nXis - Well Integrity Inspection in Unconventional Gas Wells

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Matthias Kasten, Ph.D.
General Electric Company

U.S. Department of Energy
National Energy Technology Laboratory
Mastering the Subsurface Through Technology, Innovation and Collaboration:
Carbon Storage and Oil and Natural Gas Technologies Review Meeting
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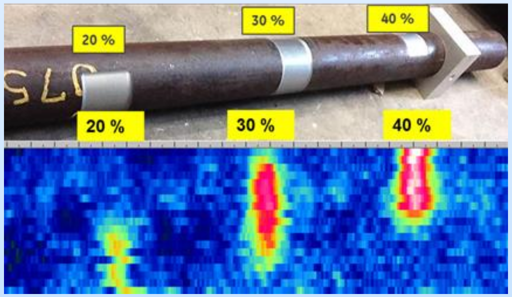
Presentation Outline

- Project Goals & Objectives
- Technical Status
  - Neutron Modality
  - X(γ)-Ray Modality
  - Ultrasound Modality
  - Electromagnetic Modality
  - Multi-Modality Data Fusion
  - Test Pit Testing



- Accomplishments to Date
- Summary

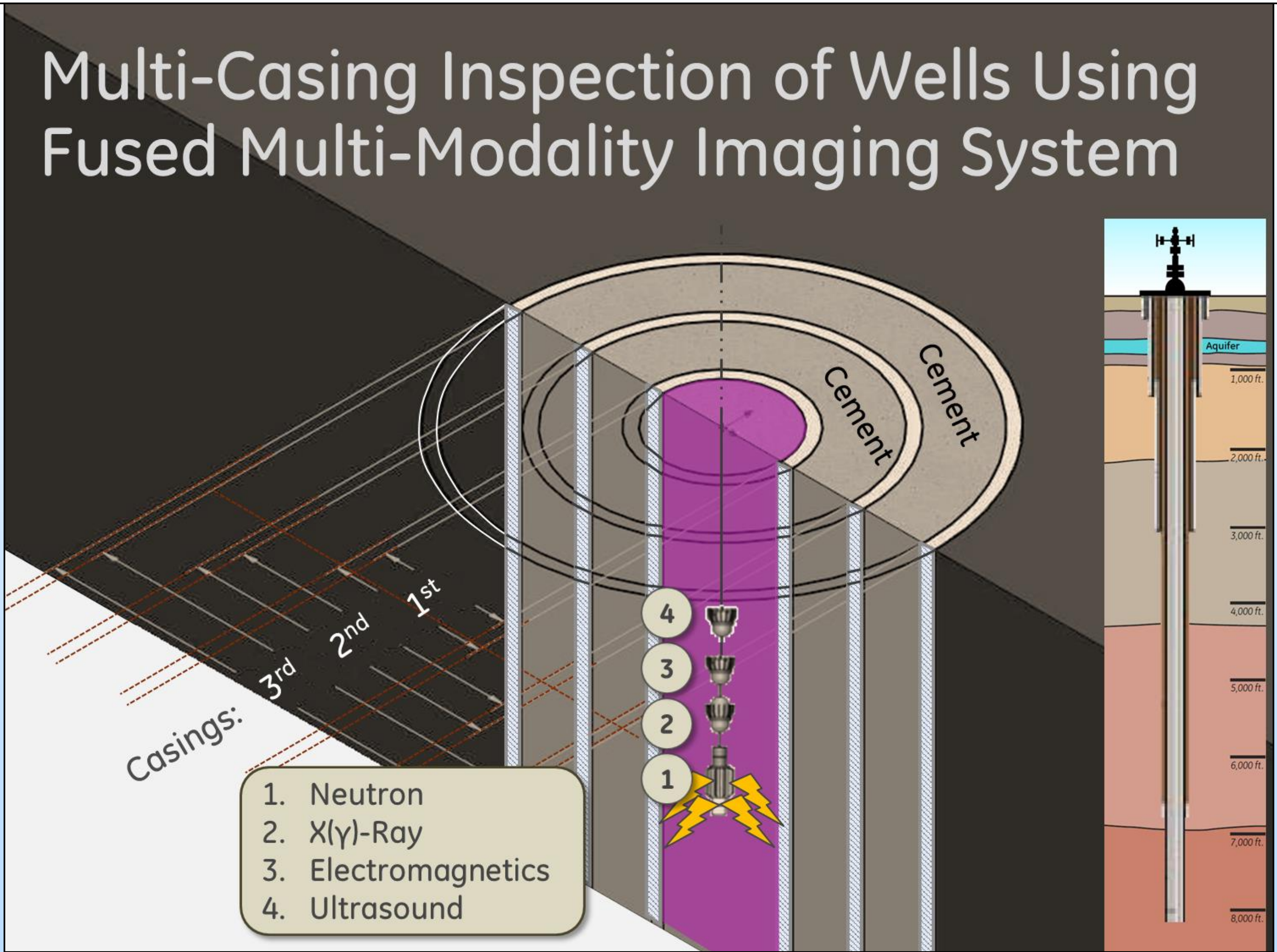
Benefit to the Program

- Well integrity inspection for multi-casing gas wells to enhance safety and environmental protection.
- Dual-particle imaging technique using neutron and X(γ)-ray backscatter.
- The research project is developing a new dual-particle imaging technique, combining neutron and X(γ)-ray modalities, and algorithmically fusing this data with information obtained from electromagnetic imaging to obtain results which are intrinsically more accurate than the simple union of individual modality results.

Project Overview:
Goals and Objectives

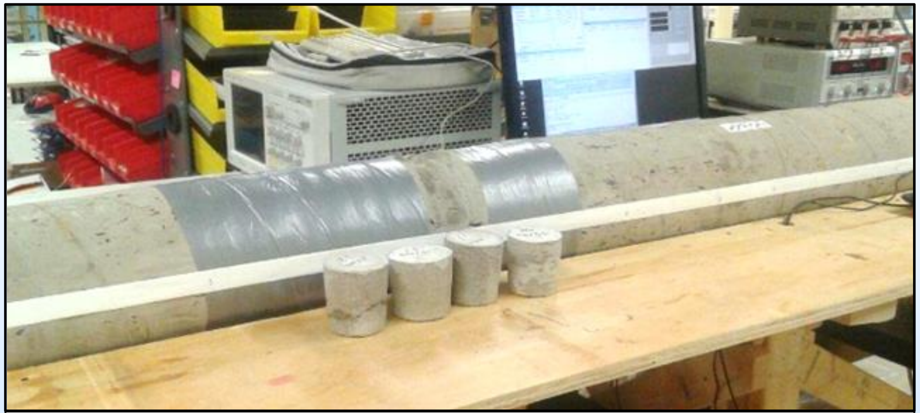
- Measuring the integrity of multiple well casings and cement annuli at intermediate-to-surface depths along major ground water zones.
- Current imaging technologies cannot resolve multiple annuli in the intermediate zone above 10,000 ft. where there are 2 to 5 stacked casing/cement rings.
- Ultrasound-based techniques do not operate reliably in gas filled wellbores.
- Electromagnetic tools are sensitive only to damages in metallic structures. Internal pipe strings magnetically shield external pipes to significantly reduce sensitivity.

Project Overview:
Goals and Objectives

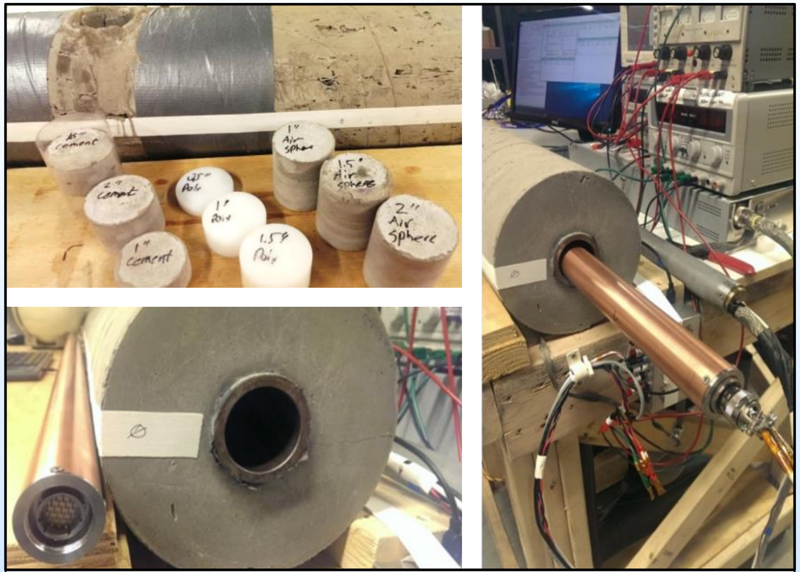


Technical Status

Neutron Modality

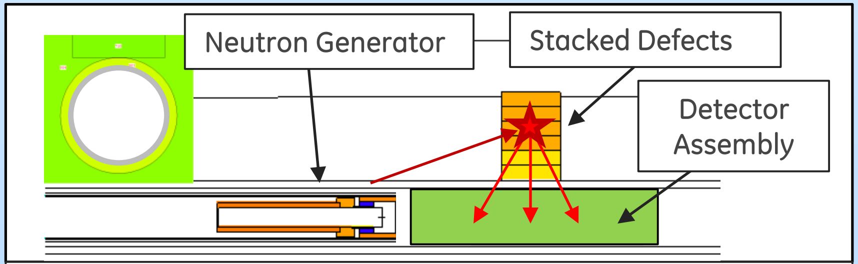


Neutron Backscatter Experimental Setup



Photographs of integrated neutron generator prototype system (1-11/16" form factor).

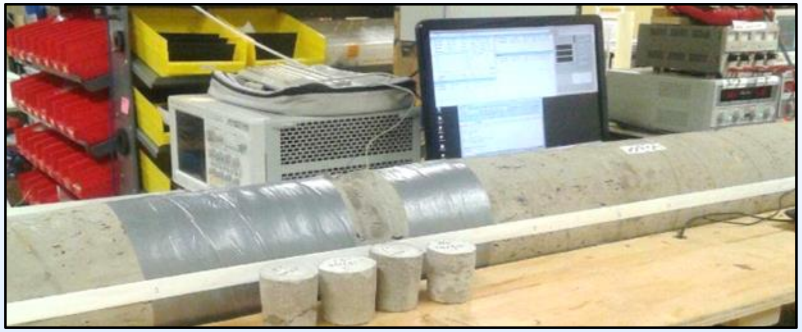
Neutron Detector Assembly



MCNP simulation input showing neutron generator, defects, and detector assembly.

Technical Status

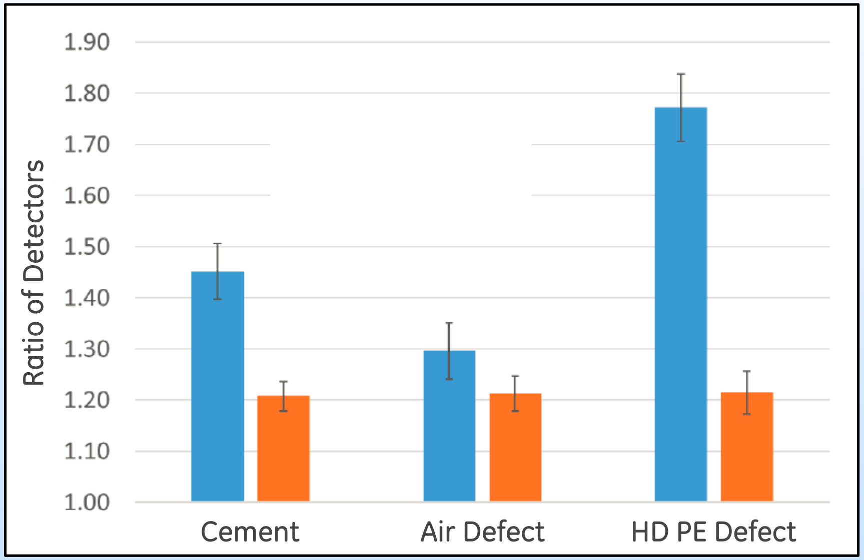
Neutron Modality



Phantom with 3”×2.5” diameter defects: cement (no defect), air void, and HD PE.

Detection Results:

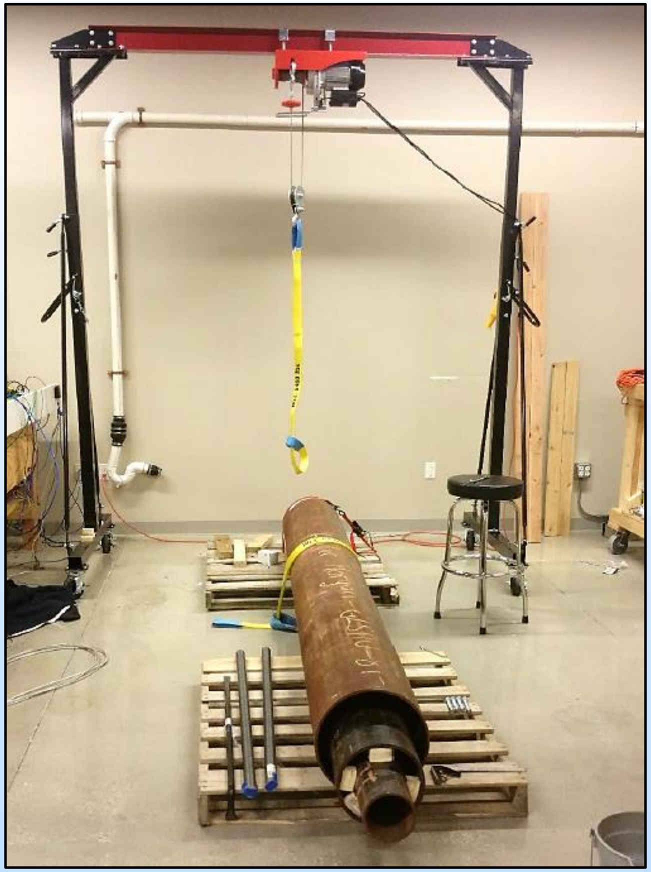
- Clear distinction between cement (no defect), air void, and high-density polyethylene (HD PE) for 3” by 2.5” size defect.
- Azimuthal defect detection.

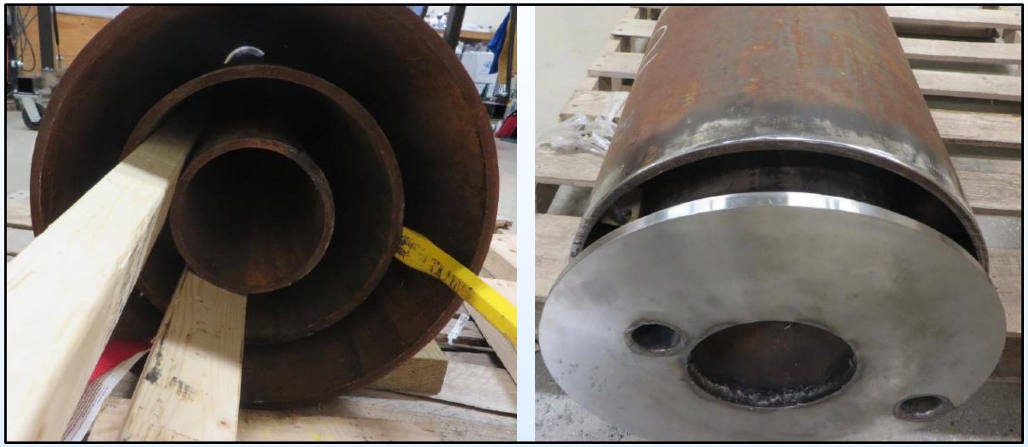


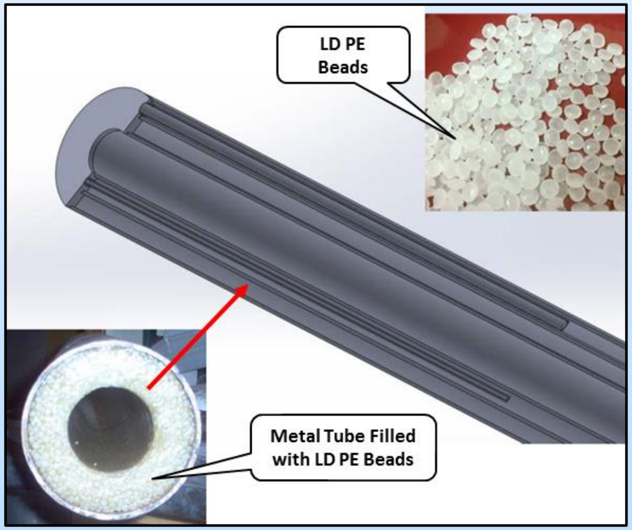
Experimental Data

Technical Status

Neutron Modality







Multi-Annulus Experimental Setup

Technical Status

X(γ)-Ray Modality

Monte Carlo N-Particle (MCNP) Simulation:

Definition of Detectability:

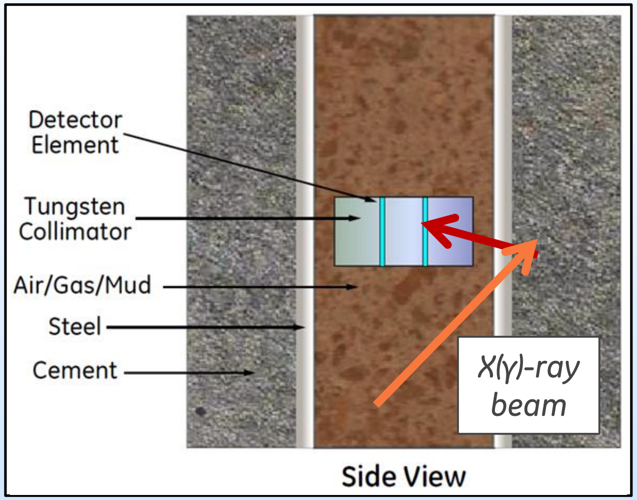
A defect is deemed detectable if the threshold metric of 2σ is met (95% confidence).

Defect:

Air void defects with various diameters (e.g. ⅛")

Source:

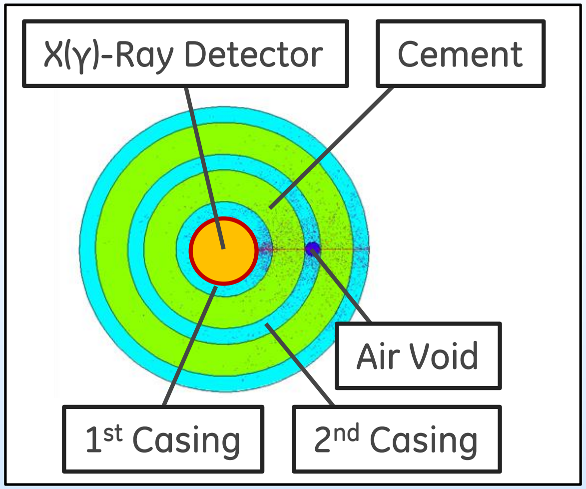
X(γ)-Ray source

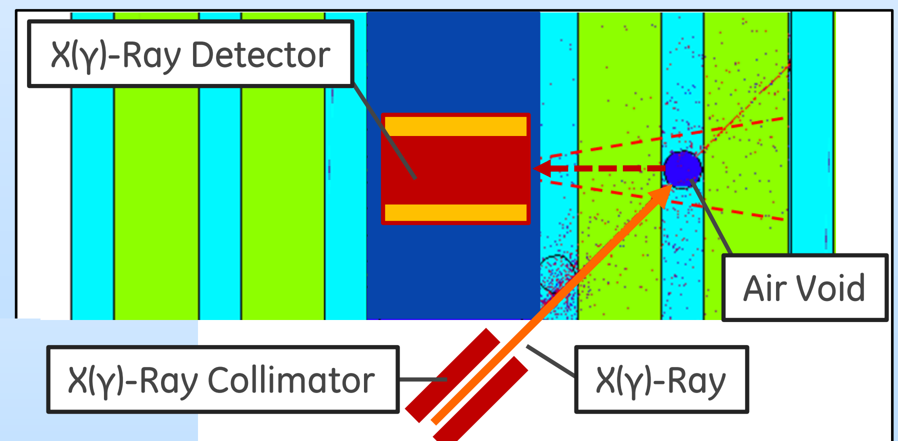


Top and side view of detector internal configuration

Technical Status

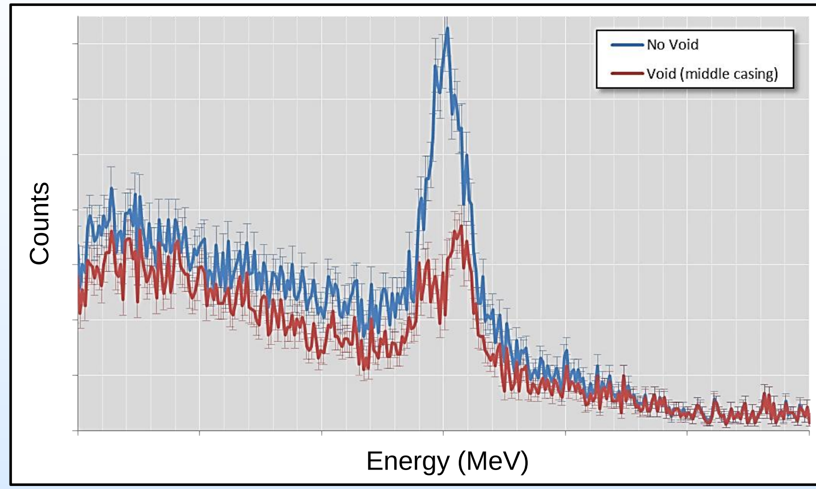
X(γ)-Ray Modality

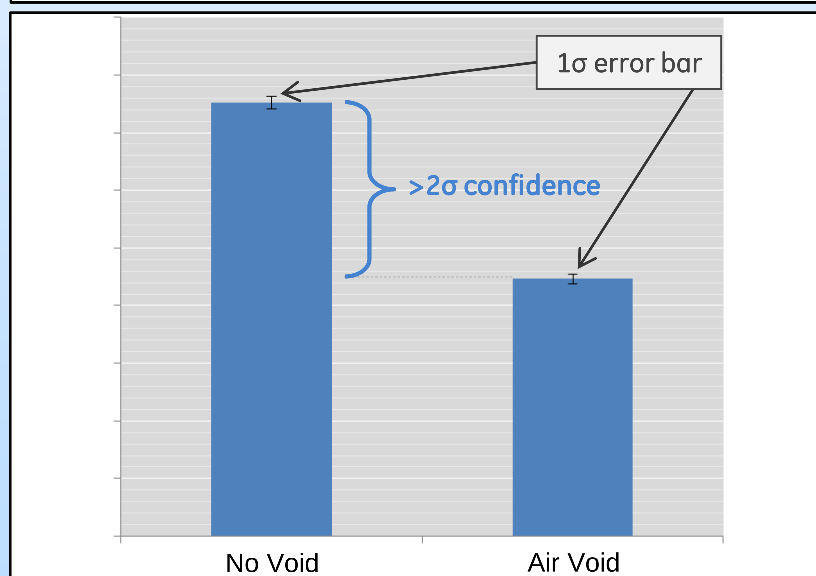




Top & side view of detector configuration

MCNP: Air Void Detection in 2nd Casing

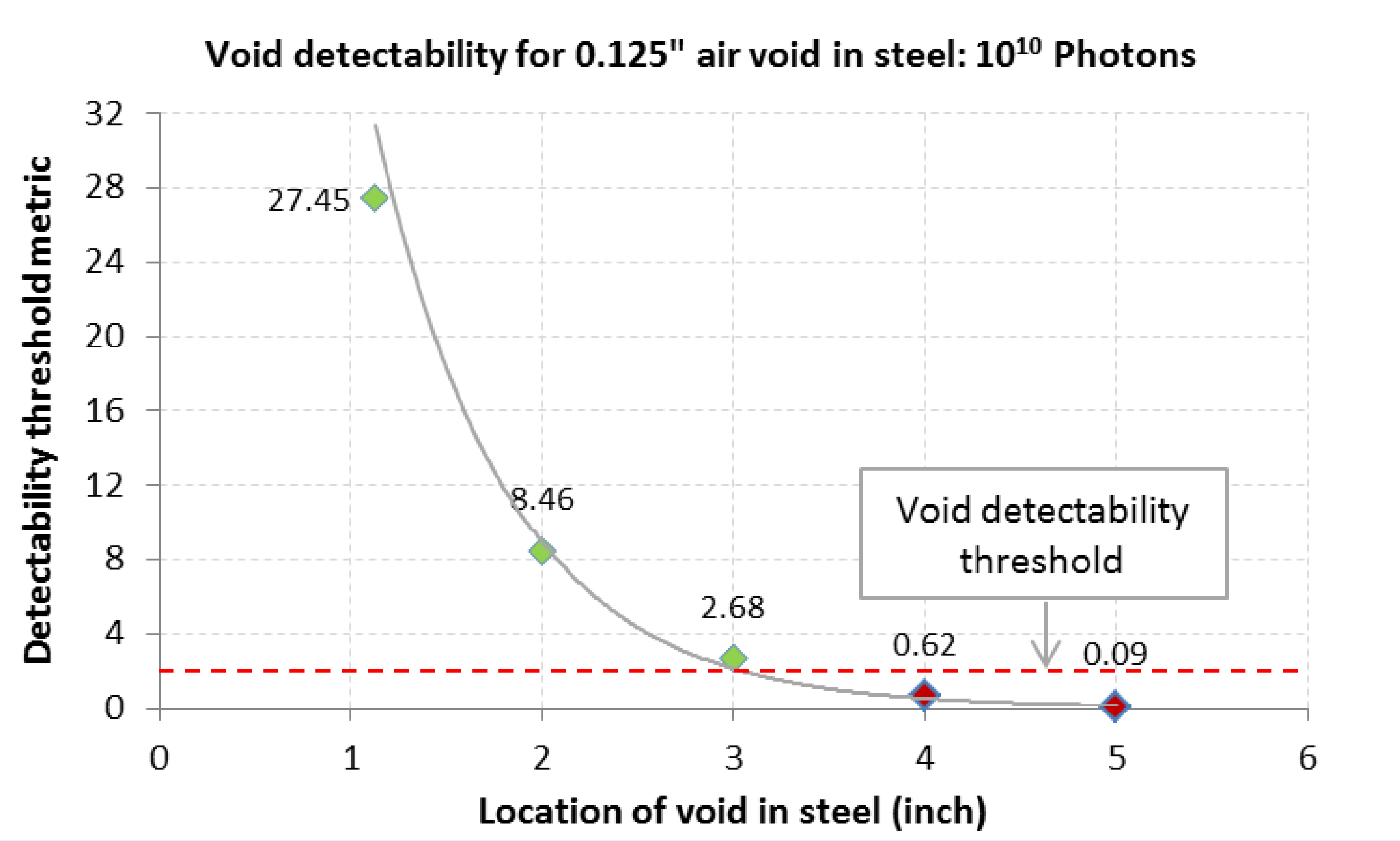




Technical Status

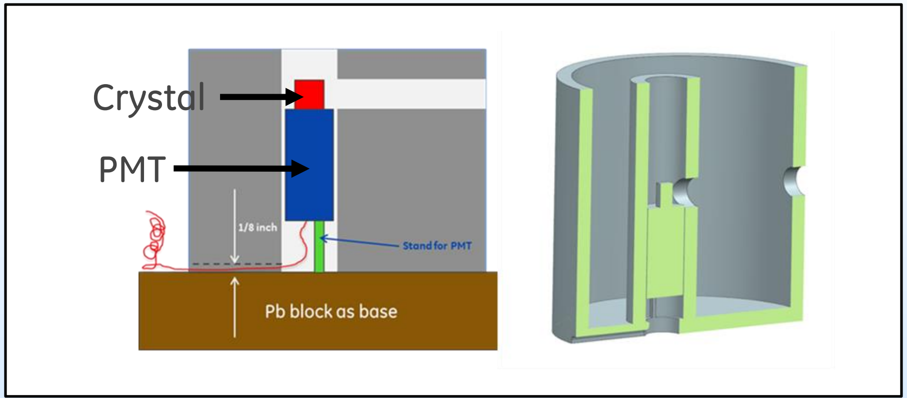
X(γ)-Ray Modality

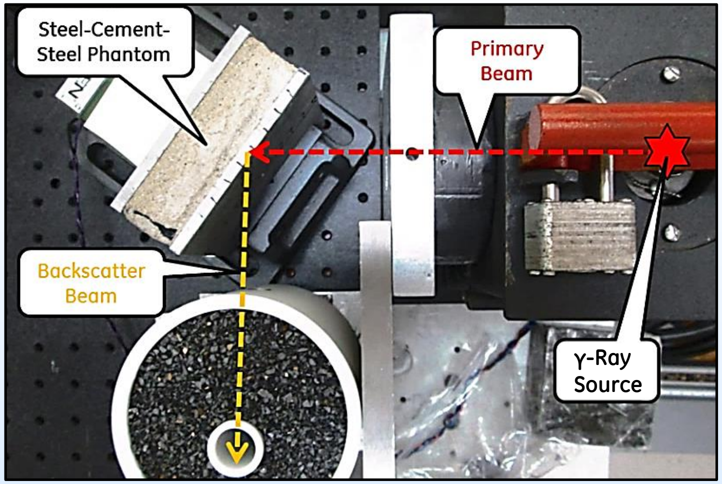
MCNP Simulations: Air Void Detection in 2nd Casing



Technical Status

X(γ)-Ray Modality

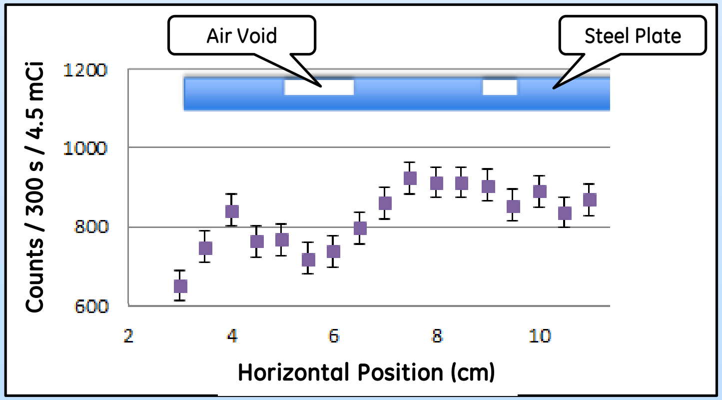




Photograph of ¼" through hole steel-cement-steel void detection experiment.

Detection Results:

- Detection of ⅛" air void in 2nd metal casing and cement annulus (from MCNP simulations).
- Defect detectability up to 3.5" past first casing (from MCNP simulations).
- Azimuthal defect detection.

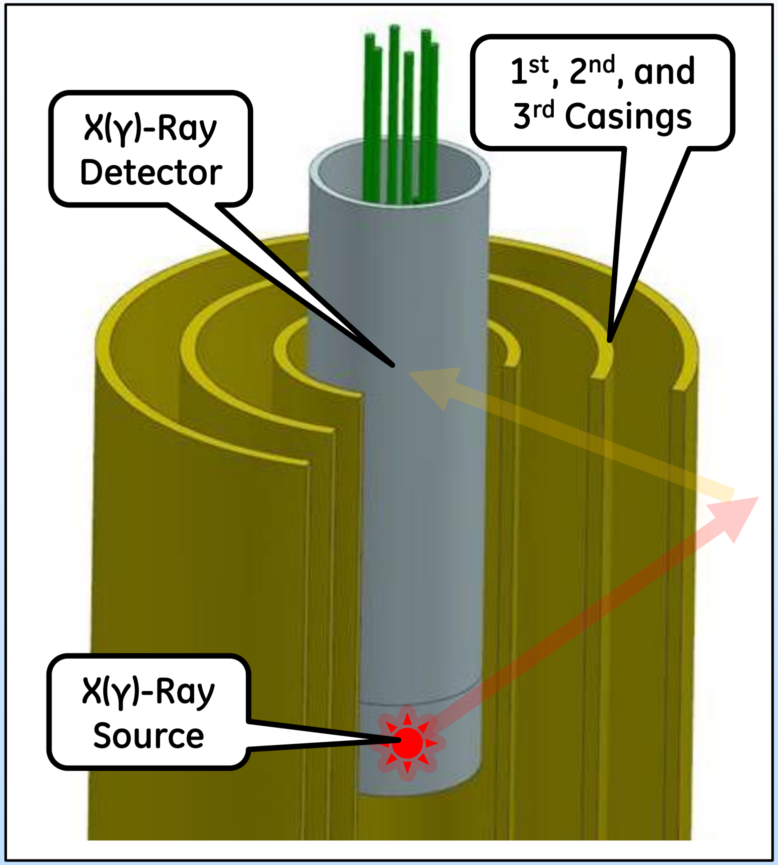


Backscatter rate vs. defect position for ½" and ¼" blind hole (3mm depth, 50%).

Technical Status

X(γ)-Ray Modality

Multi-Annulus Experimental Lab Setup

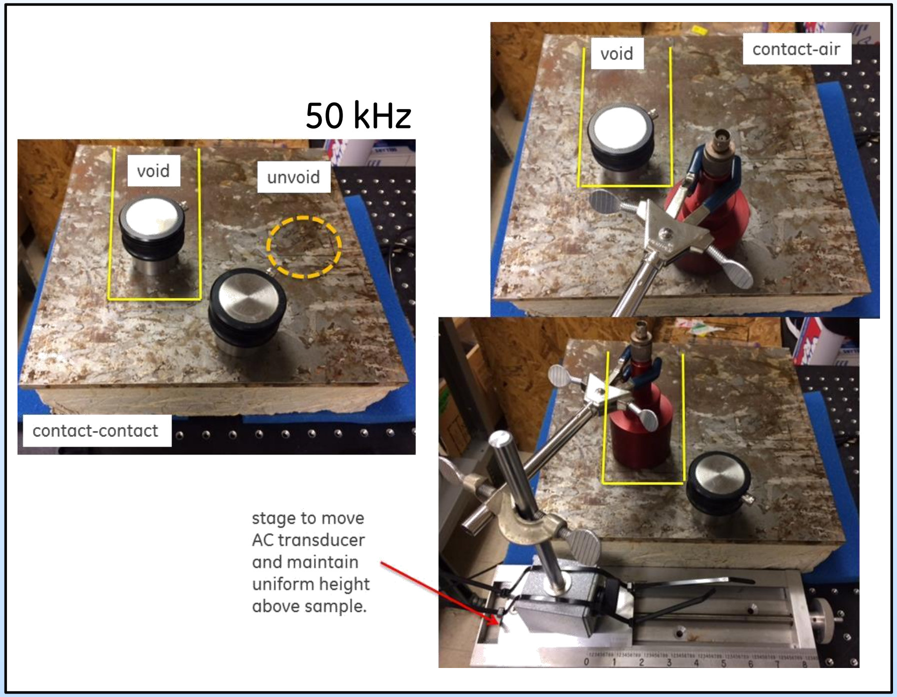


Multi-Annulus X(γ)-Ray Detector

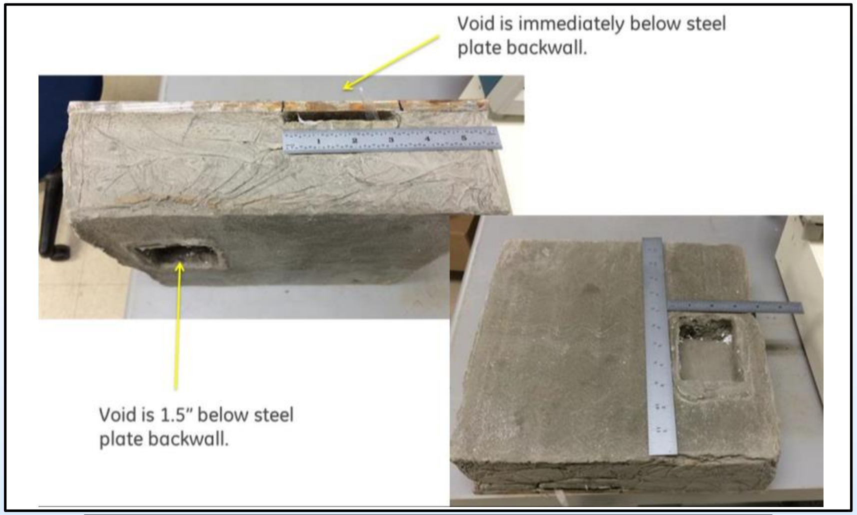
Technical Status

Ultrasound Modality

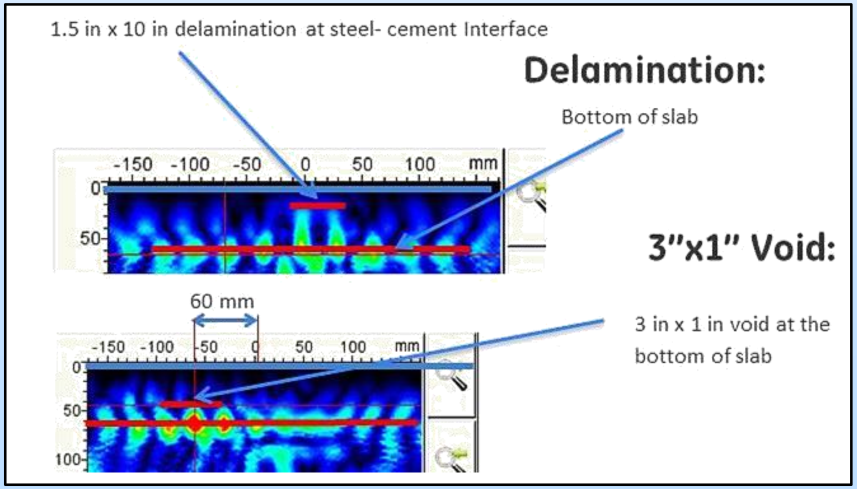
Low Frequency Air-Contact Experiments



"Pitch-Catch" experimental setup



Concrete phantom with air void defects

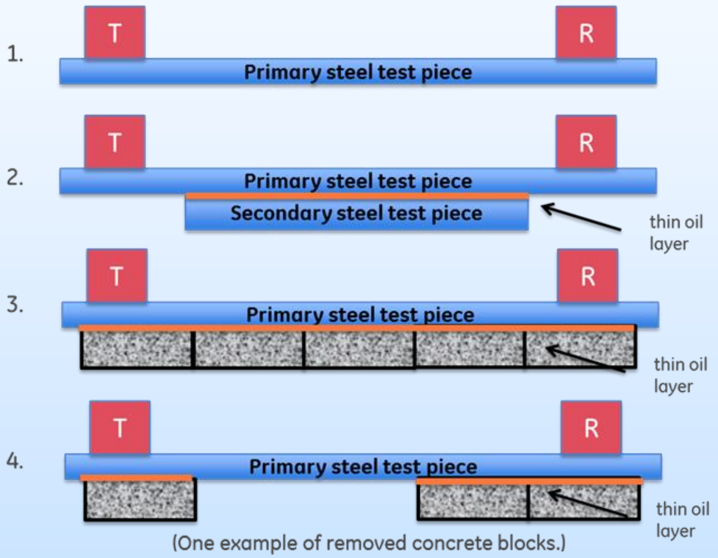


Detection of air void defects in concrete

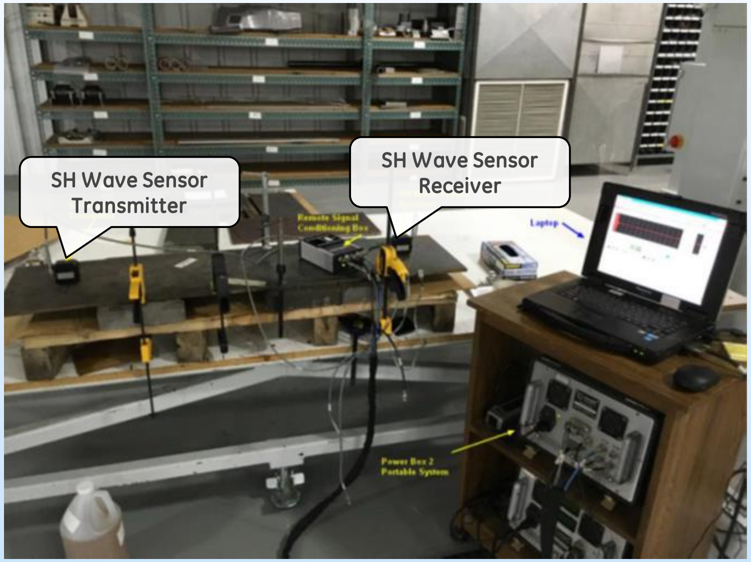
Technical Status

Ultrasound Modality

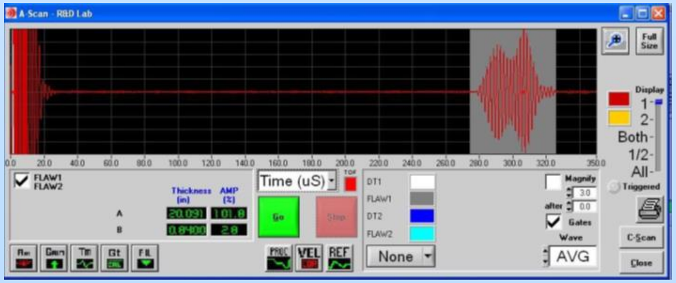
Electro Magnetic Acoustic Transducer (EMAT) Testing



Various test setups used for EMAT evaluation



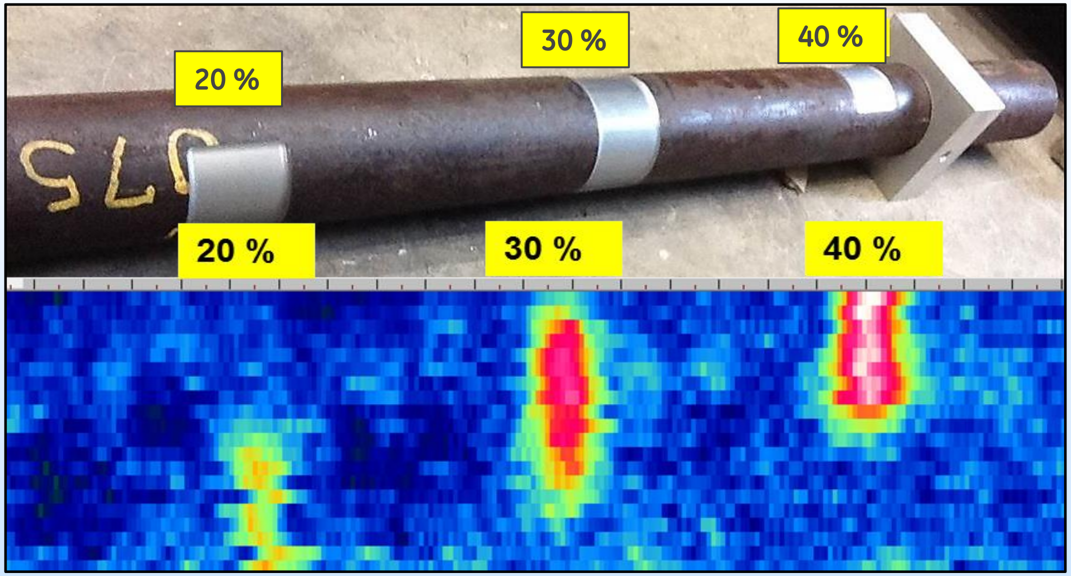
Photograph of laboratory setup



Small signal variations for SH wave experiment!

Technical Status

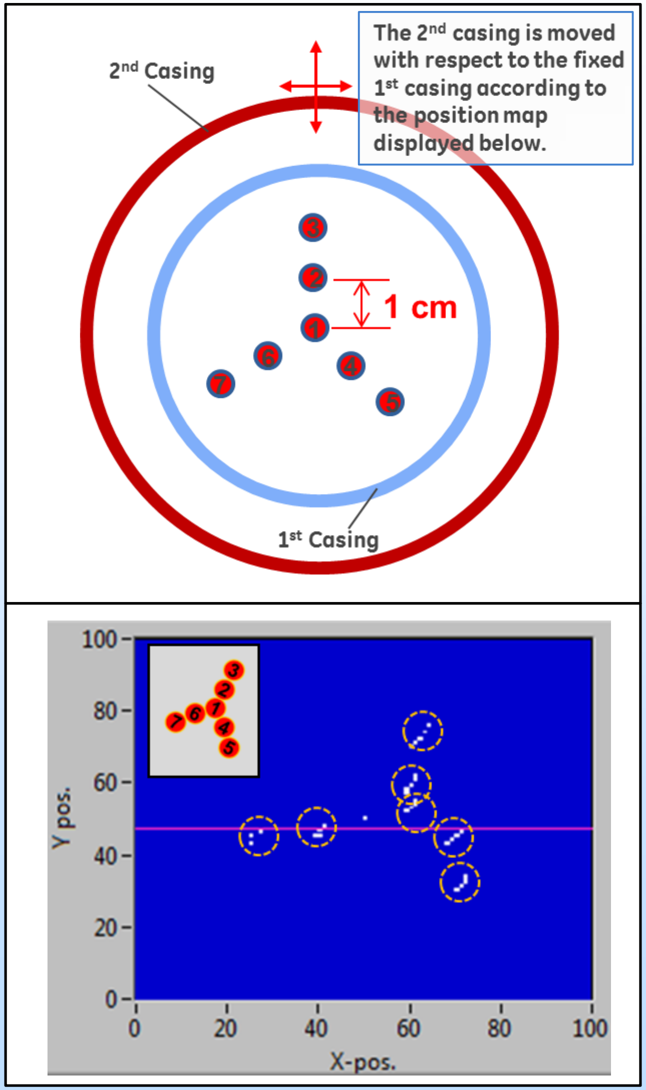
Electromagnetic Modality



Production tube inspection with a 1.5" transceiver probe. External area material losses of 20%, 30%, and 40%.

Detection Results:

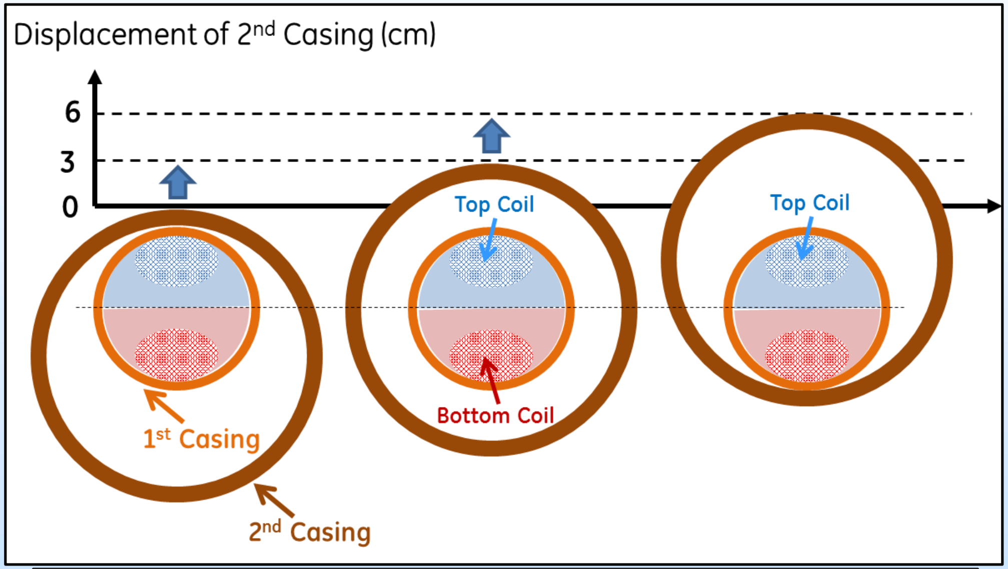
- Defect detectability (material loss) in 1st casing.
- Eccentricity detectability between 1st and 2nd casing.
- Azimuthal defect detection.



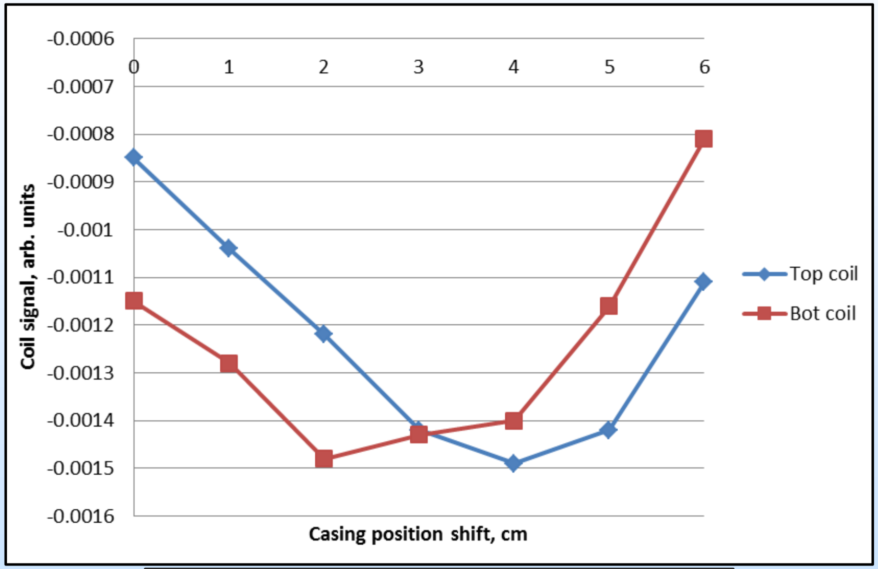
Casing Eccentricity Measurements

Technical Status

Electromagnetic Modality



Eccentricity measurements between 1st and 2nd casing

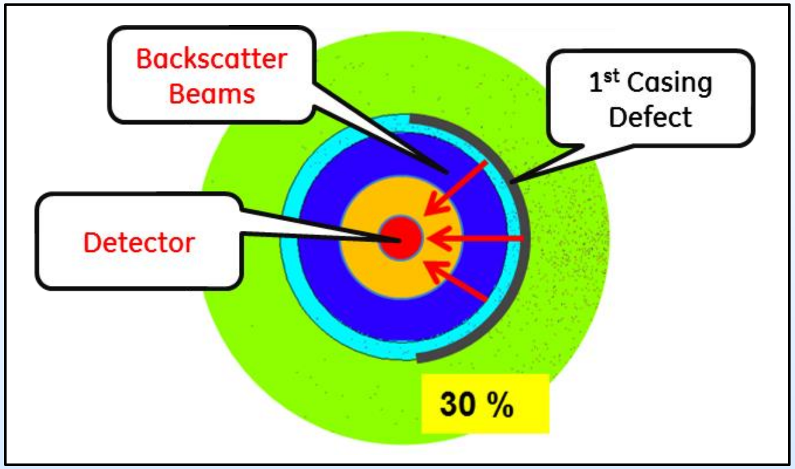


Signal response for two coils

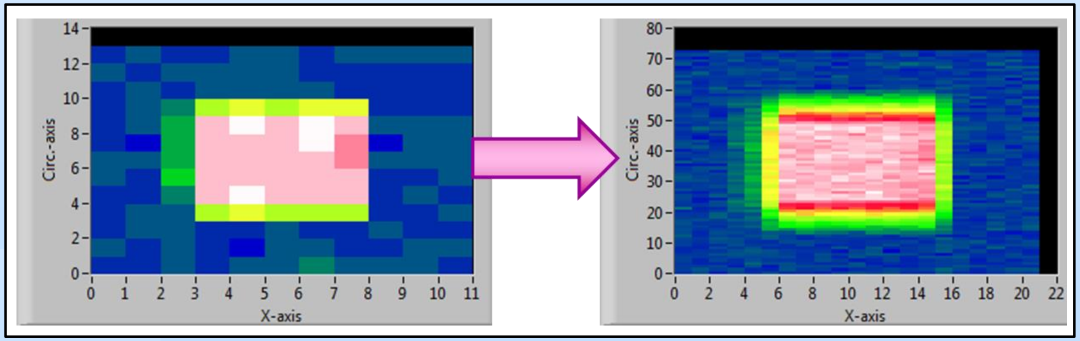
Signals from multiple coils allow for unique identification of the pipe position/eccentricity.

Technical Status

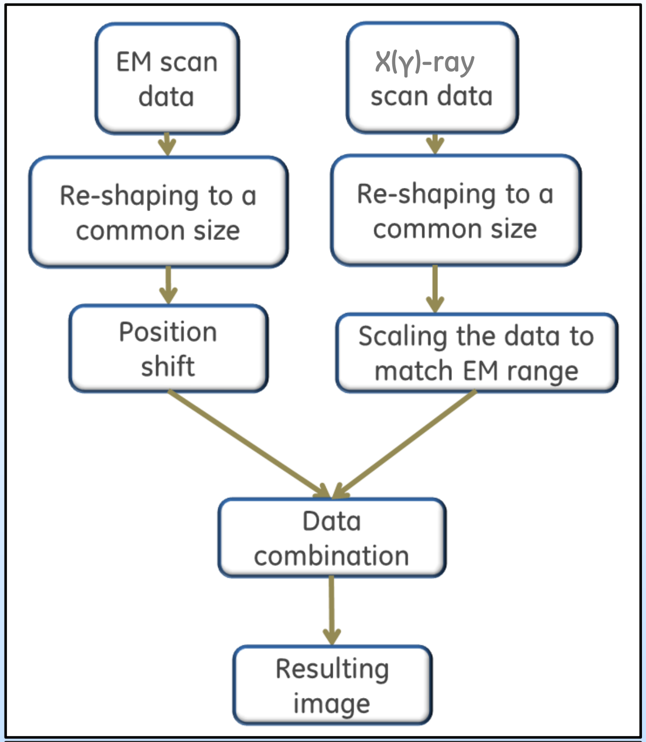
Multi-Modality Data Fusion



Simulated material defect for X(γ)-ray data



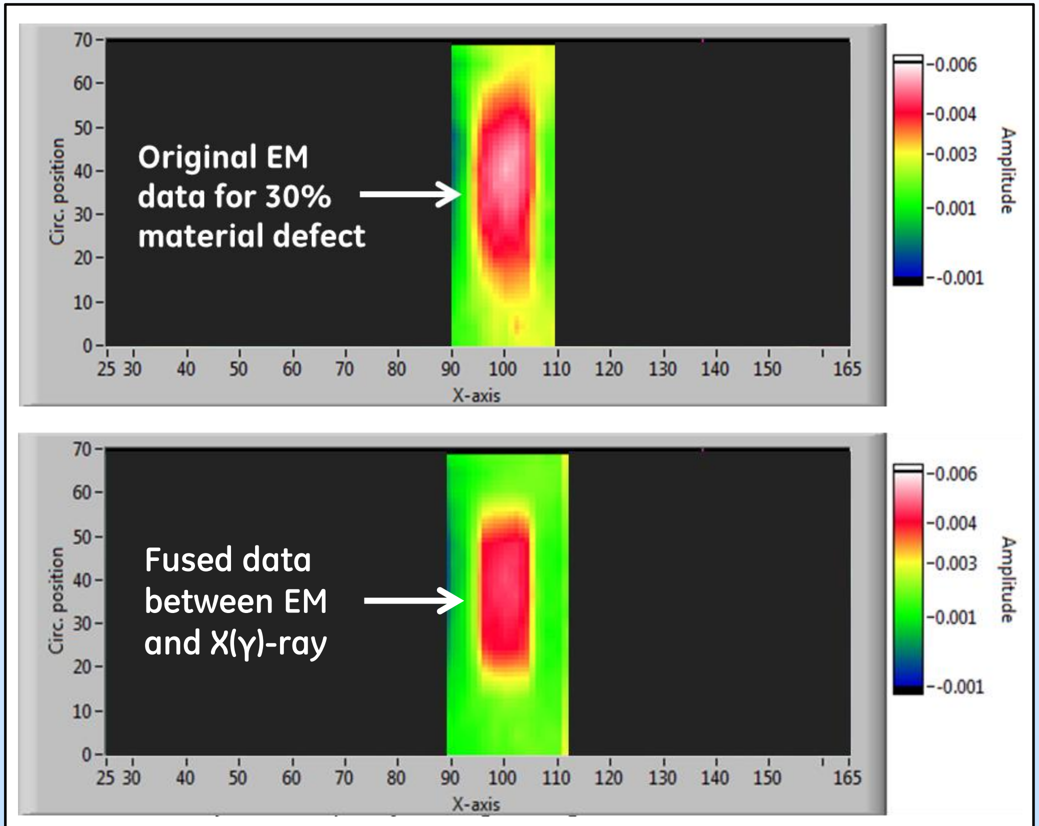
Reshaping of simulated X(γ)-ray image to match electromagnetic defect image



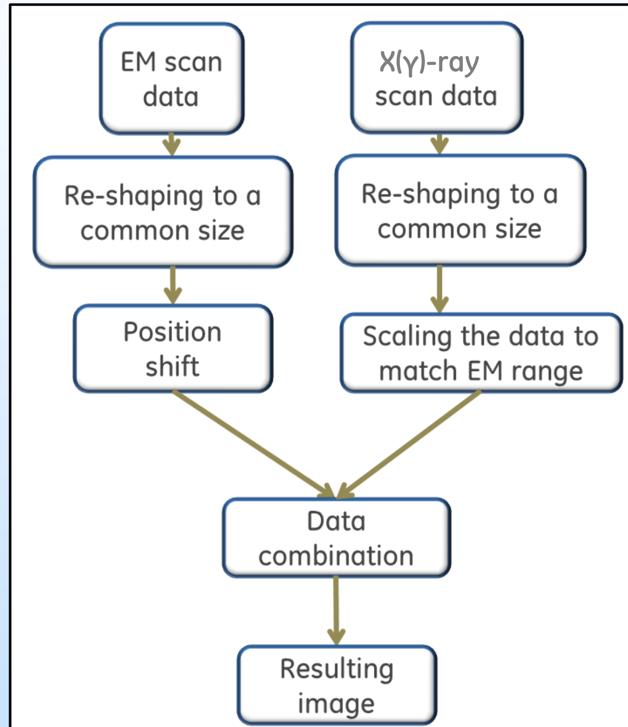
Block diagram of multi-modality data fusion approach

Technical Status

Multi-Modality Data Fusion



Experimental EM image (top) and fused data image between EM and X(γ)-ray (bottom)



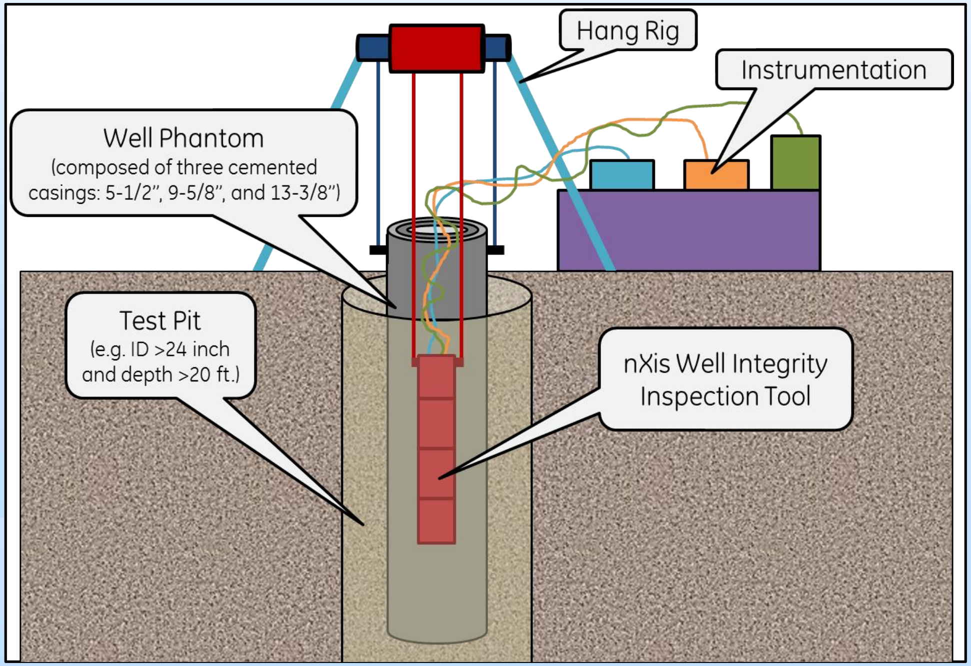
Block diagram of multi-modality data fusion approach

Technical Status

Test Pit Testing

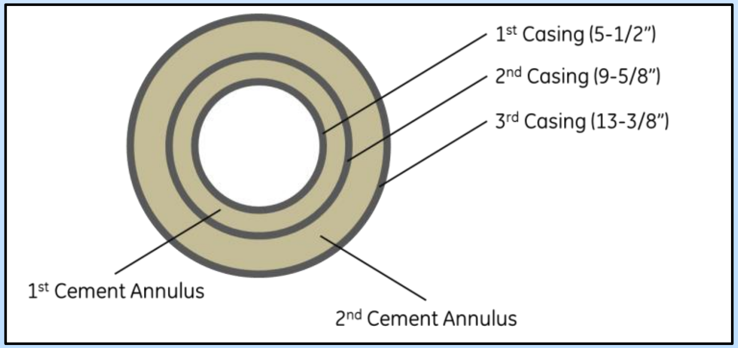
Test Plan:

- Testing of neutron, X(γ)-ray, and EM modality in vertical test pit
- Using multi-casing well phantom with engineered defects
- Performance characterization for each modality
- Data fusion between modalities



Schematic Sketch of Test Pit Setup

GE Oil & Gas Test Facility



Multi-Casing Well Phantom

Accomplishments to Date

- Established capabilities of high-energy modalities (neutron and X(γ)-ray backscatter based detection) through Monte Carlo N-Particle (MCNP) simulations.
- Built high- and low energy modality prototypes and performed experiments in laboratory environment.
- Conducted data analysis and data fusion between electromagnetic and X(γ)-ray modality.
- Optimized designs for all inspection modalities.

Synergy Opportunities

- Collaboration with DOE projects such as:
  - Integrated Wellbore Integrity Analysis Program for CO_2 Storage Applications - Battelle Memorial Institute
  - Wellbore and Seal Integrity - Los Alamos National Laboratory
  - Improving Science-Base for Wellbore Integrity, Barrier Interface Performance – National Energy Technology Laboratory
- Joint test well preparation with engineered structural flaws in multi-casing/multi cement annuli for field testing and performance evaluation.

Summary

- Key Findings
  - X(γ)-ray modality can detect defects as small ⅛'' in diameter at distance up to 3.5'' past the first casing (through MCNP simulations).
  - Neutron modality provides azimuthal defect resolution between defects such as air voids, cement, or high-density polyethylene.
  - Electromagnetic inspection modality detects material loss in 1^{st} casing and directional eccentricity between 1^{st} and 2^{nd} casing.
  - Data fusion between modalities can enhance detection capabilities.

Summary

- Lessons Learned
  - Low ultrasound frequencies (<65kHz) are required to overcome impedance mismatch between gas filled well and steel casing.

- Future Plans
  - Finalize design optimization, build subsystem prototypes, and perform system calibration in controlled lab environment.
  - Conduct performance analysis of nXis prototypes in vertical test pit (multi-casing wellbore phantom with engineered defects).
  - Perform data analysis & fusion between imaging modalities.

Acknowledgement

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Appendix

Organization Chart

Technical Review Team

GE Global Research

Jim LeBlanc, Technology Ldr.
Loucas Tsakalakos, Lab Manager

GE Oil & Gas

Mike Wells, Strategic COE Ldr.
Guy Mason, Engineering Manager
Taylor Shinn, Innovation Adoption Ldr.

Principal Investigator

Dr. Matthias Kasten

GE Global Research

NDE X(γ)-Ray & Neutron Detection/Imaging
Electromagnetic/Ultrasound System Integration

Dr. Helene Climent
X-Ray Photonics

Dr. Scott Price
X-Ray Sources/Imaging

Dr. Frederick Wheeler
Data Fusion

Dr. Adrian Ivan
Detector Physics

Dr. William Ross
NDE/X-Ray, γ-Ray

Edward J. Nieters
NDE/Ultrasound

Dr. Yuri Plotnikov
NDE/Eddy Current

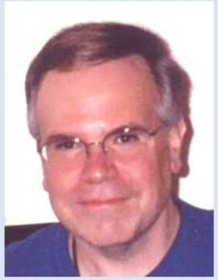
Dr. Sergei Dolinsky
Detector Physics

starfire industries

Neutron Generator Design

Brian E. Jurczyk

GE Project Team


Bill Ross


Scott Price


Helene Climent

X(γ)-Ray Team


Fred Wheeler

Data Analysis/Fusion


Ed Nieters


Yuri Plotnikov

US & EM Team


Sergei Dolinsky


Adrian Ivan


Stanislav Soloviev

Detector Team

GE Project Team

Juan-Pablo Celia

Robert Tait

Paul Chen

Design & Mechanical Engineering Team

Tom Williams

Bill Johnson

Drilling & Completion Team

Khanh Duong

Mechanical Engineering

Matthias Kasten

PI

Starfire Industries Team

Brian Jurczyk, Robert Stubbers, Matt Coventry, Aaron Krites, and Darren Alman

Technical Review Team

Helene Climent

Principal Engineer
GE Corporate
Oklahoma City, OK

Michael Wells

Strategic COE Ldr.
GE Corporate
Oklahoma City, OK

Taylor Shinn

Innov. Adoption Ldr.
GE Corporate
Oklahoma City, OK

Guy Mason

Engineering Mgr.
GE Oil & Gas
Farnborough, GB

Jim LeBlanc

Technology Ldr.
Electronics - ETS
GE Corporate, GRC

Loucas Tsakalakos

Lab Manager
Photonics Laboratory
GE Corporate, GRC

Sandra McSurdy

Progr. Manager
NETL
U.S. Department of Energy

Gantt Chart

Program Activities

Phase I — Prove-out of subcomponent technologies

Task 1 — Project Management Plan
Milestones:
- *Program kick-off*
- *Project plan development*

Task 2 — Technology Status Assessment
Milestone: *State of-the-technology report*

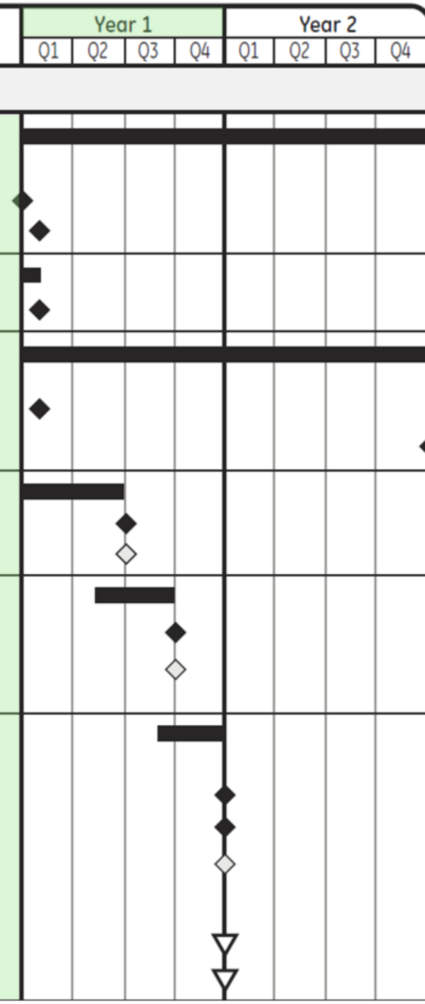
Task 3 — Technology Transfer
Milestones:
- *Technology transfer plan*
- *Final technology transfer status and report*

Task 4 — Determine Single-Modality Casing Fault Detection and Inspection Entitlement
Milestone: *Single modality entitlement established*
Go/No Go: *Entitlement recommendation based on risk evaluation and sensor performance*

Task 5 — Down-Select the Cross-Modality Well Casing Integrity Sensing Components
Milestone: *Multi-modality well casing integrity sensing components selected*
Go/No Go: *Recommendation for proceeding the cross-modality inspection system based on design specifications and the evaluation of the associated risks*

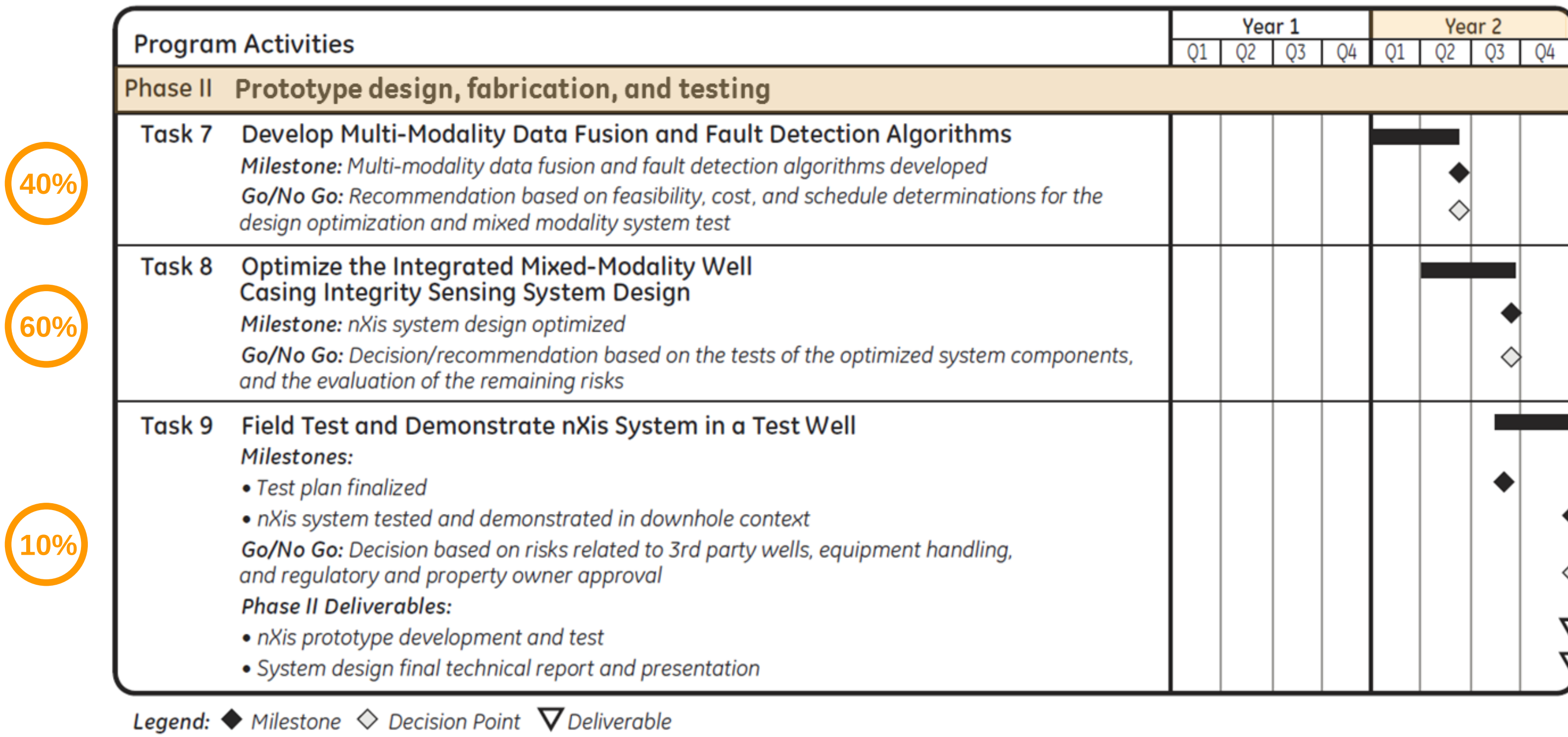
Task 6 — Design and Build the nXis Prototype System
Milestones:
- *nXis prototype system designed*
- *System specification report based on risk assessment*

Go/No Go: *Decision/recommendation based on the tests of the designed system components, and the evaluation of the remaining risks*
Phase I Deliverables:
- *Subcomponent technologies of the nXis system proven-out*
- *Final technical report and presentation*



Legend: ◆ Milestone ◇ Decision Point ▽ Deliverable

Gantt Chart



The official program end date is September 30, 2016. However, a 6-months no-cost extension has been requested to complete all the tasks.

Bibliography

Conference Presentations/ Proceedings:

- Y.A. Plotnikov, F.W. Wheeler, S. Mandal, W.R. Ross, J.S. Price, E.J. Nieters, A. Ivan, S. Dolinsky, H.C. Climent, and A.M. Kasten, 2016, Review of Progress in Quantitative NDE Conference: Development of an Electromagnetic Imaging System for Well Bore Integrity Inspection. QNDE, July 2016, Atlanta, GA.

Accepted Conference Presentations:

- SPE Liquids-Rich Basins Conference, September 21-23, 2016, Midland, TX
- 2016 AIChE Annual Meeting, November 13-18, 2016, San Francisco, CA

Multiple patent disclosures have been filed. Journal publications will be submitted after completion of technical work.