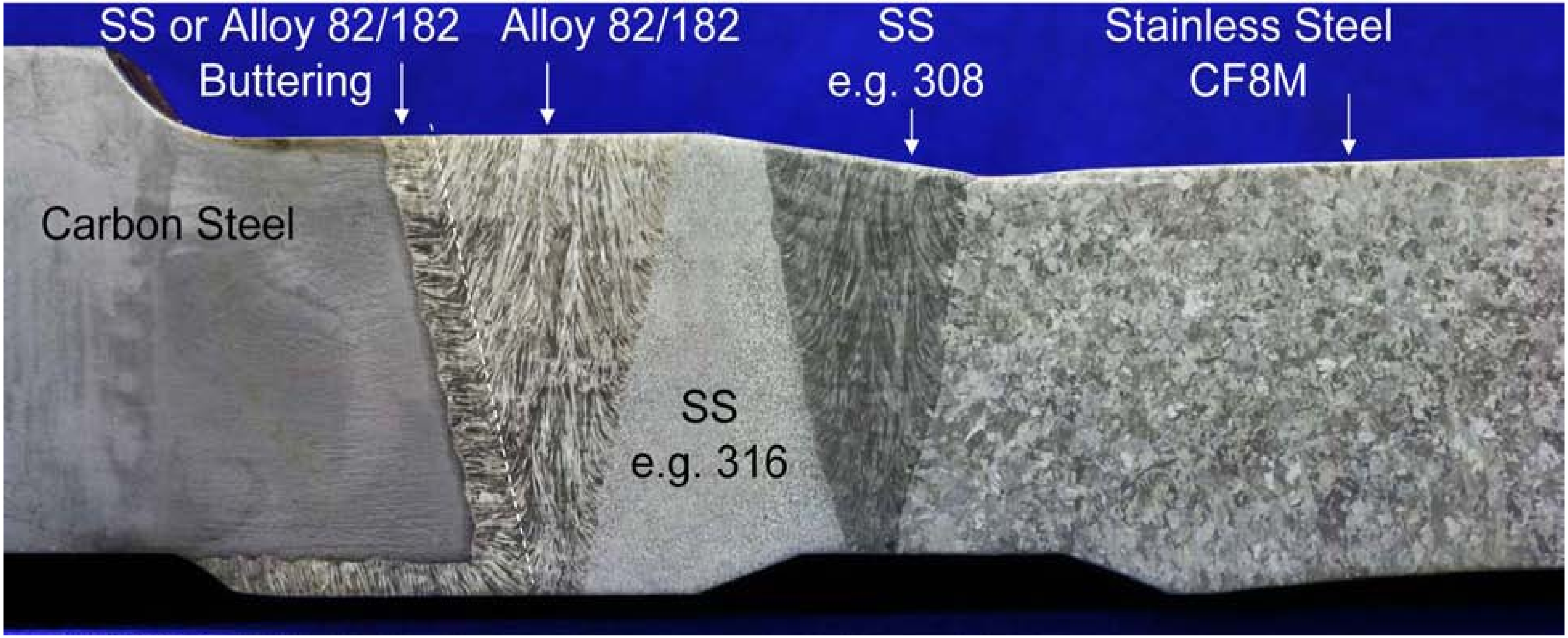
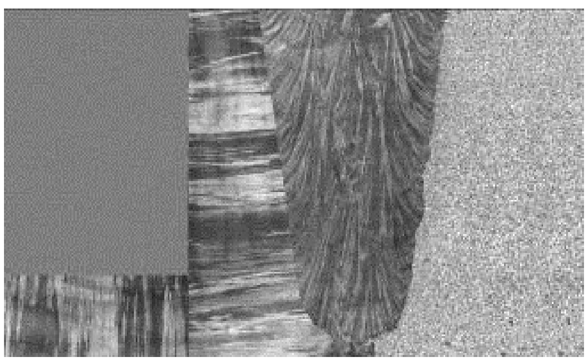
ULTRASONIC INSPECTION of DISSIMILAR WELDS



Standard PWR Steam Generator Nozzle DMW Configuration (1)

State-of-the-Art Ultrasonic Material Inspection

Austenitic Weld



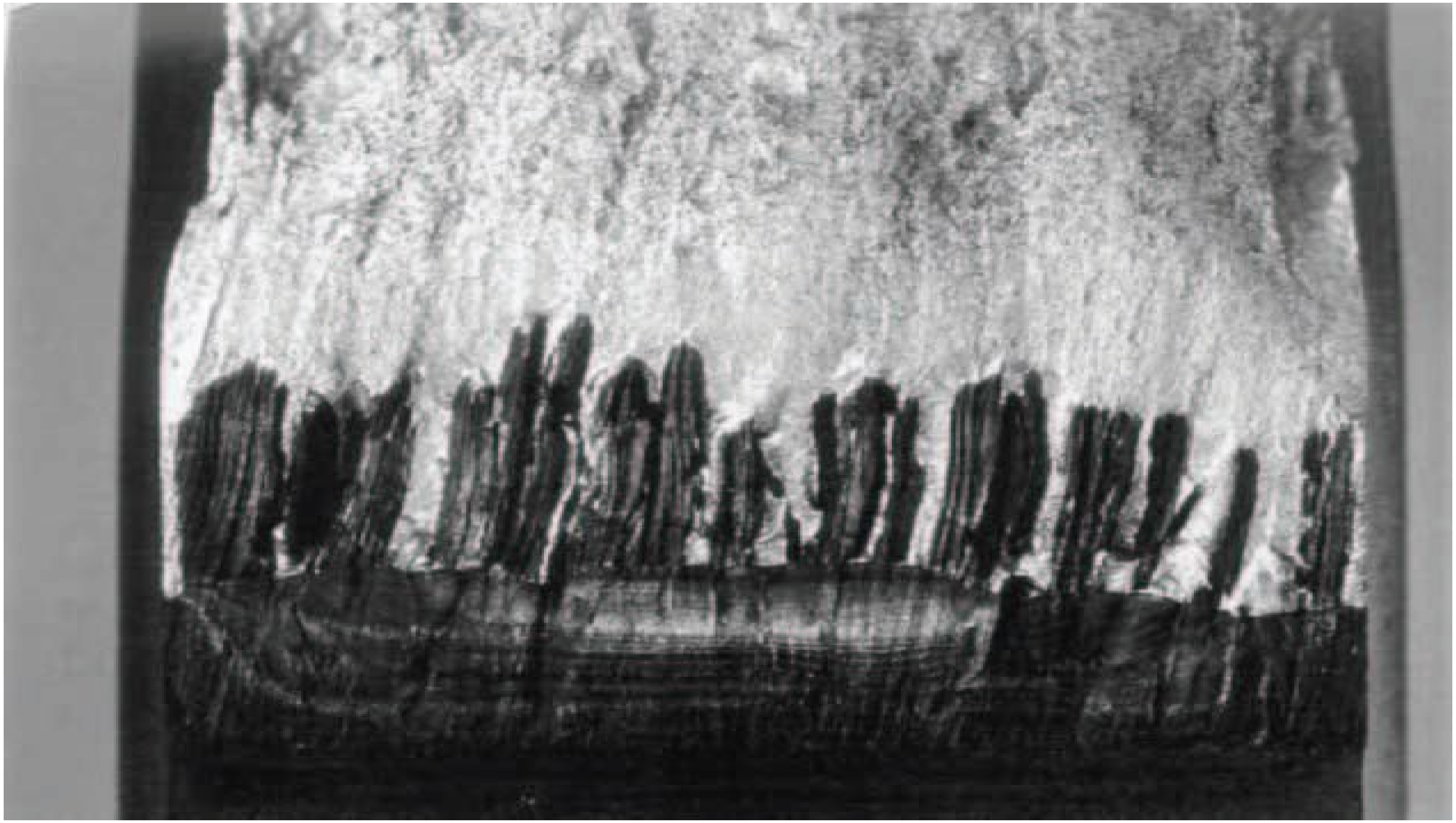
Dissimilar Weld

Limitations

- Anisotropic Material
- Coarse Grain Material
- Dispersive Material
- Evaluation of Flaws
- Scanning Surface

A Scan

INSPECTION BY CAUSE
Primary Water Stress Corrosion Cracking - PWSCC

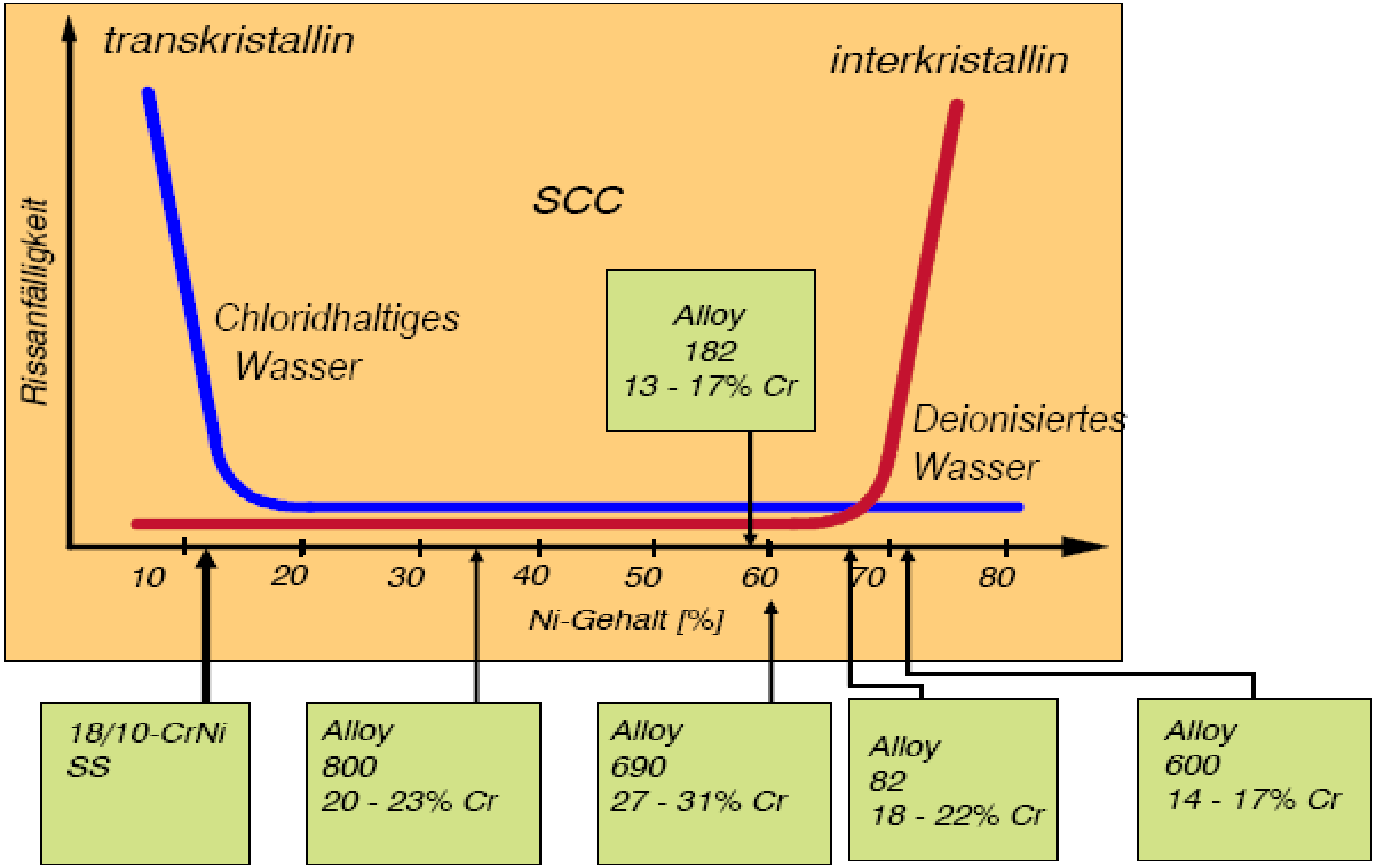


Fracture Surface of Alloy 182 Weld Metal with Irregular Crack Front (2)

Q NET CONSULTING

TOLMI

INSPECTION BY CAUSE
Primary Water Stress Corrosion Cracking - PWSCC



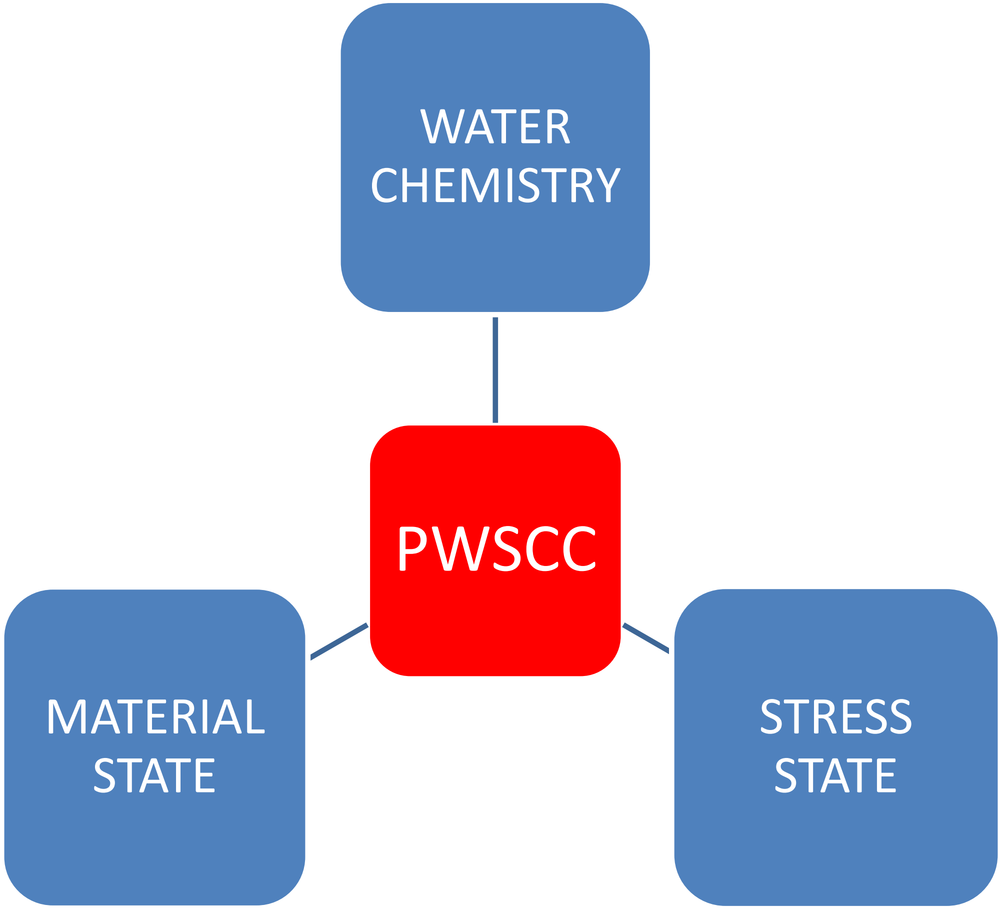
Cracking Susceptibility of various Alloys (3)

INSPECTION BY CAUSE
Primary Water Stress Corrosion Cracking - PWSCC

Component Item	Date PWSCC Initially Observed	Service Life[a] (Calendar Years)
Steam Generator Hot Leg Tubes and Plugs	~1973	~2
Pressurizer Instrument Nozzles	1986	2
Steam Generator Cold Leg Tubes	1986	18
Pressurizer Heaters and Sleeves	1987	5
Steam Generator Channel Head Drain Pipes	1988	1
Control Rod Drive Mechanism Nozzles	1991	12
Hot Leg Instrument Nozzles	1991	5
Power Operated Relief Valve Safe End	1993	22
Pressurizer Nozzle Welds	1994	1
Cold Leg Piping Instrument Nozzles	1997	13
Reactor Vessel Hot Leg Nozzle Buttering/Piping Welds	2000	17
Control Rod Drive Mechanism Nozzle/RV Head Welds	2000	27
Surge Line Nozzle Welds	2002	21
Reactor Vessel Lower Head In-Core Instrumentation Nozzles/Welds	2003	14

Alloy 600 PWSCC Experience in Commercial PWRs
Crack Initiation Times

INSPECTION BY CAUSE
Primary Water Stress Corrosion Cracking - PWSCC



INSPECTION BY CAUSE
Primary Water Stress Corrosion Cracking - PWSCC

*The generic IGSCC of the nickel-based Alloy 600 … in PWR has been studied extensively. Despite considerable experimental efforts, **no consensus exists** as to the nature of the cracking mechanism, and life modeling and remedial measures have had to rely on empirical, phenomenological correlations. By contrast, its counterpart in BWR, in terms of extent and cost of remedial measures, of IGSCC of sensitized, austenitic materials, benefits from a solid basis of fundamental understanding of the cracking mechanism for life modeling and repair remedies.*

2000 F.N. Speller Award Lecture by P.M. Scott, Framatome.

INSPECTION BY CAUSE
Primary Water Stress Corrosion Cracking - PWSCC

WATER CHEMISTRY

Main Parameters

- *hydrogen partial pressure (or corrosion potential)*
- *temperature*

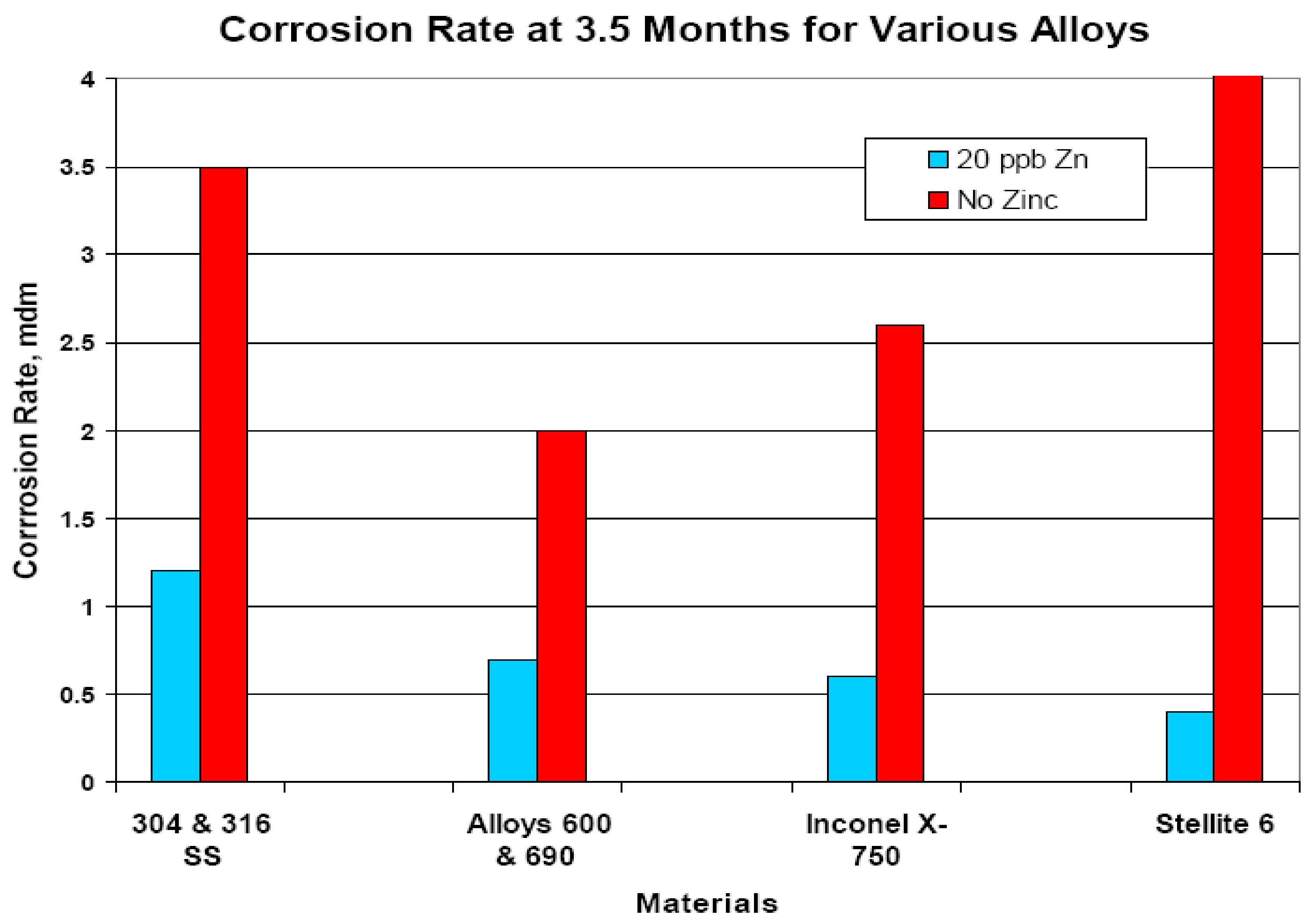
Mitigation Potential

- *zinc additions to the reactor coolant system (Reduction of general corrosion)*
- *temperature reduction (thermally-activated mechanism)*

NET CONSULTING

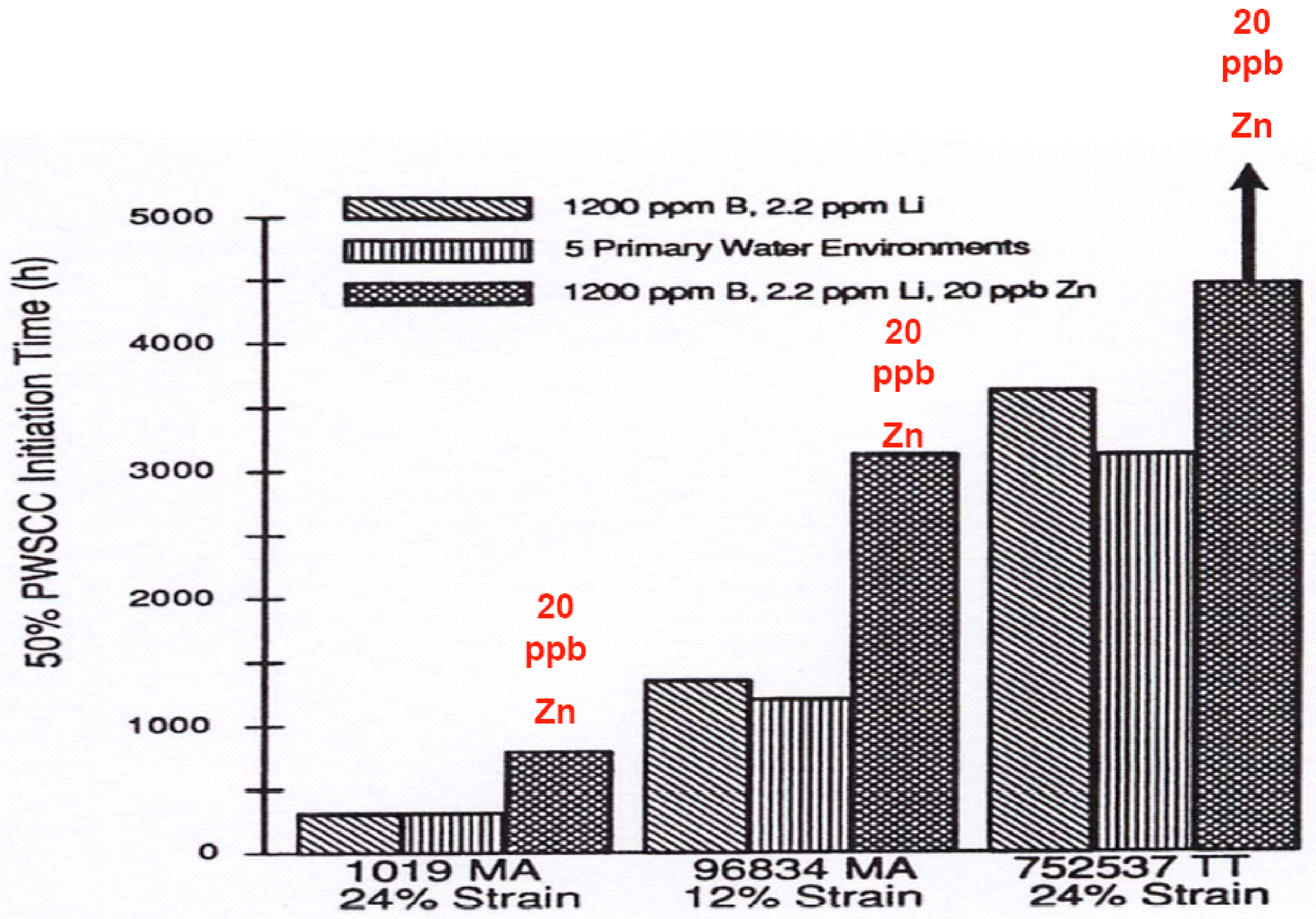
INSPECTION BY CAUSE
Primary Water Stress Corrosion Cracking - PWSCC

TOLMI



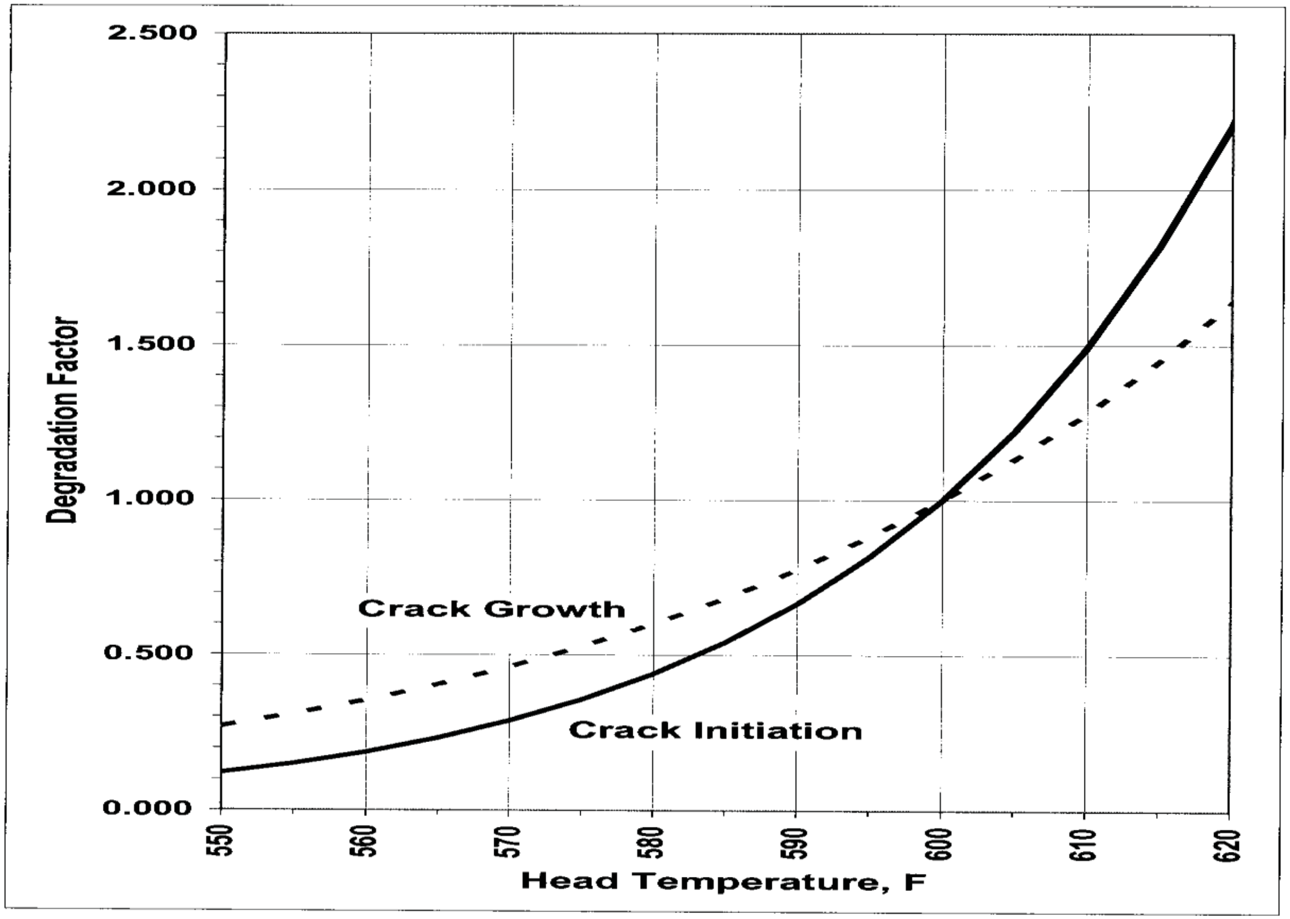
Effect of zinc on corrosion rates of various alloys in laboratory tests (after Esposito et al.**)**

INSPECTION BY CAUSE
Primary Water Stress Corrosion Cracking - PWSCC



Example for the effect of zinc on time to initiate PWSCC in laboratory tests
(after Esposito et al. 1991**)**

INSPECTION BY CAUSE
Primary Water Stress Corrosion Cracking - PWSCC



Degradation Factor as a Function of Temperature

(ref. (David R. Forsyth, 2005)**)**

INSPECTION BY CAUSE
Primary Water Stress Corrosion Cracking - PWSCC

STRESS STATE

Main Parameters

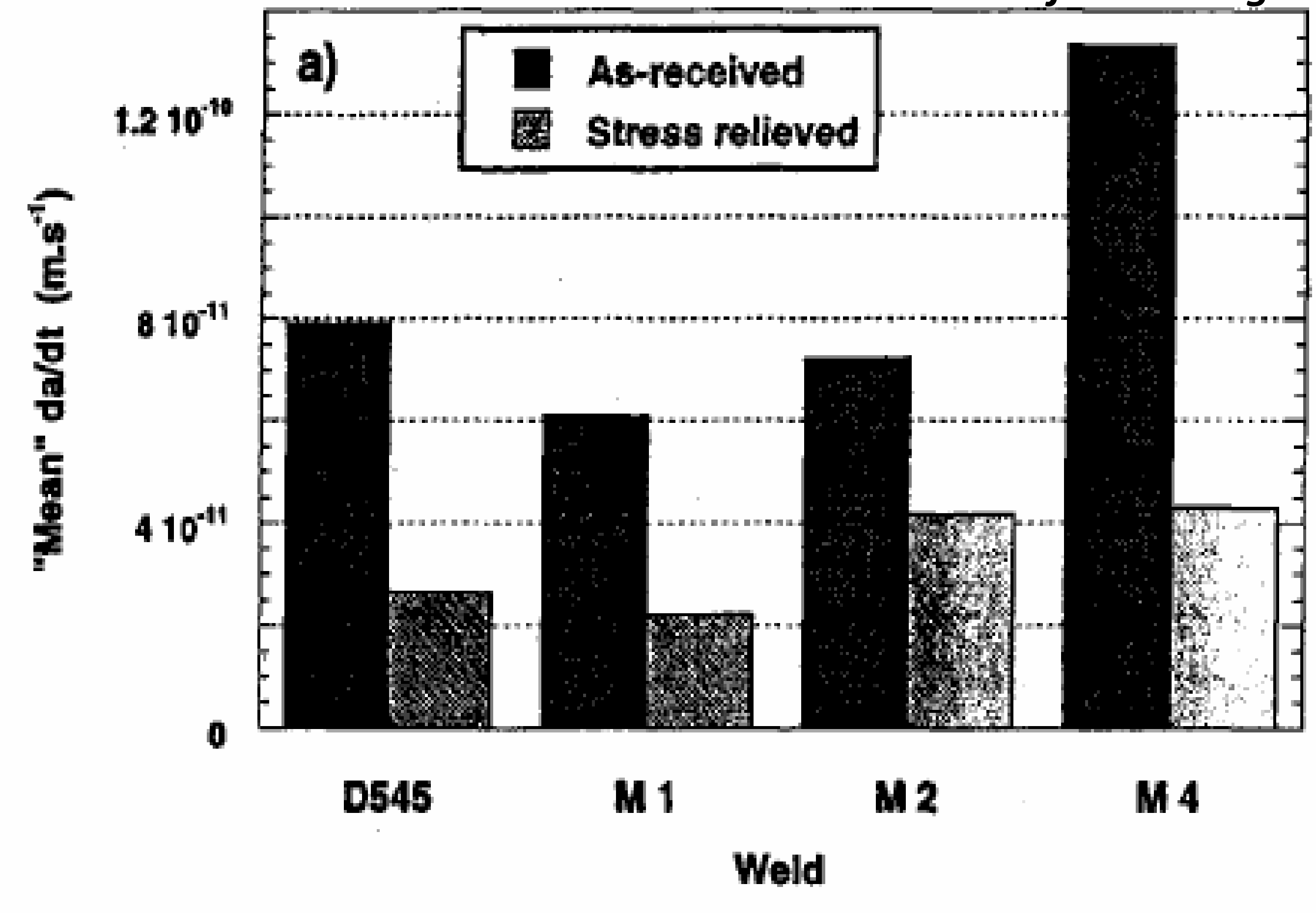
- *welding procedure*
- *heat treatment*

Mitigation Potential

- *Mechanical Surface Enhancement (MSE)*
- *stress relief heat treatment*

INSPECTION BY CAUSE
Primary Water Stress Corrosion Cracking - PWSCC

stress relief annealing



Effects of heat treatment on SCC susceptibility of Alloy 182

Mechanical Surface Enhancement (MSE):

shot peening
flapper wheel grinding
electrical-discharge machining
electro-polishing
abrasive water jet conditioning
mechanical stress improvement process

INSPECTION BY CAUSE
Primary Water Stress Corrosion Cracking - PWSCC

MATERIAL STATE

Main Parameters

- *material and weld microstructure*
- *weld defects*

  (relatively large and sharp defects, lack of fusion areas, promote PWSCC by acting as stress concentrators)

Mitigation Potential

- *metals with 30% chromium*

  (threshold for PWSCC resistance: between 22 and 30% chromium)
- *quality assessment*

  (no repair, weld bead size, heat treatment, weld design)

INSPECTION BY CAUSE
Primary Water Stress Corrosion Cracking - PWSCC

Assessment of Dissimilar Welds: „Risk for PWSCC"

Monitored Subject: „Nickel-Base Weld Metal"

(1 = no risk up to 4 = higher risk)

Design Layout	1	2	3	4
- Nickel-base root	no	yes	yes	yes
- One sided welding	yes	yes	yes	no
- ID repair	no	no	no	yes
- OD repair	no	yes	yes	yes
- Shop weld	n.r.	n.r.	?	no
- E manual/mechanized	n.r.	n.r.	?	manual
- Alloy 182/82	n.r.	n.r.	?	182
- with/without buffer	n.r.	without	?	with
- with/without annealing	n.r.	n.r.	?	with
- ISI yes/no	n.r.	n.r.	?	?
Suspect for PWSCC	**no**	**no**	**?**	**Yes**
NDT recommended	**no**	**no**	**yes**	**yes**

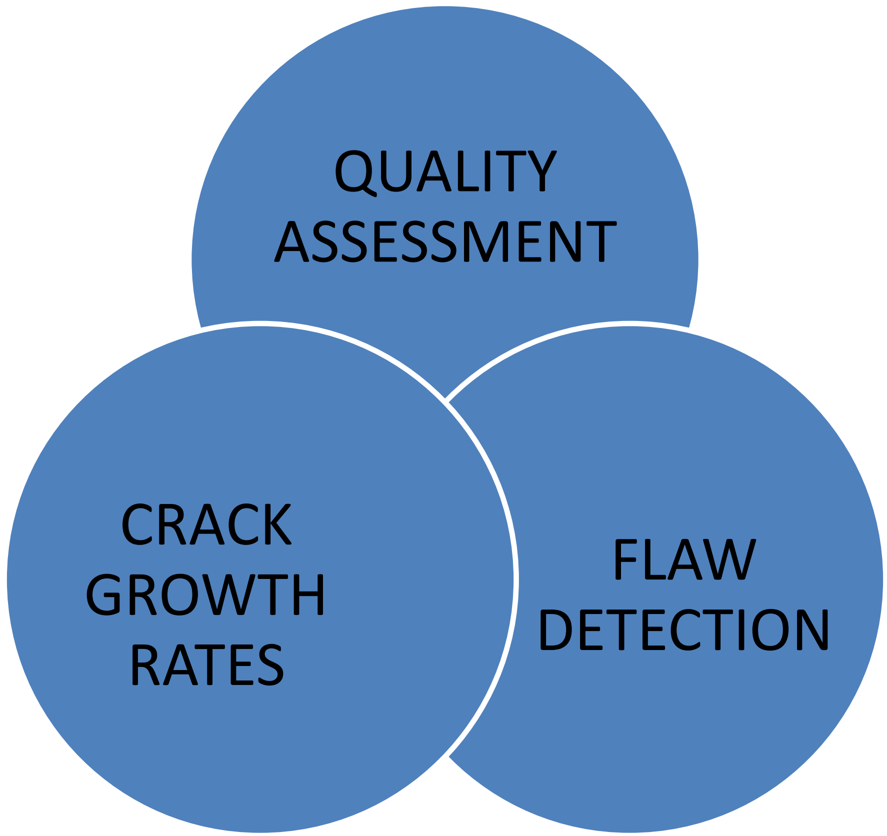
n.r. = nonrelevant ? = unknown

Assessment of Dissimilar Welds: "Risk for PWSCC"

INSPECTION BY CAUSE
Primary Water Stress Corrosion Cracking - PWSCC

The risk for PWSCC in alloy 600 components and its weld metal alloy 128/28 is low when best craftsmanship, optimized design, manufacturing and fabrication can be certified by documentation. Under these conditions, both the stress resp. strain state and the material's microstructure state of the critical component area are on a level to ascertain a low susceptibility to PWSCC.

INSPECTION BY CAUSE
Primary Water Stress Corrosion Cracking - PWSCC

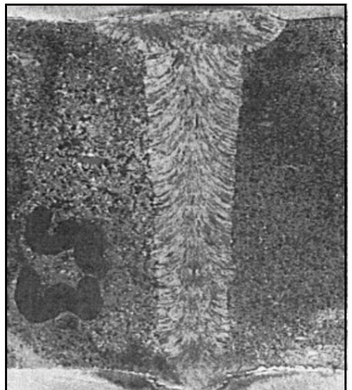


NDT SUPPORTED MITIGATION CONCEPT

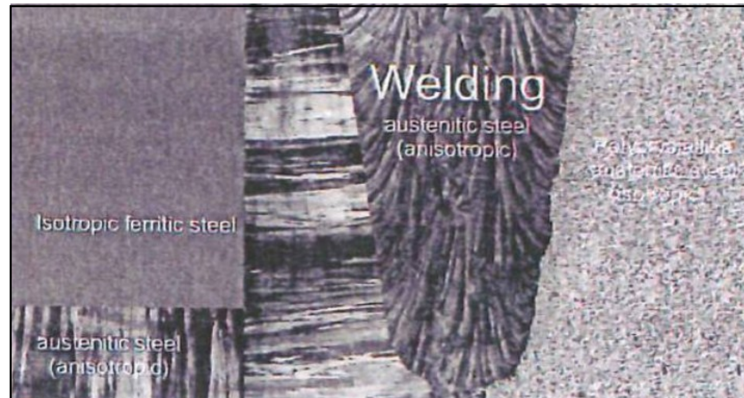
PAUSE

INSPECTION PROBLEM
Acoustic Anisotropy

a - standard pipe to pipe weld



b - narrow gap weld



c - dissimilar weld

PHOTOMICROGRAPHS
of
WELD SECTIONS

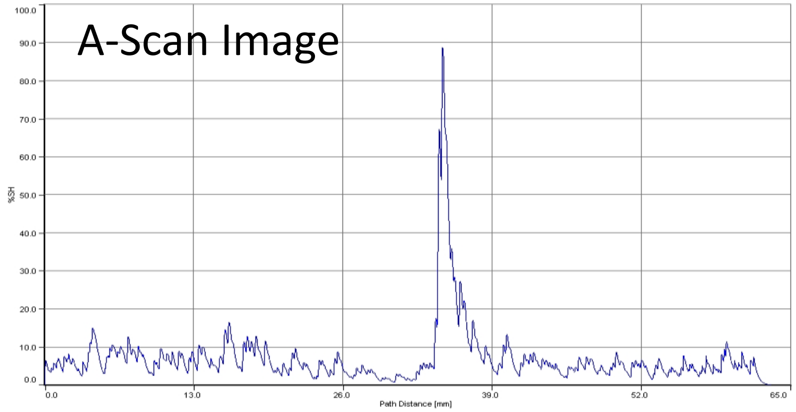
INSPECTION PROBLEM
Acoustic Anisotropy

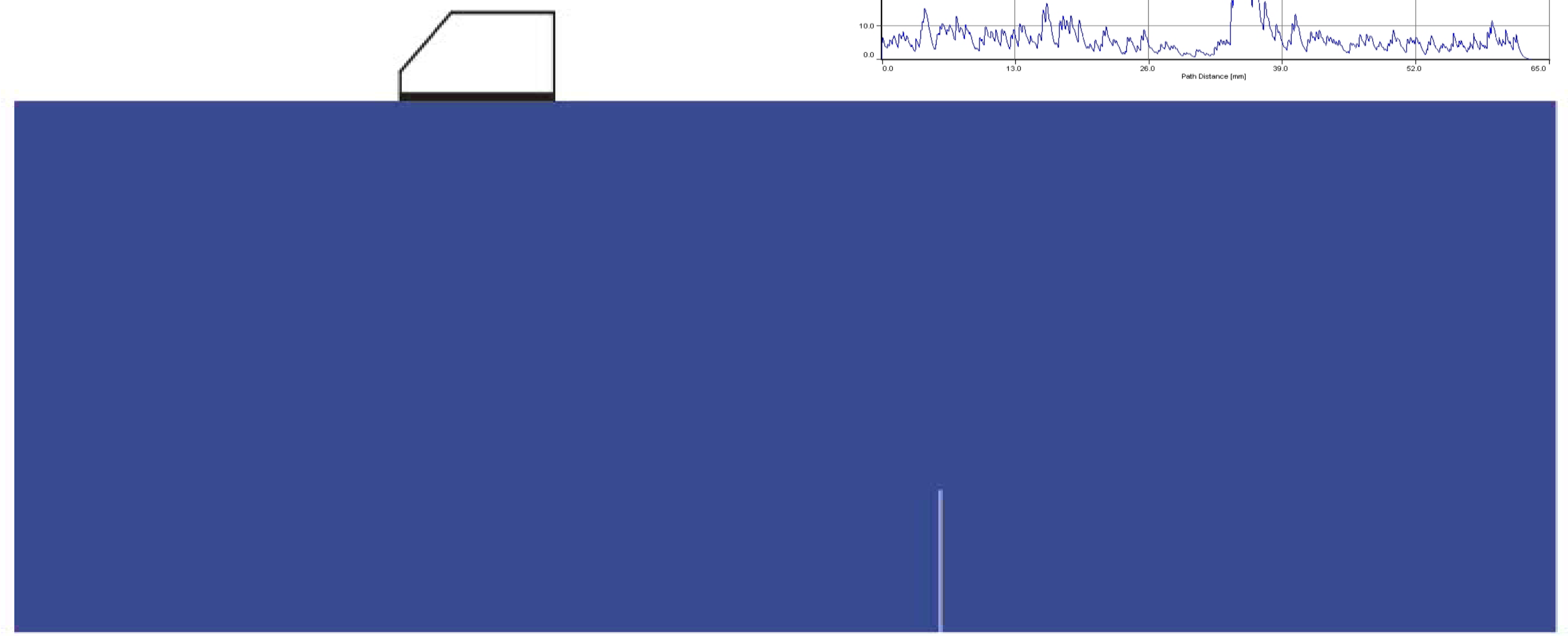
SIMULATION

akustisch isotrop

Impulse – Echo Technique

45° Shear Wave Transducer





INSPECTION PROBLEM

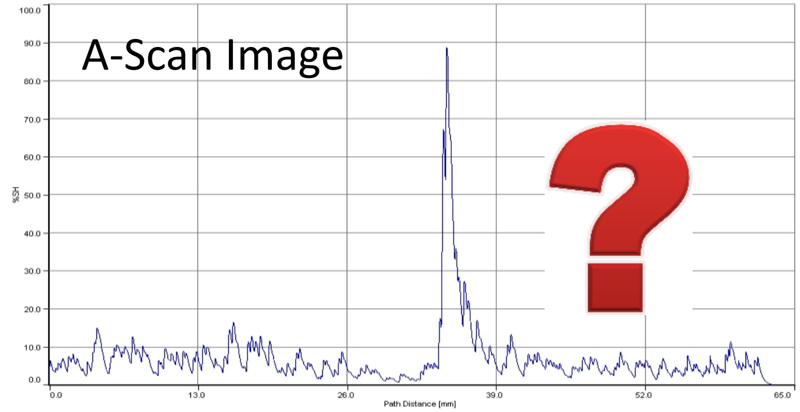
Acoustic Anisotropy

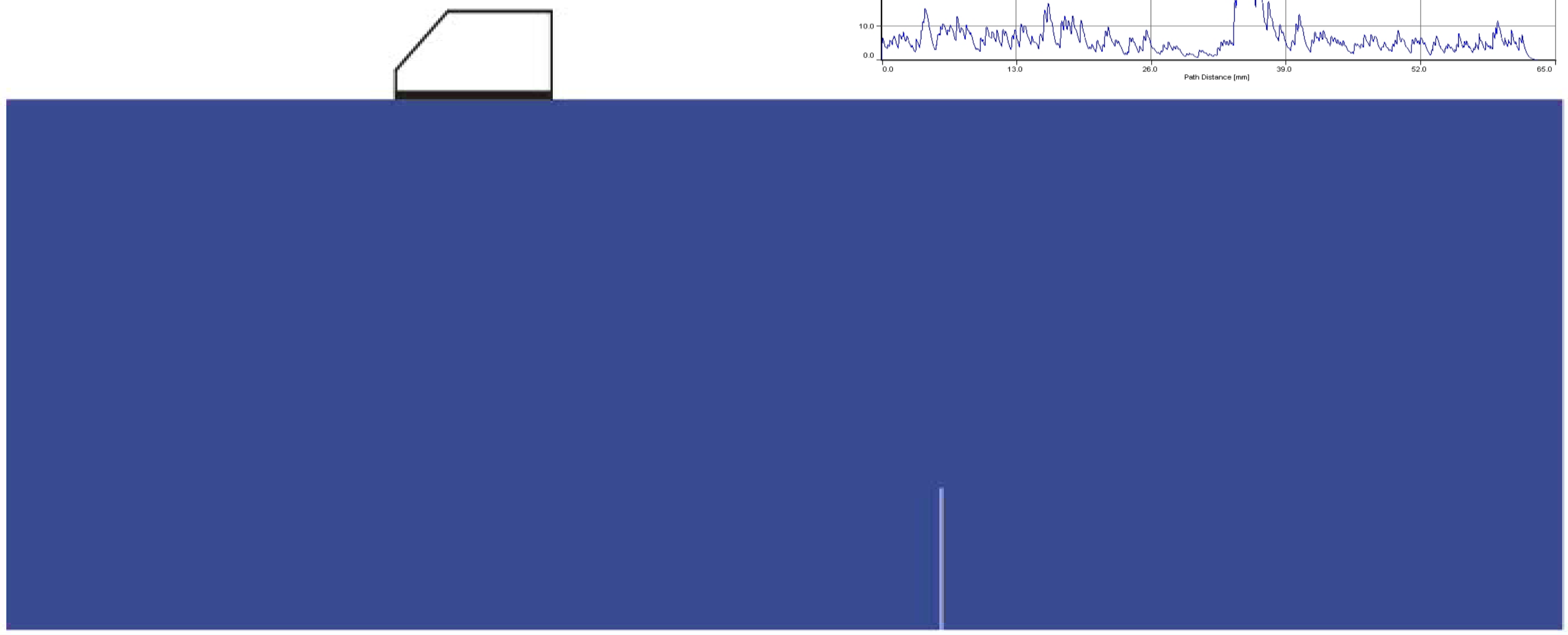
SIMULATION

transversal isotrop

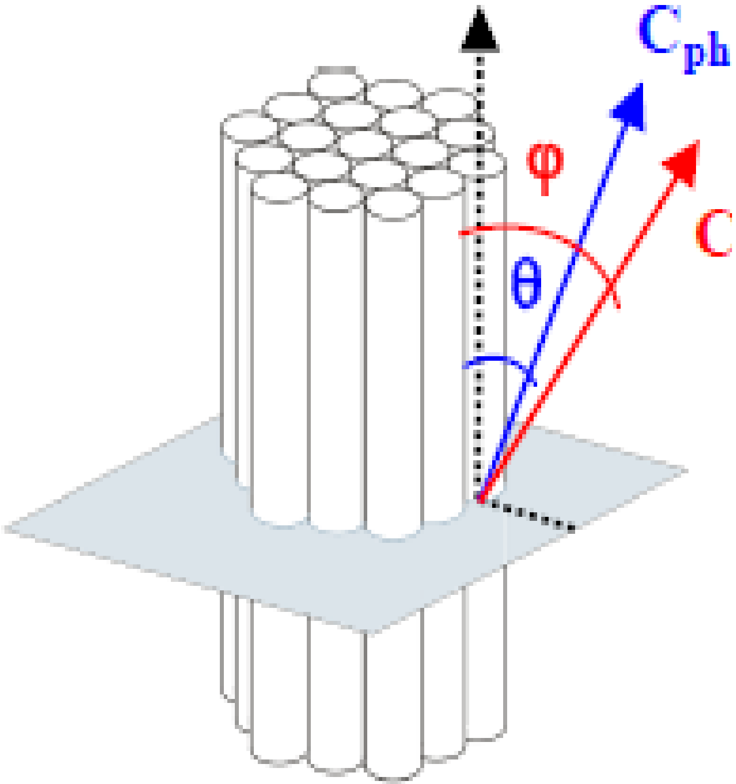
Impulse – Echo Technique

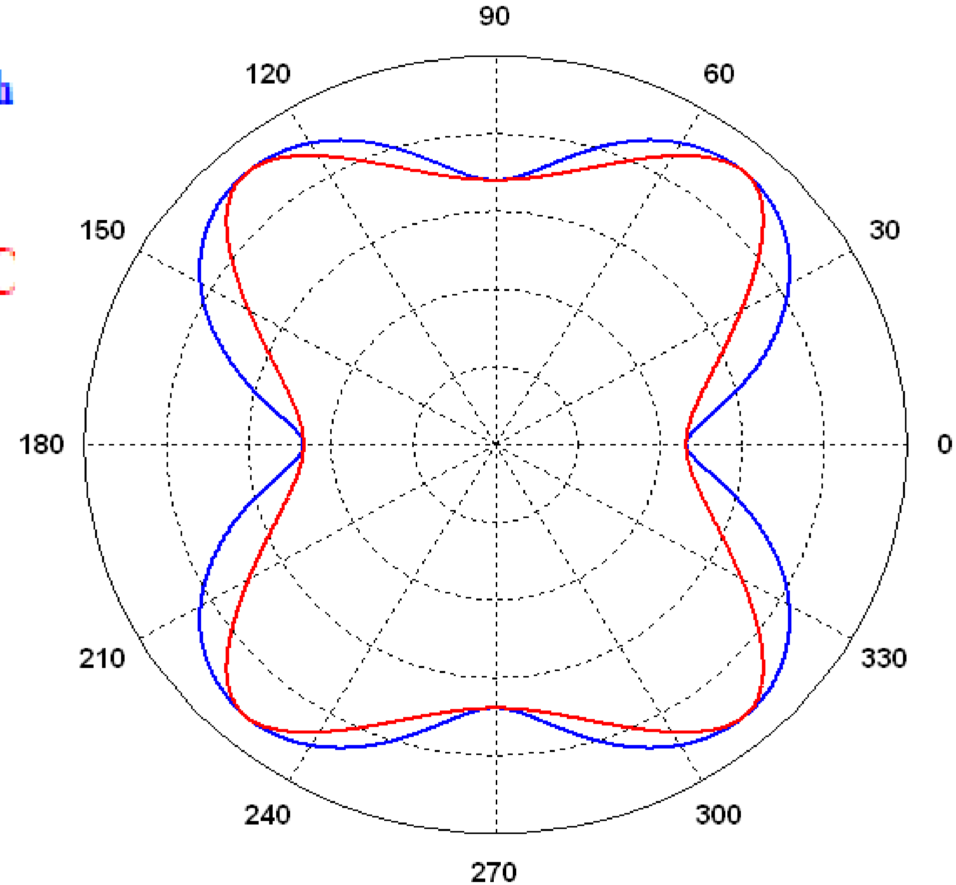
45° Shear Wave Transducer





INSPECTION PROBLEM
Acoustic Anisotropy





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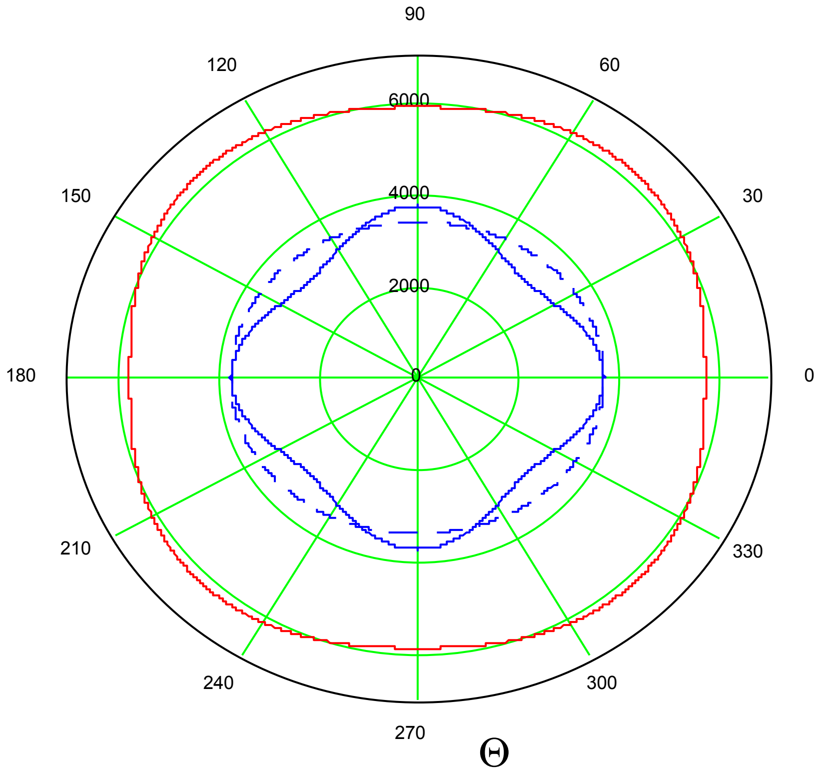
INSPECTION PROBLEM
Acoustic Anisotropy

TOLMI

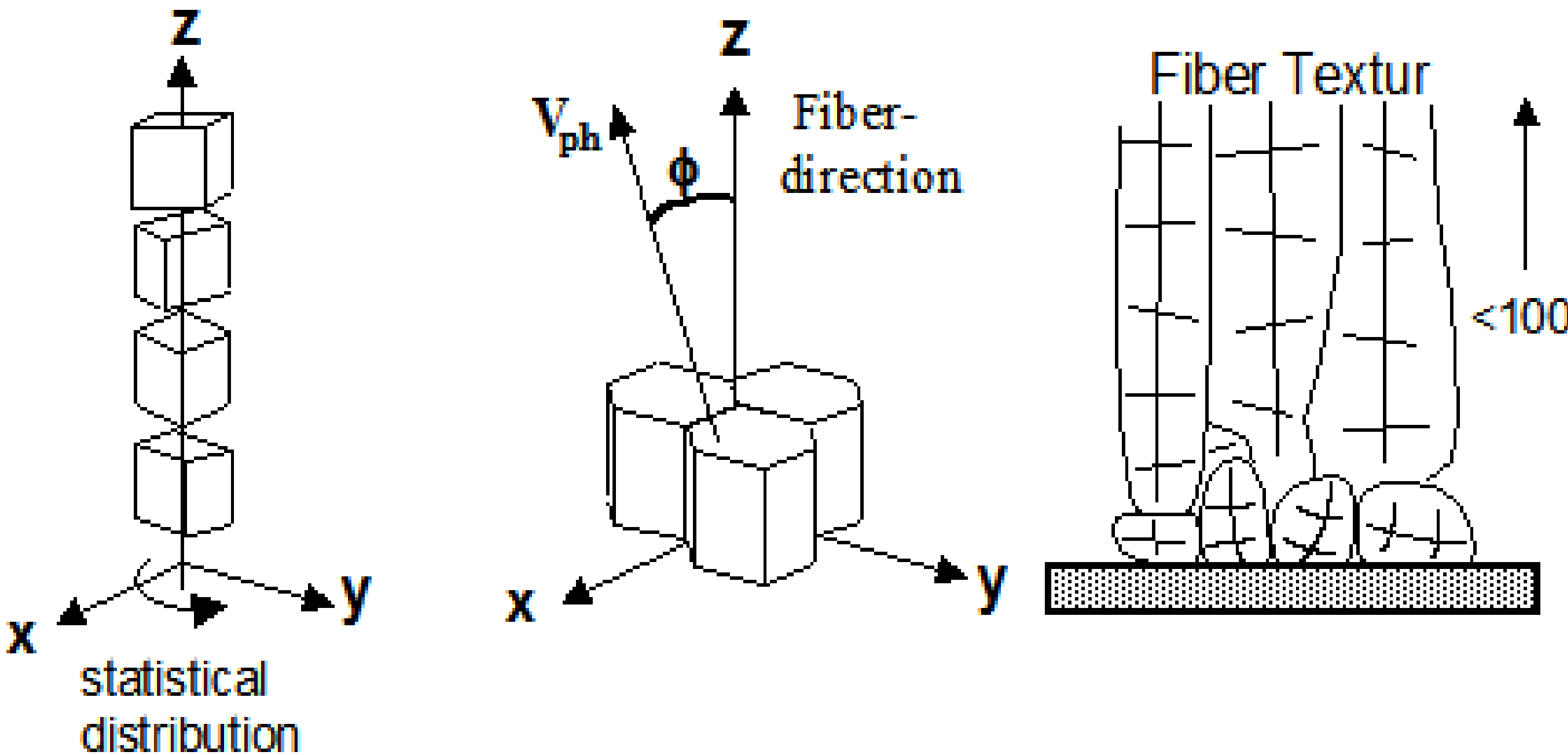


---- pressure wave

---- vertical shear wave

---- horizontal shear wave

INSPECTION PROBLEM
Acoustic Anisotropy



$$V_{ph} = f\,(\,\rho\,,\,C11\,,\,C13\,,\,C33\,,\,C44\,,\,C66\,,\,\Theta\,)$$

Model of the transverse isotropic structure of stainless steel weld joints

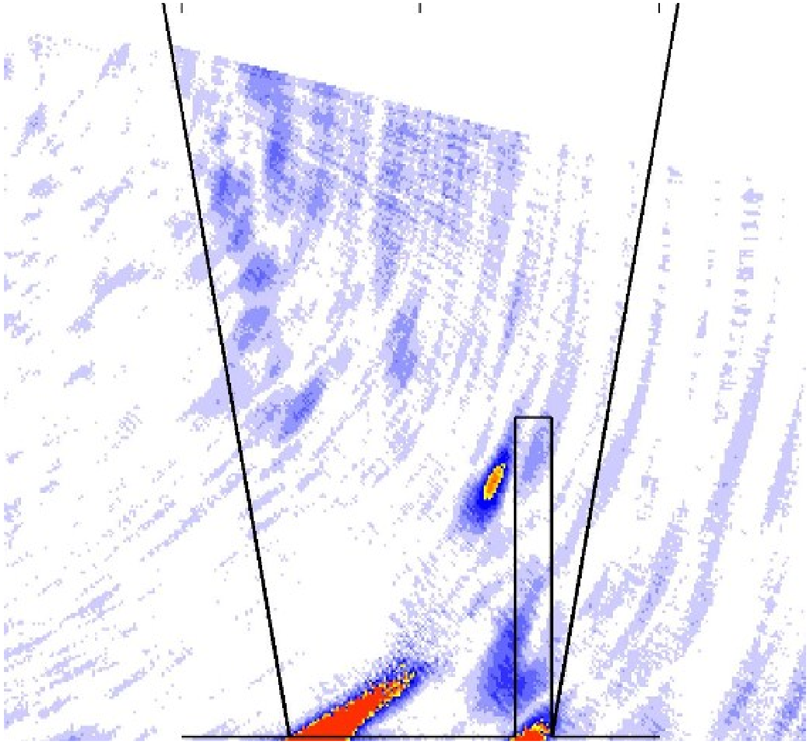
V_{ph} = Phase Velocity; Cij = Elastic Constant;
ρ - Density, Φ – Fiber Orientation

Rules for Practitioners

SCATTERING:

- LONGITUDINAL MODE
  ~ 8 times less than shear mode
- FOCUSSING (T/R Transducers)
  limits the contribution of scattering
- FILTERING and BEAM FORMING
  reduction of scattering contribution
  (TOPIC of R&D)

INSPECTION PROBLEM
Acoustic Anisotropy



S. PUDOVIKOV, A. BULAVINOV, R. PINCHUK, R. SRIDARAN VENKAT
Quantitative Ultraschallprüfungen an anisotropen Materialien mittels Sampling Phased Array Technik, DGZfP-Jahrestagung 2010

False Call by Interface Reflection

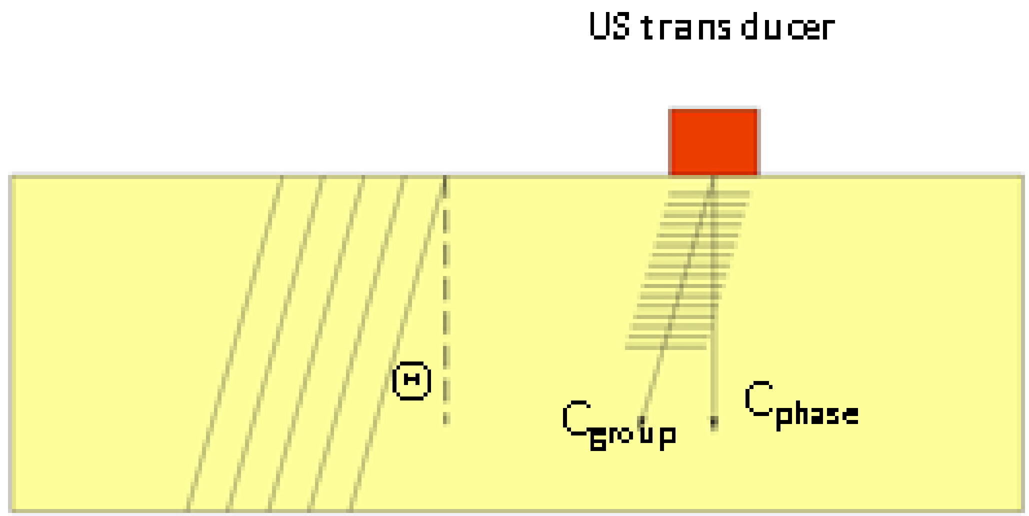
INSPECTION PROBLEM
Acoustic Anisotropy

Rules for Practitioners

BENDING:

- LONGITUDINAL & SHEAR MODE
  opposite behavior
- FOCUSSING of LONG. MODE
  at intersecting angles of 0° and 90°
- DEFOCUSSING of LONG. MODE
  at intersecting angles of +/- 45°
- TENDENCY of BENDING
  into the columnar grain orientation

INSPECTION PROBLEM
Acoustic Anisotropy



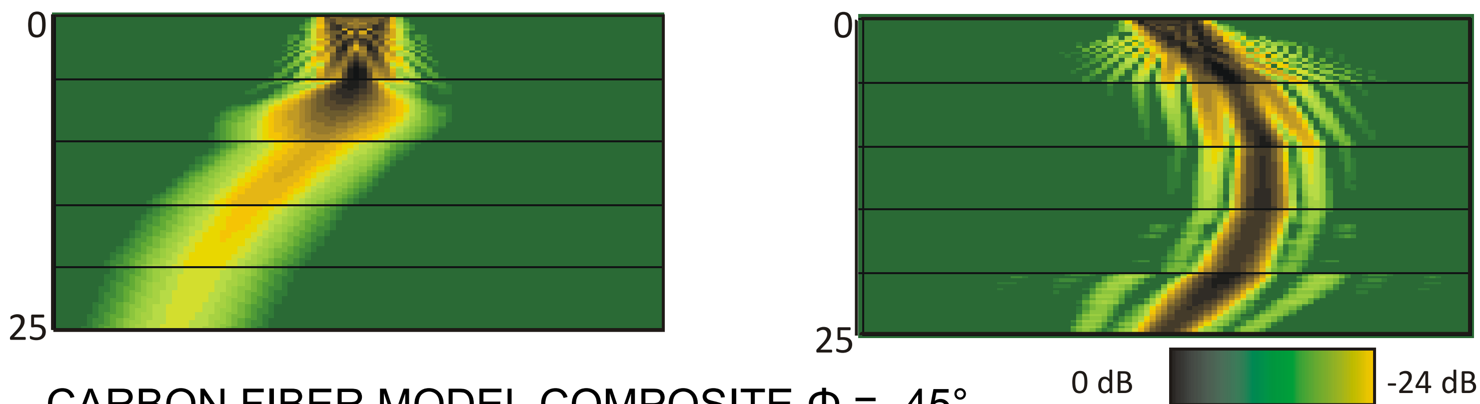
CARBON FIBER MODEL COMPOSITE

SOUND FIELD BENDING

QNET CONSULTING

TOLMI

INSPECTION PROBLEM
Acoustic Anisotropy



CARBON FIBER MODEL COMPOSITE Φ = -45°

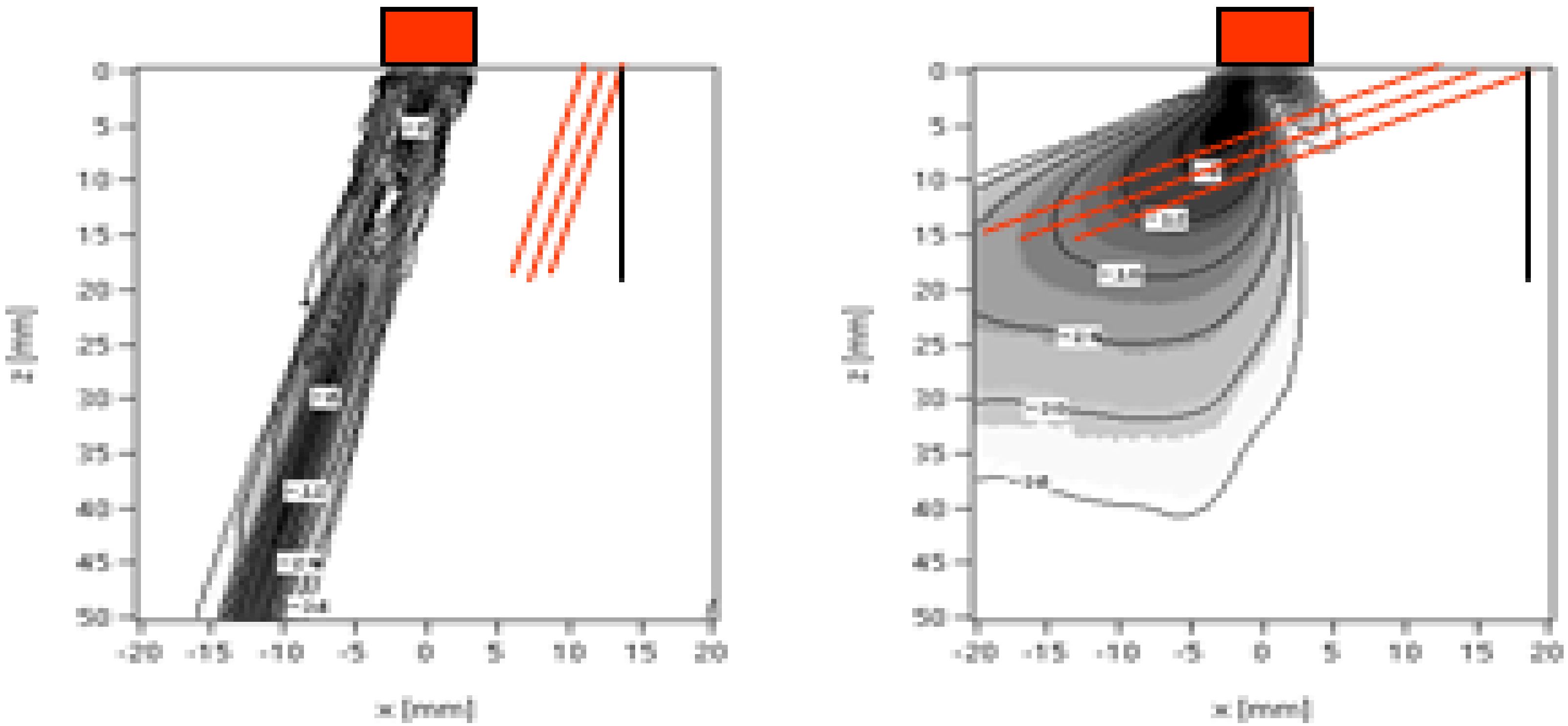
BENDING INTO THE FIBER/GRAIN ORIENTATION

Modeling of sound propagation
in
transverse isotropic media*

*Simulation by:
Dr. Schubert, Dr. Spies,
Fraunhofer IZFP

INSPECTION PROBLEM

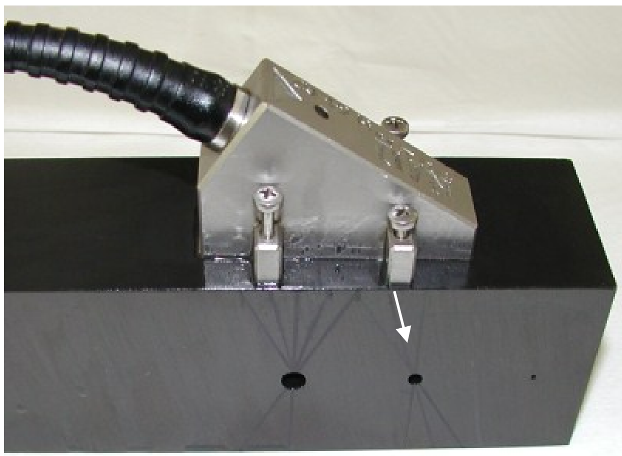
Acoustic Anisotropy



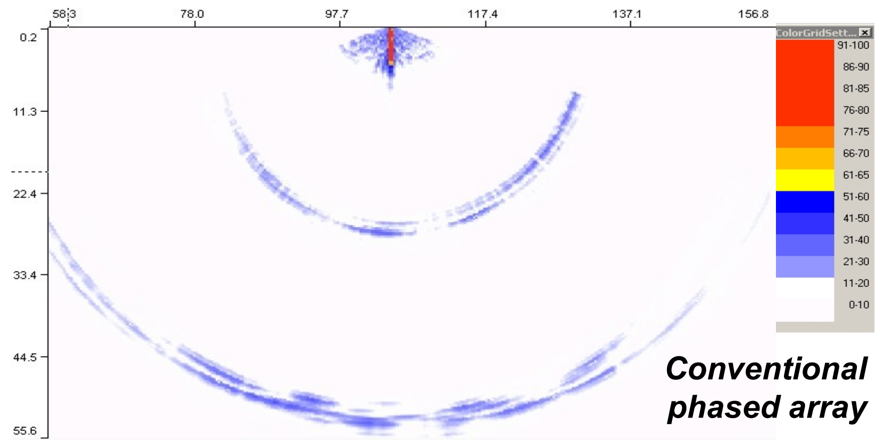
FOKUSSING & DEFOKUSSING
OF SOUND FIELDS IN
TRANSVERSE ISOTRPIC MATERIALS

INSPECTION PROBLEM
Acoustic Anisotropy

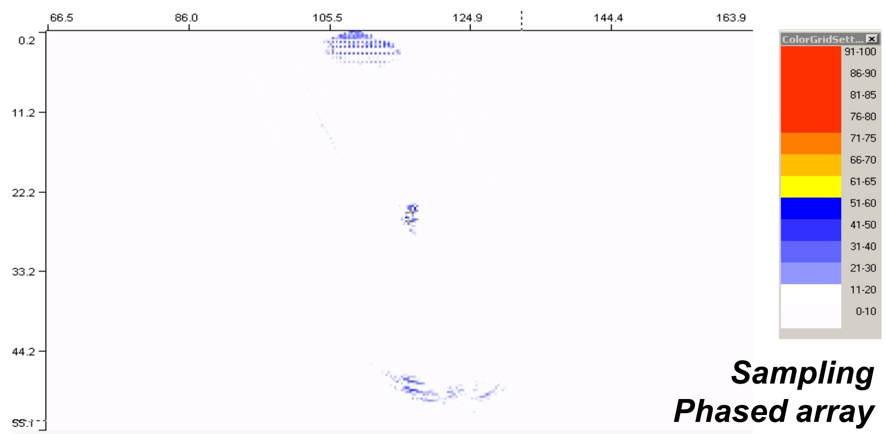
Inspection of carbon-fiber structures



Angle beam (12°) insonification of side drilled hole ⌀ 3 mm



Conventional phased array

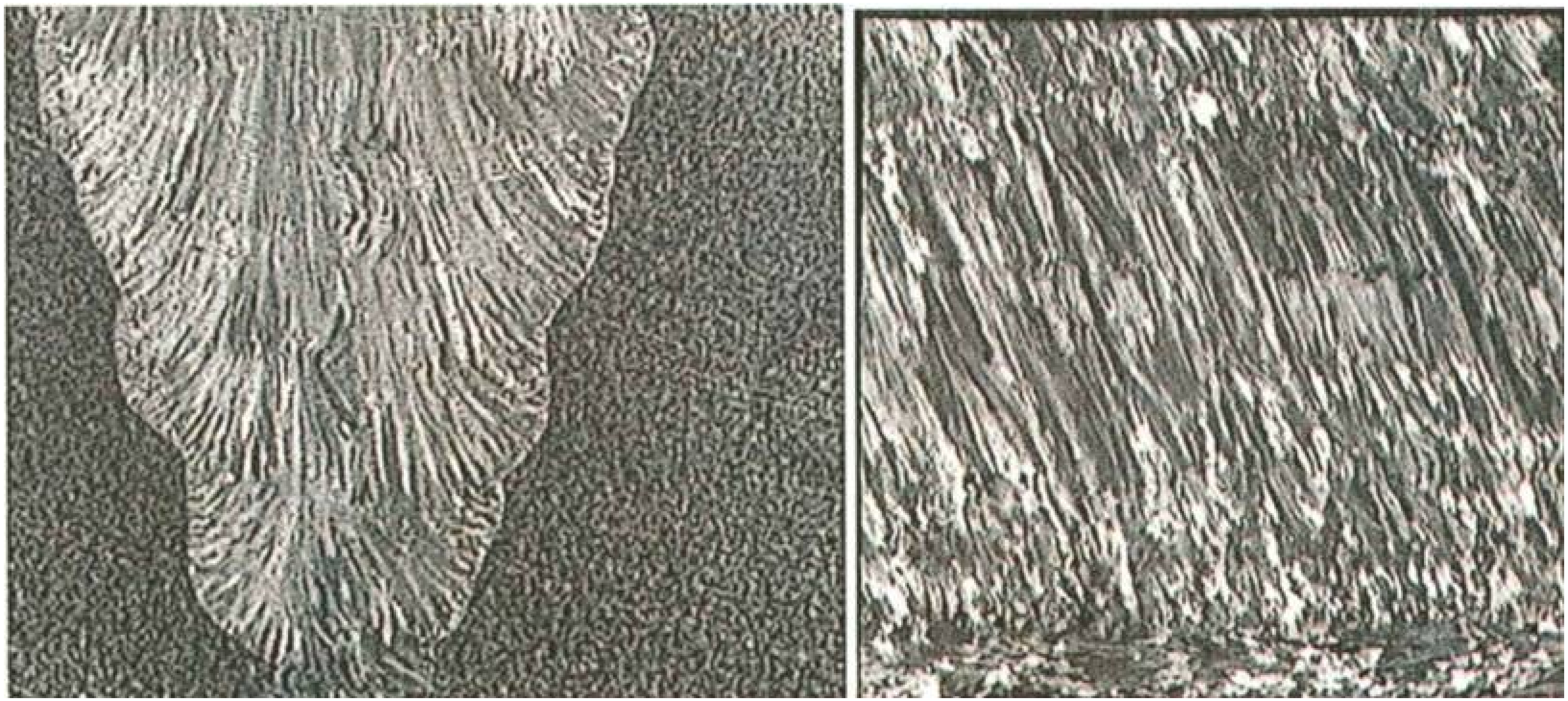


Sampling Phased array

R&D
Reverse Phase Matching

INSPECTION PROBLEM

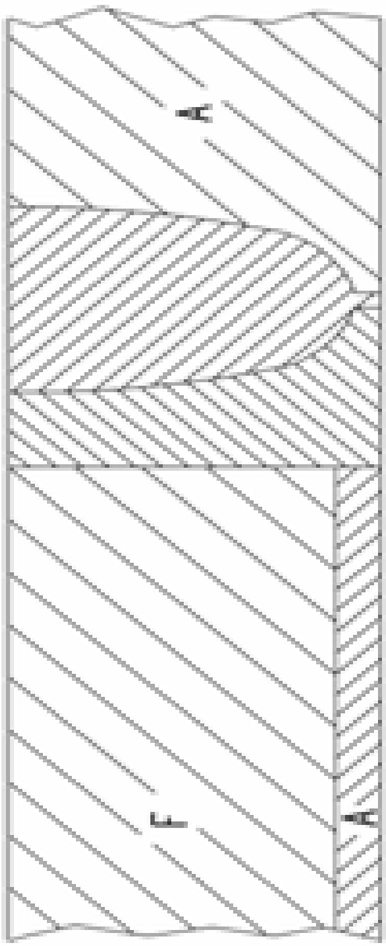
Acoustic Anisotropy

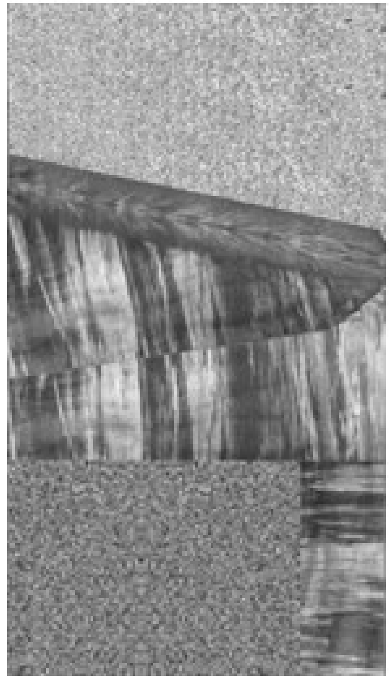


Transverse and Longitudinal Sections with Homogeneous Anisotropic Structure

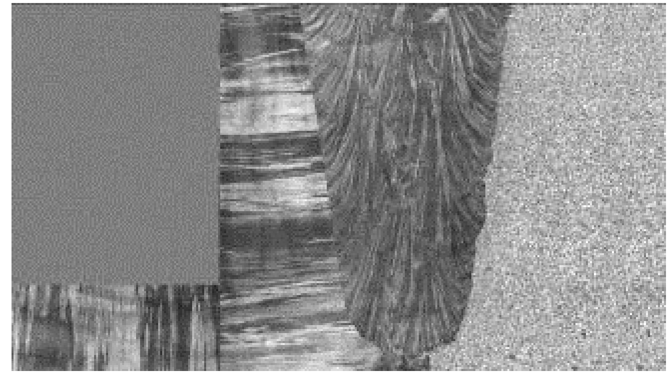
Structure of columnar grains

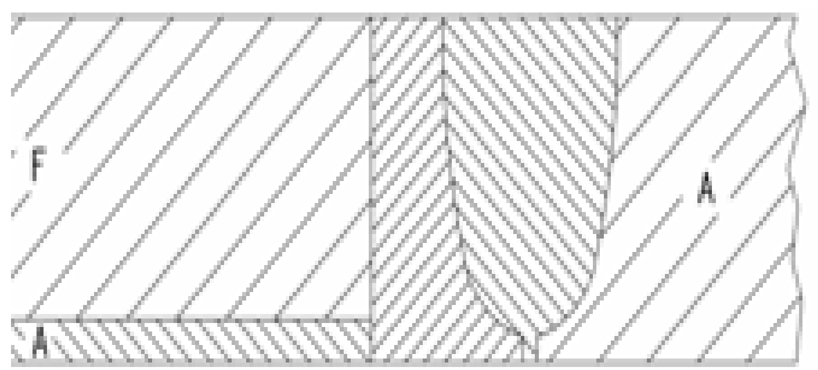
INSPECTION PROBLEM
Acoustic Anisotropy





Horizontal weld pipe vertical

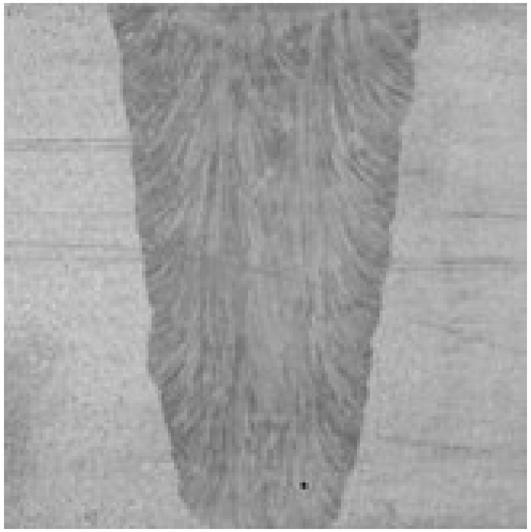


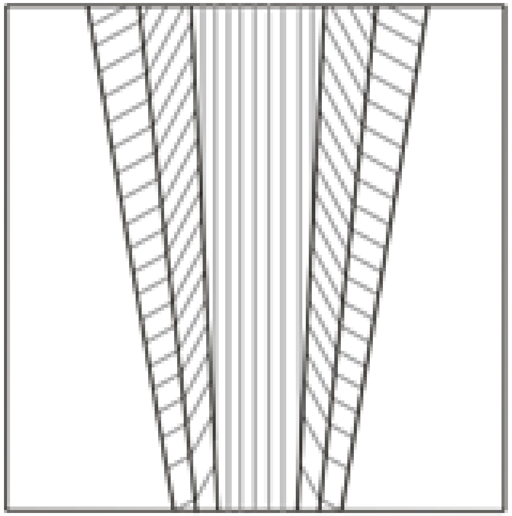


Vertical weld, pipe horizontal

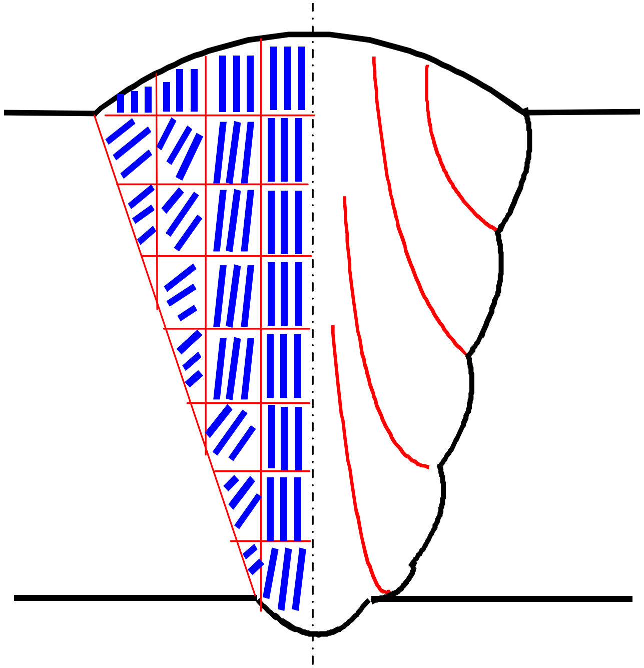
Structure of columnar grains

INSPECTION PROBLEM
Acoustic Anisotropy





STRIP MODEL



PIXEL/VOXEL MODEL

DEFINITION:

ACOUSTIC TRANSVERSAL ISOTROPIC DOMAINS TID
SECTIONS WITH HOMOGENEOUS ACOUSTIC PROPERTIES

TRANSVERSAL ISOTROPIC DOMAINS
TID

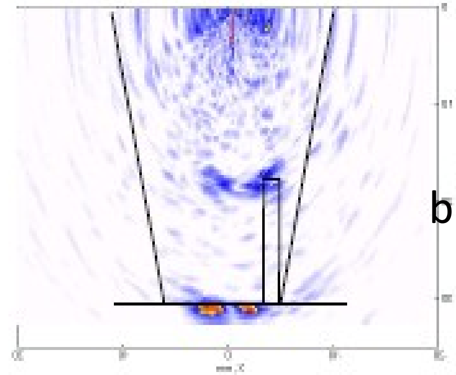
Q NET CONSULTING

TOLMI

INSPECTION PROBLEM
Acoustic Anisotropy

a Test Specimen

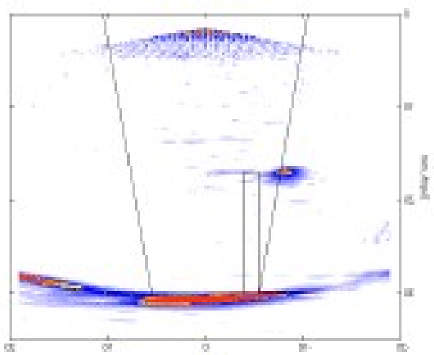
a



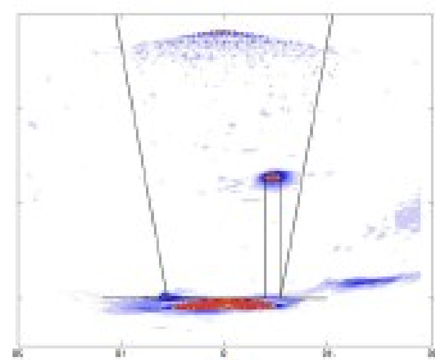
b

b Phased Array

c Sampling
Phased Array



c



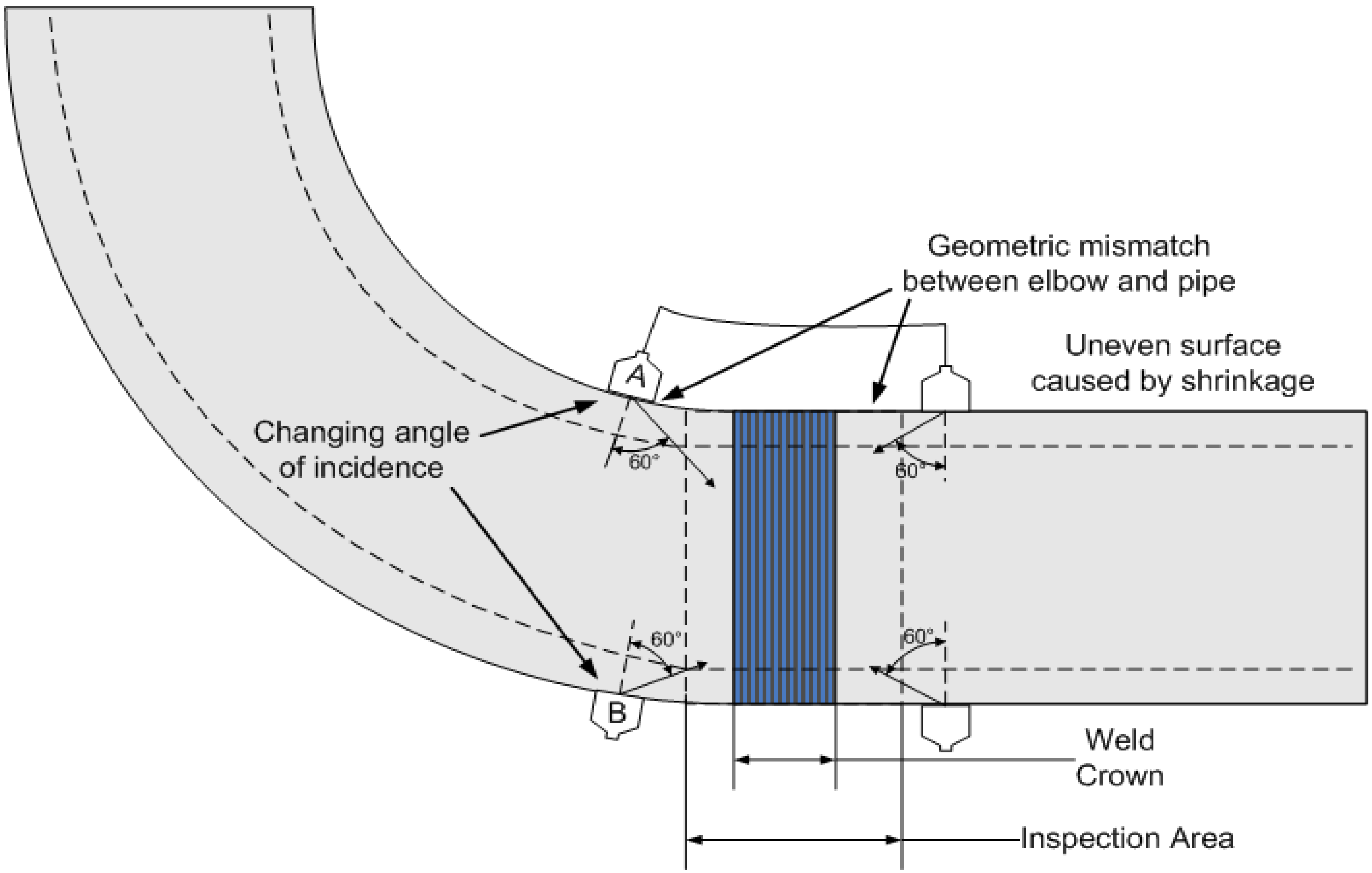
d

d Sampling
Phased Array
Phases Matched

REFLECTOR POSITIONING
BY
MODEL SUPPORTED PHASE MATCHING

PAUSE

INSPECTION PROBLEM
Geometry

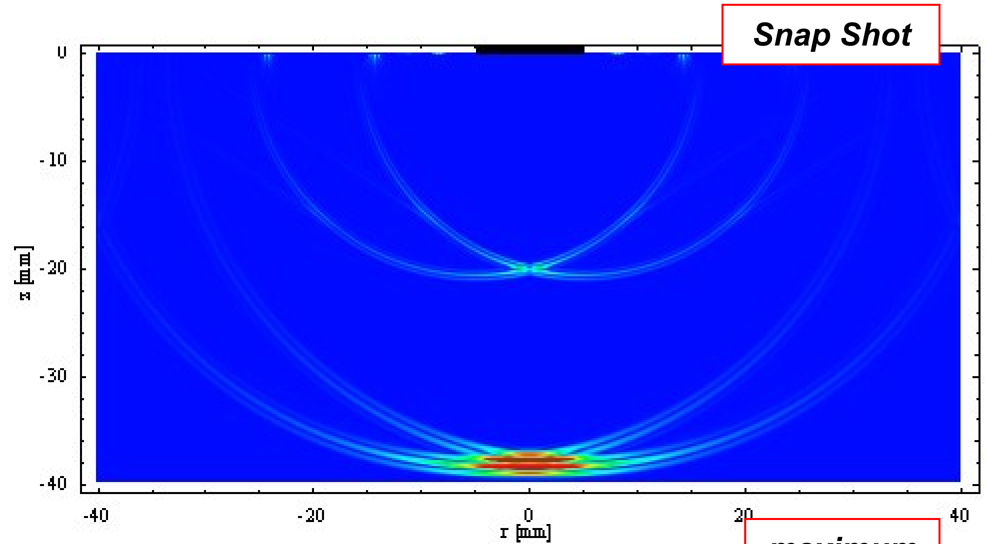


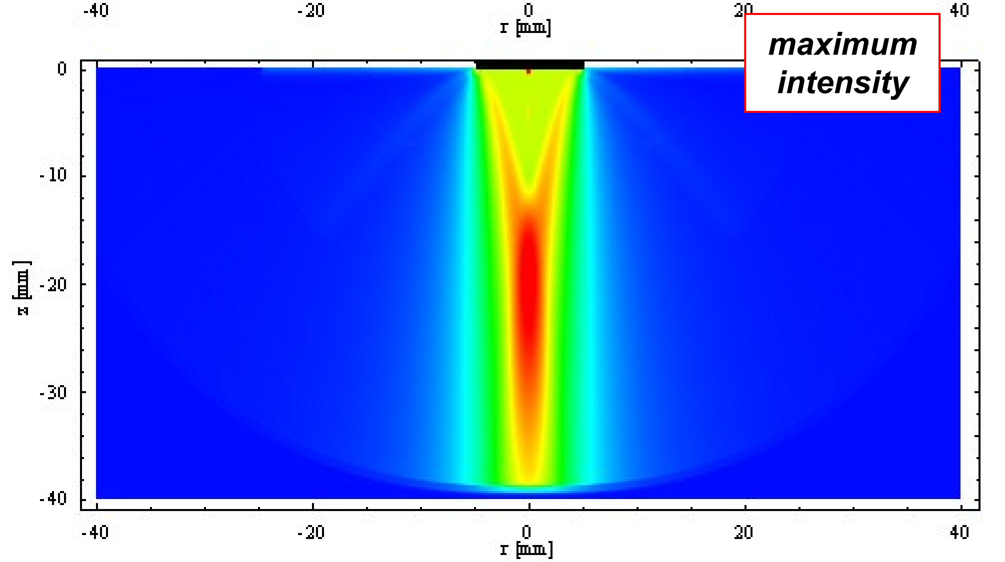
INSPECTION PROBLEM
Geometry

Case Studies: Surfaces

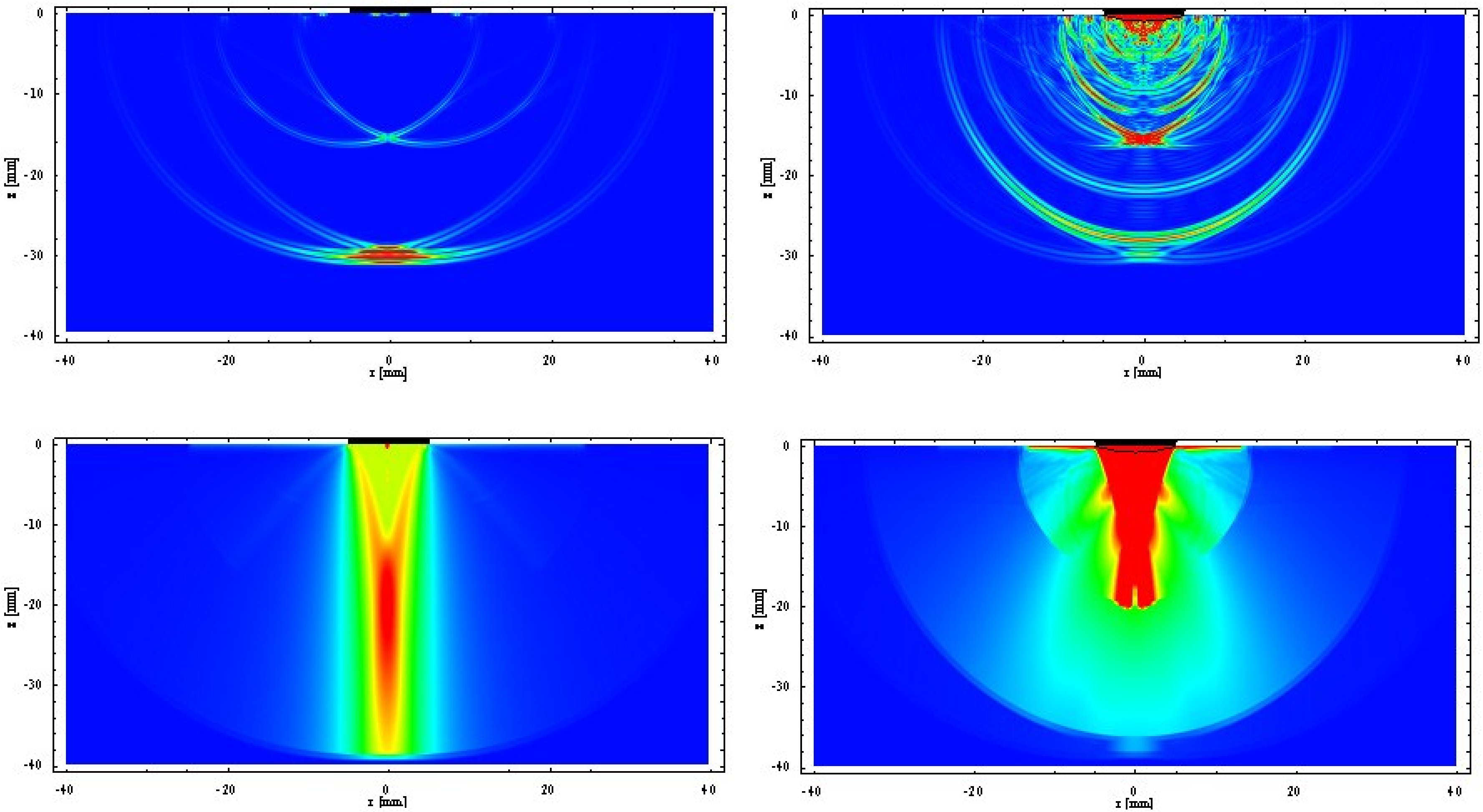
Simulation by Dr. Schubert
Fraunhofer IZFP-D

Transducer:	normal probe f = 4 MHz
Aperture:	A = 10 mm
Surface:	flat





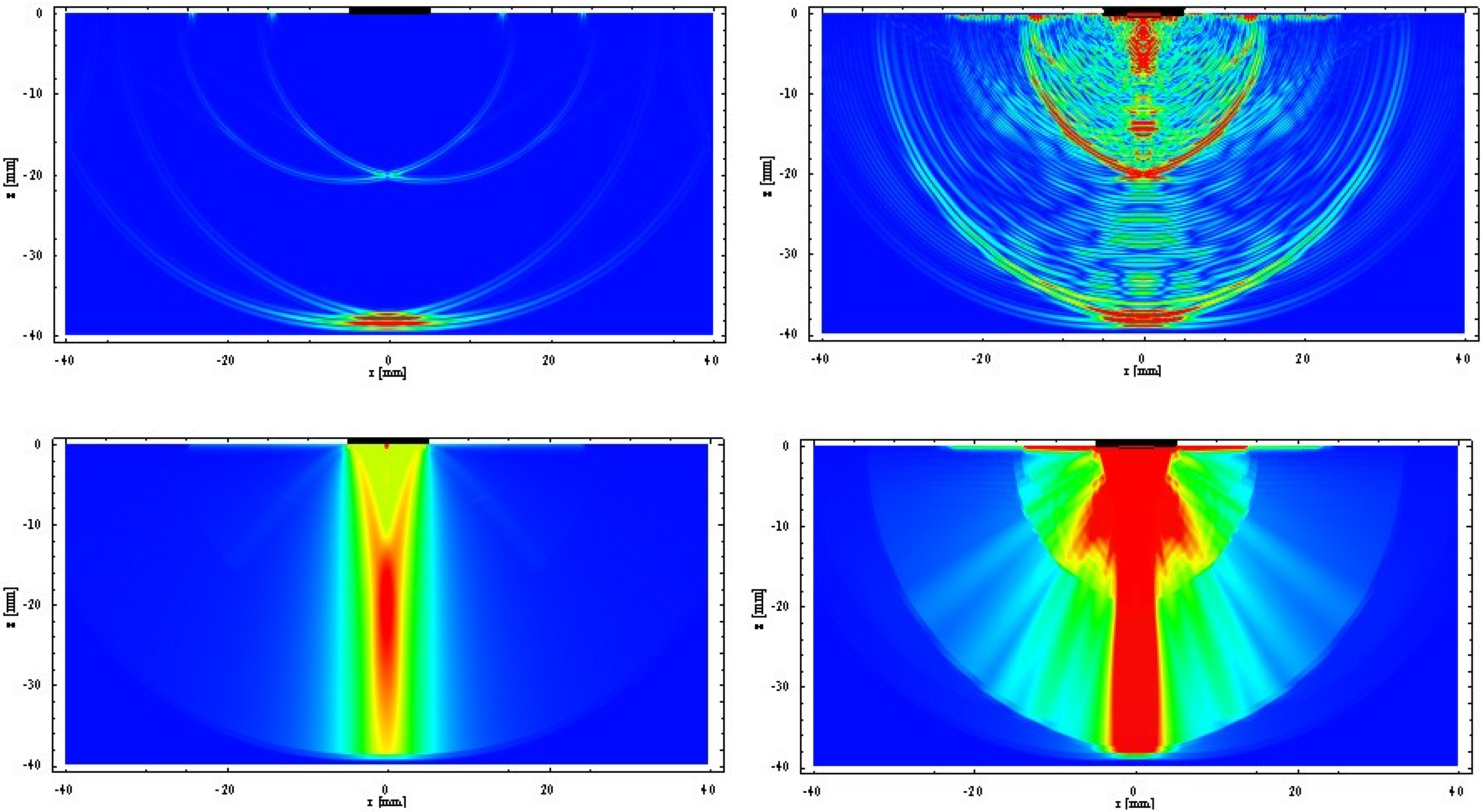
INSPECTION PROBLEM
Geometry



Water gap depth (lense shaped):
0.74 mm (λ/2 in steel, 2λ in water)

INSPECTION PROBLEM

Geometry

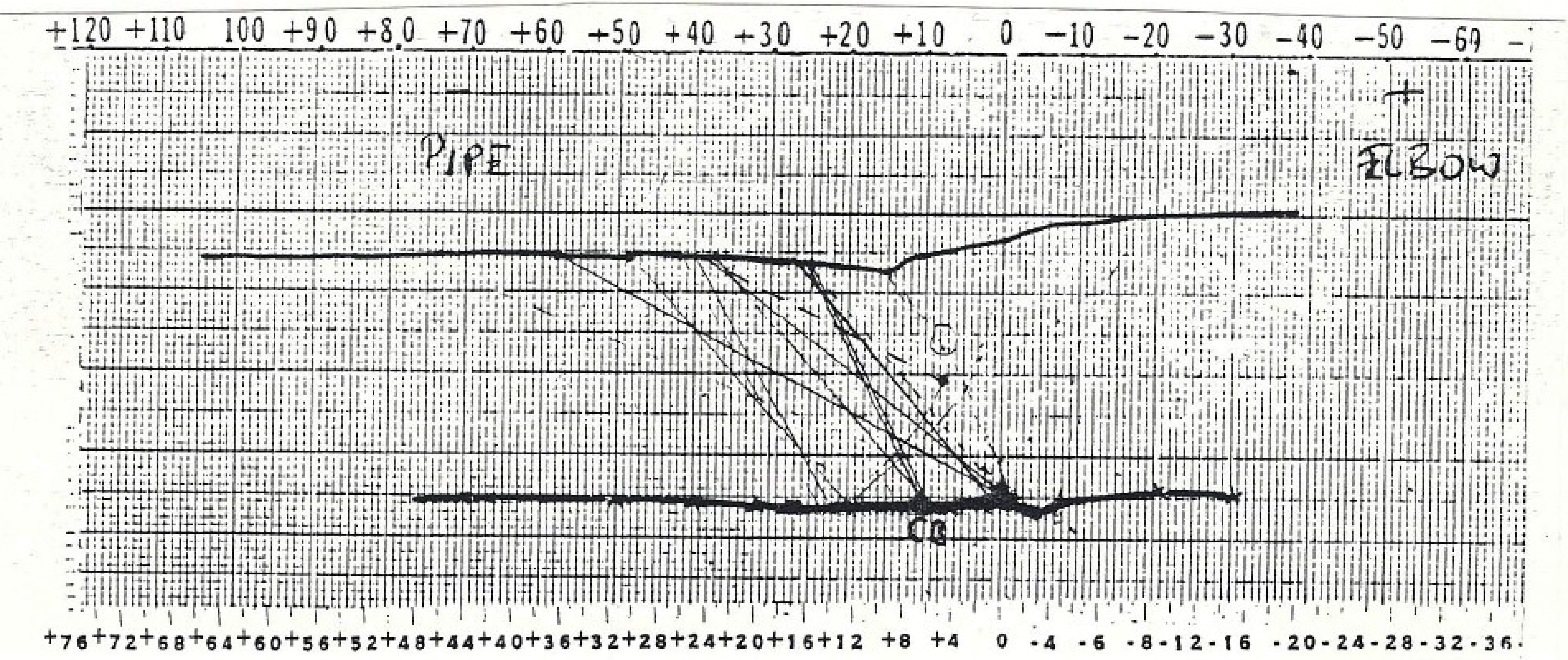


Water gap depth (lense shaped):

0.18 mm ($\lambda/8$ in steel, $\lambda/2$ in water)

INSPECTION PROBLEM

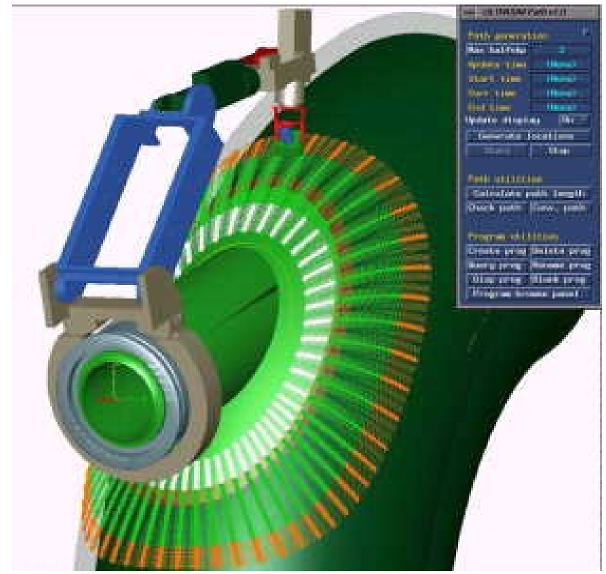
Geometry



Surface Contour of Pipe to Elbow Weld

CONTOUR ANALYSIS

INSPECTION PROBLEM
Geometry



LOCALIZATION
OF
REFLECTOR INDICATIONS

INSPECTION PROBLEM
Geometry

Coupling; Bending; Attenuation; Shaped Inspection Geometry Affect with Systematic Errors:

REGISTRATION: AMPLITUDE CRITERIA IN REFERENCE TO CALIBRATION REFLECTORS

EVALUATION: LOCALIZATION, CONTRAST & RESOLUTION SENSITIVITY

CONCLUSIONS

IMAGING OF SYSTEMATIC INDICATIONS

PAUSE

INSPECTION PROBLEM OPTIMIZATION

INSPECTION BY CAUSE	⟺	**DEFECT MODELING**
MICROSTRUCTURE	⟺	**SCATTERING REDUCTION**
TI DOMAINS	⟺	**ASSESSMENT OF SOUND PROPAGATION**

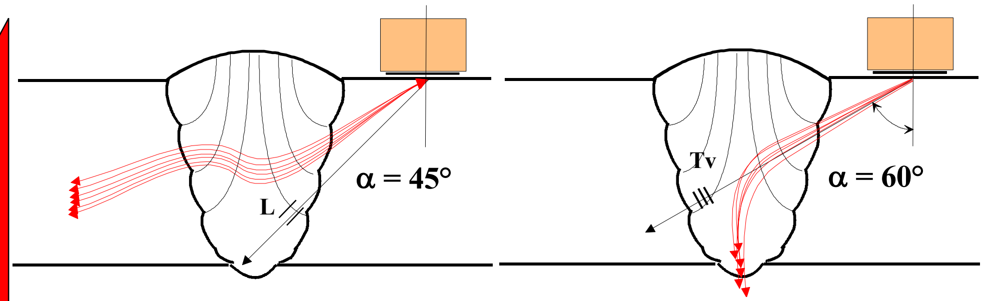
SELECTION OF TRANSDUCERS

INSPECTION PROBLEM OPTIMIZATION

List of Possible Transducers

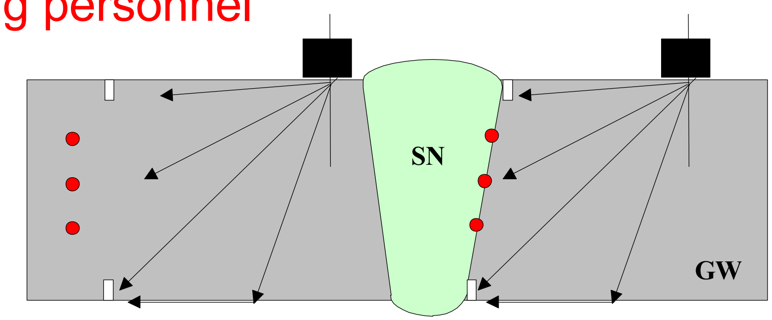
- 45°, 60°, 70° Shear Wave
- 45°, 60°, 70° Longitudinal Wave
- Double Element Transducers ADEPT
- LLT Transducers
- Mode Conversion Transducers
- **'Creeping wave'** Transducers

(1) Simulation of US wave propagation



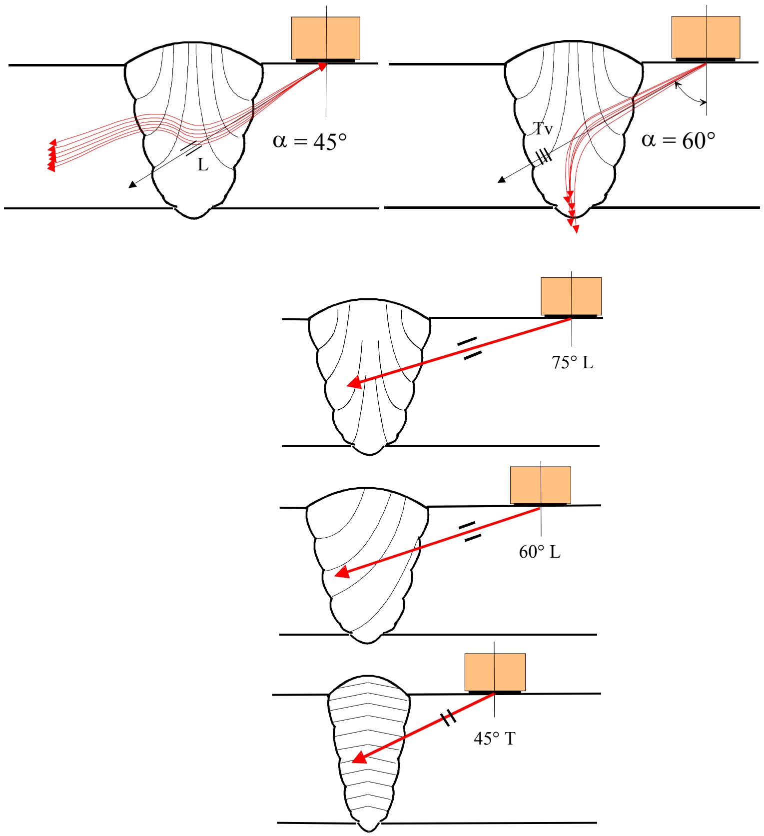
(2) Choice of appropriate transducers

(3) Qualification of inspection technique & testing personnel

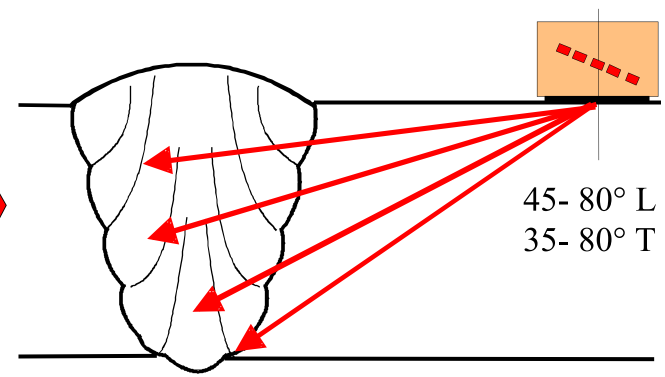


Example of inspection planning

INSPECTION PROBLEM OPTIMIZATION



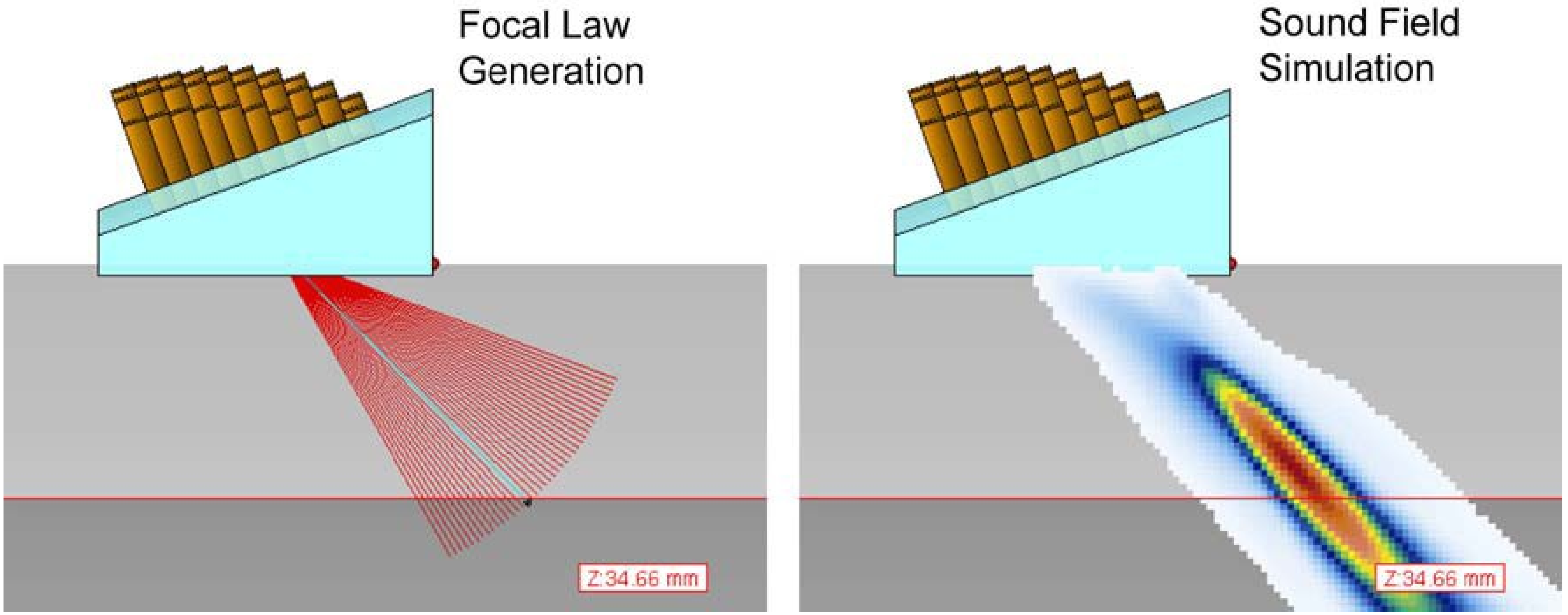
Most suitable



Phased Array

REPLACEMENT OF TRANSDUCERS

INSPECTION PROBLEM OPTIMIZATION

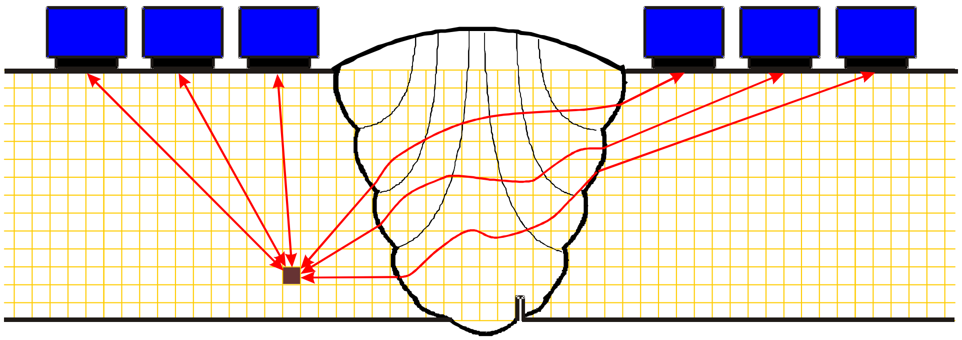


The ZETEC Advanced Phased Array Calculator is Useful for Generating Focal Laws (left) and Simulating the Sound Field for the Focal Law (right) to Determine Beam Characteristics

PAUSE

The Principle of Inverse Phase Matching

$$\sum A_{ij}\left(t+\Delta\varphi_{ij}\right)$$

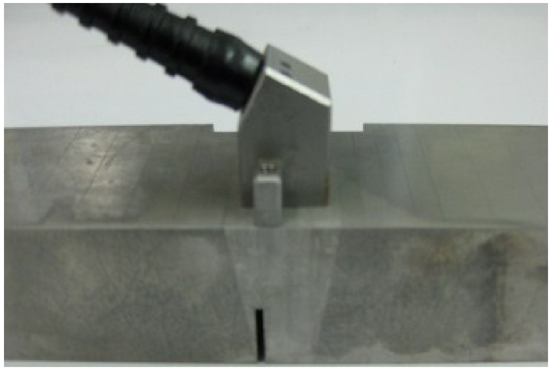


Calculation of time of flight in consideration of acoustic anisotropy

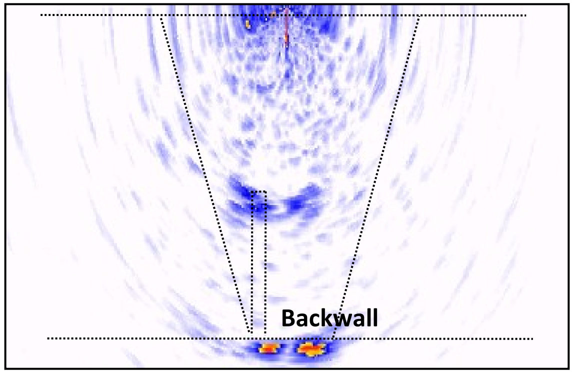
Phase corrected summation

RESEARCH & DEVELOPMENT
REVERSE PHASE MATCHING

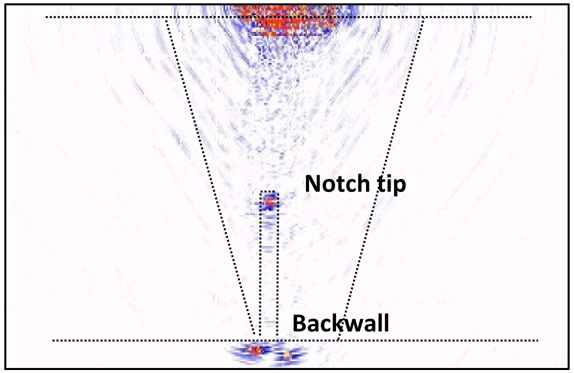
INSPECTION PROBLEM
RESEARCH & DEVELOPMENT



Phased array transducer and test specimen



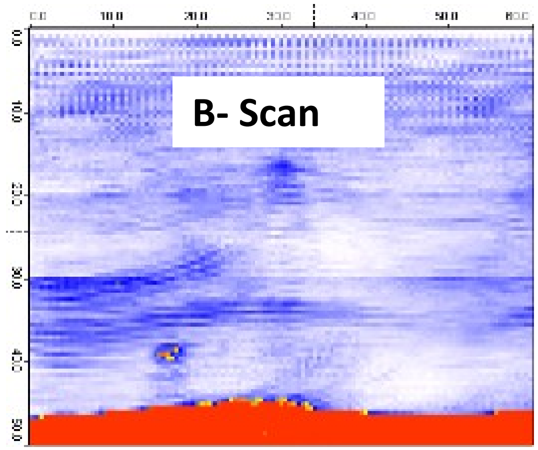
Conventional Phased Array

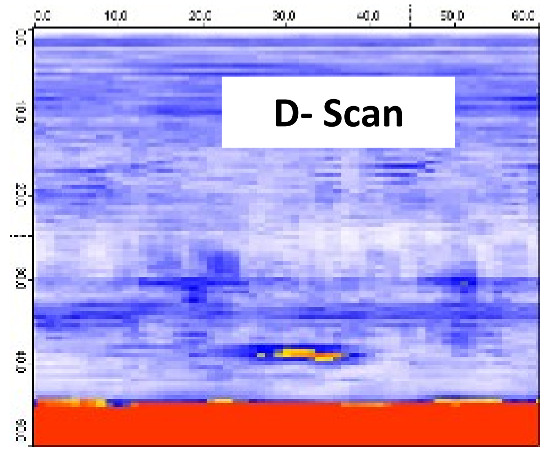


Sampling Array with Reverse Phase Matching

Ultrasonics

INSPECTION PROBLEM
RESEARCH & DEVELOPMENT



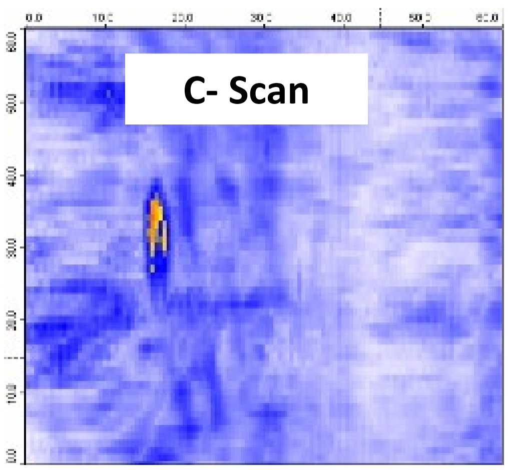


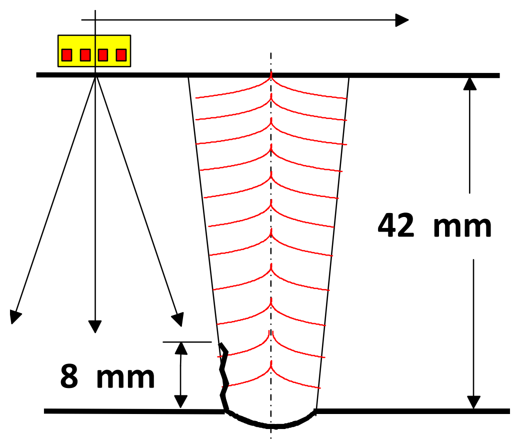
US- Probe:

- 16 Element SPA
- Frequency 2 MHz

Technique:

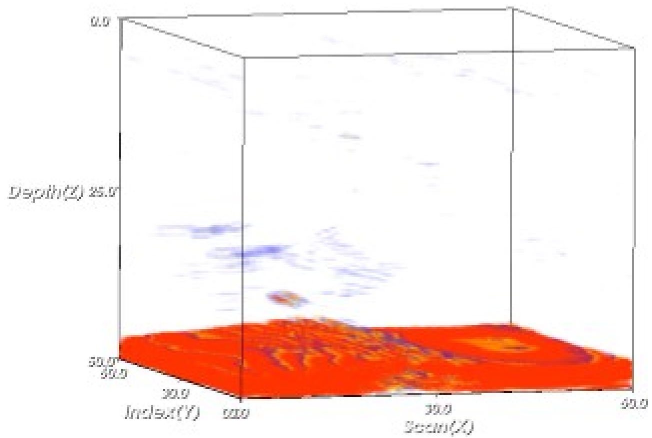
- 3D Sampling Phased Array with SAFT Reconstruction

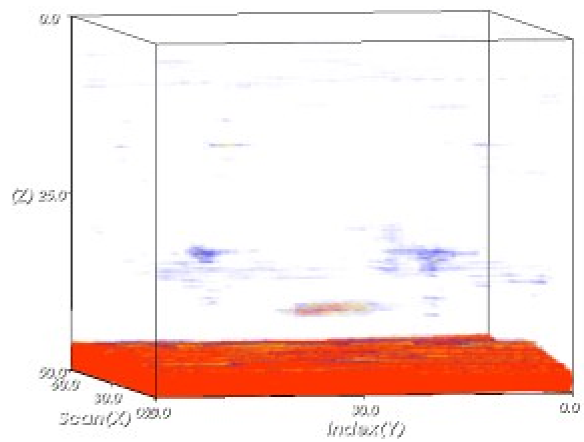


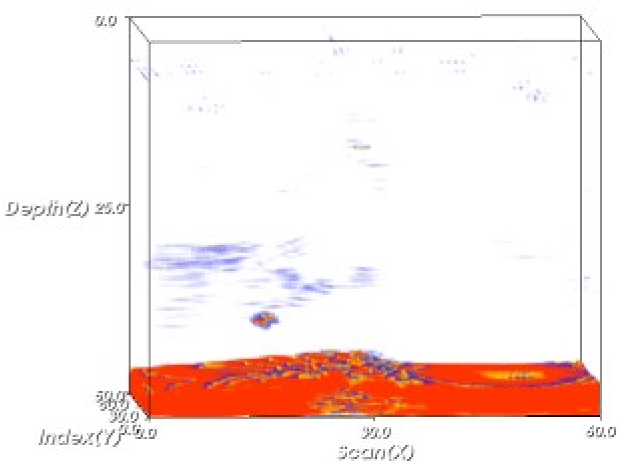


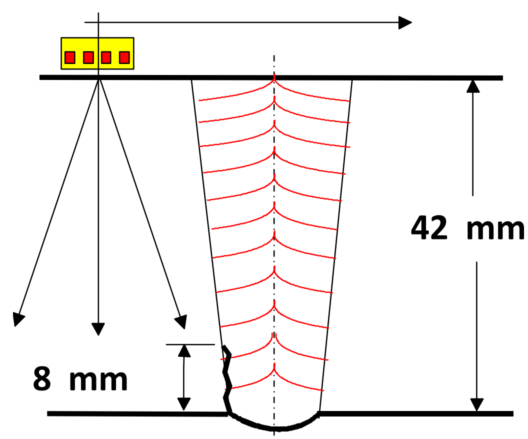
Inspection of austenitic narrow gap weld with root crack

INSPECTION PROBLEM
RESEARCH & DEVELOPMENT









Inspection of austenitic narrow gap weld with root crack

3D VISUALIZATION

LET'S GO FOR INSPECTION