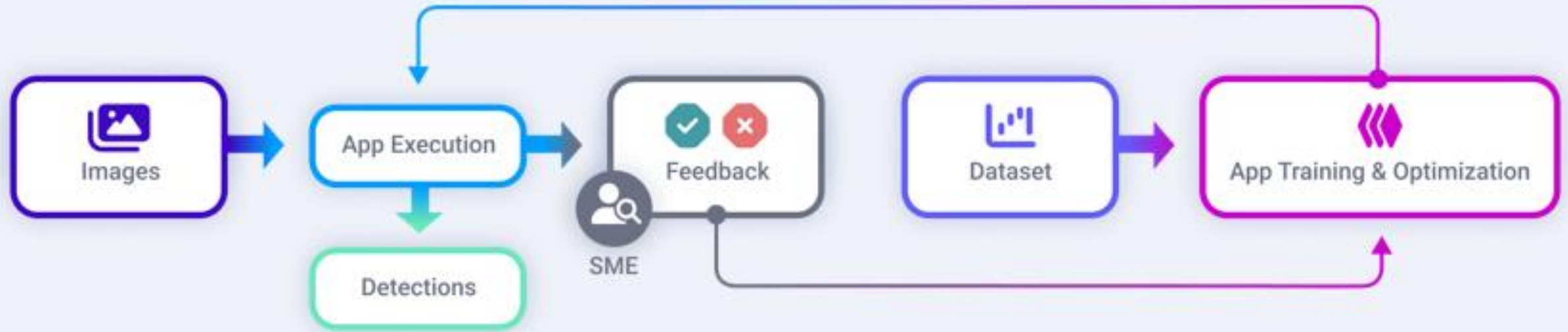


- ▶ Application models are deployed from Cogniac for real-time conclusion based on evidence + reasoning
- ▶ New image data is uploaded for AI continuous training



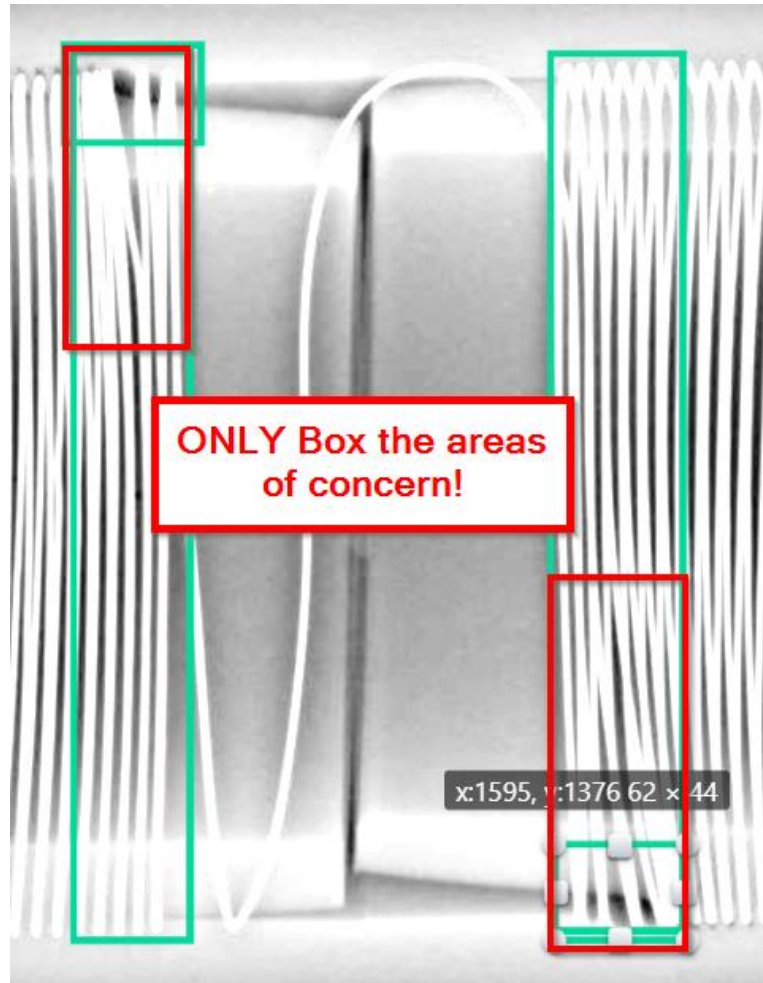


# Cogniac Computer Vision with Active Learning

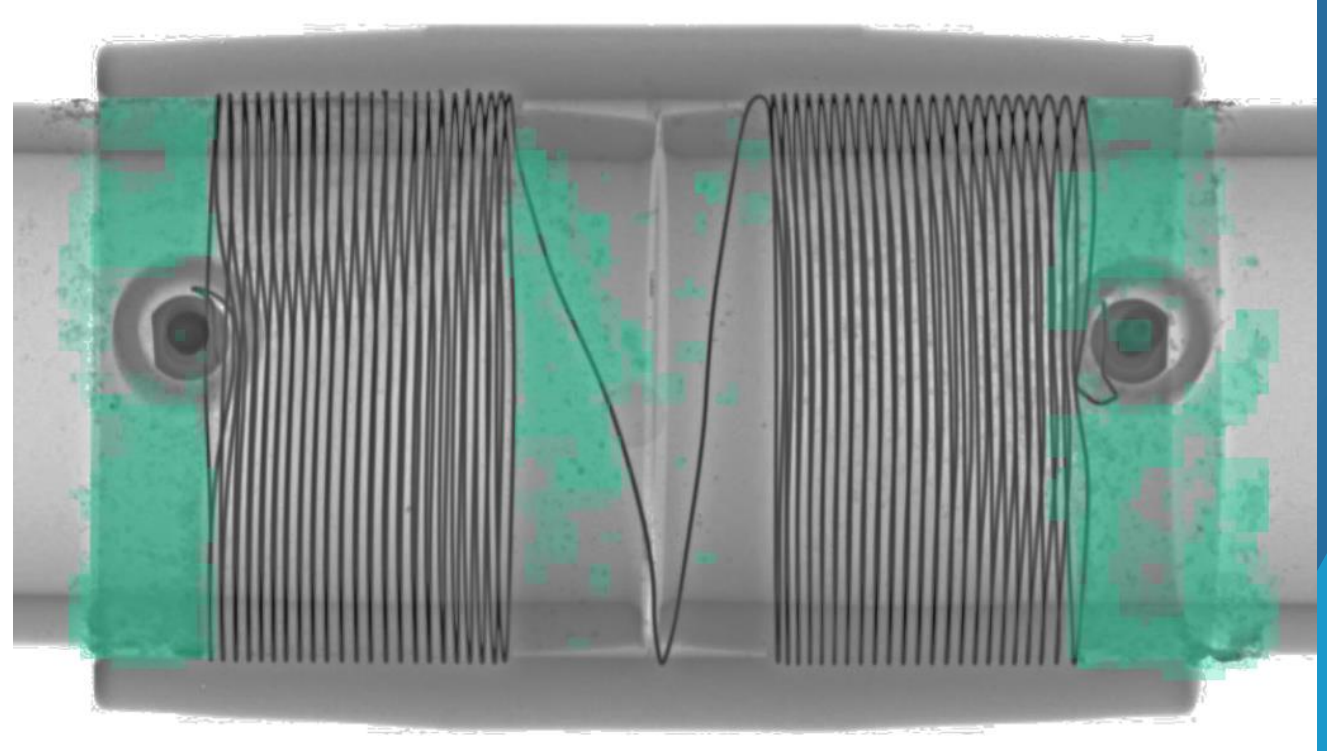


- ▶ Application (App) models covering various types of flaws are being developed for detections
- ▶ App models are executed to determine pass/fail status while image information is added for continuous training

# SME Criteria for Assessment of Anomalies



“Box” Method for Over-Peeling + Misalignment



“Area Detection” Method for Sand Contamination

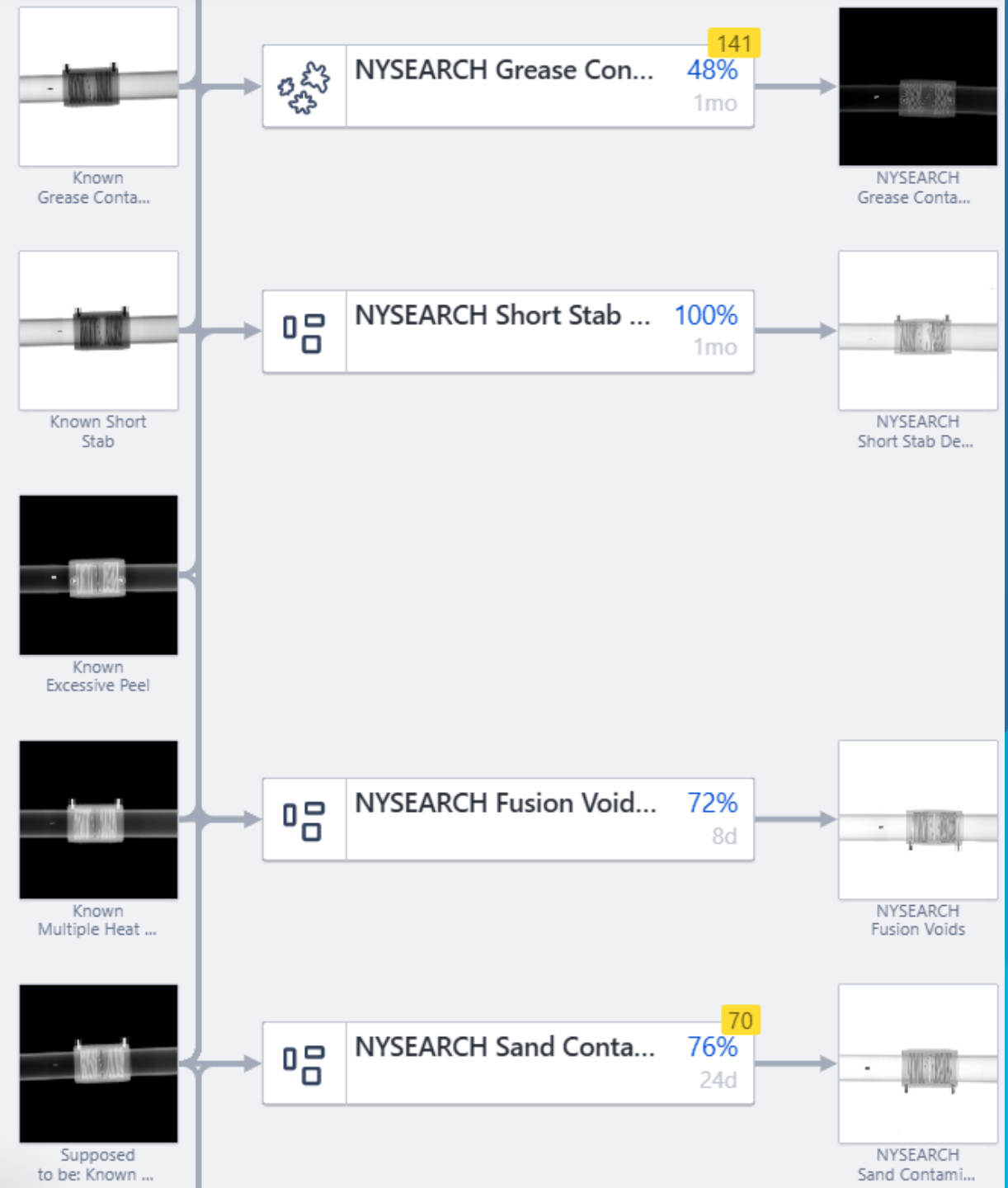


# Cogniac Application Models

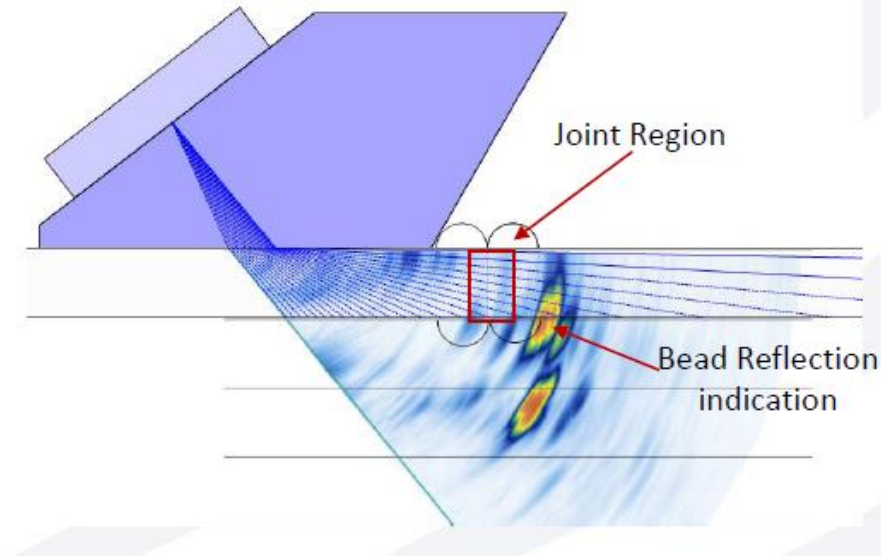
- ▶ App models are deployed from Cogniac for real-time conclusion based on evidence + reasoning
- ▶ New image data is uploaded for AI continuous training



Application Builder ↕

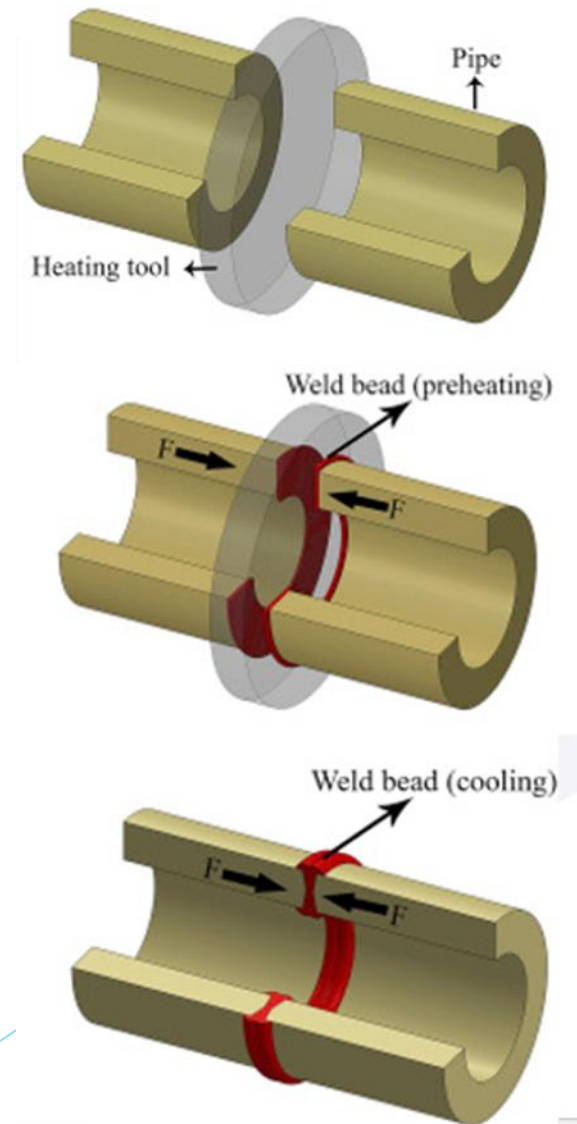


# Phased Array Ultrasonic Testing (PAUT) Technology



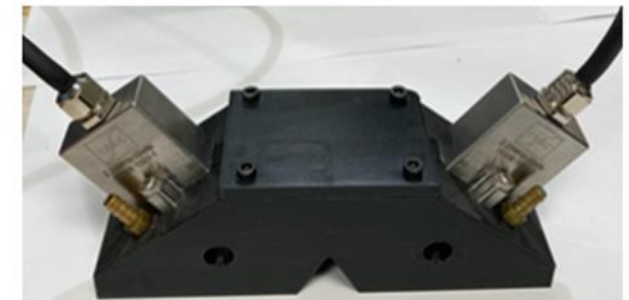
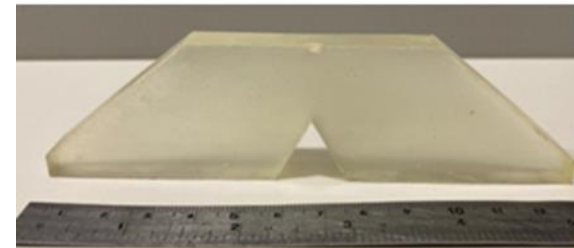
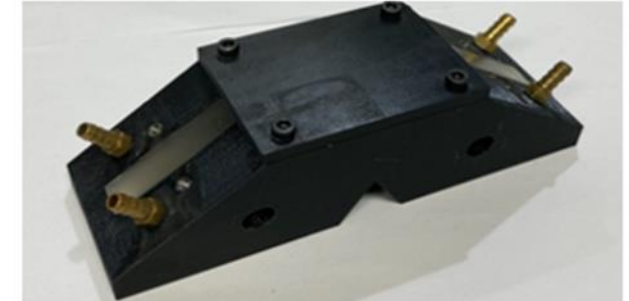
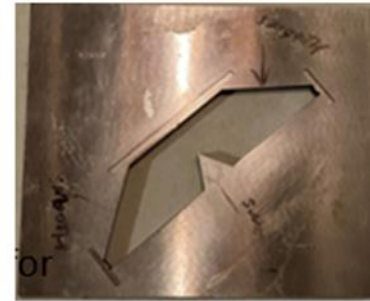
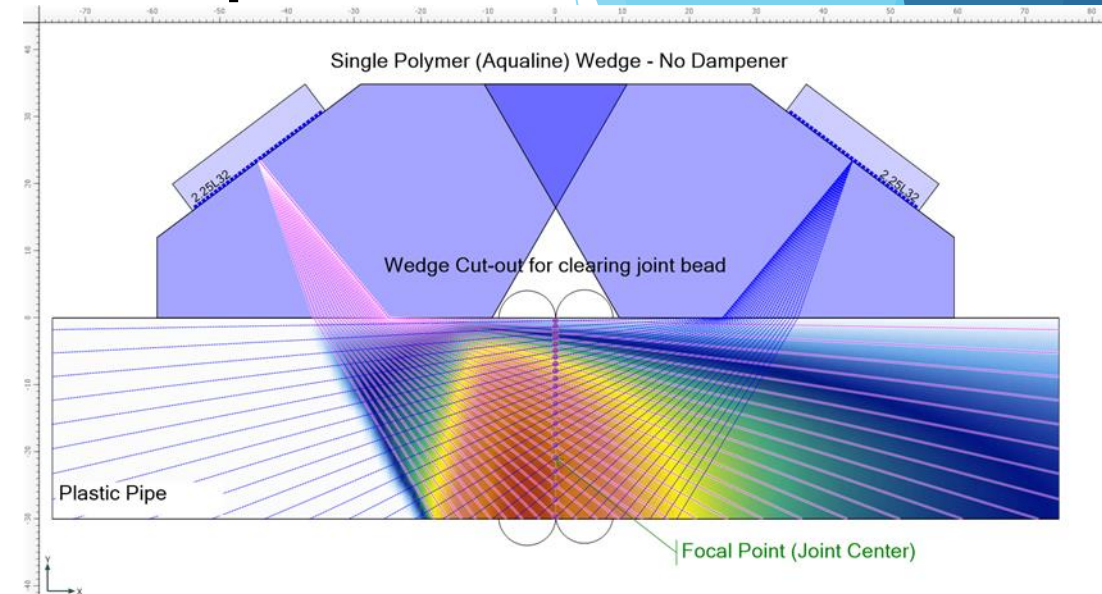
# Phased Array Ultrasonic Testing (PAUT)

- ▶ In 2018, NYSEARCH sought Eclipse-Scientific (Acuren) ultrasonic-based, field practical inspection tool (hardware and software) for inspection of PE pipe butt fusion (BF) + electrofusion (EF) joints
- ▶ The project was designed to achieve 3 goals:
  - ▶ To be operated by welding/fusion technician with **NO** knowledge of ultrasonic testing
  - ▶ To be capable of automatically identifying common joint defects
  - ▶ To provide go/green light for a non-flawed joint or no go/red light to discard a flawed joint and make a new one



# Butt Fusion Joint Inspection Technique

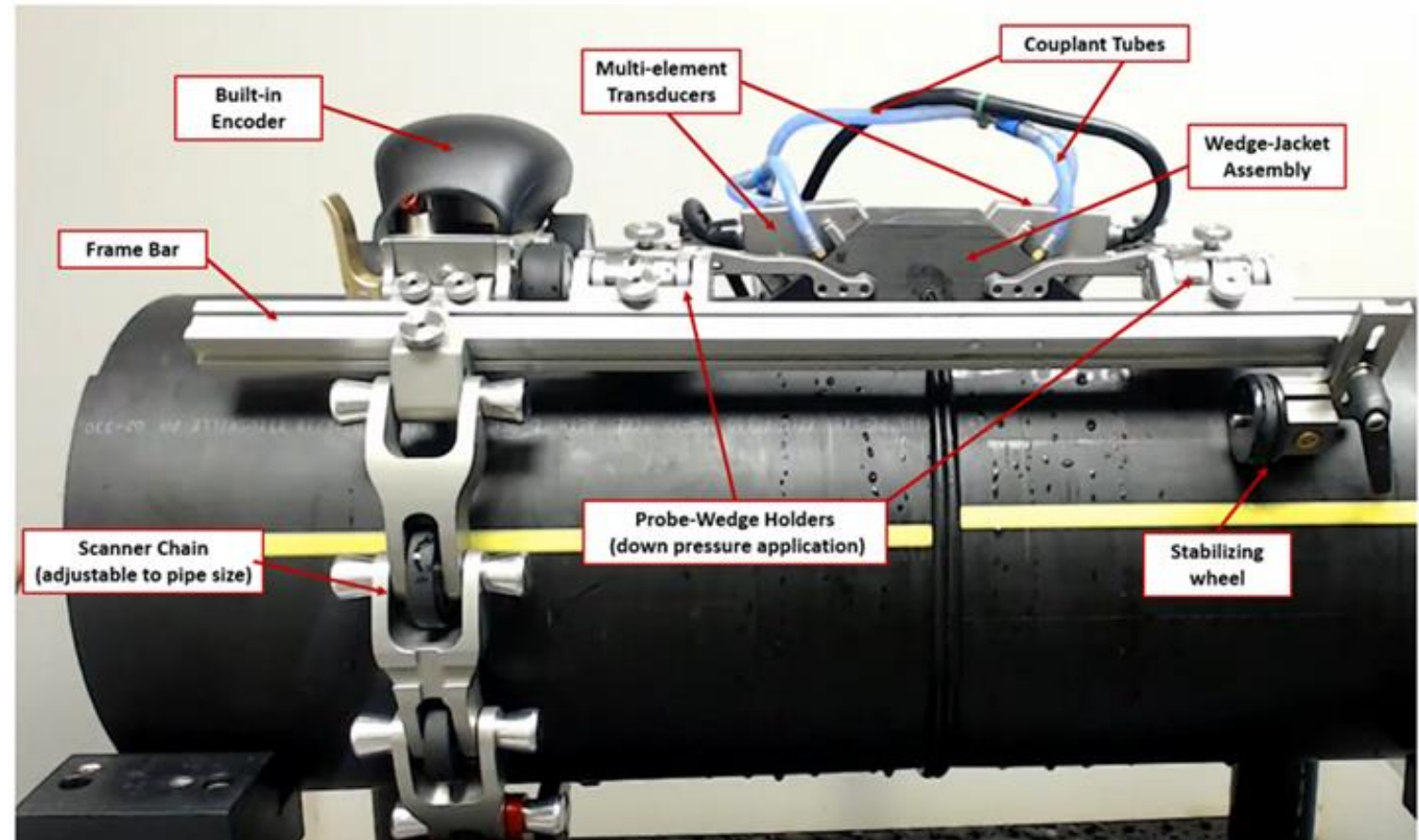
- ▶ Wedges made of aqualene elastomer accommodate transducer probes set at an angle to scan fusion bead
- ▶ Each transducer probe contains 32 elements that deliver the phased array in a focused beam
- ▶ Each element can transmit and receive ultrasonic waves





# Inspection System Overview

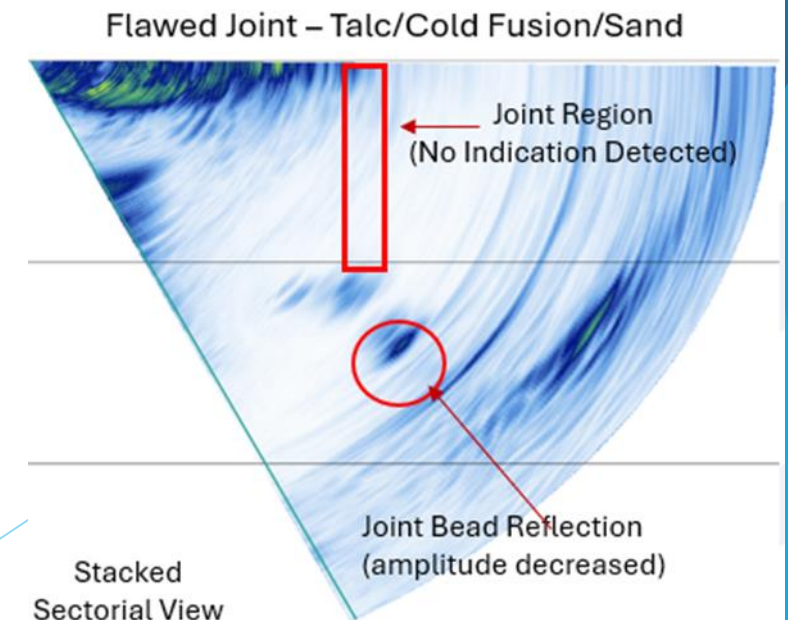
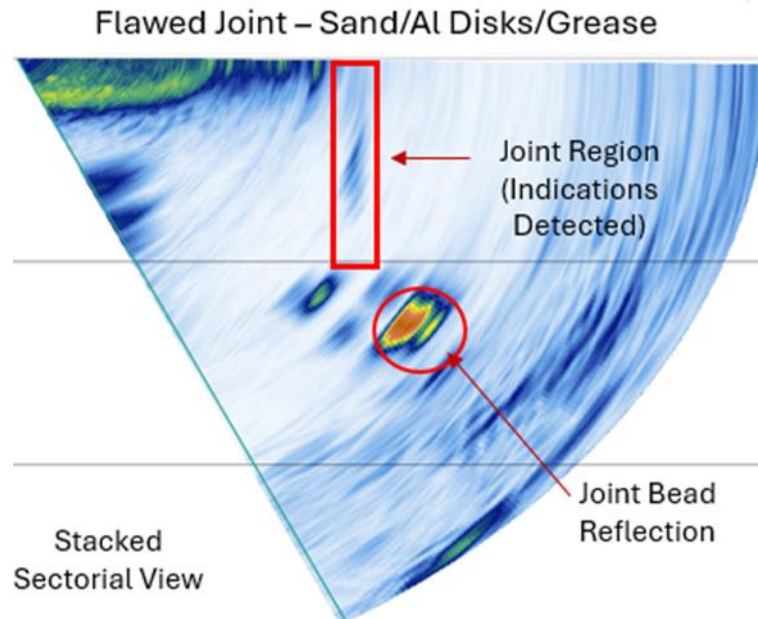
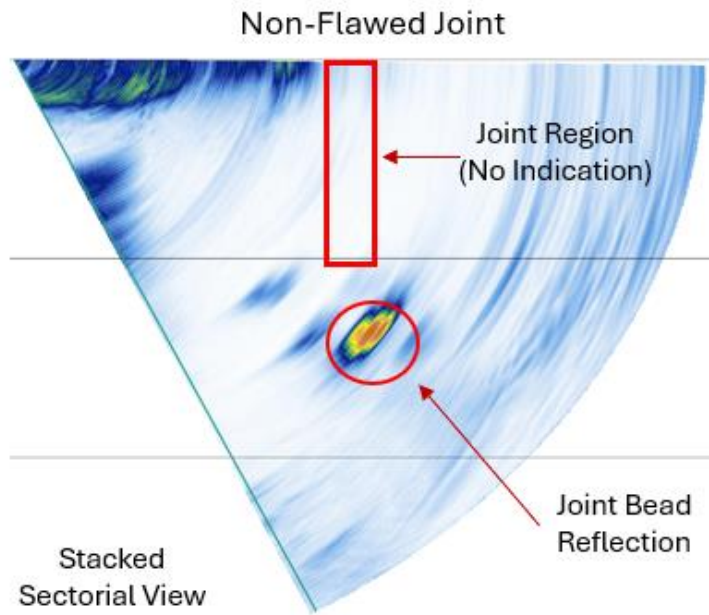
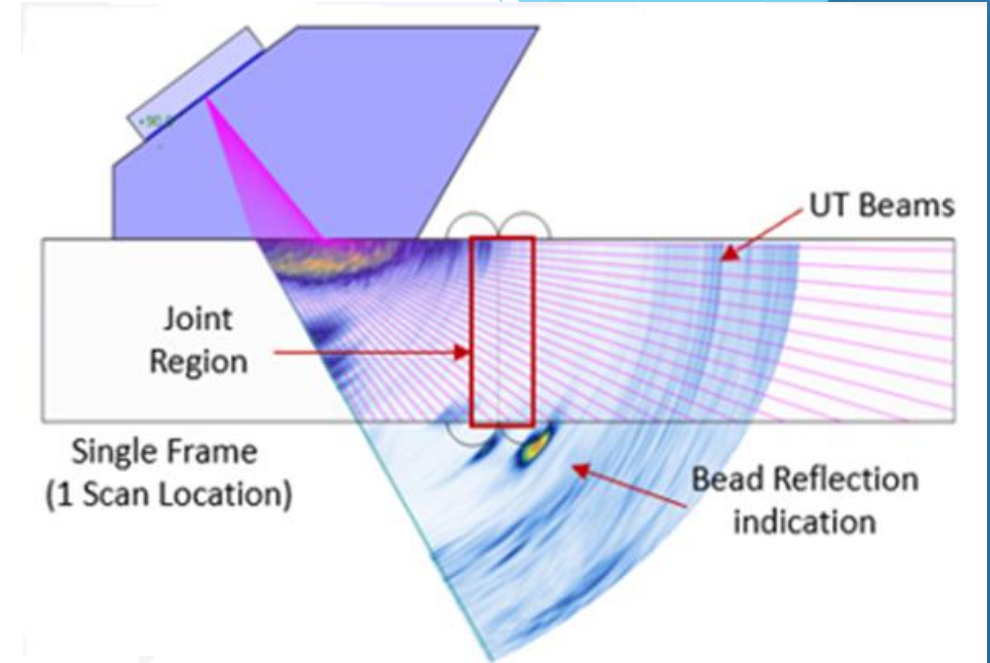
- ▶ Manual chain scanner rotates probe-wedge assembly around the pipe
- ▶ Water is circulated to maintain uniform contact for transfer of ultrasonic sound waves as the assembly is rotated





# PAUT Scan Features for Analysis - BF Joints

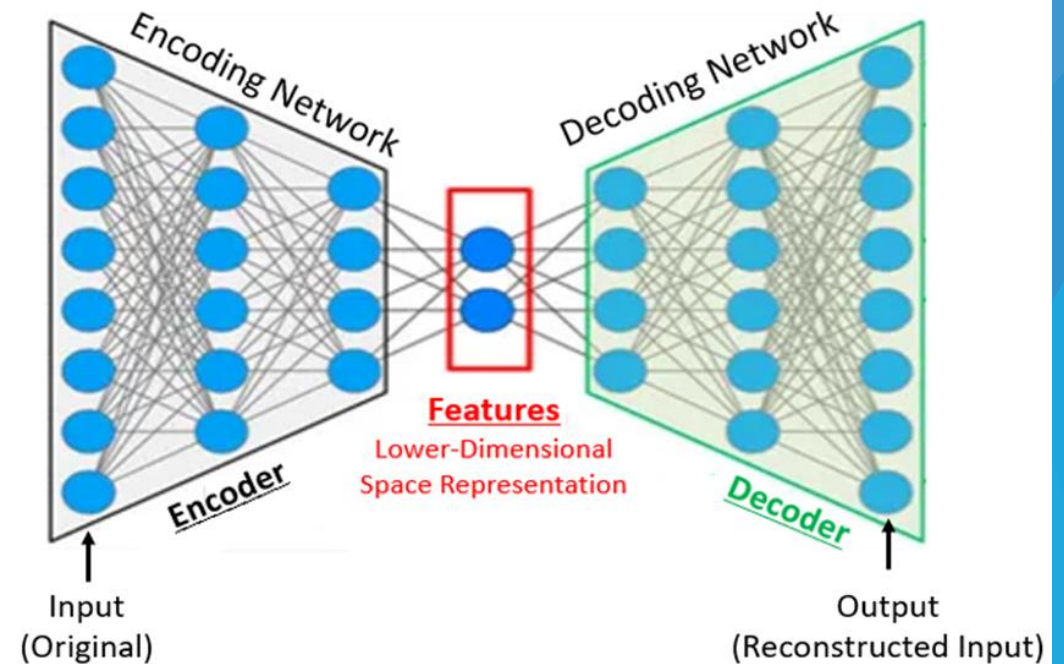
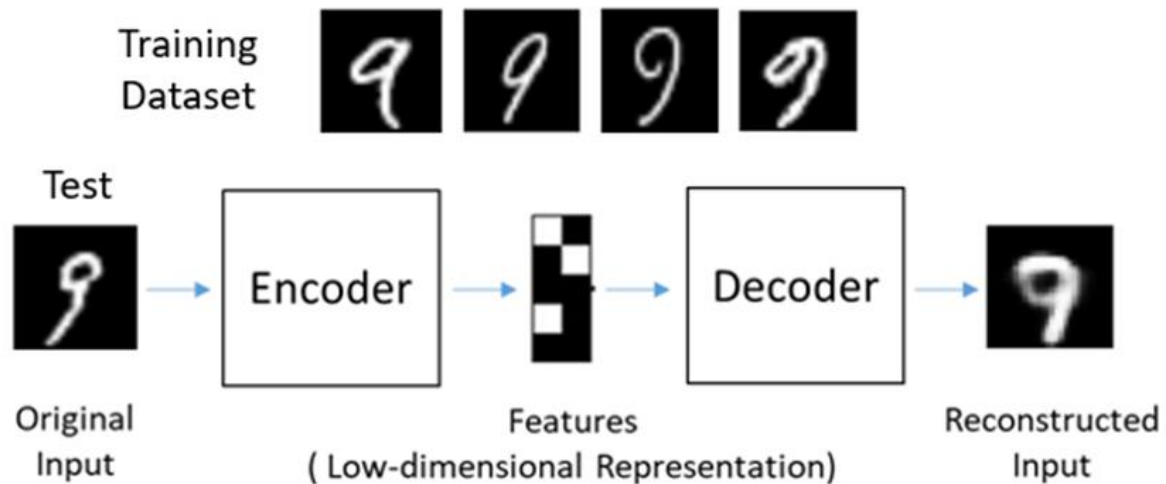
- ▶ Non-Flawed Joint Features
  - ▶ High bead reflection amplitude
  - ▶ No indication in joint region
- ▶ Flawed Joint Features
  - ▶ Indication in joint (Al disk, LOF, grease)
  - ▶ Low bead reflection amplitude (sound blockage)



# Auto Encoders for AI

- ▶ Neural Network design mimics the human brain to process data
- ▶ Two interconnected networks: Encoder and Decoder
- ▶ Encoder takes the input and transforms it into a lower-dimensional space to only preserve key features
- ▶ Decoder tries to reconstruct original higher dimensional input from lower dimensional key features
- ▶ May lead to “Reconstruction Error” (RE) = (reconstructed input - original input)

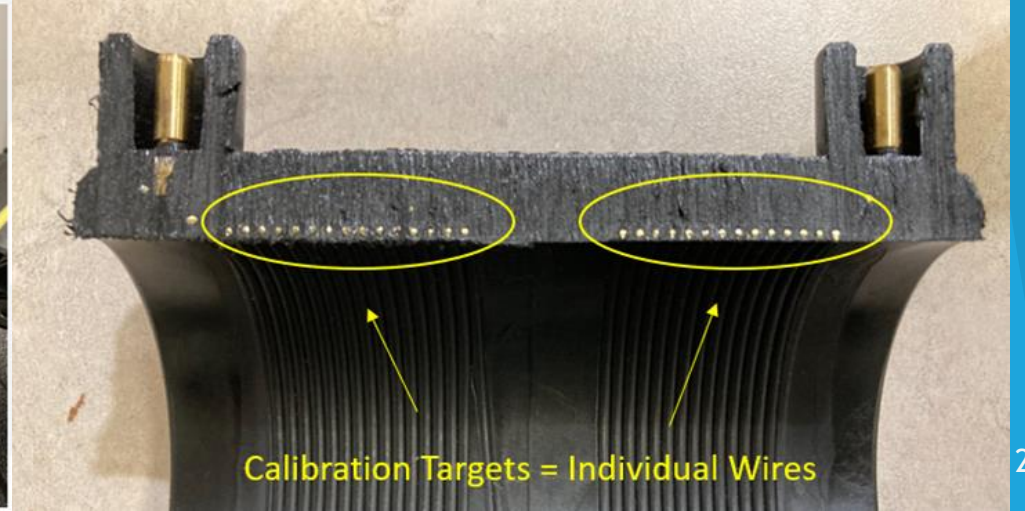
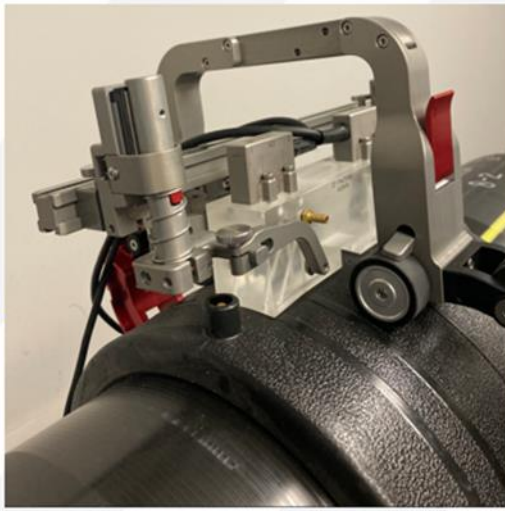
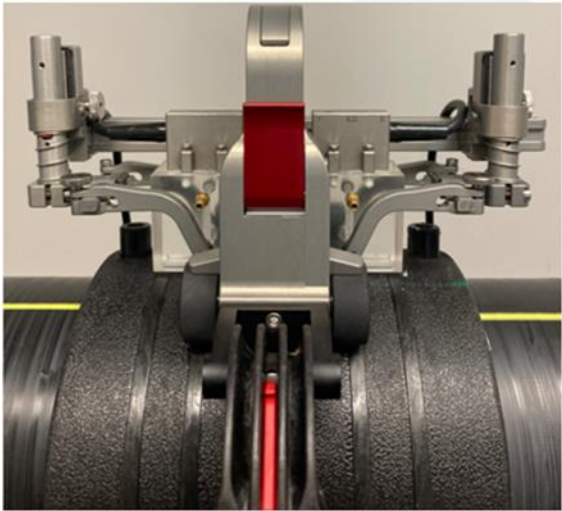
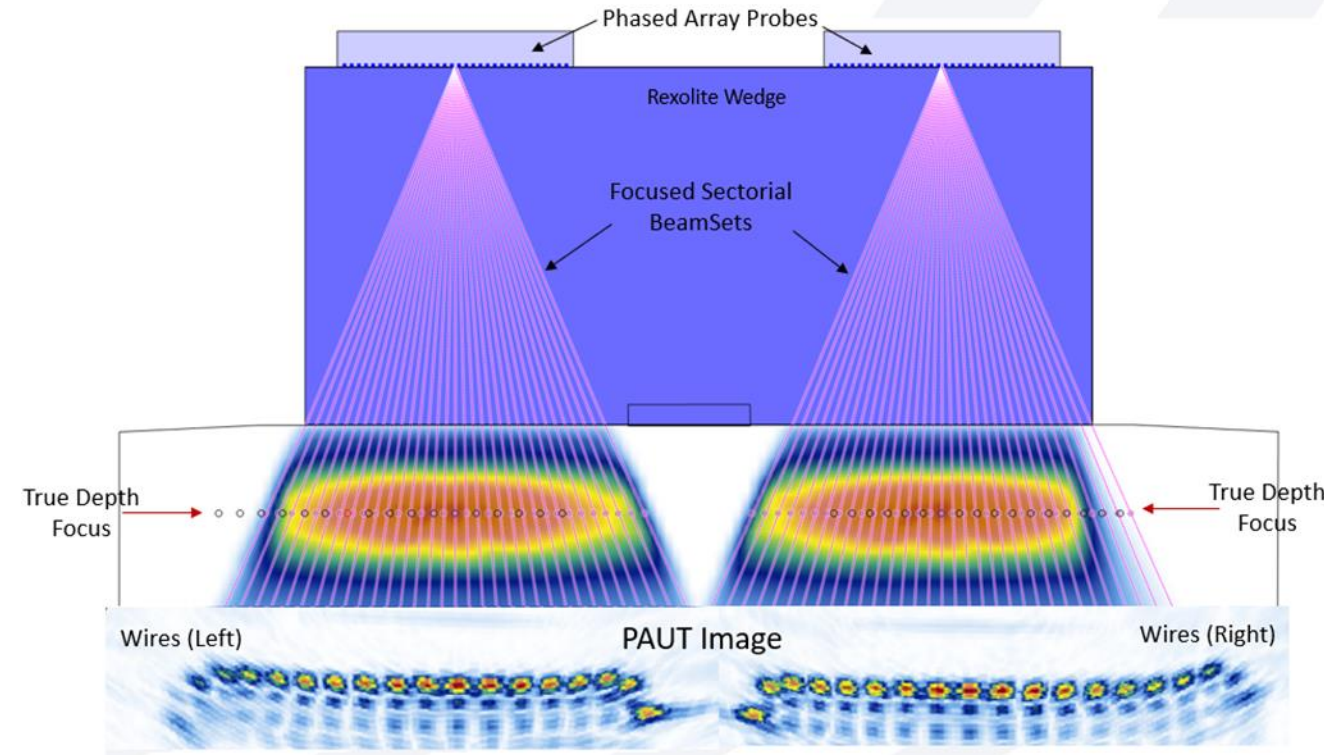
Reconstructing handwritten No. 9





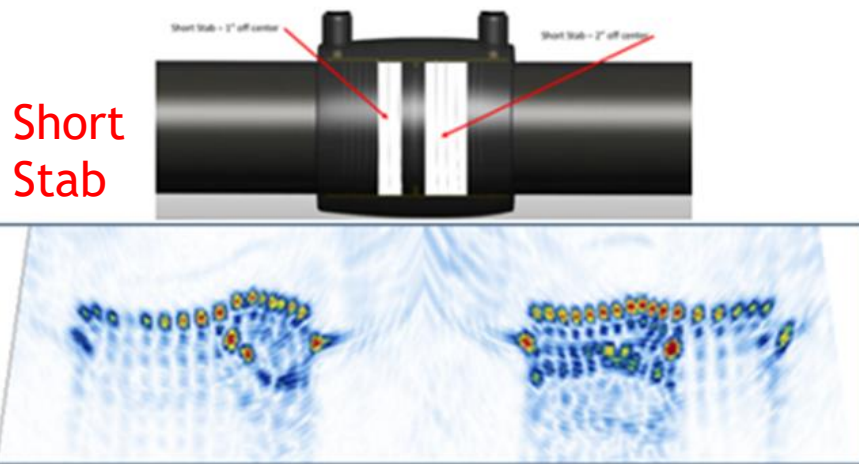
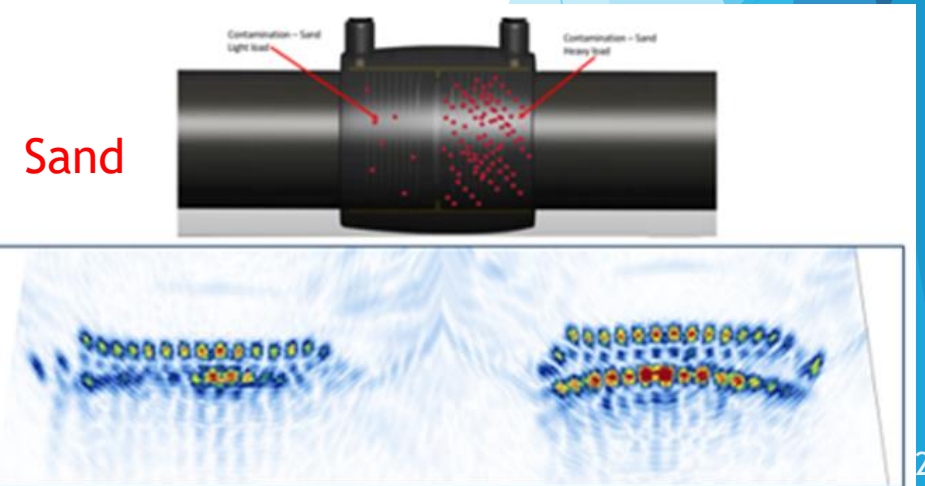
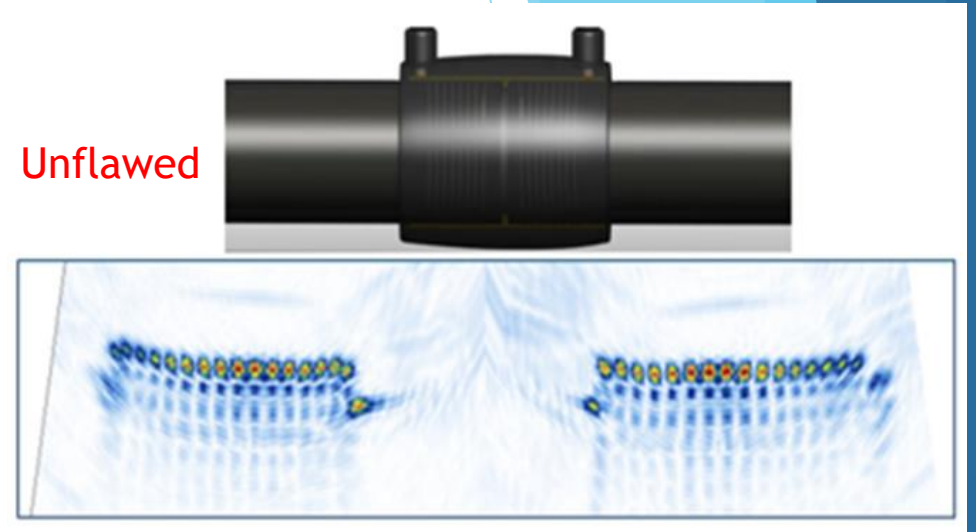
# PE Electrofusion (EF) Joint Inspection Technique

- ▶ Phased Array Probes line up directly over fusion area
- ▶ Provides high resolution images of coupling wires
- ▶ Variations in wire positions and spacing can be quantified with acceptable tolerance



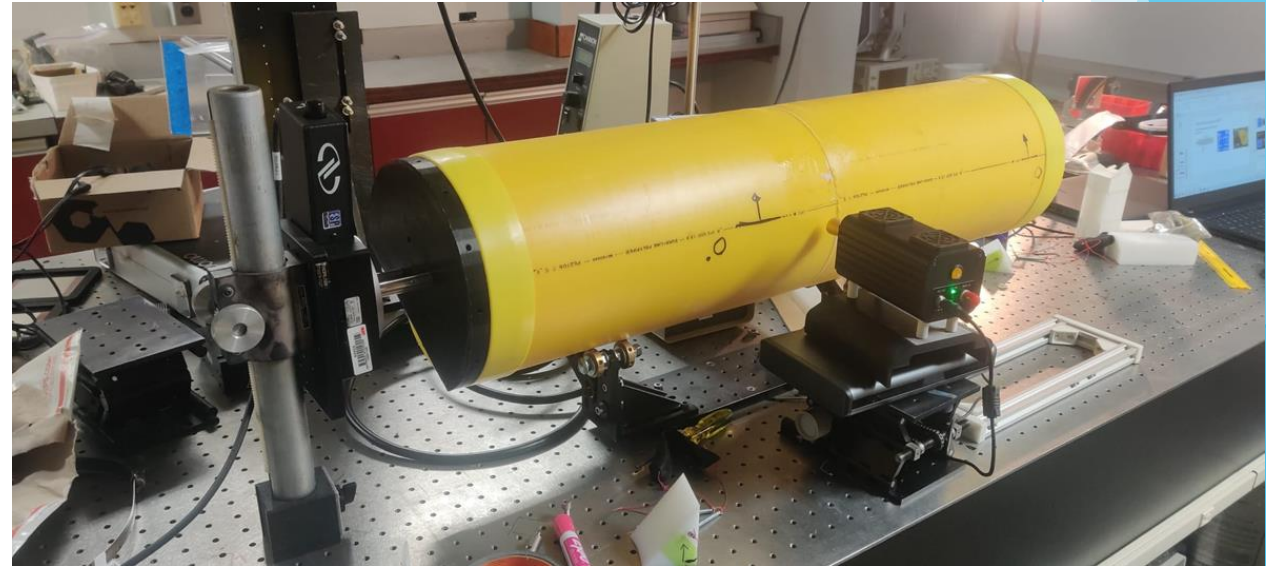
# PAUT Scan Features - Electrofusion Joints

- ▶ Unflawed Joint - spaced uniformly with no indication in fusion zone
- ▶ Sand/Grease Contamination - detectable in fusion zone below coupling wires due to ultrasonic beam reflection or diffraction from contamination particles
- ▶ Improper Joint Preparation - major deviation in wires position





# Terahertz (THz) Technology





# Terahertz (THz) NDE of PE BF Joints

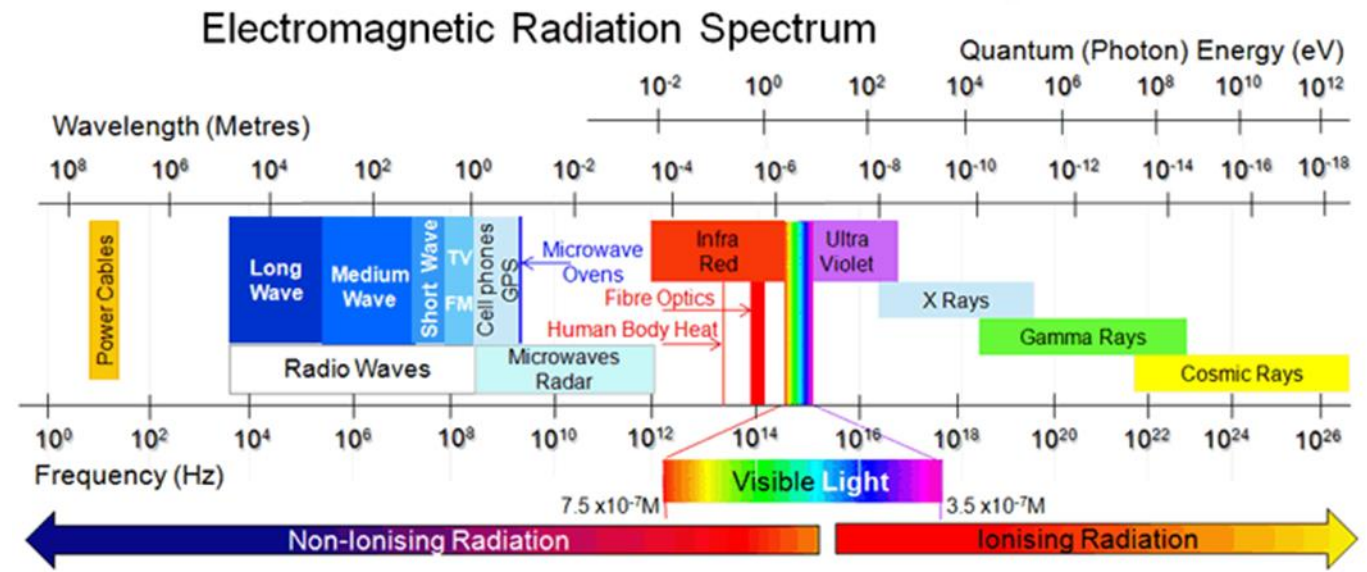
- ▶ In 2018, NYSEARCH initiated THz feasibility testing with Iowa State University and transitioned development in recent years to a team of light refraction experts at New Jersey Institute of Technology (NJIT).
- ▶ Late last year, NJIT purchased a miniaturized THz power source and camera equipment to perform testing on existing PE BF samples with embedded defects.
- ▶ Testing camera capabilities and designing enhancements for optimal clarity proved to be a challenge.



# How does Terahertz (THz) Testing Work?

- ▶ THz radiation falls between microwave and infrared regions of the electromagnetic spectrum (approximately 0.1 to 10 THz) for non-destructive analysis of materials and structures.
- ▶ This safe non-ionising type of testing is used in materials science, electronics, biology, and security processes.
- ▶ THz works by emitting terahertz radiation (illumination) at a material and analyzing how the material interacts.

**Ionising** = process where a molecule acquires positive or negative charge by gaining or losing electrons

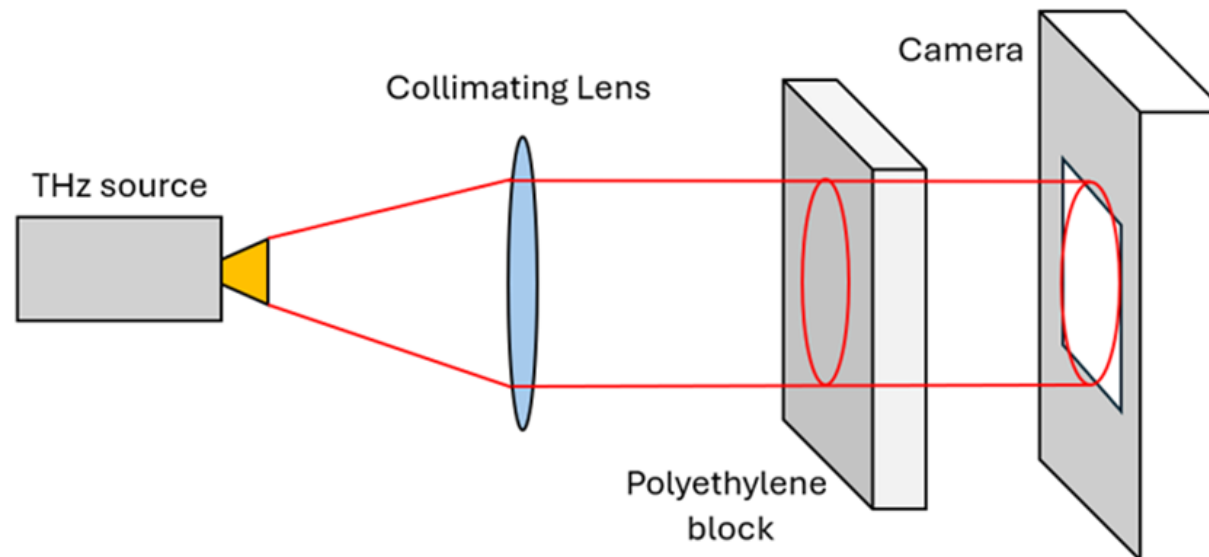


# TeraSense Power Source, THz Camera + Equipment Setup



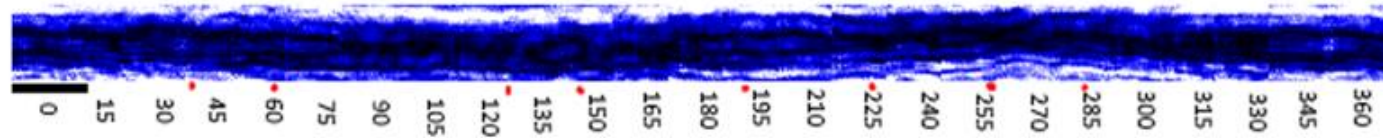
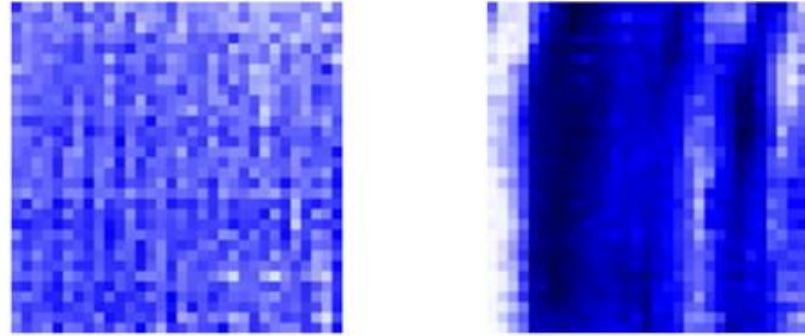
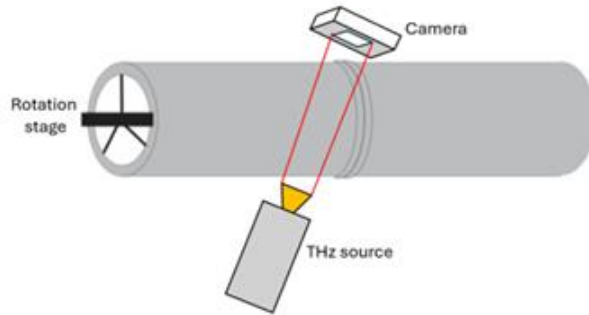
Terahertz camera  
**Tera-1024**

- 1024 pixels (32 x 32 array)
- 1.5 mm pixel pitch
- NEP =  $1 \text{ nW}/\sqrt{\text{Hz}}$
- 11.6 cm x 11.6 cm x 4.5 cm device size

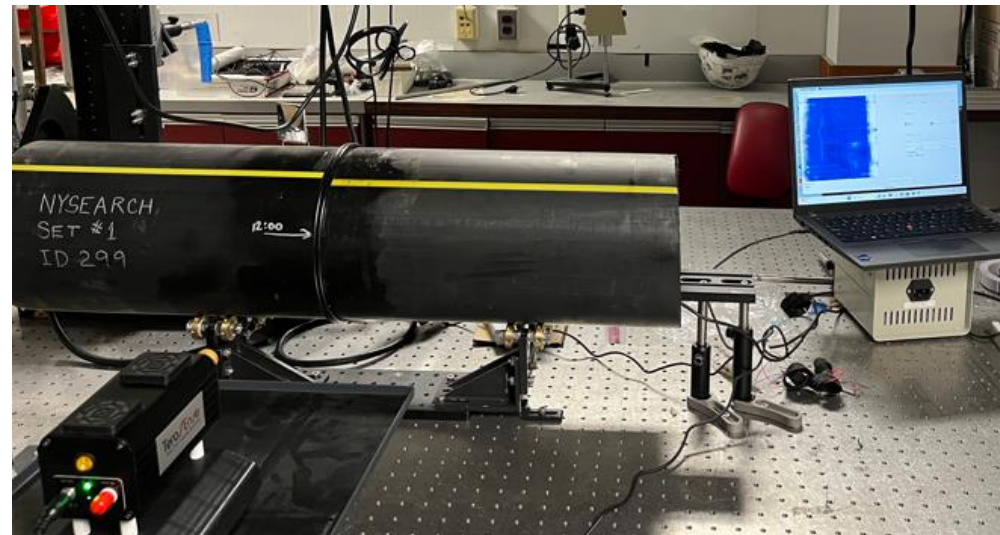


# THz Testing of PE Butt Fusion Joint

- Imaging of pipe joint



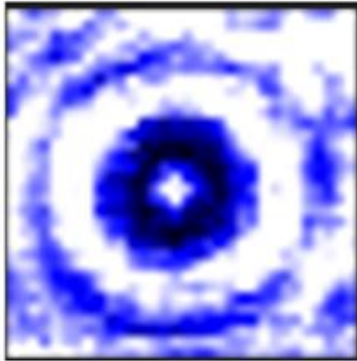
Reconstruct image of full joint



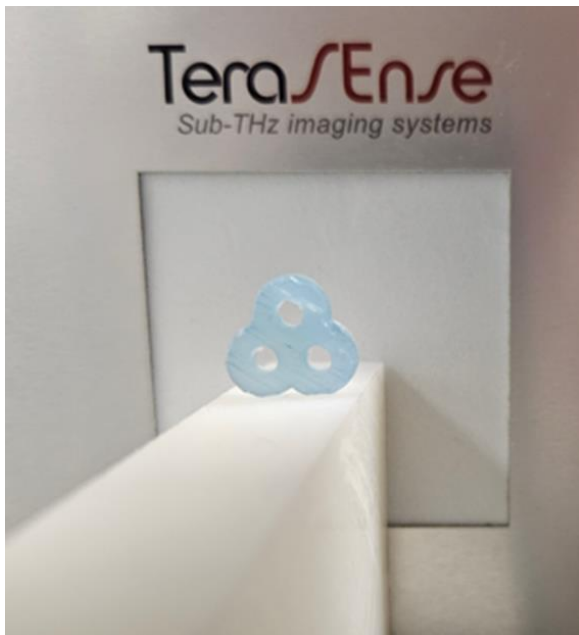
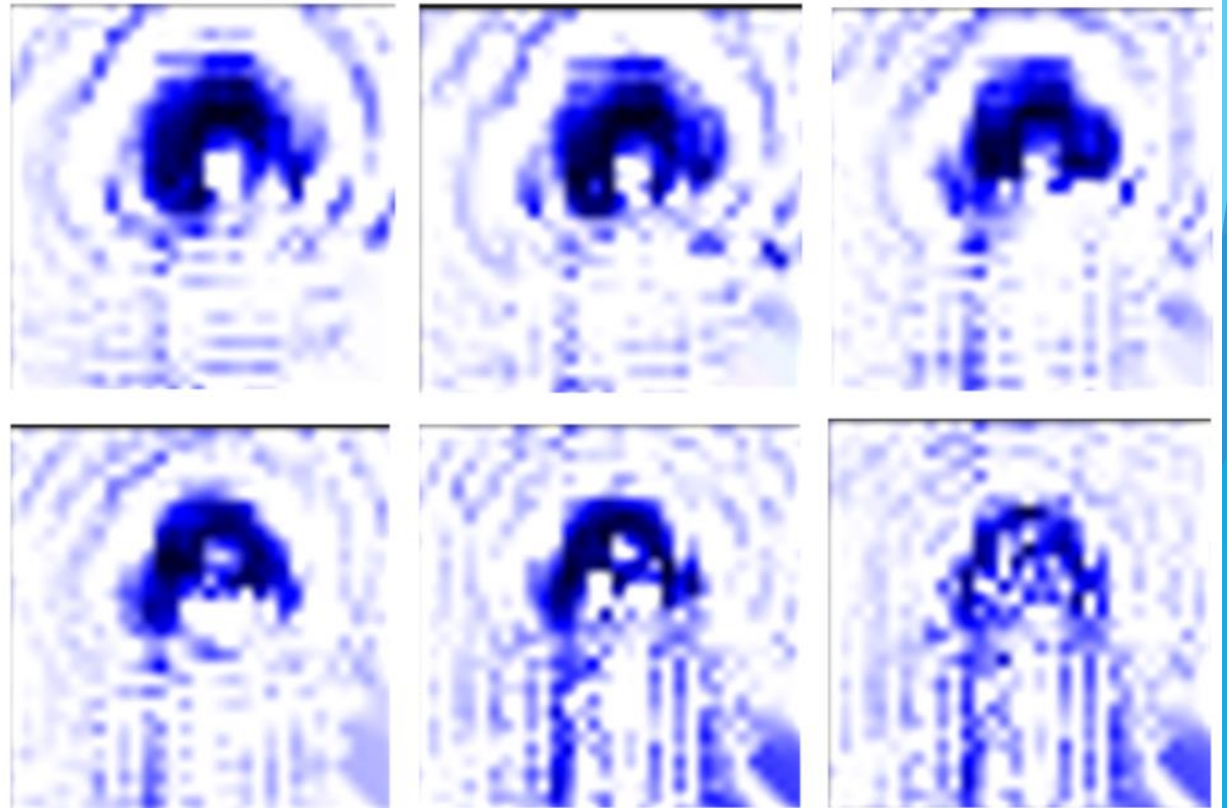


# THz Testing of Objects + Defects in PE Block

8mm diameter drill hole 5mm deep in HDPE



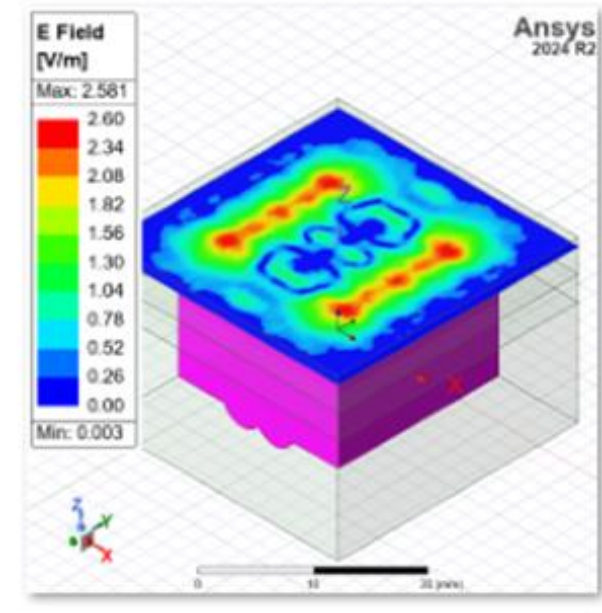
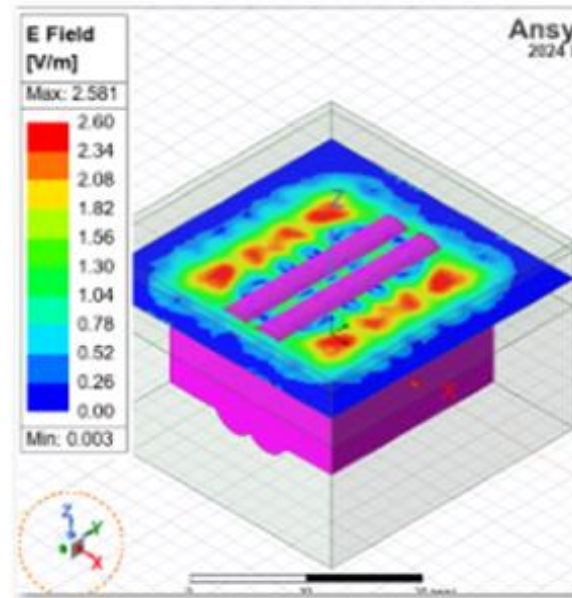
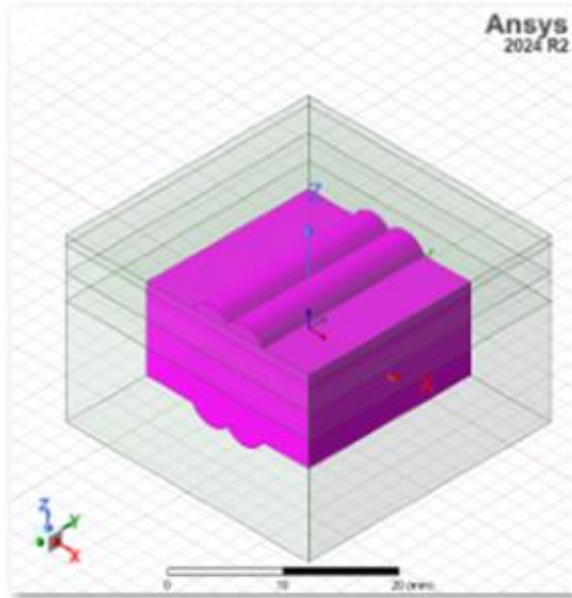
Notice how the block warps the pattern as distance from target changes!





# Techniques to Improve THz Imaging

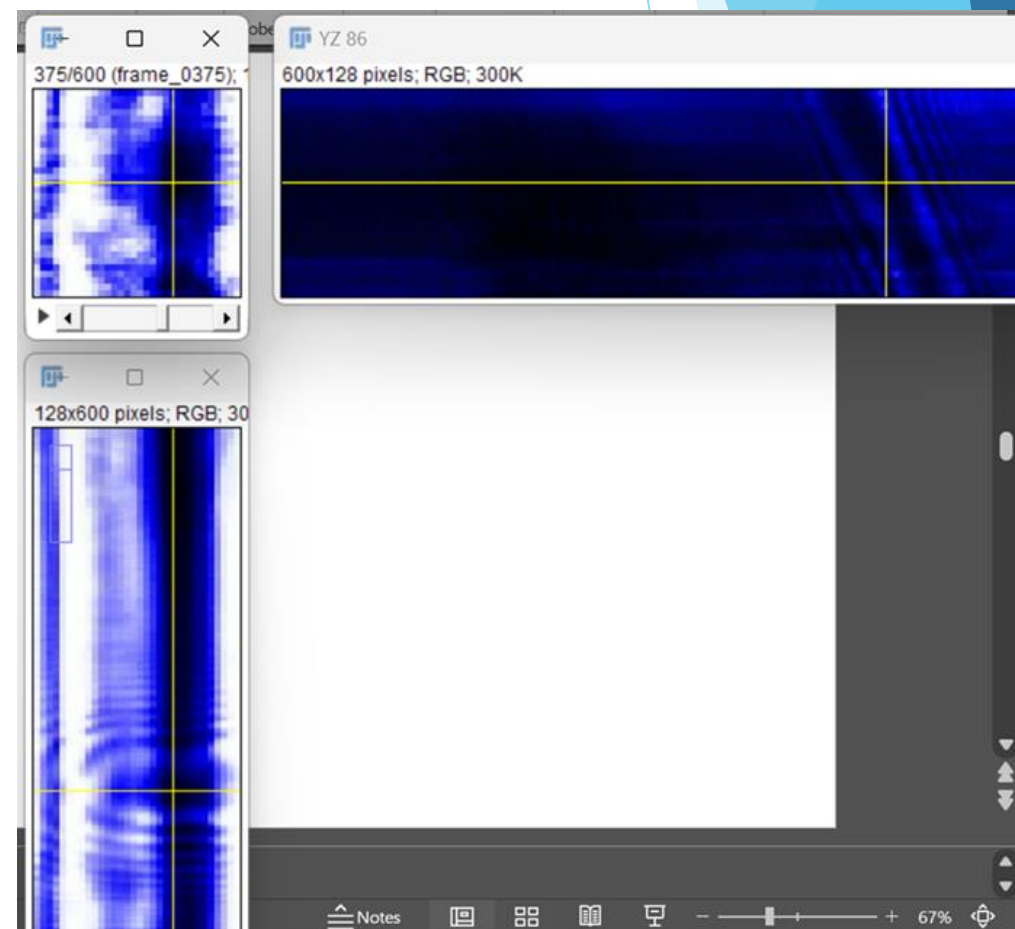
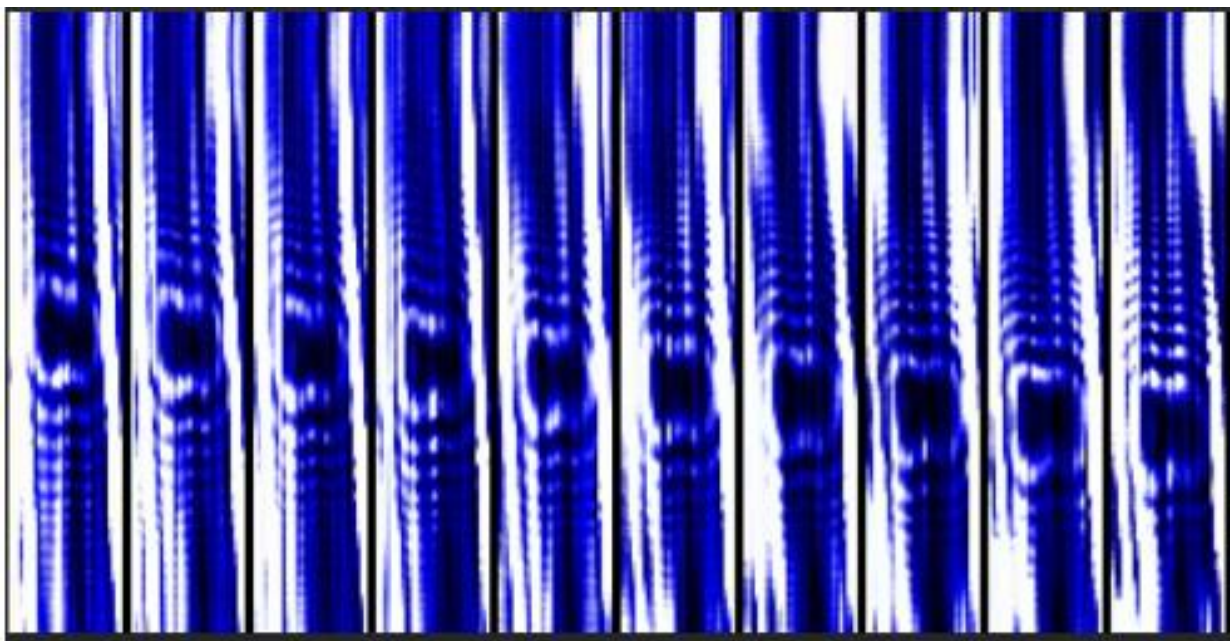
## Ansys 3D THz Model Software - Electronic Imaging



- NJIT light refraction experts were able to use Ansys 3D THz modeling software + videotape to analyze PE blocks and pipes containing anomalies.

# Techniques to Improve THz Imaging

- NJIT found that defects became more detectable when videos were slowed down to display one frame at a time.
- This enabled operators to detect grease contamination more clearly in a PE BF pipe sample.



# Next steps for THz NDE Development

- ▶ Improve experimental setup and automate data collection.
- ▶ Explore alternative data reduction schemes.
- ▶ Build better models to guide experiments and expectations.
- ▶ Develop AI approaches + pre-commercialization with Acuren (Eclipse-Scientific).
- ▶ Obtain upgraded THz camera with higher frequency for further testing.



# The Future is Bright!

- **New NDE Technologies are advancing very quickly toward implementation!**





# Thank You NYSEARCH Funders!





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